Abstract: The definition of the language syntax and accompanying semantics for the specification of verification intent and behaviors reusable across multiple target platforms and allowing for the automation of test generation is provided. This standard provides a declarative environment designed for abstract behavioral description using actions, their inputs, outputs, and resource dependencies, and their composition into use cases including data and control flows. These use cases capture verification intent that can be analyzed to produce a wide range of possible legal scenarios for multiple execution platforms. It also includes a preliminary mechanism to capture the programmer’s view of a peripheral device, independent of the underlying platform, further enhancing portability.

Keywords: behavioral model, constrained randomization, functional verification, hardware-software interface, portability, PSS, test generation.
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Suggestions for improvements to the Portable Test and Stimulus Standard 2.1 are welcome. They should be posted to the PSS Community Forum at:

https://forums.accellera.org/forum/44-portable-stimulus-discussion/

The current Working Group web page is:

http://www.accellera.org/activities/working-groups/portable-stimulus
**Introduction**

The definition of a Portable Test and Stimulus Standard (PSS) will enable user companies to select the best tool(s) from competing vendors to meet their verification needs. Creation of a specification language for abstract use-cases is required. The goal is to allow stimulus and tests, including coverage and results checking, to be specified at a high level of abstraction, suitable for tools to interpret and create scenarios and generate implementations in a variety of languages and tool environments, with consistent behavior across multiple implementations.

This revision adds new features, corrects errors, clarifies aspects of the language and semantic definitions, removes some features, and reorganizes some sections relative to version 2.0 of the Portable Test and Stimulus Standard (April 2021). The most substantial feature removed relative to version 2.0 is the use of C++ as an input format for PSS.

The new features include (by section number):

<table>
<thead>
<tr>
<th>Section(s)</th>
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<tr>
<td>4.6, 7.3, 23.5</td>
<td>Floating-point data types and associated math functions</td>
</tr>
<tr>
<td>7.5.1</td>
<td>Added the ability to specify a base data type for enumerated types</td>
</tr>
<tr>
<td>7.9.3.4, 16.4.2</td>
<td>Support for randomizing the content of the list collection type</td>
</tr>
<tr>
<td>12.3.7</td>
<td>Support for specifying atomic regions protected from interference by inferred actions</td>
</tr>
<tr>
<td>15.3.1</td>
<td>Convenience features to assist with static binding to arrays of components</td>
</tr>
<tr>
<td>16.1.11</td>
<td>Support for specifying value distributions across expressions of random variables</td>
</tr>
<tr>
<td>16.4.6, 21.7.12, 23.4</td>
<td>Support for randomizing data inside procedural functions and exec blocks</td>
</tr>
<tr>
<td>22.2.1</td>
<td>Support for conditional compilation directives in covergroups, exec blocks, constraints, and override blocks</td>
</tr>
<tr>
<td>21.1.2</td>
<td>Addition of a <strong>pre_body</strong> solve-platform exec block, in which assignment of memory allocation and executors is guaranteed to be complete</td>
</tr>
<tr>
<td>21.2</td>
<td>Support for static functions in component contexts</td>
</tr>
<tr>
<td>23.1</td>
<td>Functions for string formatting and output</td>
</tr>
<tr>
<td>23.2</td>
<td>Functions for operating on files</td>
</tr>
<tr>
<td>23.3</td>
<td>Functions for error reporting</td>
</tr>
<tr>
<td>23.7.3.1, 23.9.8</td>
<td>Support for associating a string tag with an address-space region, and retrieving the tag associated with an address handle</td>
</tr>
<tr>
<td>23.9</td>
<td>Allow packed structs to contain Boolean fields, and enumerated types that specify a base data type</td>
</tr>
<tr>
<td>23.9.6, 23.9.7</td>
<td>Functions to query resolved memory-allocation addresses on the solve platform</td>
</tr>
<tr>
<td>23.9.9.5</td>
<td>Support user-specified address translation on a per-executor basis</td>
</tr>
<tr>
<td>23.10.1</td>
<td>Added register masked-write functions to simplifying writing individual register fields</td>
</tr>
</tbody>
</table>
Participants

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_Arteris, Inc._  _Synopsys, Inc._
_Breker Verification Systems, Inc._  _Vayavya Labs Pvt. Ltd._
_Cadence Design Systems, Inc._  _Western Digital Corporation_
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1. Overview

This clause explains the purpose of this standard, describes its key concepts and considerations, details the conventions used, and summarizes its contents.

The Portable Test and Stimulus Standard syntax is specified using Backus-Naur Form (BNF). The rest of this standard is intended to be consistent with the BNF description. If any discrepancies between the two occur, the BNF formal syntax in Annex B shall take precedence.

1.1 Purpose

The Portable Test and Stimulus Standard defines a specification for creating a single representation of stimulus and test scenarios, usable by a variety of users across different levels of integration under different configurations, enabling the generation of different implementations of a scenario that run on a variety of execution platforms, including, but not necessarily limited to, simulation, emulation, FPGA prototyping, and post-silicon. With this standard, users can specify a set of behaviors once, from which multiple implementations may be derived.

1.2 Language design considerations

The Portable Test and Stimulus Standard (PSS) describes a declarative domain-specific language (DSL), intended for modeling scenario spaces of systems, generating test cases, and analyzing test runs. Scenario elements and formation rules are captured in a way that abstracts from implementation details and is thus reusable, portable, and adaptable. The portable stimulus specification captured in the DSL is herein referred to as PSS.

PSS borrows its core concepts from object-oriented programming languages, hardware-verification languages, and behavioral modeling languages. PSS features native constructs for system notions, such as data/control flow, concurrency and synchronization, resource requirements, and states and transitions. It also includes native constructs for mapping these to target implementation artifacts.

Introducing a new language has major benefits insofar as it expresses user intention that would be lost in other languages. However, user tasks that can be handled well enough in existing languages should be left to the language of choice, so as to leverage existing skill, tools, flows, and code bases. Thus, PSS focuses on
the essential domain-specific semantic layer and links with other languages to achieve other related purposes. This eases adoption and facilitates project efficiency and productivity.

Finally, PSS builds on prevailing linguistic intuitions in its constructs. In particular, its lexical and syntactic conventions come from the C/C++ family, and its constraint and coverage language uses SystemVerilog (IEEE Std 1800)\(^1\) as a reference.

### 1.3 Modeling basics

A PSS *model* is a representation of some view of a system’s behavior, along with a set of abstract flows. It is essentially a set of class definitions augmented with rules constraining their legal instantiation. A model consists of two types of class definitions: elements of behavior, called *actions*; and passive entities used by actions, such as resources, states, and data flow items, collectively called *objects*. The behaviors associated with an action are specified as *activities*. Actions and object definitions may be encapsulated in *components* to form reusable model pieces. All of these elements may also be encapsulated and extended in a *package* to allow for additional reuse and customization.

A particular instantiation of a given PSS model is a called a *scenario*. Each scenario consists of a set of action instances and data object instances, as well as scheduling constraints and rules defining the relationships between them. The scheduling rules define a partial-order dependency relation over the included actions, which determines the execution semantics. A *consistent scenario* is one that conforms to model rules and satisfies all constraints.

Actions constitute the main abstraction mechanism in PSS. An action represents an element in the space of modeled behavior. Actions may correspond directly to operations of the underlying system under test (SUT) and test environment, in which case they are called *atomic actions*. Actions also use *activities* to encapsulate flows of simpler actions, constituting some joint activity or scenario intention. As such, actions can be used as top-level test intent or reusable test specification elements. Actions and objects have data attributes and data constraints over them.

Actions define the rules for legal combinations in general, not relative to a specific scenario. These are stated in terms of references to objects, having some role from the action’s perspective. Objects thus serve as data, and control inputs and outputs of actions, or they are exclusively used as resources. Assembling actions and objects together, along with the scheduling and arithmetic constraints defined for them, produces a model that captures the full state-space of possible scenarios. A scenario is a particular solution of the constraints described by the model to produce an implementation consistent with the described intent.

### 1.4 Test realization

A key purpose of PSS is to automate the generation of test cases and test suites. Tests for electronic systems often involve code running on embedded controllers, exercising the underlying hardware and software layers. Tests may involve code in hardware-verification languages (HVLs) controlling bus functional models, as well as scripts, command files, data files, and other related artifacts. From the PSS model perspective, these are called *target files*, and *target languages*, which jointly implement the test case for a *target platform*.

The execution of a *consistent scenario* essentially consists of invoking its actions’ implementations, if any, in their respective scheduling order. An action is invoked immediately after all its dependencies have completed, and subsequent actions wait for it to complete. Thus, actions that have the same set of

---

\(^1\)Information on references can be found in Clause 2.
dependencies are logically invoked at the same time. Mapping atomic actions to their respective implementation for a target platform is captured in several ways, defined in Clause 21.

PSS features a native mechanism for referring to the actual state of the system under test (SUT) and the environment. Runtime values accessible to the generated test can be sampled and fed back into the model as part of an action’s execution. These external values are sampled and, in turn, affect subsequent generation, which can be checked against model constraints and/or collected as coverage. The system/environment state can also be sampled during pre-run processing utilizing models and during post-run processing, given a run trace.

Similarly, the generation of a specific test-case from a given scenario may require further refinement or annotations, such as the external computation of expected results, memory modeling, and/or allocation policies. For these, external models, software libraries, or dedicated algorithmic code in other languages or tools may need to be employed. In PSS, the execution of these pre-run computations is defined using the same scheme as described above, with the results linked in the target language of choice.

1.5 Conventions used

The conventions used throughout the document are included here.

1.5.1 Visual cues (meta-syntax)

The meta-syntax for the description of the syntax rules uses the conventions shown in Table 1.

Table 1—Document conventions

<table>
<thead>
<tr>
<th>Visual cue</th>
<th>Represents</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>bold</strong></td>
<td>The <em>bold</em> font is used to indicate keywords and punctuation, text that shall be typed exactly as it appears. For example, in the following line, the keyword &quot;state&quot; and special characters &quot;{&quot; and &quot;}&quot; shall be typed exactly as they appear:</td>
</tr>
<tr>
<td></td>
<td><strong>state</strong> identifier [ template_param_decl_list ] [ struct_super_spec ] { { struct_body_item } }</td>
</tr>
<tr>
<td>plain text</td>
<td>The normal or plain text font indicates syntactic categories. For example, an identifier shall be specified in the following line (after the &quot;state&quot; keyword):</td>
</tr>
<tr>
<td></td>
<td><strong>state</strong> identifier [ template_param_decl_list ] [ struct_super_spec ] { { struct_body_item } }</td>
</tr>
<tr>
<td><em>italics</em></td>
<td>The <em>italics</em> font in running text indicates a definition. For example, the following line shows the definition of “activities”:</td>
</tr>
<tr>
<td></td>
<td>The behaviors associated with an action are specified as <em>activities</em>.</td>
</tr>
<tr>
<td></td>
<td>The <em>italics</em> font in syntax definitions depicts a meta-identifier, e.g., <em>action_identifier</em>. See also 4.2.</td>
</tr>
<tr>
<td><em>courier</em></td>
<td>The <em>courier</em> font in running text indicates PSS code. For example, the following line indicates PSS code (for a <em>state</em>):</td>
</tr>
<tr>
<td></td>
<td>state power_state_s { int in [0..4] val; };</td>
</tr>
<tr>
<td>square brackets</td>
<td>[ ] square brackets indicate optional items. For example, the <em>struct_super_spec</em> is optional in the following line:</td>
</tr>
<tr>
<td></td>
<td><strong>state</strong> identifier [ template_param_decl_list ] [ struct_super_spec ] { { struct_body_item } }</td>
</tr>
</tbody>
</table>
Table 1—Document conventions (Continued)

<table>
<thead>
<tr>
<th>Visual cue</th>
<th>Represents</th>
</tr>
</thead>
<tbody>
<tr>
<td>{ } curly braces</td>
<td>Curly braces ( { } ) indicate items that can be repeated zero or more times. For example, the following line shows that zero or more <em>struct_body_items</em> can be specified in this declaration: state identifier [ template_param_decl_list ] [ struct_super_spec ] { { struct_body_item } }</td>
</tr>
<tr>
<td></td>
<td>The separator bar (</td>
</tr>
<tr>
<td>( ) parentheses</td>
<td>Parentheses ( ( ) ) group together alternative choices. For example, the following line shows that a flow object reference begins with either an &quot;input&quot; or an &quot;output&quot; keyword: flow_ref_field_declaration ::= ( input</td>
</tr>
</tbody>
</table>

1.5.2 Notational conventions

The terms “required”, “shall”, “shall not”, “should”, “should not”, “recommended”, “may”, and “optional” in this document are to be interpreted as described in the IETF Best Practices Document 14, RFC 2119.

1.5.3 Examples

Any examples shown in this standard are for information only and are only intended to illustrate the use of PSS.

Many of the examples use “...” to indicate code omitted for brevity.

1.6 Use of color in this standard

This standard uses a minimal amount of color to enhance readability. The coloring is not essential and does not affect the accuracy of this standard when viewed in pure black and white. The places where color is used are the following:

---

Cross references that are hyperlinked to other portions of this standard are shown in *underlined-blue text* (hyperlinking works when this standard is viewed interactively as a PDF file).

---

Syntactic keywords and tokens in the formal language definitions are shown in *boldface-red text* when initially defined.

1.7 Contents of this standard

The organization of the remainder of this standard is as follows:

---

Clause 2 provides references to other applicable standards that are assumed or required for this standard.

---

Clause 3 defines terms and acronyms used throughout the different specifications contained in this standard.

---

Clause 4 defines the lexical conventions used in PSS.

---

Clause 5 defines the PSS modeling concepts.
— Clause 6 defines the PSS execution semantic concepts.
— Clause 7 highlights the PSS data types.
— Clause 8 describes the operators and operands that can be used in expressions and how expressions are evaluated.
— Clause 9 - Clause 20 describe the PSS abstract modeling constructs.
— Clause 21 describes the realization of PSS atomic actions.
— Clause 22 describes the process for conditional code processing.
— Clause 23 describes the PSS core library, which consists of portable functionality and utilities that PSS tools must implement.
— Annexes. Following Clause 23 is a series of annexes.
2. References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ANSI X3.4-1986: Coded Character Sets—7-Bit American National Standard Code for Information Inter-change (7-Bit ASCII)2 (ISO 646 International Reference Version)


The IETF Best Practices Document (for notational conventions) is available from the IETF web site: https://www.ietf.org/rfc/rfc2119.txt.

ISO/IEC 14882:2011, Programming Languages—C++.5

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2 ANSI publications are available from the American National Standards Institute (https://www.ansi.org/).
3 The IEEE standards or products referred to in this clause are trademarks of the Institute of Electrical and Electronics Engineers, Inc.
4 IEEE publications are available from the Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Lane, Piscataway, NJ 08854, USA (https://standards.ieee.org/).
3. Definitions, acronyms, and abbreviations

For the purposes of this document, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards Terms* [B1] should be referenced for terms not defined in this clause.

3.1 Definitions

*action*: An element of behavior.

*activity*: An abstract, partial specification of a *scenario* that is used in a *compound action* to determine the high-level intent and leaves all other details open.

*atomic action*: An *action* that corresponds directly to operations of the underlying system under test (SUT) and test environment.

*component*: A structural entity, defined per type and instantiated under other components.

*compound action*: An *action* that includes an *activity* to traverse one or more sub-actions.

*constraint*: An algebraic expression relating attributes of model entities used to limit the resulting scenario space of the *model*.

*coverage*: A metric to measure the percentage of possible *scenarios* that have actually been processed for a given *model*.

*exec block*: Specifies the mapping of PSS scenario entities to their non-PSS implementation.

*field*: A variable associated with an instance of a type.

*inheritance*: The process of deriving one model element from another of a similar type, but adding or modifying functionality as desired. It allows multiple types to share functionality that only needs to be specified once, thereby maximizing reuse and portability.

*loop*: A traversal region of an *activity* in which a set of sub-actions is repeatedly executed. Values for the fields of the *action* are selected for each traversal of the loop, subject to the active constraints and resource requirements present.

*model*: A representation of some view of a system’s behavior, along with a set of abstract flows.

*object*: A passive entity used by an *action*, such as resources, states, and data flow items.

*override*: To replace one or all instances of an element of a given type with an element of a compatible type inherited from the original type.

*package*: A way to group, encapsulate, and identify sets of related definitions, namely type declarations and type extensions.

*resource*: A computational element available in the target environment that may be claimed by an *action* for the duration of its execution.

---

[^6]: The numbers in brackets correspond to those of the bibliography in Annex A.
**root action**: An action designated explicitly as the entry point for the generation of a specific scenario. Any action in a model can serve as the root action of some scenario.

**scenario**: A particular instantiation of a given PSS model.

**solve platform**: The platform on which the test scenario is solved and, where applicable, target test code is generated. In some generation flows, the solve and target platforms may be the same.

**target file**: Contains textual content to be used in realizing the test intent.

**target language**: The language used to realize a specific unit of test intent, e.g., ANSI C, assembly language, Perl.

**target platform**: The execution platform on which test intent is executed.

**type extension**: The process of adding additional functionality to a model element of a given type, thereby maximizing reuse and portability. As opposed to inheritance, extension does not create a new type.

### 3.2 Acronyms and abbreviations

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>API</td>
<td>Application Programming Interface</td>
</tr>
<tr>
<td>PI</td>
<td>Procedural Interface</td>
</tr>
<tr>
<td>PSS</td>
<td>Portable Test and Stimulus Standard</td>
</tr>
<tr>
<td>SUT</td>
<td>System Under Test</td>
</tr>
<tr>
<td>UVM</td>
<td>Universal Verification Methodology</td>
</tr>
</tbody>
</table>
4. Lexical conventions

PSS borrows its lexical conventions from the C language family.

4.1 Comments

The token /* introduces a comment, which terminates with the first occurrence of the token */. The C++
comment delimiter // is also supported and introduces a comment which terminates at the end of the
current line.

4.2 Identifiers

An identifier is a sequence of letters, digits, and underscores; it is used to give an object a unique name so
that it can be referenced. In a given namespace, identifiers shall be unique. Identifiers are case-sensitive.

A meta-identifier can appear in syntax definitions using the form: construct_name_identifier, e.g.,
action_identifier. See also B.18.

4.3 Escaped identifiers

Escaped identifiers shall start with the backslash character (\) and end with white space (space, tab,
newline). They provide a means of including any of the printable non-whitespace ASCII characters in an
identifier (the decimal values 33 through 126, or 0x21 through 0x7E in hexadecimal).

Neither the leading backslash character nor the terminating white space is considered to be part of the
identifier. Therefore, an escaped identifier \cpu3 is treated the same as a non-escaped identifier cpu3.

Some examples of legal escaped identifiers are shown here:
\busa+index
\-clock
\***error-condition***
\net1/\net2
\{a,b}\n\a*(b+c)
4.4 Keywords

PSS reserves the keywords listed in Table 2.

<table>
<thead>
<tr>
<th>abstract</th>
<th>action</th>
<th>activity</th>
<th>array</th>
<th>as</th>
<th>assert</th>
</tr>
</thead>
<tbody>
<tr>
<td>atomic</td>
<td>bind</td>
<td>bins</td>
<td>bit</td>
<td>body</td>
<td>bool</td>
</tr>
<tr>
<td>break</td>
<td>buffer</td>
<td>chandle</td>
<td>class</td>
<td>compile</td>
<td>component</td>
</tr>
<tr>
<td>const</td>
<td>constraint</td>
<td>continue</td>
<td>covergroup</td>
<td>coverpoint</td>
<td>cross</td>
</tr>
<tr>
<td>declaration</td>
<td>default</td>
<td>disable</td>
<td>dist</td>
<td>do</td>
<td>dynamic</td>
</tr>
<tr>
<td>else</td>
<td>enum</td>
<td>exec</td>
<td>export</td>
<td>extend</td>
<td>false</td>
</tr>
<tr>
<td>file</td>
<td>float32</td>
<td>float64</td>
<td>forall</td>
<td>foreach</td>
<td>function</td>
</tr>
<tr>
<td>has</td>
<td>header</td>
<td>if</td>
<td>iff</td>
<td>ignore_bins</td>
<td>illegal_bins</td>
</tr>
<tr>
<td>import</td>
<td>in</td>
<td>init</td>
<td>init_down</td>
<td>init_up</td>
<td>inout</td>
</tr>
<tr>
<td>input</td>
<td>instance</td>
<td>int</td>
<td>join_branch</td>
<td>join_first</td>
<td>join_none</td>
</tr>
<tr>
<td>join_select</td>
<td>list</td>
<td>lock</td>
<td>map</td>
<td>match</td>
<td>null</td>
</tr>
<tr>
<td>output</td>
<td>override</td>
<td>package</td>
<td>parallel</td>
<td>pool</td>
<td>post_solve</td>
</tr>
<tr>
<td>pre_body</td>
<td>pre_solve</td>
<td>private</td>
<td>protected</td>
<td>public</td>
<td>pure</td>
</tr>
<tr>
<td>rand</td>
<td>randomize</td>
<td>ref</td>
<td>repeat</td>
<td>replicate</td>
<td>resource</td>
</tr>
<tr>
<td>return</td>
<td>run_end</td>
<td>run_start</td>
<td>schedule</td>
<td>select</td>
<td>sequence</td>
</tr>
<tr>
<td>set</td>
<td>share</td>
<td>solve</td>
<td>state</td>
<td>static</td>
<td>stream</td>
</tr>
<tr>
<td>string</td>
<td>struct</td>
<td>super</td>
<td>symbol</td>
<td>target</td>
<td>this</td>
</tr>
<tr>
<td>true</td>
<td>type</td>
<td>typedef</td>
<td>unique</td>
<td>void</td>
<td>while</td>
</tr>
<tr>
<td>with</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.5 Operators

Operators are single-, double-, and triple-character sequences and are used in expressions. Unary operators appear to the left of their operand. Binary operators appear between their operands. A conditional operator has two operator characters that separate three operands.
4.6 Numbers

Constant numbers are specified as integer constants (see 4.6.1) or floating-point constants (see 4.6.2). The formal syntax for numbers is shown in Syntax 1.

```
number ::= 
  integer_number 
  | floating_point_number 
integer_number ::= 
  bin_number 
  | oct_number 
  | dec_number 
  | hex_number 
  | based_bin_number 
  | based_oct_number 
  | based_dec_number 
  | based_hex_number 
bin_digit ::= [0-1] 
oct_digit ::= [0-7] 
dec_digit ::= [1-9] 
hex_digit ::= [0-9] | [a-f] | [A-F] 
bin_number ::= 0[b|B] bin_digit { bin_digit | _ } 
oct_number ::= 0 { oct_digit | _ } 
dec_number ::= [1-9] { dec_digit | _ } 
hex_number ::= 0[sX] hex_digit { hex_digit | _ } 
BASED_BIN_LITERAL ::= [sS]b[B] bin_digit { bin_digit | _ } 
BASED_OCT_LITERAL ::= [sS]o[O] oct_digit { oct_digit | _ } 
BASED_DEC_LITERAL ::= [sS]d[D] dec_digit { dec_digit | _ } 
BASED_HEX_LITERAL ::= [sS]h[H] hex_digit { hex_digit | _ } 
based_bin_number ::= [ dec_number ] BASED_BIN_LITERAL 
based_oct_number ::= [ dec_number ] BASED_OCT_LITERAL 
based_dec_number ::= [ dec_number ] BASED_DEC_LITERAL 
based_hex_number ::= [ dec_number ] BASED_HEX_LITERAL 
floating_point_number ::= 
  floating_point_dec_number 
  | floating_point_sci_number 
unsigned_number ::= dec_digit { dec_digit | _ } 
floating_point_dec_number ::= unsigned_number . unsigned_number 
floating_point_sci_number ::= 
  unsigned_number [ . unsigned_number ] exp [ sign ] unsigned_number 
exp ::= e | E 
sign ::= + | - 
```

Syntax 1—Numeric constants
4.6.1 Integer constants

*Integer literal constants* can be specified in decimal, hexadecimal, octal, or binary format.

Several forms may be used to express an integer literal constant. The first form is a simple unsized decimal number, which is specified as a sequence of digits starting with 1 through 9 and containing the digits 0 through 9.

The second form is an unsized hexadecimal number, which is specified with a prefix of 0x or 0X followed by a sequence of digits 0 through 9, a through f, and A through F.

The third form is an unsized octal number, which is specified as a sequence of digits starting with 0 and containing the digits 0 through 7.

The fourth form is an unsized binary number, which is specified with a prefix of 0b or 0B followed by a sequence of digits 0 and 1.

The fifth form specifies a *based literal constant*, which is composed of up to three tokens:

- An optional size constant
- An apostrophe character (’) followed by a *base format* character
- Digits representing the value of the number.

The first token, a *size constant*, specifies the size of the integer literal constant in bits. This token shall be specified as an unsigned non-zero decimal number.

The second token, a *base format*, is a case-insensitive letter specifying the base for the number. The base is optionally preceded by the single character s (or S) to indicate a signed quantity. Legal base specifications are d, D, h, H, o, O, b, or B. These specify, respectively, decimal, hexadecimal, octal, and binary formats. The base format character and the optional sign character shall be preceded by an apostrophe. The apostrophe character and the base format character shall not be separated by white space.

The third token, an unsigned number, shall consist of digits that are legal for the specified base format. The unsigned number token immediately follows the base format, optionally separated by white space.

Simple decimal and octal numbers without the size and the base format shall be treated as *signed integers*. Unsized unbased hexadecimal and binary numbers shall be treated as unsigned. Numbers specified with a base format shall be treated as signed integers only if the s designator is included. If the s designator is not included, the number shall be treated as an unsigned integer.

If the size of an unsigned number is smaller than the size specified for the literal constant, the unsigned number shall be padded to the left with zeros. If the size of an unsigned number is larger than the size specified for the literal constant, the unsigned number shall be truncated from the left.

The number of bits that compose an unsized number is tool-specific, but shall be at least 32. An unsized number that requires more than 32 bits shall have at least the minimum width needed to properly represent the value, including a sign bit if the number is signed. For example, 0x7_0000_0000, an *unsigned* hexadecimal number, shall have at least 35 bits. 4294967296 (2**32), a positive *signed* integer, shall be represented by at least 34 bits.

The underscore character (_) shall be legal anywhere in a number except as the first character. The underscore character can be used to break up long integer literals to improve readability.
4.6.1.1 Using integer literals in expressions

A negative value for an integer with no base specifier shall be interpreted differently from an integer with a base specifier. An integer with no base specifier shall be interpreted as a signed value in two’s-complement form. An integer with an unsigned base specifier shall be interpreted as an unsigned value.

The following example shows four ways to write the expression “minus 12 divided by 3.” Note that -12 and -’d12 both evaluate to the same two’s-complement bit pattern, but, in an expression, the -’d12 loses its identity as a signed negative number.

```c
int IntA;
IntA = -12 / 3;  // The result is -4.
IntA = -'d12 / 3;  // The result is 1431655761.
IntA = -'sd12 / 3;  // The result is -4.
IntA = -4'sd12 / 3;  // -4'sd12 is the negative of the 4-bit quantity 1100,
                     // which is -4. -(-4) = 4. The result is 1.
```

4.6.2 Floating-point constants

Floating-point constant numbers can be specified either in decimal notation (e.g., 14.72) or in scientific notation (e.g., 39e8, which means 39 multiplied by 10 to the 8th power). Floating-point numbers expressed with a decimal point shall have at least one digit on each side of the decimal point. Whitespace is not permitted between the components of a floating-point constant.

Examples:

```c
20.14  // Legal
20 .15 // Illegal. No whitespace is permitted between components.
2e6   // Legal, means 2 * 10**6
1e-9  // Legal, means 1 * 10**-9
```

4.7 String literals

A string literal is a sequence of ASCII characters enclosed by a single pair of quotation marks (" ... "), called a quoted string, or a triple pair of quotation marks (""" ... """"), called a triple-quoted string. There is no predefined limit to the length of a string literal. The formal syntax for string literals is shown in Syntax 2.

```
string_literal ::= 
    QUOTED_STRING 
  | TRIPLE_QUOTED_STRING

QUOTED_STRING ::= " { unescaped_character | escaped_character } "
TRIPLE_QUOTED_STRING ::= """{any_ASCII_character}""
unescaped_character ::= any_printable_ASCII_character
escaped_character ::= (|"|\|a|b|f|n|r|t|v|[0-7][0-7][0-7])
filename_string ::= QUOTED_STRING
```

Syntax 2—String literals

PSS also includes a string data type to which a string literal can be assigned or compared. Variables of type string have arbitrary length; they are dynamically resized to hold any string. String literals are implicitly
converted to the string type when assigned to a string type or used in an expression involving string type operands.

The empty string literal (""") represents an empty, or null, string.

Quoted string literals may only contain printable ASCII characters (the decimal values 32 through 126, or 0x20 through 0x7E in hexadecimal). Certain characters can be used in quoted string literals when preceded by an escape character (a backslash). Table 3 lists these characters, with the escape sequence that represents them. A quoted string shall be contained in a single line.

Table 3—Specifying special characters in string literals

<table>
<thead>
<tr>
<th>Escape sequence</th>
<th>ASCII hex value</th>
<th>Character produced by escape sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>\a</td>
<td>0x07</td>
<td>Alert (Beep, Bell)</td>
</tr>
<tr>
<td>\b</td>
<td>0x08</td>
<td>Backspace</td>
</tr>
<tr>
<td>\f</td>
<td>0x0C</td>
<td>Formfeed</td>
</tr>
<tr>
<td>\n</td>
<td>0x0A</td>
<td>Newline</td>
</tr>
<tr>
<td>\r</td>
<td>0x0D</td>
<td>Carriage return</td>
</tr>
<tr>
<td>\t</td>
<td>0x09</td>
<td>Horizontal tab</td>
</tr>
<tr>
<td>\v</td>
<td>0x0B</td>
<td>Vertical tab</td>
</tr>
<tr>
<td>\</td>
<td>0x5C</td>
<td>\ character (backslash)</td>
</tr>
<tr>
<td>&quot;</td>
<td>0x22</td>
<td>&quot; character (double quotation mark)</td>
</tr>
<tr>
<td>'</td>
<td>0x27</td>
<td>' character (apostrophe, single quotation mark)</td>
</tr>
<tr>
<td>?</td>
<td>0x3F</td>
<td>? character (question mark)</td>
</tr>
<tr>
<td>\ddd</td>
<td>any</td>
<td>A character specified in 3 octal digits (see Syntax 1). Implementations may issue an error if the character represented is greater than \377.</td>
</tr>
</tbody>
</table>

An escape sequence is considered a single character in the string literal. An escaped apostrophe or question mark is treated the same as an unescaped apostrophe or question mark, respectively, i.e., the backslash is ignored. The other escaped characters in the table have different meanings from their unescaped versions. It is illegal for an escape character in a quoted string literal to be followed by any character not appearing in the table above.

In contrast, a triple-quoted string literal may contain any ASCII character, printing or nonprinting. There is no escape character. All characters are passed as they are, unchanged. For example, triple-quoted strings may contain both single and double quotation marks (except for three consecutive double quotation marks) and newline characters.

Both quoted string literals and triple-quoted string literals may be used anywhere a string literal is desired or required, except for filename_strings (see target_file_exec_block in Syntax 71), where a quoted string is required.

In a string literal that appears in target-template code, mustache notation ({{expression}}) can be used to reference PSS variables. See 21.5.3 and 21.6 for details.
4.7.1 Examples

The following string literals are equivalent:

" \"Humpty Dumpty sat on a wall.\nHumpty Dumpty had a great fall.\" "

""" "Humpty Dumpty sat on a wall. 
Humpty Dumpty had a great fall." ""

4.8 Aggregate literals

Aggregate literals are used to specify the content values of collections and structure types. The different types of aggregate literals are described in the following sections. The use of aggregate literals in expressions is described in 8.4.2.

aggregate_literal ::= 
| empty_aggregate_literal |
| value_list_literal |
| map_literal |
| struct_literal |

Syntax 3—Aggregate literals

4.8.1 Empty aggregate literal

empty_aggregate_literal ::= { }

Syntax 4—Empty aggregate literal

Aggregate literals with no values specify an empty collection (see 7.9) when used in the context of a variable-sized collection type (list, set, map).

4.8.2 Value list literals

value_list_literal ::= { expression { , expression } } 

Syntax 5—Value list literal

Aggregate literals for use with arrays, lists, and sets (see 7.9) use value list literals. Each element in the list specifies an individual value. When used in the context of a variable-size data type (list, set), the number of elements in the value list literal specifies the size as well as the values. However, when used in the context of sets, each value is counted only once, even if it appears multiple times. When used in the context of arrays and lists, the value list literal also specifies the order of elements, starting with element 0. The data types of the values must match the data type specified in the collection declaration.

When a value list literal is used in the context of an array, the value list literal must have the same number of elements as the array. It is an error if the value list literal has more or fewer elements than the array.
Values in value list literals may be non-constant expressions.

### 4.8.3 Map literals

```plaintext
map_literal ::= { map_literal_item { , map_literal_item } }
map_literal_item ::= expression : expression
```

**Syntax 6—Map literal**

Aggregate literals for use with `map` (see 7.9.4) use **map literals**. The first element in each colon-separated pair is the key. The second element is the value to be associated with the key. The data types of the expressions must match the data types specified in the `map` declaration. If the same key appears more than once, the last value specified is used.

In **Example 2**, a map literal is used to set the value of a `map` with integer keys and Boolean values.

```plaintext
struct t {
    map<int,bool> m = {1:true, 2:false, 4:true, 8:false};
    constraint m[1]; // True, since the value "true" is associated with key "1"
}
```

**Example 2—Map literals**

Both keys and values in map literals may be non-constant expressions.

### 4.8.4 Structure literals

```plaintext
struct_literal ::= { struct_literal_item { , struct_literal_item } }
struct_literal_item ::= .identifier = expression
```

**Syntax 7—Structure literal**

A structure literal explicitly specifies the name of the `struct` attribute that a given expression is associated with. **Struct** attributes whose value is not specified are assigned the default value of the attribute’s data type. The order of the attributes in the literal does not have to match their order in the `struct` declaration. It shall be illegal to specify the same attribute more than once in the literal.

In **Example 3**, the initial value for the attributes of `s1` is explicitly specified for all attributes. The initial value for the attributes of `s2` is specified for a subset of attributes. The resulting value of both `s1` and `s2` is `{.a=1,.b=2,.c=0,.d=0}`. Consequently, the constraint `s1==s2` holds.
Values in structure literals may be non-constant expressions.

### 4.8.5 Nesting aggregate literals

Aggregate literals may be nested to form the value of data structures formed from nesting of aggregate data types.

In **Example 4**, an aggregate literal is used to form a list of `struct` values. Each structure literal specifies a subset of the `struct` attributes.

```c
struct s {
    int a, b, c, d;
};
struct t {
    list<s> my_l = {
        {a=1, d=4},
        {b=2, c=8}
    };
}
```

**Example 4—Nesting aggregate literals**
5. Modeling concepts

A PSS model is made up of a number of elements (described briefly in 1.3) that define a set of possible scenarios to be applied to the Design Under Test (DUT) via the associated test environment. Scenarios are composed of behaviors—ultimately executed on some combination of components that make up the DUT or on verification components that define the test environment—and the communication between them. This clause introduces the elements of a PSS model and defines their relationships.

The primary behavior abstraction mechanism in PSS is an action, which represents a particular behavior or set of behaviors. Actions combine to form the scenarios that represents the verification intent. Actions that correspond directly to operations performed by the underlying DUT or test environment are referred to as atomic actions, which contain an explicit mapping of the behavior to an implementation on the target platform in one of several supported forms. Compound actions encapsulate flows of other actions using an activity that defines the critical intent to be verified by specifying the relationships between specific actions.

The remainder of the PSS model describes a set of rules that are used by a PSS processing tool to create the scenarios that implements the critical verification intent while satisfying the data flow, scheduling, and resource constraints of the target DUT and associated test environment. In the case where the specification of intent is incomplete (partial), the PSS processing tool shall infer the execution of additional actions and other model elements necessary to make the partial specification complete and valid. In this way, a single partial specification of verification intent may be expanded into a variety of actual scenarios that all implement the critical intent, but might also include a wide range of other behaviors that may provide greater coverage of the functionality of the DUT as demonstrated in the example in Figure 1.

![Diagram](image-url)
In Figure 1, actions a, b, and c are specified to be traversed sequentially in an activity. Depending on the data flow between them, and on other constraints in the model, this may describe a complete scenario specification (see Figure 1(i)), or it may describe a partial specification, which may be expanded into multiple scenarios that infer other actions. All scenarios satisfy the critical intent defined by the activity, where a will be traversed, followed sometime later by b, followed sometime later by c. Figure 1 shows several possible scenarios that may be generated from the partial specification, depending on various factors to be discussed later in this section.

An activity primarily specifies the set of actions to be executed and the scheduling relationships between them. Actions may be scheduled sequentially, in parallel, or in various combinations based on conditional evaluation, looping, or randomization constructs. Activities may also include explicit data bindings between actions. An activity that traverses a compound action is evaluated hierarchically, i.e., when a compound sub-action is traversed in an activity, the sub-action activity is traversed fully at that point in the parent activity (see 5.3.2).

5.1 Modeling data flow

Actions may be declared to have inputs and/or outputs of a given data flow object type. The data flow object types define scheduling semantics for the given action relative to those with which it shares the object. Data flow objects may be declared directly or may inherit from user-defined data structures or other flow objects of a compatible type. An action that outputs a flow object is said to produce that object and an action that inputs a flow object is said to consume the object. Data flow objects are described in Clause 13.

5.1.1 Buffers

The first kind of data flow object is the buffer type. A buffer represents persistent data that can be written (output) by a producing action and may be read (input) by any number of consuming actions. As such, a buffer defines a strict scheduling dependency between the producer and the consumer that requires the producing action to complete its execution—and, thus, complete writing the buffer object—before execution of the consuming action may begin to read the buffer (see Figure 2). Note that other consuming actions may also input the same buffer object. While there are no implied scheduling constraints between the consuming actions, none of them may start until the producing action completes.

![Buffer flow object semantics](image)

Figure 2—Buffer flow object semantics

Figure 2 illustrates the sequential scheduling semantics between the producer and consumer of a buffer flow object.

In Figure 1(i), assume that action a produces a buffer of a particular type, and b inputs a buffer object of a compatible type. In this case, we say that the buffer object is bound from the output of a to the input of b, since the semantics of the buffer object support the activity. Similarly, in Figure 1(ii), if, instead of action a,
action \(d\) produced a buffer object of a compatible type for action \(b\), action \(d\) could be inferred as the producer of the buffer for action \(b\) to consume. The buffer scheduling semantics allow action \(d\) to be inferred at any point in the schedule prior to the start of action \(b\) (shown in Figure 1(ii) as either \(d_1\), \(d_2\), or \(d_3\)), while the activity requires only that action \(a\) completes before action \(b\) starts. In this case, there is no explicit scheduling constraint between \(a\) and \(d\).

### 5.1.2 Streams

The *stream* flow object type represents *transient* data exchanged between actions. The semantics of the stream flow object require that the producing and consuming actions execute in parallel (i.e., both activities shall begin execution when the same preceding actions complete; see Figure 3). In a stream object, there shall be a one-to-one connection between the producer and consumer.

![Figure 3—Stream flow object semantics](image)

Figure 3 illustrates the parallel scheduling semantics between the producer and the consumer of a stream flow object.

In Figure 1(iii), the parallel execution of actions \(f\) and \(g\) dictates that any data exchanged between these actions shall be of the *stream* type. Again, assuming that action \(a\) does not output a compatible buffer for action \(b\) to input, then action \(f\) may be inferred to supply the buffer to action \(b\). If action \(f\) inputs or outputs a stream object, then the one-to-one requirement of the stream object would require that action \(g\), which has a compatible stream type, also be inferred to execute in parallel with \(f\). Action \(e\) may be inferred if it is needed to supply a buffer input to either \(f\) or \(g\).

NOTE—Figure 1(iv) shows an alternate inferred scenario that also satisfies the base scenario of sequential execution of actions \(a\), \(b\), and \(c\), but in this case, the binding between \(a\) and \(b\) is legal, and action \(c\) requires a buffer input that can only be supplied by \(f\) or \(g\).

### 5.1.3 States

The *state* flow object represents the state of some element in the DUT or test environment at a given time. Multiple actions may read or write the state object, but only one write action may execute at a time. Any number of read actions may execute in parallel, but read and write actions shall be sequential (see Figure 4).
State flow objects have a built-in Boolean **initial** attribute that is automatically set to **true** initially and automatically set to **false** on the first write operation to the state object. This attribute can be used in constraint expressions to define the starting value for fields of the state object and then allow the values to be modified on subsequent writes of the state object.

### 5.1.4 Data flow object pools

Data flow objects are grouped into pools, which can be used to limit the set of actions that can communicate using objects of a given type. For buffer and stream types, the pool will contain the number of objects of the given type needed to support the communication between actions sharing the pool. For state objects, the pool will only contain a single object of the state type at any given time. Thus, all actions sharing a state object via a pool will see the same value for the state object at a given time. Pools are described in Clause 15.

### 5.2 Modeling system resources

#### 5.2.1 Resource objects

In addition to declaring inputs and outputs, actions may require system resources that must be accessible in order to accomplish the specified behavior. The resource object is a user-defined data object that represents this functionality. Similar to data flow objects, a resource may be declared directly or may inherit from a user-defined data structure or another resource object. Resource objects are described in Clause 14.

#### 5.2.2 Resource pools

Resource objects are also grouped into pools to define the set of actions that have access to the resources. A resource pool is defined to have an explicit number of resource objects in it (the default is 1), corresponding to the available resources in the DUT and/or test environment. In addition to optionally randomizable data fields, the resource has a built-in non-negative integer attribute called **instance_id**, which serves to identify the resource and is unique for each resource in the given pool. Pools are described in Clause 15.

#### 5.2.2.1 Locking resources

An action that requires exclusive access to a resource may **lock** the resource, which prevents any other action that claims the same resource instance from executing until the locking action completes. For a given pool of resource $R$, with size $S$, there may be $S$ actions that lock a resource of type $R$ executing at any given time. Each action that locks a resource in a given pool at a given time shall have access to a unique instance of the resource, identified by the integer attribute **instance_id**. For example, if a DUT contains two DMA channels, the PSS model would define a pool containing two instances of the DMA_channel resource type.
In this case, no more than two actions that lock the DMA\textunderscore channel resource could be scheduled concurrently.

### 5.2.2.2 Sharing resources

An action that requires non-exclusive access to a resource may share the resource. An action may not share a resource instance that is locked by another action, but may share the resource instance with other actions that also share the same resource instance. If all resources in a given pool are locked at a given time, then no sharing actions can execute until at least one locking action completes to free a resource in that pool.

### 5.3 Basic building blocks

#### 5.3.1 Components and binding

A critical aspect of portability is the ability to encapsulate elements of verification intent into "building blocks" that can be used to combine and compose PSS models. A component is a structural element of the PSS model that serves to encapsulate other elements of the model for reuse. A component is typically associated with a structural element of the DUT or testbench environment, such as hardware engines, software packages, or testbench agents, and contains the actions that the element is intended to perform, as well as the data and resource pools associated with those actions. Each component declaration defines a unique type that can be instantiated inside other components. The component declaration also serves as a type namespace in which other types may be declared.

A PSS model is composed of one or more component instantiations constituting a static hierarchy beginning with the top-level or root component, called pss\textunderscore top by default, which is implicitly instantiated. Components are identified uniquely by their hierarchical path. In addition to instantiating other components, a component may declare functions and class instances (see Clause 9).

When a component instantiates a pool of data flow or resource objects, it also shall bind the pool to a set of actions and/or subcomponents to define who has access to the objects in the pool. Actions may only communicate via an object pool with other actions that are bound to the same object pool. Object binding may be specified hierarchically, so a given pool may be shared across subcomponents, allowing actions in different components to communicate with each other via the pool.

#### 5.3.2 Evaluation and inference

A PSS model is evaluated starting with the top-level root action, which shall be specified to a tool. The component hierarchy, starting with pss\textunderscore top or a user-specified top-level component, provides the context in which the model rules are defined. If the root action is a compound action, its activity forms the root of a potentially hierarchical activity tree that includes all activities present in any sub-activities traversed in the activity. Additional actions may be inferred as necessary to support the data flow and binding requirements of all actions explicitly traversed in the activity, as well as those previously inferred. Resources add an additional set of scheduling constraints that may limit which actions actually get inferred, but resources do not cause additional actions to be inferred.

The semantics of data flow objects allow the tool to infer, for each action in the overall activity, connections to other actions already instantiated in the activity; or to infer and connect new action instances to conform to the scheduling constraints defined in the activity and/or by the data and resource requirements of the actions, including pool bindings. The model thus consists of a set of actions, with defined scheduling dependencies, along with a set of data flow objects that may be explicitly bound or inferred to connect between actions and a set of resources that may be claimed by the actions as each executes. Actions and flow objects and their bindings may only be inferred as required to make the (partial) activity specification legal.
A PSS implementation shall not infer an action or object binding that is not required, either directly or indirectly, to make the activity specification legal. Clause 17 describes action inferencing in more detail. Figure 5 demonstrates how actions can be inferred to generate multiple scenarios from a single activity.

Looking at Figure 5, actions a, b, and c are scheduled sequentially in an activity. The data flow and resource requirements specified in the model (which are not shown in Figure 5) allow for multiple scenarios to be generated. If action a has a buffer or state input, then an action, f in this case, is inferred to execute sequentially before a in order to provide the buffer or state object. If a does not have a buffer or state input, f may still be inferred in order to supply an input to b or c, and may ultimately be scheduled before a as shown, although the only real scheduling constraint is that f complete before the start of the action that requires the input flow object.

Once inferred, if f also has a buffer or state input, then another action shall be inferred to supply that object and so on until an action is inferred that does not have an input (or the tool’s inferencing limit is exceeded, at which point an error shall be generated). For the purposes of this example, action f does not have an input.

In Figure 5(i), presume that action a produces (or consumes) a stream object. In this case, action d is inferred in parallel with a since stream objects require a one-to-one connection between actions. Actions a and d both start upon completion of action f. If action d also has a buffer input, then another action shall be
inferred to provide that input. For Figure 5(i), action \( f \) can be presumed to have a second buffer output that gets bound to action \( d \), although a second buffer-providing action could also have been inferred.

If action \( a \) produces a buffer object, the buffer may be connected to another action with a compatible input type. In the case where \( a.out \) and \( b.in \) are incompatible, action \( e \) (or a series of actions) may be inferred to receive the output of action \( a \) and produce the input to action \( b \). If \( a.out \) and \( b.in \) are compatible, then the direct connection between \( a.out \) and \( b.in \) would be inferred here, in which case no action would be inferred between them, although an action inferred to supply the input to \( c \) (or for some other reason) could be scheduled between them.

Similarly, in the absence of an explicit binding of \( b.out \) to \( c.in \), and if they are incompatible, a series of actions may be inferred prior to the start of action \( c \) in order to provide the input of action \( c \). These inferred actions will be scheduled independent of \( b \) unless their data flow requirements create scheduling constraints relative to \( b \). As the terminal action in the activity, no action may be inferred after action \( c \) however, even if action \( c \) produces a buffer object as an output.

If \( b.out \) and \( c.in \) are incompatible, it is possible to infer another action, \( j \), to supply the buffer input to \( c.in \), as shown in Figure 5(ii). In this case, there are two constraints on when the execution of action \( c \) may begin. The activity scheduling requires action \( b \) to complete before action \( c \) starts. The buffer object semantics also require action \( j \) to complete before action \( c \) starts. If action \( j \) requires a buffer input, a series of actions could be inferred to supply the buffer object. That inferred action chain could eventually be bound to a previously inferred action, such as action \( d \) as shown in Figure 5(ii), or it may infer an independent series of actions until it infers an initial action that only produces an output or until the inferencing limit is reached. Since the output of action \( b \) is not bound to action \( c \), action \( b \) is treated as a terminating action, so no subsequent actions may be inferred after action \( b \).

Finally, Figure 5(iii) shows the case where action \( c \) produces or consumes a stream object. In this case, even though action \( c \) is the terminating action of the activity, action \( p \) shall be inferred to satisfy the stream object semantics for action \( c \). Here, action \( p \) is also treated as a terminating action, so no subsequent actions may be inferred. However, additional actions may be inferred either preceding or in parallel to action \( p \) to satisfy its data flow requirements. Each action thus inferred is also treated as a terminating action. Similarly, since action \( b \) is not bound to action \( c \), \( b \) shall also be treated as a terminating action.

5.4 Constraints and inferencing

Data flow and resource objects may define constraint expressions on the values of their data fields (including instance_id in the case of resource objects). In addition, actions may also define constraint expressions on the data fields of their input/output flow objects and locked/shared resource objects. For data flow objects, all constraints defined in the object and in all actions that are bound to the object are combined to define the legal set of values available for the object field. Similarly, the constraints defined for a resource object shall be combined with the constraints defined in all actions that claim the resource. Inferred actions or data flow objects that result in constraint contradictions are excluded from the legal scenario. At least one valid solution must exist for the scenario model for that model to be considered valid.

5.5 Summary

In portable stimulus, a single PSS model may be used to generate a set of scenarios, each of which may have different sets of inferred actions, data flow objects, and resources, while still implementing the critical verification intent explicitly specified in the activity. Each resulting scenario may be generated as a test implementation for the target platform by taking the behavior mapping implementation embedded in each resulting atomic action and generating output code that assembles the implementations and provides any other required infrastructure to ensure the behaviors execute on the target platform according to the scheduling semantics defined by the original PSS model.
6. Execution semantic concepts

6.1 Overview

A PSS test scenario is identified given a PSS model and an action type designated as the root action. The execution of the scenario consists essentially in executing a set of actions defined in the model, in some (partial) order. In the case of atomic actions, the mapped behavior of any `exec body` clauses (see 21.1.2) is invoked in the target execution environment, while for compound actions the behaviors specified by their `activity` statements are executed.

All action executions observed in a test run either correspond to those explicitly called by traversed activities or are implicitly introduced to establish flows that are correct with respect to the model rules. The order in which actions are executed shall conform to the flow dictated by the activities, starting from the root action, and shall also be correct with respect to the model rules. Correctness involves consistent resolution of actions’ inputs, outputs, and resource references, as well as satisfaction of scheduling constraints. Action executions themselves shall reflect data attribute assignments that satisfy all constraints.

6.2 Assumptions of abstract scheduling

Guarantees provided by PSS are based on general capabilities that test realizations need to have in any target execution environment. The following are assumptions and invariants from the abstract semantics viewpoint.

6.2.1 Starting and ending action executions

PSS semantics assume that target-mapped behavior associated with atomic actions can be invoked in the execution environment at arbitrary points in time, unless model rules (such as state or data dependencies) restrict doing so. They also assume that target-mapped behavior of actions can be known to have completed.

PSS semantics make no assumptions on the duration of the execution of the behavior. They also make no assumptions on the mechanism by which an implementation would monitor or be notified upon action completion.

6.2.2 Concurrency

PSS semantics assume that actions can be invoked to execute concurrently, under restrictions of model rules (such as resource contentions).

PSS semantics make no assumptions on the actual threading framework employed in the execution environment. In particular, a target may have a native notion of concurrent tasks, as in SystemVerilog simulation; it may provide native asynchronous execution threads and means for synchronizing them, such as embedded code running on multi-core processors; or it may implement time sharing of native execution thread(s) in a preemptive or cooperative threading scheme, as is the case with a runtime operating system kernel. PSS semantics do not distinguish between these.

6.2.3 Synchronized invocation

PSS semantics assume that action invocations can be synchronized, i.e., logically starting at the same time. In practice there may be some delay between the invocations of synchronized actions. However, the “sync-time” overhead is (at worse) relative to the number of actions that are synchronized and is constant with respect to any other properties of the scenario or the duration of any specific action execution.
PSS semantics make no assumptions on the actual runtime logic that synchronizes native execution threads and put no absolute limit on the “sync-time” of synchronized action invocations.

6.3 Scheduling concepts

PSS execution semantics define the criteria for legal runs of scenarios. The criterion covered in this section is stated in terms of scheduling dependency—the fundamental scheduling relation between action executions. Ultimately, scheduling is observed as the relative order of behaviors in the target environment per the respective mapping of atomic actions. This section defines the basic concepts, leading up to the definition of sequential and parallel scheduling of action executions.

6.3.1 Preliminary definitions

a) An action execution of an atomic action type is the execution of its exec-body block, with values assigned to all of its parameters (reachable attributes). The execution of a compound action consists in executing the set of atomic actions it contains, directly or indirectly. For more on execution semantics of compound actions and activities, see Clause 12.

An atomic action execution has a specific start-time—the time in which its exec-body block is entered, and end-time—the time in which its exec-body block exits (the test itself does not complete successfully until all actions that have started complete themselves). The start-time of an atomic action execution is assumed to be under the direct control of the PSS implementation. In contrast, the end-time of an atomic action execution, once started, depends on its implementation in the target environment, if any (see 6.2.1).

The difference between end-time and start-time of an action execution is its duration.

b) A scheduling dependency is the relation between two action executions, by which one necessarily starts after the other ends. Action execution \( b \) has a scheduling dependency on \( a \) if \( b \)'s start has to wait for \( a \)'s end. The temporal order between action executions with a scheduling dependency between them shall be guaranteed by the PSS implementation regardless of their actual duration or that of any other action execution in the scenario. Taken as a whole, scheduling dependencies constitute a partial order over action executions, which a PSS solver determines and a PSS scheduler obeys.

Consequently, the lack of scheduling dependency between two action executions (direct or indirect) means neither one must wait for the other. Having no scheduling dependency between two action executions implies that they may (or may not) overlap in time.

c) Action executions are synchronized (scheduled to start at the same time) if they all have the exact same scheduling dependencies. No delay shall be introduced between their invocations, except a minimal constant delay (see 6.2.3).

d) Two or more sets of action executions are independent (scheduling-wise) if there is no scheduling dependency between any two action executions across the sets. Note that within each set, there may be scheduling dependencies.

e) Within a set of action executions, the initial ones are those without scheduling dependency on any other action execution in the set. The final action executions within the set are those in which no other action execution within the set depends.

---

7Throughout this section, exec-body block is referred to in the singular, although it may be the aggregate of multiple exec-body clauses in different locations in PSS source code (e.g., multiple declarations in a given action type definition or in different extensions of the same action type).
6.3.2 Sequential scheduling

Action executions a and b are scheduled in sequence if b has a scheduling dependency on a. Two sets of action executions, S₁ and S₂, are scheduled in sequence if every initial action execution in S₂ has a scheduling dependency on every final action execution in S₁. Generally, sequential scheduling of N action execution sets S₁ .. Sₙ is the scheduling dependency of every initial action execution in Sᵢ on every final action execution in Sᵢ₋₁ for every i from 2 to N, inclusive.

For examples of sequential scheduling, see 12.3.3.2.

6.3.3 Parallel scheduling

N sets of action executions S₁ .. Sₙ are scheduled in parallel if the following two conditions hold:

— All initial action executions in all N sets are synchronized (i.e., all have the exact same set of scheduling dependencies).
— S₁ .. Sₙ are all scheduled independently with respect to one another (i.e., there are no scheduling dependencies across any two sets Sᵢ and Sⱼ).

For examples of parallel scheduling, see 12.3.4.2.

6.3.4 Concurrent scheduling

N sets of action executions S₁ .. Sₙ are scheduled concurrently if S₁ .. Sₙ are all scheduled independently with respect to one another (i.e., there are no scheduling dependencies across any two sets Sᵢ and Sⱼ).
7. Data types

7.1 General

In this document, “scalar” means a single data item of type bit, int, bool, enum, string, float32, float64, or chandle, unless otherwise specified. A struct (see 7.8) or collection (see 7.9) is not a scalar. A typedef (see 7.11) of a scalar data type is also a scalar data type.

The term “aggregate” refers both to collections and to structs. The term “aggregate” does not include actions, components, flow objects, or resource objects. Aggregates may be nested. A typedef of an aggregate data type is also an aggregate data type.

A “plain-data type” is a scalar or an aggregate of scalars. Nested aggregates are also plain-data types. A typedef of a plain-data type is also a plain-data type.

Fields of all scalar types except chandle, float32, and float64 are randomizable. Array and list collections of randomizable types are also randomizable, but the map and set collection types are not randomizable.

A field of randomizable type may be declared as random by preceding its declaration with the rand keyword. It shall be an error to declare a field of non-randomizable type as rand.

7.1.1 Syntax

The syntax for data types and data declarations is shown in Syntax 8.

```plaintext
data_type ::= scalar_data_type | collection_type | reference_type | type_identifier
scalar_data_type ::= chandle_type | integer_type | string_type | bool_type | enum_type | float_type

data_declaration ::= data_type data_instantiation { , data_instantiation } ;
data_instantiation ::= identifier [ array_dim ] [ = constant_expression ]
array_dim ::= [ constant_expression ]
attr_field ::= [ access_modifier ] [ rand | static const ] data_declaration
access_modifier ::= public | protected | private
```

_Syntax 8—Data types and data declarations_

Scalar data types are described in 7.2 through 7.7, structure data types are described in 7.8, and collection data types are described in 7.9. Reference types are described in 7.10. Access protection and access modifiers are described in 19.4.
7.2 Integer types

PSS supports two 2-state integer data types. These fundamental integer data types are summarized in Table 4, along with their default widths and value domains.

<table>
<thead>
<tr>
<th>Data type</th>
<th>Default width</th>
<th>Default domain</th>
<th>Signed/Unsigned</th>
</tr>
</thead>
<tbody>
<tr>
<td>int</td>
<td>32 bits</td>
<td>(-2^31 \ldots (2^31-1))</td>
<td>Signed</td>
</tr>
<tr>
<td>bit</td>
<td>1 bit</td>
<td>0..1</td>
<td>Unsigned</td>
</tr>
</tbody>
</table>

4-state values are not supported. If 4-state values are passed into the PSS model via the foreign procedural interface (see 21.4), any \(X\) or \(Z\) values are converted to 0.

7.2.1 Syntax

The syntax for integer types is shown in Syntax 9.

```
integer_type ::= integer_atom_type
               [ [ constant_expression [ : 0 ] ] ]
               [ in [ domain_open_range_list ] ]
integer_atom_type ::= int | bit
domain_open_range_list ::= domain_open_range_value { , domain_open_range_value }
domain_open_range_value ::= constant_expression [ .. constant_expression ]
                           | constant_expression ..
                           | .. constant_expression
```

**Syntax 9—Integer type declaration**

The following also apply:

a) Integer values of `bit` type are unsigned. Integer values of `int` type are signed.

b) The default value of the `bit` and `int` types is 0.

c) Widths should be specified with a single expression with a constant positive integer value (e.g., `bit{4}`). A specification of \([N]\) is equivalent to \([N-1:0]\). A type specified using dual bounds shall use 0 as the lower bound and a constant non-negative integer value as the upper bound. Specifying a width using dual bounds is considered deprecated in PSS 2.0, and may be removed in a future version.

d) A value domain may be specified for the type. The domain specification consists of a list of one or more values and/or value ranges.

e) The width and value domain specifications are independent. A variable of the declared type can hold values within the intersection of the possible values determined by the specified width (or the default width, if not specified) and the explicit value domain specification, if present.
7.2.2 Examples

PSS integer data type examples are shown in-line in this section.

Declare a signed variable that is 32 bits wide.

    int a;

Declare a signed variable that is 5 bits wide.

    int [4:0] a;

Declare an unsigned variable that is 5 bits wide and has the valid values 0..31.

    bit [5] in [0..31] b;

Declare an unsigned variable that is 5 bits wide and has the valid values 1, 2, and 4.

    bit [5] in [1,2,4] c;

Declare an unsigned variable that is 5 bits wide and has the valid values 0..10.

    bit [5] in [..10] b; // 0 <= b <= 10

Declare an unsigned variable that is 5 bits wide and has the valid values 10..31.

    bit [5] in [10..] b; // 10 <= b <= 31

7.3 Floating-point types

PSS supports two floating-point computation data types, as summarized by Table 5 below.

Table 5—Floating-point computation data types

<table>
<thead>
<tr>
<th>Data type</th>
<th>Width</th>
<th>Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>float32</td>
<td>32 bits</td>
<td>IEEE 754 binary32</td>
</tr>
<tr>
<td>float64</td>
<td>64 bits</td>
<td>IEEE 754 binary64</td>
</tr>
</tbody>
</table>

7.3.1 Syntax

The syntax for floating-point computation data types is shown in Syntax 10 below.
Variables of floating-point type may not be declared `rand`, and may not be randomized using the `randomize` statement.

PSS also defines packed-struct `storage` types as part of the core library (see 23.9.1). These types support various non-IEEE floating-point number formats.

Arithmetic operations may be performed on the `computation` data types. Arithmetic operations may not be performed directly on storage data types. Data held in a variable of floating-point storage type must first be converted into a computation type.

### 7.3.2 Cross-platform results

Floating-point computation has platform dependencies, with different processors and algorithms legitimately producing slightly different results. These differences may be apparent, for example, when comparing the result of computations performed on the solve platform with those performed on the target platform. The PSS LRM makes no attempt to force the result of floating-point computations to be identical across platforms.

### 7.4 Booleans

The PSS language supports a built-in Boolean type, with the type name `bool`. The `bool` type has two enumerated values `true` (1) and `false` (0). When not initialized, the default value of a `bool` type is `false`.

### 7.5 Enumeration types

An `enumeration type` is a distinct user-defined type whose value is restricted to a specified set of integral named constants. Enumeration data types also can be easily referenced or displayed using the enumeration constant names as opposed to their numeric values.

#### 7.5.1 Syntax

The syntax for declaration of enumeration types is shown in Syntax 11.
An enumeration type declaration (\textit{enum\_declaration}) consists of the keyword \texttt{enum} followed by the name of the type (\textit{enum\_identifier}), an optional base type name (\textit{data\_type}), and a list in curly braces of constant names (\textit{enum\_items}) with optional constant integer value assignments.

The optional \textit{data\_type} denotes the base type. It must be the name of an integer type, which shall determine the set of possible values to be assigned to \textit{enum\_items}, for example: \texttt{int}, or \texttt{bit[16]}, or \texttt{int[3]}. In effect, it shall determine the width and the signedness of the items. The base type shall not have a value domain (for example, \texttt{int in [1..10]} cannot be used as a base type).

The following also apply:

a) \textit{enum\_items} are considered static constant members of the enumeration type in which they are declared.

b) The first \textit{enum\_item} in the list, if not explicitly assigned a value, is by default assigned the value \texttt{0}. Each following \textit{enum\_item}, if not explicitly assigned a value, is assigned a value of the previous \textit{enum\_item} + \texttt{1}.

c) If a base type (\textit{data\_type}) is specified, \textit{enum\_item} values are limited to the set of valid values of the base type. It shall be an error to explicitly assign a value which does not belong to the base type (for example, if the base type is unsigned, it shall be an error to assign a negative value). It shall also be an error to declare an \textit{enum\_item} without an explicit value if the previous \textit{enum\_item} has been assigned the greatest possible value of the base type (for example, if the base type is \texttt{bit[2]}, declaring an item without an explicit value is illegal if the previous item has the value \texttt{3}).

d) \textit{enum\_item} values need not be contiguous, nor need they be in ascending arithmetic order. An \textit{enum\_item} may be assigned a negative value (unless the base type is unsigned).

e) Each \textit{enum\_item} must have a distinct integer value. No two \textit{enum\_items} may have the same value.

f) Enumeration types may be extended with the \texttt{extend} statement. See \texttt{19.2}, particularly \texttt{19.2.4}.

g) \textit{enum\_item} identifiers must be unique in the scope of the enumeration type across its initial definition and extensions, if any. However, they need not be unique across different enumeration types declared in the same namespace.

h) \textit{enum\_items} can be referenced using their qualified name in the form `'\texttt{enum\_type-name:enum\_item-name}'`.

i) In expression contexts where the expected type is an enumeration type, \textit{enum\_items} of that type can be referenced without qualification (see \texttt{8.4.3} for the definition of the expected type in expression contexts).

j) An \textit{enum\_declaration} may contain an empty set of \textit{enum\_items}, and then have \textit{enum\_items} added in extensions. It shall be illegal to declare an enumeration variable whose type contains no \textit{enum\_items} across its initial definition and extensions.

k) When not initialized, the default value of an \texttt{enum} field shall be the first \textit{enum\_item} in the list. This is not necessarily the value \texttt{0} nor the \textit{enum\_item} with the minimum value.

\begin{verbatim}
enum\_declaration ::= enum enum\_identifier [: data\_type] { [ enum\_item { , enum\_item } ] }
enum\_identifier ::= identifier
enum\_item ::= identifier [ = constant\_expression ]
enum\_type\_identifier ::= type\_identifier
enum\_type ::= enum\_type\_identifier [ in [ domain\_open\_range\_list ] ]
\end{verbatim}
Like numeric types, an enumeration type can be restricted to a range of values specified by a `domain_open_range_list` (see 7.2.1 and 7.2.2). The domain specification cannot be specified in the `enum_declaration` itself. See examples of use in 7.5.2.

An `enum` attribute or `enum_item` may be used to assign values to an attribute of the same enumeration type or in an equality comparison.

An `enum` attribute or `enum_item` of one enumeration type may be cast to another enumeration type using the cast operator (see 7.12). An `enum` attribute or `enum_item` may be cast to integer and Boolean data types using the cast operator. Similarly, an integer or Boolean value may be explicitly cast to an enumeration type.

### 7.5.2 Examples

Examples of enum usage are shown in Example 5.

```plaintext
enum config_modes_e {UNKNOWN, MODE_A=10, MODE_B=20, MODE_C=35, MODE_D=40};

component uart_c {
  action configure {
    rand config_modes_e mode;
    constraint {mode != UNKNOWN;}
  }
}
```

**Example 5—enum data type**

See an example of extending an enumeration in 19.2.4.

Examples of domain specifications for enumeration types are shown below:

Declare an enum of type `config_modes_e` with values `MODE_A`, `MODE_B`, or `MODE_C`.

```plaintext
rand config_modes_e in [MODE_A..MODE_C] mode_ac;
```

Declare an enum of type `config_modes_e` with values `MODE_A` or `MODE_C`.

```plaintext
rand config_modes_e in [MODE_A, MODE_C] mode_ac;
```

Declare an enum of type `config_modes_e` with values `UNKNOWN`, `MODE_A`, or `MODE_B`.

```plaintext
rand config_modes_e in [..MODE_B] mode_ub;
```

Declare an enum of type `config_modes_e` with values `MODE_B`, `MODE_C`, or `MODE_D`.

```plaintext
rand config_modes_e in [MODE_B..] mode_bd;
```

Note that an `open_range_list` of enums may be used in set membership `(in)` expressions (see 8.5.9) and as a `match_choice` expression in `match` statements (see 12.4.6 and 21.7.10).
7.6 Strings

The PSS language supports a built-in string type with the type name `string`. When not initialized, the default value of a `string` shall be the empty string literal (""").

7.6.1 Syntax

```plaintext
string_type ::= string [ in | string_literal { , string_literal } ]
```

*Syntax 12—string declaration*

Comma-separated domain specifications are allowed for string data types (see 7.2.1).

7.6.2 Examples

The value of a random string-type field can be constrained with equality constraints and can be compared using equality operators, as shown in Example 6.

```plaintext
struct string_s {
  rand bit     a;
  rand string  s;

  constraint {
    if (a == 1) {
      s == "FOO";
    } else {
      s == "BAR";
    }
  }
}
```

*Example 6—String data type*

Declare string with values "Hello", "Hallo", or "Ni Hao".

```plaintext
rand string in ["Hello", "Hallo", "Ni Hao"] hello_s;
```

Note that an `open_range_list`, composed solely of individual string literals, may also be used in set membership (in) expressions (see 8.5.9) and as a `match_choice` expression in `match` statements (see 12.4.6 and 21.7.10). Ranges of string literals (e.g., "a"..'b") are not permitted.

7.7 Chandles

The `chandle` type (pronounced “see-handle”) represents an opaque handle to a foreign language pointer as shown in Syntax 13. A `chandle` is used with the foreign procedural interface (see 21.4) to store foreign language pointers in the PSS model and pass them to foreign language functions. See Annex D for more information about the foreign procedural interface.

A `chandle` has the following restrictions:

- The `rand` qualifier may not be applied to it.
- The only logical operators it may be used with are `==` and `!=`. 
The only literal value with which it may be compared is 0, which is equivalent to a null handle in the foreign language.

When not initialized, the default value of a chandle shall be 0.

7.7.1 Syntax

<table>
<thead>
<tr>
<th>chandle_type ::= chandle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Syntax 13—chandle declaration</td>
</tr>
</tbody>
</table>

7.7.2 Example

Example 7 shows a struct containing a chandle field that is initialized by the return of a foreign language function.

```plaintext
function chandle do_init();

struct info_s {
    chandle ptr;

    exec pre_solve {
        ptr = do_init();
    }
}
```

Example 7—chandle data type
7.8 Structs

A struct type is an aggregate of data items, as shown in Syntax 14.

7.8.1 Syntax

A struct type is a plain-data type (see 7.1). That is, a struct may contain scalar data items and aggregates thereof. A struct declaration may specify a struct_super_spec, a previously defined struct type from which the new type inherits its members, by using a colon (:), as in C++. In addition, structs may

— include constraints (see 16.1) and covergroups (see 18.1 and 18.2);
— include exec blocks of any kind other than init_down, init_up, and body (see 21.1).

Data items in a struct shall be of plain-data types (whether randomizable or not). Declarations of randomizable data items may optionally include the rand keyword to indicate that the element shall be randomized when the overall struct is randomized (see Example 8). 16.4.1 describes struct randomization in detail.
### 7.8.2 Examples

A `struct` example is shown in Example 8.

```plaintext
struct axi4_trans_req {
    rand bit[31:0] axi_addr;
    rand bit[31:0] axi_write_data;
    bit is_write;
    rand bit[3:0] prot;
    rand bit[1:0] sema4;
}
```

**Example 8—Struct with rand qualifiers**

### 7.9 Collections

Collection types are built-in data types. PSS supports fixed-size `array` and variable-size `list`, `map`, and `set` collections of plain-data types (see §7.1). Each kind of collection has its own keyword, and its declaration specifies the data type of the collection elements (and for maps, also the data type of the key).

PSS also has limited support for fixed-sized arrays of action handles, components, and flow and resource object references, as described in §7.9.2. These are not considered plain-data types. All other collections are plain-data types.

#### 7.9.1 Syntax

```plaintext
collection_type ::=  
   array < data_type , array_size_expression >  
   | list < data_type >  
   | map < data_type , data_type >  
   | set < data_type >  
array_size_expression ::= constant_expression
```

**Syntax 15—Collection data types**

In an `array`, each element is initialized to the default initial value of the element type, unless the `array` declaration contains an initialization assignment. A `list`, `map` or `set` is initialized as an empty collection unless the declaration contains an initialization assignment. A collection that is empty is as if it was assigned an *empty aggregate literal* ( `{}` ). See §4.8 for more information on literal syntax and semantics used to initialize collection types.

Collections store both scalar and aggregate elements by value. This means that an element’s value is captured when it is added or assigned to a collection. Modifying the value of an element in a collection does not modify the element originally added to the collection. In the example below, `v1`, a `struct` with two integer values, is assigned as the first element of `my_list`. Modifying `a` in that element does not modify `v1`. (See §7.9.3 for more details on `list` operators and methods.)
Example 9—Modifying collection contents

Collection variables can be operated on with built-in operators using standard operator symbols (e.g., [], =, ==, etc.) or with built-in methods using a method name and an argument list in parentheses.

Operators and methods that modify the contents of a collection shall not be used in activities, constraints, or covergroups. These are allowed only in exec blocks (see 21.1) and native functions (see 21.3). Operators and methods that do not modify collection contents may be used in activities, constraints, and covergroups.

Arrays and lists of randomizable types are randomizable. Maps and sets are non-randomizable. It is legal to have a rand struct field that contains non-randomizable collection types.

Collection types may be nested to describe more complex collections.

Example 10—Nested collection types

7.9.2 Arrays

PSS supports fixed-sized arrays of plain-data types. Arrays may be declared with two different syntaxes, the classical syntax where arrays are declared by adding square brackets with the array size ([ constant_expression ]) after the array name, referred to as the square array syntax, and the syntax that is aligned to the other collection types, using angle brackets, referred to as the template array syntax.

Example 11—Array declarations

The same operators and methods may be applied to arrays declared using both syntaxes. However, the template array syntax may be used where a data_type is required, enabling such capabilities as use as a function return type, nested array types, and more.
An array with \( N \) elements, is ordered, with the first element accessed using \( 0 \) as an index value with the \([\] \) operator, and the last element accessed using \( N-1 \) as an index value.

The square array syntax can also be used to declare fixed-size arrays of action handles, components, and flow and resource object references. Individual elements of such arrays may be accessed using the \([\] \) operator. However, other operators and methods do not apply to these arrays, unless otherwise specified. Action handle arrays are described in 12.3.1.1 and 12.3.2, component arrays are described in 9.4, and object reference arrays are described in 13.4 and 14.2. Note that the elements of action handle arrays and object reference arrays have reference semantics (see 7.10).

7.9.2.1 Array operators

The following operators are defined for arrays:

**Index operator \([\] \)**

Used to access a specific element of an array, given an index into the array. The index shall be an integral value. See 8.6.2 for more information on the index operator.

**Assignment operator \(=\)**

Creates a copy of the array-type expression on the RHS and assigns it to the array on the LHS. See 8.3 for more information on the assignment operator.

**Equality operator \(==\)**

Evaluates to \( true \) if all elements with corresponding indexes are equal. Two arrays of different element types or different sizes are incomparable. See 8.5.3 for more information on the equality operator.

**Inequality operator \(!=\)**

Evaluates to \( true \) if not all elements with corresponding indexes are equal. Two arrays of different element types or different sizes are incomparable. See 8.5.3 for more information on the inequality operator.

**Set membership operator \(\text{in}\)**

The set membership operator can be applied to an array to check whether a specific element is currently within the array. It evaluates to \( true \) if the element specified on the left of the operator exists in the array collection on the right of the operator. The type of the element shall be the same as the array’s element data type. See 8.5.9 for more information on the set membership operator.

**foreach statement**

The **foreach** statement can be applied to an array to iterate over the array elements within an activity, a constraint or native exec code. See 12.4.3, 16.1.7, and 21.7.8, respectively, for more information on the **foreach** statements in these contexts.
7.9.2.2 Array methods

The following methods are defined for arrays:

**function int size();**

Returns the number of elements in the array. Since arrays have fixed sizes, the returned value is considered a constant expression. This function can also be used with arrays of action handles, components, and flow and resource object references.

**function <data_type> sum();**

Returns the sum of all elements currently stored in the array. This function can only be used on arrays of a numeric data type (int, bit, or floating-point type). The method can be used in a constraint to constrain an array of random int or bit elements to have a sum of a certain value.

The return type of this function is dependent on the type of the data element:

<table>
<thead>
<tr>
<th>Data type</th>
<th>Return type</th>
</tr>
</thead>
<tbody>
<tr>
<td>int, bit</td>
<td>int</td>
</tr>
<tr>
<td>float32, float64</td>
<td>float64</td>
</tr>
<tr>
<td>Other (e.g., string, struct)</td>
<td>Not applicable</td>
</tr>
</tbody>
</table>

**function list<data_type> to_list();**

Returns a list containing the elements of the array. The list’s element data type is the same as the data type of the array elements. The list elements are ordered in the same order as the array.

**function set<data_type> to_set();**

Returns a set containing the elements of the array. Each element value will appear once. The set’s element data type is the same as the data type of the array elements. The set is unordered.

7.9.2.3 Examples

Examples of fixed-size array declarations are shown in Example 12.

```plaintext
int fixed_sized_arr [16]; // array of 16 signed integers
array<bit[7:0],256> byte_arr; // array of 256 bytes
array<route,8> east_routes; // array of 8 route structs
```

Example 12—Fixed-size arrays

In Example 12, individual elements of the east_routes array are accessed using the index operator [], i.e., east_routes[0], east_routes[1],....
The following example shows use of array operators and methods. In this example, action type $A$ is traversed six times, once for each element in $foo_arr$, and once more since $foo_arr[0]$ is greater than 3.

```
component pss_top {
    array<bit[15:0],5> foo_arr;
    set <bit[15:0]> foo_set;

    exec init_up {
        foo_arr = {1, 2, 3, 4, 4};       // Array initialization assignment
        foo_arr[0] = 5;                  // Use of [] to select an array element
        foo_set = foo_arr.to_set();      // Use of to_set() method
    }

    action A{ rand bit[15:0] x; }
    action B{}
    action C{}

    action traverse_array_a {
        // foo_arr has 5 elements and foo_set has 4
        rand int in [1..] y;
        constraint y < comp.foo_arr.size(); // Use of size() method in constraint

        activity {
            foreach (elem: comp.foo_arr)   // "foreach" used on an array
                do A with { x == elem; };

            if (comp.foo_arr[0] > 3)
                do A;
            else if (4 in comp.foo_arr)     // Use of "in" operator
                do B;
            else if (comp.foo_arr.size() < 4) // Use of size() method
                do C;
        }
    }
}
```

Example 13—Array operators and methods

7.9.2.4 Array properties

Arrays provide the properties `size` and `sum`, which may be used in expressions. These properties are deprecated and have matching methods that should be used instead. They are used as follows:

```c
int data[4];
... data.size ... // same as data.size()
... data.sum ... // same as data.sum()
```

7.9.3 Lists

The `list` collection type is used to declare a variable-sized ordered list of elements. Using an index, an element in the list can be assigned or used in an expression. A list with $N$ elements, is ordered, with the first element accessed using $0$ as an index value with the `[[]` operator, and the last element accessed using $N-1$ as an index value.
A list is initialized as an empty collection unless the declaration contains an initialization assignment. A list that is empty is as if it was assigned an empty aggregate literal ({}). List elements can be added or removed in exec blocks; therefore the size of a list is not fixed like an array.

A list declaration consists of the keyword list, followed by the data type of the list elements between angle brackets, followed by the name(s) of the list(s).

```plaintext
struct my_s {
    list<int> my_list;
}
```

**Example 14—Declaring a list in a struct**

### 7.9.3.1 List operators

The following operators are defined for lists:

**Index operator []**

Used to access a specific element of a list, given an index into the list. The index shall be an integral value. See 8.6.2 for more information on the index operator.

**Assignment operator =**

Creates a copy of the list-type expression on the RHS and assigns it to the list on the LHS. See 8.3 for more information on the assignment operator.

**Equality operator ==**

Evaluates to true if the two lists are the same size and all elements with corresponding indexes are equal. Two lists of different element types are incomparable. See 8.5.3 for more information on the equality operator.

**Inequality operator !=**

Evaluates to true if the two lists are not the same size or not all elements with corresponding indexes are equal. Two lists of different element types are incomparable. See 8.5.3 for more information on the inequality operator.

**Set membership operator in**

The set membership operator can be applied to a list to check whether a specific element is currently in the list. It evaluates to true if the element specified on the left of the operator exists in the list collection on the right of the operator. The type of the element shall be the same as the list’s element data type. See 8.5.9 for more information on the set membership operator.

**foreach statement**

The foreach statement can be applied to a list to iterate over the list elements within an activity, a constraint or native exec code. See 12.4.3, 16.1.7, and 21.7.8, respectively, for more information on the foreach statements in these contexts.
7.9.3.2 List methods

The following methods are defined for lists:

function int size();

Returns the number of elements in the list.

function void clear();

Removes all elements from the list.

function data_type delete(int index);

Removes an element at the specified index of type integer and returns the element value. The return value data type is the same as the data type of the list elements. If the index is out of bounds, the operation is illegal.

function void insert(int index, data_type element);

Adds an element to the list at the specified index of type integer. If the index is equal to the size of the list, insert is equivalent to push_back(). If the index is less than the size of the list, then elements at and beyond the index are moved by one. If the index is greater than the size of the list, the operation is illegal. The inserted element’s data type shall be the same as the data type of the list elements.

function data_type pop_front();

Removes the first element of the list and returns the element value. This is equivalent to delete(0).

function void push_front(data_type element);

Inserts an element at the beginning of the list. This is equivalent to insert(0, element).

function data_type pop_back();

Removes the last element of the list and returns the element value. This is equivalent to delete(size()-1).

function void push_back(data_type element);

Appends an element to the end of the list. This is equivalent to insert(size(), element).

function set< data_type > to_set();

Returns a set containing the elements of the list. Each element value will appear once. The set’s element data type is the same as the data type of the list elements. The set is unordered.

function void shuffle();

Randomly reorders the elements in the list.

7.9.3.3 Examples

The following example shows use of list operators and methods. In this example, an action of type B will be traversed six times. There are six elements in foo_list3, foo_list2[0] is 1 and 4 is in comp.foo_list1. Action A and action C are never traversed.
7.9.3.4 List randomization

When the context containing the list attribute is randomized, the elements of the list are randomized. Random-size lists are not supported. Consequently, it is illegal to place a constraint on the size() method of a list outside an iterative constraint on the same list. The list size is considered to be an invariant inside an iterative constraint. Consequently, the size() method may be referenced in constraints within an iterative constraint. Example 16 shows declaration of a list with bit-type elements and illustrates valid and invalid constraints on the size() method.
Example 16—List randomization

7.9.4 Maps

The map collection type is used to declare a variable-sized associative array that associates a key with an element (or value). The keys serve as indexes into the map collection. Using a key, an element in the map can be assigned or used in an expression. A map is unordered.

A map is initialized as an empty collection unless the declaration contains an initialization assignment. A map that is empty is as if it was assigned an empty aggregate literal ({}). Map elements can be added or removed within exec blocks.

A map declaration consists of the keyword map, followed by the data type of the map keys and the data type of map elements, between angle brackets, followed by the name(s) of the map(s). Both keys and element values may be of any plain-data type. Maps are non-randomizable.

Example 17—Declaring a map in a struct

struct S {
    rand list<bit[8]> lst;

    exec pre_solve { // Initialize the list
        repeat (100) {
            lst.push_back(0);
        }
    }

    constraint {
        lst.size() in [4..100]; // Error: illegal constraint on size()
        foreach (lst[i]) {
            lst[i] == i+lst.size(); // OK: size() is an invariant in foreach
        }
    }
}

Example 17—Declaring a map in a struct

struct my_s {
    map<int, string> my_map;
}

7.9.4.1 Map operators

The following operators are defined for maps:

Index operator []

Used to access a specific element of a map, given a key of the specified data type. When used on the LHS in an assignment, the index operator sets the element value associated with the specified key. If the key already exists, the current value associated with the key is replaced with the value of the expression on the RHS. If the key does not exist, then a new key is added to the map collection and the value of the expression on the RHS is assigned to the new key’s associated map entry. Use of a key that does not exist in the map to reference an element in the map is illegal. See 8.6.2 for more information on the index operator.
Assignment operator =

Creates a copy of the map-type expression on the RHS and assigns it to the map on the LHS. If the same key appears more than once in the expression on the RHS, the last value specified is used. See 8.3 for more information on the assignment operator.

Equality operator ===

Evaluates to true if the two maps are the same size, have the same set of keys, and all elements with corresponding keys are equal. Two maps of different key or element types are incomparable. See 8.5.3 for more information on the equality operator.

Inequality operator !=

Evaluates to true if the two maps are not the same size, do not have the same set of keys, or not all elements with corresponding keys are equal. Two maps of different key or element types are incomparable. See 8.5.3 for more information on the inequality operator.

foreach statement

The foreach statement can be applied to a map to iterate over the map elements within an activity, a constraint or native exec code. See 12.4.3, 16.1.7, and 21.7.8, respectively, for more information on the foreach statements in these contexts.

The set membership operator (in) cannot be applied directly to a map. However, it may be applied to the set of keys or the list of values produced by the keys() and values() methods, respectively, described below.

7.9.4.2 Map methods

The following methods are defined for maps:

function int size();

Returns the number of elements in the map.

function void clear();

Removes all elements from the map.

function data_type delete(data_type key);  

Removes the element associated with the specified key from the map and returns the element value. The return value data type is the same as the data type of the map elements. The key argument shall have the same type as specified in the map declaration. If the specified key does not exist in the map, the operation is illegal.

function void insert(data_type key, data_type value);  

Adds the specified key/value pair to the map. If the key currently exists in the map, then the current value is replaced with the new value. The arguments shall have the same types as specified in the map declaration.

function set<data_type> keys();  

Returns a set containing the map keys. The set’s element data type is the same as the data type of the map keys. Since each key is unique and no order is defined on the keys, the method returns a set collection.
function list<data_type> values();

Returns a list containing the map element values. The list’s element data type is the same as the data type of the map elements. Since element values may not be unique, the method returns a list collection. However, the order of the list elements is unspecified.

7.9.4.3 Example

The following example shows use of map operators and methods. In this example, an action of type B will be traversed four times: foo_map1 is not equal to foo_map2, foo_map3 has four elements, foo_map2["a"] is 1 which is not greater than 3, and "b" exists in foo_map1.
7.9.5 Sets

The `set` collection type is used to declare a variable-sized unordered set of unique elements of plain-data type. Sets can be created, modified, and queried using the operators and methods described below.

A `set` is initialized as an empty collection unless the declaration contains an initialization assignment. A `set` that is empty is as if it was assigned an `empty aggregate literal` (`{}`). `Set` elements can be added or removed within `exec` blocks; therefore the size of a list is not fixed like an array.
A `set` declaration consists of the keyword `set`, followed by the data type of the `set` elements between angle brackets, followed by the name(s) of the `set(s`). Sets are non-randomizable.

```plaintext
struct my_s {  
    set<int> my_set;  
}
```

**Example 19—Declaring a set in a struct**

### 7.9.5.1 Set operators

The following operators are defined for `sets`:

**Assignment operator =**

Creates a copy of the set-type expression on the RHS and assigns it to the `set` on the LHS. The same value may appear more than once in the expression on the RHS, but it will appear only once in the `set`. See 8.3 for more information on the assignment operator.

**Equality operator ==**

Evaluates to `true` if the two `sets` have exactly the same elements. Note that sets are unordered. Two `sets` of different element types are incomparable. See 8.5.3 for more information on the equality operator.

**Inequality operator !=**

Evaluates to `true` if the two `sets` do not have exactly the same elements. Two `sets` of different element types are incomparable. See 8.5.3 for more information on the inequality operator.

**Set membership operator in**

The set membership operator can be applied to a `set` to check whether a specific element is currently within the `set`. It evaluates to `true` if the element specified on the left of the operator exists in the `set` collection on the right of the operator. The type of the element shall be the same as the `set`’s element data type. See 8.5.9 for more information on the set membership operator.

**foreach statement**

The `foreach` statement can be applied to a `set` to iterate over the `set` elements within an activity, a constraint or native exec code. When applied to a set, the `foreach` statement shall specify an `iterator variable` and shall not specify an `index variable`. See 12.4.3, 16.1.7, and 21.7.8, respectively, for more information on the `foreach` statements in these contexts.

### 7.9.5.2 Set methods

The following methods are defined for `sets`:

**function int size();**

Returns the number of elements in the `set`.

**function void clear();**

Removes all elements from the `set`. 
function void delete(data_type element);

Removes the specified element from the set. The element argument data type shall be the same as the data type of the set elements. If the element does not exist in the set, the operation is illegal.

function void insert(data_type element);

Adds the specified element to the set. The inserted element’s data type shall be the same as the data type of the set elements. If the element already exists in the set, the method shall have no effect.

function list<data_type> to_list();

Returns a list containing the elements of the set in an arbitrary order. The list’s element data type is the same as the data type of the set elements.

7.9.5.3 Examples

The following example shows use of set operators and methods. In this example, A is traversed two times and B is traversed three times: foo_set1 is not equal to foo_set2, there are five elements in foo_set3, two of the foo_set3 elements are in foo_set2, and "b" is in foo_set1.
PSS supports a limited form of reference types for actions, components, and flow/resource objects, but does not support references to plain-data types. References in PSS are similar in their semantics to class variables in such languages as Java and SystemVerilog. Variables of reference types can be assigned and compared (see more in 8.3 and 8.5.3).

Example 20—Set operators and methods
7.10.1 Syntax

The following also apply:

a) The `ref` modifier can be used in the declaration of local variables, fields of components, function parameters, and function return values. The `ref` modifier shall not be used in the declaration of fields in the scope of actions, flow/resource objects, and structs. Nor shall it be used to declare static constants or the key or element type in collections.

b) Fields and instance functions can be accessed through a reference expression in the same way as through an instance path, using the dot (‘.’) operator.

c) An expression of reference type may evaluate to the special value `null`, indicating that it does not reference any entity. It shall be an error to access members of an entity through a null reference. See also §8.3 and §8.5.3.

d) When not initialized, the default value of a reference variable is `null`.

Note that PSS supports special reference fields that are automatically resolved as part of the solving process. They are:

- The context component reference `comp` (see §9.5)
- Action handles to sub-actions within compound actions (see §12.3.1.1)
- The previous state reference `prev` (see §13.3.1)
- Input and output reference fields of actions (see §13.4)
- Resource claim reference fields (see §14.2)
7.10.2 Examples

Example 21 demonstrates the use of a reference as a local variable and as a return type of a function. In the body of action call_foo, a reference to A is stored in a local variable, and then used to call function foo(). In addition, a reference to A is returned from function choose_A(), and it is used in turn to call foo() on the chosen instance of A.

```plaintext
component A {
    function void foo();
};

component B {
    A a_arr[5];

    function ref A choose_A(int code) {
        return a_arr[code % 5];
    }

    action call_foo {
        exec body {
            ref A aref = comp.a_arr[3];
            aref.foo();
            comp.choose_A(123).foo();
        }
    }
};
```

Example 21—Use of reference as local variable and function return value

In Example 22, a reference field is declared under component my_comp. After the construction of the component instance tree, the attribute sibling_size of c2 is equal to 10, having been assigned in the init_down block through the sibling reference field. However, the attribute sibling_size of c1 is still equal to its default value 0, because for c1, reference field sibling was not initialized, and therefore c1.sibling is equal to null.

```plaintext
component my_comp {
    ref my_comp sibling;
    int size, sibling_size;

    exec init_down {
        if (sibling != null) {
            sibling_size = sibling.size;
        }
    }
}

component pss_top {
    my_comp c1, c2;
    exec init_down {
        c1.size = 10;
        c2.sibling = c1;
    }
};
```

Example 22—Use of reference field and null value
7.11 User-defined data types

The `typedef` statement declares a user-defined type name in terms of an existing data type, as shown in Syntax 17.

7.11.1 Syntax

```
typedef_declaration ::= typedef data_type identifier ;
```

Syntax 17—User-defined type declaration

7.11.2 Examples

A `typedef` example is shown in Example 23.

```
typedef bit[31:0] uint32_t;
```

Example 23—typedef

7.12 Data type conversion

Expressions of types `int`, `bit`, `bool`, `enum`, or floating-point type can be changed to another type in this list by using a `cast operator`. In addition, an expression of a reference type can be changed to a compatible reference type.

7.12.1 Syntax

Syntax 18 defines the `cast operator`.

```
cast_expression ::= ( casting_type ) expression
    casting_type ::= integer_type | bool_type | enum_type | float_type | reference_type | type_identifier
```

Syntax 18—cast operation

In a `cast_expression`, the `expression` to be cast shall be preceded by the casting data type enclosed in parentheses. The `cast` shall return the value of the `expression` represented as the `casting_type`. A `type_identifier` specified as a `casting_type` shall refer to a numeric, Boolean, enumeration, or reference type.

The following also apply:

a) A numeric, Boolean, or enumeration value can only be cast to another numeric, Boolean or enumeration type. A reference value can only be cast to a compatible reference type.
b) Any non-zero value cast to a `bool` type shall evaluate to `true`. A zero value cast to a `bool` type shall evaluate to `false`. When casting a `bool` type to another type, `false` evaluates to 0 and `true` evaluates to 1.

c) When casting a value to a `bit` type, the `casting_type` shall include the width specification of the resulting bit vector. The `expression` shall be converted to a bit vector of sufficient width to hold the value of the `expression`, and then truncated or left-zero-padded as necessary to match the `casting_type`.

d) When casting a value to a user-defined `enum` type, the value shall correspond to the result of an implicit cast to the resulting underlying numeric type. When used in a constraint, the domain of a field of `enum` type consists of the values of the `enum` type.

e) All integer expressions (`int` and `bit` types) are type compatible, so an explicit `cast` is not required from one to another.

f) All floating-point expressions (`float32` and `float64` types) are type compatible, so an explicit `cast` is not required from one to another.

g) Floating-point expressions are type-compatible with integer expressions, so an explicit `cast` is not required from one to another. Conversion from floating-point to integer is performed by truncating the fractional part of the floating-point expression.

h) A reference value cast to a (direct or indirect) supertype reference or to its own reference type (`upcast`) shall evaluate to the same reference. An explicit cast is not required in this case; an upcast is implicit.

i) A reference value cast to a (direct or indirect) subtype reference (`downcast`) shall evaluate to the same reference if the dynamic value of the reference belongs to the casting type, and shall evaluate to `null` otherwise.
7.12.2 Examples

Example 24 shows the overlap of possible enum values (from 7.12.1 (d)) when used in constraints.

```verilog
import std_pkg::*;

enum config_modes_e {UNKNOWN, MODE_A=10, MODE_B=20};
enum foo_e {A=10, B, C};
function bit[32] get_cfg_mode() {return 30;}
    // a new cfg_mode that has not been added to the enum type yet

action my_a {
    config_modes_e top_cfg;
    rand config_modes_e cfg;
    rand foo_e foo;
    constraint cfg == (config_modes_e)11;
        // contradiction - no possible value
    constraint cfg == (config_modes_e)foo;
        // cfg==MODE_A, the only value in the numeric domain of both cfg and foo
    exec pre_solve {
        config_modes_e cfg_mode = (config_modes_e)get_cfg_mode();
        match (cfg_mode) {
            [MODE_A, MODE_B] : top_cfg = cfg_mode;
            [UNKNOWN]: print("Unknown configuration mode\n");
            default : print("Invalid configuration mode = %d\n", (int)cfg_mode);
        }
    }
}
```

Example 24—Overlap of possible enum values

Example 25 shows the casting of al from the align_e enum type to a 4-bit vector to pass into the alloc_addr imported function.

```verilog
package external_fn_pkg {
    enum align_e {byte_aligned=1, short_aligned=2, word_aligned=4};
    function bit[31:0] alloc_addr(bit[31:0] size, bit[3:0] align);
    buffer mem_seg_s {
        rand bit[31:0] size;
        bit[31:0] addr;
        align_e al;
        exec post_solve {
            addr = alloc_addr(size, (bit[3:0])al);
        }
    }
}
```

Example 25—Casting of variable to a bit vector
Example 26 shows reference type casting on the `comp` field of an action.

```plaintext
component C {
    action A {}  
}

cOMPONENT sub_C: C {
    int a = 17;
}

extend action C::A {
    int b;
    exec post_solve {
        if ((ref sub_C)comp != null) {
            b = ((ref sub_C)comp).a;
        }
    }
}
```

Example 26—Casting of reference type
8. Operators and expressions

This section describes the operators and operands available in PSS and how to use them to form expressions.

An expression is a construct that can be evaluated to determine a specific value. Expressions may be primary expressions, consisting of a single term, or compound expressions, combining operators with sub-expressions as their operands.

The various types of primary expressions are specified in 8.6.

8.1 Syntax

```
expression ::= primary
  | unary_operator primary
  | expression binary_operator expression
  | conditional_expression
  | in_expression

unary_operator ::= - | ! | ~ | & | | | ^

binary_operator ::= * | / | % | + | - | << | >> | == | != | < | <= | > | >= | == | || | & | | | | ^ | & | **

assign_op ::= = | += | -= | <<= | >>= | |= | &=

primary ::= number
  | aggregate_literal
  | bool_literal
  | string_literal
  | null_ref
  | paren_expr
  | cast_expression
  | ref_path
  | compile_has_expr

paren_expr ::= ( expression )

cast_expression ::= ( casting_type ) expression
```

8.2 Constant expressions

Some constructs require an expression to be a constant expression. The operands of a constant expression consist of numeric and string literals, aggregate literals with constant values, named constants (e.g., static const, template parameters), bit-selects and part-selects of named constants, enum items, and calls of pure functions with constant arguments.
8.3 Assignment operators

The assignment operators defined by the PSS language are listed in the table below.

<table>
<thead>
<tr>
<th>Operator token</th>
<th>Operator name</th>
<th>Operand data types</th>
</tr>
</thead>
<tbody>
<tr>
<td>=</td>
<td>Binary assignment operator</td>
<td>Any plain-data type or reference type</td>
</tr>
<tr>
<td>+= -=</td>
<td>Binary arithmetic assignment operators</td>
<td>Numeric</td>
</tr>
<tr>
<td>&amp;=</td>
<td>=</td>
<td>Binary bitwise assignment operators</td>
</tr>
<tr>
<td>&gt;&gt;= &lt;&lt;=</td>
<td>Binary shift assignment operators</td>
<td>Integer</td>
</tr>
</tbody>
</table>

Table 7—Assignment operators and data types

The assignment (=) operator is used in the context of attribute initializers and procedural statements.

The arithmetic assignment (+=, -=), shift assignment (<<=, >>=), and bitwise assignment (|=, &=) operators are used in the context of procedural statements. These compound assignment operators are equivalent to assigning to the left-hand operand the result of applying the leading operator to the left-hand and right-hand operands. For example, a <<= b is equivalent to a = a << b.

While these operators may not be used as a part of an expression, they are documented here for consistency.

The type of the right-hand side of an assignment shall be assignment-compatible with the type of the left-hand side. In an aggregate assignment, assignment is performed element by element. In an assignment of a fixed-size array, the left-hand and right-hand sides of the assignment shall have the same size.

In assignment of struct types, the right-hand side shall be of the same type as the left-hand side or a derived type thereof. When the left-hand side of an assignment is of struct type and the right-hand side is of a type that inherits from the type of the left-hand side, the elements present in the left-hand type are assigned element-by-element while elements only present in the right-hand type are ignored.

In assignment of reference types, the right-hand side shall be one of the following:

— A reference expression of the same type as the left-hand side or a derived type of it
— An instance path to a component of the same type as the left-hand side or a derived type of it
— The value null

Following the assignment of a reference, the left-hand side variable shall point to (be an alias to) the same entity (component, action, flow/resource object) referred to by the right-hand side (or have the value null in case the right-hand side evaluates to null).
8.4 Expression operators

The expression operators defined by the PSS language are listed in the table below.

Table 8—Expression operators and data types

<table>
<thead>
<tr>
<th>Operator token</th>
<th>Operator name</th>
<th>Operand data types</th>
<th>Result data type</th>
</tr>
</thead>
<tbody>
<tr>
<td>?:</td>
<td>Conditional operator</td>
<td>Any plain-data type or reference type (condition is Boolean)</td>
<td>Same as operands</td>
</tr>
<tr>
<td>−</td>
<td>Unary arithmetic negation operator</td>
<td>Numeric</td>
<td>Same as operand</td>
</tr>
<tr>
<td>~</td>
<td>Unary bitwise negation operator</td>
<td>Integer</td>
<td>Same as operand</td>
</tr>
<tr>
<td>!</td>
<td>Unary Boolean negation operator</td>
<td>Boolean</td>
<td>Boolean</td>
</tr>
</tbody>
</table>
| &  | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ | ^ |^
Operators shown in the same row in the table shall have the same precedence. Rows are arranged in order of decreasing precedence for the operators. For example, \( * \), \( / \), and \( \% \) all have the same precedence, which is higher than that of the binary \( + \) and \( - \) operators.

All operators shall associate left to right with the exception of the conditional (?:) and cast operators, which shall associate right to left. Associativity refers to the order in which the operators having the same precedence are evaluated. Thus, in the following example, \( B \) is added to \( A \), and then \( C \) is subtracted from the result of \( A + B \).

\[
A + B - C
\]

When operators differ in precedence, the operators with higher precedence shall associate first. In the following example, \( B \) is divided by \( C \) (division has higher precedence than addition), and then the result is added to \( A \).

\[
A + B / C
\]

Parentheses can be used to change the operator precedence, as shown below.

\[
(A + B) / C \quad // \text{not the same as } A + B / C
\]

### 8.4.2 Using aggregate literals in expressions

Aggregate literals (i.e., value list, map, and structure literals, see 4.8) can be used as expression operands. For example, aggregate literals can be used to initialize the contents of aggregate types as part of a variable declaration, in constraint contexts, as foreign language function parameters, and as template-type value parameters. An aggregate literal may not be the target of an assignment.

When the operands of an assignment or equality operator are a structure aggregate literal and a struct-type variable, any elements not specified by the literal are given the default values of the data type of the element. When the operands of an assignment or equality operator are a value list literal and an array, the number of elements in the aggregate literal must be the same as the number of elements in the array.
In Example 27, a `struct` type is declared that has four integer fields. A non-random instance of that `struct` is created where all field values are explicitly specified. A constraint compares the fields of this `struct` with an aggregate literal in which only the first two struct fields are specified explicitly. Because a `struct` is a fixed-size data structure, the fields that are not explicitly specified in the aggregate literal are given default values—in this case 0. Consequently, the constraint holds.

```cpp
struct s {
    int a, b, c, d;
};
struct t {
    s s1 = {.a=1,.b=2,.c=0,.d=0};
    constraint s1 == {.b=2,.a=1};
}
```

**Example 27—Using a structure literal with an equality operator**

When an aggregate literal is used in the context of a variable-sized data type, the aggregate literal specifies both size and content.

In Example 28, a `set` variable is compared with an aggregate literal using a constraint. The size of the `set` variable is three, since there are three unique values in the initializing literal, while the size of the aggregate literal in the constraint is two. Consequently, the constraint does not hold.

```cpp
struct t {
    set<int>   s =  {1, 2, 0, 0};
    constraint s == {1, 2}; // False: s has 3 elements, but the literal has 2
}
```

**Example 28—Using an aggregate literal with a set**

Values in aggregate literals may be non-constant expressions. Example 29 shows use of a `repeat`-loop index variable and a function call in a value list literal.

```cpp
function int get_val(int idx);
import solve function get_val;
struct S {
    list<array<int,2>>  pair_l;
    exec pre_solve {
        repeat(i : 4) {
            array<int,2> pair = {i, get_val(i)};
            pair_l.push_back(pair);
        }
    }
}
```

**Example 29—Using non-constant expressions in aggregate literals**
8.4.3 Type inference rules

The expected type of an expression shall be inferred according to the rules below. The expected type is used in the resolution of unqualified `enum_item` names (see 7.5) and in the interpretation of aggregate literals (see 8.4.2).

— The type of the expression on the left-hand side of an assignment determines the expected type of the expression on the right-hand side. This includes initialization assignments.

— The type of the formal parameter of a function determines the expected type of the respective actual parameter expression (see 21.2). This is true also for `covergroup` instantiations (see 18.2).

— The return type of a function determines the expected type of the expression in its `return` statement (see 21.7.5).

— An expression of a known type on the left-hand side of an equality operator (`==, !=`) determines the expected type of the right-hand side (see 8.5.3).

— The expected type of a `conditional_expression` (`?:`) determines the expected type of the second and third operands of the expression (see 8.5.8).

— The type of the expression on the left-hand side of a set membership (`in`) operator determines the expected type of the expressions in the `open_range_list`, or the elements of the `collection_expression`, on the right-hand side (see 8.5.9).

— An explicit data type of a `coverpoint` determines the expected type of the coverpoint expression (see 18.3).

— The type (explicit or implicit) of a `coverpoint` determines the expected type of its bin values (see 18.3.3).

— In a `cast_expression`, the specified target type (`casting_type`) determines the expected type of the expression to be cast (see 7.12).

For the purposes of this section, all integer types are considered to be a single type, as all integer expressions are type compatible, and all floating-point types are considered to be a single type, as all floating-point expressions are type compatible (see 7.12). See more on the evaluation of numeric expressions in 8.7 and 8.8.

In Example 30, contextual typing is required to interpret structure literals. Based on the type of the left operand of an equality operator, the structure literal on the right-hand side is interpreted differently in two different constraints within the same `action`. 
Example 30—Contextual typing in structure literal interpretation

Example 31 shows two cases of unqualified enum item resolution based on contextual typing—an assignment and a function call. Note that in calling function print_num(), whose formal parameter is declared with type int, the identifier ORANGE cannot be resolved, because the expected type is an int. The enum item must be qualified in this case.

Example 31—Contextual typing in enum item resolution

8.4.4 Operator expression short-circuiting

The logical operators (\&\&, ||) and the conditional operator (? :) shall use short-circuit evaluation. In other words, operand expressions that are not required to determine the final value of the operation shall not be
evaluated. All other operators shall not use short-circuit evaluation. In other words, all of their operand expressions are always evaluated.

8.5 Operator descriptions

The following sections describe each of the operator categories. The legal operand types for each operator are listed in Table 8.

8.5.1 Arithmetic operators

The binary arithmetic operators are given in Table 10.

<table>
<thead>
<tr>
<th>Expression</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>a + b</td>
<td>a plus b</td>
</tr>
<tr>
<td>a - b</td>
<td>a minus b</td>
</tr>
<tr>
<td>a * b</td>
<td>a multiplied by b (or a times b)</td>
</tr>
<tr>
<td>a / b</td>
<td>a divided by b</td>
</tr>
<tr>
<td>a % b</td>
<td>a modulo b</td>
</tr>
<tr>
<td>a ** b</td>
<td>a to the power of b</td>
</tr>
</tbody>
</table>

Integer division shall truncate the fractional part toward zero. The modulus operator (for example, a % b) gives the remainder when the first operand is divided by the second, and thus zero when b divides a exactly. The result of a modulus operation shall take the sign of the first operand. Division or modulus by zero shall be considered illegal.

If either operand of the power operator is of floating-point type, then the result type shall also be of floating-point type. The result of the power operator is unspecified if the first operand is zero and the second operand is negative or if the first operand is negative and the second operand is not an integer value.

<table>
<thead>
<tr>
<th>op1 is &lt; -1</th>
<th>op1 is = -1</th>
<th>op1 is 0</th>
<th>op1 is 1</th>
<th>op1 is &gt; 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>op2 is positive</td>
<td>op2 ** op2</td>
<td>op2 is odd -&gt; -1</td>
<td>op2 is even -&gt; 1</td>
<td>0</td>
</tr>
<tr>
<td>op2 is zero</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>op2 is negative</td>
<td>0</td>
<td>op2 is odd -&gt; -1</td>
<td>op2 is even -&gt; 1</td>
<td>undefined</td>
</tr>
</tbody>
</table>

The unary arithmetic negation operator (−) shall take precedence over the binary operators.

8.5.1.1 Arithmetic expressions with unsigned and signed types

bit-type variables are unsigned, while int-type variables are signed.

A value assigned to an unsigned variable shall be treated as an unsigned value. A value assigned to a signed variable shall be treated as signed. Signed values shall use two’s-complement representation. Conversions
between signed and unsigned values shall keep the same bit representation. Only the bit interpretation changes.

8.5.2 Relational operators

Table 12 lists and defines the relational operators. Relational operators may be applied only to numeric operands.

<table>
<thead>
<tr>
<th>Operator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>a &lt; b</td>
<td>a less than b</td>
</tr>
<tr>
<td>a &gt; b</td>
<td>a greater than b</td>
</tr>
<tr>
<td>a &lt;= b</td>
<td>a less than or equal to b</td>
</tr>
<tr>
<td>a &gt;= b</td>
<td>a greater than or equal to b</td>
</tr>
</tbody>
</table>

An expression using these relational operators shall yield the Boolean value true if the specified relation holds, or the Boolean value false if the specified relation does not hold.

When one or both operands of a relational expression are unsigned, the expression shall be interpreted as a comparison between unsigned values. If the operands are of unequal bit lengths, the smaller operand shall be zero-extended to the size of the larger operand.

When both operands are signed, the expression shall be interpreted as a comparison between signed values. If the operands are of unequal bit lengths, the smaller operand shall be sign-extended to the size of the larger operand.

All the relational operators have the same precedence, and have lower precedence than arithmetic operators.

8.5.3 Equality operators

The equality operators rank lower in precedence than the relational operators. Table 13 defines the equality operators.

<table>
<thead>
<tr>
<th>Operator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>a == b</td>
<td>a equal to b</td>
</tr>
<tr>
<td>a != b</td>
<td>a not equal to b</td>
</tr>
</tbody>
</table>

Both equality operators have the same precedence. When the operands are numeric, these operators compare operands bit for bit. As with the relational operators, the result shall be false if the comparison fails and true if it succeeds.

When one or both operands are unsigned, the expression shall be interpreted as a comparison between unsigned values. If the operands are of unequal bit lengths, the smaller operand shall be zero-extended to the size of the larger operand.

When both operands are signed, the expression shall be interpreted as a comparison between signed values. If the operands are of unequal bit lengths, the smaller operand shall be sign-extended to the size of the larger operand.
When the operands of an equality operator are of `string` type, both the sizes and the values of the string operands are compared.

Aggregate data (`structs` and `collections`) may be compared using equality operators. When the equality operators are applied to aggregate data, both operands shall be of the same type. Aggregate operands are compared element-by-element to assess equality.

The following rules apply to comparison of collections:

- It shall be illegal to compare two fixed-size arrays of different sizes. Variable-sized collections of the same type may be compared, but they shall be considered not equal if they have different sizes.
- Two fixed-size arrays are considered equal if they have the same elements in the same order.
- Two `lists` are considered equal if they have the same size and they have the same elements in the same order.
- Two `maps` are considered equal if they have the same size and the same `key-value` pairs, regardless of order (maps are unordered).
- Two `sets` are considered equal if they have the same size and the same elements, regardless of order (sets are unordered).

The right-hand side of an equality operator may be an aggregate literal of the same type as the left-hand side. The left-hand side of an equality operator may not be an aggregate literal. See more details about collections in 7.9 and about aggregate literals in 4.8 and 8.4.2.

References can be compared with equality operators. The operands may be one of the following:

- Two expressions of the same reference type, or one expression of a reference to a derived type of the other
- One expression of a component reference type, and the other an instance path to a component of the same type, or a derived type of it
- An expression of a reference type and the value `null`

The expression evaluates to `true` if both operands refer to the same entity (component, action, flow/resource object) or if both evaluate to `null`. Otherwise it evaluates to `false`. Note that these rules apply to variables declared with the `ref` modifier, the built-in `comp` reference, and other reference fields (see 7.10).

### 8.5.4 Logical operators

The binary operators `logical AND` (`&&`) and `logical OR` (`||`) are logical connective operators and have a Boolean result. The precedence of `&&` is greater than that of `||`, and both have a lower precedence than the relational and equality operators.

The unary `logical negation` operator (`!`) converts a `true` operand to `false` and a `false` operand to `true`.

In procedural contexts, the `&&` and `||` operators shall use short-circuit evaluation as follows:

- The first operand expression shall always be evaluated.
- For `&&`, if the first operand evaluates to `false`, then the second operand shall not be evaluated.
- For `||`, if the first operand evaluates to `true`, then the second operand shall not be evaluated.
8.5.5 Bitwise operators

The bitwise operators perform bitwise manipulations on the operands. Specifically, the binary bitwise operators combine a bit in one operand with the corresponding bit in the other operand to calculate one bit for the result. The following truth tables show the result for each operator and input operands.

Table 14—Bitwise binary AND operator

<table>
<thead>
<tr>
<th>&amp;</th>
<th>0</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 15—Bitwise binary OR operator

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 16—Bitwise binary XOR operator

<table>
<thead>
<tr>
<th>^</th>
<th>0</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

The bitwise unary negation operator (~) negates each bit of a single operand.

Table 17—Bitwise unary negation operator

<table>
<thead>
<tr>
<th>~</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

These operators may be applied only to integer operands.
8.5.6 Reduction operators

The unary reduction operators perform bitwise operations on a single operand to produce a single-bit result.

The unary AND operator (&) returns 1'b1 if all the bits of the operand are 1, and returns 1'b0 otherwise. The unary OR operator (|) returns 1'b1 if any bit of the operand is 1, and returns 1'b0 otherwise. The unary XOR operator (^) returns 1'b1 if an odd number of bits of the operand are 1, and returns 1'b0 otherwise.

These operators may be applied only to integer operands. The table below shows the results of applying the three reduction operators to four example bit patterns.

<table>
<thead>
<tr>
<th>Operand</th>
<th>&amp;</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>4'b0000</td>
<td>0 0 0</td>
<td>No bits set</td>
</tr>
<tr>
<td>4'b1111</td>
<td>1 1 0</td>
<td>All bits set</td>
</tr>
<tr>
<td>4'b0110</td>
<td>0 1 0</td>
<td>Even number of bits set</td>
</tr>
<tr>
<td>4'b1000</td>
<td>0 1 1</td>
<td>Odd number of bits set</td>
</tr>
</tbody>
</table>

8.5.7 Shift operators

PSS provides two bitwise shift operators: shift-left (<<) and shift-right (>>). The left shift operator shifts the left operand to the left by the number of bit positions given by the right operand. The vacated bit positions shall be filled with zeros. The right shift operator shifts the left operand to the right by the number of bit positions given by the right operand. If the left operand is unsigned or if the left operand has a non-negative value, the vacated bit positions shall be filled with zeros. If the left operand is signed and has a negative value, the vacated bit positions shall be filled with ones. The right operand shall be a non-negative number. These operators may be applied only to integer operands.

8.5.8 Conditional operator

The conditional operator (?:) is right-associative and is composed of three operands separated by two operators as shown in Syntax 20. The first operand (the cond_predicate) shall be of Boolean type. The second and third operands shall be of the same type, and may be of any plain-data or reference type.

```
conditional_expression ::= cond_predicate ? expression : expression
cond_predicate ::= expression
```

Syntax 20—Conditional operator

If cond_predicate is true, then the operator evaluates to the first expression without evaluating the second expression. If false, then the operator evaluates to the second expression without evaluating the first expression.
8.5.9 Set membership operator

PSS supports the set membership operator \texttt{in}, as applied to value sets and collection data types. Syntax 21 shows the syntax for the set membership operator.

8.5.9.1 Syntax

\begin{verbatim}
in_expression ::= 
    expression \texttt{in} | open_range_list |
    \| expression \texttt{in} collection_expression
open_range_list ::= open_range_value \{ , open_range_value \}
open_range_value ::= expression [ .. expression ]
collection_expression ::= expression
\end{verbatim}

Syntax 21—Set membership operator

The set membership operator returns \texttt{true} if the value of the \texttt{expression} on the left-hand side of the \texttt{in} operator is found in the \texttt{open_range_list} or \texttt{collection_expression} on the right-hand side of the operator, and \texttt{false} otherwise.

The expression on the left-hand side shall have a self-determined type; in particular, the left-hand side shall not be an unqualified \texttt{enum_item} (see 7.5) or an aggregate literal (see 4.8). The elements of the right-hand side of the \texttt{in} operator shall have a type compatible with the \texttt{expression} on the left-hand side.

If the \texttt{expression} on the left-hand side is of a scalar type, the right-hand side may be an \texttt{open_range_list} or a \texttt{collection_expression}. If the \texttt{expression} on the left-hand side is of a collection type, the right-hand side shall be a \texttt{collection_expression}.

An \texttt{open_range_list} on the right-hand side of the \texttt{in} operator shall be a comma-separated list of scalar value expressions or ranges. When specifying a range, the expressions shall be of a numeric or enumeration type. If the left-hand bound of the range is greater than the right-hand bound of the range, the range is considered empty. Values can be repeated; therefore, values and value ranges can overlap. The evaluation order of the expressions and ranges within the \texttt{open_range_list} is nondeterministic.

A \texttt{collection_expression} on the right-hand side of the \texttt{in} operator shall evaluate to an \texttt{array}, \texttt{list}, or \texttt{set} type that contains elements whose type is compatible with the type of the \texttt{expression} on the left-hand side. For example, the \texttt{collection_expression} may be a \texttt{value_list_literal} or a hierarchical reference to a \texttt{set}. The \texttt{collection_expression} may also be an array of \texttt{action handles}, \texttt{components}, or \texttt{flow and resource object references}. In this case, the expression on the left-hand side shall be a corresponding \texttt{ref} type.

8.5.9.2 Examples

Example 32 constrains the \texttt{addr} attribute field to the range \texttt{0x0000} to \texttt{0xFFFF}.

\begin{verbatim}
collection addr_c { 
    addr in [0x0000..0xFFFF]; 
}
\end{verbatim}

Example 32—Value range constraint
In the example below, $v$ is constrained to be in the combined value set of $values$ and the values specified directly in the $open_range_list$. In other words, the value of $v$ will be in $[1, 2, 3, 4, 5]$. The variable $values$ of type list may not be referenced in an $open_range_list$.

```
struct s {
    list<int> values = {3, 4, 5};
    rand int v;
    constraint v in [1,2] || v in values;
}
```

**Example 33—Set membership in collection**

In the example below, $v$ is constrained to be in the range $1, 2$, and between $a$ and $b$. The range $a..b$ may overlap with the values $1$ and $2$.

```
struct s {
    rand int v, a, b;
    constraint a < b;
    constraint v in [1,2,a..b];
}
```

**Example 34—Set membership in variable range**

### 8.6 Primary expressions

There are several types of primary expressions (or simple operands).

The simplest type of primary expression is a reference (simple or hierarchical) to a variable, constant, or template parameter.

In order to select a single bit of an integer variable or integer named constant (e.g., static const or template parameter), a bit-select shall be used. In order to select a bit range of a integer variable or integer named constant, a part-select shall be used.

A collection variable of plain-data type can be referenced as a primary expression. In order to select an element within a collection, an index operator shall be used.

A struct variable can be referenced as a primary expression.

A function call is a primary expression.

There are additional types of primary expressions. Formally, an expression is a primary expression if it is a primary as defined in B.17 and unparenthesized.

#### 8.6.1 Bit-selects and part-selects

**Bit-selects** select a particular bit from a named integer variable or constant using the syntax

```
identifier [ expression ]
```

The index may be any integer expression and may be non-constant.

**Part-selects** select a fixed range of contiguous bits using the syntax
The value of the first \texttt{constant_expression} shall be greater than or equal to the value of the second \texttt{constant_expression}.

Bit-selects and part-selects may be used as operands of other operators and as targets of assignments. It shall be illegal for a bit-select or a part-select to access an out-of-bounds bit index.

\textbf{8.6.2 Selecting an element from a collection (indexing)}

The \texttt{index operator} \([\texttt{]}\) is applied to an \texttt{array}, \texttt{list}, or \texttt{map} collection to select a single element. In the case of an \texttt{array} or a \texttt{list}, the index shall be an integer expression whose value is between 0 and the size of the \texttt{array/list} - 1. In the case of a \texttt{map}, the index shall be of the same type as that of the key in the \texttt{map} declaration.

An indexed collection may be used as an operand of other operators and as a target of assignments.

In the case of an \texttt{array} or a \texttt{list}, it shall be illegal to access an out-of-bounds index. In the case of a \texttt{map}, it shall be illegal to read an element whose key does not appear in the \texttt{map}. An assignment to a \texttt{map} element whose key does not currently appear in the \texttt{map} shall add that key and value pair to the \texttt{map}.

\textbf{8.7 Bit sizes for numeric expressions}

The size, in bits, of a numeric expression is determined by the operands involved in the expression and the context in which the expression appears. Casting can be used to set the size context of an intermediate value (see 7.12).

\textbf{8.7.1 Rules for expression bit sizes}

A \textit{self-determined expression} is one where the size of the expression is solely determined by the expression itself. A \textit{context-determined expression} is one where the size of the expression is determined both by the expression itself and by the fact that it is part of another expression. For example, the size of the right-hand expression of an assignment depends on itself and the size of the left-hand side.

\textbf{Table 19} shows how the form of an expression determines the sizes of the results of the expression. In \textbf{Table 19}, \texttt{i}, \texttt{j}, and \texttt{k} represent operands of an expression, and \texttt{L(i)} represents the size of the operand represented by \texttt{i}.

<table>
<thead>
<tr>
<th>Expression</th>
<th>Bit size</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unsized constant number</td>
<td>At least 32</td>
<td></td>
</tr>
<tr>
<td>Sized constant number</td>
<td>As specified</td>
<td></td>
</tr>
<tr>
<td>\texttt{i op j}, where \texttt{op} is:</td>
<td>\texttt{max(L(i),L(j))}</td>
<td></td>
</tr>
<tr>
<td>\texttt{+}, \texttt{-}, \texttt{*}, \texttt{/}, \texttt{%}, \texttt{&amp;}, \texttt{</td>
<td>}, \texttt{^}</td>
<td></td>
</tr>
<tr>
<td>\texttt{op i}, where \texttt{op} is:</td>
<td>\texttt{L(i)}</td>
<td></td>
</tr>
<tr>
<td>\texttt{+}, \texttt{-}, \texttt{~}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>\texttt{op i}, where \texttt{op} is:</td>
<td>\texttt{1}</td>
<td></td>
</tr>
<tr>
<td>\texttt{&amp;}, \texttt{</td>
<td>}, \texttt{^}</td>
<td></td>
</tr>
<tr>
<td>\texttt{i op j}, where \texttt{op} is:</td>
<td>\texttt{L(i)}</td>
<td>\texttt{j} is self-determined</td>
</tr>
<tr>
<td>\texttt{&gt;&gt;}, \texttt{&lt;&lt;}, \texttt{**}</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
8.8 Evaluation rules for numeric expressions

8.8.1 Rules for expression signedness

The following apply when determining the signedness of an expression:

a) Expression signedness depends only on the operands. In an assignment, the signedness does not depend on the left-hand side.

b) Unsized unbased decimal and octal numbers are signed. Unsized unbased hexadecimal numbers are unsigned.

c) Based numbers are unsigned, except when they are designated as signed with the 's notation (e.g., 4'sd12).

d) Bit-select results are unsigned, regardless of the operands.

e) Part-select results are unsigned, regardless of the operands, even if the part-select specifies the entire width.

f) Floating-point numbers are signed when converted to integers.

g) The signedness and size of a self-determined operand are determined by the operand itself, independent of the remainder of the expression.

h) If any context-determined operand of an expression is of floating-point type, the result is of floating-point type.

i) If any context-determined operand of an expression is unsigned, the result is unsigned regardless of the operators.

j) If all context-determined operands of an expression are signed, the result is signed regardless of the operators, unless specified otherwise.

8.8.2 Steps for evaluating a numeric expression

The following are the steps for evaluating a numeric expression:

a) Determine the expression size based on the expression size rules (see 8.7.1).

b) Determine the signedness of the expression using the rules described above.

c) Propagate the signedness and size of the expression to the context-determined operands of the expression. In general, context-determined operands of an operator shall have the same signedness and size as the result of the operator. However, there is one exception:

1) If the result type of the operator is floating-point and if it has a context-determined operand that is not floating-point, that operand shall be treated as if it were self-determined and then converted to floating-point just before the operator is applied.

d) When propagation reaches a simple operand (see 8.6), that operand shall be converted to the propagated signedness and size. If the operand must be size-extended, it shall be sign-extended if the propagated type is signed and zero-extended if the propagated type is unsigned.

---

Table 19—Bit sizes resulting from self-determined expressions (Continued)

<table>
<thead>
<tr>
<th>Expression</th>
<th>Bit size</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>i ? j : k</td>
<td>max(L(j),L(k))</td>
<td>i must be Boolean</td>
</tr>
<tr>
<td>cast, where casting_type is</td>
<td>L(casting_type)</td>
<td></td>
</tr>
<tr>
<td>integer type</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
8.8.3 Steps for evaluating an assignment

The following are the steps for evaluating an assignment when the operands are of numeric type:

a) Determine the size of the right-hand side of the assignment using the size determination rules described in 8.7.1.

b) If required, extend the size of the right-hand side, using sign extension if the type of the right-hand side is signed and zero-extension if the type of the right-hand side is unsigned.
9. Components

Components serve as a mechanism to encapsulate and reuse elements of functionality in a portable stimulus model. Typically, a model is broken down into parts that correspond to roles played by different actors during test execution. Components often align with certain structural elements of the system and execution environment, such as hardware engines, software packages, or testbench agents.

Components are structural entities, defined per type and instantiated under other components (see Syntax 22). Component instances constitute a hierarchy (tree structure), beginning with the top or root component, called \texttt{pss\_top} by default, which is implicitly instantiated. Each component instance has a unique hierarchical path name, and may also contain data attributes, but not constraints. Components may also encapsulate function declarations (see 21.2.1) and imported class instances (see 21.4.2). In addition, components may be derived from other components via inheritance, or a component may be extended to add elements to the component type (see Clause 19).

9.1 Syntax

\begin{verbatim}
component_declaration ::= [ pure ] component component_identifier [ template_param_decl_list ]
[ component_super_spec ] { { component_body_item } }
component_super_spec ::= : type_identifier
component_body_item ::= 
    override_declaration 
    | component_data_declaration 
    | component_pool_declaration 
    | action_declaration 
    | abstract_action_declaration 
    | object_bind_stmt 
    | exec_block 
    | struct_declaration 
    | enum_declaration 
    | covergroup_declaration 
    | function_decl 
    | import_class_decl 
    | procedural_function 
    | import_function 
    | target_template_function 
    | export_action 
    | typedef_declaration 
    | import_stmt 
    | extend_stmt 
    | compile_assert_stmt 
    | attr_group 
    | component_body_compile_if 
    | stmt_terminator
\end{verbatim}

Syntax 22—component declaration
9.2 Examples

For an example of how to declare a component, see Example 35.

```
component uart_c { ... };
```

Example 35—Component

9.3 Components as namespaces

Component types serve as namespaces for their nested types, e.g., action and struct types defined under them. The fully-qualified name of nested types is of the form 'package-namespace::component-type::nested-type'. References to nested types in a component shall follow the name resolution rules defined in 20.3.

For an example of how to use a component as a namespace, see Example 36.

```
component usb_c {
    action write {...}
}
component uart_c {
    action write {...}
}
component pss_top {
    uart_c s1;
    usb_c s2;
    action entry {
        uart_c::write wr; //refers to the write action in uart_c
        ...
    }
}
```

Example 36—Namespace

In Example 37 below, a component C1 is declared in a package. That component is instantiated in component pss_top, and an action within component C1 is traversed in action pss_top::entry. In the traversal of action P::C1::A, the qualified name elements are the following:

- package-namespace: P
- component-type: C1
- class-type: A
9.4 Component instantiation

Components are instantiated under other components as their fields, much like data fields of structs, and may be arrays thereof.

9.4.1 Semantics

a) Component fields are non-random; therefore, the `rand` modifier shall not be used. Component data fields represent configuration data that is accessed by actions declared in the component. To avoid infinite component instantiation recursion, a component type and all template specializations thereof shall not be instantiated under its own sub-tree.

b) In any model, the component instance tree has a predefined root component, called `pss_top` by default, but this may be user-defined. There can only be one root component in any valid scenario.

c) Other components are instantiated (directly or indirectly) under the root component. See also Example 38.

d) Plain-data fields may be initialized using a constant expression in their declaration. Data fields may also be initialized via an `exec init_down` or `init_up` block (see 21.1.2), which overrides the value set by an initialization assignment. The component tree is elaborated to instantiate each component and then the `exec init_down` and `init_up` blocks are evaluated hierarchically. See also Example 219 and Example 220 in 21.1.3.

e) Component data fields are considered immutable once construction of the component tree is complete. Actions can read the value of these fields, but cannot modify their value. Component data fields are accessed from actions relative to the `comp` field, which is a handle to the component context in which the action is executing. See also Example 221 (and 21.1).

f) It shall be illegal to access static component members using the `comp` handle.

g) It shall be illegal to reference non-static context component members from `struct` types declared within the component.

h) Any non-static component member may be referred to with a full hierarchical path starting with the root component.
9.4.2 Examples

Example 38 depicts a component tree definition. In total, there is one instance of multimedia_ss_c (instantiated in pss_top), four instances of codec_c (from the array declared in multimedia_ss_c), and eight instances of vid_pipe_c (two in each element of the codec_c array).

Example 38—Component instantiation

Example 39 shows some legal and illegal accesses to component functions and attributes.
9.5 Component references

Each action instance is associated with a specific component instance of its containing component type, the component-type scope where the action is defined. The component instance is the “actor” or “agent” that performs the action. Only actions defined in the scope of instantiated components can legally participate in a scenario.

The component instance with which an action is associated is referenced via the built-in field comp. The value of the comp field can be used for comparisons of references (see 8.5.3). Unlike user-defined reference variables, the comp field is assigned automatically as part of the solving process (see 16.4.5) and may not be assigned by the user. The static type of the comp field is the ref type of the action’s context component. Consequently, attributes and sub-components of the containing component may be referenced via the comp field using relative paths.

9.5.1 Semantics

A compound action can only instantiate sub-actions that are defined in its containing component or defined in component types that are instantiated in its containing component's instance sub-tree. In other words, compound actions cannot instantiate actions that are defined in components outside their context component hierarchy. This maximizes the reusability of components in other contexts.
9.5.2 Examples

Example 40 illustrates the need to define a sub-action in a containing component or its sub-tree. In action graphics::gr_a, the traversal of bus_c::write is illegal since the component bus_c is not instantiated in the action's containing component (graphics).

```
component bus_c {
   import bar_pkg::*;
   action write{input bar_s b;...} // bar_s is a stream
}

component graphics {
   import bar_pkg::*;
   action foo {output bar_s b;...}
   action gr_a {
      activity {
         parallel {
            do bus_c::write; // illegal
            do foo;
         }
      }
   }
}

component pss_top {
   import bar_pkg::*;
   bus_c a0;
   graphics g;
   pool bar_s bar_p;
   bind bar_p *;
}
```

Example 40—Illegal traversal of an action outside of the containing component hierarchy

Example 41 demonstrates the use of the comp reference. The constraint within the decode action forces the value of the action's mode bit to be 0 for the codecs[0] instance, while the value of mode is randomly selected for the other instances. The sub-action type program is available on both sub-component instances, pipeA and pipeB, but in this case is assigned specifically to pipeA using the comp reference.

See also 16.1.3.
Example 41—Using the comp attribute in constraints

9.6 Pure components

Pure components are restricted types of components that provide PSS implementations with opportunities for significant optimization of storage and initialization. Pure components are used to encapsulate realization-level functionality and cannot contain scenario model features. Register structures are one possible application for pure components (see 23.10).

The following rules apply to pure components, that is, component types declared with the pure modifier:

a) In the scope of a pure component, it shall be an error to declare action types, pool instances, pool-binding directives, non-static data attributes, instances of non-pure component types, or exec blocks.

b) A pure component may be instantiated under a non-pure component. However, a non-pure component may not be instantiated under a pure component.

c) A pure component may not be derived from a non-pure component. However, both a pure component and a non-pure component may be derived from a pure component.
An example of the use of pure components is shown in Example 42.

```
pure component my_register {
    function bit[32] read();
    function void write(bit[32] val);
};

pure component my_register_group {
    my_register regs[10];
};

component my_ip {
    my_register_group reg_groups[100]; // sparsely-used large structure
};
```

Example 42—Pure components
10. Actions

Actions are a key abstraction unit in PSS. Actions serve to decompose scenarios into elements whose definitions can be reused in many different contexts. Along with their intrinsic properties, actions also encapsulate the rules for their interaction with other actions and the ways to combine them in legal scenarios. Atomic actions may be composed into higher-level actions, and, ultimately, to top-level test actions, using activities (see Clause 12). The activity of a compound action specifies the intended schedule of its sub-actions, their object binding, and any constraints. Activities are a partial specification of a scenario: determining their abstract intent and leaving other details open.

Actions prescribe their possible interactions with other actions indirectly, by using flow (see Clause 13) and resource (see Clause 14) objects. Flow object references specify the action’s inputs and outputs and resource object references specify the action’s resource claims.

By declaring a reference to an object, an action determines its relation to other actions that reference the very same object without presupposing anything specific about them. For example, one action may reference a data flow object of some type as its input, which another action references as its output. By referencing the same object, the two actions necessarily agree on its properties without having to know about each other. Each action may constrain the attributes of the object. In any consistent scenario, all constraints shall hold; thus, the requirements of both actions are satisfied, as well as any constraints declared in the object itself.

Actions may be atomic, in which case their implementation is supplied via one or more exec body blocks (see 21.1.2), or they may be compound, in which case they contain one or more activity statements (see Clause 12) that instantiate and schedule other actions. A single action can have multiple implementations in different packages, so the actual implementation of the action is determined by which package is used.

An action is declared using the action keyword and an action_identifier, as shown in Syntax 23.
10.1 Syntax

An action declaration optionally specifies an action_super_spec, a previously defined action type from which the new type inherits its members.

The following also apply:

a) The activity_declaration and body exec_block_stmt (see 21.1.2) action body items are mutually exclusive. An atomic action may specify body exec_block_stmt items; it shall not specify activity_declaration items. A compound action, which contains instances of other actions and activity_declaration items, shall not specify body exec_block_stmt items.

b) An abstract action may be declared as a template that defines a base set of field attributes and behavior from which other actions may inherit. Non-abstract derived actions may be instantiated like any other action. Abstract actions shall not be instantiated directly.

c) An abstract action may be derived from another abstract action, but not from a non-abstract action.

d) Abstract actions may be extended, but the action remains abstract and may not be instantiated directly.
10.2 Examples

10.2.1 Atomic actions

Examples of an atomic action declaration are shown in Example 43.

```
action write {
    output data_buf data;
    rand int size;
    //implementation details
    ...
}
```

Example 43—atomic action

10.2.2 Compound actions

Compound actions instantiate other actions within them and use activity statements (see Clause 12) to define the relative scheduling of these sub-actions.

Examples of compound action usage are shown in Example 44.

```
action sub_a {...};

action compound_a {
    sub_a a1, a2;
    activity {
        a1;
        a2;
    }
}
```

Example 44—compound action
10.2.3 Abstract actions

Abstract action types are used to capture common features of different actions, including actions of different components. Abstract actions may not be traversed directly. Rather, they are used through inheritance, as base types for non-abstract action types. Abstract action types may be declared outside the scope of a component, unlike non-abstract actions, which may only be declared in a component scope.

An example of abstract action usage is shown in Example 45. In this example, abstract action base is declared outside a component scope, in package mypkg, and subsequently extended in the same package. Action derived is declared as a non-abstract subtype of action base.

```plaintext
package mypkg {
    abstract action base {
        rand int i;
        constraint i>5 && i<10;
    }

    // action base remains abstract
    extend action base {
        rand int j;
    }
}

cOMPONENT pss_top {
    import mypkg::*;

    action derived : base {
        constraint i>6;
        constraint j>9;
    }
}

Example 45—abstract action
```
11. Template types

11.1 General

Template types in PSS provide a way to define generic parameterized types.

In many cases, it is useful to define a generic parameterizable type (struct/flow object/resource object/action/component) that can be instantiated with different parameter values (e.g., array sizes or data types). Template types maximize reuse, avoid writing similar code for each parameter value (value or data type) combination, and allow a single specification to be used in multiple places.

Template types must be explicitly instantiated by the user, and only an explicit instantiation of a template type represents an actual type.

The following sections describe how to define, use, and extend a template type when using the PSS input.

11.2 Template type declarations

A template type (struct, action, component, etc.) declaration specifies a list of formal type or value template parameter declarations. The parameters are provided as a comma-separated list enclosed in angle brackets (<>) following the name of the template type.

A template type may inherit from another template or non-template data type. A non-template type may inherit from a template type instance. In both cases, the same inheritance rules and restrictions as for the corresponding non-template type of the same type category are applied (e.g., a template struct may inherit from a struct, or from a template struct).

The syntax specified in the corresponding struct/action/component sections contains the template_param_decl_list nonterminal marked as optional. When the parameter declaration list enclosed in angle brackets is provided on a struct/action/component declaration, it denotes that the struct/action/component type is a template generic type.

11.2.1 Syntax

```
struct_declaration ::= struct_kind identifier [ template_param_decl_list ]
  [ struct_super_spec ] { { struct_body_item } }
component_declaration ::= component component_identifier [ template_param_decl_list ]
  [ component_super_spec ] { { component_body_item } }
action_declaration ::= action action_identifier [ template_param_decl_list ]
  [ action_super_spec ] { { action_body_item } }
template_param_decl_list ::= < template_param_decl { , template_param_decl } >
template_param_decl ::= type_param_decl | value_param_decl
```

Syntax 24—Template type declaration
11.2.2 Examples

Generic template-type declaration for various type categories are shown in Example 46.

```
struct my_template_s <type T> {
  T t_attr;
}

buffer my_buff_s <type T> {
  T t_attr;
}

abstract action my_consumer_action <int width, bool is_wide> {
  compile assert (width > 0);
}

component eth_controller_c <struct ifg_config_s, bool full_duplex = true> {
}
```

Example 46—Template type declarations

11.3 Template parameter declarations

A template parameter is declared as either a type or a value parameter. All template parameters have a name and an optional default value. All parameters subsequent to the first one that is given a default value shall also be given default values. Therefore, the parameters with defaults shall appear at the end of the parameter list. Specifying a parameter with a default value followed by a parameter without a default value shall be reported as an error.

A template parameter can be referenced using its name inside the body and the supertype specification of the template type and all subsequent generic template type extensions, including the template type instance extensions. A template parameter may not be referenced from within subtypes that inherit from the template type that originally defined the parameter.

11.3.1 Template value parameter declarations

Value parameters are given a data type and optionally a default value, as shown below.

11.3.1.1 Syntax

```
value_param_decl ::= data_type identifier [ = constant_expression ]
```

Syntax 25—Template value parameter declaration

The following also apply:

a) A value parameter can be referenced using its name anywhere a constant expression is allowed or expected inside the body and the supertype specification of the template type.

b) Valid data types for a `value_param_decl` are the scalar types, except `chandle`.

c) The default value, if provided, may also reference one or more of the previously defined parameters.

d) To avoid parsing ambiguity, a Boolean greater-than (>) or less-than (<) expression provided as a default value shall be enclosed in parentheses.
11.3.1.2 Examples

An example of declaring an action type that consumes a varying number of resources is shown in Example 47.

```plaintext
action my_consumer_action <int n_locks = 4> {  
    compile assert (n_locks in [1..16]);  
    lock my_resource res[n_locks];  
}
```

**Example 47—Template value parameter declaration**

**Example 48** contains a Boolean greater-than expression that must be enclosed in parentheses and depends on a previous parameter:

```plaintext
action my_consumer_action <int width, bool is_wide = (width > 10) > {  
    compile assert (width > 0);  
}
```

**Example 48—Another template value parameter declaration**

11.3.2 Template type parameter declarations

Type parameters are prefixed with either the `type` keyword or a type-category keyword in order to identify them as type parameters.

When the `type` keyword is used, the parameter is fully generic. In other words, it can take on any type.

Specifying category type parameters provides more information to users of a template type on acceptable usage and allows tools to flag usage errors earlier. A category type parameter enforces that a template instance parameter value must be of a certain category/class of type (e.g., `struct`, `action`, etc.). A category type parameter can be further restricted such that the specializing type (the parameter value provided on instantiation) must be related via inheritance to a specified base type.

The syntax for declaring a type parameter is shown below.

11.3.2.1 Syntax

```plaintext
type_param_decl ::= generic_type_param_decl [ category_type_param_decl ]  
generic_type_param_decl ::= type identifier [ = type_identifier ]  
category_type_param_decl ::= type_category identifier [ type_restriction ] [ = type_identifier ]  
type_restriction ::= : type_identifier  
type_category ::=  
    action  
    | component  
    | struct_kind
```

**Syntax 26—Template type parameter declaration**
The following also apply:

a) A type parameter can be referenced using its name anywhere inside the body of the template type where a type is allowed or expected.
b) The default value, if provided, may also reference one or more of the previously defined parameters.

11.3.2.2 Examples

Examples of a generic type and a category type parameter are shown in Example 49.

```c
struct my_container_s <struct T> {  
    T t_attr;
}
struct my_template_s <type T> {  
    T t_attr;
}
```

**Example 49—Template generic type and category type parameters**

In the example above, the template parameter T of my_container_s must be of struct type, while in the case of my_template_s, the template parameter T may take on any type.

An example of how to use type restrictions in the case of a type-category parameter is shown in Example 50.

```c
struct base_t {  
    rand bit[3:0] core;
}
struct my_sub1_t : base_t {  
    rand bit[3:0] add1;
}
struct my_sub2_t : base_t {  
    rand bit[3:0] add2;
}
buffer b1 : base_t {  }
buffer b2 : base_t {  }
abstract action my_action_a <buffer B : base_t> {  }
struct my_container_s <struct T : base_t = my_sub1_t> {  
    T t_attr;
    constraint t_attr.core >= 1;
}
```

**Example 50—Template parameter type restriction**

In the example above, the template parameter T of my_container_s must be of type base_t or one of its struct subtypes (my_sub1_t or my_sub2_t, but not b1 or b2). This allows my_container_s to reasonably assume that T contains an attribute named ‘core’, and communicates this requirement to users of this type and to the PSS processing tool. The template parameter B of my_action_a must be of one of the buffer subtypes of base_t (b1 or b2).
The base type of the template type may also be a type parameter. In this way, the inheritance can be controlled when the template type is instantiated.

In Example 51, the `my_container_s` template struct inherits from the struct type template type parameter.

```
struct my_base1_t {
    rand int attr1;
}

struct my_base2_t {
    rand int attr2;
}

struct my_container_s <struct T> : T {
}

struct top_s {
    rand my_container_s <my_base1_t> cont1;
    rand my_container_s <my_base2_t> cont2;
    constraint cont1.attr1 == cont2.attr2;
}
```

Example 51—Template parameter used as base type

### 11.4 Template type instantiation

A template type is instantiated using the name of the template type followed by the parameter value list (specialization) enclosed in angle brackets (<>). Template parameter values are specified positionally.

The explicit instantiation of a template type represents an actual type. All explicit instantiations provided with the same set of parameter values are the same actual type.

#### 11.4.1 Syntax

```
type_identifier ::= [ :: ] type_identifier_elem { :: type_identifier_elem }
type_identifier_elem ::= identifier [ template_param_value_list ]
template_param_value_list ::= < [ template_param_value { , template_param_value } ] >
template_param_value ::= constant_expression | data_type
```

Syntax 27—Template type instantiation

The following also apply:

a) Parameter values must be specified for all parameters that were not given a default value.

b) An instance of a template type must always specify the angle brackets (<>), even if no parameter value overrides are provided for the defaults.

c) The specified parameter values must comply with parameter categories and parameter type restrictions specified for each parameter in the original template declaration, or an error shall be generated.

d) To avoid parsing ambiguity, a Boolean greater-than (>) or less-than (<) expression provided as a parameter value must be enclosed in parentheses.
11.4.2 Examples

Example 52—Template type instantiation

In Example 52 above, two attributes of my_container_s type are created. The first uses the default parameter value. The second specifies the my_sub2_t type as the value for the T parameter.

Type qualification for an action declared in a template component is shown in Example 53 below.

Example 53—Template type qualification
Example 54 depicts various ways of overriding the default values. In the example below, the `my_struct_t<2>` instance overrides the parameter `A` with 2, and preserves the default values for parameters `B` and `C`. The `my_struct_t<2, 8>` instance overrides the parameter `A` with 2, parameter `B` with 8, and preserves the default value for `C`.

```
struct my_s_1 { }
struct my_s_2 { }

struct my_struct_t <int A = 4, int B = 7, int C = 3> { _ }

struct container_t {
    my_struct_t<2> a; // instantiated with <2, 7, 3>
    my_struct_t<2,8> b; // instantiated with <2, 8, 3>
}
```

11.5 Template type user restrictions

A generic template type may not be used in the following contexts:

- As a root component
- As a root action
- As an inferred action to complete a partially specified scenario

Template types are explicitly instantiated by the user, and only an explicit instantiation of a template type represents an actual type. Only action actual types can be inferred to complete a partially specified scenario. The root component and the root action must be actual types.

Template types may not be used as parameter types or return types of imported functions.
12. Activities

When a compound action includes multiple operations, these behaviors are described within the action using one or more activity statements. An activity specifies the set of actions to be executed and the scheduling relationship(s) between them. If more than one activity is specified in an action, the execution semantics are the same as if the activity statements were combined in a schedule statement (see 12.3.5 and 12.6). A reference to an action within an activity is via an action handle, and the resulting action traversal causes the referenced action to be evaluated and randomized (see 12.3.1).

An activity, on its own, does not introduce any scheduling dependencies for its containing action. However, flow object or resource scheduling constraints of the sub-actions may introduce scheduling dependencies for the containing action relative to other actions in the system.

12.1 Activity declarations

Because activities are explicitly specified as part of an action, activities themselves do not have a separate name. Relative to the sub-actions referred to in the activity, the action that contains the activity is referred to as the context action.

12.2 Activity constructs

Each node of an activity represents an action, with the activity specifying the temporal, control, and/or data flow between them. These relationships are described via activity rules, which are explained herein. See also Syntax 28.
12.2.1 Syntax

```
activity_declaration ::= activity { { activity_stmt } }
activity_stmt ::=  
    [ label_identifier : ] labeled_activity_stmt
    | activity_action_traversal_stmt
    | activity_data_field
    | activity_bind_stmt
    | action_handle_declaration
    | activity_constraint_stmt
    | activity_scheduling_constraint
    | stmt_terminator
labeled_activity_stmt ::=  
    activity_sequence_block_stmt
    | activity_parallel_stmt
    | activity_schedule_stmt
    | activity_repeat_stmt
    | activity_foreach_stmt
    | activity_select_stmt
    | activity_if_else_stmt
    | activity_match_stmt
    | activity_replicate_stmt
    | activity_super_stmt
    | activity_atomic_block_stmt
    | symbol_call
```

Syntax 28—activity statement

12.3 Action scheduling statements

By default, statements in an activity specify sequential behaviors, subject to data flow constraints. In addition, there are several statements that allow additional scheduling semantics to be specified. Statements within an activity may be nested, so each element within an activity statement is referred to as a sub-activity.

12.3.1 Action traversal statement

An action traversal statement designates the point in the execution of an activity where an action is randomized and evaluated (see Syntax 29). The action being traversed may be specified via an action handle referring to an action field or local variable that was previously declared. Alternatively, the action being traversed may be specified by type, in which case a label, if specified, serves as an action handle. In the absence of a label, the action instance is anonymous.
12.3.1.1 Syntax

```
activity_action_traversal_stmt ::=  
    identifier [ [ expression ] ] inline_constraints_or_empty  
    [ [ label_identifier : ] do type_identifier inline_constraints_or_empty  
    inline_constraints_or_empty ::=  
        with constraint_set  
    | ;
```

Syntax 29—Action traversal statement

`identifier` names a unique action handle or variable in the context of the containing action type or activity scope. If `identifier` refers to an action handle array (see 12.3.2), then a specific array element may be specified with the optional array subscript. The alternative forms are specified by the keyword `do`, followed by an action-type specifier. Given a `label_identifier`, the action instance can be referenced using the label. In the absence of a `label_identifier`, the action instance is anonymous. Either form of the action traversal statement may include an optional in-line constraint.

The following also apply:

a) The action variable is randomized and evaluated at the point in the flow where the statement occurs. The variable may be of an action type or a data type declared in the context action with the action modifier. In the latter case, it is randomized, but has no observed execution or duration (see Example 144).

1) An action handle is considered uninitialized until it is first traversed. The fields within the action cannot be referenced in an exec block or conditional activity statement until after the action is first traversed. The steps that occur as part of the action traversal are as follows:

   i) The `pre_solve` block (if present) is executed.
   ii) Random values are selected for `rand` fields.
   iii) The `post_solve` block (if present) is executed.
   iv) The `body exec` block (if present) is executed.
   v) The `activity` block (if present) is evaluated.
   vi) The validity of the constraint system is confirmed, given any changes by the `post_solve` or `body exec` blocks.

2) Upon entry to an activity scope, all action handles traversed in that scope are reset to an uninitialized state.

b) The labeled traversal statement is semantically equivalent to a traversal statement with an explicitly declared action variable. With this form, the `label_identifier` serves as an action handle, equivalent to an explicitly declared variable of the specified action type in the enclosing activity scope.

c) The anonymous action traversal statement is semantically equivalent to the other two forms with the exception that it does not create an action handle that may be referenced from elsewhere in the stimulus model.

d) A named action handle may only be traversed once in the following scopes and nested scopes thereof:

1) sequential activity scope (e.g., `sequence` or `repeat`)
2) parallel
3) `schedule`
e) Formally, a traversal statement is equivalent to the sub-activity of the specified action type, with the optional addition of in-line constraints. The sub-activity is scheduled in accordance with the scheduling semantics of the containing activity or sub-activity.

f) Other aspects that impact action-evaluation scheduling, are covered via binding inputs or outputs (see 13.4), resource claims (see 14.2), or attribute value assignment.

12.3.1.2 Examples

Example 55 shows an example of traversing an action handle. Action A is an atomic action that contains a 4-bit random field f1. Action B is a compound action encapsulating an activity involving two invocations of action A. The default constraints for A apply to the evaluation of a1. An additional constraint is applied to a2, specifying that f1 shall be less than 10. Execution of action B results in two sequential evaluations of action A.

```
action A {
    rand bit[3:0] f1;
    ...
}

action B {
    A a1, a2;

    activity {
        a1;
        a2 with {
            f1 < 10;
        };
    }
}
```

Example 55—Action traversal

Example 56 shows an example of anonymous action traversal, including in-line constraints.

```
action A {
    rand bit[3:0] f1;
    ...
}

action B {
    activity {
        do A;
        do A with {f1 < 10;};
    }
}
```

Example 56—Anonymous action traversal

Example 57 shows the use of a label of an action traversal statement to constrain a sub-action instance from a higher activity context.
Example 57—Labeled action traversal

Example 58 shows an example of traversing a compound action as well as a random action variable field. The activity for action C traverses the random action variable field max, then traverses the action-type field b1. Evaluating this activity results in a random value being selected for max, then the sub-activity of b1 being evaluated, with a1.f1 constrained to be less than or equal to max.

Example 58—Compound action traversal
12.3.2 Action handle array traversal

Arrays of action handles may be declared within an action. These action handle arrays may be traversed as a whole or traversed as individual elements.

The semantics of traversing individual action handle array elements are the same as those of traversing individually-declared action handles.

Example 59 below shows traversing an individual action handle array element and one action handle. The semantics of both action traversal statements are the same.

```
component pss_top {
  action A { }
  action entry {
    A   a_arr[4];
    A   a1, a2, a3, a4;
    activity {
      a_arr[0];
      a1;
    }
  }
}
```

**Example 59—Individual action handle array element traversal**

When an action handle array is traversed as a whole, each array element is traversed independently according to the semantics of the containing scope.

Example 60 below shows an action that traverses the elements of the a_arr action handle array in two ways, depending on the value of a rand action attribute. Both ways of traversing the elements of a_arr have identical semantics.

```
component pss_top {
  action A { }
  action entry {
    rand bool traverse_arr;
    A   a_arr[2];
    activity {
      if (traverse_arr) {
        a_arr;
      } else {
        a_arr[0];
        a_arr[1];
      }
    }
  }
}
```

**Example 60—Action handle array traversal**

The contexts in which action handle arrays may be traversed, and the resulting semantics, are described in the table below.
Table 20—Action handle array traversal contexts and semantics

<table>
<thead>
<tr>
<th>Context</th>
<th>Semantics</th>
</tr>
</thead>
<tbody>
<tr>
<td>parallel</td>
<td>All array elements are scheduled for traversal in parallel.</td>
</tr>
<tr>
<td>schedule</td>
<td>All array elements are scheduled for traversal independently.</td>
</tr>
<tr>
<td>select</td>
<td>One array element is randomly selected and traversed.</td>
</tr>
<tr>
<td>sequence</td>
<td>All array elements are scheduled for traversal in sequence from 0 to N-1.</td>
</tr>
</tbody>
</table>

12.3.3 Sequential block

An activity sequence block statement specifies sequential scheduling between sub-activities (see Syntax 30).

12.3.3.1 Syntax

```
activity_sequence_block_stmt ::= [ sequence ] { { activity_stmt } }
```

Syntax 30—Activity sequence block

The following also apply:

a) Statements in a sequential block execute in order so that one sub-activity completes before the next one starts.

b) Formally, a sequential block specifies sequential scheduling between the sets of action executions per the evaluation of `activity_stmt1 .. activity_stmtn`, keeping all scheduling dependencies within the sets and introducing additional dependencies between them to obtain sequential scheduling (see 6.3.2).

c) Sequential scheduling does not rule out other inferred dependencies affecting the nodes in the sequence block. In particular, there may be cases where additional action executions must be scheduled in between sub-activities of subsequent statements.

12.3.3.2 Examples

Assume A and B are action types that have no rules or nested activity (see Example 61).

Action my_test specifies one execution of action A and one of action B with the scheduling dependency (A) -> (B); the corresponding observed behavior is {start A, end A, start B, end B}.

Now assume action B has a state precondition which only action C can establish. C may execute before, concurrently to, or after A, but it shall execute before B. In this case the scheduling dependency relation would include (A) -> (B) and (C) -> (B) and multiple behaviors are possible, such as {start C, start A, end A, end C, start B, end B}. 
Finally, assume also $C$ has a state precondition which only $A$ can establish. Dependencies in this case are $(A) \rightarrow (B), (A) \rightarrow (C)$ and $(C) \rightarrow (B)$ (note that the first pair can be reduced) and, consequently, the only possible behavior is\{start $A$, end $A$, start $C$, end $C$, start $B$, end $B$\}.

Example 61—Sequential block

Example 62 shows all variants of specifying sequential behaviors in an activity. By default, statements in an activity execute sequentially. The sequence keyword is optional, so placing sub-activities inside braces (\{\}) is the same as an explicit sequence statement, which includes sub-activities inside braces. The examples show a total of six sequential actions: $A, B, A, B, A, B$.

Example 62—Variants of specifying sequential execution in activity

12.3.4 parallel

The parallel statement specifies sub-activities that execute concurrently (see Syntax 31).

12.3.4.1 Syntax

```
activity_parallel_stmt ::= parallel [ activity_join_spec ] { { activity_stmt } }
```

Syntax 31—Parallel statement

The following also apply:

a) Parallel activities are invoked in a synchronized way and then proceed without further synchronization until their completion. Parallel scheduling guarantees that the invocation of an action in one sub-activity branch does not wait for the completion of any action in another.

b) Formally, the parallel statement specifies parallel scheduling between the sets of action executions per the evaluation of activity_stmt1 .. activity_stmtn, keeping all scheduling dependencies within the sets, ruling out scheduling dependencies across the sets, and introducing additional scheduling
dependencies to initial action executions in each of the sets in order to obtain a synchronized start (see 6.3.2).

c) In the absence of an activity_join_spec (see 12.3.6), execution of the activity statement following the parallel block is scheduled to begin after all parallel branches have completed. When an activity_join_spec is specified, execution of the activity statement following the parallel block is scheduled based on the join specification.

### 12.3.4.2 Examples

Assume A, B, and C are action types that have no rules or nested activity (see Example 63).

The activity in action my_test specifies two dependencies (a) -> (b) and (a) -> (c). Since the executions of both b and c have the exact same scheduling dependencies, their invocation is synchronized.

Now assume action type C inputs a buffer object and action type B outputs the same buffer object type, and the input of c is bound to the output of b. According to buffer object exchange rules, the inputting action shall be scheduled after the outputting action. But this cannot satisfy the requirement of parallel scheduling, according to which an action in one branch cannot wait for an action in another. Thus, in the presence of a separate scheduling dependency between b and c, this activity shall be illegal.

```
action my_test {
    A a;
    B b;
    C c;
    activity {
        a;
        parallel {
            b;
            c;
        }
    }
};
```

**Example 63—Parallel statement**

In Example 64, the semantics of the parallel construct require the sequences \{A, B\} and \{C, D\} to start execution at the same time. The semantics of the sequential block require that the execution of B follows A and D follows C. It is illegal to have any scheduling dependencies between sub-activities in a parallel statement, so neither A nor B may have any scheduling dependencies relative to either C or D.

Even though actions A and D lock the same resource type from the same pool, the pool contains a sufficient number of resource instances such that there are no scheduling dependencies between the actions. If pool_R contained only a single instance, there would be a scheduling dependency in that A and D could not overlap, which would violate the rules of the parallel statement.
12.3.5 schedule

The schedule statement specifies that the PSS processing tool shall select a legal order in which to evaluate the sub-activities, provided that one exists. See Syntax 32.

12.3.5.1 Syntax

```
activity_schedule_stmt ::= schedule [ activity_join_spec ] { { activity_stmt } }
```

Syntax 32—Schedule statement

The following also apply:

a) All activities inside the schedule block shall execute, but the PSS processing tool is free to execute them in any order that satisfies their other scheduling requirements.

b) Formally, the schedule statement specifies that any scheduling of the combined sets of action executions per the evaluation of activity_stmt1 .. activity_stmtn is permissible, as long as it keeps all scheduling dependencies within the sets and introduces (at least) the necessary scheduling dependencies across the sets in order to comply with the rules of input-output binding of actions and resource assignments.

c) In the absence of an activity_join_spec (see 12.3.6), execution of the activity statement following the schedule block is scheduled to begin after all statements within the block have completed. When an activity_join_spec is specified, execution of the activity statement following the schedule block is scheduled based on the join specification.

12.3.5.2 Examples

Consider the code in Example 65, which is similar to Example 63, but uses a schedule block instead of a parallel block. In this case, the following executions are valid:

a) The sequence of action nodes a, b, c.

b) The sequence of action nodes a, c, b.

c) The sequence of action node a, followed by b and c run in any order, subject to other scheduling constraints.
Example 65—Schedule statement

Note that neither \( b \) nor \( c \) may start execution until after the completion of \( a \), and the start of execution for either may be subject to additional scheduling constraints. In contrast to \( b \) and \( c \) executing in parallel, as in Example 63, there may be scheduling dependencies between \( b \) and \( c \) in the schedule block. The scheduling graph for the activity is shown here:

![Scheduling graph of activity with schedule block](image)
For the case where \( b \) and \( c \) overlap, the runtime behaviors will execute as shown here:

![Figure 7—Runtime behavior of activity with schedule block](image)

In contrast, consider the code in Example 66. In this case, any execution order in which both \( B \) comes after \( A \) and \( D \) comes after \( C \) is valid.

If both \( A \) and \( D \) wrote to the same state variable, they would have to execute sequentially. This is in addition to the sequencing of \( A \) and \( B \) and of \( C \) and \( D \). In the case where \( D \) writes before \( A \), the sequence would be \{\( C, D, A, B \)\}. In the case where \( A \) writes before \( D \), the runtime behavior would be as shown in Figure 8.

```
action A {}
action B {}
action C {}
action D {}

action my_test {
  activity {
    schedule {
      {do A; do B;}
      {do C; do D;}
    }
  }
}
```

*Example 66—Scheduling block with sequential sub-blocks*
12.3.6 Fine-grained scheduling specifiers

Fine-grained scheduling specifiers modify the termination semantics for parallel and schedule blocks (see Syntax 31, Syntax 32, and Syntax 33). The semantics of fine-grained scheduling are defined strictly at the activity scheduling level. The semantics do not assume that any runtime execution information is incorporated by the PSS processing tool in the scheduling process. Activity scheduling in the presence of a fine-grained scheduling specifier is still subject to all other scheduling rules.

12.3.6.1 Syntax

```
activity_join_spec ::= 
    activity_join_branch | activity_join_select | activity_join_none | activity_join_first
activity_join_branch ::= join_branch ( label_identifier { , label_identifier } )
activity_join_select ::= join_select ( expression )
activity_join_none ::= join_none
activity_join_first ::= join_first ( expression )
```

Syntax 33—Activity join specification

The following also apply:

a) join_branch accepts a list of labels referring to labeled activity statements. The activity statement following the fine-grained scheduling block is scheduled after all the listed activity statements have completed.

1) The label_identifier used in the join_branch specification must be the label of a top-level branch within the parallel or schedule block to which the join_branch specification is applied.
2) When the *label_identifier* used in the **join_branch** specification applies to traversal of an array, the activity statement following the fine-grained scheduling block is scheduled after all actions in the array have completed.

b) **join_select** accepts an *expression* specifying the number of top-level activity statements within the fine-grained scheduling block on which to condition execution of the activity statement following the fine-grained scheduling block. The specific activity statements shall be selected randomly. Execution of the activity statement following the fine-grained scheduling block is scheduled after the selected activity statements.
   1) The *expression* shall be of an integer type. The value of the *expression* must be determinable at solve time. If the value is 0, the **join_select** is equivalent to **join_none**.
   2) When an action array is traversed, each element of the array is considered a separate action that may be selected independently.

c) **join_none** specifies that the activity statement following the fine-grained scheduling block has no scheduling dependency on activity statements within the block.

d) **join_first** specifies that the activity statement following the fine-grained scheduling block has a runtime execution dependency on the first N activity statements within the fine-grained scheduling block to complete execution. The activity statement following the fine-grained scheduling block has no scheduling dependency on activity statements within the block, only a runtime dependency.
   1) The *expression* shall be of an integer type. The value of the *expression* must be determinable at solve time. If the value is 0, the **join_first** is equivalent to **join_none**.
   2) When an action array is traversed, each element of the array is considered a separate action that may be selected independently.

The application scope of a fine-grained scheduling block is bounded by the sequential block that contains it. In other words, all activity statements that start within the fine-grained scheduling block must complete before the statement following the containing sequential block begins. Activities started, but not joined, within a fine-grained scheduling block are not implicitly waited for by any containing parallel or schedule blocks. Only the containing sequential block causes a join on activities started within it.

### 12.3.6.2 Examples

In Example 67, the innermost parallel block (L4) starts two activities (L5 and L6), while only waiting for one (L5) to complete before continuing. Since L5 traverses the action array b, all elements of b must complete before continuing. The next level of parallel block (L2) waits for its two branches to complete (L3 and L4), but does not wait for L6 to complete. The outermost parallel block (L1) waits for one of its branches (L2) to complete before proceeding. This means that both L7 and L6 may be in-flight when L8 is traversed.
Example 67—join_branch

The scheduling graph of the activity is shown in Figure 9.

```
B b[2];
activity {
    L1: parallel join_branch(L2) {
        L2: parallel {
            L3: do A;
            L4: parallel join_branch (L5) {
                L5: b;
                L6: do C;
            }
        }
        L7: do D;
    }
    L8: do F;
}
```

Figure 9—join_branch scheduling graph
The runtime behavior is shown in Figure 10.

![Figure 10—join_branch runtime behavior](image)

Activity scheduling in the presence of a fine-grained scheduling block is still subject to all other scheduling rules. For example, if both L6 and L8 in the example above contend for the same single resource, they must be scheduled sequentially in order to avoid a resource conflict.

For the following four examples, assume that each of the three actions in the activity locks a resource from the same pool.

In Example 68, the parallel block causes traversal of branches L1 and L2 to be scheduled in parallel. The join_branch specifier causes traversal of action C to be scheduled with a sequential dependency on the activity statement labeled L2. Traversal of action C may not begin until the activity statement labeled L2 has completed. To avoid adding additional scheduling dependencies, the resource pool would need a minimum of two resource instances. Actions A and B would each lock a resource instance, and C, since it is guaranteed not to start until A completes, would lock the same resource instance as that assigned to A. Note that this allocation is handled at solve-time, and is independent of whether B completes before or after A completes.
The scheduling graph of the activity is shown in Figure 11.

![Scheduling graph of join_branch with scheduling dependency](image)

**Figure 11—Scheduling graph of join_branch with scheduling dependency**

The runtime behavior is shown in Figure 12.

![Runtime behavior of join_branch with scheduling dependency](image)

**Figure 12—Runtime behavior of join_branch with scheduling dependency**

In Example 69, the parallel block causes traversal of the branches labeled L2 and L3 to be scheduled in parallel. The join_select specifier causes traversal of action C to be scheduled with a sequential dependency on a random selection of either the branch labeled L2 or L3. This means that traversal of C may not begin until after the selected target activity statement has completed. The tool randomly selects N (in this case, 1) target branch(es) from the candidate branches on which to make traversal of the following activity statement dependent.

In this example, the resource pool would need a minimum of two resource instances. Because the tool may not know which of A or B will complete first, it must choose one and assign the same resource instance to action C. If the tool selected L2 as the branch on which C depends, the behavior would be identical to the previous example.
In Example 70, the `join_none` specifier causes traversal of action C to be scheduled with no dependencies. To avoid additional scheduling dependencies, the minimum size of the resource pool must be three, since each action traversed in the activity must have a unique resource instance.

Actions A and B are scheduled in parallel, and action C is scheduled concurrently with both of them. This means that C could start at the same time as A and B, but it may not. While the `parallel` statement precludes any dependencies between A and B, the `join_none` qualifier allows action C to be scheduled concurrently, but there may be additional dependencies between action C and action A and/or B.

The scheduling graph of the activity is shown in Figure 13.

In Example 71, the `join_first` specifier causes the PSS processing tool to condition execution of action C on runtime execution completion of the first of either action A or B. Since the scheduling tool may not know which action will complete first, there must be a minimum of three resource instances in the pool in order to guarantee that C may execute immediately after whichever of A or B completes first. If there are two instances in the pool, the tool may assign either resource instance to C at solve-time. If the other action
assigned the same resource instance completes last, then action C, because it starts execution after the previous action completes, will also start its execution after the completion of the first action.

```plaintext
activity {
    L1 : parallel join_first(1) {
        L2: do A;
        L3: do B;
    }
    L4: do C;
}
```

*Example 71—join_first*

The runtime behavior is shown in *Figure 14*.

![Figure 14—join_first runtime behavior](image)

*Example 72—Scope of join inside sequence block*

*Example 72* illustrates how a `sequence` block bounds the impact of the fine-grained scheduling specifier. The execution of L5 is scheduled in sequence with L3. L4 and L5 may be scheduled concurrently. L6 is scheduled strictly sequentially to all statements inside L1, the `sequence` block.

```plaintext
activity {
    L1: sequence {
        L2: parallel join_branch(L3) {
            L3: do A;
            L4: do B;
        }
        L5: do C;
    }
    L6: do D;
}
```

*Example 72—Scope of join inside sequence block*
The scheduling graph is shown in Example 15.

Figure 15—Scheduling graph of join inside sequence block

The runtime behavior is shown in Figure 16.

Figure 16—Runtime behavior of join inside sequence block
Example 73 shows how the join specification may also be used with the schedule block.

```
activity {
    L1 : schedule join_branch(L2) {
        L2: do A;
        L3: do B;
    }
    L4: do C;
}
```

**Example 73—join with schedule block**

Assuming there are no scheduling dependencies between actions A and B, the scheduling graph of schedule block L1 is shown in Figure 17.

In all cases, action C is scheduled subsequent to action A. If A is scheduled before B, then B and C may–or may not–be scheduled concurrently, although there may be additional dependencies between them. If B is scheduled before A, the actions are executed in the order B, A, C. If A and B are scheduled concurrently, then C is still scheduled after A, but again may be concurrent with B, subject to any dependencies between B and C.

![Figure 17—Scheduling graph join with schedule block](image)

### 12.3.7 Atomic block specifier

Within an activity block, the atomic block specifier is used to preserve intended scheduling structure of its sub-activity, by preventing potential interference from other actions in the larger scenario. Example 74 and Example 75 in 12.3.7.2 demonstrate two typical causes for such interference: action inference and scheduling issues due to resource allocation. The atomic block specifier restricts the legal solution space by
ruling out “unintended” (but otherwise legal) scheduling dependencies between actions within an atomic block and the rest of the scenario. The following section defines which scheduling dependencies are ruled out and which remain legal.

An atomic block is analogous to an atomic action from a scheduling point of view, meaning that it can be substituted by an atomic action without change to the outside scheduling relations. All actions explicitly traversed in an atomic block are part of a single scheduling “cluster” (a nested subgraph of the scheduling dependency graph). In a transitive-reduced scheduling graph, the atomic block would have exactly one incoming edge and one outgoing edge. The incoming edge would represent “upward” dependencies, scheduling dependencies of an action traversed in the atomic block on outside actions. These outside actions become scheduling dependencies of the block as a whole (i.e., of all other actions in the cluster). The outgoing edge would represent “downward” dependencies, scheduling dependencies of an action within the cluster to an action outside the cluster. The outside action has a scheduling dependency on the block as a whole (i.e., on all other actions within the cluster).

12.3.7.1 Syntax

```
activity_atomic_block_stmt ::= atomic { { activity_stmt } }
```

An atomic set is the set of all action executions corresponding to action traversal statements under the scope of an atomic block.

- This recursively includes all sub-actions of a compound action traversed in the atomic block.
- One atomic set can be a subset of another, but two atomic sets cannot have a non-empty intersection unless one is a subset of the other (this is guaranteed by the structure of activities).
- Inferred actions are never within an atomic set.

The following applies:

- If AS is an atomic set, a₁ ∈ AS, and a₂ ∉ AS, then:
  1) If a₁ → a₂, then for every a₃ ∈ AS, a₃ → a₅; that is, if an action outside the atomic set has a scheduling dependency on an action inside the atomic set, then the outside action has a scheduling dependency on all actions in the atomic set.
  2) If a₂ → a₁ then for every a₃ ∈ AS, a₂ → a₃; that is, if an action inside the atomic set has a scheduling dependency on an action outside the atomic set, then all actions in the atomic set have a scheduling dependency on the outside action.

12.3.7.2 Examples

Consider the code in Example 74. It demonstrates how the atomic specifier prevents the PSS solver from generating an unintended scenario scheduling due to the action inference process.

The atomic block specifier is used to ensure that B_a starts immediately after A_a completes. B_a may only start after configX_a completes. configX_a could require a meaningful amount of time to complete. configX_a needs to be inferred. Without the atomic specifier, configX_a could be inferred to execute after A_a and before B_a. With the atomic specifier, we are guaranteed a stress scenario where B_a is executed immediately after A_a completes.
Example 74—Atomic block to avoid action interference

**Figure 18** illustrates undesired scheduling of the configX_a action when inferred, which can occur if the atomic specifier is not used.

In reality, B_a may start long after A_a. Stress is not achieved because relevant behavior is spaced apart or diluted.

**Figure 18**—Scheduling graph of action interference
Figure 19 illustrates the cluster of actions in an atomic block (i.e., A_a and B_a) and how the configX_a action is an “upward” scheduling dependency of the atomic block. The figure shows two examples where configX_a is scheduled: a) after the bring-up and before the atomic block; b) in parallel with the bring-up and before the atomic block.

Figure 19—Scheduling graph of atomic block avoiding interference

Consider the code in Example 75. It demonstrates how the atomic specifier prevents the PSS solver from generating an unintended scenario scheduling due to a possible outcome of the resource allocation process.

Test intent of my_stress_seq is that B follows A as soon as possible. Figure 20 shows a scheduling solution that would violate this intent within the my_test scenario. C could be scheduled in parallel with A when both B and C happen to be assigned same resource slot, causing B to wait for completion of C which may take longer than A.
Example 75—Atomic block to avoid resource allocation issues

```plaintext
resource core_r {}
pool [4] core_r core_pool;

action A {}

action B {
  lock core_r core;
}

action C {
  lock core_r core;
}

action my_stress_seq {
  atomic {
    do A;
    do B;
  }
}

action my_test {
  activity {
    schedule {
      do my_stress_seq;
      do C;
    }
  }
}
```

In reality, B may start long after A completes.

Resource assignment randomized to be the same.

Figure 20—Scheduling graph of resource allocation issues
12.4 Activity control flow constructs

In addition to defining sequential and parallel blocks of action execution, repetition and branching statements can be used inside the activity clause.

12.4.1 repeat (count)

The repeat statement allows the specification of a loop consisting of one or more actions inside an activity. This section describes the count-expression variant (see Syntax 35) and 12.4.2 describes the while-expression variant.

12.4.1.1 Syntax

Syntax 35—repeat-count statement

```
activity_repeat_stmt ::= 
  repeat ( [ index_identifier : ] expression ) activity_stmt 
  | . . .
```

The following also apply:

a) expression shall be a non-negative integer expression (int or bit).

b) Intuitively, the activity_stmt is iterated the number of times specified in the expression. An optional index-variable identifier can be specified that ranges between 0 and one less than the iteration count. If the expression evaluates to 0, the activity_stmt is not evaluated at all.

c) Formally, the repeat-count statement specifies sequential scheduling between N sets of action executions per the evaluation of activity_stmt N times, where N is the number to which expression evaluates (see 6.3.2).

d) The choice of values to rand attributes figuring in the expression shall be such that it yields legal execution scheduling.

12.4.1.2 Examples

In Example 76, the resulting execution is six sequential action executions, alternating A’s and B’s, with five scheduling dependencies: \((A_0) -> (B_0), (B_0) -> (A_1), (A_1) -> (B_1), (B_1) -> (A_2), (A_2) -> (B_2)\).

```
action my_test {
  A a;
  B b;
  activity {
    repeat (3) {
      a;
      b;
    }
  }
};
```

Example 76—repeat statement
Example 77 shows an additional example of using repeat-count.

```c
action my_test {
  my_action1 action1;
  my_action2 action2;
  activity {
    repeat (i : 10) {
      if ((i % 4) == 0) {
        action1;
      } else {
        action2;
      }
    }
  }
};
```

**Example 77—Another repeat statement**

### 12.4.2 repeat-while

The repeat statement allows the specification of a loop consisting of one or more actions inside an activity. This section describes the while-expression variant (see Syntax 36).

#### 12.4.2.1 Syntax

```plaintext
activity_repeat_stmt ::= 
  . . .
  | repeat activity_stmt while ( expression ) :
```

**Syntax 36—repeat-while statement**

The following also apply:

a) expression shall be of type bool.

b) Intuitively, the activity_stmt is iterated so long as the expression condition is true, as sampled after the activity_stmt.

c) Formally, the repeat-while statement specifies sequential scheduling between multiple sets of action executions per the iterative evaluation of activity_stmt. The evaluation of activity_stmt continues repeatedly so long as expression evaluates to true. expression is evaluated after the execution of each set in the repeat-while block.
12.4.2.2 Examples

Example 78—repeat-while statement

```
component top {
    function bit is_last_one();

    action do_something {
        bit last_one;
        exec post_solve {
            last_one = comp.is_last_one();
        }
        exec body C = ""
            printf("Do Something\n");
            "";
    }

    action entry {
        do_something s1;
        activity {
            repeat {
                s1;
            } while (s1.last_one !=0);
        }
    }
}
```

12.4.3 foreach

The `foreach` construct iterates over the elements of a collection (see Syntax 37). See also Example 79.

12.4.3.1 Syntax

```
```

Syntax 37—foreach statement

The following also apply:

a) `expression` shall be of a collection type (i.e., array, list, map or set), including fixed-sized arrays of action handles, components, and flow and resource object references.

b) The body of the `foreach` statement is a sequential block in which `activity_stmt` is evaluated once for each element in the collection.

c) `iterator_identifier` specifies the name of an iterator variable of the collection element type. Within `activity_stmt`, the iterator variable, when specified, is an alias to the collection element of the current iteration.

d) `index_identifier` specifies the name of an index variable. Within `activity_stmt`, the index variable, when specified, corresponds to the element index of the current iteration.
1) For **arrays** and **lists**, the index variable shall be a variable of type `int`, ranging from 0 to one less than the size of the collection variable, in that order.

2) For **maps**, the index variable shall be a variable of the same type as the **map** keys, and range over the values of the keys. The order of key traversal is undetermined.

3) For **sets**, an index variable shall not be specified.

e) Both the index and iterator variables, if specified, are implicitly declared within the **foreach** scope and limited to that scope. Regular name resolution rules apply when the implicitly declared variables are used within the **foreach** body. For example, if there is a variable in an outer scope with the same name as the index variable, that variable is shadowed (masked) by the index variable within the **foreach** body. The index and iterator variables are not visible outside the **foreach** scope.

f) Either an index variable or an iterator variable or both shall be specified. For a **set**, an iterator variable shall be specified, but not an index variable.

### 12.4.3.2 Examples

```
action my_action1 {
  rand bit[4] val;
  // ...
}

action my_test {
  rand bit[4] in [0..7] a[16];
  my_action1 action1;

  activity {
    foreach (a[j]) {
      action1 with {val <= a[j];};
    }
  }
};
```

*Example 79—foreach statement*

### 12.4.4 select

The **select** statement specifies a branch point in the traversal of the activity (see Syntax 38).

#### 12.4.4.1 Syntax

```
activity_select_stmt ::= select { select_branch select_branch { select_branch } }
select_branch ::= [ [ ( expression ) ] ] [ expression ] : ] activity_stmt
```

*Syntax 38—select statement*

The following also apply:

a) Intuitively, a **select** statement executes one out of a number of possible activities.

b) One or more of the **activity stmts** may optionally have a guard condition specified in parentheses `()`. Guard condition expressions shall be of Boolean type. When the **select** statement is evaluated, only those **activity stmts** whose guard condition evaluates to `true` or that do not have a guard condition are considered enabled.
c) Formally, each evaluation of a select statement corresponds to the evaluation of just one of the select_branch statements. All scheduling requirements shall hold for the selected activity statement.
d) Optionally, all activity_stmts may include a weight expression, which is a numeric expression that evaluates to a non-negative integer value. The probability of choosing an enabled activity_stmt is the weight of the given statement divided by the sum of the weights of all enabled statements. If the activity_stmt is an array of action handles, then the weight expression is assigned to each element of the array, from which one element is selected and traversed.
e) If any activity_stmt has a weight expression, then any statement without an explicit weight expression associated with it shall have a weight of 1.
f) It shall be illegal if no activity statement is valid according to the active constraint and scheduling requirements and the evaluation of the guard conditions.

12.4.4.2 Examples

In Example 80, the select statement causes the activity to select action1 or action2 during each execution of the activity.

```plaintext
action my_test {
  my_action1         action1;
  my_action2         action2;
  activity {
    select {
      action1;
      action2;
    }
  }
}
```

**Example 80—Select statement**

In Example 81, the branch selected shall depend on the value of a when the select statement is evaluated.

a) a==0 means that all three branches could be chosen, according to their weights.
   1) action1 is chosen with a probability of 20%.
   2) action2 is chosen with a probability of 30%.
   3) action3 is chosen with a probability of 50%.
b) a in [1..3] means that action2 or action3 is traversed according to their weights.
   1) action2 is chosen with a probability of 37.5%.
   2) action3 is chosen with a probability of 62.5%.
c) a==4 means that only action3 is traversed.
In Example 82, the select statement causes the activity to select action1 or one element of action2 during the execution of the activity. Since the weight expression of 2 is applied to each element of the action2 array, there is a 40% chance that either element of that array is chosen, and a 20% (weight of 1) chance of choosing action1.

Example 82—Select statement with guard conditions and weights

```action my_test {
    my_action1 action1;
    my_action2 action2;
    my_action3 action3;
    rand int in [0..4] a;
    activity {
        select {
            (a == 0) [20]: action1;
            (a in [0..3]) [30]: action2;
            [50]: action3;
        }
    }
}
```

Example 81—Select statement with guard conditions and weights

12.4.5 if-else

The if-else statement introduces a branch point in the traversal of the activity (see Syntax 39).

12.4.5.1 Syntax

```
activity_if_else_stmt ::= if ( expression ) activity_stmt [ else activity_stmt ]
```

Syntax 39—if-else statement

The following also apply:

a) expression shall be of type bool.
b) Intuitively, an if-else statement executes some activity if a condition holds, and, otherwise (if specified), the alternative activity.
c) Formally, the if-else statement specifies the scheduling of the set of action executions per the evaluation of the first activity_stmt if expression evaluates to true or the second activity_stmt (following else) if present and expression evaluates to false.
d) The scheduling relationships need only be met for one branch for each evaluation of the activity.
e) The choice of values to \texttt{rand} attributes figuring in the \textit{expression} shall be such that it yields legal execution scheduling.

12.4.5.2 Examples

If the scheduling requirements for Example 83 required selection of the \texttt{b} branch, then the value selected for \texttt{x} must be $\leq 5$. 

```plaintext
action my_test {
    rand int in [1..10] x;
    A a;
    B b;
    activity {
        if (x > 5)
            a;
        else
            b;
    }
}
```

\textit{Example 83—if-else statement}

12.4.6 match

The \texttt{match} statement specifies a multi-way decision point in the traversal of the activity that tests whether an expression matches any of a number of other expressions and traverses one of the matching branches accordingly (see Syntax 40).

12.4.6.1 Syntax

```plaintext
activity_match_stmt ::= \texttt{match} ( match_expression ) \{ match_choice \{ match_choice \} \}
match_expression ::= expression
match_choice ::= [ open_range_list ]\texttt{:} activity_stmt
| \texttt{default}\texttt{:} activity_stmt
```

\textit{Syntax 40—match statement}

The following also apply:

a) When the \texttt{match} statement is executed, the \textit{match_expression} is evaluated.
b) After the \textit{match_expression} is evaluated, the \textit{open_range_list} of each \textit{match_choice} shall be compared to the \textit{match_expression}. \textit{open_range_lists} are described in 8.5.9.1.
c) If there is exactly one match, then the corresponding branch shall be traversed.
d) If there is more than one match, then one of the matching \textit{match_choices} shall be randomly traversed.
e) If there are no matches, then the \texttt{default} branch, if provided, shall be traversed.
f) The \texttt{default} branch is optional. There may be at most one \texttt{default} branch in the \texttt{match} statement.
g) As with a select statement, it shall be an error if no match_choice is valid according to the active constraint and scheduling requirements and the evaluation of the match_expression against the match_choice open_range_lists.

### 12.4.6.2 Examples

In Example 84, the match statement causes the activity to evaluate the data field in_security_data.val and select a branch according to its value at each execution of the activity. If the data field is equal to LEVEL2, action1 is traversed. If the data field is equal to LEVEL5, action2 is traversed. If the data field is equal to LEVEL3 or LEVEL4, then either action1 or action2 is traversed at random. For any other value of the data field, action3 is traversed.

```plaintext
action my_test {
    rand security_data in_security_data;
    my_action1 action1;
    my_action2 action2;
    my_action3 action3;
    activity {
        match (in_security_data.val) {
            [LEVEL2..LEVEL4]:
                action1;
            [LEVEL3..LEVEL5]:
                action2;
            default:
                action3;
        }
    }
}
```

**Example 84—match statement**

### 12.5 Activity construction statements

#### 12.5.1 replicate

The replicate statement is a generative activity statement interpreted as an in-place expansion of a specified statement multiple times. The replicate statement does not introduce an additional layer of scheduling or control flow. The execution semantics applied to the expanded statements depend on the context. In particular, replicating a statement N times under a parallel statement executes the same statement N times in parallel. Unlike a repeat statement, replicate provides a way to reference specific expansion instances from above using a label array.

#### 12.5.1.1 Syntax

```plaintext
activity_replicate_stmt ::= 
  replicate ([ index_identifier : ] expression) [ label_identifier [ ] : ] labeled_activity_stmt 
```

**Syntax 41—replicate statement**

The following also apply:

a) expression shall be a positive integer expression (int or bit).
b) The **replicate** statement expands in-place to `labeled_activity_stmt` replicated the number of times specified in the **expression**. An optional index variable `index_identifier` may be specified that ranges between 0 and one less than the iteration count.

c) The execution semantics of a **replicate** statement where **expression** evaluates to N are equivalent to the execution semantics of N occurrences of `labeled_activity_stmt` directly traversed in its enclosing activity scope.

d) The number of replications must be known as part of the solve process. In other words, **expression** may not contain an attribute that is assigned in the context of a runtime `exec block` (`body/run_start/run_end`).

e) A `label_identifier` may optionally be used to label the replicated statement in the form of a label array. If used, each expanded occurrence of `labeled_activity_stmt` becomes a named sub-activity with the label `label_identifier[0] ... label_identifier[N-1]` respectively, where N is the number of expanded occurrences. Reference can be made to labels and action handles declared under the **replicate** and its nested scopes using array indexing on the label. (See more on hierarchical activity references in **12.8**.

f) Labels may be used to name sub-activities inside the scope of a **replicate** statement only if the `label_identifier` is specified. A label under a **replicate** statement without a named label array leads to name conflict between the replicated sub-activities (see scoping rules for named sub-activities in **12.8.2**).

g) Traversing a named action handle within a **replicate** scope that is declared outside the **replicate** scope shall not result in multiple traversal when the **replicate** statement is expanded (see **12.3.1.1(d)**). Both anonymous action traversal and action traversal of an action handle declared locally inside the **replicate** scope are allowed.

### 12.5.1.2 Examples

In **Example 85**, the resulting execution is either two, three, or four parallel executions of the sequence `A -> B`.

```plaintext
action my_test {
    rand int in [2..4] count;
    activity {
        parallel {
            replicate (count) {
                do A;
                do B;
            }
        }
    }
}
```

**Example 85—replicate statement**
In Example 86, the execution of action my_test results in one execution of A as well as four executions of B, all in the scope of the schedule statement, that is, invoked in any order that satisfies the scheduling rules.

```
action my_test {
    activity {
        schedule {
            do A;
            replicate (i: 4) do B with { size == i*10; };
        }
    }
};
```

**Example 86—replicate statement with index variable**

Example 86 can be rewritten in the following equivalent way to eliminate the replicate statement:

```
action my_test {
    activity {
        schedule {
            do A;
            do B with { size == 0*10; };
            do B with { size == 1*10; };
            do B with { size == 2*10; };
            do B with { size == 3*10; };
        }
    }
};
```

**Example 87—Rewriting previous example without replicate statement**
Example 88 illustrates the use of a `replicate` label array for unique hierarchical paths to specific expansion instances. References are made to action handles declared and traversed in specific expansion instances of a `replicate` statement from outside its scope.

```
action my_compound {
    rand int in [2..4] count;
    activity {
        parallel {
            replicate (count) RL[]: {
                A a;
                B b;
                a;
                b;
            }
        }
        if (RL[count-1].a.x ==0) { // 'a' of the last replicate expansion
            do C;
        }
    }
}
```

```
Example 88—replicate statement with label array
```

In Example 89 a number of error situations are demonstrated. Note that label L in this example causes a name conflict between the named sub-activities in the expansion of the `replicate` statement (see also 12.8.2).

```
action my_test {
    activity {
        do my_compound with {
            RL[0].a.x == 10; // 'a' of the first replicate expansion
        };
    }
}
```

```
Example 89—replicate statement error situations
```
12.6 Activity evaluation with extension and inheritance

Compound actions support both type inheritance and type extension (see Clause 19). When type extension is used to contribute one or more activities to an action type, the execution semantics are the same as if all the contributed activities were scheduled along with all the activities from the initial definition.

In Example 90, action type entry traverses action type A. Extensions to action type entry include activities that traverse action types B and C.

```haskell
component pss_top {
  action A { };
  action B { };
  action C { };

  action entry {
    activity {
      do A;
    }
  }

  extend action entry {
    activity {
      do B;
    }
  }

  extend action entry {
    activity {
      do C;
    }
  }
}
```

Example 90—Extended action traversal

The semantics of activity in the presence of type extension state that all three activity blocks will be traversed in an implied schedule block. In other words, Example 90 is equivalent to the hand-coded example shown in Example 91.
Example 91—Hand-coded action traversal

When a compound action inherits from another compound action, any activities declared in the inheriting action shadow (mask) the activity (or activities) declared in the base action. The "super;" statement can be used to traverse the activity (or activities) declared in the base action.

In Example 92, action base declares an activity that traverses action type A. Action ext1 inherits from base and replaces the activity declared in base with an activity that traverses action type B. Action ext2 inherits from base and replaces the activity declared in base with an activity that first traverses the activity declared in base, then traverses action type C.

Example 92—Inheritance and traversal
12.7 Symbols

To assist in reuse and simplify the specification of repetitive behaviors in a single activity, a symbol may be declared to represent a subset of activity functionality (see Syntax 42). The symbol may be used as a node in the activity.

A symbol may activate another symbol, but symbols are not recursive and may not activate themselves.

12.7.1 Syntax

```
symbol_declaration ::= symbol symbol_identifier [ ( symbol_paramlist ) ] { { activity_stmt } }
symbol_paramlist ::= [ symbol_param { , symbol_param } ]
symbol_param ::= data_type identifier
```

**Syntax 42—symbol declaration**

12.7.2 Examples

Example 93 depicts using a symbol. In this case, the desired activity is a sequence of choices between \(a^N\) and \(b^N\), followed by a sequence of \(c^N\) actions. This statement could be specified in-line, but for brevity of the top-level activity description, a symbol is declared for the sequence of \(a^N\) and \(b^N\) selections. The symbol is then referenced in the top-level activity, which has the same effect as specifying the \(a^N/b^N\) sequence of selects in-line.

```
component entity {
    action a { }
    action b { }
    action c { }

    action top {
        a a1, a2, a3;
        b b1, b2, b3;
        c c1, c2, c3;

        symbol a_or_b {
            select {a1; b1; }
            select {a2; b2; }
            select {a3; b3; }
        }

        activity {
            a_or_b;
            c1;
            c2;
            c3;
        }
    }
}
```

**Example 93—Using a symbol**
Example 94 depicts using a parameterized symbol.

```
component entity {
    action a { }
    action b { }
    action c { }
    action top {
        a a1, a2, a3;
        b b1, b2, b3;
        c c1, c2, c3;
        symbol ab_or_ba (a aa, b bb) {
            select {
                { aa; bb; }
                { bb; aa; }
            }
        }
        activity {
            ab_or_ba(a1,b1);
            ab_or_ba(a2,b2);
            ab_or_ba(a3,b3);
            c1;
            c2;
            c3;
        }
    }
}
```

**Example 94—Using a parameterized symbol**

### 12.8 Named sub-activities

**Sub-activities** are structured elements of an activity. Naming sub-activities is a way to specify a logical tree structure of sub-activities within an activity. This tree serves for making hierarchical references, both to action-handle variables declared in-line, as well as to the `activity` statements themselves. The hierarchical paths thus exposed abstract from the concrete syntactic structure of the activity, since only explicitly labeled statements constitute a new hierarchy level.

#### 12.8.1 Syntax

A named sub-activity is declared by labeling an `activity` statement, see Syntax 28.

#### 12.8.2 Scoping rules for named sub-activities

Activity statement labels shall be unique in the context of the containing named sub-activity—the nearest lexically-containing statement which is labeled. Activity statement labels shall not conflict with local variable names, including named action handles. Unlabeled activity statements do not constitute a separate naming scope for sub-activities.

Note that labeling activity statements inside the scope of a `replicate` statement leads to name conflicts between the expanded sub-activities, unless a label array is specified (see 12.5.1.1). With a `replicate` label array, each expanded named sub-activity has a unique hierarchical path.

In Example 95, some `activity` statements are labeled while others are not. The second occurrence of label L2 is conflicting with the first because the `if` statement under which the first occurs is not labeled and hence is not a separate naming scope for sub-activities.
Example 95—Scoping and named sub-activities

Example 96 below demonstrates a name conflict between a local action-handle variable and a label of an activity statement in the same named sub-activity. This is not allowed, as it would render the hierarchical path $L.a$ from action $A$’s scope ambiguous.

```plaintext
action A {}; 

action B {
    int x;
    activity {
        L1: parallel { // 'L1' is 1st level named sub-activity
            if (x > 10) {
                L2: { // 'L2' is 2nd level named sub-activity
                    A a;
                    a;
                }
                A a; // OK - this is a separate naming scope for variables
                a;
            }
        }
        L2: { // Error - this 'L2' conflicts with 'L2' above
            A a;
            a;
        }
    }
}
```
A hierarchical activity path uses labels in a way similar to variables of struct and array types. The dot operator (.) in the case of simple labels, or the indexing operator ([[]]) and other array operators in the case of label arrays (introduced by `replicate` statements), may be used to reference named sub-activity blocks.

Only action handles declared directly under a labeled activity statement can be accessed outside their direct lexical scope. Action handles declared in an unnamed activity scope cannot be accessed from outside that scope.

Note that the top activity scope is unnamed. For an action handle to be directly accessible in the top-level action scope, or from outside the current scope, it shall be declared at the top-level action scope.

In Example 97, action `B` declares action-handle variables in labeled activity statement scopes, thus making them accessible from outside by using hierarchical paths. Action `C` uses hierarchical paths to constrain the sub-actions of its sub-actions `b1` and `b2`.

```plaintext
action A { rand int x; }

action B {
    A a;
    activity {
        a;
        my_seq: sequence {
            A a;
            a;
            parallel {
                my_rep: repeat (3) {
                    A a;
                    a;
                };
                sequence {
                    A a; // this 'a' is declared in unnamed scope
                    a;   // can't be accessed from outside
                };
            };
        };
    };
}

action C {
    B b1, b2;
    constraint b1.a.x == 1;
    constraint b1.my_seq.a.x == 2;
    constraint b1.my_seq.my_rep.a.x == 3; // applies to all three iterations
                        // of the loop
    activity {
        b1;
        b2 with { my_seq.my_rep.a.x == 4; }; // likewise
    }
}
```

Example 97—Hierarchical references and named sub-activities
12.9 Explicitly binding flow objects

Input and output fields of actions may be explicitly connected to actions using the bind statement (see Syntax 43). It states that the fields of the respective actions reference the same object—the output of one action is the input of another.

12.9.1 Syntax

```
activity_bind_stmt ::= bind hierarchical_id activity_bind_item_or_list ;
activity_bind_item_or_list ::= hierarchical_id
                        | { hierarchical_id_list }
```

The following also apply:

a) Reference fields that are bound shall be of the same object type.
b) Explicit binding shall conform to the scheduling and connectivity rules of the respective flow object kind defined in 13.4.
c) Explicit binding can only associate reference fields that are statically bound to the same pool instance (see 15.3).
d) The order in which the fields are listed does not matter.
12.9.2 Examples

Examples of binding are shown in Example 98.

```
component top{
    buffer B {rand int a;};
    action P1 {
        output B out;
    };
    action P2 {
        output B out;
    };
    action C {
        input B inp;
    };

    pool B B_p;
    bind B_p {*};

    action T {
        P1 p1;
        P2 p2;
        C c;
        activity {
            p1;
            p2;
            c;
            bind p1.out c.inp; // c.inp.a == p1.out.a
        }
    }
};
```

Example 98—bind statement

12.10 Hierarchical flow object binding

As discussed in 13.4, actions, including compound actions, may declare inputs and/or outputs of a given flow object type. When a compound action has inputs and/or outputs of the same type and direction as its sub-action and which are statically bound to the same pool (see 15.3), the bind statement may be used to associate the compound action’s input/output with the desired sub-action input/output. The compound action’s input/output shall be the first argument to the bind statement.

The outermost compound action that declares the input/output determines its scheduling implications, even if it binds the input/output to that of a sub-action. The binding to a corresponding input/output of a sub-action simply delegates the object reference to the sub-action.

In the case of a buffer object input to the compound action, the action that produces the buffer object must complete before the activity of the compound action begins, regardless of where within the activity the sub-action to which the input buffer is bound begins. Similarly, the compound action’s activity shall complete before the compound action’s output buffer is available, regardless of where in the compound action’s activity the sub-action that produces the buffer object executes. The corollary to this statement is that no other sub-action in the compound action’s activity may have an input explicitly hierarchically bound to the compound action’s buffer output object. Similarly, no sub-action in the compound action’s activity may have an output that is explicitly hierarchically bound to the compound action’s input object. Consider Example 99.
Example 99—Hierarchical flow binding for buffer objects

For stream objects, the compound action’s activity shall execute in parallel with the action that produces the input stream object to the compound action or consumes the stream object output by the compound action. A sub-action within the activity of a compound action that is bound to a stream input/output of the compound action shall be an initial action in the activity of the compound action. Consider Example 100.

Example 100—Hierarchical flow binding for stream objects

For state object outputs of the compound action, the activity shall complete before any other action may write to or read from the state object, regardless of where in the activity the sub-action executes within the activity. Only one sub-action may be bound to the compound action’s state object output. Any number of sub-actions may have input state objects bound to the compound action’s state object input.
12.11 Hierarchical resource object binding

As discussed in 14.2, actions, including compound actions, may claim a resource object of a given type. When a compound action claims a resource of the same type as its sub-action(s) and where the compound action and the sub-action are bound to the same pool, the bind statement may be used to associate the compound action’s resource with the desired sub-action resource. The compound action’s resource shall be the first argument to the bind statement.

The outermost compound action that claims the resource determines its scheduling implications. The binding to a corresponding resource of a sub-action simply delegates the resource reference to the sub-action.

The compound action’s claim on the resource determines the scheduling of the compound action relative to other actions and that claim is valid for the duration of the activity. The sub-actions’ resource claim determines the relative scheduling of the sub-actions in the context of the activity. In the absence of the explicit resource binding, the compound action and its sub-action(s) claim resources from the pool to which they are bound. Thus, it shall be illegal for a sub-action to lock the same resource instance that is locked by the compound action.

A resource locked by the compound action may be bound to any resource(s) in the sub-action(s). Thus, only one sub-action that locks the resource reference may execute in the activity at any given time and no sharing sub-actions may execute at the same time. If the resource that is locked by the compound action is bound to a shared resource(s) in the sub-action(s), there is no further scheduling dependency.

A resource shared by the compound action may only be bound to a shared resource(s) in the sub-action(s). Since the compound action’s shared resource may also be claimed by another action, there is no way to guarantee exclusive access to the resource by any sub-action; so, it shall be illegal to bind a shared resource to a locking sub-action resource.

In Example 101, the compound action locks resources crlkA and crlkB, so no other actions outside of compound_a may lock either resource for the duration of the activity.

```
example 101—Hierarchical resource binding

action sub_a {
    lock res_r rlkA, rlkB;
    share res_r rshA, rshB;
}

action compound_a {
    lock res_r crlkA, crlkB;
    share res_r crshA, crshB;
    sub_a a1, a2;
    activity {
        schedule {
            a1;
            a2;
        }
        bind crlkA {a1.rlkA, a2.rlkA};
        bind crshA {a1.rshA, a2.rshA};
        bind crlkB {a1.rlkB, a2.rshB};
        bind crshB {a1.rshB, a2.rlkB}; //illegal
    }
}
```
13. Flow objects

A flow object represents incoming or outgoing data/control flow for actions, or their pre-condition and post-condition. A flow object can have two modes of reference by actions: input and output.

13.1 Buffer objects

Buffer objects represent data items in some persistent storage that can be written and read. Once their writing is completed, they can be read as needed. Typically, buffer objects represent data or control buffers in internal or external memories. See Syntax 44.

13.1.1 Syntax

<table>
<thead>
<tr>
<th>buffer identifier [ template_param_decl_list ] [ struct_super_spec ] { { struct_body_item } }</th>
</tr>
</thead>
</table>

`${\text{Syntax 44—buffer declaration}}$`

The following also apply:

a) Note that the buffer type does not imply any specific layout in memory for the specific data being stored.

b) Buffer types can inherit from previously defined structs or buffers.

c) Buffer object reference fields can be declared under actions using the input or output modifier (see 13.4). Instance fields of buffer type (taken as a plain-data type) can only be declared under higher-level buffer types, as their data attribute.

d) A buffer object shall be the output of exactly one action. A buffer object may be the input of any number (zero or more) of actions.

e) Execution of a consuming action that inputs a buffer shall not begin until after the execution of the producing action completes (see Figure 1).

f) An action may not have the same buffer object declared as both an input and an output.

13.1.2 Examples

Examples of buffer objects are show in Example 102.

```c
struct mem_segment_s {...};
buffer data_buff_s {
    rand mem_segment_s seg;
};
```

`${\text{Example 102—buffer object}}$`

13.2 Stream objects

Stream objects represent transient data or control exchanged between actions during concurrent activity, e.g., over a bus or network, or across interfaces. They represent data item flow or message/notification exchange. See Syntax 45.
13.2.1 Syntax

The following also apply:

a) Stream types can inherit from previously defined structs or streams.

b) Stream object reference fields can be declared under actions using the input or output modifier (see 13.4). Instance fields of stream type (taken as a plain-data type) can only be declared under higher-level stream types, as their data attribute.

c) A stream object shall be the output of exactly one action and the input of exactly one action.

d) The outputting and inputting actions shall begin their execution at the same time, after the same preceding action(s) completes. The outputting and inputting actions are said to run in parallel. The semantics of parallel execution are discussed further in 12.3.4.

13.2.2 Examples

Examples of stream objects are show in Example 103.

```c
struct mem_segment_s {...};
stream data_stream_s {
    rand mem_segment_s seg;
};
```

Example 103—stream object

13.3 State objects

State objects represent the state of some entity in the execution environment at a given time. See Syntax 46.

13.3.1 Syntax

The following also apply:

a) The writing and reading of states in a scenario is deterministic. With respect to a pool of state objects, writing shall not take place concurrently to either writing or reading.

b) The initial state of a given type is represented by the built-in Boolean initial attribute. See 15.5 for more on state pools (and initial).

c) State object reference fields can be declared under actions using the input or output modifier (see 13.4). Instance fields of state type (taken as a plain-data type) can only be declared under higher-level state types, as their data attribute. It shall be illegal to access the built-in attributes initial and prev on an instance field.

d) State types can inherit from previously defined structs or states.
e) An action that has an input or output of state object type operates on a pool of the corresponding state object type to which its field is bound. Static pool bind directives are used to associate the action with the appropriate state object pool (see 15.3).

f) At any given time, a pool of state object type contains a single state object. This object reflects the last state specified by the output of an action bound to the pool. Prior to execution of the first action that outputs to the pool, the object reflects the initial state specified by constraints involving the initial built-in field of state object types.

g) The built-in variable prev is a reference from this state object to the previous one in the pool. prev has the same type as this state object. The value of prev is unresolved in the context of the initial state object. In the context of an action, prev may only be referenced relative to a state object output. In all cases, only a single level of prev reference is supported, i.e., out_s.prev.prev.prev shall be illegal.

h) An action that inputs a state object reads the current state object from the state object pool to which it is bound.

i) An action that outputs a state object writes to the state object pool to which it is bound, updating the state object in the pool.

j) Execution of an action that outputs a state object shall complete at any time before the execution of any inputting action begins.

k) Execution of an action that outputs a state object to a pool shall not be concurrent with the execution of any other action that either outputs or inputs a state object from that pool.

l) Execution of an action that inputs a state object from a pool may be concurrent with the execution of any other action(s) that input a state object from the same pool, but shall not be concurrent with the execution of any other action that outputs a state object to the same pool.

13.3.2 Examples

Examples of state objects are shown in Example 104.

enum mode_e {...};
state config_s {
    rand mode_e mode;
    ...
};

Example 104—state object
13.4 Using flow objects

*Flow object references* are specified by actions as **inputs** or **outputs**. These references are used to specify rules for combining actions in legal scenarios. An action that outputs a flow object is said to *produce* that object and an action that inputs a flow object is said to *consume* the object. See Syntax 47.

A consumer may consume flow objects that are produced by multiple producers, and vice versa.

An action can produce or consume a fixed-size array of flow objects. Declaring such an array is equivalent to declaring multiple distinct object reference fields of the same type.

13.4.1 Syntax

| action_field_declaration ::= |
| attr_field |
| activity_data_field |
| action_handle_declaration |
| object_ref_field_declaration |

| object_ref_field_declaration ::= |
| flow_ref_field_declaration |
| resource_ref_field_declaration |

| flow_ref_field_declaration ::= |
| ( input | output ) flow_object_type object_ref_field { , object_ref_field } ; |

| flow_object_type ::= |
| buffer_type_identifier |
| state_type_identifier |
| stream_type_identifier |

| object_ref_field ::= identifier [ array_dim ] |

| array_dim ::= [ constant_expression ] |

Syntax 47—Flow object reference

The following apply for arrays of flow object references:

a) Individual elements in the array may be referenced by using the array name and the element index in square brackets.

b) A flow object array is specified as entirely input or entirely output. The mode cannot be specified separately for an individual element of the array.

c) The different elements in an array may be bound to different pools. Explicit binding must be used for array elements associated with different pools. Default (type-based) pool binding applies to all elements of an object-reference array, and therefore cannot be used for this purpose (see 15.3 for more details).

d) For an array of state object references, each object reference must be bound to a different state pool, since a state pool can store only one state object at a time (see 13.3.1 and Example 115).
13.4.2 Examples

Examples of using buffer flow objects are shown in Example 105.

```
struct mem_segment_s {...};
buffer data_buff_s {
    rand mem_segment_s seg;
};
action cons_mem_a {
    input data_buff_s in_data;
};
action prod_mem_a {
    output data_buff_s out_data;
};
```

Example 105—buffer flow object

For a timing diagram showing the relative execution of two actions sharing a buffer object, see Figure 2.

Examples of using stream flow objects are shown in Example 106.

```
struct mem_segment_s {...};
stream data_stream_s {
    rand mem_segment_s seg;
};
action cons_mem_a {
    input data_stream_s in_data;
};
action prod_mem_a {
    output data_stream_s out_data;
};
```

Example 106—stream flow object

For a timing diagram showing the relative execution of two actions sharing a stream object, see Figure 3.

In Example 107, four buffer objects are produced, one by action prod_1b and three by action prod_3b, and five buffer objects are consumed, one by cons_1b, two by cons_2b_0, and two by cons_2b_1. All the buffer objects are produced and consumed from the same pool, buff_p. All the buffer objects have a random integer attribute, int_attr. Consumer objects in cons_2b_0 constrain their int_attr attribute to 3, while in cons_2b_1, the first consumer object’s int_attr attribute is constrained to be greater than or equal to 2, and the second is constrained to be less than 3. prod_3b’s producer objects int_attr attributes are all constrained to 3.

There is an explicit bind to bind the second consumer object in cons_2b_1 with the first producer object in prod_3b, The explicit bind constraint will fail because int_attr in the consumer object is constrained to be less than 3, while int_attr in the producer object is constrained to 3. If we remove the explicit bind, then that same consumer object will bind to the producer prod_1b’s output object because its int_attr is constrained to be less than 3.
Example 107—Multiple producers/consumers using the same buffer pool

An example of use of an array of state object references can be seen in Example 115.
14. Resource objects

Resource objects represent computational resources available in the execution environment that may be assigned to actions for the duration of their execution.

14.1 Declaring resource objects

Resource types can inherit from previously defined structs or resources. See Syntax 48. Resources reside in pools (see Clause 15) and may be claimed by specific actions.

14.1.1 Syntax

```
resource identifier [ template_param_declar_list ] [ struct_super_spec ] { { struct_body_item } }
```

Syntax 48—resource declaration

The following also apply:

a) Resources have a built-in non-negative integer attribute called `instance_id`. This attribute represents the relative index of the resource instance in the pool. The value of `instance_id` ranges from 0 to `pool_size - 1`. See also 15.4.

b) There can only be one resource object per `instance_id` value for a given pool. Thus, actions referencing a resource object of some type with the same `instance_id` are necessarily referencing the very same object and agreeing on all its properties.

c) `Resource object reference` fields can be declared under actions using the `lock` or `share` modifier (see 14.2). Instance fields of resource type (taken as a plain-data type) can only be declared under higher-level resource types, as their data attribute.

14.1.2 Examples

For examples of how to declare a resource, see Example 108.

```
resource DMA_channel_s {
    rand bit[3:0] priority;
};
```

Example 108—Declaring a resource

14.2 Claiming resource objects

Resource objects may be `locked` or `shared` by actions. This is expressed by declaring the resource reference field of an action. See Syntax 49.

An action can claim a fixed-size array of resource objects. Declaring such an array is equivalent to declaring multiple distinct object reference fields of the same type.
14.2.1 Syntax

```
action_field_declaration ::= 
   attr_field 
   | activity_data_field 
   | action_handle_declaration 
   | object_ref_field_declaration 
object_ref_field_declaration ::= 
   flow_ref_field_declaration 
   | resource_ref_field_declaration 
resource_ref_field_declaration ::= 
   ( lock | share ) resource_object_type object_ref_field { , object_ref_field } ; 
resource_object_type ::= resource_type_identifier 
object_ref_field ::= identifier [ array_dim ] 
array_dim ::= [ constant_expression ]
```

**Syntax 49—Resource object reference**

**lock** and **share** are modes of resource use by an action. They serve to declare resource requirements of the action and restrict legal scheduling relative to other actions. **Locking** excludes the use of the resource instance by another action throughout the execution of the locking action and **sharing** guarantees that the resource is not locked by another action during its execution.

In a PSS-generated test scenario, no two actions may be assigned the same resource instance if they overlap in execution time and at least one is locking the resource. In other words, there is a strict scheduling dependency between an action referencing a resource object in **lock** mode and all other actions referencing the same resource object instance.

The following apply for arrays of resource object references:

a) Individual elements in the array may be referenced by using the array name and the element index in square brackets.

b) A resource object array is specified as entirely locked or entirely shared. The mode cannot be specified separately for an individual element of the array.

c) All elements of a resource object array must be bound to the same pool.

d) When claiming an array of resource objects, the pool size must be at least as large as the array, in order to accommodate all distinct resource claims.

14.2.2 Examples

**Example 109** demonstrates resource claims in lock and share mode. Action **two_chan_transfer** claims exclusive access to two different **DMA_channel_s** instances. It also claims one **CPU_core_s** instance in non-exclusive share mode. While **two_chan_transfer** executes, no other action may claim either instance of the **DMA_channel_s** resource, nor may any other action lock the **CPU_core_s** resource instance.
Example 109—Resource object

In Example 110, there is a pool of 16 resource objects of type config. The action baz_lock_a claims a lock for 8 resource objects. The action baz_share_a claims to share 16 resource objects. The action entry_a can legally traverse two baz_share_a actions in parallel, as the same resource object can be shared between concurrent activities. It can also legally traverse two baz_lock_a actions in parallel because overall there are 16 resource objects and each action instance consumes only 8.

Example 110—Locking and sharing arrays of resource objects
15. Pools

Pools are used to determine possible assignment of objects to actions, and thus shape the space of legal test scenarios. Pools represent collections of resources, state variables, and connectivity for data flow purposes. Flow object exchange is always mediated by a pool. One action outputs an object to a pool and another action inputs it from that same pool. Similarly, actions lock or share a resource object within some pool.

Pools are structural entities instantiated under components. They are used to determine the accessibility that actions (see Clause 10) have to flow and resource objects. This is done by binding object reference fields of action types to pools of the respective object types. Bind directives in the component scope associate resource references with a specific resource pool, state references with a specific state pool (or state variable), and buffer/stream object references with a specific data flow object pool (see 15.3).

15.1 Syntax

Syntax 50—Pool instantiation

In Syntax 50, type_identifier refers to a flow/resource object type, i.e., a buffer, stream, state, or resource struct type.

The expression applies only to pools of resource type; it specifies the number of resource instances in the pool. If omitted, the size of the resource pool defaults to 1.

The following also apply:

a) The execution semantics of a pool are determined by its object type.

b) A pool of state type can hold one object at any given time, a pool of resource type can hold up to the given maximum number of unique resource objects throughout a scenario, and a pool of buffer or stream type is not restricted in the number of objects at a given time or throughout the scenario.

15.2 Examples

Example 111 demonstrates how to declare a pool.

```
buffer data_buff_s {
    rand mem_segment_s seg;
};
resource channel_s {...};
component dmac_c {
    pool data_buff_s buff_p;
    ...
    pool [4] channel_s chan_p;
}
```

Example 111—Pool declaration
15.3 Static pool binding directive

Every action executes in the context of a single component instance, and every object resides in some pool. Multiple actions may execute concurrently, or over time, in the context of the same component instance, and multiple objects may reside concurrently, or over time, in the same pool. Actions of a specific component instance output objects to or input objects from a specific pool. Actions of a specific component instance can only be assigned a resource of a certain pool.

Static bind directives determine which pools are accessible to the actions’ object references under which component instances (see Syntax 51). Binding is done relative to the component sub-tree of the component type in which the bind directive is applied. See also 19.1.

15.3.1 Syntax

| object_bind_stmt ::= bind hierarchical_id object_bind_item_or_list ; |
| object_bind_item_or_list ::= |
| object_bind_item_path |
| { object_bind_item_path { , object_bind_item_path } } |
| object_bind_item_path ::= { component_path_elem . } object_bind_item |
| component_path_elem ::= component_identifier [ [ domain_open_range_list ] ] |
| object_bind_item ::= |
| action_type_identifier . identifier [ [ domain_open_range_list ] ] |
| * |

Syntax 51—Static bind directives

Pool binding can take one of two forms:

— Explicit binding: associating a pool with a specific object reference field (input/output/resource-claim) of an action type under a component instance or one or more elements of a component instance array.
— Default binding: associating a pool generally with a component instance sub-tree, or array of component instances, by object type.

The following also apply:

a) Components (and arrays thereof) and pools are identified with a relative instance path expression. A specific object reference field is identified with the component instance path expression, followed by an action-type name and field name, separated by dots (,).

b) Default binding can be specified for an entire sub-tree by using a wildcard instead of specific paths. When referring to an entire array, the array may be referred to by name, without needing to specify the range of elements in brackets (“[]”).

c) Explicit binding always takes precedence over default bindings.

d) Conflicting explicit bindings for the same object reference field shall be illegal.

e) If multiple bindings apply to the same object reference field, the bind directive in the context of the top-most component instance takes precedence (i.e., the order of default binding resolution is top-down).

f) Applying multiple default bindings to the same object reference field(s) from the same component shall be illegal.
g) When binding object reference fields to a pool, the object and the pool must be of the exact same type. Thus, it shall be illegal to bind an object of a derived type to a pool of its base type, or vice versa.

15.3.2 Examples

Example 112 illustrates default binding pools.

In these examples, the `buff_p` pool of `data_buff_s` objects is bound using the wildcard specifier `(*`). Because the `bind` statement is applied in the context of component `dma_c`, the `buff_p` pool is bound to all component instances and actions defined in `dma_c` (i.e., component instances `dmas1` and `dmas2`, and action `mem2mem_a`). Thus, the `in_data` input and `out_data` output of the `mem2mem_a` action share the same `buff_p` pool. The `chan_p` pool of `channel_s` resources is bound to the two instances.

```c
struct mem_segment_s {...};
buffer data_buff_s {
    rand mem_segment_s seg;
};
resource channel_s {...};
component dma_sub_c {
    ...
};
component dma_c {
    dma_sub_c dmas1, dmas2;
    pool data_buff_s buff_p;
    bind buff_p (*);
    pool [4] channel_s chan_p;
    bind chan_p {dmas1.*, dmas2.*};
    action mem2mem_a {
        input data_buff_s in_data;
        output data_buff_s out_data;
        ...
    };
};
```

Example 112—Static binding

Example 113 illustrates the binding of pools to arrays of components. Each declared pool is of a different type, each of which will be bound to a different subset of the array of `mem_c` components.
Example 113—Binding of pools to array of components

Example 114 illustrates the two forms of binding: explicit and default. Action `power_transition_a`'s input and output are both associated with the context component's (``graphics_c``) state object pool. However, action `observe_same_power_state_a` has two inputs, each of which is explicitly associated with a different state object pool, the respective sub-component state variable. The `channel_s` resource pool is instantiated under the multimedia subsystem and is shared between the two engines.
Example 114—Pool binding

```verilog
state power_state_s { rand int in [0..4] level; }
resource channel_s {}
component graphics_c {
    pool power_state_s power_state_var;
    bind power_state_var *; // accessible to all actions under this
                // component (specifically power_transition's
                // input/output)
    action power_transition_a {
        input power_state_s curr; // current state
        output power_state_s next; // next state
        lock channel_s chan;
    }
}
component my_multimedia_ss_c {
    graphics_c gfx0;
    graphics_c gfx1;
    pool [4] channel_s channels;
    bind channels {gfx0.*,gfx1.*}; // accessible by default to all actions
                     // under these component sub-trees
                     // (specifically power_transition's chan)
    action observe_same_power_state_a {
        input power_state_s gfx0_state;
        input power_state_s gfx1_state;
        constraint gfx0_state.level == gfx1_state.level;
    }
    // explicit binding of the two power state variables to the
    // respective inputs of action observe_same_power_state_a
    bind gfx0.power_state_var observe_same_power_state_a.gfx0_state;
    bind gfx1.power_state_var observe_same_power_state_a.gfx1_state;
}
```
In Example 115, there is a `observe_same_power_state_a` action type with an array of 2 input state objects. Action `power_transition_a` will cause at least one inferred instance to bind with the respective `observe_same_power_state_a` action’s object for each one of the `graphics_c` component instances. Using explicit pool bind statements, each element in the object array of `observe_same_power_state_a` is bound to a different pool.

```plaintext
state power_state_s {
    rand int in [0..4] level;
    constraint initial -> level == 0;
}

// graphics component with power state
component graphics_c {
    pool power_state_s power_state_var;
    bind power_state_var *; // accessible to all actions under this
    // component (specifically power_transition's
    // input/output)
    action power_transition_a {
        input power_state_s curr; // current state
        output power_state_s next; // next state
    }
}

component my_multimedia_ss_c {
    graphics_c gfx[2];

    action observe_same_power_state_a {
        rand int in [1..4] observed_level;

        input power_state_s gfx_state[2];
        constraint [ foreach (s: gfx_state) {
            s.level == observed_level;
        } ]

        // explicit binding of the two power state variables to the
        // respective inputs of action observe_same_power_state_a
        bind gfx[0].power_state_var observe_same_power_state_a gfx_state[0];
        bind gfx[1].power_state_var observe_same_power_state_a gfx_state[1];
    }
}
```

**Example 115—Multiple state pools of the same state type**
15.4 Resource pools and the instance_id attribute

Each object in a resource pool has a unique instance_id value, ranging from 0 to the pool’s size – 1. Two actions that reference a resource object with the same instance_id value in the same pool are referencing the same resource object. See also 16.1.

For example, in Example 116, action transfer is locking two kinds of resources: channel_s and cpu_core_s. Because channel_s is defined under component dma_c, each dma_c instance has its own pool of two channel objects. Within action par_dma_xfers, the two transfer actions can be assigned the same channel instance_id because they are associated with different dma_c instances. However, these same two actions must be assigned a different cpu_core_s object, with a different instance_id, because both dma_c instances are bound to the same resource pool of cpu_core_s objects defined under pss_top and they are scheduled in parallel. The bind directive designates the pool of cpu_core_s resources is to be utilized by both instances of the dma_c component.

```
resource cpu_core_s {}
component dma_c {
    resource channel_s {}
    pool[2] channel_s channels;
    bind channels [*]; // accessible to all actions
    // under this component (and its sub-tree)
    action transfer {
        lock channel_s chan;
        lock cpu_core_s core;
    }
}
component pss_top {
    dma_c dma0,dma1;
    pool[4] cpu_core_s cpu;
    bind cpu {dma0.*, dma1.*}; // accessible to all actions
    // under the two sub-components
    action par_dma_xfers {
        dma_c::transfer xfer_a;
       dma_c::transfer xfer_b;

        constraint xfer_a.comp != xfer_b.comp;
        constraint xfer_a.chan.instance_id=xfer_b.chan.instance_id; //OK
        constraint xfer_a.core.instance_id=xfer_b.core.instance_id; //conflict!
    activity {
        parallel {
            xfer_a;
            xfer_b;
        }
    }
}
```

Example 116—Resource object assignment
15.5 Pool of states and the initial attribute

Each pool of a state type contains exactly one state object at any given point in time throughout the execution of the scenario. A state pool serves as a state variable instantiated on the context component. Actions outputting to a state pool can be viewed as transitions in a finite state machine. See also 16.1.

Prior to execution of an action that outputs a state object to the pool, the pool contains the initial object. The initial flag is true for the initial object and false for all other objects subsequently residing in the pool. The initial state object is overwritten by the first state object (if any) which is output to the pool. The initial object is only input by actions that are scheduled before any action that outputs a state object to the same pool.

Consider, for example, the code in Example 117. The action codec_c::configure has an UNKNOWN mode as its configuration state precondition, due to the constraint on its input prev_conf. Because it outputs a new state object with a different mode value, there can only be one such action per codec component instance (unless another action, not shown here, sets the mode back to UNKNOWN).

```plaintext
enum codec_config_mode_e {UNKNOWN, A, B}  
component codec_c {  
  state configuration_s {  
    rand codec_config_mode_e mode;  
    constraint initial -> mode == UNKNOWN;  
  }  
  pool configuration_s config_var;  
  bind config_var *;  
  action configure {  
    input configuration_s prev_conf;  
    output configuration_s next_conf;  
    constraint prev_conf.mode == UNKNOWN && next_conf.mode in [A, B];  
  }  
}  
```

Example 117—State object binding
16. Randomization specification constructs

Scenario properties can be expressed in PSS declaratively, as algebraic constraints over attributes of scenario entities.

a) There are several categories of **struct** and **action** fields.
   1) **Random attribute field** - a field of a plain-data type (e.g., `bit`) that is qualified with the `rand` keyword.
   2) **Non-random attribute field** - a field of a plain-data type (e.g., `int`) that is not qualified with the `rand` keyword.
   3) **Sub-action field** - a field of an action type or a plain-data type that is qualified with the `action` keyword.
   4) **Input/output flow object reference field** - a field of a flow object type that is qualified with the `input` or `output` keyword.
   5) **Resource claim reference field** - a field of a resource object type that is qualified with the `lock` or `share` keyword.

b) Constraints may shape every aspect of the scenario space. In particular:
   1) Constraints are used to determine the legal value space within the type domain for attribute fields of actions.
   2) Constraints affect the legal assignment of resources to actions and, consequently, the scheduling of actions.
   3) Constraints may restrict the possible binding of action inputs to action outputs, and, thus, possible action inferences from partially specified scenarios.
   4) Constraints determine the association of actions with context component instances.
   5) Constraints may be used to specify all of the above properties in a specific context of a higher level activity encapsulated via a compound action.
   6) Constraints may also be applied also to the operands of control flow statements—determining loop count and conditional branch selection.

Constraints are typically satisfied by more than just one specific assignment. There is often room for randomness or the application of other considerations in selecting values. The process of selecting values for scenario variables is called **constrained randomization** or simply **randomization**.

Randomized values of variables become available in the order in which they are used in the execution of a scenario, as specified in activities. This provides a natural way to express and reason about the randomization process. It also guarantees values sampled from the environment and fed back into the PSS domain during the generation and/or execution have clear implications on subsequent evaluation. However, this notion of ordering in variable randomization does not introduce ordering into the constraint system—the solver is required to look ahead and accommodate for subsequent constraints.

16.1 Algebraic constraints

16.1.1 Member constraints

PSS supports two types of constraint blocks (see Syntax 52) as **action/struct** members: static constraints that always hold and dynamic constraints that only hold when they are referenced by the user by traversing them in an activity (see 16.4.11) or referencing them inside a constraint. Dynamic constraints associate a name with a constraint that would typically be specified as an in-line constraint.
16.1.1.1 Syntax

```
constraint_declaration ::=  
    constraint constraint_set  
    | [ dynamic ] constraint identifier constraint_block
constraint_set ::=  
    constraint_body_item  
    | constraint_block
constraint_block ::=  
    { constraint_body_item }
constraint_body_item ::=  
    expression_constraint_item  
    | foreach_constraint_item  
    | forall_constraint_item  
    | if_constraint_item  
    | implication_constraint_item  
    | unique_constraint_item  
    | default hierarchical_id == constant_expression ;  
    | default disable hierarchical_id ;  
    | dist_directive  
    | constraint_body_compile_if  
    | stmt_terminator
```

**Syntax 52—Member constraint declaration**

16.1.1.2 Examples

Example 118 declares a static constraint block, while Example 119 declares a dynamic constraint block. In the case of the static constraint, the name is optional.

```
action A {  
    rand bit[31:0]   addr;
    
    constraint addr_c {  
        addr == 0x1000;
    }  
}
```

**Example 118—Declaring a static constraint**
Example 119—Declaring a dynamic constraint

Example 120 shows a dynamic constraint inside a static constraint. In the examples, the `send_pkt` action sends a packet of a random size. The static constraint `pkt_sz_c` ensures the packet is of a legal size and the two dynamic constraints, `small_pkt_c` and `jumbo_pkt_c`, specialize the packet size to be small or large, respectively. The static constraint `interesting_sz_c` restricts the size to be either <=100 for `small_pkt_c` or >1500 for `jumbo_pkt_c`.

Example 120—Referencing a dynamic constraint inside a static constraint

16.1.2 Constraint inheritance

As discussed in 19.1, an `action/struct` subtype has all of the constraints that are declared in the context of its supertype or that are inherited by the supertype. Unnamed static constraints in a subtype are added to all other constraints. A named static or dynamic `constraint` in a subtype shadows (masks) a constraint of the same name from the supertype. Constraint inheritance applies in the same way to static constraints and dynamic constraints.

Example 121 illustrates a simple case of constraint inheritance and shadowing. Instances of `struct corrupt_data_buff` satisfy the unnamed constraint of `data_buff` based on which `size` is in the...
range 1 to 1024. Additionally, size is greater than 256, as specified in the subtype. Finally, per constraint size_align as specified in the subtype, size divided by 4 has a reminder of 1.

```
buffer data_buff {
    rand int size;
    constraint size in [1..1024];
    constraint size_align { size%4 == 0; } // 4-byte aligned
}

buffer corrupt_data_buff : data_buff {
    constraint size_align { size%4 == 1; } // alignment 1 byte off
    constraint corrupt_data_size { size > 256; } // additional constraint
}
```

Example 121—Inheriting and shadowing constraints

### 16.1.3 Action traversal in-line constraints

Constraints on sub-action data attributes can be in-lined directly in the context of an action traversal statement in the activity clause (for syntax and other details, see 12.3.1).

In the context of in-line constraints, attribute field paths of the traversed sub-action can be accessed without the sub-action field qualification. Fields of the traversed sub-action take precedence over fields of the containing action. Other attribute field paths are evaluated in the context of the containing action. In cases where the containing-action fields are shadowed (masked) by fields of the traversed sub-action, they can be explicitly accessed using the built-in variable `this`. In particular, fields of the context component of the containing action shall be accessed using the prefix path `this.comp` (see also Example 123).

If a sub-action field is traversed uniquely by a single traversal statement in the activity clause, in-lining a constraint has the same effect as declaring the same member constraint on the sub-action field of the containing action. In cases where the same sub-action field is traversed multiple times, in-line constraints apply only to the specific traversal in which they occur.

Unlike member constraints, in-line constraints are evaluated in the specific scheduling context of the action traversal statement. If attribute fields of sub-actions other than the one being traversed occur in the constraint, these sub-action fields shall have already been traversed in the activity. In cases where a sub-action field has been traversed multiple times, the most recently selected values are considered.

Example 122 illustrates the use of in-line constraints. The traversal of `a3` is illegal, because the path `a4.f` occurs in the in-line constraint, but `a4` has not yet been traversed at that point. Constraint `c2`, in contrast, equates `a1.f` with `a4.f` without having a specific scheduling context, and is, therefore, legal and enforced.
Example 122—Action traversal in-line constraint

Example 123 illustrates different name resolutions within an in-line with clause.

Example 123—Name resolution inside with constraint block
16.1.4 Logical expression constraints

A logical (Boolean) constraint can be used to specify a constraint. Syntax 53 shows the syntax for an expression constraint.

16.1.4.1 Syntax

```
expression_constraint_item ::= expression ;
```

*Syntax 53—Expression constraint*

*expression* may be any logical expression. The constraint is satisfied if the expression evaluates to *true*.

16.1.5 Implication constraints

Conditional constraints can be specified using the implication operator (\(\rightarrow\)). Syntax 54 shows the syntax for an implication constraint.

16.1.5.1 Syntax

```
implication_constraint_item ::= expression -> constraint_set
```

*Syntax 54—Implication constraint*

*expression* may be any logical expression. *constraint_set* represents any valid constraint or an unnamed constraint set.

The following also apply:

a) The Boolean equivalent of the implication operator \(a \rightarrow b\) is \((\neg a \lor b)\). This states that if the *expression* is *true*, all of the constraints in *constraint_set* shall be satisfied. In other words, if the *expression* is *true*, then the random values generated are constrained by the constraint set. Otherwise, the random values generated are unconstrained.

b) The implication constraint is bidirectional.

16.1.5.2 Examples

Consider Example 124. Here, \(b\) is forced to have the value 1 whenever the value of the variable \(a\) is greater than 5. However, since the constraint is bidirectional, if \(b\) has the value 1, then the evaluation expression \((\neg (a>5) \lor (b=1))\) is *true*, so the value of \(a\) is unconstrained. Similarly, if \(b\) has a value other than 1, \(a\) is \(\leq 5\).

```
struct impl_s {
    rand bit[7:0] a, b;

    constraint ab_c {
        (a > 5) -> b == 1;
    }
}
```

*Example 124—Implication constraint*
16.1.6 if-else constraints

Conditional constraints can be specified using the if and if-else constraint statements.

**Syntax 55** shows the syntax for an if-else constraint.

### 16.1.6.1 Syntax

```plaintext
if_constraint_item ::= if ( expression ) constraint_set [ else constraint_set ]
```

**Syntax 55—Conditional constraint**

*expression* may be any logical expression. *constraint_set* represents any valid constraint or an unnamed constraint set.

The following also apply:

a) If the *expression* is *true*, all of the constraints in the first *constraint_set* shall be satisfied; otherwise, all the constraints in the optional *else constraint_set* shall be satisfied.

b) Constraint sets may be used to group multiple constraints.

c) Just like implication (see 16.1.5), if-else style constraints are bidirectional.

### 16.1.6.2 Examples

In **Example 125**, the value of *a* constrains the value of *b* and the value of *b* constrains the value of *a*.

Attribute *a* cannot take the value 0 because both alternatives of the if-else constraint preclude it. The maximum value for attribute *b* is 4, since in the if alternative it is 1 and in the else alternative it is less than *a*, which itself is <= 5.

In evaluating the constraint, the if-clause evaluates to !(a>5) || (b==1). If *a* is in the range {1,2,3,4,5}, then the !(a>5) expression is *true*, so the (b==1) constraint is ignored. The else-clause evaluates to !(a<=5), which is *false*, so the constraint expression (b<a) is *true*. Thus, *b* is in the range {0..(a−1)}. If *a* is 2, then *b* is in the range {0,1}. If *a* > 5, then *b* is 1.

However, if *b* is 1, the (b==1) expression is *true*, so the !(a>5) expression is ignored. At this point, either !(a<=5) or a > 1, which means that *a* is in the range {2, 3, ... 255}.

```plaintext
struct if_else_s {
    rand bit[7:0]     a, b;

    constraint ab_c {
        if (a > 5) {
            b == 1;
        } else {
            b < a;
        }
    }
}
```

**Example 125—if constraint**
16.1.7 foreach constraints

Elements of collections can be iteratively constrained using the **foreach** constraint.

**Syntax 56** shows the syntax for a **foreach** constraint.

16.1.7.1 Syntax

```
foreach_constraint_item ::= 
```

`constraint_set` represents any valid constraint or an unnamed constraint set.

The following also apply:

a) `expression` shall be of a collection type (i.e., **array**, **list**, **map** or **set**), including fixed-sized arrays of **action handles**, **components**, and **flow** and resource **object references**.

b) All of the constraints in `constraint_set` shall be satisfied for each of the elements in the collection specified by `expression`.

c) `iterator_identifier` specifies the name of an iterator variable of the collection element type. Within `constraint_set`, the iterator variable, when specified, is an alias to the collection element of the current iteration.

d) `index_identifier` specifies the name of an index variable. Within `constraint_set`, the index variable, when specified, corresponds to the element index of the current iteration.

1) For **arrays** and **lists**, the index variable shall be a variable of type **int**, ranging from 0 to one less than the size of the collection variable.

2) For **maps**, the index variable shall be a variable of the same type as the **map** keys, and range over the values of the keys.

3) For **sets**, an index variable shall not be specified.

e) Both the index and iterator variables, if specified, are implicitly declared within the **foreach** scope and limited to that scope. Regular name resolution rules apply when the implicitly declared variables are used within the **foreach** body. For example, if there is a variable in an outer scope with the same name as the index variable, that variable is shadowed (masked) by the index variable within the **foreach** body. The index and iterator variables are not visible outside the **foreach** scope.

f) Either an index variable or an iterator variable or both shall be specified. For a **set**, an iterator variable shall be specified, but not an index variable.

16.1.7.2 Examples

**Example 126** shows an iterative constraint that ensures that the values of the elements of a fixed-size array increment.
The \texttt{forall} constraint is used to apply constraints to all instances of a specific type within the instance subtree in which the constraint is placed.

Syntax \texttt{57} shows the syntax for a \texttt{forall} constraint.

16.1.8.1 Syntax

\begin{verbatim}
forall_constraint_item ::= 
  forall ( iterator_identifier : type_identifier [ in ref_path ] ) constraint_set
\end{verbatim}

\textit{Syntax 57—forall constraint}

\textit{type_identifier} specifies the type of the entity (\texttt{action, struct, stream, buffer, state, resource}) to which the constraint applies. \textit{iterator_identifier} can be used inside \texttt{constraint_set} as an alias to each instance, much like the \textit{iterator_identifier} in a \texttt{foreach} constraint is an alias to each element in the collection (see \texttt{16.1.7}). \textit{ref_path} is optionally used to restrict the constraint’s scope of application to a certain instance subtree.

The following also apply:

\begin{enumerate}
  \item All of the constraints in \texttt{constraint_set} shall be satisfied for every instance of the specified type in the \texttt{forall} constraint’s application scope.
  \item When \textit{ref_path} is omitted, the application scope is the subtree of the constraint’s enclosing scope:
    \begin{enumerate}
      \item In the case of a member (type-level) non-dynamic constraint, its application scope includes all of the context type’s fields (attributes, object references), and in the case of a compound action, also its entire activity.
      \item In the case of an in-line \texttt{with} constraint (see \texttt{16.1.3}), its application scope is the traversed sub-action’s fields and, if compound, also its entire activity.
      \item In the case of an activity constraint statement or the activation of a named dynamic constraint, the application scope is the activity scope immediately enclosing the activity statement.
    \end{enumerate}
  \item When \textit{ref_path} is specified, the application scope is the subtree under the entity (\texttt{action, object, or struct}) designated by \textit{ref_path}.
  \item The \texttt{forall} constraint applies to sub-actions within its application scope regardless of whether they are traversed using an action handle or anonymously.
\end{enumerate}
16.1.8.2 Examples

Example 127 demonstrates the use of a forall constraint in a compound action, constraining sub-actions traversed directly and indirectly under its activity (case b.1 above). Action entry places a constraint on all instances of action A, relating attribute x to its own attribute ax_limit. The constraint does not apply to an attribute of sub-action B by the same name.

```
action A {
    rand int in [0..9] x;
};

action B {
    rand int in [0..9] x;
};

action C {
    A a;
    B b;
    activity {
        schedule {
            a; b;
        }
    }
}

action entry {
    rand int in [0..9] ax_limit;
    A a;
    C c;
    constraint {
        forall (a_it: A) {
            a_it.x <= ax_limit;
        }
    }
    activity {
        a; c;
    }
};
```

Example 127—forall constraint

The forall constraint in Example 127 is equivalent to the corresponding constraint on each path to an action handle of type A. Hence, action entry in Example 127 can be rewritten in the way shown in Example 128.
Example 128—rewrite of forall constraint in terms of explicit paths

Example 129 demonstrates the use of `forall` constraints in two different contexts inside an activity. The first is an in-line `with` constraint item (case b.2 above), applying to all instances of type `A` under action `C` that is being traversed in this statement. The second is an activity constraint statement (case b.3 above). It applies to all instances of type `A` in the immediately enclosing activity scope – in this case the `parallel` statement. Hence this constraint applies to action `A` in the first `parallel` branch, and to all actions of type `A` under action `C` in the second `parallel` branch.

Example 129—forall constraint in different activity scopes

Example 130 demonstrates the use of a `forall` constraint item in a dynamic constraint under an action. The dynamic constraint is activated from above for one traversal of that action, and not for the other. In this case, `A`'s attributes `s1.x` and `s2.x` may be randomized to the value `0xff` in the first execution of `B`, but not in the second.
16.1.9 Unique constraints

The `unique` constraint causes unique values to be selected for each element in the specified set.

Syntax 58 shows the syntax for a `unique` constraint.

16.1.9.1 Syntax

```
unique_constraint_item ::= unique { hierarchical_id_list };
```

```
hierarchical_id_list ::= hierarchical_id { , hierarchical_id };
```

**Syntax 58—unique constraint**

16.1.9.2 Examples

Example 131 forces the solver to select unique values for the random attribute fields A, B, and C. The `unique` constraint is equivalent to the following constraint statement: \((A \neq B) \land (A \neq C) \land (B \neq C)\).

```
struct S {
    rand bit[8] x;
}

action A {
    rand S s1, s2;
}

action B {
    dynamic constraint c1 {
        forall (it: S) { it.x != 0xff; }
    }
    activity { do A; }
}

action entry {
    activity {
        do B;
        do B with { c1; }
    }
}
```

**Example 130—for all constraint item in a dynamic constraint**

```
struct my_struct {
    constraint unique_abc_c {
        unique {A, B, C};
    }
}
```

**Example 131—unique constraint**
16.1.10 Default value constraints

A default value constraint determines the value of an attribute, unless explicitly disabled for that specific attribute from its direct or indirect containing type. Default value constraints may only take the form of equality of the attribute to a constant expression. Disabling a default value is done with the default disable constraint form.

16.1.10.1 Syntax

| constraint_body_item ::= |
| ... |
| default hierarchical_id == constant_expression ; |
| default disable hierarchical_id ; |
| ... |

Syntax 59—Default constraints

The following also apply:

a) A default value constraint has the same semantics as the corresponding equality constraint, unless explicitly disabled. The equality must hold, and conflict with other constraints shall be flagged as a contradiction.

b) A default disable constraint is a directive to remove default constraints on the designated attribute, if any are specified.

c) hierarchical_id for both default and default disable constraints shall be a random attribute (a field with rand modifier). It shall be an error to apply a default constraint on a non-rand attribute.

d) Multiple default constraints and default disable constraints may be applied to the same attribute, with the following precedence rules:

1) A constraint from a higher-level containing context overrides one from a lower-level containing context.

2) A constraint from a derived type context overrides one from a base type context.

3) A constraint overrides another in the same type context if it occurs later in the code.

e) default value constraints and default disable constraints may be applied to an attribute of an aggregate data type. The semantics in this case are equivalent to applying the corresponding constraints to all the rand scalar attributes it comprises. In particular, applying a default disable constraint to an attribute of an aggregate data type disables default value constraints on all attributes under it.

f) default and default disable constraints may not be conditioned on non-constant expressions.

g) default and default disable constraints may not be used under dynamic constraints (constraints prefixed with the dynamic modifier).

16.1.10.2 Examples

In Example 132, my_struct has two attributes, and a default value constraint on one of them. This struct is instantiated three times under my_action.
Example 132—Use of default value constraints

When randomizing `my_action`, `s1.attr1` is resolved to 0 because of constraint (1), and `s1.attr2` is randomized in the domain 1..3 because of constraint (2). `s2.attr1` is resolved to 2, because constraint (3) overrides constraint (1), and `s2.attr2` is resolved to 3 because of constraint (2). Within `s3`, constraint (1) was disabled by (4), and has no effect. Due to constraints (2) and (5), `s3.attr1` is randomized in the domain 1..2 and `s3.attr2` in the domain 2..3 such that `s3.attr1` is less than `s3.attr2`.

In Example 133 below, two attributes of `my_action` have default value constraints. If `my_derived_action` is randomized, `attr1` is resolved to 0, because default constraint (1) is disabled (3) and a different constraint is in effect (4). However, there is no consistent assignment to `attr2`, because both default constraint (2) and the regular constraint (5) are in effect and conflicting.

Example 133—Contradiction with default value constraints

```
action my_action {
    rand int attr1;
    constraint default attr1 == -1; // (1)
    rand int attr2;
    constraint default attr2 == -1; // (2)
}

action my_derived_action : my_action {
    constraint {
        default disable attr1;    // (3)
        attr1 == 0;              // (4) OK
    }
    constraint attr2 == 0;      // (5) contradiction!
}
```

Example 134 below shows how default value constraints and default disable constraints apply to aggregate data types. A default value constraint is placed on an array as a whole (1). Under `my_action`, for instance `s1` of the struct, the default is replaced by another for a specific element (3), while the other elements retain their original default. Constraint (4) disables the default for all array elements under `s2`, and they are
randomized over their full domain. Constraint (5) disables defaults of all attributes under the struct, including the 4 arr elements and attr. A subsequent constraint determines that s3.attr randomizes to 50.

```c
struct my_struct {
    rand array<int,4> arr;
    constraint default arr == {0, 10, 20, 30}; // (1)

    rand int attr;
    constraint default attr == 40; // (2)
};

action my_action {
    rand my_struct s1, s2, s3;

    constraint default s1.arr[3] == 100; // (3)
    constraint default disable s2.arr; // (4)
    constraint default disable s3; // (5)
    constraint s3.attr == 50;
};
```

**Example 134—Default value constraints on compound data types**

### 16.1.11 Distribution directive

The distribution directive provides a value-distribution specification for a given expression to the constraint solver within the PSS processing tool.

```c
constraint_body_item ::= |
    ... |
    | dist_directive
    ... |

dist_directive ::= dist expression in | dist_list |

dist_list ::= dist_item { , dist_item }

dist_item ::= open_range_value [ dist_weight ]

dist_weight ::= :
            := expression
            | :/ expression
```

**Syntax 60—Distribution directive**

A `dist` directive is a standalone statement from a syntax perspective. It is used to influence the value distribution of the target expression, but is not itself an expression.

The `dist_list` is a comma-separated list of integral expressions and ranges. Each term in the list can be given a non-negative weight, specified via the `:=` or `/` operators. If no weight is specified for a given item, the default weight is `:= 1`. 
In the absence of conflicting constraints, the value of the distribution target expression must fall within the \textit{dist_list}; the probability that the distribution target expression matches any value in the \textit{dist_list} is proportional to its specified weight. Constraints take priority over the \textit{dist} directive and may force the distribution target expression to fall outside the set of values captured by the \textit{dist_list}.

Value-distribution probability is only specified with respect to a single \textit{dist} directive acting on an expression. In the presence of multiple \textit{dist} directives acting on common expression elements with different distribution weights, the resulting value distribution across the common expression elements is undefined.

The \texttt{:=} operator assigns the specified weight to the item in the case of a single-value \textit{dist_item}. In the case of a value-range \textit{dist_item}, the weight is assigned to each value in the value range.

The \texttt{:/} operator assigns the specified weight to the item in the case of a single-value \textit{dist_item}. In the case of a value-range \textit{dist_item}, the weight is distributed across the values in the range. In other words, if there are \( n \) values in the range, each value will have a weight of \( \text{weight} / n \).

The following also apply:

\begin{itemize}
  \item[a)] The left-hand expression shall be an integer expression and contain at least one \texttt{rand} variable.
  \item[b)] \texttt{rand} variables may not be used in \textit{dist} weights or value ranges.
  \item[c)] The total weight associated with a value is the sum of all weights applied to that value in the \textit{dist_list} using the \texttt{:=} and \texttt{:/} operators.
\end{itemize}

**16.1.11.1 Examples**

\begin{verbatim}
struct S {
    rand bit[32] x;
    constraint dist x in [100..102 := 1, 200 := 2, 300 := 5];
}
\end{verbatim}

\textit{Example 135—Distribution directive on single variable}

In the example above, \( x \) is weighted to have a value range \([100..102, 200, 300]\). Additionally, value selection is weighted 1, 1, 1, 2, 5.

\begin{verbatim}
struct S {
    rand bit[32] x;
    constraint dist (x+6) in [100..102 := 1, 200 := 2, 300 := 5];
}
\end{verbatim}

\textit{Example 136—Distribution directive on expression}

Distribution weights may be applied to expressions as well as to individual variables. In the example above, the expression \((x+6)\) is weighted to have a value range \([100..102, 200, 300]\) with weights 1, 1, 1, 2, 5. Note that this is equivalent to applying the value ranges \([94..96, 194, 294]\) to \( x \).

\begin{verbatim}
struct S {
    rand bit[32] x;
    constraint dist x in [100..102 :/ 1, 200 := 2, 300 := 5];
}
\end{verbatim}

\textit{Example 137—Distribution directive weight specification forms}
In the example above, $x$ is weighted to have a value range $[100..102, 200, 300]$. Additionally, value selection is weighted $1/3, 1/3, 1/3, 2, 5$.

```plaintext
struct S {
    rand bit[32] x;
    bit y;
    constraint dist x in [100..102 := 1, 200 := 2, 300 := 5];
    constraint (y==1) -> x > 300;
}
```

**Example 138—Constraint priority over distribution directive**

In the example above, a constraint can cause the value of $x$ to be outside the `dist` directive range in some cases. When $y$ is set to 1, the implication constraint prevents the `dist` directive from biasing the distribution of the target expression. This case does not result in a solve failure.

```plaintext
struct S {
    rand bit[32] x;
    bit[32] w; // default value is 0
    constraint dist x in [100..102 := 1, 200 := 2, 300 := w];
}
```

**Example 139—Zero-valued distribution weight**

In **Example 139** above, $x$ is constrained using the declared value range of $[100..102, 200, 300]$. However, value 300 is given a weight of 0. Consequently, the effective value range of $x$ will be $[100..102, 200]$. The value selection is weighted 1, 1, 1, 2.

### 16.2 Scheduling constraints

Scheduling constraints relate two or more actions or sub-activities from a scheduling point of view. Scheduling constraints do not themselves introduce new action traversals. Rather, they affect actions explicitly traversed in contexts that do not already dictate specific relative scheduling. Such contexts necessarily involve actions directly or indirectly under a schedule statement (see 12.3.5). Similarly, scheduling constraints can be applied to named sub-activities, see Syntax 61.

#### 16.2.1 Syntax

```plaintext
activity_scheduling_constraint ::= constraint ( parallel | sequence )
{ hierarchical_id , hierarchical_id { , hierarchical_id } } ;
```

**Syntax 61—Scheduling constraint statement**

The following also apply:

a) **constraint sequence** schedules the related actions so that each completes before the next one starts (equivalent to a sequential activity block, see 12.3.3).

b) **constraint parallel** schedules the related actions such that they are invoked in a synchronized way and then proceed without further synchronization until their completion (equivalent to a parallel activity statement, see 12.3.4).
c) Scheduling constraints may not be applied to action handles that are traversed multiple times. In particular, they may not be applied to actions traversed inside an iterative statement: repeat, repeat-while, and foreach (see 12.4). However, the iterative statement itself, as a named sub-activity, can be related in scheduling constraints.

d) Scheduling constraints involving action-handle variables that are not traversed at all, or are traversed in branches not actually chosen from select or if statements (see 12.4), hold vacuously.

e) Scheduling constraints shall not undo or conflict with any scheduling requirements of the related actions.

16.2.2 Example

Example 140 demonstrates the use of a scheduling constraint. In it, compound action my_sub_flow specifies an activity in which action a is executed, followed by the group b, c, and d, with an unspecified scheduling relation between them. Action my_top_flow schedules two executions of my_sub_flow, relating their sub-actions using scheduling constraints.

```plaintext
action my_sub_flow {
    A a; B b; C c; D d;
    activity {
        sequence {
            a;
            schedule {
                b; c; d;
            };
        };
    };
}

action my_top_flow {
    my_sub_flow sf1, sf2;
    activity {
        schedule {
            sf1;
            sf2;
        };
    };
    constraint sequence {sf1.a, sf2.b};
    constraint parallel {sf1.b, sf2.b, sf2.d};
};
```

Example 140—Scheduling constraints
16.3 Sequencing constraints on state objects

A pool of state type stores exactly one state object at any given time during the execution of a test scenario, thus serving as a state variable (see 15.5). Any action that outputs a state object to a pool is considered a state transition with respect to that state variable. Within the context of a state type, reference can be made to attributes of the previous state, relating them in Boolean expressions to attributes values of this state. This is done by using the built-in reference variable prev (see 13.3).

NOTE—Any constraint in which prev occurs is vacuously satisfied in the context of the initial state object.

In Example 141, the first constraint in power_state_s determines that the value of domain_B may only decrement by 1, remain the same, or increment by 1 between consecutive states. The second constraint determines that if a domain_C in any given state is 0, the subsequent state has a domain_C of 0 or 1 and domain_B is 1. These rules apply equally to the output of the two actions declared under component power_ctrl_c.

```
state power_state_s {
    rand int in [0..3] domain_A, domain_B, domain_C;
    constraint domain_B in { prev.domain_B - 1, prev.domain_B, prev.domain_B + 1};
    constraint prev.domain_C==0 -> domain_C in [0,1] || domain_B==0;
};

component power_ctrl_c {
    pool power_state_s psvar;
    bind psvar *;
    action power_trans1 {
        output power_state_s next_state;
    };
    action power_trans2 {
        output power_state_s next_state;
        constraint next_state.domain_C == 0;
    };
};
```

Example 141—Sequencing constraints

16.4 Randomization process

PSS supports randomization of plain-data type fields associated with scenario elements, as well as randomization of different relations between scenario elements, such as scheduling, resource allocation, and data flow. Moreover, the language supports specifying the order of random value selection, coupled with the flow of execution, in a compound action’s sub-activity, the activity clause. Activity-based random value selection is performed with specific rules to simplify activity composition and reuse and minimize complexity for the user.

Random attribute fields of struct type are randomized as a unit. Traversal of a sub-action field triggers randomization of random attribute fields of the action and the resolution of its flow/resource object references. This is followed by evaluation of the action’s activity if the action is compound.
16.4.1 Random attribute fields

This section describes the rules that govern whether an element is considered randomizable.

16.4.1.1 Semantics

a) Struct attribute fields qualified with the `rand` keyword are randomized if a field of that struct type is also qualified with the `rand` keyword.

b) Action attribute fields qualified with the `rand` keyword are randomized at the beginning of action execution. In the case of compound actions, `rand` attribute fields are randomized prior to the execution of the activity and, in all cases, prior to the execution of the action’s `exec blocks` (except `pre_solve`, see 16.4.12).

NOTE—It is often helpful to directly traverse attribute fields within an activity. This is equivalent to creating an intermediate action with a random attribute field of the plain-data type.

16.4.1.2 Examples

In Example 142, struct `S1` contains two attribute fields. Attribute field `a` is qualified with the `rand` keyword, while `b` is not. Struct `S2` creates two attribute fields of type `S1`. Attribute field `s1_1.a` is also qualified with the `rand` keyword. `s1_1.a` will be randomized, while `s1_1.b` will not. Attribute field `s1_2` is not qualified with the `rand` keyword, so neither `s1_2.a` nor `s1_2.b` will be randomized.

```plaintext
struct S1 {
    rand bit[3:0]  a;
    bit[3:0]        b;
}

struct S2 {
    rand S1         s1_1;
    S1              s1_2;
}
```

**Example 142—Struct rand and non-rand fields**

Example 143 shows two actions, each containing a `rand`-qualified data field (`A::a` and `B::b`). Action `B` also contains two fields of action type `A` (`a_1` and `a_2`). When action `B` is executed, a value is assigned to the random attribute field `b`. Next, the `activity` body is executed. This involves assigning a value to `a_1.a` and subsequently to `a_2.a`.

```plaintext
action A {
    rand bit[3:0]  a;
}

action B {
    A  a_1, a_2;
    rand bit[3:0]  b;

    activity {
        a_1;
        a_2;
    }
}
```

**Example 143—Action rand-qualified fields**
Example 144 shows an action-qualified field in action B named a_bit. The PSS processing tool assigns a value to a_bit when it is traversed in the activity body. The semantics are identical to assigning a value to the rand-qualified action field A::a.

```plaintext
action A {
  rand bit[3:0] a;
}

action B {
  action bit[3:0] a_bit;
  A a_1;

  activity {
    a_bit;
    a_1;
  }
}
```

**Example 144—Action-qualified fields**

16.4.2 Randomization of lists

When a rand-qualified list variable is randomized, its elements are randomized and given values consistent with any constraints on them. The size of the array is not randomized, and may not be constrained (see 7.9.3.4).

Hierarchical constraint references to list elements can be declared in locations where it is not yet known whether the list element exists. Example 145 illustrates such a case.

```plaintext
action sub_a {
  rand list<bit[8]> lst;
  exec pre_solve {
    lst.push_back(0);
  }
}

action parent_a {
  sub_a a;
  rand int yy;
  constraint a.lst[0] == yy;

  activity {
    a;
  }
}
```

**Example 145—Hierarchical constraint reference to list element**

Constraints on list elements must hold when the list is randomized. In this example, the list is randomized as part of the traversal of action handle a. At this point in time, the list contains a single element, and the constraint on this element is valid. If the referenced list element does not exist at the point of list randomization, then the PSS processing tool shall flag an error.
16.4.3 Randomization of flow objects

When an action is randomized, its input and output fields are assigned a reference to a flow object of the respective type. On entry to any of the action’s exec blocks (except pre_solve, see 21.1.2), as well as its activity clause(s), values for all rand data attributes accessible through its inputs and outputs fields are resolved. The values accessible in these contexts satisfy all constraints. Constraints can be placed on attribute fields from the immediate type context, from a containing struct or action at any level or via the input/output fields of actions.

The same flow object may be referenced by an action outputting it and one or more actions inputting it. The binding of inputs to outputs may be explicitly specified in an activity clause or may be left unspecified. In cases where binding is left unspecified, the counterpart action of a flow object’s input/output may already be one explicitly traversed in an activity or it may be introduced implicitly by the PSS processing tool to satisfy the binding rules (see Clause 17). In the case where multiple actions input the same buffer object type, the input references may be constrained to indicate that they refer to the same object. In all of these cases, value selection for the data attributes of a flow object shall satisfy all constraints coming from the action that outputs it and actions that input it.

Consider the model in Example 146. Assume a scenario is generated starting from action test. The traversal of action write1 is scheduled, followed by the traversal of action read. When read is randomized, its input in_obj must be resolved. Every buffer object shall be the output of some action. The activity does not explicitly specify the binding of read’s input to any action’s output, but it must be resolved regardless. Action write1 outputs a mem_obj whose dat is in the range 1 to 5, due to a constraint in action write1. But, dat of the mem_obj instance read inputs must be in the range 8 to 12. So read.in_obj cannot be bound to write1.out_obj without violating a constraint. The PSS processing tool shall schedule another action of type write2 at some point prior to read, whose mem_obj is bound to read’s input. In selecting the value of read.in_obj.dat, the PSS processing tool shall consider the following:

— dat is an even integer, due to the constraint in mem_obj.
— dat is in the range 6 to 10, due to a constraint in write2.
— dat is in the range 8 to 12, due to a constraint in read.

This restricts the legal values of read.in_obj.dat to either 8 or 10.
16.4.4 Randomization of resource objects

When an action is randomized, its resource claim fields (of resource type declared with lock / share modifiers, see 14.1) are assigned a reference to a resource object of the respective type. On entry to any of the action’s exec blocks (except pre_solve, see 21.1.2) or its activity clause, values for all random attribute fields accessible through its resource fields are resolved. The same resource object may be referenced by any number of actions, given that no two concurrent actions lock it (see 14.2). Value selection for random attribute fields of a resource object satisfy constraints coming from all actions to which it was assigned, either in lock or share mode.

Consider the model in Example 147. Assume a scenario is generated starting from action test. In this scenario, three actions are scheduled to execute in parallel: a1, a2, and a3, followed sequentially by a traversal of a4. In the parallel statement, action a3 of type do_something else shall be exclusively assigned one of the two instances of resource type rsr_obj, since do_something else claims it in lock mode. Therefore, the other two actions, of type do_something, necessarily share the other instance. When selecting the value of attribute kind for that instance, the PSS processing tool considers the following constraints:

— kind is an enumeration whose domain has the values A, B, C, and D.
— kind is not A, due to a constraint in do_something.
— a1.my_rsrc_inst is referencing the same rsr_obj instance as a2.my_rsrc_inst, as there would be a resource conflict otherwise between one of these actions and a3.
— kind is not B, due to an in-line constraint on a1.
— kind is not C, due to an in-line constraint on a2.
D is the only legal value for \texttt{a1.my_rsrc_inst.kind} and \texttt{a2.my_rsrc_inst.kind}.

Since there are only two instances of \texttt{rsrc_obj} in \texttt{rsrc_pool}, and one of the instances is claimed via the \texttt{share} in \texttt{a1} and \texttt{a2}, the other instance will be locked by \texttt{a3}. In order to determine the value of its \texttt{kind} field, we must consider the in-line constraint on the traversal of \texttt{a4}. Since \texttt{a4.my_rsrc_inst.kind} is constrained to the value \texttt{A}, this must be a different instance from the one shared by \texttt{a1} and \texttt{a2}. Therefore, this is the same instance that is claimed by \texttt{a3}, and therefore \texttt{a3.my_rsrc_inst.kind} shall also have the value of \texttt{A}.

```plaintext
component top {
  enum rsrc_kind_e {A, B, C, D};
  resource rsrc_obj {
    rand rsrc_kind_e kind;
  }
  pool[2] rsrc_obj rsrc_pool;
  bind rsrc_pool *;
  action do_something {
    share rsrc_obj my_rsrc_inst;
    constraint my_rsrc_inst.kind != A;
  }
  action do_something_else {
    lock rsrc_obj my_rsrc_inst;
  }
  action test {
    do_something      a1, a2;
    do_something_else a3, a4;
    activity {
      parallel {
        a1 { my_rsrc_inst.kind != B; }
        a2 { my_rsrc_inst.kind != C; }
        a3;
      }
      a4 with { my_rsrc_inst.kind == A; }
    }
  }
}
```

\textit{Example 147—Randomizing resource object attributes}

\textbf{16.4.5 Randomization of component assignment}

When an \texttt{action} is randomized, its association with a component instance is determined. The built-in field \texttt{comp} is assigned a reference to the selected component instance. The assignment shall satisfy constraints where \texttt{comp} fields occur (see 9.5). Furthermore, the assignment of an action’s \texttt{comp} field corresponds to the pools in which its inputs, outputs, and resources reside. If action \texttt{a} is assigned resource instance \texttt{r}, \texttt{r} is taken out the pool bound to \texttt{a}’s resource reference field in the context of the component instance assigned to \texttt{a}. If action \texttt{a} outputs a flow object which action \texttt{b} inputs, both output and input reference fields shall be bound to the same pool under \texttt{a}’s component and \texttt{b}’s component respectively. See \textbf{Clause 15} for more on pool binding.
16.4.6 Procedural randomization of data

Procedural constrained randomization is performed using the randomize statement shown in Syntax 88.

The randomization target is composed of one or more variables of plain-data type. The entire set of variables is randomized together. Additional constraints may be added via the optional with block.

The set of variables and constraints involved in a procedural randomization statement is determined from the variables and in-line constraints passed to the statement. The variables and constraints described below are solved together.

- Randomization target variables are those that are specified as operands of the randomize statement. Target variables are treated as random, independent of whether they are declared rand.
- If a target variable is of a struct type, sub-fields declared rand are treated as random. Those not declared rand are treated as invariants.
- Constraints declared inside the target-variable types are applied.
- In-line constraints are applied.

```
struct S1 {
    rand bit[8] a, b;
}

struct S2 {
    rand S1 f1;
    S1 f2;
    constraint f1.a < f2.a;
}

action A {
    exec post_solve {
        S2 v1;
        bit[4] v2;

        v1.f2.a = 100;
        randomize v1, v2 with {v1.f1.a < v2;}
    }
}
```

Example 148—procedural randomization

In Example 148 above, A::post_solve performs procedural randomization on two variables (v1, v2):

a) v1 is of struct type S2, and has two struct-type fields of the same type S1.
   1) f1 is declared random.
   2) f2 is declared non-random.
   3) A constraint is placed between sub-fields of f1 and f2.

b) v2 is of bit[4] type and thus has a maximum value of 15.

An in-line constraint is placed between v1.f1.a and v2. When the procedural randomization statement executes, it considers:

a) Random variables: v1.f1.a, v1.f1.b, v2
b) Invariants: v1.f2.a, v1.f2.b

c) Invariant values:
1) \texttt{v1.f2.a == 100}
2) \texttt{v1.f2.b == 0}

d) Constraints:
1) \texttt{v1.f1.a < v2}
2) \texttt{v1.f1.a < v1.f2.a}

\texttt{v1.f1.a} will have a value \([0..14]\) because it is required to be less than \(100\) (\texttt{v1.f2.a}) and less than the maximum value of \texttt{v2} (15).

**16.4.6.1 Support on solve and target platforms**

Support for procedural randomization in target \texttt{exec} blocks is restricted to built-in functions (e.g., \texttt{urandom()}) and randomization of scalar integer quantities. Randomization of \texttt{struct} data types is restricted to the solve platform, and may not be performed directly or indirectly from target \texttt{exec} blocks.

When procedural randomization is performed on the solve platform, any solve-time \texttt{exec} blocks within the scope of variables that are part of a procedural randomization are evaluated as part of the randomization process.

```vhdl
import std_pkg::*;

struct S1 {
    rand bit[8] a, b;
    exec pre_solve { print("Pre S1"); }
    exec post_solve { print("Post S1"); }
}

struct S2 {
    rand S1 f1;
    S1 f2;
    constraint f1.a < f2.a;
    exec pre_solve { print("Pre S2"); }
    exec post_solve { print("Post S2"); }
}

action A {
    exec post_solve {
        S2 v1;
        bit[4] v2;

        v1.a = 100;
        randomize v1, v2 with {v1.f1.a < v2;}
    }
}
```

*Example 149—Evaluation of solve-time exec blocks in procedural randomization*

In *Example 149* above, we would expect to see the following when procedural randomization is invoked:

```bash
Pre S2
Pre S1
Pre S1
Post S2
Post S1
Post S1
```
16.4.6.2 Random stability

When procedural randomization features are used in solve-time exec blocks (pre_solve, post_solve, pre_body), random stability shall be ensured when the PSS description and the random seed specified to the PSS processing tool remain the same.

When procedural randomization features are used in target exec blocks (body), random stability shall be ensured when the PSS description, random seed specified to the runtime environment (if applicable), and design behavior remain the same.

16.4.7 Random value selection order

A PSS processing tool conceptually assigns values to sub-action fields of the action in the order they are encountered in the activity. On entry into an activity, the value of plain-data fields qualified with action and rand sub-fields of action-type fields are considered to be undefined.

Example 150 shows a simple activity with three action-type fields (a, b, c). A PSS processing tool might assign \( a.val=2 \), \( b.val=4 \), and \( c.val=7 \) on a given execution.

```
action A {
    rand bit[3:0] val;
}

action my_action {
    A a, b, c;

    constraint abc_c {
        a.val < b.val;
        b.val < c.val;
    }

    activity {
        a;
        b;
        c;
    }
}
```

*Example 150—Activity with random fields*

16.4.8 Evaluation of expressions with action handles

Upon entry to an activity, all action handles (fields of action type) are considered uninitialized. Additionally, action handles previously traversed in an activity are reset to their uninitialized state upon entry to an activity block in which they are traversed again (an action handle may be traversed only once in any given activity scope and its nested scopes (see 12.3.1.1)). This applies equally to traversals of an action handle in a loop and to multiple occurrences of the same action handle in different activity blocks.

The value of all attributes reachable through uninitialized action handles, including direct attributes of the sub-actions and attributes of objects referenced by them, are unresolved. Only when all action handles in an expression are initialized, and all accessed attributes assume definite value, can the expression be evaluated.

Constraints accessing attributes through action handles are never violated. However, they are considered vacuously satisfied so long as these action handles are uninitialized. The Boolean expressions only need to evaluate to true at the point(s) in an activity when all action handles used in a constraint have been traversed.
Expressions in activity statements accessing attributes through action handles shall be illegal if they are evaluated at a point in which any of the action handles are uninitialized. Similarly, expressions in solve-exec (pre_solve and post_solve) statements of compound actions accessing attributes of sub-actions shall be illegal, since these are evaluated prior to the activity (see 16.4.12), and all action handles are uninitialized at that point. This applies equally to right-value and left-value expressions.

Example 151 shows a root action (my_action) with sub-action fields and an activity containing a loop. A value for a.x is selected, then two sets of values for b.x and c.x are selected.

```
action A {
    rand bit[3:0] x;
}

action my_action {
    A a, b, c;
    constraint abc_c {
        a.x < b.x;
        b.x < c.x;
    }
    activity {
        a;
        repeat (2) {
            b;
            c; // at this point constraint 'abc_c' must hold non-vacuously
        }
    }
}
```

**Example 151—Value selection of multiple traversals**

The following breakout shows valid values that could be selected here:

<table>
<thead>
<tr>
<th>Repetition</th>
<th>a.x</th>
<th>b.x</th>
<th>c.x</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>9</td>
<td>13</td>
</tr>
</tbody>
</table>

Note that b.x of the second iteration does not have to be less than c.x of the first iteration since action handle c is uninitialized on entry to the second iteration. Note also that similar behavior would be observed if the repeat would be unrolled, i.e., if the activity contained instead two blocks of b, c in sequence.

Example 152 demonstrates two cases of illegal access of action-handle attributes. In these cases, accessing sub-action attributes through uninitialized action handles shall be flagged as errors.
16.4.9 Relationship lookahead

Values for random fields in an activity are selected and assigned as the fields are traversed. When selecting a value for a random field, a PSS processing tool shall take into account both the explicit constraints on the field and the implied constraints introduced by constraints on those fields traversed during the remainder of the activity traversal (including those introduced by inferred actions, binding, and scheduling). This rule is illustrated by Example 153.

16.4.9.1 Example 1

Example 153 shows a simple struct with three random attribute fields and constraints between the fields. When an instance of this struct is randomized, values for all the random attribute fields are selected at the same time.
16.4.9.2 Example 2

Example 154 shows a root action (my_action) with three sub-action fields and an activity that traverses these sub-action fields. It is important that the random-value selection behavior of this activity and the struct shown in Example 153 are the same. If a value for a.val is selected without knowing the relationship between a.val and b.val, the tool could select a.val=15. When a.val=15, there is no legal value for b.val, since b.val must be greater than a.val.

a) When selecting a value for a.val, a PSS processing tool shall consider the following:
   1) a.val is in the range 0 to 15, due to its domain.
   2) b.val is in the range 0 to 15, due to its domain.
   3) c.val is in the range 0 to 15, due to its domain.
   4) a.val < b.val.
   5) b.val < c.val.

   This restricts the legal values of a.val to 0 to 13.

b) When selecting a value for b.val, a PSS processing tool shall consider the following:
   1) The value selected for a.val.
   2) b.val is in the range 0 to 15, due to its domain.
   3) c.val is in the range 0 to 15 due to its domain.
   4) a.val < b.val.
   5) b.val < c.val.

```
action A {
    rand bit[3:0] val;
}

action my_action {
    A a, b, c;

    constraint abc_c {
        a.val < b.val;
        b.val < c.val;
    }

    activity {
        a;
        b;
        c;
    }
}
```

Example 154—Activity with random fields

16.4.10 Lookahead and sub-actions

Lookahead shall be performed across traversal of sub-action fields and must comprehend the relationships between action attribute fields.

Example 155 shows an action named sub that has three sub-action fields of type A, with constraint relationships between those field values. A top-level action has a sub-action field of type A and type sub, with a constraint between these two action-type fields. When selecting a value for the top_action.v.val random attribute field, a PSS processing tool shall consider the following:

- top_action.s1.a.val == top_action.v.val
- top_action.s1.a.val < top_action.s1.b.val

This implies that top.v.val shall be less than 14 to satisfy the top_action.s1.a.val < top_action.s1.b.val constraint.

Example 155—Sub-activity traversal

```
component top {
  action A {
    rand bit[3:0] val;
  }
  action sub {
    A a, b, c;
    constraint abc_c {
      a.val < b.val;
      b.val < c.val;
    }
    activity {
      a;
      b;
      c;
    }
  }
  action top_action {
    A v;
    sub s1;
    constraint c {
      s1.a.val == v.val;
    }
    activity {
      v;
      s1;
    }
  }
}
```

16.4.11 Lookahead and dynamic constraints

Dynamic constraints introduce traversal-dependent constraints. A PSS processing tool must account for these additional constraints when making random attribute field value selections. A dynamic constraint shall hold for the entire activity branch on which it is referenced, as well to the remainder of the activity.

Example 156 shows an activity with two dynamic constraints which are mutually exclusive. If the first branch is selected, b.val <= 5 and b.val < a.val. If the second branch is selected, b.val <= 7 and b.val > a.val. A PSS processing tool shall select a value for a.val such that a legal value for b.val also exists (assuming this is possible).

Given the dynamic constraints, legal value ranges for a.val are 1 to 15 for the first branch and 0 to 6 for the second branch.
16.4.12 pre_solve and post_solve exec blocks

The pre_solve and post_solve exec blocks enable external code to participate in the solve process. pre_solve and post_solve exec blocks may appear in struct and action type declarations.

Statements in pre_solve blocks are used to set non-random attribute fields that are subsequently read by the solver during the solve process. Statements in pre_solve blocks can read the values of non-random attribute fields and their non-random children. Statements in pre_solve blocks cannot access handle-type fields (input/output, lock/share, action handles) or their children since these fields are null handles prior to the completion of randomization. Accessing plain-data random fields (e.g., bit, int, struct) is permitted. Reading the value of these fields in pre_solve blocks returns the initial value of the field. Values written to scalar plain-data random fields in pre_solve will be overwritten by the solve process.

Statements in post_solve blocks are evaluated after the solver has resolved values for random attribute fields and are used to set the values for non-random attribute fields based on randomly-selected values.

The execution order of pre_solve and post_solve exec blocks, respectively, corresponds to the order random attribute fields are assigned by the solver. The ordering rules are as follows:

a) Order within a compound action is top-down—both the pre_solve and post_solve exec blocks, respectively, of a containing action are executed before any of its sub-actions are traversed, and, hence, before the pre_solve and post_solve, respectively, of its sub-actions.

b) Order between actions follows their relative scheduling in the scenario: if action $a_1$ is scheduled before $a_2$, $a_1$’s pre_solve and post_solve blocks, if any, are called before the corresponding block of $a_2$. 

Example 156—Activity with dynamic constraints

```plaintext
action A {
    rand bit[3:0] val;
}

action dyn {
    A a, b;

    dynamic constraint d1 {
        b.val < a.val;
        b.val <= 5;
    }

    dynamic constraint d2 {
        b.val > a.val;
        b.val <= 7;
    }

    activity {
        a;
        select {
            d1;
            d2;
        }
        b;
    }
}

```
c) Order for flow objects (instances of struct types declared with a buffer, stream, or state modifier) follows the order of their flow in the scenario: a flow object’s pre_solve or post_solve exec block is called after the corresponding exec block of its outputting action and before that of its inputting action(s).

d) A resource object’s pre_solve or post_solve exec blocks are called before the corresponding exec block(s) of all actions referencing it, regardless of their use mode (lock or shared).

e) Order within an aggregate data type (nested struct and collection fields) is top-down—the exec blocks of the containing instance are executed before those of the contained.

PSS does not specify the execution order in other cases. In particular, any relative order of execution for sibling random struct attributes is legitimate and so is any order for actions scheduled in parallel where no flow objects are exchanged between them.

See 21.1 for more information on the exec block construct.

16.4.12.1 Example 1

Example 157 shows a top-level struct S2 that has rand and non-rand scalar fields, as well as two fields of struct type S1. When an instance of S2 is randomized, the exec block of S2 is evaluated first, but the execution for the two S1 instances can be in any order. The following is one such possible order:

a) pre_solve in S2
b) pre_solve in S2.s1_2
c) pre_solve in S2.s1_1
d) assignment of attribute values
e) post_solve in S2
f) post_solve in S2.s1_1
g) post_solve in S2.s1_2
Example 157—pre_solve/post_solve

```verbatim
function bit[5:0] get_init_val();
function bit[5:0] get_exp_val(bit[5:0] stim_val);

struct S1 {
    bit[5:0] init_val;
    rand bit[5:0] rand_val;
    bit[5:0] exp_val;

    exec pre_solve {
        init_val = get_init_val();
    }

    constraint rand_val_c {
        rand_val <= init_val+10;
    }

    exec post_solve {
        exp_val = get_exp_val(rand_val);
    }
}

struct S2 {
    bit[5:0] init_val;
    rand bit[5:0] rand_val;
    bit[5:0] exp_val;
    rand S1 s1_1, s1_2;

    exec pre_solve {
        init_val = get_init_val();
    }

    constraint rand_val_c {
        rand_val > init_val;
    }

    exec post_solve {
        exp_val = get_exp_val(rand_val);
    }
}
```

16.4.12.2 Example 2

Example 158 illustrates the relative order of execution for post_solve exec blocks of a containing action test, two sub-actions: read and write, and a buffer object exchanged between them.

The calls therein are executed as follows:
   a) post_solve in test
   b) post_solve in write
   c) post_solve in mem_obj
   d) post_solve in read
16.4.13 Body blocks and sampling external data

`exec body` blocks, or functions invoked by them, can assign values to attribute fields. `exec body` blocks are evaluated for atomic actions as part of the test execution on the target platform (see 21.1). The impact of any field values modified by an `exec body` block is evaluated after the entire `exec body` block has completed.

Example 159 shows an `exec body` block that assigns two non-rand attribute fields. The impact of the new values applied to `y1` and `y2` are evaluated against the constraint system after the `exec body` block completes execution. It shall be illegal if the new values of `y1` and `y2` conflict with other attribute field values and constraints. Backtracking is not performed.
function bit[3:0] compute_val1(bit[3:0] v);
function bit[3:0] compute_val2(bit[3:0] v);
component pss_top {
  action A {
    rand bit[3:0] x;
    bit[3:0] y1, y2;

    constraint assume_y_c {
      y1 >= x && y1 <= x+2;
      y2 >= x && y2 <= x+3;

      y1 <= y2;
    }

    exec body {
      y1 = compute_val1(x);
      y2 = compute_val2(x);
    }
  }
}

Example 159—exec body block sampling external data
17. Action inferencing

Perhaps the most powerful feature of PSS is the ability to focus purely on the user’s verification intent, while delegating the means to achieve that intent. Previous clauses have introduced the semantic concepts to define such abstract specifications of intent. The modeling constructs and semantic rules thus defined for a portable stimulus model allow a tool to generate a number of scenarios from a single (partial) specification to implement the desired intent.

Beginning with a root action, which may contain an activity, a number of actions and their relative scheduling constraints is used to specify the verification intent for a given model. The other elements of the model, including flow objects, resources and their binding, as well as algebraic constraints throughout, define a set of rules that shall be followed to generate a valid scenario matching the specified intent. It is possible to fully specify a verification intent model, in which only a single valid scenario of actions may be generated. The randomization of data fields in the actions and their respective flow and resource objects would render this scenario as what is generally referred to as a “directed random” test, in which the actions are fully defined, but the data applied through the actions is randomized. The data values themselves may also be constrained so that there is only one scenario that may be generated, including fully-specified values for all data fields, in which case the scenario would be a “directed” test.

There are a number of ways to specify the scheduling relationship between actions in a portable stimulus model. The first, which allows explicit specification of verification intent, is via an activity. As discussed in Clause 12, an activity may define explicit scheduling dependencies between actions, which may include statements, such as schedule, select, if-else and others, to allow multiple scenarios to be generated even for a fully-specified intent model. Consider Example 160.

```plaintext
component pss_top {
  buffer data_buff_s {
    rand int val;
  };
  pool data_buff_s data_mem;
  bind data_mem *;
  action A_a {output data_buff_s dout;};
  action B_a {output data_buff_s dout;};
  action C_a {input data_buff_s din;};
  action D_a {input data_buff_s din;};
  action root_a {
    A_a a;
    B_a b;
    C_a c;
    D_a d;
    activity {
      select {a; b;}
      select {c; d;}
    }
  }
}
```

Example 160—Generating multiple scenarios

While an activity may be used to fully express the intent of a given model, it is more often used to define the critical actions that must occur to meet the verification intent while leaving the details of how the actions may interact unspecified. In this case, the rules defined by the rest of the model, including flow object
requirements, resource limitations, pool bindings, and algebraic constraints, permit a tool to introduce the traversal of additional actions as defined by the model to ensure the generation of a valid scenario that meets the critical intent as defined by the activity. The introduction of an action in the execution of a scenario to complete a partially specified flow is called **action inferencing**.

The evaluation ordering rules for **pre_solve** and **post_solve** exec blocks of actions, objects, and structs, as specified in 16.4.12, apply regardless of whether the actions are explicitly traversed or inferred, and whether objects are explicitly or implicitly bound. In particular, the order conforms to the scheduling relations between actions, such that if an action is scheduled before another, its **pre_solve** and **post_solve** execs are evaluated before the other’s. Backtracking is not performed across exec blocks. Assignments in exec blocks to attributes that figure in constraints may therefore lead to unsatisfied constraint errors. This applies to inferred parts of the scenarios in the same way as to parts that are explicitly specified in activities.

### 17.1 Implicit binding and action inferences

In a scenario description, the explicit binding of outputs to inputs may be left unspecified. In these cases, an implementation shall execute a scenario that reflects a valid completion of the given partial specification in a way that conforms to pool binding rules. If no valid scenario exists, the tool shall report an error. Completing a partial specification may involve decisions on output-to-input binding of flow objects in actions that are explicitly traversed. It may also involve introducing the traversal of additional actions, beyond those explicitly traversed, to serve as the counterpart of a flow object exchange. Once an action traversal is inferred to complete a given flow object exchange, it may also be considered for completing other flow object exchanges with which it may also be compatible.

Action inferences are necessary to make a scenario execution legal if the following conditions hold:

a) An input of any kind is not explicitly bound to an output, or an output of stream kind is not explicitly bound to an input.

b) There is no action explicitly traversed or inferred that is available to legally bind its output/input to the unbound input/output, i.e.,
   1) There is no action that is or may be scheduled before the inputting action in the case of buffer or state objects.
   2) There is no action that is or may be scheduled in parallel to the inputting/outputting action in the case of stream objects.

The inferencing of actions may be based on random or policy-driven (which may include specified coverage goals) decisions of a processing tool. Actions may only be inferred to complete a partially-specified flow. If all required input-to-output bindings are specified by explicit bindings to the traversed actions in the activity, an implementation may not introduce additional actions in the execution. See Annex E for more details on inference rules.

Consider the model in Example 161.

If action **send_data** is designated as the root action, this is clearly a case of partial scenario description, since action **send_data** has an input and an output, neither of which is explicitly bound. The buffer input **src_data** is bound to the **data_mem** object pool, so there must be a corresponding output object also bound to the same pool to provide the buffer object. The only action type outputting an object of the required type that is bound to the same object pool is **load_data**. Thus, an implementation shall infer the prior traversal of **load_data** before traversing **send_data**.

Similarly, **load_data** has a state input that is bound to the **config_var** pool. Since the output objects of action types **setup_A** and **setup_B** are also bound to the same pool, **load_data.curr_cfg** can be bound to the output of either **setup_A** or **setup_B**, but cannot be the initial state due to the constraint in
load_data. In the absence of other constraints, the choice of whether to infer setup_A or setup_B may be randomized and the chosen action traversal shall occur before the traversal of load_data.

Moreover, send_data has a stream output out_data, which shall be bound to the corresponding input of another action that is also bound to the data_bus pool. So, an implementation shall infer the traversal of an action of type receive_data in parallel to send_data.

```plaintext
component pss_top {
    state config_s {};
    pool config_s config_var;
    bind config_var *;

    buffer data_buff_s {};
    pool data_buff_s data_mem;
    bind data_mem *;

    stream data_stream_s {};
    pool data_stream_s data_bus;
    bind data_bus *;

    action setup_A {
        output config_s new_cfg;
    };

    action setup_B {
        output config_s new_cfg;
    };

    action load_data {
        input config_s curr_cfg;
        constraint !curr_cfg.initial;
        output data_buff_s out_data;
    };

    action send_data {
        input data_buff_s src_data;
        output data_stream_s out_data;
    };

    action receive_data {
        input data_stream_s in_data;
    };
}
```

**Example 161—Action inferences for partially-specified flows**

Note that action inferences may be more than one level deep. The scenario executed by an implementation shall be the transitive closure of the specified scenario per the flow object dependency relations. Consider adding another action within the pss_top component in Example 161, e.g.,

```plaintext
action xfer_data {
    input data_buff_s src_data;
    output data_buff_s out_data;
}
```
In this case, the xfer_data action could also be inferred, along with setup_A or setup_B to provide the data_buff_s input to send_data.src_data. If xfer_data were inferred, then its src_data input would require the additional inference of another instance of setup_A, setup_B, or xfer_data to provide the data_buff_s. This “inference chain” would continue until either an instance of setup_A or setup_B is inferred, which would require no further inferencing, or the inferencing limit of the tool is exceeded, in which case an error would be reported.

Since the type of the inferred action is randomly selected from all available compatible action types, a tool may ensure that either setup_A or setup_B gets inferred before the inferencing limit is exceeded.

Consider Example 162. Starting with the constr_test action, two instances of the get_data action are traversed in parallel. Since each instance inputs a buffer of type data_buff_s, at least one instance of load_data must be inferred to provide the input buffer. The equality constraint c2 requires that gd1.src_data and gd2.src_data are actually the same object, so only a single instance of load_data will be inferred. Without the c2 constraint, it would have been possible to infer two separate instances of load_data, each of which would provide a buffer object to either gd1 or gd2, although inferring a single instance is also legal. Note that the c1 constraint by itself is not sufficient to guarantee a single instance inference since there could be two distinct buffers with identical contents. With the c2 constraint present, the c1 constraint is redundant (but legal).

```
component pss_top {
    buffer data_buff_s {bit[4] val;};
    pool data_buff_s dbuf_p;
    bind dbuf_p *
    
    action load_data {
        output data_buff_s out_data;
    }

    action get_data {
        input data_buff_s src_data;
    }

    action constr_test {
        get_data gd1, gd2;

        constraint c1 {gd1.src_data.val == gd2.src_data.val;}
        constraint c2 {gd1.src_data == gd2.src_data;}

        activity {
            parallel {gd1; gd2;}
        }
    }
}
```

Example 162—Buffer equality constraint to limit inferencing

Consider Example 163. In the constr_rsrc_test action, two instances of the m2m action are scheduled and traversed, each of which inputs and outputs a data_buff_s buffer object and locks a dma_descr resource object, followed by the parallel traversal of two instances of the get_data action. Constraint c3 ensures that both m2m instances input the same data_buff_s object and therefore a single instance of either load_data or m2m is inferred to provide it. Constraint c4 guarantees that the two get_data instances will each consume a different data_buff_s object, so each will be provided by either m2m1 or m2m2. Constraint c5 requires the two m2m instances to claim the same resource object, so the schedule
statement must require one instance to be traversed before the other, in either order. Note that the commented-out constraint \( c_6 \) is equivalent to \( c_5 \).

```
component pss_top {
  buffer  data_buff_s {bit[4] val;};
  resource dma_descr {bit[4] chan;};
  pool   data_buff_s dbuf_p;
  bind   dbuf_p *;
  pool [16] dma_descr descr_p;
  bind   descr_p *;

  action load_data {
    output data_buff_s out_data;
  }

  action get_data {
    input  data_buff_s src_data;
  }

  action m2m {
    input  data_buff_s ibuf;
    output data_buff_s obuf;
    lock dma_descr descr;
  }

  action constr_rsrc_test {
    get_data gd1, gd2;
    m2m   m2m1, m2m2;

    constraint c3 {m2m1.ibuf == m2m2.ibuf;}
    constraint c4 {gd1.src_data != gd2.src_data;}
    constraint c5 {m2m1.descr == m2m2.descr;}
    // constraint c6 {m2m1.descr.instance_id == m2m2.descr.instance_id;}

    activity {
      schedule {m2m1; m2m2;}
      parallel {gd1; gd2;}
    }
  }
}
```

*Example 163—Resource equality constraint may affect scheduling*

17.2 Object pools and action inferences

Action traversals may be inferred to support the flow object requirements of actions that are traversed in the model, whether they are explicitly traversed or inferred. The set of actions from which a traversal may be inferred is determined by object pool bindings.

In *Example 164*, there are two object pools of type `data_buff_s`, each of which is bound to a different set of object field references. The `select` statement in the activity of `root_a` will randomly choose either `c` or `d`, each of which has a `data_buff_s` buffer input type that requires a corresponding action to be inferred to supply the buffer object. Since `C_a` is bound to the same pool as `A_a`, if the generated scenario chooses `c`, then an instance of `A_a` shall be inferred to supply the `c.din` buffer input. Similarly, if `d` is chosen, then an instance of `B_a` shall be inferred to supply the `d.din` buffer input.
Example 164—Object pools affect inferencing

Consider the following modified version of Example 40 from 9.5.2. In this example, the traversal of action foo in the activity of action gr_a requires the inference of an action that can be bound to the same pool as graphics::foo and supply the compatible bar_s type flow object. Since the bar_p pool is bound by default to all components under graphics and bus_c, it is legal to infer the traversal of bus_c::write in parallel with foo, even though it was illegal to traverse this action explicitly as shown in Example 40.

Example 165—Inferred traversal of an action outside of the containing component hierarchy
17.3 Data constraints and action inferences

As mentioned in Clause 16, introducing data constraints on flow objects or other elements of the design may affect the inferencing of actions. Consider a slightly modified version of Example 160, as shown in Example 166.

Since the explicit traversal of c does not constrain the val field of its input, it may be bound to the output of either explicitly traversed action a or b; thus, there are two legal scenarios to be generated with the second select statement evaluated to traverse action c. However, since the data constraint on the traversal of action d is incompatible with the in-line data constraints on the explicitly-traversed actions a or b, another instance of either A_a or B_a shall be inferred whose output shall be bound to d.din. Since there is no requirement for the buffer output of either a or b to be bound, one of these actions shall be traversed from the first select statement, but no other action shall be inferred.

```
component pss_top {
    buffer data_buff_s {
        rand int val;
    };
    pool data_buff_s data_mem;
    bind data_mem *;
    action A_a {output data_buff_s dout;}
    action B_a {output data_buff_s dout;}
    action C_a {input data_buff_s din;}
    action D_a {input data_buff_s din;}
    action root_a {
        A_a a;
        B_a b;
        C_a c;
        D_a d;
        activity {
            select {a with{dout.val<5;}; b with {dout.val<5;};}
            select {c; d with {din.val>5;};}
        }
    }
}
```

Example 166—In-line data constraints affect action inferencing
Consider, instead, if the in-line data constraints were declared in the action types, as shown in Example 167.

In this case, there is no valid action type available to provide the `d.in` input that satisfies its constraint as defined in the `D_a` action declaration, since the only actions that may provide the `data_buff_s` type, actions `A_a` and `B_a`, have constraints that contradict the input constraint in `D_a`. Therefore, the only legal action to traverse in the second select statement is `C_a`. In fact, it would be illegal to traverse action `D_a` under any circumstances for this model, given the contradictory data constraints on the flow objects.

```
component pss_top {
  buffer data_buff_s {
    rand int val;
  };
  pool data_buff_s data_mem;
  bind data_mem *;

  action A_a {
    output data_buff_s dout;
    constraint {dout.val<5;}
  };
  action B_a {
    output data_buff_s dout;
    constraint {dout.val<5;}
  };
  action C_a {
    input data_buff_s din;
  };
  action D_a {
    input data_buff_s din;
    constraint {din.val > 5;}
  };

  action root_a {
    A_a a;
    B_a b;
    C_a c;
    D_a d;
    activity {
      select {a; b;}
      select {c; d;}
    }
  }
}
```

Example 167—Data constraints affect action inferencing
18. Coverage specification constructs

The legal state space for all non-trivial verification problems is very large. Coverage goals identify key value ranges and value combinations that need to occur in order to exercise key functionality. The `covergroup` construct is used to specify these targets.

The coverage targets specified by the `covergroup` construct are more directly related to the test scenario being created. As a consequence, in many cases the coverage targets would be considered coverage targets on the “generation” side of stimulus. PSS also allows data to be sampled by calling external functions. Coverage targets specified on data fields set by external functions can be related to the system state.

18.1 Defining the coverage model: covergroup

The `covergroup` construct encapsulates the specification of a coverage model. Each `covergroup` specification can include the following elements:

- A set of coverage points
- Cross coverage between coverage points
- Optional formal arguments
- Coverage options

The `covergroup` construct is a user-defined type. There are two forms of the `covergroup` construct. The first form allows an explicit type definition to be written once and instantiated multiple times in different contexts. The second form allows an in-line specification of an anonymous `covergroup` type and a single instance.

a) An explicit `covergroup` type can be defined in a `package`, `component`, `action`, or `struct`. In order to be reusable, an explicit `covergroup` type shall specify a list of formal parameters and shall not reference fields in the scope in which it is declared. An instance of an explicit `covergroup` type can be created in an `action` or `struct`. Syntax 62 defines an explicit `covergroup` type.

b) An in-line `covergroup` can be defined in an `action` or `struct` scope. An in-line covergroup can reference fields in the scope in which it is defined. 18.2 contains more information on in-line covergroups.
18.1.1 Syntax

The syntax for **covergroups** is shown in Syntax 62.

![Syntax 62—covergroup declaration]

The following also apply:

a) The identifier associated with the **covergroup** declaration defines the name of the coverage model type.

b) A **covergroup** can contain one or more coverage points. A **coverage point** can cover a variable or an expression.

c) Each coverage point includes a set of bins associated with its sampled value. The bins can be user-defined or automatically created by a tool. Coverage points are detailed in 18.3.

d) A **covergroup** can specify cross coverage between two or more coverage points or variables. Any combination of more than two variables or previously declared coverage points is allowed. See also Example 169.

e) A **covergroup** can also specify one or more options to control how coverage data are structured and collected. Coverage options can be specified for the **covergroup** as a whole or for specific items within the **covergroup**, i.e., any of its coverage points or crosses. In general, a coverage option specified at the **covergroup** level applies to all of its items unless overridden in a specific item’s definition. Coverage options are described in 18.5.

18.1.2 Examples

Example 168 defines an in-line covergroup **cs1** with a single coverage point labeled **c** associated with struct field **color**. The value of the variable **color** is sampled at the default sampling point: the end of an action’s traversal in which the field **color** is randomized. Sampling is discussed in more detail in 18.6.

Because the coverage point does not explicitly define any bins, the tool automatically creates three bins, one for each possible value of the enumeration type. Automatic bins are described in 18.3.4.
Example 168—Single coverage point

Example 169 creates an in-line covergroup `cs2` that includes two coverage points and two cross coverage items. Explicit coverage points labeled `Offset` and `Hue` are defined for variables `pixel_offset` and `pixel_hue`. PSS implicitly declares coverage points for variables `color` and `pixel_adr` to track their cross coverage. Implicitly declared coverage points are described in 18.4.

Example 169—Two coverage points and cross coverage items

18.2 covergroup instantiation

A covergroup type can be instantiated in struct and action contexts. If the covergroup declared formal parameters, these shall be bound to variables visible in the instantiation context. Instance-specific coverage options (see 18.5) may be specified as part of instantiation. If a covergroup is specific to the containing type, it cannot be generally instantiated in other types. In these cases, it is possible to declare a covergroup instance in-line. In this case, the covergroup type is anonymous.
18.2.1 Syntax

Syntax 63 specifies how a `covergroup` is instantiated and how an in-line covergroup instance is declared.

```plaintext
covergroup_instantiation ::=  
    covergroup_type_instantiation  
    | inline_covergroup
inline_covergroup ::= covergroup { { covergroup_body_item } } identifier ;
covergroup_type_instantiation ::= covergroup_type_identifier covergroup_identifier
    ( covergroup_portmap_list ) covergroup_options_or_empty
covergroup_type_identifier ::= type_identifier
covergroup_portmap_list ::=  
    covergroup_portmap { , covergroup_portmap }
    | hierarchical_id_list
covergroup_portmap ::= . identifier ( hierarchical_id )
covergroup_options_or_empty ::=  
    with { { covergroup_option } }
    | ;
```

Syntax 63—covergroup instantiation

18.2.2 Examples

Example 170 defines a covergroup type with a formal parameter list and creates a covergroup instance.

```plaintext
enum color_e {red, green, blue};
struct s {
    rand color_e color;
    covergroup cs1(color_e c) {
        c : coverpoint c;
    }
    cs1 cs1_inst(color);
}
```

Example 170—Creating and instantiating a covergroup type with a formal parameter list
Example 171 defines a covergroup type and creates a covergroup instance with instance-specific options.

```vhdl
enum color_e {red, green, blue};
struct s {
    rand color_e color;
    covergroup cs1 (color_e color) {
        c: coverpoint color;
    }
    cs1 cs1_inst (color) with {
        option.at_least = 2;
    }
}
```

*Example 171—Creating a covergroup instance with instance-specific options*

Example 172 creates an in-line covergroup instance.

```vhdl
enum color_e {red, green, blue};
struct s {
    rand color_e color;
    covergroup {
        option.at_least = 2;
        c: coverpoint color;
    } cs1_inst;
}
```

*Example 172—Creating an in-line covergroup instance*

18.3 Defining coverage points

A covergroup can contain one or more coverage points. A coverage point specifies an integer expression or enum that is to be covered. Each coverage point includes a set of bins associated with the sampled values of the covered expression. The bins can be explicitly defined by the user or automatically created by the PSS processing tool. The syntax for specifying coverage points is shown in Syntax 64.

Evaluation of the coverage point expression (and of its enabling iff condition, if any) takes place when the covergroup is sampled (see 18.6).

18.3.1 Syntax

The syntax for coverpoints is shown in Syntax 64.
The following also apply:

a) A coverpoint coverage point creates a hierarchical scope and can be optionally labeled. The label (coverpoint_identifier) designates the name of the coverage point. This name can be used to add this coverage point to a cross coverage specification. If the coverage point is associated with a single variable and the label is omitted, the variable name becomes the name of the coverage point. A coverage point on an expression is required to specify a label.

b) A data type for the coverpoint may be specified. The data type shall be an integer or enum type. If a data type is specified, then a label shall also be specified.

c) If a data type is specified, the coverpoint expression shall be assignment compatible with the data type. Values for the coverpoint shall be of the specified data type and shall be determined as though the coverpoint expression were assigned to a variable of the specified type.

d) If no data type is specified, the inferred type for the coverpoint shall be the self-determined type of the coverpoint expression.

e) The expression within the iff construct specifies an optional condition that disables coverage sampling for that coverpoint. If the iff expression evaluates to false at a sampling point, the coverage point is not sampled.

f) A coverage point bin associates a name and a count with a set of values. The count is incremented every time the coverage point matches one of the values in the set. The bins for a coverage point can be defined using the bins construct to name each bin. If the bins are not explicitly defined, they are automatically created by the PSS processing tool. The number of automatically created bins can be controlled using the auto_bin_max coverage option. Coverage options are described in Table 21.

18.3.2 Examples

In Example 173, coverage point s0 is covered only if is_s0_enabled is true.

```plaintext
struct s {
    rand bit[4] s0;
    rand bool is_s0_enabled;

covergroup {
    coverpoint s0 iff (is_s0_enabled);
} cs4;
}
```

Example 173—Specifying an iff condition
18.3.3 Specifying bins

The `bins` construct creates a separate bin for each value in the given range list or a single bin for the entire range of values. The syntax for defining bins is shown in Syntax 65.

18.3.3.1 Syntax

The syntax for `bins` is shown in Syntax 65.

```
covergroup_coverpoint_binspec ::= bins_keyword identifier
coverpoint_bins ::= 
    [ covergroup_range_list ] [with ( covergroup_expression ) ] ;
    | coverpoint_identifier with ( covergroup_expression ) ;
    | default ;
covergroup_range_list ::= covergroup_value_range { , covergroup_value_range }
covergroup_value_range ::= 
    expression
    | expression .. [ expression ]
    | [ expression ] .. expression
bins_keyword ::= bins | illegal_bins | ignore_bins
covergroup_expression ::= expression
```

Syntax 65—bins declaration

The following also apply:

a) To create a separate bin for each value (an array of bins), add square brackets ([ ]) after the bin name.
   1) To create a fixed number of bins for a set of values, a single positive integral expression can be specified inside the square brackets.
   2) The bin name and optional square brackets are followed by a `covergroup_range_list` that specifies the set of values associated with the bin.
   3) It shall be legal to use the range value form `expression..` and `.expression` to denote a range that extends to the upper or lower value (respectively) of the coverpoint data type.

b) If a fixed number of bins is specified and that number is smaller than the specified number of values, the possible bin values are uniformly distributed among the specified bins.
   1) The first $N$ specified values (where $N = \text{int}(\text{number of values} / \text{number of bins})$) are assigned to the first bin, the next $N$ specified values are assigned to the next bin, etc.
   2) Duplicate values are retained; thus, the same value can be assigned to multiple bins.
   3) If the number of values is not evenly divisible by the number of bins, then the last bin will include the remaining items, e.g., for
      ```
bins fixed [4] = [1..10, 1, 4, 7];
```
      The 13 possible values are distributed as follows: \(<1, 2, 3>, <4, 5, 6>, <7, 8, 9>, <10, 1, 4, 7>\).

c) A `covergroup_expression` is an `expression`. In the case of a `with` `covergroup_expression`, the expression can involve constant terms and the `coverpoint` variable (see 18.3.3.3).
d) The **default** specification defines a bin that catches the values of the coverage point that do not lie within any of the defined bins. The default is useful for catching unplanned or invalid values. The coverage calculation for a coverage point shall not take into account the coverage captured by default bins. Default bins are also excluded from cross coverage (see 18.4). A default bin cannot be explicitly ignored (see 18.3.5).

### 18.3.3.2 Examples

In **Example 174**, the first **bins** construct associates bin `a` with the values of `v_a`, between 0 and 63 and the value 65. The second **bins** construct creates a set of 65 bins `b[127], b[128], ... b[191]`. Note that when empty square brackets are specified, each value is assigned one bin, including values that are specified more than once. Likewise, the third **bins** construct creates 3 bins: `c[200], c[201], and c[202]`. The fourth **bins** construct associates bin `d` with the values between 1000 and 1023 (the trailing .. represents the maximum value of `v_a`). Every value that does not match bins `a, b[], c[], or d` is added into its own distinct bin (e.g., the value 64), using the **default** specification.

```markdown
struct s {
    rand bit[10] v_a;

covergroup {
    coverpoint v_a {
        bins a = [0..63, 65];
        bins b[] = [127..150, 148..191];
        bins c[] = [200, 201, 202];
        bins d = [1000..];
        bins others[] = default;
    }
} cs;
}
```

*Example 174—Specifying bins*

### 18.3.3.3 Coverpoint bin with covergroup expressions

The **with** clause specifies that only those values in the **covergroup_range_list** (see Syntax 65) that satisfy the given expression (i.e., for which the expression evaluates to **true**) are included in the bin. In the expression, the name of the **coverpoint** shall be used to represent the candidate value. The candidate value is of the same type as the **coverpoint**.

The **with** clause behaves as if the expression were evaluated for every value in the **covergroup_range_list** at the time the covergroup instance is created. The **with covergroup_expression** is applied to the set of values in the **covergroup_range_list** prior to distribution of values to the bins. The result of applying a **with covergroup_expression** shall preserve multiple, equivalent bin items as well as the bin order. The intent of these rules is to allow the use of non-simulation analysis techniques to calculate the bin (e.g., formal symbolic analysis) or for caching of previously calculated results.

Consider **Example 175**, where the bin definition selects all values from 0 to 255 that are evenly divisible by 3.
The name of the `coverpoint` itself may be used in place of the `covergroup_range_list`, preceding the `with` keyword, to denote all values of the `coverpoint`. Only the name of the `coverpoint` containing the bin being defined shall be allowed.

In Example 176, `coverpoint` name `a` is used in place of the `covergroup_range_list` to denote that the `with` `covergroup_expression` will be applied to all values of the `coverpoint`.

```
struct s {
    rand bit[8] x;

    covergroup {
        a: coverpoint x {
            bins mod3[] = [0..255] with ((a % 3) == 0);
        }
    } cs;
}
```

**Example 176—Using with in a coverpoint**

18.3.4 Automatic bin creation for coverage points

If a coverage point does not define any bins, PSS automatically creates bins. This provides an easy-to-use mechanism for binning different values of a coverage point. Users can either let the tool automatically create bins for coverage points or explicitly define named bins for each coverage point.

When the automatic bin creation mechanism is used, PSS creates \( N \) bins to collect the sampled values of a coverage point. The value \( N \) is determined as follows:

- For an `enum` coverage point, \( N \) is the cardinality of the enumeration.
- For an integer coverage point, \( N \) is the minimum of \( 2^M \) and the value of the `auto_bin_max` option (see Table 21), where \( M \) is the number of bits needed to represent the coverage point.

If the number of automatic bins is smaller than the number of possible values \( (N < 2^M) \), the \( 2^M \) values are uniformly distributed in the \( N \) bins. If the number of values, \( 2^M \), is not divisible by \( N \), then the last bin will include the additional remaining items. For example, if \( M = 3 \) and \( N = 3 \), the eight possible values are distributed as follows: \(<0..1>, <2..3>, <4..7>\).

PSS implementations can impose a limit on the number of automatic bins. See Table 21 for the default value of `auto_bin_max`.

Each automatically created bin will have a name of the form `auto[value]`, where `value` is either a single coverage point value or the range of coverage point values included in the bin (in the form...
low..high). For enumeration types, value is the named constant (enum item) associated with the particular enumeration value.

18.3.5 Excluding coverage point values

A set of values associated with a coverage point can be explicitly excluded from coverage by specifying them as ignore_bins. See Example 177.

All values associated with ignored bins are excluded from coverage. Each ignored value is removed from the set of values associated with any coverage bin. The removal of ignored values shall occur after distribution of values to the specified bins.

Example 177 may result in a bin that is associated with no values or sequences. Such empty bins are excluded from coverage.

```
struct s {
    rand bit[4] a;

    covergroup {
        coverpoint a {
            ignore_bins ignore_vals = [7, 8];
        }
    } cs23;
}
```

Example 177—Excluding coverage point values

18.3.6 Specifying illegal coverage point values

A set of values associated with a coverage point can be marked as illegal by specifying them as illegal_bins. See Example 178.

All values associated with illegal bins are excluded from coverage. Each illegal value is removed from the set of values associated with any coverage bin. The removal of illegal values shall occur after the distribution of values to the specified bins. If an illegal value occurs, a runtime error shall be issued. Illegal bins take precedence over any other bins, i.e., they result in a runtime error even if they are also included in another bin.

Example 178 may result in a bin that is associated with no values or sequences. Such empty bins are excluded from coverage.

```
struct s {
    rand bit[4] a;

    covergroup {
        coverpoint a {
            illegal_bins illegal_vals = [7, 8];
        }
    } cs23;
}
```

Example 178—Specifying illegal coverage point values
18.3.7 Value resolution

A coverpoint expression, the expressions in a bins construct, and the coverpoint type, if present, are all involved in comparison operations in order to determine into which bins a particular value falls. Let e be the coverpoint expression and b be an expression in a bins covergroup_range_list. The following rules shall apply when evaluating e and b:

a) If there is no coverpoint type, the effective type of e shall be self-determined. In the presence of a coverpoint type, the effective type of e shall be the coverpoint type.

b) b shall be statically cast to the effective type of e. An implementation shall issue a warning under the following conditions:
   1) If the effective type of e is unsigned and b is signed with a negative value.
   2) If assigning b to a variable of the effective type of e would yield a value that is not equal to b under normal comparison rules for ==.

If a warning is issued for a bins element, the following rules shall apply:

— If an element of a bins covergroup_range_list is a singleton value b, that element shall not appear in the bins values.
— If an element of a bins covergroup_range_list is a range b1..b2 and there exists at least one value in the range for which a warning would not be issued, the range shall be treated as containing the intersection of the values in the range and the values expressible by the effective type of e.

Example 179 leads to the following:

— For b1, a warning is issued for the range 6..10. b1 is treated as though it had the specification [1, 2..5, 6..7].
— For b2, a warning is issued for the range 1..10 and for the values -1 and 15. b2 is treated as though it had the specification [1..7].
— For b3, a warning is issued for the ranges 2..5 and 6..10. b3 is treated as though it had the specification [1, 2..3].
— For b4, a warning is issued for the range 1..10 and for the value 15. b4 is treated as though it had the specification [-1, 1..3].

```verbatim
struct s {
    rand bit[3] p1;        // type expresses values in the range 0 to 7
    int [3]     p2;        // type expresses values in the range -4 to 3

covergroup {
    coverpoint p1 {
        bins b1 = [1, 2..5, 6..10]; // warning issued for range 6..10
        bins b2 = [-1, 1..10, 15];  // warning issued for range 1..10
    }                             //           and values -1 and 15
    coverpoint p2 {
        bins b3 = [1, 2..5, 6..10]; // warning issued for ranges 2..5
        // and 6..10
        bins b4 = [-1, 1..10, 15];  // warning issued for range 1..10
        // and value 15
    }
} c1;
}
```

Example 179—Value resolution
18.4 Defining cross coverage

A **covergroup** can specify cross coverage between two or more coverage points or variables. Cross coverage is specified using the **cross** construct (see Syntax 66). When a variable \( V \) is part of a cross coverage, the PSS processing tool shall implicitly create a coverage point for the variable, as if it had been created by the statement `coverpoint V;`. Thus, a **cross** involves only coverage points. Expressions cannot be used directly in a **cross**; a coverage point must be explicitly defined first.

### 18.4.1 Syntax

Syntax 66 declares a **cross**.

```plaintext
covergroup_cross ::= covercross_identifier : cross
coverpoint_identifier { , coverpoint_identifier }
[iff ( expression )] cross_item_or_null
cross_item_or_null ::= 
{ { covergroup_cross_body_item } } |
; 
covergroup_cross_body_item ::= 
covergroup_option |
covergroup_cross_binspec
covergroup_cross_binspec ::= 
bins_keyword identifier = covercross_identifier with ( covergroup_expression ) ; 
covergroup_expression ::= expression
```

*Syntax 66—cross declaration*

The following also apply:

a) The label is required for a **cross**.

b) The expression within the optional **iff** provides a conditional sampling guard for the cross coverage. If the condition evaluates to `false` at any sampling point, the cross coverage is not sampled.

c) Cross coverage of a set of \( N \) coverage points is defined as the coverage of all combinations of all bins associated with the \( N \) coverage points, i.e., the Cartesian product of the \( N \) sets of coverage point bins. See also Example 180.

### 18.4.2 Examples

The covergroup **cov** in Example 180 specifies the cross coverage of two 4-bit variables, \( a \) and \( b \). The PSS processing tool implicitly creates a coverage point for each variable. Each coverage point has 16 bins, specifically `auto[0]..auto[15]`. The cross of \( a \) and \( b \) (labeled \( a\times b \)), therefore, has 256 cross products and each cross product is a bin of \( a\times b \).
18.4.3 Defining cross bins

In addition to specifying the coverage points that are crossed, PSS allows the definition of cross coverage bins. Cross coverage bins are specified to group together a set of cross products. A cross coverage bin associates a name and a count with a set of cross products. The count of the bin is incremented any time any of the cross products match; i.e., every coverage point in the cross matches its corresponding bin in the cross product.

User-defined bins for cross coverage are defined using bins with expressions. The names of the coverpoints used as elements of the cross coverage are used in the with expressions. User-defined cross bins and automatically generated bins can coexist in the same cross. Automatically generated bins are retained for those cross products that do not intersect cross products specified by any user-defined cross bin.

Consider Example 181, where two coverpoints are declared for fields a and b. A cross coverage is specified between these two coverpoints. The small_a_b bin collects those bins where both \( a \leq 10 \) and \( b \leq 10 \).

```vhdl
struct s {
    rand bit[4] a, b;

    covergroup {
        aXb : cross a, b;
    } cov;
}
```

Consider Example 181—Specifying cross bins

18.5 Specifying coverage options

Options control the behavior of the covergroup, coverpoint, and cross elements. Options can be specified when creating an instance of a reusable covergroup, and are specific to that covergroup instance.

Specifying a value for the same option more than once within the same covergroup definition shall be an error. Specifying a value for the option more than once when creating a covergroup instance shall be an error.
Table 21 lists the instance-specific `covergroup` options and their description. Each instance of a reusable `covergroup` type can initialize an instance-specific option to a different value.

<table>
<thead>
<tr>
<th>Option name</th>
<th>Default</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>weight=number</code></td>
<td>1</td>
<td>If set at the <code>covergroup</code> syntactic level, it specifies the weight of this <code>covergroup</code> instance relative to all other instances when computing overall instance coverage. If set at the <code>coverpoint</code> (or <code>cross</code>) syntactic level, it specifies the weight of a <code>coverpoint</code> (or <code>cross</code>) for computing the instance coverage of the enclosing <code>covergroup</code>. The specified weight shall be a non-negative integral value.</td>
</tr>
<tr>
<td><code>goal=number</code></td>
<td>100</td>
<td>Specifies the target goal for a <code>covergroup</code> instance or for a <code>coverpoint</code> or <code>cross</code>. The specified value shall be a non-negative integral value.</td>
</tr>
<tr>
<td><code>name=string</code></td>
<td>unique name</td>
<td>Specifies a name for the <code>covergroup</code> instance. If unspecified, a unique name for each instance shall be automatically generated by the tool.</td>
</tr>
<tr>
<td><code>comment=string</code></td>
<td>&quot;&quot;</td>
<td>A comment that appears with the <code>covergroup</code> instance or with a <code>coverpoint</code> or <code>cross</code> of a <code>covergroup</code> instance. The comment is saved in the coverage database and included in the coverage report.</td>
</tr>
<tr>
<td><code>at_least=number</code></td>
<td>1</td>
<td>Minimum number of hits for each bin. A bin with a hit count that is less than <code>number</code> is not considered covered. The specified value shall be a positive integral value.</td>
</tr>
<tr>
<td><code>detect_overlap=bool</code></td>
<td>false</td>
<td>When <code>true</code>, a warning is issued if there is an overlap between the range list of two bins of a <code>coverpoint</code>.</td>
</tr>
<tr>
<td><code>auto_bin_max=number</code></td>
<td>64</td>
<td>Maximum number of automatically created bins when no bins are explicitly defined for a <code>coverpoint</code>. The specified value shall be a positive integral value.</td>
</tr>
<tr>
<td><code>per_instance=bool</code></td>
<td>false</td>
<td>Each instance contributes to the overall coverage information for the <code>covergroup</code> type. When <code>true</code>, coverage information for this <code>covergroup</code> instance shall be saved in the coverage database and included in the coverage report. When <code>false</code>, implementations are not required to save instance-specific information.</td>
</tr>
</tbody>
</table>

Instance options can be specified at the `covergroup` level. Except for the `weight`, `goal`, `comment`, and `per_instance` options (see Table 21), all other options set at the covergroup syntactic level act as a default value for the corresponding option of all `coverpoints` and `crosses` in the `covergroup`. Individual `coverpoints` and `crosses` can overwrite these defaults. When set at the `covergroup` level, the `weight`, `goal`, `comment`, and `per_instance` options do not act as default values to the lower syntactic levels.
18.5.1 Examples

The instance-specific options mentioned in Table 21 can be set in the covergroup definition. Example 182 shows this, and how coverage options can be set on a specific coverpoint.

```verbatim
covergroup cs1 (bit[64] a_var, bit[64] b_var) {
  option.per_instance = true;
  option.comment = "This is CS1";
  a : coverpoint a_var {
    option.auto_bin_max = 128;
  }
  b : coverpoint b_var {
    option.weight = 10;
  }
}
```

Example 182—Setting options

18.6 covergroup sampling

Coverage credit can be taken once execution of the action containing covergroup instance(s) is complete. Thus, by default, all covergroup instances that are created as a result of a given action’s traversal are sampled when that action’s execution completes. Table 22 summarizes when covergroups are sampled, based on the context in which they are instantiated.

<table>
<thead>
<tr>
<th>Instantiation context</th>
<th>Sampling point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow objects</td>
<td>Sampled when the outputting action completes traversal.</td>
</tr>
<tr>
<td>Resource objects</td>
<td>Sampled before the first action referencing them begins traversal.</td>
</tr>
<tr>
<td>Action</td>
<td>Sampled when the instantiating action completes traversal.</td>
</tr>
<tr>
<td>Data structures</td>
<td>Sampled along with the context in which the data structure is instantiated, e.g., if a data structure is instantiated in an action, the covergroup instantiated in the data structure is sampled when the action completes traversal.</td>
</tr>
</tbody>
</table>

18.7 Per-type and per-instance coverage collection

By default, covergroups collect coverage on a per-type basis. This means that all coverage values sampled by instances of a given covergroup type, where per_instance is false, are merged into a single collection.

Per-instance coverage is collected when per_instance is true for a given covergroup instance and when a contiguous path of named handles exists from the root component or root action to where new instances of the containing type are created. If one of these conditions is not satisfied, per-type coverage is collected for the covergroup instance.
18.7.1 Per-instance coverage of flow and resource objects

Per-instance coverage of flow objects (buffer (see 13.1), stream (see 13.2), state (see 13.3)) and resource objects (see 14.1)) is collected for each pool of that type.

In Example 183, there is one pool (pss_top.b1_p) of buffer type b1. When the PSS model runs, coverage from all 10 executions of P_a and C_a is placed in the same coverage collection that is associated with the pool through which P_a and C_a exchange the buffer object b1.

```
enum mode_e { M0, M1, M2 }
buffer b1 {
    rand mode_e mode;
    covergroup {
        option.per_instance = true;
        coverpoint mode;
    } cs;
}
component pss_top {
    pool b1 b1_p;
    bind b1_p *;
    action P_a {
        output b1 b1_out;
    } 
    action C_a {
        input b1 b1_in;
    }
    action entry {
        activity {
            repeat (10) {
                do C_a;
            }
        }
    }
}
```

Example 183—Per-instance coverage of flow objects

18.7.2 Per-instance coverage in actions

Per-instance coverage for actions is enabled when per_instance is true for a covergroup instance and when a contiguous path of named handles exists from the root action to the location where the covergroup is instantiated.

In Example 184, a contiguous path of named handles exists from the root action to the covergroup instance inside al(entry.al.cg). Coverage data collected during traversals of action A are placed in a coverage collection unique to this named path. Plus, four samples are placed in the coverage collection associated with the instance path entry.al.cg because the named action handle al is traversed four times.
Also in Example 184, a contiguous path of named handles does not exist from the root action to the covergroup instance inside the action traversal by type (do A). In this case, coverage data collected during the 10 traversals of action A by type (do A) are placed in the per-type coverage collection associated with covergroup type A::cg.

```
enum mode_e { M0, M1, M2 }

component pss_top {

    action A {
        rand mode_e mode;

        covergroup {
            option.per_instance = true;

            coverpoint mode;
        } cg;
    }

    action entry {
        A a1;
        activity {
            repeat (4) {
                a1;
            }
            repeat (10) {
                do A;
            }
        }
    }
}
```

Example 184—Per-instance coverage in actions
19. Type inheritance, extension, and overrides

PSS supports the concepts of object-oriented inheritance and type extension to maximize reuse and portability of the model. Type inheritance allows the declaration of model entities such as actions, objects, components and struct types to be derived from a base type (or supertype), where the new derived type (or subtype) includes all attributes and other members of the base type, and allows the declaration of the derived type to add new members or mask the definition of existing members. Type extension allows the declaration of additional fields in an existing type using a separate declaration. Type inheritance is described in 19.1, and type extension is described in 19.2. Type overrides allow type-specific and instance-specific replacement of the declared type of a field with a specified subtype, and are described in 19.5.

19.1 Type inheritance

For actions, components, structs, data flow and resource objects, the declaration may include an optional super-spec qualifier to declare a base type of the same type category (action, component, struct, buffer, stream, state, resource), from which the element is to be derived. The only exception is that data flow and resource objects may inherit from an element of the same type category or from a struct.

A derived type includes all elements from the base type, and may declare new elements that may or may not have the same name as a corresponding element in the base type. For fields declared in a derived type with the same name as a field in the base type, the derived type’s field shadows (masks) the base type’s field, and the base type’s field may be referenced as “super.<name>”. Certain unnamed elements, such as activities and procedural exec blocks, may invoke the corresponding element(s) from the base type by the “super;” statement.

The behavior of specific elements when declared in a derived type is shown in Table 23.
Activities in derived actions shadow the activities from the base action type. However, the “super;” statement may be used to traverse the base activity (or activities). See Example 92 in 12.6.

Procedural exec blocks defined in a derived type shadow same-kind exec block(s) defined in the base type. The exec block in the derived type may include the “super;” statement, which will execute the contents of the corresponding base-type exec block(s) at that point. See 21.1.4.1 and 21.1.4.2.

Target-template exec blocks defined in a derived type shadow same-kind exec blocks with the same target language identifier in the base type. The “super;” statement shall not be allowed in a target-template exec block.

Example 185 shows a simple case of declaring a component base_c, which contains an action declaration, base_a. Derived component der_c inherits from base_c, so it is treated as having action base_a already declared within it. Note that base_c and der_c are different component types. Action der_a inherits from base_a, so it already includes random integer i and bit-vector b, as well as the unnamed constraint limiting i to be less than 10 and constraint c forcing b > 7. Derived action der_a adds an additional random integer, j, a new unnamed constraint that relates the values of i and j, and a new constraint c that relates the values of b and j, shadowing constraint c from action base_a.

---

### Table 23—Derived type element behaviors

<table>
<thead>
<tr>
<th>Element kind</th>
<th>In a component</th>
<th>In an action</th>
<th>In a struct, data flow or resource object</th>
</tr>
</thead>
<tbody>
<tr>
<td>activity</td>
<td>n/a</td>
<td>shadow, may call super;</td>
<td>n/a</td>
</tr>
<tr>
<td>dynamic constraint</td>
<td>n/a</td>
<td>shadow (may access base constraint as super.name)</td>
<td>shadow (may access base constraint as super.name)</td>
</tr>
<tr>
<td>named static constraint</td>
<td>n/a</td>
<td>shadow</td>
<td>shadow</td>
</tr>
<tr>
<td>unnamed static constraint</td>
<td>n/a</td>
<td>added</td>
<td>added</td>
</tr>
<tr>
<td>field</td>
<td>shadow (may access base field as super.name)</td>
<td>shadow (may access base field as super.name)</td>
<td>shadow (may access base field as super.name)</td>
</tr>
<tr>
<td>instance function</td>
<td>shadow (may call base function as super.name(args))</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>static function</td>
<td>shadow</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>override declaration</td>
<td>added</td>
<td>added</td>
<td>n/a</td>
</tr>
<tr>
<td>object pool bind</td>
<td>added</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>procedural exec block</td>
<td>shadow, may call super;</td>
<td>shadow, may call super;</td>
<td>shadow, may call super;</td>
</tr>
<tr>
<td>target-template exec block</td>
<td>n/a</td>
<td>shadow</td>
<td>shadow</td>
</tr>
</tbody>
</table>

*If field is not a pool instance. Accessing the pool instance of a supertype component to do a bind in the subtype is not allowed.*
When a pool `bind` statement (see 15.3) is used in a base component type, it may also apply to a derived type, provided that any new component instances and actions in the derived type also match the path specification in the `bind` statement and that the types of the object references match the pool type exactly.

In Example 186, the default `bind` statement in `base_c` binds the `cpu_p` pool to the actions `act1_a` and `act2_a` defined therein. Since `der_c` is derived from `base_c`, it also inherits the `bind` statement, which applies to all action definitions in `der_c` that match the path specification. In the context of `der_c`, the default bind statement binds all three actions `act1_a`, `act2_a` and `act3_a` to the `cpu_p` pool.

As mentioned above, a derived type inherits all members from the base type and may declare additional elements specific to the derived type. When a named element (other than a function) is declared in the
derived type with the same name as an element in the base type, the derived type’s declaration shadows (masks) the base type’s declaration (as with constraint c in Example 185).

When the shadowed element is a function, the function call is polymorphic, that is, the actual function called depends on its context component. In Example 187, component der_c shadows the definition of function foo() in component base_c. Action call_foo invokes the appropriate definition of foo() depending on the type of its context component. Action test schedules call_foo in the context of a component of type base_c, followed by call_foo in the context of der_c. Executing test will call the core library target function message() to add the following messages to the execution log, at LOW verbosity:

```plaintext
base_c::foo
der_c::foo
```

```
import std_pkg::*;

component base_c {
    target function void foo() {
        message(LOW, "base_c::foo");
    }

    action call_foo {
        exec body {
            comp.foo();
        }
    }
}

component der_c : base_c {
    function void foo() {
        message(LOW, "der_c::foo");
    }
};

component pss_top {
    base_c b;
    der_c d;
    action test {
        base_c::call_foo b_foo, d_foo;
        constraint {b_foo.comp == this.comp.b;
                     d_foo.comp == this.comp.d;}

        activity {
            b_foo;
            d_foo;
        }
    }
}
```

Example 187—Polymorphic function calls

As discussed in 9.3, the qualified name of an action declared in a component is of the form 'component-type::action-type'. In Example 188, the base component dma_base_c declares action xfer_a. The derived component dma_der_c declares the compound action mult_xfer_a, which traverses the xfer_a action. Since dma_der_c inherits the xfer_a action, the anonymous (by type) traversal in mult_xfer_a correctly resolves to the xfer_a action declared in the base component. It is thus not necessary to further qualify the type name xfer_a in the anonymous traversal in mult_xfer_a.
The component \texttt{dma_test_c} instantiates the derived component \texttt{dma_der_c}. The first traversal statement in the activity is an anonymous traversal of the \texttt{dma_der_c::mult_xfer_a} action. The next statement anonymously traverses the \texttt{dma_base_c::xfer_a} action. We can use the \texttt{dma_base_c} path qualifier because the instantiated subcomponent of type \texttt{dma_der_c} \textit{is also} considered a \texttt{dma_base_c} component. It would be illegal to refer to \texttt{dma_base_c::mult_xfer_a} because \texttt{mult_xfer_a} is not declared in \texttt{dma_base_c}. To promote reuse, the third anonymous traversal statement is preferred, referring to \texttt{dma_der_c::xfer_a}, since \texttt{xfer_a} can be used without knowing whether it was declared in the base component or the derived component. Note that, since there is only a single instance of the \texttt{dma_der_c} component, the instance context of these traversals is the same.

\begin{verbatim}
component dma_base_c {
    action xfer_a {
        ...
    }
}

component dma_der_c : dma_base_c {
    action mult_xfer_a {
        activity {
            repeat(3) {
                do xfer_a; // dma_base_c::xfer_a
            }
        }
    }
}

component dma_test_c {
    dma_der_c dma;

    action test_a {
        activity {
            do dma_der_c::mult_xfer_a;
            do dma_base_c::xfer_a;
            do dma_der_c::xfer_a; // dma_base_c::xfer_a
        }
    }
}
\end{verbatim}

\textbf{Example 188—Derived type is also a base type}

In \textbf{Example 189}, there are two instances of the \texttt{dma_der_c} component instantiated in \texttt{dma_test_c}. For the first anonymous traversal of \texttt{dma_base_c::xfer_a}, either instance may be chosen as context for the \texttt{xfer_a} action. In the second anonymous traversal, the \texttt{comp} attribute is constrained to specify that the context component must be \texttt{dma_test_c.dma1}. As stated in \textbf{9.5}, the static type of the \texttt{comp} attribute of \texttt{dma_der_c::xfer_a} is actually \texttt{dma_base_c}, since that is its containing component type (See also \textbf{16.1.3}).

Because \texttt{comp} is of type \texttt{dma_base_c} and not \texttt{dma_der_c}, it would be illegal to refer to fields of \texttt{dma_der_c} as relative to \texttt{comp}, since these fields are not in \texttt{dma_base_c}. Rather, fields of \texttt{dma_der_c} may be referred to relative to \texttt{this.comp.dma1}, which is the actual instance of \texttt{dma_der_c} (which is also a \texttt{dma_base_c}) in which \texttt{xfer_a} will execute. Thus, based on the actual instance of a context component, we can constrain the fields of \texttt{xfer_a} even though \texttt{xfer_a} may not have visibility otherwise to the \texttt{dma_der_c} fields that control the constraints.
When declaring a new component, it shall be illegal to declare types that derive from types declared in an existing component type unless the new component derives from the existing component.

Example 190 demonstrates why this kind of inheritance is problematic. Action new_a, derived from existing_c::existing_a, inherits constraint con that constrains k based on the value of attribute i of component existing_c. The comp field of action new_a is of type new_c and not existing_c, and therefore does not have attribute i. For that reason, the action new_a is not able to evaluate constraint con. Thus, modeling with this kind of inheritance cannot work.
19.2 Type extension

Type extensions in PSS enable the decomposition of model code so as to maximize reuse and portability. Model entities, actions, objects, components, and data types, may have a number of properties that are logically independent. Moreover, distinct concerns with respect to the same entities often need to be developed independently. Later, the relevant definitions need to be integrated, or woven into one model, for the purpose of generating tests.

Some typical examples of concerns that cut across multiple model entities are:

- Implementation of actions and objects for, or in the context of, some specific target platform/language.
- Model configuration of generic definitions for a specific device under test (DUT) / environment configuration, affecting components and data types that are declared and instantiated elsewhere.
- Definition of functional elements of a system that introduce new properties to common objects, which define their inputs and outputs.

Such crosscutting concerns can be decoupled from one another by using type extensions and then encapsulated as packages (see 20.1).

Composite and enumeration types in PSS are extensible. They are declared once, along with their initial definition, and may later be extended any number of times, with new body items being introduced into their scope. Items introduced in extensions may be of the same kinds as those introduced in the initial definition. Extension statements may appear in package and component definitions.

An extension statement explicitly specifies the kind of type being extended, which must agree with the specific type named (see Syntax 67).
The overall definition of any given type in a model is the sum total of its definition statements—the initial one along with extensions in active packages (see 20.1). The semantics of extensions are those of weaving all those statements into a single definition.

Every type extension, regardless of whether it extends a package-level type or a component-level inner type, is associated with the nearest package that lexically encloses its definition (an explicit package if enclosed in a package_declaration statement or otherwise the unnamed global package (see 20.1)).

Members introduced in an extension of a type can be referenced throughout the package in which they were introduced. As a corollary, members introduced in extensions associated with the global package can be referenced everywhere. Members introduced in extensions cannot be referenced outside the scope of the package in which the extension is defined unless the reference occurs in a lexical scope that wildcard-imports that package.

These rules concern reference of static members as well as non-static members, and apply regardless of whether fully-qualified static paths are used (for static members).

19.2.1 Syntax

```
extend_stmt ::=  
  extend action type_identifier { { action_body_item } }  
| extend component type_identifier { { component_body_item } }  
| extend struct_kind type_identifier { { struct_body_item } }  
| extend enum type_identifier { [ enum_item { , enum_item } ] }
```

Syntax 67—type extension

19.2.2 Examples

Examples of type extension are shown in Example 191.

```
enum config_modes_e {UNKNOWN, MODE_A=10, MODE_B=20};

component uart_c {
  action configure {
    rand config_modes_e mode;
    constraint {mode != UNKNOWN;}
  }
}

package additional_config_pkg {
  extend enum config_modes_e {MODE_C=30, MODE_D=50}

  extend action uart_c::configure {
    constraint {mode != MODE_D;}
  }
}
```

Example 191—Type extension
19.2.3 Composite type extensions

Any kind of member declared in the context of the initial definition of a composite type can be declared in the context of an extension, as per its entity category (action, component, buffer, stream, state, resource, struct, or enum).

Named type members of any kind, fields in particular, may be introduced in the context of a type extension. Names of fields introduced in an extension shall not conflict with those declared in the initial definition of the type. They shall also be unique in the scope of their type within the package in which they are declared. However, field names do not have to be unique across extensions of the same type in different packages.

Fields are always accessible within the scope of the package in which they are declared, shadowing (masking) fields with the same name declared in other packages. Members declared in a different package are accessible if the declaring package is wildcard-imported into the scope of the accessing package or component, given that the reference is unique. If the same field name or type name is wildcard-imported from two or more separate packages, it shall be an error to reference it.

In Example 192, an action type is initially defined in the context of a component and later extended in a separate package. Ultimately the action type is used in a compound action of a parent component. The component explicitly wildcard-imports the package with the extension and can therefore constrain the attribute introduced in the extension.
19.2.4 Enumeration type extensions

Enumeration types can be extended in one or more package contexts, introducing new enum items to the domain of all variables of that type. Each enum item in an `enum` type shall be associated with an integer value that is unique across the initial definition and all the extensions of the type. Enum item values are assigned according to the same rules they would be if all the enum items appeared in the initial definition, according to the order of package evaluations. An explicit conflicting value assignment shall be illegal.

```verilog
component mem_ops_c {
    enum mem_block_tag_e {SYS_MEM, A_MEM, B_MEM, DDR};

    buffer mem_buff_s {
        rand mem_block_tag_e mem_block;
    }

    pool mem_buff_s mem;
    bind mem *;

    action memcpy {
        input mem_buff_s src_buff;
        output mem_buff_s dst_buff;
    }
}

package soc_config_pkg {
    extend action mem_ops_c::memcpy {
        rand int in [1, 2, 4, 8] ta_width; // introducing new attribute
        constraint { // layering additional constraint
            src_buff.mem_block in [SYS_MEM, A_MEM, DDR];
            dst_buff.mem_block in [SYS_MEM, A_MEM, DDR];
            ta_width < 4 -> dst_buff.mem_block != A_MEM;
        }
    }
}

component pss_top {
    import soc_config_pkg::*; // explicitly importing the package grants
    // access to types and type members
    mem_ops_c mem_ops;

    action test {
        mem_ops_c::memcpy cpy1, cpy2;
        constraint cpy1.ta_width == cpy2.ta_width; // constraining an
        // attribute introduced in an extension
        activity {
            repeat (3) {
                parallel { cpy1; cpy2; }
            }
        }
    }
}
```

Example 192—Action type extension
An enum item introduced in an extension can be referenced within the `package` in which the extension is defined. Outside that `package`, enum items can be referenced inside a lexical scope that wildcard-imports the respective package.

In **Example 193**, an `enum` type is initially declared empty and later extended in two independent `packages`. Ultimately items are referenced from a `component` that wildcard-imports both `packages`.

```plaintext
package mem_defs_pkg { // reusable definitions
    enum mem_block_tag_e {}; // initially empty
    buffer mem_buff_s {
        rand mem_block_tag_e mem_block;
    }
} // reusable definitions
package AB_subsystem_pkg {
    import mem_defs_pkg::*;
    extend enum mem_block_tag_e {A_MEM, B_MEM};
} // reusable definitions
package soc_config_pkg {
    import mem_defs_pkg::*;
    extend enum mem_block_tag_e {SYS_MEM, DDR};
} // reusable definitions
component dma_c {
    import mem_defs_pkg::*;
    action mem2mem_xfer {
        input mem_buff_s src_buff;
        output mem_buff_s dst_buff;
    }
} // reusable definitions
extend component dma_c {
    import AB_subsystem_pkg::*; // wildcard-importing the package
    import soc_config_pkg::*;   // grants access to enum items
    action dma_test {
        activity {
            do mem2mem_xfer with {
                src_buff.mem_block == A_MEM;
                dst_buff.mem_block == DDR;
            };
        }
    }
} // reusable definitions
```

**Example 193—Enum type extensions**

### 19.2.5 Ordering of type extensions

Multiple type extensions of the same type can be coded independently, and be integrated and woven into a single stimulus model, without interfering with or affecting the operation of one another. Methodology should encourage making no assumptions on their relative order.
From a semantics point of view, order would be visible in the following cases:

- Invocation order of `exec blocks` of the same kind
- Multiple `default` value constraints, `default disable` constraints, and type override declarations occurring in a scope of the same type
- Integer values associated with enum items that do not explicitly have a value assignment

The initial definition always comes first in ordering of members. The order of extensions conforms to the order in which packages are processed by a PSS implementation.

NOTE—This standard does not define specific ways in which a user can control the package processing order.

### 19.2.6 Template type extensions

Template types, as all other user-defined types, may be extended using the `extend` statement.

Template types may be extended in two ways:

a) Extending the generic template type. The extension will apply to all instances of the template type.

b) Extending the template type instance. The extension will apply to all instances of the template type that are instantiated with the same set of parameter values.

NOTE—Partial template specialization is not supported.

#### 19.2.6.1 Examples

Examples of extending the generic template type and the template type instance are shown in Example 194.
In the example above, the generic template type extension is used to add attr_all to all instances of domain_s. The template type instance extension is used to add attr_2_7 to the specific \(<2,7>\) instance of domain_s.

19.3 Combining inheritance and extension

It is important to understand that inheritance creates a new type derived from the base type, while extension modifies the definition of an existing type. Once a derived type is created by inheriting from a base type, the derived type may be extended just as any other type. In this case, the extensions to the derived type do not affect the base type. However, since a derived type inherits from its base type, any extensions to the base type will also affect the derived type. If multiple types are derived from the same base type, extensions to the base type will affect all derivations thereof.

Extending types in a component scope is only allowed for types that are defined in that scope. It shall be illegal to extend a type defined in a base component type from a derived or unrelated component type.
In Example 195, by extending action `der_a` in component `der_c`, we add a new constraint on the `j` field. This constraint is added to the existing constraints in the initial definition of `der_a`. By extending action `base_a` in the `base_c` extension, we add a new constraint, `i > 2`, which is then inherited by the derived action, `der_a`. The result is that `j` is constrained to be greater than 7, implying that `i` must be less than 5, and the additional constraint requires that `i` must also be greater than 2.

The attempt to extend action `base_a` in component `der_c` is illegal, since `base_a` was originally declared in `base_c`, which is a different type from `der_c`.

```plaintext
component base_c {
  action base_a {
    rand int i;
    rand bit[31:0] b;
    constraint { i < 10; }
    constraint c { b > 7; }
  }
}

component der_c : base_c {
  action der_a : base_a {
    rand int j;
    constraint { j > 5 -> i < 5; }
    constraint c { j < 10 -> b < 128; }
  }

  extend action der_a {
    constraint { j > 7; }
  }

  extend action base_a {...} // ILLEGAL
}

extend component base_c {
  extend action base_a {
    constraint { i > 2; }
  }
}
```

Example 195—Combining inheritance and extension

In Example 196, in the `pss_top` root action, the anonymous traversal of `der_c::base_a` will use the `base_a` action as extended in `base_c` in the global scope. Thus, the constraints `i > 2` and `i < 10` will apply. Its execution context will be either instance `c1` or `c2` of `der_c`.

The anonymous traversal of `der_c::der_a` similarly will use the extended definition of `der_a`, but the `with` constraint forces the execution context to be instance `c1`. Note that the constraint `c` in `der_c::der_a` masks the original constraint `c` in `base_c::base_a`, so the resolved set of applicable constraints will be:
- `j > 7`
- `i < 5` (due to constraint `j > 5 -> i < 5`)
- `j < 10 -> b < 128`
19.4 Access protection

By default, all data attributes of components, actions, and structs have public accessibility. The default accessibility can be modified for a single data attribute by prefixing the attribute declaration with the desired accessibility. The default accessibility can be modified for all attributes going forward by specifying a block-access modifier.

The following also apply:

a) A public attribute is accessible from any element in the model.
b) A private attribute is accessible only from the element in which the attribute is declared.
c) A protected attribute is accessible only from the element in which the attribute is declared, from sub-elements that inherit from it, and from their extensions.
Example 197 shows using a per-attribute access modifier to change the accessibility of the random attribute \( b \). Fields \( a \) and \( c \) are publicly accessible.

```
struct S1 {
    rand int a;         // public accessibility (default)
    private rand int b; // private accessibility
    rand int c;         // public accessibility (default)
}
```

**Example 197—Per-attribute access modifier**

Example 198 shows using block access modifiers to set the accessibility of a group of attributes. Fields \( w \) and \( x \) are private due to the `private:` directive. Field \( y \) is public because its access modifier is explicitly specified. Field \( z \) is private, since the `private:` block access modifier is in effect. Field \( s \) is public, since the preceding `public:` directive has changed the default accessibility back to public.

```
struct S2 {
    private:
        rand int w;         // private accessibility
        rand int x;         // private accessibility
        public rand int y;  // public accessibility
        rand int z;         // private accessibility
    public:
        rand int s;         // public accessibility
}
```

**Example 198—Block access modifier**

19.5 Overriding types

The `override` block (see Syntax 68) allows type- and instance-specific replacement of the declared type of a field with some specified subtype.

Overrides apply to action fields, struct attribute fields, and component instance fields. In the presence of `override` blocks in the model, the actual type that is instantiated under a field is determined according to the following rules:

- a) Walking from the field up the hierarchy from the contained entity to the containing entity, the applicable `override` directive is the one highest up in the containment tree.
- b) Within the same container, `instance` override takes precedence over `type` override.
- c) For the same container and kind, an override introduced later in the code takes precedence.

Overrides do not apply to reference fields, namely fields with the modifiers `input`, `output`, `lock`, and `share`. Component-type overrides under actions as well as action-type overrides under components are not applicable to any fields; this shall be an error.
19.5.1 Syntax

\[
\text{override_declaration ::= } \text{override } \{ \text{ override_stmt } \} \\
\text{override_stmt ::= } \\
\quad \text{type_overide} \\
\quad \mid \text{instance_overide} \\
\quad \mid \text{override_compile_if} \\
\quad \mid \text{stmt_terminator} \\
\text{type_overide ::= } \text{type type_identifier with type_identifier ;} \\
\text{instance_overide ::= } \text{instance hierarchical_id with type_identifier ;}
\]

Syntax 68—override declaration

19.5.2 Examples

Example 199 combines type- and instance-specific overrides with type inheritance. Action \text{reg2axi}\_\text{top} specifies that all \text{axi_write}\_\text{action} instances shall be instances of \text{axi_write}\_\text{action}\_\text{x}. The specific instance \text{xlator.axi}\_\text{action} shall be an instance of \text{axi_write}\_\text{action}\_\text{x2}. Action \text{reg2axi}\_\text{top}\_\text{x} specifies that all instances of \text{axi_write}\_\text{action} shall be instances of \text{axi_write}\_\text{action}\_\text{x4}, which supersedes the override in \text{reg2axi}\_\text{top}. In addition, action \text{reg2axi}\_\text{top}\_\text{x} specifies that the specific instance \text{xlator.axi}\_\text{action} shall be an instance of \text{axi_write}\_\text{action}\_\text{x3}. 
action axi_write_action { ... };

action xlator_action {
    axi_write_action axi_action;
    axi_write_action other_axi_action;
    activity {
        axi_action; // overridden by instance
        other_axi_action; // overridden by type
    }
}

action axi_write_action_x : axi_write_action { ... };

action axi_write_action_x2 : axi_write_action_x { ... };

action axi_write_action_x3 : axi_write_action_x { ... };

action axi_write_action_x4 : axi_write_action_x { ... };

action reg2axi_top {
    override {
        type axi_write_action with axi_write_action_x;
        instance xlator.axi_action with axi_write_action_x2;
    }

    xlator_action xlator;
    activity {
        repeat (10) {
            xlator; // override applies equally to all 10 traversals
        }
    }
}

action reg2axi_top_x : reg2axi_top {
    override {
        type axi_write_action with axi_write_action_x4;
        instance xlator.axi_action with axi_write_action_x3;
    }
}

Example 199—Type inheritance and overrides
20. Source organization and processing

A PSS model is captured in one or more source units. Source units contain declarations of PSS elements. Name resolution rules for types are specified with respect to source units. The bounds of a source unit are specified either by a single file or by a collection of files identified to the PSS processing tool as being part of a single source unit. The files comprising a multi-file source unit could be identified to the PSS processing tool in several different ways. For example, the PSS processing tool could be instructed to consider all PSS source files in a given directory to be a single source unit. The PSS processing tool could be instructed to consider all PSS source files listed in a filelist to be a single source unit. Tool implementations shall support both single-file and multi-file source unit processing modes, but this standard does not dictate the mechanism by which source units shall be specified to the PSS processing tool.

A lexical scope must be fully contained within a single source file, independent of whether source files are processed as single- or multi-file source units.

The processing order of a set of source units is user-specified to the PSS processing tool. This standard does not dictate a specific processing order for files within a multi-file source unit, but tools may provide users with means to control it.

20.1 Packages

Packages are a way to group, encapsulate, and identify sets of related definitions, namely type declarations and type extensions. In a verification project, some definitions may be required for the purpose of generating certain tests, while others need to be used for different tests. Moreover, extensions to the same types may be inconsistent with one another, e.g., by introducing contradicting constraints or specifying different mappings to the target platform. By enclosing these definitions in packages, they may coexist and be managed more easily.

Packages also constitute namespaces for the types, functions, and constants declared in their scope. From a namespace point of view, packages and components have the same meaning and use (see also 9.3). However, in contrast to components, packages cannot be instantiated, and cannot contain attributes, sub-component instances, or concrete action definitions.

Type declarations, functions, and constants declared under the scope of a package declaration statement are members of that package. Package members may be referenced from outside the package using a qualified reference or made visible by importing them into the referencing scope (see 20.1.3).

Definition statements that do not occur inside the lexical scope of a package declaration are implicitly associated with the unnamed global package. Elements in the unnamed global package are visible to all user-defined namespaces without the need for an import statement.

Tools may provide means to control and query which packages are active in the generation of a given test. Tools may also provide ways to locate source files of a given package in the file system. However, these means are not covered herein.
20.1.1 Package declarations

20.1.1.1 Syntax

The following also apply:

a) Multiple package statements can apply to the same package name. The package contains the members and type extensions declared in all package scopes with the same name.

b) In a const_field_declaration, the static keyword is optional, but the field is a static constant even if the static keyword is not used.

20.1.1.2 Examples

For an example of package usage, see 21.2.6.

20.1.2 Nested packages

A package may be nested inside another package. There are two way to declare a nested package.
One way is to include a package declaration inside the outer package declaration, as shown in the following example:

```
package my_lib {
    package impl {
        struct internal_impl_s {}
    }
}
```

**Example 200—Hierarchical declaration of nested package**

In the example above, the fully-qualified type name of the `struct internal_impl_s` is `my_lib::impl::internal_impl_s`.

Nested packages can also be specified with double-colon-separated package identifier paths. In the example below, the fully-qualified type name of the `struct internal_impl_s` is also `my_lib::impl::internal_impl_s`.

```
package my_lib::impl {
    struct internal_impl_s {}
}
```

**Example 201—Direct declaration of nested package**

Declaring a package inside another is equivalent to directly specifying a hierarchical name for a package namespace.

The declaration order of package namespaces is not significant. So, for example, it is not necessary to declare an outer namespace prior to declaring an inner namespace. In the example below, two `structs` are declared. `my_lib::impl::internal_impl_s` is declared first, while `my_lib::public_s` is declared second.

```
package my_lib::impl {
    struct internal_impl_s {}
}
package my_lib {
    struct public_s {}
}
```

**Example 202—Declaration of nested package before outer package**

20.1.3 Referencing package members

There are three ways to reference package members from outside the scope of their declaring package: qualified reference, explicit import, and wildcard import.

One way to use a declaration from a package is to reference it explicitly using the scope resolution operator `::`. This is called a qualified reference. Example:

```
my_lib::public_s my_struct;
```
An alternate method for referencing package declarations is via the `import` statement. Importing an identifier into a `package` or `component` makes that identifier visible within that lexical scope without requiring the scope resolution operator. An `import` statement is a name resolution directive, and does not introduce symbol declarations or symbol aliases into the namespace in which it appears.

Two forms of the `import` statement are provided: `explicit import` and `wildcard import`. An `explicit import` only imports the symbols specifically referenced by the `import`. Example:

```plaintext
import my_lib::public_s;
public_s my_struct;
```

It shall be illegal to explicitly import an identifier from a package if the same name is already declared in the importing namespace or to explicitly import the same identifier from two different packages.

A `wildcard import` allows all identifiers declared within a package to be imported into a lexical scope, provided the identifier is not otherwise defined anywhere in the importing `component` or `package`. A wildcard import also allows access from the lexical scope to members declared in type extensions found in the imported package. Note that type extensions are unnamed and therefore cannot be explicitly imported.

A wildcard import is of the following form:

```plaintext
import my_lib::*;
public_s my_struct;
```

A local declaration of an identifier takes precedence over a wildcard import of the same identifier. An explicit import of an identifier takes precedence over a wildcard import of the same identifier from a different package. If the same name is declared in two wildcard-imported packages, neither is imported, a qualified reference must be used.

`import` specifications may appear in `package` and `component` declaration statements and in `component` extension statements, but shall come first in those statements. The scope of an `import` statement is limited to the declaration statement or extension statement in which it appears.

Elements in the unnamed global package are visible to all user-defined namespaces without the need for an explicit `import` statement. To explicitly refer to a type declared in the unnamed global package, prefix the type name with `::`.

`import` statements are not transitive. If package B imports package A, package B does not have unqualified access to contents declared in packages that A may have imported. Package B must import those packages directly in order to have unqualified access to contents declared within them.

### 20.1.3.1 Syntax

```plaintext
import_stmt ::= import package_import_pattern ;
package_import_pattern ::= type_identifier [ package_import_qualifier ]
package_import_qualifier ::= package_import_wildcard | package_import_alias
package_import_wildcard ::= :: *
package_import_alias ::= as package_identifier
```

Syntax 70—`import statement`

Note: Package aliases are described in 20.1.4.
Importing content from a **package** namespace using a wildcard only imports content from that exact namespace, and does not import content from **nested** namespaces.

Note that using a wildcard import on an outer package namespace, as shown with `p1::*` in the example below, allows inner package namespaces to be located without specifying the fully-qualified name of the namespace. In this example, **struct** `p1::p2::u` can be referenced as `p2::u` because the elements of `p1` are imported with a wildcard import.

```plaintext
package p1 {
  struct s { }
  package p2 {
    struct u { }
  }
}
struct t { }
struct s { }

package top {
  import p1::*;
  struct my_s {
    s   v1; // Resolves to p1::s
    ::s  v2; // Explicit reference to ::s
    t    v3; // Resolves to ::t
    p2::u v4; // Resolves to p1::p2::u
  }
}
```

**Example 203—Importing the name of a nested package**

### 20.1.4 Package aliases

The use of nested namespaces benefits from the ability to define a named **alias** for a given namespace. This is used when it is necessary to disambiguate between content declared in different namespaces and it is undesirable to use the fully-qualified name of the namespace. The syntax for declaring a package alias is shown in **Syntax 70**.

A namespace alias is only visible in the lexical scope (e.g., a package declaration statement) in which it appears. It is a name resolution shortcut, and does not introduce a new entity into the scope in which it is specified.

In the example below, this means that `p1` and `p2` are not visible in the scope of any other declaration statement of `consumer_pkg`. `p1` and `p2` may not be referenced from outside the package (e.g., as `consumer_pkg::p1`). Wildcard-importing `consumer_pkg` into another package namespace does not make symbols `p1` and `p2` visible in that namespace.
Example 204—Package alias

A package alias shall not have the same name as a package name added to the same namespace in previous or current source units. However, it shall be legal to add a package name with the same name as the package alias in subsequent source units. In addition, two package aliases defined in the same lexical scope shall not have the same name.

Example 205—Illegal package alias declarations

20.2 Declaration and reference ordering

Elements may be referenced after their declaration, within the same source unit or in a subsequent source unit. PSS also enables referencing most elements prior to their declaration within the same source unit, but places stronger ordering requirements on some elements. The following apply:

a) A variable declared and referenced within a procedural block or an activity block may only be referenced after its declaration.

b) A constant or enum item may be referenced in the initialization assignment expression of another constant only after its declaration.

c) A constant declared within a type may reference type-level and package-level constants in its initialization assignment expression. A package-level constant may only reference other package-level constants in its initialization assignment expression.
20.2.1 Examples

In the example below, file1.pss (the first source unit) declares a component named lib_base_c. file2.pss (the second source unit) declares a type my_base_c that inherits from lib_base_c, so file1.pss must be processed before file2.pss. However, within file2.pss, the declaration of my_a_c that refers to my_base_c as a supertype may be placed either before or after the declaration of my_base_c.

```c
// Source Unit 1 (file1.pss)
component lib_base_c { /* ... */ }

// Source Unit 2 (file2.pss)
component my_a_c : my_base_c { /* ... */ }
component my_base_c : lib_base_c { /* ... */ }
```

Example 206—Reference to a previous source unit

In the example below, action pss_top::entry declares a field named val that is referenced in the constraint val_c. Field val may be declared before or after the constraint that references it.

```c
component pss_top {
  action entry {
    constraint val_c {
      val < 10;
    }
    rand bit[4] val;
  }
}
```

Example 207—Reference to a later-declared action field

In the example below, a local variable is declared within an exec block. As per requirement a) above, the variable val may only be referenced after it is declared.

```c
function int get_val();
component pss_top {
  exec init_up {
    int val;
    val = get_val();
  }
}
```

Example 208—Reference to local variable after declaration

In the example below, constants are declared and referenced in initialization expressions of other constants. As per requirement b) above, a constant must be declared prior to its reference in an initialization expression of a constant or in a type-width expression. Consequently, it is an error to reference the yet undeclared constant C in the initialization expression for A. It is legal to reference the previously declared constant A in the initialization expression for B.
20.3 Name resolution

For the purpose of the following description, the term namespace refers to either a package or a type (e.g., component, struct) under which static members (types, static constants, static functions, and enum items) may be declared.

The members of a package namespace include the members declared in the union of all the package definition statements of that package (see 20.1.1.1). The visible members of a type namespace include the members declared in the union of the type’s initial definition and all visible extensions of the type (see 19.2).

Members of PSS namespaces shall have unique names in the context of their namespace, but members may have the same name if declared under different namespaces.

Types can be referenced in different contexts, such as declaring a variable, extending a type, or inheriting from a type. In all cases, a qualified name of the type can be used, using the scope operator ::.

Constants, static functions, and enum items can be referenced in expression contexts. In these cases too, a qualified name can be used, using the scope operator.

Informally, unqualified entity names can be used in the following cases:

— when referencing an entity that was declared in the same namespace or in an enclosing namespace.
— when referencing an entity that was declared in a package imported into a logical scope enclosing the reference.

Precedence is given to the current namespace scope; explicit qualification can be used to override the precedence.

Formally, unqualified names are resolved using the following process, starting with step a, continuing with step b, and then step c, in the absence of resolution in previous steps:

a) If the reference occurs within an expression whose expected type is an enumeration type (see 8.4.3 for definition of expected type):
   1) Search enum items declared in the expected type’s initial definition.
   2) Search enum items declared in the expected type’s extensions that are defined under the current package or one of its containing packages (see 19.2), or in the expected type’s extensions that are within a package wildcard-imported into a lexical scope enclosing the reference.

b) If the reference occurs within the definition of a type:
   1) Search members of the type declared in its initial definition.
   2) Search members of the type declared in its extensions that are defined under the current package or one of its containing packages (see 19.2), or in its extensions that are within a package wildcard-imported into a lexical scope enclosing the reference.
   3) If the type inherits from a supertype, search members declared in the supertype using the process described in steps 1 and 2. Repeat for all supertypes in the inheritance hierarchy.

Example 209—Initialization of constants

```plaintext
package my {
    const int A = C /* Error: C is not yet declared */;
    const int B = A + 2;
    const int C = 3;
}
```
4) If the scope is a component initial definition or extension:
   i) Search package members explicitly imported into the lexical scope of the initial definition or extension, respectively.
   ii) Search members of packages wildcard-imported into the lexical scope of the initial definition or extension, respectively.

5) If the type is an inner type (e.g., an `action` declared inside a `component`), search members declared in the outer type using the process described in steps 1 through 4 above.

c) Search package namespaces, starting with the package namespace of the immediate lexical scope and working outward along the package hierarchy. At each level, do the following:

1) Search package members declared under all `package_declarations` of the same package.

2) If the reference is enclosed in a lexical package scope corresponding to the namespace being searched:
   i) If the package member being searched for is itself a package, search for a package alias name defined in the lexical scope of the corresponding `package_declaration` statement.
   ii) Search package members explicitly imported into the lexical scope of the corresponding `package_declaration` statement.
   iii) Search members of packages wildcard-imported into the lexical scope of the corresponding `package_declaration` statement.

A qualified name is composed of double-colon-separated elements. Qualified name elements are resolved by first applying the same process for unqualified names described above on the first element of the static path. Having resolved the first element to a certain `package`/type, the rest of the static path is used to access down from it.

### 20.3.1 Name resolution examples

In Example 210, `s` is declared in three places: imported package `P1`, encapsulating package `P2`, and nested component `C1`. The `s` referenced in nested component `C1` is resolved to the `s` locally defined in nested component `C1`. Using qualifiers, `P1::s` would be used to resolve to `s` in imported package `P1`, and `P2::s` would be used to resolve to `s` in encapsulating package `P2`.

```plaintext
package P1 {
   struct s {};
};

package P2 {
   struct s {};

   component C1 {
      import P1::*;
      struct s {};
      s f;
   }
};

Example 210—Name resolution to declaration in nested namespace
```
In **Example 211**, \( s \) is declared in two places: imported package \( P1 \) and encapsulating package \( P2 \). The \( s \) referenced in nested component \( C1 \) is resolved to the \( s \) defined in imported package \( P1 \). Using qualifiers, \( P2::s \) would be used to resolve to \( s \) in encapsulating package \( P2 \).

```plaintext
package P1 {
    struct s {};
};

package P2 {
    struct s {};

    component C1 {
        import P1::*;
        s f;
    };
};
```

*Example 211—Name resolution to declaration in imported package in nested namespace*

In **Example 212**, \( s \) is declared in two places: imported package \( P1 \) and encapsulating package \( P2 \). The \( s \) referenced in nested component \( C1 \) is resolved to the \( s \) defined in encapsulating package \( P2 \). Using qualifiers, \( P1::s \) would be used to resolve to \( s \) in package \( P1 \) imported in encapsulating package \( P2 \).

```plaintext
package P1 {
    struct s {};
};

package P2 {
    import P1::*;
    struct s {};

    component C1 {
        s f;
    };
};
```

*Example 212—Name resolution to declaration in encapsulating package*

In **Example 213**, \( s \) is declared in one place: imported package \( P1 \). The \( s \) referenced in nested component \( C1 \) is resolved to the \( s \) defined in package \( P1 \) imported inside encapsulating package \( P2 \).

```plaintext
package P1 {
    struct s {};
};

package P2 {
    import P1::*;

    component C1 {
        s f;
    };
}
```

*Example 213—Name resolution to declaration in imported package in encapsulating package*
Example 214 shows a case where importing the encapsulating package has no effect on the resolution rules. 
s will resolve to the same s in P2.

```plaintext
package P1 {
    struct s {};
};

package P2 {
    import P1::*;
    struct s {};

    component C1 {
        import P2::*;
        s f;
    }
};

Example 214—Package import has no effect on name resolution
```

Example 215 shows a case where importing the encapsulating package does have effect on the resolution 
rules. s will resolve to s in P1 due to the wildcard import of P1.

```plaintext
package P1 {
    struct s {};

    package P2 {
        struct s {};
        component C1 {
            import P1::*;
            s f; // P1::s
            P2::s g; // P1::P2::s
        }
    }
}

Example 215—Package import affects name resolution
```

In Example 216 below, a_pkg declares a struct S1, b_pkg imports content from a_pkg, and b_pkg 
declares a struct S2 that inherits from S1.pss_top imports content from b_pkg.

---
- Line (1): S2 is resolved via the import of b_pkg.
- Line (2): Imports are not transitive. Therefore, the import of b_pkg does not make content from 
a_pkg visible in component pss_top.
- Line (3): S1 can be referenced with a fully-qualified type name, a_pkg::S1.
- Line (4): Importing a package does not introduce symbols into the importing namespace.
Example 216—Package import is not a declaration

Example 216 demonstrates the use of qualified and unqualified enum item references. The unqualified references are resolved based on the expected type in context, namely the type of the expression on the other side of the equality operator and on the left-hand side of the `in` operator.

Example 217—Resolution of enum item references

Example 217 demonstrates how name resolution is affected by using package aliases. `P2::s` is resolved to `P3::P4::s` and not to `P1::P2::s`, because the package alias takes precedence over the wildcard import in resolving `P2`. 
package P1 {
    package P2 {
        struct s {}
    }
}

package P3 {
    package P4 {
        struct s {}
    }
}

cOMPONENT pss_top {
    import P1::*;
    import P3::P4 as P2;
    action test {
        P2::s f;
    }
}

Example 218—Resolution in presence of package alias
21. Test realization

A PSS model interacts with foreign languages in order to drive, or bring about, the behaviors that leaf-level actions represent in a test scenario. This is done by calling application programming interfaces (APIs) available in the execution environment, or generating foreign language code that executes as part of the test. In addition, external code, such as reference models and checkers, may be used to help compute stimulus values or expected results during stimulus generation.

The platform on which test generation takes place is generally referred to as the solve platform, while the platform on which test execution takes place is called the target platform.

Logic used to help compute stimulus values is coded using procedural constructs (see 21.7), possibly invoking a foreign procedural interface on the solve platform (see 21.4). The implementation of runtime behavior of leaf-level actions can similarly be specified with procedural constructs, possibly invoking a foreign procedural interface on the target platform or invoking target template functions (see 21.6). Alternatively, implementation of actions and other scenario entities can be specified as target code template blocks (see 21.5). In all cases, the constructs for specifying implementation of PSS entities are called exec blocks.

Functions can be defined in PSS as a means to factor out and reuse portable procedural logic required for the implementation of scenario entities in exec blocks (see 21.3). Functions may take parameters and optionally return a result value. Like exec blocks, functions are defined in terms of procedural constructs or as target code templates.

21.1 exec blocks

eexec blocks provide a mechanism for associating specific functionality with a component, an action, a flow/resource object, or a struct (see Syntax 71). A number of exec block kinds are used to implement scenario entities.

— init_down and init_up exec blocks allow component data fields to be assigned a value as the component tree is being elaborated (see 9.4).

— body exec blocks specify the actual runtime implementation of atomic actions.

— pre_solve and post_solve exec blocks of actions, flow/resource objects, and structs are a way to involve arbitrary computation as part of the scenario solving.

— Other exec kinds serve more specific purposes in the context of pre-generated test code and auxiliary files.
21.1.1 Syntax

```
exec_block_stmt ::= 
    exec_block  
    | target_code_exec_block  
    | target_file_exec_block  
    | stmt_terminator
exec_block ::= exec exec_kind { { exec_stmt } }
exec_kind ::= 
    pre_solve  
    | post_solve  
    | pre_body  
    | body  
    | header  
    | declaration  
    | run_start  
    | run_end  
    | init_down  
    | init_up  
    | init
exec_stmt ::= 
    procedural_stmt  
    | exec_super_stmt
exec_super_stmt ::= super ;
target_code_exec_block ::= exec exec_kind language_identifier = string_literal ;
target_file_exec_block ::= exec file filename_string = string_literal ;
```

Syntax 71—exec block declaration

The following also apply:
- **a)** *exec block* content is given in one of two forms: as a sequence of procedural constructs (possibly involving foreign function calls) or as a text segment of target code parameterized with PSS attributes.
- **b)** In either case, a single *exec block* is always mapped to implementation in no more than one foreign language.
- **c)** In the case of a target-template block, the target language shall be explicitly declared; however, when using procedural constructs, the corresponding language may vary.
- **d)** “*exec init*” is an alias for “*exec init_up*,” and is considered deprecated as of PSS 2.0. The keyword “*init*” may be removed in a future version of this standard. Users should use “*init_up*” instead.
- **e)** Multiple *exec blocks* of the same kind may be declared in a given definition scope. If multiple *exec blocks* of the same kind are declared in a given definition scope, they shall be considered as a single *exec block* of the given kind, processed in source order.

21.1.2 exec block kinds

The following list describes the different *exec block* kinds:
— **pre_solve**—valid in **action**, flow/resource object, and **struct** types. The **pre_solve** block is processed prior to solving of random-variable relationships in the PSS model. **pre_solve** exec blocks are used to initialize non-random variables that the solve process uses. See also 16.4.12.

— **post_solve**—valid in **action**, flow/resource object, and **struct** types. The **post_solve** block is processed after random-variable relationships have been solved. The **post_solve** exec block is used to compute values of non-random fields based on the solved values of random fields. See also 16.4.12.

— **pre_body**—valid in **action**, flow/resource object, and **struct** types. The **pre_body** block is an exec block evaluated on the solve platform that is evaluated after exec **post_solve** and before exec **body** is evaluated as part of the test realization process. It is evaluated after executor assignments and memory allocations are completed for the given action, but before code is generated to represent the body block. Solve functions may be called in this exec block, as well as the **executor()**, **addr_value_solve()**, and **addr_value_abs()** functions.

— **body**—valid in **action** types. The **body** block constitutes the implementation of an atomic **action**. The **body** block of each **action** is invoked in its respective order during the execution of a scenario—after the **body** blocks of all predecessor **actions** complete. Execution of an **action**'s **body** may be logically time-consuming and concurrent with that of other actions. In particular, the invocation of exec blocks of **actions** with the same set of scheduling dependencies logically takes place at the same time. Implementation of the standard should guarantee that executions of exec blocks of same-time **actions** take place as close as possible.

— **run_start**—valid in **action**, flow/resource object, and **struct** types. The **run_start** block is a procedural non-time-consuming code block to be executed before any **body** block of the scenario is invoked. It is used typically for one-time test bring-up and configuration required by the context action or object. **exec run_start** is restricted to pre-generation flow (see [Table 25](#)).

— **run_end**—valid in **action**, flow/resource object, and **struct** types. The **run_end** block is a procedural non-time-consuming code block to be executed after all **body** blocks of the scenario are completed. It is used typically for test bring-down and post-run checks associated with the context action or object. **exec run_end** is restricted to pre-generation flow (see [Table 25](#)).

— **init_down/init_up**(init)—valid in **component** types. The **init_down** and **init_up** blocks are used to assign values to component attributes and to initialize foreign language objects. Component **init_down** and **init_up** blocks are called before the scenario root action’s **pre_solve** block is invoked. **init_down** and **init_up** blocks may not call target template functions.

1) **init_down**—Starting with the root component, **init_down** blocks are evaluated top-down for each component in the hierarchy. The relative order of evaluating **init_down** blocks for components at the same level of hierarchy is undefined. For any component, the **init_down** block shall be evaluated before its **init_up** block is evaluated.

2) **init_up**—For a leaf-level component (i.e., one that does not instantiate any subcomponents), the **init_up** block shall be evaluated after its **init_down** block (if any). A parent component’s **init_up** block shall be evaluated only after all subcomponent **init_up** blocks have been evaluated.

— **header**—valid in **action**, flow/resource object, and **struct** types. The **header** block specifies top-level statements for header declarations presupposed by subsequent code blocks of the context action or object. Examples are '#include' directives in C, or forward function or class declarations.

— **declaration**—valid in **action**, flow/resource object, and **struct** types. The **declaration** block specifies declarative statements used to define entities that are used by subsequent code blocks. Examples are the definition of global variables or functions.

**exec header** and **declaration** blocks shall only be specified in terms of target code templates. All other **exec** kinds may be specified in terms of procedural constructs or target code templates.
21.1.3 Examples

In Example 219, the init_up exec blocks are evaluated in the following order:

a) init_up in pss_top.s1
b) init_up in pss_top.s2
c) init_up in pss_top

This results in the component fields having the following values:

a) s1.base_addr=0x2000 (init_up in pss_top overwrote the value set by init_up in sub_c)
b) s2.base_addr=0x1000 (value set by init_up in sub_c)

```
cOMPONENT sub_c {
  int base_addr;
  
  exec init_up {
    base_addr = 0x1000;
  }
};

COMPONENT pss_top {
  sub_c s1, s2;
  
  exec init_up {
    s1.base_addr = 0x2000;
  }
};
```

Example 219—Data initialization in a component

In Example 220, the init_down and init_up blocks will be evaluated in the following order:

- init_down in T
- init_down in T.c1
- init_down in T.c2
- init_up in T.c1
- init_up in T.c2
- init_up in T
A diagram of the example is shown below:

```
component C {
    exec init_down {
    }
    exec init_up {
    }
}

component T {
    C c1, c2;
    exec init_down {
    }
    exec init_up {
    }
}
```

Example 220—-init_down and init_up exec blocks

The order of initialization calls is annotated on each of the `init_d(own)` and `init_u(p)` blocks. Note that `init_down` in `T` is called first, followed by `init_down` in `T.c1`, etc.

Note that a tool is free to execute the `exec init_down` and `exec init_up` blocks of sibling instances in arbitrary order. For example, while the diagram above shows `init_down` in `T.c1` executing before `init_down` in `T.c2`, the opposite order is also correct. The key requirements are that the `exec init_down` block of a parent component instance (e.g., `T`) execute before the `exec init_down` block of any child component instances, and that the `exec init_up` block of a parent component instance (e.g., `T`) execute after all `exec init_up` blocks of child component instances have executed. This implies that the following ordering of execution is also legal:

- `init_down` in `T`
- `init_down` in `T.c1`

Figure 21—Order of invocation of init_down and init_up exec blocks
— init_up in T.c1
— init_down in T.c2
— init_up in T.c2
— init_up in T

In **Example 221**, component `pss_top` contains two instances of component `sub_c`, named `s1` and `s2`. Component `sub_c` contains a data field named `base_addr` that controls the value to function `activate()` when action `A` is traversed.

During construction of the component tree, component `pss_top` sets `s1.base_addr=0x1000` and `s2.base_addr=0x2000`.

Action `pss_top::entry` traverses action `sub_c::A` twice. Depending on which component instance `sub_c::A` is associated with during traversal, it will cause `sub_c::A` to be associated with a different `base_addr`.

— If `sub_c::A` executes in the context of `pss_top.s1`, `sub_c::A` uses `0x1000`.
— If `sub_c::A` executes in the context of `pss_top.s2`, `sub_c::A` uses `0x2000`.

```
component sub_c {
    bit[32] base_addr = 0x1000;
    action A {
        exec body {
            // reference base_addr in context component
            activate(comp.base_addr + 0x10);
            // activate() is an imported function
        }
    }
}

component pss_top {
    sub_c s1, s2;
    exec init_up {
        s1.base_addr = 0x1000;
        s2.base_addr = 0x2000;
    }
    action entry {
        sub_c::A a;
        activity {
            repeat (2) {
                a; // Runs sub_c::A with 0x1000 as base_addr when
                // associated with s1
                // Runs sub_c::A with 0x2000 as base_addr when
                // associated with s2
            }
        }
    }
}
```

**Example 221**—Accessing component data field from an action

For additional examples of `exec block` usage, see 21.2.6.
21.1.4 exec block evaluation with inheritance and extension

Both inheritance and type extension can impact the behavior of exec blocks. See also 19.1 and 19.2.

21.1.4.1 Inheritance and shadowing

exec blocks are considered to be virtual, in that a derived type that defines an exec block completely replaces the behavior of any same-kind exec block (e.g., body) specified by its base type. Procedural exec blocks may include the “super;” statement, which will execute the contents of the corresponding base-type exec block(s) at that point (see 21.1.4.2).

The following examples use the core library target function message() to add a formatted line as a message to the execution log, at LOW verbosity. In Example 222, action B inherits from action A and shadows the pre_solve and body exec blocks defined by action A.

```pGORITHM
import std_pkg::*;

action A {
  int a;

  exec pre_solve {
    a=1;
  }
  exec body {
    message(LOW,"Hello from A %d", a);
  }
}

action B : A {
  exec pre_solve {
    a=2;
  }
  exec body {
    message(LOW,"Hello from B %d", a);
  }
}
```

Example 222—Inheritance and shadowing

When an instance of action B is evaluated, the following is printed:

Hello from B 2

21.1.4.2 Using super

Specifying “super;” as a statement in a subtype executes the behavior of the same-kind procedural exec block(s) from the base type, allowing a type to prepend or append behavior. The “super;” statement shall not be allowed in a target-template exec block.

In Example 223, both A1 and A2 inherit from action A. Both execute the pre_solve exec block inherited from A. A1 invokes the body behavior of A, then displays an additional statement. A2 displays an additional statement, then invokes the body behavior of A.
Type extension enables additional features to be contributed to action, component, and struct types. Type extension is additive and all exec blocks contributed via type extension are evaluated, along with exec blocks specified within the initial definition. First, the initial definition’s exec blocks (if any) are evaluated. Next, the exec blocks (if any) contributed via type extension are evaluated, in the order that they are processed by the PSS processing tool.
In Example 224, a type extension contributes an *exec block* to action A1.

```verilog
import std_pkg::*;

action A {
  int a;

  exec pre_solve {
    a=1;
  }
  exec body {
    message(LOW,"Hello from A %d", a);
  }
}

action A1 : A {
  exec body {
    super;
    message(LOW,"Hello from A1 %d", a);
  }
}

extend action A1 {
  exec body {
    message(LOW,"Hello from A1 extension %d", a);
  }
}
```

*Example 224—Type extension contributes an exec block*

When an instance of A1 is evaluated, the following is printed:

```
Hello from A 1
Hello from A1 1
Hello from A1 extension 1
```
In Example 225, two `exec` blocks are added to action A1 via extension.

```vhdl
import std_pkg::*;

action A {
    int a;

    exec pre_solve {
        a=1;
    }
    exec body {
        message(LOW,"Hello from A %d", a);
    }
}

action A1 : A {
    exec body {
        super;
        message(LOW,"Hello from A1 %d", a);
    }
}

extend action A1 {
    exec body {
        message(LOW,"Hello from A1(1) extension %d", a);
    }
}

extend action A1 {
    exec body {
        message(LOW,"Hello from A1(2) extension %d", a);
    }
}
```

**Example 225—exec blocks added via extension**

If the PSS processing tool processes the first extension followed by the second extension, then the following is produced:

Hello from A 1  
Hello from A1 1  
Hello from A1(1) extension 1  
Hello from A1(2) extension 1

If the PSS processing tool processes the second extension followed by the first extension, then the following is produced:

Hello from A 1  
Hello from A1 1  
Hello from A1(2) extension 1  
Hello from A1(1) extension 1

21.2 Functions

Functions are a means to encapsulate behaviors used by actions and other entities to implement test scenarios. Functions are called in procedural description contexts, and are akin to procedures in conventional programming languages.

Functions can be declared in global, package, or component scopes. Functions can be static or instance (non-static) functions. A global or package function is always static. A component function can be explicitly declared as static. If a component function is non-static, each function call is associated with a specific instance of that component type.

A function may be defined in one of three ways:

— Using native PSS procedural statements, possibly calling other functions (see 21.3).
— As bound to a procedural interface in a foreign programming language, such as a function in C/C++, or a function/task in SystemVerilog (see 21.4). This only applies to static functions; an instance function cannot be bound.
— As a target code template block (see 21.6).

The definition of a functions in one of these three ways may be coupled with the function’s initial declaration. The definition may also be provided separately, in a different lexical scope. The intent and semantics of a function are fixed by its declaration, but its implementation could vary between different environments and contexts.

Functions may be called from procedural exec blocks, namely exec init_down, init_up, pre_solve, post_solve, body, run_start, and run_end. Functions called from exec init_down, init_up, pre_solve, and post_solve are evaluated on the solve platform, whereas functions called from exec body, run_start and run_end are evaluated on the target platform.

A static function declared in a component scope may be shadowed by a function declaration with the same name in a derived component, which can be static or non-static. The function declaration in the derived component may have a different return type or arguments than in the base component.

An instance function declared in a component scope may be shadowed by an instance function declaration with the same name in a derived component. The function declaration in the derived component must have the same return type and arguments as that in the base component. The function in the base type may be called from within the function in the derived type by calling "super.<function name>(...)".

However, an instance function cannot be shadowed by a static function.

When the shadowed element is an instance function, the function call is polymorphic, that is, the actual function called depends on its context component. See 19.1 for details. On the other hand, static functions calls are not polymorphic.

21.2.1 Function declarations

A function prototype is declared in a package or component scope within a PSS description. The function prototype specifies whether the function is static, the function name, return type, and function parameters. See Syntax 72. Note that the syntax shown here is for the declaration of a function prototype only, where the definition is provided separately. A function can also be declared and defined at once using a procedural statement block or a target code template (see 21.3 and 21.6, respectively). The same syntax is used for specifying the prototype in these cases also.
21.2.1.1 Syntax

The following also apply:

a) Functions declared in global or package scopes are considered static, regardless of whether the static qualifier is used.
b) Static functions (declared any scope) are called optionally using package or component type qualification with the scope operator (: :).
c) Instance functions are called optionally using the dot operator (.) on a component instance expression.

21.2.1.2 Examples

For an example of declaring a function, see 21.2.2, below.

21.2.2 Parameters and return types

A function shall explicitly specify a data type as its return type or use the keyword void to indicate that the function does not return a value. Function return values shall be either plain-data types (scalars and aggregates thereof) or reference types. Functions shall not return action types, component types, or flow/resource object types without the ref modifier.

A function may specify any number of formal parameters, stating their types and names. Function parameters shall be either plain-data types or reference types. Functions shall not have parameters of action types, component types, or flow/resource object types without the ref modifier. Functions may also declare
generic parameters without stating their specific type, and may declare a variable number of parameters—see 21.2.4. Note that the set of types allowed for imported foreign functions is restricted (see 21.4).

Parameter direction modifiers (input, output, or inout) are optional in the function declaration. However, if they are specified in the function declaration, such a function may only be imported (see 21.4). In the declaration of native functions and target-template functions, direction modifiers shall not be used.

Example 226 declares a function in a package scope. In this case, the function `compute_value` returns an int, accepts an input value (val), and returns an output value via the out_val parameter.

```plaintext
package generic_functions {
    function int compute_value(
        int val,
        output int out_val);
}
```

**Example 226—Function declaration**

21.2.3 Default parameter values

Default parameter values serve as the actual values for the respective parameters if explicit actual parameters are missing in the function call.

The following also apply:

a) A default parameter value shall be specified as a constant expression, and therefore can only be specified for a parameter of a plain-data type.

b) In a function declaration, following a parameter with a specified default value, all subsequent parameters must also have default values specified.

c) A default parameter value is in effect for redeclarations (and overrides) of a function. A default parameter value shall not be specified in the redeclaration of a function if already declared for the same parameter in a previous declaration, even if the value is the same.

d) In an import function declaration, default parameters are not allowed on output or inout arguments.

Example 227 demonstrates the declaration and use of a default parameter value.

```plaintext
function void foo(int x, int y = 100);
function void bar() {
    foo(3,200); // the value 200 is used for parameter y
    foo(3);    // the value 100 is used for parameter y
}
```

**Example 227—Default parameter value**

21.2.4 Generic and varargs parameters

Generic parameters and varargs parameters are means to declare functions that are generic or variadic with respect to their parameters. Examples are functions that apply to all actions or objects as such, and functions that involve string formatting.

Generic and varargs parameters are used for the declaration of functions whose definition is built into implementations. In particular, they are used to declare functions included in the PSS core library (see...
Clause 23). PSS does not provide a native mechanism to operate on an unspecified number of parameters or on parameters with no declared type, nor does PSS define mapping of functions with generic/varargs parameters to foreign languages.

The following also apply:

a) A generic parameter is declared either with the keyword type or with a type category, rather than with a specific type. A value of any type (if type was specified), or any type that belongs to the specified category (if a type category was specified), is accepted in the function call. In the case of the struct category, the ref modifier shall not be used, but for the other categories (component, action, one of the object kinds), the ref modifier shall be used. See more on the use of type categories in 11.3.2.

b) Default values may not be specified for generic parameters.

c) The varargs parameter (ellipsis notation — “...”) signifies that zero or more trailing values may be passed as actual parameters in the function call. Note that a varargs parameter may only occur as the last parameter in the parameter list.

d) In a function call, the expressions corresponding to a varargs parameter must all be of the declared type if a type is specified, or belong to the same type category if one is specified. Note that in the case of a type category, the types of the actual parameter expressions may vary, so long as they all belong to the specified category. When a varargs parameter is declared with the keyword type, actual parameters types may vary with no restriction.

Example 228 demonstrates the declaration and use of a generic parameter.

```c
function void foo(struct x);
struct my_struct {};
struct your_struct {};
function void bar() {
    my_struct s1;
    your_struct s2;
    foo(s1);
    foo(s2);
}
```

**Example 228—Generic parameter**

Example 229 demonstrates the declaration and use of a varargs parameter.

```c
function string format_string(string format, type ... args);
function void bar() {
    string name = "John";
    int age = 55;
    string result;
    result = format_string("name %s: age %d", name, age);
}
```

**Example 229—Varargs parameter**

21.2.5 Pure functions

Pure functions are functions for which the return value depends only on the values of their parameters, and their evaluation has no side-effects. Declaring a function as pure may provide the PSS implementation with
opportunities for optimization. Note that a function declared as pure may lead to unexpected behavior if it fails to obey these rules.

The following rules apply to pure functions, that is, functions declared with the pure modifier:

a) Only non-void functions with no output or inout parameters may be declared pure.

b) A pure function will be considered pure in derived types even if the pure modifier is not explicitly specified in the derived type function declaration.

A non-pure function shall not be declared as pure in derived types.

**21.2.5.1 Examples**

**Example 230** demonstrates declaration and use of pure functions.

```pss
pure function int factorial(int n);
action A {
    rand int vals[10];
    int factorial_vals[10];

    exec post_solve {
        foreach (vals[i]) {
            factorial_vals[i] = factorial(vals[i]);
        }
    }
}
```

**Example 230—Pure function**

In the example above, the function factorial() is pure and therefore will not necessarily be re-evaluated for each element in the array. If some elements in the array are equal, the PSS implementation may choose to use the result of a previous evaluation, and not evaluate the function again.

**21.2.6 Calling functions**

Functions may be called directly from exec blocks or from other functions using procedural constructs (see 21.7). Recursive function calls are allowed.

Functions not returning a value (declared with void return type) may only be called as standalone procedural statements. Functions returning a value may be used as operands in expressions; the value of that operand is the value returned by the function. The function can be used as a standalone statement and the return value discarded by casting the function call to void:

```pss
(void)function_call();
```

Calling a nonvoid function as if has no return value shall be legal, but it is recommended to explicitly discard the return value by casting the function call to void, as shown above.

**Example 231** demonstrates calling various functions. In this example, the mem_segment_s buffer object captures information about a memory buffer with a random size. The specific address in an instance of the mem_segment_s object is computed using the alloc_addr function. alloc_addr is called after the solver has selected random values for the rand fields (specifically, size in this case) to select a specific address for the addr field.
21.3 Native PSS functions

It is possible to specify the definition for native PSS functions using the procedural constructs described in Section 21.7.

For an instance function, the definition (if provided) shall be in the same component type as the original declaration (either in its initial definition or in an extension) or in a derived component. For a static function, the definition shall be in the same package or component as the original declaration (in case of a component, either in its initial definition or in an extension).
21.3.1 Syntax

```
procedural_function ::= [ platform_qualifier ] [ pure ] [ static ] function function_prototype
   { { procedural_stmt } }  
platform_qualifier ::= 
   target  
   | solve  
function_prototype ::= function_return_type function_identifier function_parameter_list_prototype  
function_return_type ::=  
   void  
   | data_type  
function_parameter_list_prototype ::=  
   ( [ function_parameter { , function_parameter } ] )  
   | ( { function_parameter , } varargs_parameter )  
function_parameter ::=  
   [ function_parameter_dir ] data_type identifier [ = constant_expression ]  
   | ( type | ref type_category | struct ) identifier  
function_parameter_dir ::=  
   input  
   | output  
   | inout  
varargs_parameter ::= ( data_type | type | ref type_category | struct ) ... identifier  
type_category ::=  
   action  
   | component  
   | struct_kind
```

Syntax 73—Function definition

The optional platform_qualifier (either solve or target) specifies function availability. An unqualified function is assumed to be available during all phases of test generation and execution.

For native PSS functions, function_parameter_dir shall be left unspecified for all parameters of the function, both in the original function declaration (if provided) and in the native PSS function definition.

21.3.2 Parameter passing semantics

Parameter direction shall be unspecified in the function prototype for native PSS functions. This implies that the parameter direction (input, output, or inout) shall not be used.

In the implementation of these functions, the following apply:

- Parameters of scalar data types are passed by value. Any changes to these parameters in the callee do not update the values in the caller.
- Parameters of aggregate data types are passed as a handle to the instance in the caller. Updates to these parameters in the callee will modify the instances in the caller. When a variable of inherited type is passed as a parameter of base type, only the fields present in the base type are visible within
the function. Note that as variables, parameters of aggregate data types have value semantics in assignment and equality expressions (see 8.3 and 8.5.3).

Parameters of reference data types are passed as reference assignments. The parameter points to (is an alias to) the entity referred to in the actual parameter expression. Note that as variables, parameters of reference types have reference semantics in assignment and equality expressions (see 8.3 and 8.5.3), and may evaluate to null.

Example 232 shows the parameter passing semantics.
package generic_functions {
    struct params_s {
        int x;
    };

    struct params_inh_s : params_s {
        int y;
    }

    // Prototypes
    function void set_val0(params_s p, int a);
    function void set_val1(params_s p_dst, params_s p_src);
    function params_s zero_attributes();

    // Definitions
    function void set_val0(params_s p, int a)
    {
        p.x = a;
        a = 0;
    }
    function void set_val1(params_s p_dst, params_s p_src)
    {
        p_dst.x = p_src.x;
    }
    function params_s zero_attributes()
    {
        params_s s;
        s.x = 0;
        return s;
    }

    component A {
        params_s p;
        params_inh_s p_inh1, p_inh2;
        int a;

        exec init_up {
            a = 10;
            p.x = 20;
            set_val0(p, a);
            // p.x is set to 10 at this point and a is unchanged
            set_val1(p, zero_attributes());
            // p.x is set to 0 at this point
            // Variables of inherited type may be passed as
            // function parameters of base type
            p_inh1.x = 5;
            p_inh1.y = 15;
            p_inh2.x = 10;
            p_inh2.y = 20;
            set_val1(p_inh1, p_inh2);
            // The value of p_inh1.y can never be changed by set_val1 because
            // set_val1 can only access fields of params_s (i.e., x)
        }
    }
}
21.4 Foreign procedural interface

Static function declarations in PSS may expose, and ultimately be bound to, foreign language APIs (functions, tasks, procedures, etc.) available on the target platform and/or on the solve platform. A function that was previously declared in the PSS description can be designated as imported. Calling an imported function from a PSS procedural context invokes the respective API in the foreign language. Parameters and result passing are subject to the type mapping defined for that language.

Instance functions may not be imported.

21.4.1 Definition using imported functions

Additional qualifiers are added to imported functions to provide more information to the tool about the way the function is implemented and/or in what phases of the test-creation process the function is available. Imported function qualifiers are specified separately from the function declaration for modularity (see Syntax 74). In typical use, qualifiers are specified in an environment-specific package (e.g., a UVM environment-specific package or C-test-specific package).

A static function declared in a component may only be imported in the scope of the same component type. It shall be illegal to import a function declared in a base component type within a derived or unrelated component type.

It shall be illegal to import a function declared in a template component type.

21.4.1.1 Syntax

The following also apply:

a) Return values and parameter values of imported functions are restricted to the following types:

1) bit or int, provided width is no more than 64 bits
2) bool
3) enum
4) string
5) chandle
6) struct
7) array whose element type is one of these listed types, including a sub-array


b) Parameter direction modifiers may be used in the function declaration or in the import declaration to specify the passing semantics between PSS and the foreign language:

1) If the value of an input parameter is modified by the foreign language implementation, the updated value is not reflected back to the PSS model.
2) An output parameter sets the value of a PSS model variable. The foreign language implementation shall consider the value of an output parameter to be unknown on entry; it shall specify a value for an output parameter.

3) An inout parameter takes an initial value from a variable in the PSS model and reflects the value specified by the foreign language implementation back to the PSS model.

c) In the absence of an explicit direction modifier, parameters default to input.

In addition, the following apply when the second form of import_function is used (with the function prototype specified):

a) If the direction for a parameter is left unspecified in the import declaration, it defaults to input.

b) The prototype specified in the import declaration shall match the prototype specified in the function declaration in the following ways:
   1) For a static function declared in a component, the static qualifier shall be used.
   2) The number of parameters shall be identical.
   3) The parameter names and types shall be identical.
   4) The return types shall be identical.

c) If the function declaration specifies a parameter direction explicitly, the direction specified in the import declaration (either explicitly or by default) must match the function declaration.

d) If in the function declaration, the direction was unspecified for any parameter, the prototype specified in the import declaration can provide the direction of the parameter as input, output or inout.

21.4.1.2 Specifying function availability

In some environments, test generation and execution are separate activities. In those environments, some functions may only be available during test generation, on the solve platform, while others are only available during test execution, on the target platform. For example, reference model functions may only be available during test generation while the utility functions that program hardware devices may only be available during test execution.

An unqualified imported function is assumed to be available during all phases of test generation and execution. Qualifiers are specified to restrict a function’s availability. Functions restricted to the solve platform shall not be called directly or indirectly from target execs, namely body, run_start, and run_end. Similarly, functions restricted to the target platform shall not be called from solve execs, namely init_down, init_up, pre_solve, post_solve, and pre_body.

Example 233 specifies function availability. Two imported functions are declared in the external_functions_pkg package. The alloc_addr function allocates a block of memory, while the transfer_mem function causes data to be transferred. Both of these functions are present in all phases of test execution in a system where solving is done on-the-fly as the test executes.

In a system where a pre-generated test is to be compiled and run on an embedded processor, memory allocation may be pre-computed. Data transfer shall be performed when the test executes. The pregen_tests_pkg package specifies these restrictions: alloc_addr is only available during the solving phase of stimulus generation, while transfer_mem is only available during the execution phase of stimulus generation. PSS processing uses this specification to ensure that the way imported functions are used aligns with the restrictions of the target environment.
Example 233—Function availability

Example 234 demonstrates an activity with reactive control flow based on values returned from a target function called in an exec body block.

Example 234—Reactive control flow
21.4.1.3 Specifying an implementation language

The implementation language for an imported function can be specified implicitly or explicitly. In many cases, the implementation language need not be explicitly specified because the PSS processing tool can use sensible defaults (e.g., all imported functions are implemented in C++). Explicitly specifying the implementation language using a separate statement allows different imported functions to be implemented in different languages, however (e.g., reference model functions are implemented in C++, while functions to drive stimulus are implemented in SystemVerilog).

Example 235 shows explicit specification of the foreign language in which the imported function is implemented. In this case, the function is implemented in C. Notice that only the name of the imported function is specified and not the full function prototype.

Example 235—Explicit specification of the implementation language

21.4.2 Imported classes

In addition to interfacing with external foreign language functions, the PSS description can interface with foreign language classes. See also Syntax 75.

21.4.2.1 Syntax

import_class_decl ::= import class import_class_identifier [ import_class_extends ]
{ { import_class_function_decl } }
import_class_extends ::= : type_identifier { , type_identifier }
import_class_function_decl ::= function_prototype ;

Syntax 75—Import class declaration

The following also apply:

a) Imported class functions support the same return and parameter types as imported functions. import class declarations also support capturing the class hierarchy of the foreign language classes.

b) Fields of import class type can be instantiated in package and component scopes. An import class field in a package scope is a global instance. A unique instance of an import class field in a component exists for each component instance.

c) Imported class functions are called from an exec block just as imported functions are.

21.4.2.2 Examples

Example 236 declares two imported classes. import class base declares a function base_function, while import class ext extends from import class base and adds a function named ext_function.
21.5 Target-template implementation of exec blocks

Implementation of execs may be specified using a target template—a string literal containing code in a specific foreign language, optionally embedding references to fields in the PSS description. Target-template implementation is restricted to target exec kinds (body, run_start, run_end, header, and declaration). In addition, target templates can be used to generate other text files using exec file. Target-template implementations may not be used for solve execs (init_down, init_up, pre_solve, post_solve, and pre_body).

Target-template execs are inserted by the PSS tool verbatim into the generated test code, with embedded expressions substituted with their actual values. Multiple target-template exec blocks of the same kind are allowed for a given action, flow/resource object, or struct. They are (logically) concatenated in the target file, as if they were all concatenated in the PSS source.

21.5.1 Target language

A language_identifier serves to specify the intended target programming language of the code block. Clearly, a tool supporting PSS must be aware of the target language to implement the runtime semantics. PSS does not enforce any specific target language support, but recommends implementations reserve the identifiers C, CPP, and SV to denote the languages C, C++, and SystemVerilog respectively. Other target languages may be supported by tools, given that the abstract runtime semantics are kept. PSS does not define any specific behavior if an unrecognized language_identifier is encountered.

Each target-template exec block is restricted to one target language in the context of a specific generated test. However, the same action may have target-template exec blocks in different languages under different packages, given that these packages are not used for the same test.

21.5.2 exec file

Not all the artifacts needed for the implementation of tests are coded in a programming language that tools are expected to support as such. Tests may require scripts, command files, make files, data files, and files in other formats. The exec file construct (see 21.1) specifies text to be generated out to a given file. exec file constructs of different actions/objects with the same target are concatenated in the target file in their respective scenario flow order.

21.5.3 Referencing PSS fields in target-template exec blocks

Implementing test intent requires using data from the PSS model in the code created from target-template exec blocks. PSS variables are referenced using mustache notation: {{expression}}. A reference is to an expression involving variables declared in the scope in which the exec block is declared. Only scalar variables (except chandle) can be referenced in a target-template exec block.
21.5.3.1 Examples

Example 237 shows referencing PSS variables inside a target-template exec block using mustache notation.

```pss
component top {
    struct S {
        rand int b;
    }
    action A {
        rand int a;
        rand S sl;
        exec body C = ""
            printf("a={a} s1.b={s1.b} a+b={a+s1.b}\n");
        "";
    }
}
```

Example 237—Referencing PSS variables using mustache notation

A variable reference can be used in any position in the generated code. Example 238 shows a variable reference used to select the function being called.

```pss
component top {
    action A {
        rand bit[1:0] func_id;
        rand bit[3:0] a;
        exec body C = ""
            func_{{func_id}}{{a}};
        "";
    }
}
```

Example 238—Variable reference used to select the function

One implication of this is that a mustache reference cannot be used to assign a value to a PSS variable.

Example 238 also declares a random `func_id` variable that identifies a C function to call. When a PSS tool processes this description, the following output shall result, assuming `func_id==1` and `a==4`:

```
func_1(4);
```

Example 238 also declares a random `func_id` variable that identifies a C function to call. When a PSS tool processes this description, the following output shall result, assuming `func_id==1` and `a==4`:

```
func_1(4);
```

Example 239 shows how a procedural `pre_solve` exec block is used along with a target-template declaration exec block to allow programmatic declaration of a target variable declaration.
Assume that the solver selects `my_int16` as the value of the `obj_type` field and that the `get_unique_obj_name()` function returns `field__0`. In this case, the PSS processing tool shall generate the following content in the declaration section:

```c
static my_int16 field__0;
```

### 21.5.3.2 Formatting

When a variable reference is converted to a string, the result is formatted as follows:

- **int** signed decimal (%d)
- **bit** unsigned decimal (%ud)
- **bool** "true" | "false"
- **string** string (%s)
- **chandle** pointer (%p)
- **float32, float64** floating-point (%f)

### 21.6 Target-template implementation for functions

When integrating with languages that do not have the concept of a “function,” such as assembly language, the implementation for functions can be provided by target-template code strings.

The target-template form of functions (see Syntax 76) allows interactions with a foreign language that do not involve a procedural interface. Examples are injecting assembly code or global variables into generated tests. The target-template forms of functions are always target implementations. Variable references may only be used in expression positions. Function return values shall not be provided, i.e., only functions that return `void` are supported. If a target-template function is an instance (non-static) function, PSS expressions embedded in the target code (using mustache notation) may make reference to the instance attributes, optionally using `this`.

See also 21.5.3.
21.6.1 Syntax

```plaintext
target_template_function ::= target language_identifier [ static ]
  function function_prototype = string_literal ;
```

Syntax 76—Target-template function implementation

The following also apply:

a) If the direction for a parameter is left unspecified in the target template declaration, it defaults to `input`.

b) The prototype specified in the target template declaration must match the prototype specified in the `function` declaration in the following way:
   1) The number of parameters must be identical.
   2) The parameter names and types must be identical.
   3) The return types must be identical.

c) If the `function` declaration specifies a parameter direction explicitly, the direction specified in the target template declaration (either explicitly or by default) must match the `function` declaration.

d) If in the `function` declaration, the direction was unspecified for any parameter, the prototype specified in the target template declaration can provide the direction of the parameter as `input`, `output` or `inout`.

21.6.2 Examples

Example 240 provides an assembly-language target-template code block implementation for the `do_stw` function. Function parameters are referenced using mustache notation ({{variable}}).

```plaintext
package thread_ops_pkg {
  function void do_stw(bit[31:0] val, bit[31:0] vaddr);
}

package thread_ops_asm_pkg {
  target ASM function void do_stw(bit[31:0] val, bit[31:0] vaddr) = ""
    loadi RA {{val}}
    store RA {{vaddr}}
  "";
}
```

Example 240—Target-template function implementation

21.7 Procedural constructs

This section specifies the procedural control flow constructs. When relevant, these constructs have the same syntax and execution semantics as the corresponding activity control flow statements (see 12.4).

21.7.1 Scoped blocks

A scoped block creates a new unnamed nested scope, similar to C-style blocks.
21.7.1.1 Syntax

```
procedural_stmt ::= 
    procedural_sequence_block_stmt 
  | ... 
procedural_sequence_block_stmt ::= [ sequence ] { { procedural_stmt } } 
```

Syntax 77—Procedural block statement

The `sequence` keyword before the block statement is optional, and is provided to let users state explicitly that the statements are executed in sequence.

Typically, blocks are used to group multiple statements that are part of a control flow statement (such as `repeat`, `if-else`, etc.). It is also valid to have a stand-alone block that is not part of a control flow statement, in which case the following equivalencies apply:

— A stand-alone block that does not create new variables (and hence does not destroy any variables when the scope ends) is equivalent (in so far as to the AST constructed) to the case where the contents of the code block are merged with the enclosing parent block. For example:

```
{ 
  int a;
  int b;
  { 
    b = a;
  }
}
```

is equivalent to

```
{ 
  int a;
  int b;
  b = a;

```  

— If the start of an enclosing block coincides with the start of the stand-alone nested block (i.e., with no statements in between) and similarly the end of that enclosing block coincides with the end of the stand-alone nested block, it is then equivalent to the case where there is just a single code-block with the contents of the nested block. For example:

```
{
  
    int a;
    int b;
    //
  }
```

is equivalent to

```
{
  int a;
  int b;
  //
}
```
21.7.2 Variable declarations

Variables may be declared with the same notation used in other declarative constructs (e.g., action). The declaration may be placed at any point in a scope (i.e., C++ style) and does not necessarily have to be declared at the beginning of a scope. However, the declaration shall precede any reference to the variable.

All data types listed in Clause 7 may be used for variable types. It shall be an error to instantiate rand variables in a procedural context.

21.7.2.1 Syntax

```
procedural_stmt ::= 
    procedural_sequence_block_stmt
  | procedural_data_declaration
  | ... 
procedural_data_declaration ::= data_type procedural_data_instantiation 
  { , procedural_data_instantiation } ;
procedural_data_instantiation ::= identifier [ array_dim ] [ = expression ]
```

*Syntax 78—Procedural variable declaration*

21.7.3 Assignments

Assignments to variables in the scope may be made.

21.7.3.1 Syntax

```
procedural_stmt ::= 
    procedural_sequence_block_stmt
  | procedural_data_declaration
  | procedural_assignment_stmt
  | ... 
procedural_assignment_stmt ::= ref_path assign_op expression ;
```

*Syntax 79—Procedural assignment statement*

The following rules apply to assignments in native PSS functions and execs:

a) A plain-data variable declared within a function/exec scope may be assigned in the scope where it is visible with no restriction.

b) A native PSS function definition may set data attributes of component instances through component references passed as parameters. Instance functions may similarly set data attributes of their context component directly. Since component attributes can only be set during the initialization phase, a function that sets such data attributes shall be called only from within exec init_down or init_up.

c) An exec init_down or init_up block may set the data attributes of the component instance directly in the body of the exec.
d) Data attributes of a `struct` instance may be set using the handle passed as a parameter. Similarly, data attributes of `actions` and flow/resource objects may be set using the reference passed as a parameter. A function that sets such data attributes may be invoked in `init`, `solve` or `body` execs.

e) A `struct` instance may be assigned to another `struct` instance of the same type, which results in a deep-copy operation of the data attributes. That is, this single assignment is equivalent to individually setting data attributes of the left-side instance to the corresponding right-side instance, for all the data attributes directly present in that type or in a contained `struct` type. A `struct` instance may be assigned from another `struct` instance that is of a type that inherits from the type of the left-hand side of the assignment. This results in a deep copy of all data attributes present in the base `struct` type (left-hand type) from the right-hand `struct` instance to the left-hand `struct` instance. See 8.3.

### 21.7.4 Void function calls

Functions not returning a value (declared with `void` return type) may only be called as standalone procedural statements. Functions returning a value may be used as a standalone statement and the return value discarded by casting the function call to `void`:

```
(void) function_call();
```

Calling a nonvoid function as if has no return value shall be legal, but it is recommended to explicitly discard the return value by casting the function call to `void`, as shown above.

#### 21.7.4.1 Syntax

```
procedural_stmt ::= 
    procedural_sequence_block_stmt 
  | procedural_data_declaration 
  | procedural_assignment_stmt 
  | procedural_void_function_call_stmt 
  | ... 

procedural_void_function_call_stmt ::= [ ( void ) ] function_call ;
```

**Syntax 80—Void function call**

### 21.7.5 return statement

PSS functions shall return a value to the caller using the `return` statement. In PSS functions that do not return a value, the `return` statement without an argument shall be used.

The `return` statement without an argument can also be used in `execs`. The `return` signifies end of execution—no further statements in the `exec` are executed.
21.7.5.1 Syntax

```
procedural_stmt ::= 
    procedural_sequence_block_stmt 
    | procedural_data_declaration 
    | procedural_assignment_stmt 
    | procedural_void_function_call_stmt 
    | procedural_return_stmt 
    | ...

procedural_return_stmt ::= return [ expression ] ;
```

Syntax 81—Procedural return statement

21.7.5.2 Examples

```
target function int add(int a, int b) {
    return (a+b);
}
```

Example 241—Procedural return statement

21.7.6 repeat (count) statement

The procedural repeat statement allows the specification of a loop consisting of one or more procedural statements. This section describes the count-expression variant (see Syntax 82) and 21.7.7 describes the while-expression variants.

21.7.6.1 Syntax

```
procedural_stmt ::= 
    procedural_sequence_block_stmt 
    | procedural_data_declaration 
    | procedural_assignment_stmt 
    | procedural_void_function_call_stmt 
    | procedural_return_stmt 
    | procedural_repeat_stmt 
    | ...

procedural_repeat_stmt ::= 
    repeat ( [ index_identifier : ] expression ) procedural_stmt
    | ...
```

Syntax 82—Procedural repeat-count statement

The following also apply:

a) expression shall be a non-negative integer expression (int or bit).
b) Intuitively, the `procedural_stmt` is iterated the number of times specified in the `expression`. An optional index-variable identifier can be specified that ranges between 0 and one less than the iteration count. If the expression evaluates to 0, the `procedural_stmt` is not evaluated at all.

### 21.7.6.2 Examples

```c
#define sum(a, b) {
   int res = 0;
   repeat(b) {
      res = res + a;
   }
   return res;
}
```

**Example 242—Procedural repeat-count statement**

### 21.7.7 repeat-while statement

The procedural `repeat` statement allows the specification of a loop consisting of one or more procedural statements. This section describes the `while-expression` variants (see Syntax 83).

#### 21.7.7.1 Syntax

```c
procedural_stmt ::= 
   procedural_sequence_block_stmt 
   | procedural_data_declaration 
   | procedural_assignment_stmt 
   | procedural_void_function_call_stmt 
   | procedural_return_stmt 
   | procedural_repeat_stmt 
   | ... 
procedural_repeat_stmt ::= 
   repeat procedural_stmt while ( expression ) ; 
   | while ( expression ) procedural_stmt
```

**Syntax 83—Procedural repeat-while statement**

The following also apply:

a) `expression` shall be of type `bool`.

b) Intuitively, the `procedural_stmt` is iterated so long as the `expression` condition is `true`, as sampled before the `procedural_stmt` (in the `while` variant) or after (in the `repeat-while` variant).
21.7.7.2 Examples

```c
target function bool get_parity(int n) {
    bool parity;
    parity = false;
    while (n != 0) {
        parity = !parity;
        n = n & (n-1);
    }
    return parity;
}
```

*Example 243—Procedural while statement*

21.7.8 foreach statement

The procedural **foreach** statement allows the specification of a loop that iterates over the elements of a collection (see Syntax 84).

21.7.8.1 Syntax

```
procedural_stmt ::=  
    procedural_sequence_block_stmt 
    | procedural_data_declaration 
    | procedural_assignment_stmt 
    | procedural_void_function_call_stmt 
    | procedural_return_stmt 
    | procedural_repeat_stmt 
    | procedural_foreach_stmt 
    | ... 

procedural_foreach_stmt ::=  
```

*Syntax 84—Procedural foreach statement*

The following also apply:

a) *expression* shall be of a collection type (i.e., **array**, **list**, **map** or **set**). *expression* may also be an array of **action handles**, **components**, or **flow and resource object references**.

b) The body of the **foreach** statement is a sequential block in which **procedural_stmt** is evaluated once for each element in the collection.

c) **iterator_identifier** specifies the name of an iterator variable of the collection element type. Within **procedural_stmt**, the iterator variable, when specified, is an alias to the collection element of the current iteration.

d) **index_identifier** specifies the name of an index variable. Within **procedural_stmt**, the index variable, when specified, corresponds to the element index of the current iteration.

1) For **arrays** and **lists**, the index variable shall be a variable of type **int**, ranging from 0 to one less than the size of the collection variable, in that order.

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2) For maps, the index variable shall be a variable of the same type as the map keys, and range over the values of the keys. The order of key traversal is undetermined.

3) For sets, an index variable shall not be specified.

e) Both the index and iterator variables, if specified, are implicitly declared within the foreach scope and limited to that scope. Regular name resolution rules apply when the implicitly declared variables are used within the foreach body. For example, if there is a variable in an outer scope with the same name as the index variable, that variable is shadowed (masked) by the index variable within the foreach body. The index and iterator variables are not visible outside the foreach scope.

f) Either an index variable or an iterator variable or both shall be specified. For a set, an iterator variable shall be specified, but not an index variable.

g) The index and iterator variables are read-only. Their values shall not be changed within the foreach body. It shall be an error to change the contents of the iterated collection variable with the foreach body.

21.7.9 if-else statement

The procedural if-else statement introduces a branch point (see Syntax 85).

21.7.9.1 Syntax

```plaintext
procedural_stmt ::= 
    procedural_sequence_block_stmt
  | procedural_data_declaration
  | procedural_assignment_stmt
  | procedural_void_function_call_stmt
  | procedural_return_stmt
  | procedural_repeat_stmt
  | procedural_foreach_stmt
  | procedural_if_else_stmt
  | ...
procedural_if_else_stmt ::= if ( expression ) procedural_stmt [ else procedural_stmt ]
```

Syntax 85—Procedural if-else statement

expression shall be of type bool.
21.7.9.2 Examples

```
target function int max(int a, int b) {
  int c;
  if (a > b) {
    c = a;
  } else {
    c = b;
  }
  return c;
}
```

Example 244—Procedural if-else statement

21.7.10 match statement

The procedural `match` statement specifies a multi-way decision point that tests whether an expression matches one of a number of other expressions and executes the matching branch accordingly (see Syntax 86).

21.7.10.1 Syntax

```
procedural_stmt ::= 
  procedural_sequence_block_stmt 
  | procedural_data_declaration 
  | procedural_assignment_stmt 
  | procedural_void_function_call_stmt 
  | procedural_return_stmt 
  | procedural_repeat_stmt 
  | procedural_foreach_stmt 
  | procedural_if_else_stmt 
  | procedural_match_stmt 
  | ...
procedural_match_stmt ::= 
  match ( match_expression ) { procedural_match_choice { procedural_match_choice } } 
match_expression ::= expression 
procedural_match_choice ::= 
  [ open_range_list ] : procedural_stmt 
  | default : procedural_stmt
```

Syntax 86—Procedural match statement

The following also apply:

a) When the `match` statement is evaluated, the `match_expression` is evaluated.

b) After the `match_expression` is evaluated, the `open_range_list` of each `procedural_match_choice` shall be compared to the `match_expression`. `open_range_lists` are described in 8.5.9.1.
c) If there is exactly one match, then the corresponding branch shall be evaluated.

d) It shall be an error if more than one match is found for the match_expression.

e) If there are no matches, then the default branch, if provided, shall be evaluated.

f) The default branch is optional. There may be at most one default branch in the match statement.

g) If a default branch is not provided and there are no matches, it shall be an error.

21.7.10.2 Examples

target function int bucketize(int a) {
int res;

match (a) {
[0..3]: res = 1;
[4..7]: res = 2;
[8..15]: res = 3;
default: res = 4;
}
return res;
}

Example 245—Procedural match statement

21.7.11 break/continue statement

The procedural break and continue statements allow for additional control in loop termination (see Syntax 87).

21.7.11.1 Syntax

procedural_stmt ::= 
   procedural_sequence_block_stmt
| procedural_data_declaration
| procedural_assignment_stmt
| procedural_void_function_call_stmt
| procedural_return_stmt
| procedural_repeat_stmt
| procedural_foreach_stmt
| procedural_if_else_stmt
| procedural_match_stmt
| procedural_break_stmt
| procedural_continue_stmt
| ...

procedural_break_stmt ::= break ;
procedural_continue_stmt ::= continue ;

Syntax 87—Procedural break/continue statement
The following also apply:

a) The semantics are similar to `break` and `continue` in C++.

b) `break` and `continue` may only appear within loop statements (repeat-count, repeat-while or foreach). Within a loop, `break` and `continue` may be nested in conditional branch or `match` statements.

c) `break` and `continue` affect the innermost loop statement they are nested within.

d) `break` signifies that execution should continue from the statement after the enclosing loop construct. `continue` signifies that execution should proceed to the next loop iteration.

21.7.11.2 Examples

```c
// Sum all elements of 'a' that are even, starting from a[0], except those // that are equal to 42. Stop summation if the value of an element is 0.
function int sum(array<int,100> a) {
    int res;
    res = 0;
    foreach (el : a) {
        if (el == 0) break;
        if (el == 42) continue;
        if ((el % 2) == 0) {
            res = res + el;
        }
    }
    return res;
}
```

Example 246—Procedural foreach statement with break/continue

21.7.12 randomize statement

The procedural `randomize` statement shall randomize the specified data attributes or variables.
21.7.12.1 Syntax

```plaintext
procedural_stmt ::=  
    procedural_sequence_block_stmt 
  |    procedural_data_declaration 
  |    procedural_assignment_stmt 
  |    procedural_void_function_call_stmt 
  |    procedural_return_stmt 
  |    procedural_repeat_stmt 
  |    procedural_foreach_stmt 
  |    procedural_if_else_stmt 
  |    procedural_match_stmt 
  |    procedural_break_stmt 
  |    procedural_continue_stmt 
  |    procedural_randomization_stmt 
  |    procedural_compile_if 
  |    stmt_terminator
procedural_randomization_stmt ::=  
    randomize procedural_randomization_target procedural_randomization_term
procedural_randomization_target ::= hierarchical_id {, hierarchical_id}
procedural_randomization_term ::=  
    with constraint_set 
  | ;
```

**Syntax 88—Procedural randomize statement**

The rules and semantics of the `randomize` statement are described in 16.4.6.

21.7.13 exec block

**Example 247** shows how an **exec body** can be specified using procedural constructs in PSS.

```plaintext
action A {  
  rand bool flag;

  exec body {  
    int var;
    
    if(flag) {  
      var = 10;
    } else {  
      var = 20;
    }
    // send_cmd is an imported function
    send_cmd(var);
  }
}
```

**Example 247—exec block using procedural control flow statements**
21.8 Comparison between mapping mechanisms

Previous sections describe three mechanisms for mapping PSS entities to external (non-PSS) definitions: functions that directly map to foreign API (see 21.4), functions that map to foreign language procedural code using target code templates (see 21.6), and exec blocks where arbitrary target code templates are in-lined (see 21.5). These mechanisms differ in certain respects and are applicable in different flows and situations. This section summarizes their differences.

PSS tests may need to be realized in different ways in different flows:
— by directly exercising separately-existing environment APIs via procedural linking/binding;
— by generating code once for a given model, corresponding to entity types, and using it to execute scenarios; or
— by generating dedicated target code for a given scenario instance.

Table 24 shows how these relate to the mapping constructs.

<table>
<thead>
<tr>
<th></th>
<th>No target code generation</th>
<th>Per-model target code generation</th>
<th>Per-test target code generation</th>
<th>Non-procedural binding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct-mapped functions</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Target-template functions</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Target-template exec-blocks</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

Not all mapping forms can be used for every exec kind. Solving/generation-related code must have direct procedural binding since it is executed prior to possible code generation. exec blocks that expand declarations and auxiliary files shall be specified as target-templates since they expand non-procedural code. The run_start exec block is procedural in nature, but involves up-front commitment to the behavior that is expected to run.

Table 25 summarizes these rules.

The possible use of action and struct attributes differs between mapping constructs. Explicitly declared prototypes of functions enable the type-aware exchange of values of all data types. On the other hand, free parameterization of uninterpreted target code provides a way to use attribute values as target-language meta-level parameters, such as types, variables, functions, and even preprocessor constants.

Table 26 summarizes the parameter passing rules for the different constructs.
21.9 Exported actions

Imported functions and classes specify functions and classes external to the PSS description that can be called from the PSS description. Exported actions specify actions that can be called from a foreign language. See also Syntax 89.

21.9.1 Syntax

```
export_action ::= export [ platform_qualifier ] action_type_identifier
               function_parameter_list_prototype ;
```

Syntax 89—Export action declaration

The `export` statement for an `action` specifies the action to export and the parameters of the action to make available to the foreign language, where the parameters of the exported action are associated by name with the action being exported. The `export` statement also optionally specifies in which phases of test generation and execution the exported action will be available.

The following also apply:

a) As with imported functions (see 21.2.1), the exported action is assumed to always be available if the function availability is not specified.

b) Each call into an `export` action infers an independent tree of actions, components, and resources.
c) Constraints and resource allocation are considered within the inferred action tree and are not considered across imported function / exported action call chains.

### 21.9.2 Examples

**Example 248** shows an exported action. In this case, the action `comp::A1` is exported. The foreign language invocation of the exported action supplies the value for the `mode` field of action `A1`. The PSS processing tool is responsible for selecting a value for the `val` field. Note that `comp::A1` is exported to the target, indicating the target code can invoke it.

```plaintext
component comp {
    action A1 {
        rand bit          mode;
        rand bit[31:0]    val;

        constraint {
            if (mode!=0) {
                val in [0..10];
            } else {
                val in [10..100];
            }
        }
    }

    package pkg {
        // Export A1, providing a mapping to field 'mode'
        export target comp::A1(bit mode);
    }
}
```

**Example 248—Export action**

### 21.9.3 Export action foreign language binding

An exported action is exposed as a function in the target foreign language (see **Example 249**). The component namespace is reflected using a language-specific mechanism: C++ namespaces, SystemVerilog packages. Parameters to the exported action are implemented as parameters to the foreign language function.

```plaintext
namespace comp {
    void A1(unsigned char mode);
}
```

**Example 249—Export action foreign language implementation**
22. Conditional code processing

It is often useful to conditionally process portions of a PSS model based on some configuration parameters. This clause details a compile if construct that can be evaluated as part of the elaboration process.

22.1 Overview

This section covers general considerations for using compile statements.

22.1.1 Statically-evaluated statements

A statically-evaluated statement marks content that may or may not be elaborated. The description within a statically-evaluated statement shall be syntactically correct, but need not be semantically correct when the static scope is disabled for evaluation.

A statically-evaluated statement may specify a block of statements. However, this does not introduce a new scope in the resulting description.

22.1.2 Elaboration procedure

Compile statements are processed top-to-bottom within a given source unit. The following steps are performed in processing source code in the presence of conditional compilation directives:

a) Syntactic code analysis is performed.

b) Compile-time expressions are evaluated in order within the following contexts:

1) static const initializers
2) compile if conditions (see 22.2)

These expressions are evaluated based on types and static constants declared:

1) Unconditionally, or in an enabled compile if branch, within a previously-processed source unit
2) Unconditionally, or in an enabled compile if branch, previously processed within the current source unit

c) Globally-visible content and the content within enabled compile if branches is elaborated.

22.1.3 Compile-time expressions

The value of any compile if expressions must be determinable at compile time. Because compile if statements are evaluated early in PSS source processing, only types and constants declared in package scopes may be referenced. Types and constants declared in type scopes (e.g., an action type declared within a component type) may not be referenced.

The example below highlights the reference rules for conditional compilation directives:

a) Conditional compilation directives are evaluated based on previously defined elements.

1) Consequently, the first directive (compile has(s)) evaluates true because p1::s is visible at this point in the evaluation.

2) The second directive (compile has(t)) also evaluates true because p2::t has been previously declared in the source unit.

b) Conditional compilation directives may not reference inner members of types. Consequently, attempting to reference t::A is an error, since t is a type and A is an inner member of type t.
22.2 compile if

22.2.1 Scope

compile if statements may appear in the following scopes:

- Global/package
- Action
- Component
- Struct
- Execs
- Constraints
- Covergroups
- Overrides

Example 250—Conditional compilation evaluation

```plaintext
package p1 {
  struct s {
    static const int A = 3;
  };
}

package p2 {
  import p1::*;
  // derived from p2::s defined later in this file
  struct t : s {};

  // evaluates to true because such a type has been previously defined,
  // namely p1::s
  compile if (compile has (s)) { … }

  // evaluates to true because such a type has been previously defined,
  // namely p2::t (even though its supertype is not yet known)
  compile if (compile has (t)) { … }

  // Illegal! Cannot reference a member of a struct in compile-if context
  compile if (t::A == 2) { … }
  struct s {};
}
```
22.2.2 Syntax

Syntax 90 shows the grammar for a compile if statement.

```
package_body_compile_if ::= compile if ( constant_expression )
                          package_body_compile_if_item [ else package_body_compile_if_item ]

action_body_compile_if ::= compile if ( constant_expression )
                        action_body_compile_if_item [ else action_body_compile_if_item ]

component_body_compile_if ::= compile if ( constant_expression )
                          component_body_compile_if_item [ else component_body_compile_if_item ]

struct_body_compile_if ::= compile if ( constant_expression )
                       struct_body_compile_if_item [ else struct_body_compile_if_item ]

procedural_compile_if ::= compile if ( constant_expression )
                       procedural_compile_if_stmt [ else procedural_compile_if_stmt ]

constraint_body_compile_if ::= compile if ( constant_expression )
                         constraint_body_compile_if_item [ else constraint_body_compile_if_item ]

covergroup_body_compile_if ::= compile if ( constant_expression )
                      covergroup_body_compile_if_item [ else covergroup_body_compile_if_item ]

override_compile_if ::= compile if ( constant_expression )
                  override_compile_if_stmt [ else override_compile_if_stmt ]

package_body_compile_if_item ::= { { package_body_item } }

action_body_compile_if_item ::= { { action_body_item } }

component_body_compile_if_item ::= { { component_body_item } }

struct_body_compile_if_item ::= { { struct_body_item } }

procedural_compile_if_stmt ::= { { procedural_stmt } }

constraint_body_compile_if_item ::= { { constraint_body_item } }

covergroup_body_compile_if_item ::= { { covergroup_body_item } }

override_compile_if_stmt ::= { { override_stmt } }
```

NOTE—In previous versions of PSS, a compile if branch consisting of a single item, such as a single package_body_item, did not have to be enclosed in curly braces. That syntax has been deprecated.

22.2.3 Examples

Example 251 shows an example of conditional processing if PSS were to use C pre-processor directives. If the PROTOCOL_VER_1_2 directive is defined, then action new_flow is evaluated. Otherwise, action old_flow is processed.

NOTE—Example 251 is only shown here to illustrate the functionality of C pre-processor directives in a familiar format. It is not part of PSS.
Example 251—Conditional processing (C pre-processor)

Example 252 shows a PSS version of Example 251 using a compile if statement instead.

Example 252—Conditional processing (compile if)

When the true case is triggered, the code in Example 252 is equivalent to:

```
action new_flow {
    activity { ... }
}
```

When the false case is triggered, the code in Example 252 is equivalent to:

```
action old_flow {
    activity { ... }
}
```

22.3 compile has

compile has allows conditional elaboration to reason about the existence of types and constants. The compile has expression evaluates to true if a type or constant has been previously declared unconditionally or within an enabled conditional block (see 22.1.2); otherwise, it evaluates to false.

22.3.1 Syntax

Syntax 91 shows the grammar for a compile has expression.
22.3.2 Examples

Example 253 checks whether the config_pkg::PROTOCOL_VER_1_2 field exists and tests its value if it does. In this example, old_flow will be used because config_pkg::PROTOCOL_VER_1_2 does not exist.

```
package config_pkg {
}

compile if (compile has(config_pkg::PROTOCOL_VER_1_2) &&
           config_pkg::PROTOCOL_VER_1_2) {
    action new_flow {
        activity { ... }
    }
} else {
    action old_flow {
        activity { ... }
    }
}
```

Example 253—compile has

Example 254 is composed of a single source unit.

— The first top-level compile if block checks for the existence of X. This evaluates to false, since X is only subsequently declared within the source unit.

— The second top-level compile if block checks for the non-existence of Y. This evaluates to true, since Y was not previously declared (the first compile if block was not expanded). As a consequence, Y is declared with a value of 0.

```
const int X = 1;
compile if (compile has(Y)) {
    const int Y = 2;
    compile if (compile has(Y)) {
        const int Z;
    }
} else {
    compile if (compile has(Z)) {
        const int A;
    }
}
```

Example 254—Nested conditions
22.4 compile assert

**compile assert** assists in flagging errors when the source is incorrectly configured. This construct is evaluated during elaboration. A tool shall report a failure if *constant_expression* does not evaluate to *true*, and report the user-provided message, if specified.

22.4.1 Syntax

Syntax 92 shows the grammar for a **compile assert** statement.

```
compile_assert_stmt ::= compile assert ( constant_expression [ . string_literal ] ) ;
```

**Syntax 92—compile assert statement**

22.4.2 Examples

**Example 255** shows a **compile assert** example.

```
compile if (compile has(FIELD2)) {
    static const FIELD1 = 1;
}

compile if (compile has(FIELD1)) {
    static const FIELD2 = 2;
}
compile assert(compile has(FIELD1), "FIELD1 not found");
```

**Example 255—compile assert**
23. PSS core library

The PSS core library provides standard portable functionality and utilities for common PSS applications. It defines a set of component types, data types, functions, and attributes. The interface of the core library is specified in PSS-language terms, and its use conforms to the rules of the language. However, the full semantics of its entities involve reference to type information, solving, scheduling, and runtime services. Hence, the implementation of the core library depends on inner workings of PSS processing tools and is expected to be coupled with them.

The core library currently covers functionality in the following areas:
- String formatting and output operations
- File operations
- Error reporting
- Randomization
- Manipulation and storage of floating-point values
- Representation of execution contexts in the target environment
- Assignments of actions and flow/resource objects to execution contexts
- Representation of target address spaces
- Allocation from and management of target address spaces
- Access to target address spaces
- Representation of and access to registers

The core library functionality is defined in three packages:
- \texttt{std\_pkg}, covering string formatting, file operations, error reporting, randomization, and core data types
- \texttt{executor\_pkg}, covering representation of execution contexts and assignment of actions and flow/resource objects to execution contexts
- \texttt{addr\_reg\_pkg}, covering representation of address spaces and access to memory, and representation and access to registers

This section covers the interface, semantics, and intended use of core library entities in the areas listed above. Note that it defines a library interface, not new language constructs. The code for the built-in library package contents appears in Annex C.

In the following sections, library code definitions may omit reiterating the surrounding package, and example code may omit importing core library packages for brevity.

23.1 String formatting and output

The PSS core library provides means for string formatting and output operations. The built-in package \texttt{std\_pkg} defines functions and types for these purposes, as well as for file operations and error reporting, introduced in the next two sections of this document.

On solve platforms, a complete set of input/output and file operations is provided, similar to other programming languages. Functions are defined for string formatting, printing, and reading from and writing to text files.

On target platforms, a limited portable messaging capability is provided, because some target environments may not have a file system or access to string manipulation libraries such as in C.
23.1.1 String formatting

Several output functions involve a string formatting capability. They are based on an approach similar to C printf()-style string formatting. Each of these functions gets a format string parameter `format_str` of type `string`, followed by a generic varargs parameter `args`.

The format string is used as a template, where all characters are taken literally except when the character `%` appears. A `%` followed by another `%` denotes a single literal `%`. Otherwise, a `%` starts a format specifier.

A format specifier determines how data passed in each subsequent function parameter (passed as varargs) should be embedded in the resulting string. It consists of the following optional parts followed by a formatting character:

```
%[flags][width][.precision]format
```

The optional `flags`, if specify, denote the following:

<table>
<thead>
<tr>
<th>Flag</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>Left justification (default is right justification)</td>
</tr>
<tr>
<td>+</td>
<td>Force a sign (+ or -) to precede numeric values. By default, positive numbers are not preceded with +.</td>
</tr>
<tr>
<td>space</td>
<td>If a numeric value is not preceded by a sign, it is preceded by a space.</td>
</tr>
<tr>
<td>#</td>
<td>For o, x, X, b or B format characters, the value is preceded with 0, 0x, 0X, 0b or 0B, respectively, for values different from zero. For floating-point formats, force a decimal point even if no more digits follow the decimal point.</td>
</tr>
<tr>
<td>0</td>
<td>When left padding is used, pad a numeric value with zeros instead of spaces.</td>
</tr>
</tbody>
</table>

The optional `width`, if specified, denotes the minimum number of characters to insert into the formatted string. The inserted value is not truncated if larger than the specified width. `width` is typically used to pad fixed-width fields in tabulated output.

The optional `precision`, if specified, denotes the following:

- For integer formats (including p), specifies the minimum number of digits to be inserted into the formatted string. If needed, the result is padded with leading zeros. The value is not truncated even if the result is longer. A `precision` of 0 means that no character is inserted for the value 0.
- For floating-point formats e, E, and f, specifies the number of digits to be inserted after the decimal point. By default, this is 6.
- For floating-point formats g and G, specifies the maximum number of significant digits to be inserted.
- For s and n formats, specifies the maximum number of characters to be inserted. By default, all characters in the string, the enumeration item name, or the boolean name are used. Truncation, if needed, is from the right.

If `precision` is empty (the period is specified without an explicit value for `precision`), 0 is assumed.
The formatting character determines the expected data type of the corresponding function parameter and how it is formatted, as follows:

```
<table>
<thead>
<tr>
<th>Character</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>d</td>
<td>A signed integer in decimal radix.</td>
</tr>
<tr>
<td>u</td>
<td>An unsigned integer in decimal radix.</td>
</tr>
<tr>
<td>x, X</td>
<td>An unsigned integer in hexadecimal radix. x uses lowercase letters and X uses uppercase.</td>
</tr>
<tr>
<td>o</td>
<td>An unsigned integer in octal radix.</td>
</tr>
<tr>
<td>b, B</td>
<td>An unsigned integer in binary radix. If # flag is specified, b uses lowercase 0b and B uses uppercase 0B.</td>
</tr>
<tr>
<td>f</td>
<td>A floating-point value in decimal form. For example, 123.4567.</td>
</tr>
<tr>
<td>e, E</td>
<td>A floating-point value in scientific form. For example, 1.234567e+02. e uses lowercase e for the exponent and E uses uppercase E.</td>
</tr>
<tr>
<td>g, G</td>
<td>A floating-point value in the shortest form, decimal or scientific. If scientific form, g corresponds to e, and G corresponds to E.</td>
</tr>
<tr>
<td>n</td>
<td>An enumeration item value in the form of its name, or a Boolean value in the form of &quot;false&quot; or &quot;true&quot;.</td>
</tr>
<tr>
<td>s</td>
<td>A string.</td>
</tr>
<tr>
<td>p</td>
<td>A chandle as a pointer value in hexadecimal form, including the preceding 0x (similar to %#x for integer numbers)</td>
</tr>
</tbody>
</table>
```

The following also apply:

a) If the format string contains % followed neither by another % nor by a valid format specifier, an error shall be generated.

b) The number of format specifiers in the format string shall be equal to the number of parameters in the varargs. Otherwise, an error shall be generated.

c) Each format specifier in the format string shall match the type of the corresponding parameter in the varargs. Implicit type conversions shall be allowed. For example: if %d is used for a parameter of an unsigned type, the value is converted to signed type before being formatted; if %f is used for a parameter of an integer type, the value is converted to floating-point before being formatted. If the type does not match and an implicit type conversion is not applicable, an error shall be generated.

### 23.1.2 Solve-time string formatting and output

The functions `format()` and `print()` are used on the solve platform to facilitate the string formatting functionality. The function `format()` returns a formatted string. The function `print()` outputs a formatted string to the standard output and can be used to display and log certain information.

```plaintext
class std_pkg {
  function string format(string format_str, type... args);
  function void print(string format_str, type... args);
}
```

**Syntax 93—String formatting and output functions**
Example 256 demonstrates how native functions can be used to print or to return a formatted string of the context of a given struct instance.

```
import std_pkg::*;
struct my_struct {
    int value;
    string name;
}
solve function void print_foo(my_struct s) {
    print("The context of the struct is:
";    print("value = \%d\nname = '\%s'\n", s.value, s.name);
}
solve function string get_foo_context_string(my_struct s) {
    return format("value = \%d\nname = '\%s'\n", s.value, s.name);
}
```

Example 256—Printing or formatting the context of a struct

23.1.3 Runtime messaging

The function `message()` is used to log certain information during the execution of a test in a portable way. It inserts a text line, including a trailing newline (\n), into the execution log on the target platform.

```
package std_pkg {
    enum message_verbosity_e {NONE, LOW, MEDIUM, HIGH, FULL};
    function void message (message_verbosity_e vrb_level, string format_str, type... args);
}
```

Syntax 94—Runtime messaging function

The PSS processing tool shall provide means for specifying a messaging verbosity level for a given test run. For a higher test run verbosity level, more messages will be issued and more information will be provided.

The parameter `vrb_level` denotes the verbosity level of a particular message, and determines the minimum test run verbosity level for which the message should be issued. Messages with verbosity higher than the test run verbosity level shall be ignored.

For example, a message of verbosity level `NONE` is considered non-verbose; it is typically a critical message which shall always be issued regardless of the verbosity level of the run. A message of verbosity level `LOW` shall not be issued in a run whose verbosity level is `NONE`, but shall be issued in all other cases, because it is typically an important, though not critical, message. A message of verbosity level `FULL` is considered very verbose, and it shall only be issued in a run whose verbosity level is `FULL`; it is typically a less important message which may provide some additional details or information which is not essential in most runs.

The parameter `vrb_level` shall be an expression whose value is known at solve time, i.e., an expression whose value is unchanged in target contexts. Implementations may leverage this fact to optimize generated test code based on verbosity settings.

The parameter `format_str` shall be a string expression whose value is known at solve time. If any subsequent `args` data parameters are strings (as opposed to numbers), their values must also be known at solve time. In particular, string variables that are assigned in target contexts are not allowed. This is to
enable implementations to determine on the solve platform the target memory requirements for the string formatting operation.

If expressions with side effects, such as non-pure function calls, are passed as parameters to `message()`, their evaluation is not guaranteed, because the verbosity level of a particular test run may determine whether or not they are evaluated. Therefore, users should avoid such expressions as parameters to `message()`.

**Example 257** demonstrates the usage of `message()` in an exec body block. There are two messages: the first message of verbosity level `FULL`, and the second message of verbosity level `LOW`. In test runs whose verbosity level is `NONE`, no message is issued. In runs whose verbosity level is at least `LOW` but lower than `FULL`, only the second message is issued. In runs with verbosity level `FULL`, both messages are issued.

```plaintext
import std_pkg::*;
component C {
    target function int my_func() {...}
    action A {
        rand int x;
        exec body {
            y = my_func();
            message(FULL, "The values of the variables x and y are: ");
            message(LOW, "%d, %d", x, y);
        }
    }
}
```

**Example 257—Runtime messages**

### 23.2 File operations

The PSS core library provides two flavors of text input/output operations on solve platform files. Files can be opened separately to obtain a file handle, which can then be used when calling write and read functions. Alternatively, write and read can be performed with a single function call that also opens and closes the file.

File read and write operations in both flavors use string values.

**Syntax 95** specifies types and functions used for file operations that use file handles.
The type `file_handle_t` is used to represent a text file that is open for the purpose of reading or writing. A file handle is obtained by calling function `file_open()`.

Values of the enumeration type `file_option_e` represent the purpose of the file, as follows:
- `TRUNCATE`  Delete any existing content of the file and allow write operations.
- `APPEND`    Allow write operations; text will be appended to the existing file content.
- `READ`     Allow read operations.

The function `file_open()` returns a file handle to the file whose name is specified by `filename`. If the file fails to open in the mode specified by `opt`, the special value `nullfilehandle` is returned.

The function `file_close()` closes the file represented by `file_handle`, which must have been previously opened and not closed. Once a file has been closed, the handle can no longer be used for reading or writing.

The function `file_exists()` returns true if a file with the specified filename exists in the file system, otherwise returns false.

The function `file_write()` writes a formatted string to a file represented by `file_handle`, which must have been opened with the `TRUNCATE` or `APPEND` option. A newline is not added at the end.

The function `file_read()` reads at most `size` number of characters from a file represented by `file_handle`, and returns a string containing those characters. If `size` is negative (or not specified), the entire content of the file is read and returned. The file must have been opened with the `READ` option.

The functions `file_write()`, `file_read()`, and `file_close()` shall trigger an appropriate error if the operation cannot be performed.

Syntax 96 specifies functions used for file reading and writing in a single function call.
Syntax 96—Simple text file operations

The function **file_write_lines()** writes all strings in `lines` to the file whose name is specified by `filename`. A newline character is inserted at the end of each string. `opt` must be either **TRUNCATE** or **APPEND**. If **APPEND** is used, a newline character is also inserted at the end of the existing file content, unless the last character in it is already a newline character.

The function **file_read_lines()** reads the entire file whose name is specified by `filename`, and returns a list of strings representing the text in the file. A string is terminated when a newline character in the file is reached. The newline characters themselves are not included in the strings.

Both functions trigger an appropriate error if the operation cannot be performed.

In principle, the string passed as the `filename` parameter to functions **file_open()**, **file_exists()**, **file_write_lines()**, and **file_read_lines()** can include a directory path. PSS processing tools may provide specific ways of mapping a physical file in the file system to a given `filename` string. For example, a tool may use an environment variable to provide one or more search paths for files (similar to a **PATH** environment variable used in many operating systems to search for executable files).

Example 258 shows two functions that write the content of a given struct list into a text file in a certain arbitrary format. Both functions achieve the same result, but the first function uses a file handle, and the second function uses **file_write_lines()** directly.
23.3 Error reporting

The functions `error()` and `fatal()` are used to report an error during a test and/or to abort the rest of the run in a portable way. They are similarly used for the solving process.

```plaintext
import std_pkg::*;
struct my_struct {
    int value;
    string name;
}

solve function void write_my_struct_list_using_file_handle
    (string file_name, list<my_struct> s_list)
{
    file_handle_t f = file_open(file_name, TRUNCATE);
    foreach (s: s_list) {
        file_write(f, "%d %s\n", s.value, s.name);
    }
    file_close(f);
}

solve function void write_my_struct_list_using_string_list
    (string file_name, list<my_struct> s_list)
{
    list<string> lines;
    foreach (s: s_list) {
        lines.push_back(format("%d %s", s.value, s.name));
    }
    file_write_lines(file_name, lines, TRUNCATE);
}
```

Example 258—File operations

Both `error()` and `fatal()` insert the specified formatted text into the solving or execution log, with a trailing newline character.

The parameter `format_str` shall be a string expression whose value is known at solve time. If there are strings (as opposed to numbers) among the subsequent `args` data parameters, they must also be known at solve time. In other words, when used in target contexts, the string values of those parameters must be constant at run time.

The function `fatal()` shall terminate the solving or execution flow at the nearest possible point. The value of the parameter `status` is returned to the calling environment.

The function `error()` may terminate the solving or execution flow, or it may not, depending on tool/session-specific criteria.

Example 259 demonstrates reporting of a run-time error under a particular condition.
23.4 Randomization

Randomization functions are contained within the std_pkg package.

```plaintext
package std_pkg {
  function bit[32] urandom();
  function bit[32] urandom_range(bit[32] min, bit[32] max);
}
```

Syntax 98—Randomization functions

23.4.1 urandom()

The `urandom()` function returns an unsigned 32-bit integer.

23.4.2 urandom_range(min, max)

The `urandom_range()` function returns an unsigned 32-bit integer between the specified minimum and maximum values.

23.5 Floating-point

PSS defines a set of functions for manipulating floating-point values and representing various storage formats of floating-point numbers. These functions and data types are defined in the std_pkg package.

23.5.1 Floating-point storage types

```plaintext
struct float_base_s <int Wm, int We, endianness_e E=LITTLE_ENDIAN> :
  packed_s<E> {
    rand bit[Wm] mantissa;
    rand bit[We] exponent;
    rand bit sign;
  }

typedef float_base_s<23, 8> float32_s;
typedef float_base_s<52,11> float64_s;
```

Syntax 99—Floating-point storage types
The PSS core library defines a `struct, float_base_s`, to represent the in-memory layout of floating-point numbers. Specific specializations of this templated type are used to capture specific storage layouts. The `float_base_s` struct inherits from the `packed_s` struct type, which is described in 23.9. Storage formats for the two built-in computation types are defined as part of the core library package.

### 23.5.2 Floating-point computation functions

The PSS core library defines the following floating-point computation functions. All functions return `float64` as a result, and accept parameters of type `float64`. Their behavior shall match the equivalent C language standard math library function with the same name, since `float64` is equivalent to the `double` type in C. Function prototypes may be found in Annex C.

Floating-point functions may not be used in constraints.

**Table 27—Floating-point computation functions**

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>log(x)</code></td>
<td>Natural logarithm</td>
</tr>
<tr>
<td><code>log10(x)</code></td>
<td>Decimal logarithm</td>
</tr>
<tr>
<td><code>exp(x)</code></td>
<td>Exponential</td>
</tr>
<tr>
<td><code>sqrt(x)</code></td>
<td>Square root</td>
</tr>
<tr>
<td><code>pow(x,y)</code></td>
<td>$x^y$</td>
</tr>
<tr>
<td><code>round(x)</code></td>
<td>Round to nearest value</td>
</tr>
<tr>
<td><code>floor(x)</code></td>
<td>Floor</td>
</tr>
<tr>
<td><code>ceil(x)</code></td>
<td>Ceiling</td>
</tr>
<tr>
<td><code>sin(x)</code></td>
<td>Sine</td>
</tr>
<tr>
<td><code>cos(x)</code></td>
<td>Cosine</td>
</tr>
<tr>
<td><code>tan(x)</code></td>
<td>Tangent</td>
</tr>
<tr>
<td><code>asin(x)</code></td>
<td>Arc-sine</td>
</tr>
<tr>
<td><code>acos(x)</code></td>
<td>Arc-cosine</td>
</tr>
<tr>
<td><code>atan(x)</code></td>
<td>Arc-tangent</td>
</tr>
<tr>
<td><code>atan2(y,x)</code></td>
<td>Arc-tangent of y/x</td>
</tr>
<tr>
<td><code>hypot(x,y)</code></td>
<td>$\sqrt{x^2+y^2}$</td>
</tr>
<tr>
<td><code>sinh(x)</code></td>
<td>Hyperbolic sine</td>
</tr>
<tr>
<td><code>cosh(x)</code></td>
<td>Hyperbolic cosine</td>
</tr>
<tr>
<td><code>tanh(x)</code></td>
<td>Hyperbolic tangent</td>
</tr>
<tr>
<td><code>asinh(x)</code></td>
<td>Arc-hyperbolic sine</td>
</tr>
<tr>
<td><code>acosh(x)</code></td>
<td>Arc-hyperbolic cosine</td>
</tr>
<tr>
<td><code>atanh(x)</code></td>
<td>Arc-hyperbolic tangent</td>
</tr>
</tbody>
</table>
23.5.3 Computation-type field extraction and composition

Floating-point computation and storage data types both have a sign, exponent, and mantissa component. Floating-point types differ in the width of the exponent and mantissa components. PSS defines functions for accessing the various components of computation types, and functions for forming a computation-type value from floating-point component parts.

```plaintext
function bit[52] float_mantissa(float64 fv);

Syntax 100—float_mantissa function
```

The `float_mantissa()` function extracts the mantissa bit image from the specified `float64` value as is with no conversion.

```plaintext
function bit[11] float_exponent(float64 fv);

Syntax 101—float_exponent function
```

The `float_exponent()` function extracts the exponent bit image from the specified `float64` value as is with no conversion.

```plaintext
function bit float_sign(float64 fv);

Syntax 102—float_sign function
```

The `float_sign()` function extracts the sign bit of the specified `float64` value.

```plaintext
function float64 to_float(bit[52] mantissa, bit[11] exp, bit sign);

Syntax 103—to_float function
```

The `to_float()` function composes a `float64` value from the specified sign, exponent, and mantissa component bit images.
Example 260 above shows conversion of the floating-point value 20.25 held in a float64 variable to a bfloat16_s floating-point storage data type. The bfloat16_s storage type has an exponent of 8 bits and a mantissa of 7 bits, while the float64 variable has an exponent of 11 bits and a mantissa of 52 bits.

In this example, the exponent part is stored in the storage type in biased form. To achieve this, it is first unbiased from the original bit image representation of 11 bits (by subtracting $2^{11-1-1}$) and then biased for 8 bits (by adding $2^{8-1-1}$). For the mantissa part, the 7 left-most bits are used, which is achieved by left-shifting by 52-7 bits.

Finally, the components of the bfloat16_s type are converted back to a float64 value using the to_float() function.

### 23.6 Executors

A PSS generated test calls foreign functions available in the target environment, executes target-language code blocks, and performs target operations provided in the core-library. It does so in accordance with the user-defined realization of actions and of flow/resource objects specified in the form of target exec blocks—body, run_start, and run_end—and functions called from them. Foreign function calls, target-language code blocks, and built-in target operations, all need to be performed under a certain agent of execution available to the test in the runtime environment, or in short, an executor.

An executor is an abstract notion that may correspond to different kinds of entities in different environments. For example:

- An embedded processor core or HW thread in a bare-metal environment that executes code generated by the PSS tool
- A BFM instantiated as a master on an interconnect of the DUT that exposes transactional APIs to the PSS tool
A transactor, or testbench agent, connected to an I/O interface of the system that exposes transactional APIs, or higher-level stimulus sequences, to the PSS tool

The PSS core library provides means to represent executors in the PSS description and to assign scenario entities to them. Executors are characterized by user-defined properties called traits, which serve to control the assignment of actions/objects to them. For example, the cluster of a CPU core could be represented as a trait attribute. Related executors are grouped together so that scenario entities can be assigned to a random instance out of a group. The selection of executors satisfies constraints on their trait attributes, if any are specified.

In addition, executors can be used to customize the implementation of target functions for specific environments. Actions assigned to different executors can thereby employ different mappings of portable operations.

The PSS built-in package executor_pkg defines types and functions related to the management of executors. In subsequent sections, except Syntax 104, the enclosing executor_pkg is omitted for brevity. Examples may also omit import of executor_pkg.

### 23.6.1 Executor representation

An executor is an execution agent or context available to the test in the runtime environment. Executors are represented using a core-library component type instantiated in the PSS description. Actions and flow/resource objects may subsequently be assigned to these executors. This assignment is controlled through an executor claim struct (see 23.6.2).

Representing executors in a PSS description is optional. In the absence of executor instances, PSS tools are free to determine the execution context of entities based on other considerations, such as global defaults or policies.

#### 23.6.1.1 Executor component type

An executor is represented using the template component executor_c, or a subtype of it. The template parameter is used to tag the executor and possibly to provide additional selection attributes. Template executor_c is derived from executor_base_c.

```plaintext
package executor_pkg {
    struct executor_trait_s {}
    struct empty_executor_trait_s : executor_trait_s {}
    component executor_base_c {}
    component executor_c
        <struct TRAIT : executor_trait_s = empty_executor_trait_s>
        : executor_base_c {
            TRAIT trait;
        }
    ...
}
```

**Syntax 104—Executor component**

An executor component is strictly a test-realization artifact. It shall be an error to declare in its scope scenario model elements, namely: action types, pool instances, and pool binding directives.
23.6.1.2 Executor group component type

Component `executor_group_c` is used to group one or more executors that serve similar purposes. Actions and flow/resource objects that claim an executor are assigned to an executor selected out of one specific group (see more on matching rules in 23.6.2.2).

```
component executor_group_c
    <struct TRAIT : executor_trait_s = empty_executor_trait_s> {
        function void add_executor(ref executor_c<TRAIT> exe);
    };
```

Syntax 105—Executor group component

An executor group component is strictly a test-realization artifact. It shall be an error to declare in its scope scenario model elements, namely: action types, pool instances, and pool binding directives.

23.6.1.2.1 add_executor function

Instance function `add_executor` (see Syntax 105) of `executor_group_c` is used to populate the group with executor instances. Executors added to a group must all match with the group’s trait struct type. The `add_executor` function may only be called in exec `init_down` and `init_up` blocks.

The following also apply:
- a) Any executor can be added to a given group, regardless of where it is instantiated in the component instance tree. This includes executors instantiated above the group, below it, or in a different sub-tree.
- b) An executor instance may not be added more than once to the same group.
- c) An executor instance may be added to more than one group.
- d) An executor does not have to be added to any group. An executor that is not part of any group would be inactive—no exec blocks would ever be assigned to it.

Example 261 demonstrates how executors are defined, instantiated, and added to an executor group. The executor group `my_hybrid_group_c` is populated with two different executor types. These two types may vary in properties, but are both derived from the instantiation of template `executor_c` with the struct type `master_trait_s`. The executors in this group are treated symmetrically when assigning actions to them.
Example 261—Defining an executor group

```
struct master_trait_s : executor_trait_s {};

component my_core_executor_c : executor_c<master_trait_s> { ... };

component my_bus_vip_executor_c : executor_c<master_trait_s> { ... };

component my_hybrid_group_c : executor_group_c<master_trait_s> {
  my_core_executor_c cores[4];
  my_bus_vip_executor_c bfms[2];

  exec init_down {
    foreach (c: cores) {
      add_executor(c);
    }
    foreach (b: bfms) {
      add_executor(b);
    }
  }
};
```

### 23.6.2 Executor assignment

An action or a flow/resource object can declare its claim for an executor by instantiating a *claim struct*. Each claim instance is statically matched to an executor group that is nearest in the component instance tree and parameterized by the same trait struct type. The entity is assigned to an executor out of the matching group, which satisfies the trait constraints.

It is not required that scenario entities be explicitly assigned to an executor even if they contain target `exec` blocks. In the absence of explicit assignments, PSS tools are free to determine the execution context of entities based on other considerations, such as global defaults or policies.

Executors do not generally limit concurrency of PSS behaviors in a test scenario. In cases where concurrently scheduled actions are assigned to the same underlying executor, the PSS tool is responsible for employing the means to enable concurrent execution, such as preemptive or cooperative multitasking.

#### 23.6.2.1 Executor claim struct type

An action or a flow/resource object can control its assignment to an executor by declaring an *executor claim* —an attribute of template struct type `executor_claim_s`. An executor claim can be a direct field of the entity, a field of any of its nested structs, or in the case of flow/resource objects, the supertype from which the object is derived. In all these cases, the assignment to an executor applies in the same way.

An action or a flow/resource object may be assigned to no more than one executor. Therefore, there can only be one executor claim struct anywhere under a given action or object. Multiple executor claim structs within the same action or object shall be flagged as an error. Note that the assignment of executors per an executor claim is not exclusive, and is generally unrelated to the relative scheduling of actions.
Example 262 demonstrates the use of the `executor_claim_s` struct. In this case, `action` A declares an executor claim. A's executor claim is matched with executor group `eg` that is instantiated directly under its context `component` C, as both are parameterized with the same (default) trait type. Consequently, `action` A is necessarily assigned to the executor `e` instantiated under its context component. `Component` C is instantiated twice under `pss_top`. Under the entry `action` test, `action` A is invoked three times. The generated test will call the function `do_something()` twice under the execution context associated with executor `c1.e`, and subsequently once under the execution context associated with executor `c2.e`.

```cpp
struct executor_claim_s
    <struct TRAIT : executor_trait_s = empty_executor_trait_s> { 
    rand TRAIT trait;
};
```

23.6.2.2 Rules for matching an executor claim with an executor group

An executor claim is matched with an executor group for the purpose of selecting an executor. The matching is based on the static structure of the model. A claim is resolved to an executor group that:

a) is parameterized by the same trait type as the claim;

b) is instantiated in a containing component of the declaring scenario entity (the context component hierarchy of an action or the container component of a flow/resource object pool);
c) and is nearest in the component hierarchy going up from the context component to the root component.

It shall be an error if no executor group matches a claim per the above rules. Similarly, it shall be an error if more than one executor group in the component context identified in b) matches a claim.

Note that given the above rules, instantiating a group within a group would be pointless, as no executor claim could match the inner group.

23.6.2.3 Claim trait semantics

The trait type of an executor claim must be the same as that of the executor selected for the declaring entity. In addition, the trait attribute values of the executor claim instance must be equal to the values of the corresponding attributes of the executor trait. Hence, the selected executor shall satisfy the claim trait constraints.

Example 263 demonstrates the use of the executor trait struct for the selection of executors. In this example, executors in group my_embedded_cores_group_c, representing eight CPU cores, are classified into two clusters, each consisting of four cores. Action my_ip_c::op claims an executor. It constrains the selection of the executor, relating the executor cluster ID to other attributes. Action ops_on_two_clusters executes two op actions, one on each cluster. Note that the one assigned to cluster 0 will have its input buffer mem_kind not equal to DDR, due to the constraint in action op.
struct my_core_trait_s : executor_trait_s {
    rand int in [0..1] cluster_id;
};

component my_embedded_cores_group_c : executor_group_c<my_core_trait_s> {
    executor_c<my_core_trait_s> cores[8];
    exec init_down {
        foreach (c: cores[i]) {
            c.trait.cluster_id = i/4;
            add_executor(c);
        }
    }
};

component my_ip_c {
    action op {
        input data_buff in_buff;
        rand executor_claim_s<my_core_trait_s> core;
        constraint in_buff.mem_kind == DDR -> core.trait.cluster_id != 0;
    }
};

component pss_top {
    my_embedded_cores_group_c embedded_core_group;
    my_ip_c my_ip;
    action ops_on_two_clusters {
        activity {
            do my_ip_c::op with { core.trait.cluster_id == 0; };
            do my_ip_c::op with { core.trait.cluster_id == 1; };
        }
    }
};

---

Example 263—Definition and use of executor trait
23.6.2.4 Executor resources

In some cases, the assignment of certain actions to executors needs to be exclusive, ruling out the handling of concurrent actions by the same execution agent. Resource claims and resource pools express such rules at the scenario model level, guaranteeing that random schedules satisfy the resource consistency of executors. In these cases, the executor assigned to actions needs to be in strict correspondence with the resource instance claimed by them.

A resource object that is derived from template struct `executor_claim_s` is considered a claim not just for the purpose of its own executor assignment, but also for that of the actions that claim it as a resource in either lock or share mode. In other words, from the executor assignment point of view, a reference to a resource object derived from struct `executor_claim_s` functions like an executor claim of the action itself.

In Example 264, resource object `my_core_r` represents a processor core at the scenario model level. Action `my_ip_c::op1` needs to be assigned a core exclusively for its duration, and therefore locks a resource instance. Action `my_ip_c::op2` does not require exclusive use of a core, and therefore claims a resource instance in share mode. Action `test` executes a random selection of `op1` and `op2`, which need to be scheduled consistently across the different cores.
struct my_core_trait_s : executor_trait_s {
    rand int in [0..7] core_id;
};

resource my_core_r : executor_claim_s<my_core_trait_s> {
    constraint trait.core_id == instance_id;
};

component my_cores_group_c : executor_group_c<my_core_trait_s> {
    executor_c<my_core_trait_s> cores[8];
    exec init down {
        foreach (c: cores[i]) {
            c.trait.core_id = i;
            add_executor(c);
        }
    }
};

component my_ip_c {
    action op1 {
        lock my_core_r core;
        exec body {
            my_ip_blocking_op();
        }
    }
    action op2 {
        share my_core_r core;
        exec body {
            while (!my_ip_op2_done()) { yield(); }
        }
    }
};

component pss_top {
    my_cores_group_c core_group;
    pool [8] my_core_r core_pool;
    bind core_pool *;
    my_ip_c my_ip;
    action test {
        activity {
            schedule {
                replicate (10) {
                    select {
                        do my_ip_c::op1;
                        do my_ip_c::op2;
                    }
                }
            }
        }
    }
};
23.6.2.5 Executor query function

The function `executor()` returns a reference to the executor instance currently operative. When called during the evaluation of `exec` blocks of an `action` or flow/resource object or of any function invoked by them, it returns the executor instance assigned to that entity. The function `executor()` can be used, among other purposes, to delegate generic target functions to an executor-specific implementation.

```cpp
function ref executor_base_c executor();
```

Syntax 107—Executor query function

Note that the reference returned from `executor()` for actions assigned to different executors would be different, even if these actions are executing concurrently. The returned value shall be `null` if the evaluating entity is not assigned to any executor. Since assignment to executors is only resolved as part of the solve process, calling `executor()` in `pre_solve exec` blocks shall always return `null`.

In Example 265, a call to the global function `my_target_op()` is delegated to the instance function `my_target_op_impl()` of the currently operative executor, through a call to `executor()`. Function `my_target_op_impl()` is declared in component `executor_base_c` and implemented differently in two executor subtypes. Consequently, the call to `my_target_op()` in the `exec body` of `action call_op` will be implemented differently based on the executor assignment of `call_op`. 
23.7 Address spaces

The address space concept is introduced to model memory and other types of storage in a system. An address space is a space of storage atoms accessible using unique addresses. System memory, external storage, internal SRAM, routing tables, memory mapped I/O, etc., are entities that can be modeled with address spaces in PSS.

An address space is composed of regions. Regions are characterized by user-defined properties called traits. For example, a trait could be the type of system memory of an SoC, which could be DRAM or SRAM. Address claims can be made by scenario entities (actions/objects) on an address space with optional constraints on user-defined properties. An address space handle is an opaque representation of an address within an address space.

Example 265—Function delegation to executor

```csh
function void my_target_op(int param) {
    if (executor() != null) {
        executor().my_target_op_impl(param);
    } else {
        // default implementation
    }
}

extend component executor_base_c {
    function void my_target_op_impl(int param);
};

component A_executor_c : executor_c<>
    function void my_target_op_impl(int param) {
        // implementation for execution agent of type A
    }
};

component B_executor_c : executor_c<>
    function void my_target_op_impl(int param) {
        // implementation for execution agent of type B
    }
};

component pss_top {
    executor_group_c<> exe_g;
    A_executor_c a_exe;
    B_executor_c b_exe;

    exec init_down {
        exe_g.add_executor(a_exe);
        exe_g.add_executor(b_exe);
    }

    action call_op {
        rand executor_claim_s<> my_exe;
        exec body {
            my_target_op(10);
        }
    }
};
```
Standard operations are provided to read data from and write data to a byte-addressable address space. *Registers* and *register groups* are allocated within an address space and use address space regions and handles to read and write register values. Data layout for packed PSS structs is defined for byte-addressable address spaces.

The PSS built-in package `addr_reg_pkg` defines types and functions for registers, address spaces, address allocation and operations on address spaces. In subsequent sections, except Syntax 108, the enclosing `addr_reg_pkg` is omitted for brevity. Examples may also omit import of `addr_reg_pkg` and `std_pkg`.

### 23.7.1 Address space categories

#### 23.7.1.1 Base address space type

An *address space* is a set of storage atoms accessible using unique addresses. Actions/objects may allocate one or more atoms for their exclusive use.

Address spaces are declared as components. `addr_space_base_c` is the base type for all other address space types. This component cannot be instantiated directly. The definition of `addr_space_base_c` is shown in Syntax 108.

```plaintext
package addr_reg_pkg {
    component addr_space_base_c {};  
    ...  
}
```

*Syntax 108—Generic address space component*

#### 23.7.1.2 Contiguous address spaces

A *contiguous address space* is an address space whose addresses are non-negative integer values, and whose atoms are contiguously addressed. Multiple atoms can be allocated in one contiguous chunk.

Byte-addressable system memory and blocks of data on disk drive are examples of contiguous address spaces.

A contiguous address space is defined by the built-in library component `contiguous_addr_space_c` shown in Syntax 109 below. The meanings of the struct type `addr_trait_s` and the template parameter `TRAIT` are defined in 23.7.2. Address space regions are described in 23.7.3.
A contiguous address space is created in a PSS model by creating an instance of component `contiguous_addr_space_c` in a top-level component or any other component instantiated under the top-level component.

### 23.7.1.2.1 add_region function

The `add_region` function of contiguous address space components is used to add allocatable address space regions to a contiguous address space. The function returns an address handle corresponding to the start of the region in the address space. Actions and objects can allocate space only from allocatable regions of an address space.

Address space regions are defined in 23.7.3. Address space regions are part of the static component hierarchy. The `add_region` function may only be called in `exec init_down` and `init_up` blocks. Address handles are defined in 23.9.3.

### 23.7.1.2.2 add_nonallocatable_region function

The `add_nonallocatable_region` function of contiguous address space components is used to add non-allocatable address space regions to a contiguous address space. The function returns an address handle corresponding to the start of the region in the address space.

The address space allocation algorithm shall not use non-allocatable regions for allocation.

Address space regions are defined in 23.7.3. Address space regions are part of the static component hierarchy. The `add_nonallocatable_region` function may only be called in `exec init_down` and `init_up` blocks. Address handles are defined in 23.9.3.
23.7.1.2.3 Example

Example 266 demonstrates instantiating an address space and adding regions to it (for the definition of struct addr_region_s, see 23.7.3.2).

```
component pss_top {
    import addr_reg_pkg::*;
    my_ip_c ip;
    contiguous_addr_space_c<> sys_mem;
    exec init_up {
        // Add regions to space here
        addr_region_s<> r1;
        r1.size = 0x40000000; // 1 GB
        (void)sys_mem.add_region(r1);
        addr_region_s<> mmio;
        mmio.size = 4096;
        (void)sys_mem.add_nonallocatable_region(mmio);
    }
}
```

Example 266—Contiguous address space in pss_top

23.7.1.3 Byte-addressable address spaces

A byte-addressable space is a contiguous address space whose storage atom is a byte and to/from which PSS data can be written/read using standard generic operations. The PSS core library standardizes generic APIs to write data to or read data from any address value as bytes. The read/write API and data layout of PSS data into a byte-addressable space are defined in 23.9.

By default, component contiguous_addr_space_c is a byte-addressable space unless the byte_addressable Boolean field is set to false.

23.7.1.4 Transparent address spaces

Transparent address spaces are used to enable transparent claims—constraining and otherwise operating on concrete address values on the solve platform. For more information on transparent address claims, see 23.8.3.

All regions of a transparent space provide a concrete start address and the size of the region. Only transparent regions (see 23.7.3.3) may be added to a transparent address space using function add_region(). Note however that transparent regions may be added to a non-transparent space.

Component transparent_addr_space_c is used to create a transparent address space (see Syntax 110). See Example 268.
23.7.1.5 Other address spaces

Other kinds of address spaces, with different assumptions on allocations and generic operations, are possible. These may be represented as derived types of the corresponding base space/region/claim types. An example could be a space representing a routing table in a network router. PSS does not attempt to standardize these.

23.7.2 Address space traits

An address space trait is a PSS struct. A trait struct describes properties of a contiguous address space and its regions. empty_addr_trait_s is defined as an empty trait struct that is used as the default trait type for address spaces, regions and claims.

All regions of an address space share a trait type. Every region has its specific trait value.
Figure 22—Address space regions with trait values

```c
component pss_top {
    import addr_reg_pkg::*;
    import ip_pkg::*;

    // IP component
    my_ip_c ip;

    // mem_trait_s trait struct is used for sys_mem address space
    transparent_addr_space_c<mem_trait_s> sys_mem;

    exec init_up {
        // Add regions to space here. All regions added to sys_mem space
        // must have trait type mem Trait_s

        transparent_addr_region_s<mem_trait_s> sram_region;

        sram_region.trait.kind = SRAM;
        sram_region.trait.ctype = WB;
        sram_region.trait.sec_level = 0;
        sram_region.trait.mmio = false;
        sram_region.size = 4096;
        sram_region.addr = 0x400;

        (void)sys_mem.add_region(sram_region);

        // add other regions
        // ...
    }
}
```

Example 268—Address space with trait
23.7.3 Address space regions

An address space may be composed of **regions**. Regions map to parts of an address space. A region may be characterized by values assigned to address space traits. Traits define properties of a region. Specific constraints are placed on **address claim** traits to allocate addresses from regions with desired characteristics. Regions with trait values that satisfy the claim's trait constraints are the candidate matching regions. An address claim may span more than one region that satisfies claim trait constraints.

Address space regions are part of the static component hierarchy. The **add_region** and **add_nonallocatable_region** functions (see 23.7.1.2.1 and 23.7.1.2.2) may only be called in **exec**, **init_down** and **init_up** blocks.

23.7.3.1 Base region type

**addr_region_base_s** is the base type for all address space regions (see Syntax 1). Specifying a value for the **size** field is required. Specifying a value for the **tag** field is optional.

```
struct addr_region_base_s {
    bit[64] size;
    string  tag;
};
```

Syntax 1—Base address region type

The **tag** associated with the region from which a memory claim is satisfied may be retrieved using the **get_tag()** function (see 23.9.8).

23.7.3.2 Contiguous address regions

The **addr_region_s** type represents a region in contiguous address space (see Syntax 12). The region type is fully characterized by the template **TRAIT** parameter value and the **size** attribute of the base region type.

```
struct addr_region_s <struct TRAIT : addr_trait_s = empty_addr_trait_s> : addr_region_base_s {
    TRAIT trait;
};
```

Syntax 12—Contiguous address space region type

The values of the trait struct attributes describes the contiguous address region. The PSS tool will match the trait attributes of regions to satisfy an address claim as described in 23.8. See an example of trait attribute setting in 23.8.7.

23.7.3.3 Transparent address regions

The **transparent_addr_region_s** type defines a **transparent** region over a contiguous address space. **Transparent** means that the region’s start (lower) address is known to the PSS tool for solve-time resolution of a claim address within the address space.

The **addr** field of this region is assigned the start address of the region. The end address of the region is the calculated value of the expression: **addr + size - 1**.

See Example 268 where a transparent region is added to a transparent address space.
23.8 Allocation within address spaces

The PSS input model can allocate storage atoms from an address space for the exclusive use of certain behaviors. For example, a DMA controller action might allocate a buffer in system memory for output data.

All address space allocations are done in the declarative domain of a PSS input model. An address claim struct, defined in the following sections, is used for allocation.

An instance of an address claim struct describes an address claim on an address space. A claim is matched to the address space nearest in the component instance tree, whose trait type matches the claim trait type (see 23.8.6). A claim is satisfied by allocation from a region (or regions) whose trait value satisfies the constraints on the claim trait (see 23.8.4).

A claim struct can be instantiated under an action, a flow object or resource object, or any of their nested structs. The declaration of a claim struct instance causes allocation to occur when the declaring object is instantiated or the action is traversed.

23.8.1 Base claim type

The addr_claim_base_s struct (see Syntax 114) is the base type for all address space claims.

struct addr_claim_base_s {
    rand bit[64] size;
    rand bool permanent;
    constraint default permanent == false;
};

Syntax 114—Base address space claim type

23.8.2 Contiguous claims

An address claim can be made on a contiguous address space by declaring a struct of type addr_claim_s. This claim is also known as an opaque claim. The absolute address of the claim is not assumed to be known at solve time.

This standard does not define any method by which the PSS tool might resolve address claims at solve time or might generate code for runtime allocation. One possible method could be PSS tool-specific APIs for solve-time and runtime allocation. The address space handle obtained from a claim shall fall within a region or regions whose traits satisfy the claim constraints.

An address claim in contiguous address space is always a contiguous chunk of addresses, potentially spanning multiple regions that are adjacent.

An address claim can be made on transparent (described below, in 23.8.3) or non-transparent address spaces.
The alignment attribute specifies the address alignment of the resolved claim address.

### 23.8.3 Transparent claims

A claim of type `transparent_addr_claim_s` (see Syntax 116) is required to make a transparent claim on a transparent contiguous address space. A transparent claim is characterized by the absolute allocation address attribute (addr) of the claim. A transparent claim is associated with the nearest address space with the same trait type, in the same way that a non-transparent claim is. However, a transparent claim that is thereby associated with a non-transparent space shall be flagged as an error. The PSS tool has all the information at solve time about the transparent address space necessary to perform allocation within the limits of the address space. More details about allocation and claim lifetime can be found in the following section.

The addr field of this claim type can be used to put a constraint on an absolute address of a claim.

```c
struct transparent_addr_claim_s <struct TRAIT : addr_trait_s = empty_addr_trait_s>
    : addr_claim_s<TRAIT> {
    rand bit[64] addr;
};
```

**Example 269** illustrates how a transparent claim is used. A transparent address claim is used in action my_op. A constraint is placed on the absolute resolved address of the claim. This is possible only because of the transparent address space that contain transparent regions where the base address of the region is known at solve time.
Example 269—Transparent address claim

23.8.4 Claim trait semantics

Constraints placed on the trait attribute of a claim instance must be satisfied by the allocated addresses. Allocated addresses shall be in regions whose trait values satisfy claim trait constraints.

See an example in 23.8.7.

23.8.5 Allocation consistency

An address claim struct is resolved to represent the allocation of a set of storage atoms from the nearest storage space, for the exclusive use of actions that can access the claim attribute. In the case of a contiguous address space, the set is a contiguous segment, from the start address to the start address + size - 1. All addresses in the set are uniquely assigned to that specific instance of the address claim struct for the duration of its lifetime, as determined by the actions that can access it (see details below). Two instances of an address claim struct shall resolve to mutually exclusive sets of addresses if

- Both are taken from the same address space, and
- An action that has access to one may overlap in execution time with an action that has access to the other.

The number of storage atoms in an allocation is represented by the attribute size.

The start address is represented directly by the attribute addr in transparent_addr_claim_s<> or otherwise obtained by calling the function addr_value() on the address space handle returned by make_handle_from_claim().
Following is the definition of the lifetime of scenario entities:

### Table 28—Scenario entity lifetimes

<table>
<thead>
<tr>
<th>Entity</th>
<th>Lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atomic action</td>
<td>From the time of exec body entry (immediately before executing the first statement) to the time of the exec body exit (immediately after executing the last statement).</td>
</tr>
<tr>
<td>Compound action</td>
<td>From the start time of the first sub-action(s) to the end time of the last sub-action(s).</td>
</tr>
<tr>
<td>Flow object</td>
<td>From the start time of the action outputting it (for the initial state, the start time of the first action in the scenario) to the end time of the last action(s) inputting it (if any) or the end-time of the last action outputting it (if no action inputs it).</td>
</tr>
<tr>
<td>Resource object</td>
<td>From the start time of the first action(s) locking/sharing it to the end time of the last action(s) locking/sharing it.</td>
</tr>
<tr>
<td>Struct</td>
<td>Identical with the entity that instantiates it.</td>
</tr>
</tbody>
</table>

The lifetime of the allocation to which a claim struct resolves, and hence the exclusive use of the set of addresses, may be extended beyond the scenario entity in which the claim is instantiated in one of two ways:

- A handle that originates in a claim is assigned to entities that have no direct access to the claim in solve execs (for definition of address space handles, see 23.9.3). For example, if an action assigns a handle field (of type `addr_handle_t`) of its output buffer object with a handle it obtained from its own claim, the allocation lifetime is extended to the end of the last action that inputs that buffer object.

- The attribute `permanent` is constrained to `true`, in which case the lifetime of the claim is extended to the end of the test.

### 23.8.5.1 Example

The example below demonstrates how the scheduling of actions affects possible resolutions of address claims. In this model, action `my_op` claims 20 bytes from an address space, in which there is one region of size 50 bytes and another of size 10. In action `test1`, the three actions of type `my_op` are scheduled sequentially, as the iterations of a `repeat` statement. No execution of `my_op` overlaps in time with another, and therefore each one can be allocated any set of consecutive 20 bytes, irrespective of previous allocations. Note that all three allocations must come from the 50-byte region, as the 10-byte region cannot fit any of them. In `test2`, by contrast, the three actions of type `my_op` expanded from the `replicate` statement are scheduled in parallel. This means that they would overlap in execution time, and therefore need to be assigned mutually exclusive sets of addresses. However, such allocation is not possible out of the 50 bytes available in the bigger region. Here too, the smaller region cannot fit any of the three allocations. Nor can it fit part of an allocation, because it is not known to be strictly contiguous with the other region.
component pss_top {
    action my_op {
        rand addr_claim_s<> claim;
        constraint claim.size == 20;
    };

    contiguous_addr_space_c<> mem;

    exec init_up {
        addr_region_s<> region1, region2;
        region1.size = 50;
        (void)mem.add_region(region1);
        region2.size = 10;
        (void)mem.add_region(region2);
    }

    action test1 {
        activity {
            repeat (3) {
                do my_op; // OK – allocations can be recycled
            }
        }
    };

    action test2 {
        activity {
            parallel {
                replicate (3) {
                    do my_op; // error – cannot satisfy concurrent claims
                }
            }
        }
    };
};
23.8.6 Rules for matching a claim to an address space

a) A claim is associated with a unique address space based on the static structure of the model.

b) A claim is resolved to an address space that:
   1) matches the trait type of the claim
   2) is instantiated in a containing component of the current scenario entity (the context component hierarchy of an action or the container component of a flow/resource object pool)
   3) is nearest in the component hierarchy going up from the context component to the root component

c) It shall be an error if more than one address space matches a claim at the component context identified in b).

23.8.7 Allocation example

In following example, pss_top has instances of the sub_ip and great_ip components. sub_ip is composed of the good_ip and great_ip components. good_ip and great_ip allocate space with trait mem_trait_s. Memory allocation in the top_gr_ip instance of pss_top will be matched to the sys_mem address space that is instantiated in pss_top. Memory claims in gr_ip and go_ip from pss_top.sub_system will be matched to the address space in sub_ip, as the sub_ip address_space will be the nearest space with a matching trait in the component tree.

Note how within the two address spaces, there are regions with the same base address. Claims from actions of the two instances of great_ip may be satisfied with overlapping addresses even if they are concurrent, since they are taken out of different address spaces.
import addr_reg_pkg::*;
import mem_pkg::*;

package mem_pkg {
  enum cache_attr_e {UC, WB, WT, WC, WP};

  struct mem_trait_s : addr_trait_s {
    rand cache_attr_e  ctype;
    rand int in [0..3] sec_level;
  }
};

component good_ip {
  action write_mem {
    // Allocate from nearest address space matching TRAIT type and value
    rand transparent_addr_claim_s<mem_trait_s> mem_claim;

    constraint mem_claim.size == 128;
    constraint mem_claim.trait.ctype == UC;
  }
}

component write_mem_unconstrained {
  // Allocate from nearest address space matching TRAIT type and value

  // Note that ctype field of the claim trait is unconstrained.
  // However, given there is only a single region in the address space
  // with ctype==UC, that region is chosen as it is the only match
  // available that can satisfy the trait constraints.

  // ctype cannot be randomized to have a value that is not UC because
  // it is compelled to match with one of the regions, just like when
  // an action wants to consume a buffer object, it needs to pick from
  // the available objects in the pool.
  rand transparent_addr_claim_s mem_claim;
  constraint mem_claim.size == 128;
}

component great_ip {
  action write_mem {
    // Allocate from nearest address space matching TRAIT type and value
    rand transparent_addr_claim_s<mem_trait_s> mem_claim;

    constraint mem_claim.size == 256;
    constraint mem_claim.trait.ctype == UC;
  }
}

component sub_ip {
  // Subsystem has its own address space
  transparent_addr_space_c<mem_trait_s> mem;

  good_ip  go_ip;
  great_ip gr_ip;
}
23.9 Data layout and access operations

23.9.1 Data layout

Many PSS use cases require writing structured data from the PSS model to byte-addressable space in a well-defined layout. In PSS, structured data is represented with a `struct`. For example, a DMA engine might expect DMA descriptors that encapsulate DMA operation to be in memory in a known layout. Packed structs may be beneficial to represent bit fields of hardware registers.

The built-in PSS library `struct packed_s` is used as a base `struct` to denote that a PSS `struct` is packed.

Any struct derived from built-in struct `packed_s` directly or indirectly is considered packed by the PSS tool. Packed structs are only allowed to have fields of numeric types, Boolean types, enumerated types that have a base type, packed struct types, or arrays thereof. Following are the declarations of the endianness `enum` and packed `struct` in `std_pkg`\(^8\):

```plaintext
enum endianness_e { LITTLE_ENDIAN, BIG_ENDIAN }

struct packed_s <endianness_e e = LITTLE_ENDIAN> {};  
```

---

8 In PSS 2.0, these declarations were in the `addr_reg_pkg` package. Referring to these declarations via `addr_reg_pkg` is deprecated in PSS 2.1. To support backward compatibility, PSS tools shall support referencing these declarations in either `std_pkg` or `addr_reg_pkg` as if they were the same types.
Type extensions of packed structs shall not add new fields.

### 23.9.1.1 Packing rule

PSS uses the de facto packing algorithm from the GNU C/C++ compiler. The ordering of fields of structs follows the rules of the C language. This means that fields declared first would go in lower addresses. For this purpose, if a packed struct is derived from another packed struct, fields declared in the derived struct are considered to be declared later than those declared in the base struct. The layout of fields in a packed struct is defined by the endianness template parameter of the packed struct. Bit fields in PSS structs can be of any size. For this purpose, Boolean fields are considered to be of 1 bit.

For the packing algorithm, a register of size \( N \) bytes is used, where \( N \times 8 \) is greater than or equal to the number of bits in the packed struct.

For big-endian mode, fields are packed into registers from the most significant bit (MSB) to the least significant bit (LSB) in the order in which they are defined. Fields are packed in memory from the most significant byte (MSByte) to the least significant byte (LSByte) of the packed register. If the total size of the packed struct is not an integer multiple of bytes, don't-care bits are added at the LSB side of the packed register.

For little-endian mode, fields are packed into registers from the LSB to the MSB in the order in which they are defined and packed in memory from the LSByte to the MSByte of the packed register. If the total size of the packed struct is not an integer multiple of bytes, don't-care bits are added at the MSB side of the packed register.

### 23.9.1.2 Little-endian packing example

A packed struct is shown in Example 272. This struct has 30 bits. A register for packing this struct would have 4 bytes.

```c
struct my_packed_struct : packed_s<LITTLE_ENDIAN> {
    bit[2] B;
    bit[9] C;
    bit[7] D;
}
```

**Example 272—Packed PSS little-endian struct**

Register packing will start from field A. The least significant bit of A would go in the least significant bit of the register, as shown in Figure 23. Field B would go after field A. The least significant bit of B would go in the lowest bit after A in the packed register, and so on. The layout of the packed struct in byte-addressable space is shown in Figure 24. (X means “don’t-care bit” in Figure 23 and Figure 24.)

```
MSB
XX E E E E E E D D D D D D C C C C C C B A A A A A A
LSB
XX 5 4 3 2 1 0 6 5 4 3 2 1 0 8 7 6 5 4 3 2 1 0 1 0 5 4 3 2 1 0
```

**Figure 23—Little-endian struct packing in register**
23.9.1.3 Big-endian packing example

A packed struct is shown in Example 273. This struct has 30 bits. A register for packing this struct would have 4 bytes.

```
struct my_packed_struct : packed_s<BIG_ENDIAN> {
    bit[2] B;
    bit[9] C;
    bit[7] D;
}
```

Example 273—Packed PSS big-endian struct

Register packing will start from field A. The most significant bit of A would go in the most significant bit of the register, as shown in Figure 25. Field B would go after field A. The most significant bit of B would go in the highest bit after A in the packed register, and so on. The layout of the packed struct in byte-addressable space is shown in Figure 26. (X means “don’t-care bit” in Figure 25 and Figure 26.)

```
byte 0    byte 1    byte 2    byte 3
1 0 5 4 3 2 1 0 7 6 5 4 3 2 1 0 6 5 4 3 2 1 0 8 X X 5 4 3 2 1 0
```

Figure 24—Little-endian struct packing in byte-addressable space

Figure 25—Big-endian struct packing in register

```
byte 0    byte 1    byte 2    byte 3
A A A A A A B B C C C C C C D D D D D D D E E E E E E E X X
5 4 3 2 1 0 1 0 8 7 6 5 4 3 2 1 0 6 5 4 3 2 1 0 5 4 3 2 1 0 X X
```

Figure 26—Big-endian struct packing in byte-addressable space

23.9.2 sizeof_s

The template struct `sizeof_s` is used to query the physical storage size of a PSS data type. It applies to types that can be written to or read from a byte-addressable address space, namely numeric types, Booleans, enumerated types that have a base type, packed structs, and arrays thereof. The `sizeof_s` struct is declared in the `std_pkg` package.9

9 In PSS 2.0, these declarations were in the `addr_reg_pkg` package. Referring to these declarations via `addr_reg_pkg` is deprecated in PSS 2.1. To support backward compatibility, PSS tools shall support referencing these declarations in either `std_pkg` or `addr_reg_pkg` as if they were the same types.
23.9.2.1 Definition

The static constant `nbytes` is initialized to the number of consecutive addresses required to store a value of type `T` in a byte-addressable address space. When using the read/write target functions (see 23.9.9), this number of bytes is assumed to be taken up by the data in the target storage. For types that are not byte-aligned in size, the number of bytes is rounded up. For the definition of packed struct layout in an address space, see 23.9.1.

The static constant `nbits` is initialized to the exact number of bits that are taken up by the representation of a value of type `T` in a byte-addressable address space.

`sizeof_s<>` shall not be parameterized with types other than numeric types, Booleans, enumerated types that have a base type, packed structs, and arrays thereof.

23.9.2.2 Examples

The following code snippets show the value of `nbytes` of `sizeof_s<>` instantiated for several different types:

```c
sizeof_s<int>::nbytes == 4
sizeof_s<int[3:0]>::nbytes == 1
sizeof_s<bit>::nbytes == 1
sizeof_s<bit[33]>::nbytes == 5
sizeof_s<array<int,10>>::nbytes == 40
struct my_packed_s : packed_s<> {bit[2] kind; int data;};
```

`sizeof_s<my_packed_s>::nbytes == 5`

23.9.3 Address space handles

The built-in package `addr_reg_pkg` defines PSS types for `address space handles`.

```c
typedef chandle addr_handle_t;
const addr_handle_t nullhandle = /* implementation-specific */;
struct sized_addr_handle_s < int SZ, // in bits
    int lsb = 0,
    endianness_e e = LITTLE_ENDIAN
> : packed_s<e> {`n
    addr_handle_t hndl;
};
```

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23.9.3.1 Generic address space handle

`addr_handle_t` is the generic type for address handles within an address space. A variable of type `addr_handle_t` resolves to a concrete address value during test execution, on the target platform. However, the concrete value of an address handle cannot be obtained during the solve process, on the solve platform. A field of type `addr_handle_t` cannot be declared directly in a packed struct type. Packed structs are defined in 23.9.1.

23.9.3.2 nullhandle

`nullhandle` represents the address value 0 within the target address space, regardless of the actual mapping of regions.

23.9.3.3 sized address space handle

The wrapper struct `sized_addr_handle_s` is used for specifying the size of an address handle in a packed struct. An address field within a packed struct shall only be declared using `sized_addr_handle_s`, and not directly as a field of type `addr_handle_t`.

The `SZ` parameter specifies the size of the handle itself in bits when used in a packed struct. Note that the `SZ` parameter is not the size of the data it is pointing to.

The `lsb` parameter defines the starting bit in the resolved address that would become bit 0 of sized address handle in packed struct. For example, assume that the resolved address is 64 bits and the size of the handle is 30 bits, with the the `lsb` parameter set to 2. In this case, a sized handle in a packed struct would have bits 31 to 2 from the resolved address.

See an example in 23.9.10.

23.9.4 Obtaining an address space handle

A handle in an address space can be created from an address claim (with an optional offset value), from another handle (with an offset value), or from a region in an address space. An address claim is made using a claim struct declaration in actions and objects.

Some address space regions are non-allocatable. These regions can be used to represent memory-mapped I/O (MMIO) register spaces. A handle can be created from a region in an address space, in order to access non-allocatable regions.

A handle to a region is obtained when the region is added to the address space, using the `add_region` (see 23.7.1.2.1) or `add_nonallocatable_region` (see 23.7.1.2.2) functions. To create address handles from address claims or from other handles, the following functions are defined in the built-in package `addr_reg_pkg`.

23.9.4.1 make_handle_from_claim function

The function `make_handle_from_claim()` creates an address handle from a claim, with an optional offset value.

```c
function addr_handle_t make_handle_from_claim
    (addr_claim_base_s claim, bit[64] offset = 0);
```

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The `make_handle_from_claim` function arguments are:

- A claim struct instance declared in an action or a flow/resource object
- An optional offset value, of a 64-bit type

The returned handle’s resolved address will be the sum of the claim’s resolved address and the offset. The return value of the function is of type `addr_handle_t`.

### 23.9.4.1.1 Example

```vhdl
action my_action {
    rand transparent_addr_claim_s<> claim;
    constraint claim.size == 128;
    constraint claim.alignment == 2**4;
    exec body {
        int offset = 16;
        int data = 128;

        addr_handle_t h0 = make_handle_from_claim(claim);
        write32(h0, data); // access API defined in 23.9.9.1

        // Address handle from claim with an offset
        addr_handle_t h1 = make_handle_from_claim(claim, offset);
        write32(h1, data);
    }
}
```

**Example 274—make_handle_from_claim example**

### 23.9.4.2 make_handle_from_handle function

The function `make_handle_from_handle()` creates an address handle from another handle, given an offset.

```vhdl
function addr_handle_t make_handle_from_handle
    (addr_handle_t handle, bit[64] offset);
```

**Syntax 121—make_handle_from_handle function**

The `make_handle_from_handle` function arguments are:

- A handle that was created by a different call to a `make_handle` function
- An offset value, of a 64-bit type

The returned handle’s resolved address will be the sum of the handle parameter’s resolved address and the offset. The return value of the function is of type `addr_handle_t`.
23.9.4.2.1 Example

```
action my_action {
    transparent_addr_claim_s<> claim;
    constraint claim.alignment == 2**4;

    exec body {
        int offset = 16;
        int data = 128;

        addr_handle_t h0 = make_handle_from_claim(claim, offset);
        write32(h0, data);

        // Make handle from another handle with an offset
        addr_handle_t h1 = make_handle_from_handle(h0, sizeof_s<int>::nbytes);
        write32(h1, data);
    }
}
```

Example 275—make_handle_from_handle example

23.9.5 addr_value function

The function `addr_value()` returns the resolved address of the parameter handle, as a numeric value. `addr_value()` is a target function and shall only be used in `exec body`, `run_start`, `run_end`, or functions called from these `exec` blocks.

```
function bit[64] addr_value(addr_handle_t hndl);
import target function addr_value;
```

Syntax 122—addr_value function

Per-executor custom implementations of the `addr_value()` function may be provided, much as custom implementations of read/write functions are (see 23.9.9.5).

23.9.6 addr_value_solve function

```
function bit[64] addr_value_solve(addr_handle_t hndl);
```

Syntax 123—addr_value_solve function

The solve function `addr_value_solve()` returns either the full absolute address of the `hndl` parameter or the offset of the `hndl` parameter within its containing address region as a numeric value. If the `hndl` parameter is within a transparent region, the returned value will be an absolute address. If the `hndl` parameter is within an opaque region, the returned value may be an absolute address or an offset depending on what tool-specific metadata has been supplied to the PSS processing tool. The `addr_value_abs()` function is used to determine what information will be returned by `addr_value_solve()` for a given address handle.

Users may provide executor-specific implementations of `addr_value_solve()` by overriding this method in an executor implementation.
The `addr_value_solve()` function may only be called in the context of a `pre_body` exec block. If `addr_value_solve()` is called from other contexts, the return value is undefined.

### 23.9.7 addr_value_abs function

```c
function bool addr_value_abs(addr_handle_t hndl);
```

Syntax 124—`addr_value_abs` function

The solve function `addr_value_abs()` returns ‘true’ if the absolute address value is available for the specified address handle. The absolute address value is available if `hndl` is within a transparent region, and may be available when `hndl` is within an opaque region depending on what tool-specific metadata has been supplied to the PSS processing tool.

The `addr_value_abs()` function may only be called in the context of a `pre_body` exec block. If `addr_value_abs()` is called from other contexts, the return value is undefined.

### 23.9.8 get_tag function

The function `get_tag()` returns the `tag` (see Syntax 111) of the region in which the specified address handle is located. `get_tag()` is a target function and shall only be used in `exec pre_body, body, run_start, run_end`, or in functions called from these `exec` blocks.

```c
function string get_tag(addr_handle_t hndl);
```

Syntax 125—`get_tag` function

### 23.9.9 Access operations

Read/write operations of PSS data from/to byte-addressable address space are defined as a set of target functions. Target `exec` blocks (`exec body, run_start, run_end`), and functions called from them, may call these core library functions to access allocated addresses.

Access functions use an address handle to designate the required location within an address space.

PSS provides a way to customize the implementation of access functions for different executors (see 23.9.9.5).

#### 23.9.9.1 Primitive read operations

Syntax 126 defines read operations for integer types from byte addressable address spaces to read one, two, four or eight consecutive bytes starting at the address indicated by the `addr_handle_t` argument.

```c
function bit[8] read8(addr_handle_t hndl);
function bit[16] read16(addr_handle_t hndl);
function bit[32] read32(addr_handle_t hndl);
function bit[64] read64(addr_handle_t hndl);
```

Syntax 126—Primitive read operations for byte addressable spaces

The first byte goes into bits [7:0], then the next byte goes into bits [15:8], and so on.
23.9.9.2 Primitive write operations

**Syntax 127** defines write operations for integer types to byte addressable address spaces to write one, two, four or eight consecutive bytes from the `data` argument starting at the address indicated by the `addr_handle_t` argument.

```
function void write8 (addr_handle_t hndl, bit[8] data);
function void write16(addr_handle_t hndl, bit[16] data);
function void write32(addr_handle_t hndl, bit[32] data);
function void write64(addr_handle_t hndl, bit[64] data);
```

**Syntax 127—Primitive write operations for byte addressable spaces**

Bits [7:0] of the input `data` go into the starting address specified by the `addr_handle_t` argument, bits [15:8] go into the next address (starting address + 1), and so on.

23.9.9.3 Read and write N consecutive bytes

**Syntax 128** defines operations to read and write a series of consecutive bytes from byte addressable space.

For a read operation, the read data is stored in the argument `data`. For function `read_bytes()`, the `size` argument indicates the number of consecutive bytes to read. The returned list is resized accordingly, and its previous values, if any, are overwritten.

For a write operation, the input data is taken from the argument `data`. For function `write_bytes()`, the number of bytes to write is determined by the list size of the `data` parameter.

```
function void read_bytes (addr_handle_t hndl, list<bit[8]> data, int size);
function void write_bytes(addr_handle_t hndl, list<bit[8]> data);
```

**Syntax 128—Read and write series of bytes**

The first byte read comes from the address indicated by the `hndl` argument. This byte is stored at the first location (index 0) in the `data` list. The second byte comes from the address incremented by one and is stored at the second location (index 1) in the `data` list, and so on. The same semantics apply to `write_bytes()`.

23.9.9.4 Read and write packed structs

Read and write operations to access packed structs are defined in **Syntax 129**. Argument `packed_struct` of functions `read_struct()` and `write_struct()` shall be a subtype of the `packed_s` struct. The `packed_struct` argument is read from or written to the address specified by the `hndl` argument.

```
function void read_struct (addr_handle_t hndl, struct packed_struct);
function void write_struct(addr_handle_t hndl, struct packed_struct);
```

**Syntax 129—Read and write packed structs**

The PSS implementation shall convert calls to `read_struct()` and `write_struct()` to one or more invocations of the primitive read and write operations (see 23.9.9.1 and 23.9.9.2) or to an invocation of the `read_bytes()` or `write_bytes()` function (see 23.9.9.3). Reading and writing of structs of size 8, 16, 32, or 64 bits stored at a correspondingly aligned address shall be implemented with a single primitive
operation of the corresponding size, and in other cases may be partitioned into one or more primitive operations of any size, or a single call to the `read_bytes()` or `write_bytes()` function.

### 23.9.9.5 Executor-based customization of memory functions

PSS tools may provide built-in implementations of read, write, and `addr_value()` operations for mainstream execution contexts. However, users can optionally customize the implementation of these operations for their own purposes and execution contexts.

Calls to primitive read, write, and `addr_value()` functions (defined above in 23.9.9.1, 23.9.9.2, and 23.9.5), and calls to byte list read/write functions (defined above in 23.9.9.3), are delegated to functions with the identical prototype in the executor instance assigned to the evaluation action or flow/resource object. Syntax 130 below shows the declarations of the executor implementation functions.

```plaintext
extend component executor_base_c {
  function bit[64] addr_value(addr_handle_t hndl);
  function bit[8]  read8  (addr_handle_t hndl);
  function bit[16] read16(addr_handle_t hndl);
  function bit[32] read32(addr_handle_t hndl);
  function bit[64] read64(addr_handle_t hndl);
  function void write8 (addr_handle_t hndl, bit[8]  data);
  function void write16(addr_handle_t hndl, bit[16] data);
  function void write32(addr_handle_t hndl, bit[32] data);
  function void write64(addr_handle_t hndl, bit[64] data);
  function void read_bytes (addr_handle_t hndl, list<bit[8]> data,
                             int size);
  function void write_bytes(addr_handle_t hndl, list<bit[8]> data);
};
```

**Syntax 130—Primitive operation implementation functions**

Note that struct read/write functions (defined above in 23.9.9.4) and register read/write functions (defined below in 23.10.1) are implemented in terms of their respective primitive operations. Therefore, custom implementations of the primitive operations in an executor apply similarly to struct and register read/write functions.

The code in Example 276 below illustrates how a PSS implementation may define the delegation of one of the primitive read/write functions to the corresponding function in the current executor. The actual implementation does not necessarily take this form, but should have equivalent observable behavior. See 23.6.2.5 for more on the semantics of function `executor()`.

```plaintext
function bit[32] read32(addr_handle_t hndl) {
  if (executor() != null ) {
    return executor().read32(hndl);
  } else {
    // return value per default implementation
  }
}
```

**Example 276—Illustration of read32()**
Example 277 below demonstrates how primitive operations `read32()` and `write32()` are mapped to calls to functions of a C bus transactor in the context of a user-defined executor type.

```verilog
function bit[32] my_transactor_read_word(bit[64] addr);
import target C function my_transactor_read_word;

function void my_transactor_write_word(bit[64] addr, bit[32] data);
import target C function my_transactor_write_word;

component my_transactor_executor_c<struct TRAIT : executor_trait_s = empty_executor_trait_s> : executor_c<TRAIT> {
    function bit[32] read32(addr_handle_t hndl) {
        return my_transactor_read_word(addr_value(hndl));
    }

    function void write32(addr_handle_t hndl, bit[32] data) {
        my_transactor_write_word(addr_value(hndl), data);
    }
};
```

**Example 277—Mapping of primitive operations to foreign C functions**

In Example 278 below, executor type `uvm_ubus_executor_c` corresponds to a UVM bus master. The `write8()` function is defined in terms of a SystemVerilog imported function (task) that starts a write-byte sequence on the agent designated by the path parameter. The executor type is instantiated twice under `pss_top`, and each instance is associated with a different UVM agent in the target environment using the UVM path.

```verilog
import target SV function void ubus_write8(string uvm_path, bit[64] addr, bit[8] data);

component uvm_ubus_executor_c : executor_c<bus_trait_s> {
    string uvm_path;

    function void write8(addr_handle_t hndl, bit[8] data) {
        ubus_write8(uvm_path, addr_value(hndl), data);
    }
};

extend component pss_top {
    uvm_ubus_executor_c masters[2];
    executor_group_c<bus_trait_s> bus_group;
    exec init_down {
        foreach (m: masters) {
            bus_group.add_executor(m);
        }
        masters[0].uvm_path = "uvm_test_top.env.ubus_master0";
        masters[1].uvm_path = "uvm_test_top.env.ubus_master1";
    }
};
```

**Example 278—Mapping of primitive operations to UVM sequences**
In Example 279 below, an executor corresponding to a 32-bit architecture CPU customizes the read64() and write64() operations to be implemented in terms of the built-in read32() and write32() operations.

```
component my_32bit_cpu_c : executor_c<my_core_trait_s> {
    function bit[64] read64(addr_handle_t hndl) {
        bit[64] result;
        result[31: 0] = read32(hndl);
        result[63:32] = read32(make_handle_from_handle(hndl,4));
        return result;
    }

    function void write64(addr_handle_t hndl, bit[64] data) {
        write32(hndl, data[31:0]);
        write32(make_handle_from_handle(hndl,4), data[63:32]);
    }
};
```

Example 279—Implementing primitive operations in terms of other operations

In the example below, the user has an address map where each of a set of executors is allocated a unique set of addresses within the address space. While each executor is assigned a unique portion of the global address space, the executor-specific address window is mapped at the same address from the perspective of the executor. Allocations are modeled using the global address map to ensure claims are globally unique. However, depending on the executor, an address may need to be transformed to conform to the executor-specific address map.

Figure 27—Executor address mapping

Overriding the addr_value() function can be used to perform such custom translations. The addr_window_exec_c executor shown below overrides the addr_value() function and applies a translation if the address falls within a specific window that is configurable on a per-executor instance basis.

Let’s assume that the executor-specific address windows are located at 0x80000000 and 0x80001000 in the global address map. Each executor maps this shared window at 0x1000. The executor instantiation and configuration below show how we could configure this translation scheme. When, for example, an action running on exec1 accesses address 0x8000_0100, the customized addr_value() function will convert the address to 0x0000_1100.
Example 280—Customization of `addr_value()`

```vhdl
component addr_window_exec_c : executor_base_c {
  bit[64] window_base   = 0x80000000;
  bit[64] window_size   = 0x1000;
  bit[64] window_offset = 0x80000000;

  function bit[64] addr_value(addr_handle_t hndl) {
    bit[64] addr = super.addr_value(hndl);
    if (addr >= window_base && addr < (window_base+window_size)) {
      addr = (addr-window_offset)+0x1000;
    }
    return addr;
  }
}

component subsystem_c {
  addr_window_exec_c exec1;
  addr_window_exec_c exec2;

  exec init_down {
    exec1.window_base   = 0x8000_0000;
    exec1.window_offset = 0x8000_0000;
    exec2.window_base   = 0x8000_1000;
    exec2.window_offset = 0x8000_1000;
  }
}
```
23.9.10 Target data structure setup example

The following example demonstrates use of packed PSS data written to allocations on byte addressable space. It also demonstrates the use of address handles to construct complex data structures in target memory. Lifetime of allocation is extended by using address handles in flow objects.

```
buffer data_buff {
  rand addr_claim_s<> mem_seg;
};

comp ament dma_c {

  struct descriptor_s : packed_s<> {
    sized_addr_handle_s<32> src_addr;
    sized_addr_handle_s<32> dst_addr;
    int size;
    sized_addr_handle_s<32> next_descr;
  };

  state descr_chain_state {
    list<addr_handle_t> handle_list;
  }

  pool descr_chain_state descr_chain_statevar;
  bind descr_chain_statevar *;

  action alloc_first_descr {
    output descr_chain_state out_chain;

    rand addr_claim_s<> next_descr_mem;
    constraint next_descr_mem.size == sizeof_s<descriptor_s>::nbytes;

    exec post_solve {
      out_chain.handle_list.push_back(
        make_handle_from_claim(next_descr_mem));
    }
  }
};
```

Example 281—Example using complex data structures
action chained_xfer {
    input data_buff src_buff;
    output data_buff dst_buff;
    constraint dst_buff.mem_seg.size == src_buff.mem_seg.size;

    input descr_chain_state in_chain;
    output descr_chain_state out_chain;

    rand bool last;

    descriptor_s descr;

    rand addr_claim_s<> next_descr_mem;
    constraint next_descr_mem.size == sizeof_s<descriptor_s>::nbytes;

    addr_handle_t descr_hndl;

    exec post_solve {
        descr.src_addr.hndl = make_handle_from_claim(src_buff.mem_seg);
        descr.dst_addr.hndl = make_handle_from_claim(dst_buff.mem_seg);
        descr.size = src_buff.mem_seg.size;
        if (last) {
            descr.next_descr.hndl = nullhandle;
        } else {
            descr.next_descr.hndl = make_handle_from_claim(next_descr_mem);
        }

        // tail of current list
        descr_hndl = in_chain.handle_list[in_chain.handle_list.size()-1];

        // copy over list from input to output
        out_chain.handle_list = in_chain.handle_list;
        // add next pointer
        out_chain.handle_list.push_back(
            make_handle_from_claim(next_descr_mem));
    }

    exec body {
        write_struct(descr_hndl,descr);
    }
}

action execute_xfer {
    input descr_chain_state in_chain;

    addr_handle_t descr_list_head;

    exec post_solve {
        descr_list_head = in_chain.handle_list[0]; // head of list
    }

    exec body {
        // Initiate chained-transfer with descr_list_head
        // Wait for the chained-transfer to complete
    }
}
In this example, the `chained_xfer` action represents the data flow (source/destination buffers) associated with this transaction. It populates the descriptor, including a pointer to the next descriptor, which it allocates. Its runtime execution writes the full descriptor out to memory, in the location allocated for it by the previous link in the chain.

### 23.10 Registers

A PSS model will often specify interaction with the hardware SUT to control how the PSS tool-generated code will read/write to programmable registers of the SUT. This section shows how to associate meaningful identifiers with register addresses that need to be specified in the PSS model description, as well as manipulation of the value of register fields by name.

All the core library constructs in this section are declared in the `addr_reg_pkg` package. For brevity, the definitions below do not include the package name.

#### 23.10.1 PSS register definition

A register is a logical aggregation of fields that are addressed as a single unit.

The `reg_c` component is a base type for specifying the programmable registers of the DUT. Note that it is a pure component (see §9.6). It shall be illegal to extend the `reg_c` class.
Component `reg_c` is parameterized by:

a) A type `R` for the value (referred to as the `register-value type`) that can be read/written from/to the register, which can be:
   1) A packed structure type (that represents the register structure)
   2) A bit-vector type (`bit[N]`)

b) Kind of access allowed to the register, which by default is `READWRITE`

c) Width of the register (`SZ`) in number of bits, which by default equals the size of the register-value type `R` (rounded up to a multiple of 8)

`SZ`, if specified by the user, shall be greater than or equal to the size of the register-value type `R`. If the size of the register-value type `R` is less than the width of the register, it will be equivalent to having `SZ - sizeof_s<R>::nbits` reserved bits at the end of the structure.

The register access functions described in Syntax 131 may be called from the test-realization layer of a PSS model. Being declared as target functions, these need to be called in an `exec body` context.

The `read()` and `read_val()` functions return the value of the register in the DUT (the former returns an instance of register-value type and the latter returns a bit vector). The `write()` and `write_val()` functions update the value of a register in a DUT (the former accepting an instance of register-value type and the latter a bit vector). If the register-value type is a bit vector, then the functions `read()` and `read_val()` are equivalent, as are `write()` and `write_val()`.
The \texttt{write\_masked()} and \texttt{write\_val\_masked()} methods cause the register to be read, a write value to be calculated from the current register value and the specified masked value, and the write value to be written back to the register. The effect is the following:

\[
\text{REG\_VAL(new)} = (\text{REG\_VAL(current)} \& \sim \text{mask}) \mid (\text{val} \& \text{mask})
\]

If dedicated read-modify-write instructions are available on a platform, a PSS processing tool may, but is not required to, implement these operations in terms of those instructions.

The \texttt{write\_masked()} and \texttt{write\_val\_masked()} methods only differ in how the mask and value are specified. In the case of \texttt{write\_val\_masked()}, both are specified as numeric quantities. In the case of \texttt{write\_masked()}, both are specified in terms of the register-value type used to define the register.

The \texttt{write\_field()} and \texttt{write\_fields()} methods specify read-write-modify operations on a register using named register fields. Note that these methods may only be used on registers specified in terms of a struct data type. The following restrictions apply to the field names specified to \texttt{write\_field()} and \texttt{write\_fields()}:

a) Only string literals may be used in specifying field names.

b) The names may only specify top-level fields, and may not specify dotted hierarchical references.

c) The field name may not refer to aggregate data type fields within the register.

d) The set of strings passed to \texttt{write\_fields()} must be unique.
In Example 282, a register is defined in terms of a packed struct with three operational fields and a reserved unused region (pad). In the action cfg_a, three different ways are shown to ensure that the mode and coeff fields are set to specific values while leaving the en field unmodified:

a) Mask and value parameters are formulated using struct literal expressions and passed to the write_masked() method. Fields in the mask parameter are set to the negation of 0 (all bits set) in order to cause the value of the corresponding register bits to be set. Unspecified fields in the mask parameter take on the default value, which PSS specifies as 0 for integer data types.

b) Numeric mask and value parameters are computed using shift and composition operations and passed to the write_val_masked() method.

c) Lists of field names and field values are passed to the write_fields() method.

See 23.10.4 for a description of the implementation of these functions. It shall be an error to call a register read or read-modify-write function on a register object whose access is set to WRITEONLY. It shall be an error to call a register write or read-modify-write function on a register object whose access is set to READONLY.
A template instantiation of the class `reg_c` (i.e., `reg_c<R, ACC, SZ>`) for some concrete values for `R`, `ACC` and `SZ`) or a component derived from such a template instantiation (directly or indirectly) is a register type. An object of register type can be instantiated only in a register group (see 23.10.2).

Example 283 shows examples of register declarations.

```
struct my_reg0_s : packed_s<> { // (1)
  bit [16] fld0;
  bit [16] fld1;
};

pure component my_reg0_c : reg_c<my_reg0_s> {} // (2)

struct my_reg1_s : packed_s<> {
  bit     fld0;
  bit [2] fld1;
  bit [2] fld2[5]; // (3)
};

pure component my_reg1_c : reg_c<my_reg1_s, READWRITE, 32> {} // (4)
```

Example 283—Examples of register declarations

Notes:

1) `my_reg0_s` is the register-value type. The endianness can be explicitly specified if needed.
2) `my_reg0_c` is the register type. Since it derives from `reg_c<my_reg0_s>`, it inherits the `reg_c` read/write functions. Note that the access is `READWRITE` by default and the width equals the size of the associated register-value type, `my_reg0_s`.
3) Fixed-size arrays are allowed.
4) `sizeof_s<my_reg1_s>::nbits = 13`, which is less than the specified register width (32). This is allowed and is equivalent to specifying a field of size `32 – 13 = 19` bits after `fld2[5]`. This reserved field cannot be accessed using `read() / write()` functions on the register object. In the numeric value passed to `write_val()` and in the return value of `read_val()`, the value of these bits is not defined by this standard.

It is recommended to declare the register type as `pure`. This allows the PSS implementation to optimally handle large static register components.

23.10.2 PSS register group definition

A register group aggregates instances of registers and of other register groups.

The `reg_group_c` component is the base type for specifying register groups. Note that it is a `pure` component (see 9.6). It shall be illegal to extend the `reg_group_c` class.
A register group may instantiate registers and instances of other register groups. An instance of a register group may be created in another register group, or directly in a non-register-group component. In the latter case, the register group can be associated with an address region. The set_handle() function associates the register group with an address region. The definition of this function is implementation-defined. See 23.10.3 for more details on use of this function.

Each element in a register group (whether an instance of a register or an instance of another group) has a user-defined address offset relative to a notional base address of the register group.

The function get_offset_of_instance() retrieves the offset of a non-array element in a register group, by name of the element. The function get_offset_of_instance_array() retrieves the offset of an array element in a register group, by name of the element and index in the array.

For example, suppose a is an instance of a register group that has the following elements:
- A register instance, r0
- A register array instance, r1[4]

Calling a.get_offset_of_instance("r0") returns the offset of the element r0. Calling a.get_offset_of_instance_array("r1", 2) returns the offset at index 2 of element r1.

The function get_offset_of_path() retrieves the offset of a register from a hierarchical path of the register, starting from a given register group. The hierarchical path of the register is specified as a list of node_s objects. Each node_s object provides the name of the element (as a string) and an index (applicable if and only if the element is of array type). The first element of the list corresponds to an object directly instantiated in the given register group. Successive elements of the list correspond to an object instantiated in the register group referred by the predecessor node. The last element of the list corresponds to the final register instance.

For example, suppose b is an instance of a register group that has the following elements: a register group array instance grp0[10], which in turn has a register group instance grp1, which in turn has a register instance, r0. The hierarchical path of register r0 in grp1 within grp0[5] within b will then be the list (e.g., path_to_r0) with the following elements in succession:
- [0]: node_s object with name = "grp0" and index = 5
- [1]: node_s object with name = "grp1" (index is not used)
- [2]: node_s object with name = "r0" (index is not used)
Calling \texttt{\texttt{b.get_offset_of_path(path_to_r0)}} will return the offset of register \texttt{r0} relative to the base address of \texttt{b}.

For a given register group, users shall provide the implementation of either \texttt{get_offset_of_path()} or of both functions \texttt{get_offset_of_instance()} and \texttt{get_offset_of_instance_array()}. It shall be an error to provide an implementation of all three functions. These may be implemented as native PSS functions, or foreign-language binding may be used. These functions (when implemented) shall provide the relative offset of \textit{all} the elements in the register group. These functions are called by a PSS tool to compute the offset for a register access (as described later in 23.10.4). Note that these functions are declared \texttt{pure} — the implementation shall not have side-effects.

\textbf{Example 284} shows an example of a register group declaration.

\begin{verbatim}
pure component my_reg_grp0_c : reg_group_c {
  my_readonly_reg0_c   reg0;            // (1)
  my_reg1_c            reg1[4];         // (2)
  my_sub_reg_grp_c     sub;             // (3)
  reg_c<my_regx_s, WRITEONLY, 32> regx; // (4)

  // May be foreign, too
  function bit[64] get_offset_of_instance(string name) {
    match(name) {
      ["reg0"]:  return 0x0;
      ["sub"]:   return 0x20;
      ["regx"]:  return 0x0;            // (5)
      default: return -1; // Error case
    }
  }

  function bit[64] get_offset_of_instance_array(string name, int index) {
    match(name) {
      ["reg1"]:  return (0x4 + index*4);
      default: return -1; // Error case
    }
  }
}
\end{verbatim}

\textit{Example 284—Example of register group declaration}

Notes:

1) \texttt{my_readonly_reg0_c, my_reg1_c, etc.}, are all register types (declarations not shown in the example).

2) Arrays of registers are allowed.

3) Groups may contain other groups (declaration of \texttt{my_sub_reg_grp_c} not shown in the example).

4) A direct instance of \texttt{reg_c<>} may be created in a register group.

5) Offsets of two elements may be same. A typical use case for this is when a \texttt{READONLY} and a \texttt{WRITEONLY} register share the same offset.

\section*{23.10.3 Association with address region}

Before the read/write functions can be invoked on a register, the top-level register group (under which the register object has been instantiated) must be associated with an address region, using the \texttt{set_handle()}
function in that register group. This is done from within an `exec init_up` or `init_down` context. Only the top-level register group shall be associated with an address region; it shall be an error to call `set_handle()` on other register group instances. An example is shown in Example 285.

```
component my_component_c
{
   my_reg_grp0_c grp0; // Top-level group
   transparent_addr_space_c<> sys_mem;

   exec init_up {
      transparent_addr_region_s<> mmio_region;
      addr_handle_t h;
      mmio_region.size = 1024;
      mmio_region.addr = 0xA0000000;
      h = sys_mem.add_nonallocatable_region(mmio_region);
      grp0.set_handle(h);
   }
}
```

**Example 285—Top-level group and address region association**

### 23.10.4 Translation of register read/write

The PSS implementation shall convert invocations of the register access functions described in Syntax 131 to invocations of the primitive read/write operations on the address associated with the register (see 23.9.9.1 and 23.9.9.2). The conversion shall proceed as follows:

a) The read/write function is selected based on the size of the register. For example, if the size of the register is 32, the function `read32(addr_handle_t hndl)` will be called for a register read.

b) The total offset is calculated by summing the offsets of all elements starting from the top-level register group to the register itself.

1) If the function `get_offset_of_path()` is available in any intermediate register group instance, the PSS implementation will use that function to find the offset of the register relative to the register group.

2) Otherwise, the function `get_offset_of_instance_array()` or `get_offset_of_instance()` is used, depending on whether or not the register instance or register group instance is an array.

For example, in the expression (where `a`, `b`, `c`, and `d` are all instances of register groups and `reg` is a register object):

```
comp.a.b.c.d[4].reg.write_val(10)
```

if the function `get_offset_of_path()` is implemented in the type of element `c`, then the offset is calculated as:

```
offset = comp.a.get_offset_of_instance("b") +
        comp.a.b.get_offset_of_instance("c") +
        comp.a.b.c.get_offset_of_path(path)
```

where `path` is the `list` `["d", 4], ["reg", 0]`.

c) The handle for the access is calculated as `make_handle_from_handle(h, offset)`, where `h` is the handle set using `set_handle()` on the top-level register group.
23.10.5 Recommended packaging

It is recommended that all the register (and register group) definitions of a device be placed in a separate file and in a separate package by themselves, as shown in Example 286.

```
// In my_IP_regs.pss
package my_IP_regs {
    import addr_reg_pkg::*;
    struct my_reg0_s : packed_s<> { ... };  
    pure component my_reg0_c : reg_c<my_reg0_s, READWRITE, 32> { ... };  
    // ... etc: other registers

    pure component my_reg_group_c : reg_group_c {
        my_reg0_c r0;
        // ... etc: other registers
    };
}
```

Example 286—Recommended packaging

This ensures that the register file can be easily generated from a register specification (e.g., IP-XACT).
Annex A

(informative)

Bibliography

Annex B
(normative)

Formal syntax

The PSS formal syntax is described using Backus-Naur Form (BNF). The syntax of the PSS source is derived from the starting symbol Model. If there is a conflict between a grammar element shown anywhere in this standard and the material in this annex, the material shown in this annex shall take precedence.

```
Model ::= { portable_stimulus_description }

portable_stimulus_description ::= 
    package_body_item 
    | package_declaration 
    | component_declaration

B.1 Package declarations

package_declaration ::= package package_id_path { { package_body_item } }

package_id_path ::= package_identifier { :: package_identifier }

package_body_item ::= 
    abstract_action_declaration 
    | struct_declaration 
    | enum_declaration 
    | covergroup_declaration 
    | function_decl 
    | import_class_decl 
    | procedural_function 
    | import_function 
    | target_template_function 
    | export_action 
    | typedef_declaration 
    | import_stmt 
    | extend_stmt 
    | const_field_declaration 
    | component_declaration 
    | package_declaration 
    | compile_assert_stmt 
    | package_body_compile_if 
    | stmt_terminator

import_stmt ::= import package_import_pattern ;

package_import_pattern ::= type_identifier [ package_import_qualifier ]

package_import_qualifier ::= 
    package_importWildcard 
    | package_import_alias

package_importWildcard ::= :: *
```
package_import_alias ::= as package_identifier

extend_stmt ::= 
extend action type_identifier { { action_body_item } }
| extend component type_identifier { { component_body_item } }
| extend struct_kind type_identifier { { struct_body_item } }
| extend enum type_identifier { [ enum_item , enum_item ] }

const_field_declaration ::= [ static ] const data_declaration

stmt_terminator ::= ;

B.2 Action declarations

action_declaration ::= action action_identifier
                   [ template_param_decl_list ] [ action_super_spec ] { { action_body_item } }

abstract_action_declaration ::= abstract action_declaration

action_super_spec ::= : type_identifier

action_body_item ::= 
activity_declaration
| override_declaration
| constraint_declaration
| action_field_declaration
| symbol_declaration
| covergroup_declaration
| exec_block_stmt
| activity_scheduling_constraint
| attr_group
| compile_assert_stmt
| covergroup_instantiation
| action_body_compile_if
| stmt_terminator

activity_declaration ::= activity { { activity_stmt } }

action_field_declaration ::= 
attr_field
| activity_data_field
| action_handle_declaration
| object_ref_field_declaration

object_ref_field_declaration ::= 
flow_ref_field_declaration
| resource_ref_field_declaration

flow_ref_field_declaration ::= 
( input | output ) flow_object_type object_ref_field { , object_ref_field } ;

resource_ref_field_declaration ::= 
( lock | share ) resource_object_type object_ref_field { , object_ref_field } ;
flow_object_type ::=  
    buffer_type_identifier  
    | state_type_identifier  
    | stream_type_identifier  

resource_object_type ::= resource_type_identifier  

object_ref_field ::= identifier [ array_dim ]  

action_handle_declaration ::= action_type_identifier action_instantiation ;  

action_instantiation ::=  
    action_handle_identifier [ array_dim ]  
    { , action_handle_identifier [ array_dim ]  }  

activity_data_field ::= action data_declaration  

activity_scheduling_constraint ::= constraint { parallel | sequence  }  
    { hierarchical_id , hierarchical_id { , hierarchical_id }  } ;  

B.3 Struct declarations  

struct_declaration ::= struct_kind struct_identifier  
    [ template_param_decl_list ] [ struct_super_spec ] { { struct_body_item } }  

struct_kind ::=  
    struct  
    | object_kind  

object_kind ::=  
    buffer  
    | stream  
    | state  
    | resource  

struct_super_spec ::= : type_identifier  

struct_body_item ::=  
    constraint_declaration  
    | attr_field  
    | typedef_declaration  
    | exec_block_stmt  
    | attr_group  
    | compile_assert_stmt  
    | covergroup_declaration  
    | covergroup_instantiation  
    | struct_body_compile_if  
    | stmt_terminator
B.4 Exec blocks

exec_block_stmt ::= 
  exec_block 
  | target_code_exec_block 
  | target_file_exec_block 
  | stmt_terminator

exec_block ::= exec exec_kind { { exec_stmt } }
exec_kind ::= 
  pre_solve 
  | post_solve 
  | pre_body 
  | body 
  | header 
  | declaration 
  | run_start 
  | run_end 
  | init_down 
  | init_up 
  | init

exec_stmt ::= 
  procedural_stmt 
  | exec_super_stmt
exec_super_stmt ::= super ;

target_code_exec_block ::= exec exec_kind language_identifier = string_literal;

target_file_exec_block ::= exec file filename_string = string_literal ;

B.5 Functions

procedural_function ::= [ platform_qualifier ] [ pure ] [ static ] function 
  function_prototype { { procedural_stmt } }

function_decl ::= [ pure ] [ static ] function function_prototype ;

function_prototype ::= 
  function_return_type function_identifier function_parameter_list_prototype

function_return_type ::= 
  void 
  | data_type

function_parameter_list_prototype ::= 
  ( [ function_parameter [ , function_parameter ] ] ) 
  | ( { function_parameter , } varargs_parameter )

function_parameter ::= 
  [ function_parameter_dir ] data_type identifier [ = constant_expression ] 
  | { type | ref type_category | struct } identifier
function_parameter_dir ::=  
  input  
  |  output  
  |  inout

varargs_parameter ::=  
  ( data_type | type | ref type_category | struct ) ... identifier

B.6 Foreign procedural interface

import_function ::=  
  import [ platform_qualifier ] [ language_identifier ]  
  function type_identifier ;  
  |  import [ platform_qualifier ] [ language_identifier ] [ static ]  
  function function_prototype ;

platform_qualifier ::=  
  target  
  |  solve

target_template_function ::=  
  target language_identifier [ static ]  
  function function_prototype = string_literal ;

import_class_decl ::= import class import_class_identifier  
  [ import_class_extends ] { { import_class_function_decl } }

import_class_extends ::= : type_identifier { , type_identifier }

import_class_function_decl ::= function_prototype ;

export_action ::= export [ platform_qualifier ] action_type_identifier  
  function_parameter_list_prototype ;

B.7 Procedural statements

procedural_stmt ::=  
  procedural_sequence_block_stmt  
  | procedural_data_declaration  
  | procedural_assignment_stmt  
  | procedural_void_function_call_stmt  
  | procedural_return_stmt  
  | procedural_repeat_stmt  
  | procedural_foreach_stmt  
  | procedural_if_else_stmt  
  | procedural_match_stmt  
  | procedural_break_stmt  
  | procedural_continue_stmt  
  | procedural_randomization_stmt  
  | procedural_compile_if  
  | stmt_terminator

procedural_sequence_block_stmt ::= [ sequence ] { { procedural_stmt } }
procedural_data_declaration ::= data_type procedural_data_instantiation 
   { , procedural_data_instantiation } ;

procedural_data_instantiation ::= identifier [ array_dim ] [ = expression ]

procedural_assignment_stmt ::= ref_path assign_op expression ;

procedural_void_function_call_stmt ::= [ ( void ) ] function_call ;

procedural_return_stmt ::= return [ expression ] ;

procedural_repeat_stmt ::= 
   repeat ( [ index_identifier : ] expression ) procedural_stmt 
   | repeat procedural_stmt while ( expression ) ;
   | while ( expression ) procedural_stmt

procedural_foreach_stmt ::= 

procedural_if_else_stmt ::= 
   if ( expression ) procedural_stmt [ else procedural_stmt ]

procedural_match_stmt ::= 
   match ( match_expression ) 
   { procedural_match_choice { procedural_match_choice } }

procedural_match_choice ::= 
   | open_range_list : procedural_stmt 
   | default : procedural_stmt

procedural_break_stmt ::= break ;

procedural_continue_stmt ::= continue ;

procedural_randomization_stmt ::= 
   randomize procedural_randomization_target procedural_randomization_term

procedural_randomization_target ::= hierarchical_id { , hierarchical_id }

procedural_randomization_term ::= 
   with constraint_set 
   | ;

B.8 Component declarations

component_declaration ::= 
   [ pure ] component component_identifier [ template_param_decl_list ] 
   [ component_super_spec ] { { component_body_item } } 

component_super_spec ::= : type_identifier

component_body_item ::= 
   override_declaration 
   | component_data_declaration
component_data_declaration ::= 
    [ access_modifier ] [ static const ] data_declaration

component_pool_declaration ::= 
    pool [ [ expression ] ] type_identifier identifier ;

object_bind_stmt ::= bind hierarchical_id object_bind_item_or_list ;

object_bind_item_or_list ::= 
    object_bind_item_path 
    | { object_bind_item_path , object_bind_item_path } 

object_bind_item_path ::= { component_path_elem . } object_bind_item

component_path_elem ::= component_identifier [ [ domain_open_range_list ] ]

object_bind_item ::= 
    action_type_identifier . identifier [ [ domain_open_range_list ] ] 
    | *

B.9 Activity statements

activity_stmt ::= 
    [ label_identifier : ] labeled_activity_stmt 
    | activity_action_traversal_stmt 
    | activity_data_field 
    | activity_bind_stmt 
    | action_handle_declaration 
    | activity_constraint_stmt 
    | activity_scheduling_constraint 
    | stmt_terminator

labeled_activity_stmt ::= 
    activity_sequence_block_stmt

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| activity_parallel_stmt
| activity_schedule_stmt
| activity_repeat_stmt
| activity_foreach_stmt
| activity_select_stmt
| activity_if_else_stmt
| activity_match_stmt
| activity_replicate_stmt
| activity_super_stmt
| activity_atomic_block_stmt
| symbol_call

activity_action_traversal_stmt ::= identifier [ [ expression ] ] inline_constraints_or_empty
| [ label_identifier : ] do type_identifier inline_constraints_or_empty

inline_constraints_or_empty ::= with constraint_set
| ;

activity_sequence_block_stmt ::= [ sequence ] { { activity_stmt } }

activity_parallel_stmt ::= parallel [ activity_join_spec ] { { activity_stmt } }

activity_schedule_stmt ::= schedule [ activity_join_spec ] { { activity_stmt } }

activity_join_spec ::= activity_join_branch
| activity_join_select
| activity_join_none
| activity_join_first

activity_join_branch ::= join_branch ( label_identifier { , label_identifier } )

activity_join_select ::= join_select ( expression )

activity_join_none ::= join_none

activity_join_first ::= join_first ( expression )

activity_repeat_stmt ::= repeat ( [ index_identifier : ] expression ) activity_stmt
| repeat activity_stmt while ( expression ) ;

activity_foreach_stmt ::= foreach ( [ iterator_identifier : ] expression
[ [ index_identifier ] ] ) activity_stmt

activity_select_stmt ::= select { select_branch select_branch { select_branch } }

select_branch ::= [[ ( expression ) ][ expression | ] : ] activity_stmt

activity_if_else_stmt ::= if ( expression ) activity_stmt [ else activity_stmt ]

activity_match_stmt ::= match ( match_expression ) { match_choice { match_choice } }

match_expression ::= expression
match_choice ::=  
   [ open_range_list ] : activity_stmt
   | default : activity_stmt

activity_replicate_stmt ::= replicate( [ index_identifier[:] expression) 
   [ label_identifier[]:] labeled_activity_stmt

activity_super_stmt ::= super ;

activity_atomic_block_stmt ::= atomic { { activity_stmt } }

activity_bind_stmt ::= bind hierarchical_id activity_bind_item_or_list ;

activity_bind_item_or_list ::= 
   hierarchical_id
   | { hierarchical_id_list }

activity_constraint_stmt ::= constraint constraint_set

symbol_declaration ::= 
   symbol symbol_identifier [ ( symbol_paramlist ) ] { { activity_stmt } }

symbol_paramlist ::= [ symbol_param { symbol_param } ]

symbol_param ::= data_type identifier

B.10 Overrides

override_declaration ::= override { { override_stmt } }

override_stmt ::= 
   type_override
   | instance_override
   | override_compile_if
   | stmt_terminator

type_override ::= type type_identifier with type_identifier ;

instance_override ::= instance hierarchical_id with type_identifier ;

B.11 Data declarations

data_declaration ::= data_type data_instantiation { , data_instantiation } ;

data_instantiation ::= identifier [ array_dim ] [ = constant_expression ]

array_dim ::= [ constant_expression ]

attr_field ::= [ access_modifier ] [ rand | static const ] data_declaration

access_modifier ::= public | protected | private

attr_group ::= access_modifier :

B.12 Template types

```plaintext
template_param_decl_list ::= < template_param_decl { , template_param_decl } >

template_param_decl ::= type_param_decl | value_param_decl

type_param_decl ::= generic_type_param_decl | category_type_param_decl
generic_type_param_decl ::= type identifier [ = type_identifier ]
category_type_param_decl ::= type_category identifier [ type_restriction ] [ = type_identifier ]
type_restriction ::= : type_identifier
type_category ::=
  action
  | component
  | struct_kind

value_param_decl ::= data_type identifier [ = constant_expression ]
template_param_value_list ::= < [ template_param_value { , template_param_value } ] >
template_param_value ::= constant_expression | data_type

B.13 Data types

data_type ::= scalar_data_type
  | collection_type
  | reference_type
  | type_identifier

scalar_data_type ::= chandle_type
  | integer_type
  | string_type
  | bool_type
  | enum_type
  | float_type

casting_type ::= integer_type
  | bool_type
  | enum_type
  | float_type
  | reference_type
  | type_identifier

chandle_type ::= chandle

integer_type ::= integer_atom_type
  [ [ constant_expression [ : 0 ] ] ]
  [ in [ domain_open_range_list ] ]
```

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integer_atom_type ::= 
    int | bit

domain_open_range_list ::= 
    domain_open_range_value { , domain_open_range_value }

domain_open_range_value ::= 
    constant_expression [ .. constant_expression ]
    | constant_expression ..
    | .. constant_expression

string_type ::= string [ in | string_literal { , string_literal } ]

bool_type ::= bool

enum_declaration ::= 
    enum enum_identifier [ : data_type ] { [ enum_item { , enum_item } ] }

enum_item ::= identifier [ = constant_expression ]

enum_type ::= enum_type_identifier [ in [ domain_open_range_list ] ]

float_type ::= 
    float32 | float64

collection_type ::= 
    array < data_type , array_size_expression >
    | list < data_type >
    | map < data_type , data_type >
    | set < data_type >

array_size_expression ::= constant_expression

reference_type ::= ref entity_type_identifier

typedef_declaration ::= typedef data_type identifier ;

B.14 Constraints

constraint_declaration ::= 
    constraint constraint_set
    | [ dynamic ] constraint identifier constraint_block

constraint_set ::= 
    constraint_body_item
    | constraint_block

constraint_block ::= { { constraint_body_item } }

constraint_body_item ::= 
    expression_constraint_item
    | foreach_constraint_item
forall_constraint_item ::= \forall \{ \text{hierarchical_id\_list} \}

if_constraint_item ::= \text{if} ( \text{expression} ) \text{constraint\_set} [ \text{else} \text{constraint\_set} ]

implication_constraint_item ::= \text{expression} \rightarrow \text{constraint\_set}

unique_constraint_item ::= \text{unique} \{ \text{hierarchical_id\_list} \}

dist_directive ::= \text{dist} \text{expression in} [ \text{dist\_list} ]

dist_list ::= \text{dist\_item\_list}

dist_weight ::= \text{expression} | ::=} \text{expression} | ::/ \text{expression}

### B.15 Coverage specification

covergroup_declaration ::= \text{covergroup} \text{covergroup\_identifier}
    ( \text{covergroup\_port\_list} )\{ [ \text{covergroup\_body\_item} ] \}

covergroup_port ::= \text{data\_type\_identifier}

covergroup_body_item ::= \text{covergroup\_option}
    | \text{covergroup\_coverpoint}
    | \text{covergroup\_cross}
    | \text{covergroup\_body\_compile\_if}
    | \text{stmt\_terminator}

covergroup_option ::= \text{option\_identifier} = \text{constant\_expression} ;

covergroup_instantiation ::= \text{covergroup\_type\_instantiation}
    | \text{inline\_covergroup}
inline_covergroup ::= covergroup { { covergroup_body_item } } identifier ;

covergroup_type_instantiation ::= covergroup_type_identifier covergroup_identifier ( covergroup_portmap_list ) covergroup_options_or_empty

covergroup_portmap_list ::= covergroup_portmap { , covergroup_portmap } | hierarchical_id_list

covergroup_portmap ::= . identifier ( hierarchical_id )

covergroup_options_or_empty ::= with { { covergroup_option } } | ;

covergroup_coverpoint ::= { { data_type } coverpoint_identifier : } coverpoint expression [ iff ( expression ) ] bins_or_empty

bins_or_empty ::= { { covergroup_coverpoint_body_item } } | ;

covergroup_coverpoint_body_item ::= covergroup_option | covergroup_coverpoint_binspec


coverpoint_bins ::= [ covergroup_range_list ] [ with ( covergroup_expression ) ] ;
| coverpoint_identifier with ( covergroup_expression ) ;
| default ;

covergroup_range_list ::= covergroup_value_range { , covergroup_value_range }

covergroup_value_range ::= expression
| expression .. [ expression ]
| [ expression ] .. expression

bins_keyword ::= bins | illegal_bins | ignore_bins

covergroup_expression ::= expression

covergroup_cross ::= covercross_identifier : cross coverpoint_identifier { , coverpoint_identifier }[ iff ( expression ) ] cross_item_or_null

cross_item_or_null ::= { { covergroup_cross_body_item } } | ;

covergroup_cross_body_item ::= covergroup_option | covergroup_cross_binspec
covergroup_cross_binspec ::= bins_keyword identifier = covercross_identifier with ( covergroup_expression )

B.16 Conditional compilation

package_body_compile_if ::= compile if ( constant_expression )
    package_body_compile_if_item [ else package_body_compile_if_item ]

action_body_compile_if ::= compile if ( constant_expression )
    action_body_compile_if_item [ else action_body_compile_if_item ]

component_body_compile_if ::= compile if ( constant_expression )
    component_body_compile_if_item [ else component_body_compile_if_item ]

struct_body_compile_if ::= compile if ( constant_expression )
    struct_body_compile_if_item [ else struct_body_compile_if_item ]

procedural_compile_if ::= compile if ( constant_expression )
    procedural_compile_if_stmt [ else procedural_compile_if_stmt ]

constraint_body_compile_if ::= compile if ( constant_expression )
    constraint_body_compile_if_item [ else constraint_body_compile_if_item ]

covergroup_body_compile_if ::= compile if ( constant_expression )
    covergroup_body_compile_if_item [ else covergroup_body_compile_if_item ]

override_compile_if ::= compile if ( constant_expression )
    override_compile_if_stmt [ else override_compile_if_stmt ]

package_body_compile_if_item^{10} ::= { { package_body_item } }

action_body_compile_if_item^{10} ::= { { action_body_item } }

component_body_compile_if_item^{10} ::= { { component_body_item } }

struct_body_compile_if_item^{10} ::= { { struct_body_item } }

procedural_compile_if_stmt^{10} ::= { { procedural_stmt } }

constraint_body_compile_if_item^{10} ::= { { constraint_body_item } }

covergroup_body_compile_if_item^{10} ::= { { covergroup_body_item } }

override_compile_if_stmt^{10} ::= { { override_stmt } }

compile_has_expr ::= compile has ( static_ref_path )

compile_assert_stmt ::= compile assert ( constant_expression [ , string_literal ] )

---

^{10} In previous versions of PSS, a compile if branch consisting of a single item, such as a single package_body_item, did not have to be enclosed in curly braces. That syntax has been deprecated.
B.17 Expressions

constant_expression ::= expression

expression ::= 
  primary 
  | unary_operator primary 
  | expression binary_operator expression 
  | conditional_expression 
  | in_expression

unary_operator ::= - | ! | ~ | & | | ^

binary_operator ::= * | / | % | + | - | << | >> | == | != | < | <= | > | >= | || | & & | |
  | ^ | & | **

assign_op ::= = | += | -= | <<= | >>= | |= | &=

conditional_expression ::= cond_predicate ? expression : expression

cond_predicate ::= expression

in_expression ::= 
  expression in [ open_range_list ] 
  | expression in collection_expression

open_range_list ::= open_range_value { , open_range_value }

open_range_value ::= expression [ .. expression ]

collection_expression ::= expression

primary ::= 
  number 
  | aggregate_literal 
  | bool_literal 
  | string_literal 
  | null_ref 
  | paren_expr 
  | cast_expression 
  | ref_path 
  | compile_has_expr

paren_expr ::= ( expression )

cast_expression ::= ( casting_type ) expression

ref_path ::= 
  static_ref_path [ , hierarchical_id ] [ bit_slice ] 
  | [ super. ] hierarchical_id [ bit_slice ]

static_ref_path ::= [ :: ] { type_identifier_elem :: } member_path_elem

bit_slice ::= [ constant_expression : constant_expression ]
function_call ::= 
    super . function_ref_path
   | [ :: ] { type_identifier_elem :: } function_ref_path

function_ref_path ::= { member_path_elem . } identifier function_parameter_list

symbol_call ::= symbol_identifier function_parameter_list ;

function_parameter_list ::= ( [ expression , expression ] )

B.18 Identifiers

identifier ::= 
    ID
   | ESCAPED_ID

hierarchical_id_list ::= hierarchical_id { , hierarchical_id }

hierarchical_id ::= member_path_elem { . member_path_elem }

member_path_elem ::= identifier [ function_parameter_list ] { [ expression ] }

action_identifier ::= identifier

action_handle_identifier ::= identifier

component_identifier ::= identifier

covercross_identifier ::= identifier

covergroup_identifier ::= identifier

coverpoint_identifier ::= identifier

enum_identifier ::= identifier

function_identifier ::= identifier

import_class_identifier ::= identifier

index_identifier ::= identifier

iterator_identifier ::= identifier

label_identifier ::= identifier

language_identifier ::= identifier

package_identifier ::= identifier

struct_identifier ::= identifier

symbol_identifier ::= identifier

type_identifier ::= [ :: ] type_identifier_elem { :: type_identifier_elem }

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type_identifier_elem ::= identifier [ template_param_value_list ]

action_type_identifier ::= type_identifier
buffer_type_identifier ::= type_identifier
component_type_identifier ::= type_identifier
covergroup_type_identifier ::= type_identifier
elem_type_identifier ::= type_identifier
resource_type_identifier ::= type_identifier
state_type_identifier ::= type_identifier
stream_type_identifier ::= type_identifier

entity_type_identifier ::= action_type_identifier
| component_type_identifier
| flow_object_type
| resource_object_type

B.19 Numbers and literals

number ::= integer_number
| floating_point_number

integer_number ::= bin_number
| oct_number
| dec_number
| hex_number
| based_bin_number
| based_oct_number
| based_dec_number
| based_hex_number

bin_digit ::= [0-1]

oct_digit ::= [0-7]

dec_digit ::= [0-9]

hex_digit ::= [0-9] | [a-f] | [A-F]

bin_number ::= 0[b|B] bin_digit { bin_digit | _ }

oct_number ::= 0 { oct_digit | _ }

dec_number ::= [1-9] { dec_digit | _ }

hex_number ::= 0[x|X] hex_digit { hex_digit | _ }

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BASED_BIN_LITERAL ::= '[s|S][b|B] bin_digit { bin_digit | _ }

BASED_OCT_LITERAL ::= '[s|S][o|O] oct_digit { oct_digit | _ }

BASED_DEC_LITERAL ::= '[s|S][d|D] dec_digit { dec_digit | _ }

BASED_HEX_LITERAL ::= '[s|S][h|H] hex_digit { hex_digit | _ }

based_bin_number ::= [ dec_number ] BASED_BIN_LITERAL

based_oct_number ::= [ dec_number ] BASED_OCT_LITERAL

based_dec_number ::= [ dec_number ] BASED_DEC_LITERAL

based_hex_number ::= [ dec_number ] BASED_HEX_LITERAL

floating_point_number ::= floating_point_dec_number
| floating_point_sci_number

unsigned_number ::= dec_digit { dec_digit | _ }

floating_point_dec_number ::= unsigned_number . unsigned_number

floating_point_sci_number ::= unsigned_number [ , unsigned_number ] exp [ sign ] unsigned_number

exp ::= e | E

sign ::= + | -

aggregate_literal ::= empty_aggregate_literal
| value_list_literal
| map_literal
| struct_literal

empty_aggregate_literal ::= {}

value_list_literal ::= { expression { , expression } }

map_literal ::= { map_literal_item { , map_literal_item } }

map_literal_item ::= expression : expression

struct_literal ::= { struct_literal_item { , struct_literal_item } }

struct_literal_item ::= . identifier = expression

bool_literal ::= true
| false

null_ref ::= null
B.20 Additional lexical conventions

```plaintext
SL_COMMENT ::= //{any.ASCII.character_except_newline}\n
ML_COMMENT ::= /*{any.ASCII.character}*/

string_literal ::= QUOTED_STRING |
| TRIPLE_QUOTED_STRING

QUOTED_STRING ::= " { unescaped_character | escaped_character } "

unescaped_character ::= any_printable_ASCII_character

escaped_character ::= \('|"|\|\?\|\|\a|\b|\f|\n|\r|\t|\v|\[0-7]|\[0-7]|\[0-7])

TRIPLE_QUOTED_STRING ::= "\"\"{any.ASCII.character}\"\"\n
filename_string ::= QUOTED_STRING

ID ::= [a-z][A-Z]_ { [a-z][A-Z]_ | [0-9] }

ESCAPED_ID ::= \{any_printable_ASCII_character_except_whitespace\} whitespace

whitespace ::= space | tab | newline | end_of_file
```
Annex C
(normative)

Core library package

This annex contains the contents of the built-in core library packages std_pkg, executor_pkg and addr_reg_pkg described in Clause 23. If there is a conflict between core library package contents shown anywhere in this standard and the material in this annex, the material shown in this annex shall take precedence.

C.1 Package std_pkg

```haskell
package std_pkg {

    enum endianness_e {LITTLE_ENDIAN, BIG_ENDIAN};

    struct packed_s<endianness_e e = LITTLE_ENDIAN> {};

    struct sizeof_s<type T> {
        static const int nbytes = /* implementation-specific */;
        static const int nbits = /* implementation-specific */;
    };

    // Functions available on solve platform only
    function string format(string format_str, type... args);
    function void print(string format_str, type... args);

    enum message_verbosity_e {NONE, LOW, MEDIUM, HIGH, FULL};

    // Function available on target platform only
    function void message
        (message_verbosity_e vrb_level, string format_str, type... args);

    typedef chandle file_handle_t;
    static const file_handle_t nullfilehandle = /* implementation-specific */;

    enum file_option_e {TRUNCATE, APPEND, READ};

    // Functions available on solve platform only
    function file_handle_t file_open(string filename, file_option_e opt);
    function void file_close(file_handle_t file_handle);
    function bool file_exists(string filename);

    function void file_write
        (file_handle_t file_handle, string format_str, type... args);
    function string file_read(file_handle_t file_handle, int size = -1);

    function void file_write_lines
        (string filename, list<string> lines, file_option_e opt);
    function list<string> file_read_lines(string filename);

    function void error(string format_str, type... args);
    function void fatal(int status, string format_str, type... args);
}
```
// random functions
function bit[32] urandom();
function bit[32] urandom_range(bit[32] min, bit[32] max);

// Floating-point Storage Types
struct float_base_s <int Wm, int We, endianness_e E=LITTLE_ENDIAN> :
    packed_s<E> {
    rand bit[Wm] mantissa;
    rand bit[We] exponent;
    rand bit sign;
}

// Pre-defined storage types to match computation types
typedef float_base_s<23,8> float32_s;
typedef float_base_s<52,11> float64_s;

// Floating-point Functions
function float64 log(float64 x);
function float64 log10(float64 x);
function float64 exp(float64 x);
function float64 sqrt(float64 x);
function float64 pow(float64 x, float64 y);
function float64 round(float64 x);
function float64 floor(float64 x);
function float64 ceil(float64 x);
function float64 sin(float64 x);
function float64 cos(float64 x);
function float64 tan(float64 x);
function float64 asin(float64 x);
function float64 acos(float64 x);
function float64 atan(float64 x);
function float64 atan2(float64 y, float64 x);
function float64 hypot(float64 x, float64 y);
function float64 sinh(float64 x);
function float64 cosh(float64 x);
function float64 tanh(float64 x);
function float64 asinh(float64 x);
function float64 acosh(float64 x);
function float64 atanh(float64 x);

function bit[52] float_mantissa(float64 fv);
function bit[11] float_exponent(float64 fv);
function bit float_sign(float64 fv);
function float64 to_float(bit[52] mantissa, bit[11] exp, bit sign);
C.2 Package executor_pkg

package executor_pkg {
    struct executor_trait_s {};  
    struct empty_executor_trait_s : executor_trait_s {}; 
    component executor_base_c {}; 
    component executor_c 
        <struct TRAIT : executor_trait_s = empty_executor_trait_s> : executor_base_c { 
            TRAIT trait; 
        }; 
    component executor_group_c 
        <struct TRAIT : executor_trait_s = empty_executor_trait_s> { 
            function void add_executor(ref executor_c<TRAIT> exe); 
        }; 
    struct executor_claim_s 
        <struct TRAIT : executor_trait_s = empty_executor_trait_s> { 
            rand TRAIT trait; 
        }; 
    function ref executor_base_c executor(); 
}

C.3 Package addr_reg_pkg

package addr_reg_pkg {
    import std_pkg::*; 
    import executor_pkg::*; 
    component addr_space_base_c {}; 
    struct addr_trait_s {}; 
    struct empty_addr_trait_s : addr_trait_s {}; 
    typedef chandle addr_handle_t; 
    component contiguous_addr_space_c 
        <struct TRAIT : addr_trait_s = empty_addr_trait_s> : addr_space_base_c { 
            function addr_handle_t add_region(addr_region_s <TRAIT> r); 
            function addr_handle_t add_nonallocatable_region(addr_region_s <> r); 
            bool byte_addressable = true; 
        }; 
    component transparent_addr_space_c 
        <struct TRAIT: addr_trait_s = empty_addr_trait_s> : contiguous_addr_space_c<TRAIT> {};
struct addr_region_base_s {
    bit[64] size;
    string tag;
};

struct addr_region_s <struct TRAIT : addr_trait_s = empty_addr_trait_s>
    : addr_region_base_s {
    TRAIT trait;
};

struct transparent_addr_region_s
    <struct TRAIT : addr_trait_s = empty_addr_trait_s>
    : addr_region_s<TRAIT> {
    bit[64] addr;
};

struct addr_claim_base_s {
    rand bit[64] size;
    rand bool permanent;
    constraint default permanent == false;
};

struct addr_claim_s <struct TRAIT : addr_trait_s = empty_addr_trait_s>
    : addr_claim_base_s {
    rand TRAIT trait;
    rand bit[64] in [64'd2**0, 64'd2**1, 64'd2**2, 64'd2**3 , 64'd2**4 , 64'd2**5 , 64'd2**6 , 64'd2**7 , 64'd2**8 , 64'd2**9 , 64'd2**10, 64'd2**11, 64'd2**12, 64'd2**13, 64'd2**14, 64'd2**15, 64'd2**16, 64'd2**17, 64'd2**18, 64'd2**19, 64'd2**20, 64'd2**21, 64'd2**22, 64'd2**23, 64'd2**24, 64'd2**25, 64'd2**26, 64'd2**27, 64'd2**28, 64'd2**29, 64'd2**30, 64'd2**31, 64'd2**32, 64'd2**33, 64'd2**34, 64'd2**35, 64'd2**36, 64'd2**37, 64'd2**38, 64'd2**39, 64'd2**40, 64'd2**41, 64'd2**42, 64'd2**43, 64'd2**44, 64'd2**45, 64'd2**46, 64'd2**47, 64'd2**48, 64'd2**49, 64'd2**50, 64'd2**51, 64'd2**52, 64'd2**53, 64'd2**54, 64'd2**55, 64'd2**56, 64'd2**57, 64'd2**58, 64'd2**59, 64'd2**60, 64'd2**61, 64'd2**62, 64'd2**63] alignment;
};

struct transparent_addr_claim_s
    <struct TRAIT : addr_trait_s = empty_addr_trait_s>
    : addr_claim_s<TRAIT> {
    rand bit[64] addr;
};

const addr_handle_t nullhandle = /* implementation-specific */;

struct sized_addr_handle_s < int SZ, // in bits
    int lsb = 0,
    endianness_e e = LITTLE_ENDIAN >
    : packed_s<e> {
    addr_handle_t hndl;
};

function addr_handle_t make_handle_from_claim (addr_claim_base_s claim,
    bit[64] offset = 0);

function addr_handle_t make_handle_from_handle (addr_handle_t handle,
    bit[64] offset = 0);
function bit[64] addr_value(addr_handle_t hndl);
function bit[64] addr_value_solve(addr_handle_t hndl);
function bool addr_value_abs(addr_handle_t hndl);

import target function addr_value;

function string get_tag(addr_handle_t hndl);

function bit[8] read8(addr_handle_t hndl);
function bit[16] read16(addr_handle_t hndl);
function bit[32] read32(addr_handle_t hndl);
function bit[64] read64(addr_handle_t hndl);

function void write8 (addr_handle_t hndl, bit[8] data);
function void write16(addr_handle_t hndl, bit[16] data);
function void write32(addr_handle_t hndl, bit[32] data);
function void write64(addr_handle_t hndl, bit[64] data);

function void read_bytes (addr_handle_t hndl, list<bit[8]> data,
                          int size);
function void write_bytes(addr_handle_t hndl, list<bit[8]> data);

function void read_struct (addr_handle_t hndl, struct packed_struct);
function void write_struct(addr_handle_t hndl, struct packed_struct);

extend component executor_base_c {
    function bit[64] addr_value(addr_handle_t hndl);
    function bit[64] addr_value_solve(addr_handle_t hndl);

    function bit[8] read8(addr_handle_t hndl);
    function bit[16] read16(addr_handle_t hndl);
    function bit[32] read32(addr_handle_t hndl);
    function bit[64] read64(addr_handle_t hndl);

    function void write8 (addr_handle_t hndl, bit[8] data);
    function void write16(addr_handle_t hndl, bit[16] data);
    function void write32(addr_handle_t hndl, bit[32] data);
    function void write64(addr_handle_t hndl, bit[64] data);

    function void read_bytes (addr_handle_t hndl, list<bit[8]> data,
                              int size);
    function void write_bytes(addr_handle_t hndl, list<bit[8]> data);
};

enum reg_access {READWRITE, READONLY, WRITEONLY};

pure component reg_c < type R,
        reg_access ACC = READWRITE,
        int SZ = (8*sizeof_s<R>::nbytes)> {
    function R read();
    import target function read;

    function void write(R r);
    import target function write;

    function bit[SZ] read_val();
    import target function read_val;
function void write_val(bit[SZ] r);
import target function write_val;

function void write_masked(R mask, R val);
import target function write_masked;

function void write_val_masked(bit[SZ] mask, bit[SZ] val);
import target function write_val_masked;

function void write_field(string name, bit[SZ] val);
import target function write_field;

function void write_fields(list<string> names, list<bit[SZ]> vals);
import target function write_fields;

struct node_s {
  string name;
  int    index;
};

pure component reg_group_c {
  pure function bit[64] get_offset_of_instance(string name);
  pure function bit[64] get_offset_of_instance_array(string name, int index);
  pure function bit[64] get_offset_of_path(list<node_s> path);
  function void set_handle(addr_handle_t addr);
  import solve function set_handle;
};
Annex D

(normative)

Foreign language bindings

D.1 Function prototype mapping

Let \( f \) be a function declared under hierarchical path \( H \) in PSS with type signature as below (with \( D_x \) as the direction, \( T_x \) as the type and \( p_x \) as the parameter name):

\[
f(D_0 T_0 p_0, D_1 T_1 p_1, \ldots, D_n T_n p_n);
\]

When \( f \) is bound to a foreign language API (see 21.4), it is mapped to the following function in the target language:

\[
H'::f'(T'_0 p_0, T'_1 p_1, \ldots, T'_n p_n);
\]

If the foreign language supports parameter directions, their directions are the same as in PSS.

NOTE—See D.5 for exceptions when mapping PSS functions to SystemVerilog tasks.

Each parameter in the PSS function is mapped to a corresponding parameter in the mapped function. The details of function name and data type binding are covered further below.

D.2 Data type mapping

PSS specifies data type bindings to C/C++ and SystemVerilog. The data type binding rules apply only to parameter and return types referenced (directly or indirectly) in the declaration of functions in PSS that are bound to foreign language APIs (see 21.4). The allowed types are specified in 21.4.1.1, namely:

- Primitive types: \texttt{bit} or \texttt{int} (width no more than 64 bits), \texttt{bool}, \texttt{string}, \texttt{chandle}.
- User-defined types: \texttt{enum} and \texttt{struct}, excluding packed structs (see 23.8.1) and excluding flow/resource objects. Fields of \texttt{structs} shall be of these allowed types (recursively).
- Fixed-size arrays of these types.

The type binding is specified for parameter and return types.

D.3 C language bindings

D.3.1 Function names

PSS implementations shall support mapping a PSS function name to an identical function name in C, ignoring the hierarchical path in PSS. PSS implementations may define additional mapping schemes for function names.
D.3.2 Primitive types

The mapping between the PSS primitive types and C types is specified in Table D.1.

Table D.1—Mapping PSS primitive types and C types

<table>
<thead>
<tr>
<th>PSS type</th>
<th>C input type</th>
<th>C output/inout type</th>
<th>C return type</th>
</tr>
</thead>
<tbody>
<tr>
<td>string</td>
<td>const char *</td>
<td>char **</td>
<td>char *</td>
</tr>
<tr>
<td>bool</td>
<td>unsigned int</td>
<td>unsigned int *</td>
<td>unsigned int</td>
</tr>
<tr>
<td>chandle</td>
<td>const void *</td>
<td>void **</td>
<td>void *</td>
</tr>
<tr>
<td>bit (1-8-bit domain)</td>
<td>unsigned char</td>
<td>unsigned char *</td>
<td>unsigned char</td>
</tr>
<tr>
<td>bit (9-16-bit domain)</td>
<td>unsigned short</td>
<td>unsigned short *</td>
<td>unsigned short</td>
</tr>
<tr>
<td>bit (17-32-bit domain)</td>
<td>unsigned int</td>
<td>unsigned int *</td>
<td>unsigned int</td>
</tr>
<tr>
<td>bit (33-64-bit domain)</td>
<td>unsigned long long</td>
<td>unsigned long long *</td>
<td>unsigned long long</td>
</tr>
<tr>
<td>int (1-8-bit domain)</td>
<td>char</td>
<td>char *</td>
<td>char</td>
</tr>
<tr>
<td>int (9-16-bit domain)</td>
<td>short</td>
<td>short *</td>
<td>short</td>
</tr>
<tr>
<td>int (17-32-bit domain)</td>
<td>int</td>
<td>int *</td>
<td>int</td>
</tr>
<tr>
<td>int (33-64-bit domain)</td>
<td>long long</td>
<td>long long *</td>
<td>long long</td>
</tr>
</tbody>
</table>

Where pointers are used, the callee shall not allocate or de-allocate the memory region referenced by the pointer. Further, for non-void pointers, the callee shall assume that the memory location is valid only for the duration of the function execution, and shall not retain a reference to the parameter after the function call returns. For strings and chandles, in the case of inout/output directions, the callee may return a pointer to storage it owns.

D.3.3 Arrays

Fixed-sized arrays are mapped to fixed-size arrays in C for function arguments. Mapping PSS fixed-sized arrays to C is not supported for function return types.

D.3.4 Structs

D.3.4.1 Name mapping

The mapping between a PSS struct type ($T_{PSS}$) defined in a hierarchical path $H$ and a C type ($T_C$) is shown in Table D.2.

Table D.2—Mapping PSS struct types and C types

<table>
<thead>
<tr>
<th>PSS type</th>
<th>C input type</th>
<th>C output/inout type</th>
<th>C return type</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H::T_{PSS}$</td>
<td>const $T_C$*</td>
<td>$T_C$*</td>
<td>$T_C$</td>
</tr>
</tbody>
</table>
In the general case, the name of the type in C ($T_C$), is derived from the PSS type name ($T_{PSS}$) and its hierarchical path ($H$). A PSS implementation shall support the name mapping scheme where the name of the C type is identical to the PSS type (ignoring the hierarchical path), i.e., $T_C = T_{PSS}$. A PSS implementation may support additional name mapping schemes.

D.3.4.2 Field mapping

Each PSS `struct` field is mapped to a corresponding field in C of the corresponding type and name in the same order. If the field type is itself a user-defined type (e.g., `struct` or `enum`), the mapping of the field entails the corresponding mapping of the type (recursively). For primitive types, the field is mapped as shown in Table D.3.

<table>
<thead>
<tr>
<th>PSS field type</th>
<th>C field type</th>
</tr>
</thead>
<tbody>
<tr>
<td>string</td>
<td>char *</td>
</tr>
<tr>
<td>bool</td>
<td>unsigned int</td>
</tr>
<tr>
<td>chandle</td>
<td>void *</td>
</tr>
<tr>
<td>bit (1-8-bit domain)</td>
<td>unsigned char</td>
</tr>
<tr>
<td>bit (9-16-bit domain)</td>
<td>unsigned short</td>
</tr>
<tr>
<td>bit (17-32-bit domain)</td>
<td>unsigned int</td>
</tr>
<tr>
<td>bit (33-64-bit domain)</td>
<td>unsigned long long</td>
</tr>
<tr>
<td>int (1-8-bit domain)</td>
<td>char</td>
</tr>
<tr>
<td>int (9-16-bit domain)</td>
<td>short</td>
</tr>
<tr>
<td>int (17-32-bit domain)</td>
<td>int</td>
</tr>
<tr>
<td>int (33-64-bit domain)</td>
<td>long long</td>
</tr>
<tr>
<td>float32</td>
<td>float</td>
</tr>
<tr>
<td>float64</td>
<td>double</td>
</tr>
</tbody>
</table>

Since the C language does not support type inheritance, if the PSS `struct` $T_{PSS}$ derives from a PSS base type, then the fields of that base type are mapped directly into the mapped type $T_C$. The code listing below shows an example of `struct` type mapping in C.
Only the field name, its type and the position of the field inside a `struct` is relevant for mapping to the C type. Other field properties (such as initial value) and `struct` properties (such as constraints) are ignored.

D.3.4.3 Other mapping aspects

Tools may automatically generate C definitions for the required types, given PSS source code. Or, tools may utilize existing C declarations of the types. Regardless of whether these definitions are automatically generated or obtained in another way, PSS test generation tools may assume that these definitions are operative in the compilation of the C user implementation of the imported functions.

Note that the C declaration of a `struct` data type may have additional fields that are not reflected in the PSS type declaration. A PSS implementation may not assume that the C struct is size-compatible to the PSS `struct` type.

D.3.5 Enumeration types

A PSS enumeration type $E$ is mapped to C as a plain integer type $N$ as follows:

<table>
<thead>
<tr>
<th>PSS type</th>
<th>C input type</th>
<th>C output/inout type</th>
<th>C return type</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E$</td>
<td>$N$</td>
<td>$N^*$</td>
<td>$N$</td>
</tr>
</tbody>
</table>

where $N$ is:

a) one of: `char`, `short`, `int`, or `long long`

b) If $E$ has a base type: the mapping for the base type, according to D.3.2. Otherwise: the smallest type that includes the values of all the enum items in its domain.
A PSS implementation will pass the value of the enumeration as an argument in the generated call to the function. These values can be either explicitly user-defined or assigned by a PSS implementation.

D.4 C++ language bindings

D.4.1 Function name mapping and namespaces

Generally, PSS user-defined types correspond to C++ types with identical names. In PSS, packages and components constitute namespaces for types declared in their scopes. The C++ type definition corresponding to a PSS type declared in a package or component scope shall be inside the namespace statement scope having the same name as the PSS component/package. Consequently, both the unqualified and qualified names of the C++ mapped type are the same as in PSS.

PSS implementations shall support mapping a PSS function name to an identical function name in C++, in the same namespace hierarchical path. PSS implementations may define additional mapping schemes for function names.

D.4.2 Primitive types

a) C++ type mapping for primitive numeric types is the same as that for C.

b) A PSS bool is a C++ bool and the values: false, true are mapped respectively from PSS to their C++ equivalents.

c) C++ mapping of a PSS string is std::string (typedef-ed by the Standard Template Library (STL) to std::basic_string<char> with default template parameters).

Table D.5 provides the mapping between PSS primitive types and C++ types. Note that string is passed as a reference.

<table>
<thead>
<tr>
<th>PSS type</th>
<th>C++ input type</th>
<th>C++ output/inout type</th>
<th>C++ return type</th>
</tr>
</thead>
<tbody>
<tr>
<td>string</td>
<td>const std::string &amp;</td>
<td>std::string</td>
<td>std::string</td>
</tr>
<tr>
<td>bool</td>
<td>bool</td>
<td>bool *</td>
<td>bool</td>
</tr>
<tr>
<td>chandle</td>
<td>const void *</td>
<td>void **</td>
<td>void *</td>
</tr>
</tbody>
</table>
### D.4.3 Arrays

The C++ mapping of a PSS array is `std::vector` of the C++ mapping of the respective element type (using the default allocator class). Fixed-sized arrays in PSS are mapped to the corresponding STL vector class, just like arrays of an unspecified size. However, if modified, they are resized to the original size upon return, filling the default values of the respective element type as needed.

### D.4.4 Structs

#### D.4.4.1 Name mapping

The mapping between a PSS `struct` type ($T_{PSS}$) and a C++ type ($T_{CPP}$) is shown in Table D.6.

<table>
<thead>
<tr>
<th>PSS type</th>
<th>C++ input type</th>
<th>C++ output/inout type</th>
<th>C++ return type</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>bit (1-8-bit domain)</code></td>
<td>unsigned char</td>
<td>unsigned char *</td>
<td>unsigned char</td>
</tr>
<tr>
<td><code>bit (9-16-bit domain)</code></td>
<td>unsigned short</td>
<td>unsigned short *</td>
<td>unsigned short</td>
</tr>
<tr>
<td><code>bit (17-32-bit domain)</code></td>
<td>unsigned int</td>
<td>unsigned int *</td>
<td>unsigned int</td>
</tr>
<tr>
<td><code>bit (33-64-bit domain)</code></td>
<td>unsigned long long</td>
<td>unsigned long long *</td>
<td>unsigned long long</td>
</tr>
<tr>
<td><code>int (1-8-bit domain)</code></td>
<td>char</td>
<td>char *</td>
<td>char</td>
</tr>
<tr>
<td><code>int (9-16-bit domain)</code></td>
<td>short</td>
<td>short *</td>
<td>short</td>
</tr>
<tr>
<td><code>int (17-32-bit domain)</code></td>
<td>int</td>
<td>int *</td>
<td>int</td>
</tr>
<tr>
<td><code>int (33-64-bit domain)</code></td>
<td>long long</td>
<td>long long *</td>
<td>long long</td>
</tr>
<tr>
<td><code>float32</code></td>
<td>float</td>
<td>float *</td>
<td>float</td>
</tr>
<tr>
<td><code>float64</code></td>
<td>double</td>
<td>double *</td>
<td>double</td>
</tr>
</tbody>
</table>

Table D.5—Mapping PSS primitive types and C++ types (Continued)

<table>
<thead>
<tr>
<th>PSS type</th>
<th>C++ input type</th>
<th>C++ output/inout type</th>
<th>C++ return type</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>const T_{PSS} &amp;</code></td>
<td>$T_{CPP} &amp;$</td>
<td>$T_{CPP} &amp;$</td>
<td>$T_{CPP}$</td>
</tr>
<tr>
<td><code>T_{PSS}</code></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

PSS `struct` types are mapped to C++ structs, along with their field structure and inherited base type, if specified.

The base type declaration of the `struct`, if any, is mapped to the (public) base struct type declaration in C++ and entails the mapping of its base type (recursively).

#### D.4.4.2 Field mapping

Each PSS field is mapped to a corresponding (public, non-static) field in C++ of the corresponding type and in the same order. If the field type is itself a user-defined type (`struct` or `enum`), the mapping of the field entails the corresponding mapping of the type (recursively).
For example, given the following imported function definitions:

```plaintext
function void foo(derived_s d);
import solve CPP function foo;
```

with the corresponding PSS definitions:

```plaintext
struct base_s {
    int in [0..99] f1;
};
struct sub_s {
    string f2;
};
struct derived_s : base_s {
    sub_s f3;
    bit[15:0] f4[4];
};
```

mapping type `derived_s` to C++ involves the following definitions:

```plaintext
struct base_s {
    int f1;
};
struct sub_s {
    std::string f2;
};
struct derived_s : base_s {
    sub_s f3;
    std::vector<unsigned short> f4;
};
```

Nested `structs` in PSS are instantiated directly under the containing `struct`, that is, they have value semantics. Mapped `struct` types have no member functions and, in particular, are confined to the default constructor and implicit copy constructor.

Mapping a `struct` type does not entail the mapping of any of its subtypes. However, `struct` instances are passed according to the type of the actual parameter expression used in an `import function` call. Therefore, the ultimate set of C++ mapped types for a given PSS model depends on its function calls, not just the function prototypes.

**D.4.4.3 Other mapping aspects**

In the case of `output` and `inout` composite parameters, if a different memory representation is used for the PSS tool vs. C++, the inner state shall be copied in upon calling it and any change shall be copied back out onto the PSS entity upon return.

**D.4.5 Enumeration types**

PSS enumeration types are mapped to C++ unscoped enumeration types (as opposed to enum classes), with the corresponding base type, if any, and with the same set of enum items in the same order and identical names. When specified, explicit numeric constant values for an enum item correspond to the same value in the C++ definition.
For example, the PSS definition:

```c
enum color_e {red = 0x10, green = 0x20, blue = 0x30};
```

is mapped to the C++ type as defined by this very same code.

Consequently, enum item names within types used in PSS-to-C++ type binding must be unique.

**D.5 SystemVerilog language bindings**

**D.5.1 Function names**

PSS implementations shall support mapping a PSS function name to an identical function or task name in SystemVerilog, ignoring the hierarchical path in PSS. PSS implementations may define additional mapping schemes for function names.

**D.5.2 Primitive types**

The mapping between the PSS primitive types and SystemVerilog types for both parameter and return types is specified in Table D.7.

<table>
<thead>
<tr>
<th>PSS type</th>
<th>SystemVerilog type</th>
</tr>
</thead>
<tbody>
<tr>
<td>string</td>
<td>string</td>
</tr>
<tr>
<td>bool</td>
<td>bit</td>
</tr>
<tr>
<td>chandle</td>
<td>chandle</td>
</tr>
<tr>
<td>bit (1-8-bit domain)</td>
<td>byte unsigned</td>
</tr>
<tr>
<td>bit (9-16-bit domain)</td>
<td>shortint unsigned</td>
</tr>
<tr>
<td>bit (17-32-bit domain)</td>
<td>int unsigned</td>
</tr>
<tr>
<td>bit (33-64-bit domain)</td>
<td>longint unsigned</td>
</tr>
<tr>
<td>int (1-8-bit domain)</td>
<td>byte</td>
</tr>
<tr>
<td>int (9-16-bit domain)</td>
<td>shortint</td>
</tr>
<tr>
<td>int (17-32-bit domain)</td>
<td>int</td>
</tr>
<tr>
<td>int (33-64-bit domain)</td>
<td>longint</td>
</tr>
<tr>
<td>float32</td>
<td>shortreal</td>
</tr>
<tr>
<td>float64</td>
<td>real</td>
</tr>
</tbody>
</table>

PSS functions designated with the `target` qualifier (see 21.4.1) may be mapped either to tasks or functions in SystemVerilog, and shall be mapped to tasks by default. PSS `solve` functions shall be mapped to SystemVerilog functions. If neither platform qualifier is used, the default mapping shall be to a function. PSS functions that are mapped to SystemVerilog tasks may not be called on the solve platform.
When a PSS function is mapped to a SystemVerilog function, the return type (if any) and arguments of the SystemVerilog function shall correspond to those of the PSS function prototype.

When a PSS function is mapped to a SystemVerilog task, the following apply:

a) If the PSS function is a `void` function, then all arguments of the SystemVerilog task shall correspond to the PSS prototype:

\[ f(D_0 T_0 p_0, D_1 T_1 p_1, \ldots, D_n T_n p_n); \Rightarrow t(D'_0 T'_0 p'_0, D'_1 T'_1 p'_1, \ldots, D'_n T'_n p'_n); \]

b) If the PSS function returns a value, then the first argument of the SystemVerilog task shall be an output of the type corresponding to the return value. All other arguments shall correspond accordingly:

\[ T_r f(D_0 T_0 p_0, D_1 T_1 p_1, \ldots, D_n T_n p_n); \Rightarrow t(output T'_0 p'_0, D'_0 T'_0 p'_0, D'_1 T'_1 p'_1, \ldots, D'_n T'_n p'_n); \]

**D.5.3 Numeric value mapping**

When a numeric type or value is passed from PSS to SystemVerilog, the value shall be expanded or truncated according to SystemVerilog rules (IEEE 1800-2017, section 10.7), treating the SystemVerilog type as the left-hand side of an assignment statement where the PSS value is the right-hand side.

When a numeric type of value is passed from SystemVerilog to PSS, the value shall be expanded or truncated according to the rules in 8.7 and 8.8, treating the SystemVerilog type as the right-hand side of an assignment statement where the PSS value is the left-hand side.

**D.5.4 Arrays**

Fixed-size arrays in PSS are mapped to SystemVerilog dynamic arrays of corresponding type. Arrays are passed by value between PSS and SystemVerilog.

**D.5.5 Structs**

PSS `struct` types are mapped to classes in SystemVerilog with fields whose types correspond and whose names match. Values of all fields are deep-copied between mapped elements.

The following also apply:

a) The target SystemVerilog class must contain all fields present in the PSS `struct`. The target SystemVerilog class may be derived from a base class type.

b) Inheritance relationships may or may not be the same across the boundary. Whether the PSS `struct` is derived from a base type has no bearing on whether the SystemVerilog class to which it is mapped is derived from a similar (or any) type.

c) Passing inheritance hierarchies with shadowed fields is not supported.

d) Tools shall ignore the containing namespace of mapped structs.

**D.5.6 Enumeration types**

A PSS enumeration type is mapped to a SystemVerilog enum type. The integer values of the `enum_items` must match, but it is not required that the names of the `enum_items` match.

If a PSS enumeration type is passed to or from SystemVerilog, the `enum` value is passed as its integer equivalent, according to D.5.3.
Annex E

(informative)

Solution space

Once a PSS model has been specified, the elements of the model must be processed in some way to ensure that resulting scenarios accurately reflect the specified behaviors. This annex describes the steps a processing tool may take to analyze a portable stimulus description and create a (set of) scenario(s). See also Clause 17.

a) Identify root action:
   1) Specified by the user.
   2) Unless otherwise specified, the designated root action shall be located in the root component. By default, the root component shall be pss_top.
   3) If the specified root action is an atomic action, consider it to be the initial action traversed in an implicit activity statement.
   4) If the specified root action is a compound action:
      i) Identify all bind statements in the activity and bind the associated object(s) accordingly. Identify all resulting scheduling dependencies between bound actions.
      ii) For every compound action traversed in the activity, expand its activity to include each sub-action traversal in the overall activity to be analyzed.
      iii) Identify scheduling dependencies among all action traversals declared in the activity and add to the scheduling dependency list identified in a.4.i.

b) For each action traversed in the activity:
   1) For each resource locked or shared (i.e., claimed) by the action:
      i) Identify the resource pool of the appropriate type to which the resource reference may be bound.
      ii) Identify all other action(s) claiming a resource of the same type that is bound to the same pool.
      iii) Each resource object instance in the resource pool has an built-in instance_id field that is unique for that pool.
      iv) The algebraic constraints for evaluating field(s) of the resource object are the union of the constraints defined in the resource object type and the constraints in all actions ultimately connected to the resource object.
      v) Identify scheduling dependencies enforced by the claimed resource and add these to the set of dependencies identified in a.4.i.
         1. If an action locks a resource instance, no other action claiming that same resource instance may be scheduled concurrent with the locking action.
         2. If actions scheduled concurrently collectively attempt to lock more resource instances than are available in the pool, an error shall be generated.
         3. If the resource instance is not locked, there are no scheduling implications of sharing a resource instance.
   2) For each flow object declared in the action that is not already bound:
      i) If the flow object is not explicitly bound to a corresponding flow object, identify the object pool(s) of the appropriate type to which the flow object may be bound.
ii) The algebraic constraints for evaluating field(s) of the flow object are the union of the constraints defined in flow object type and the constraints in all actions ultimately connected to the flow object.

iii) Identify all other explicitly-traversed actions bound to the same pool that:
    1. Declare a matching object type with consistent data constraints,
    2. Meet the scheduling constraints from b.1.v, and
    3. Are scheduled consistent with the scheduling constraints implied by the type of the flow object.

iv) The set of explicitly-traversed actions from b.2.iii shall compose the inferencing candidate list (ICL).

v) If no explicitly traversed action appears in the ICL, then an anonymous instance of each action type bound to the pool from b.2.i shall be added to the ICL.

vi) If the ICL is empty, an error shall be generated.

vii) For each element in the ICL, perform step b.2 until no actions in the ICL have any unbound flow object references or the tool’s inferencing limit is reached (see c).

c) If the tool reaches the maximum inferencing depth, it shall infer a terminating action if one is available. Given the set of actions, flow and resource objects, scheduling and data constraints, and associated ICLs, pick an instance from the ICL and a value for each data field in the flow object that satisfies the constraints and bind the flow object reference from the action to the corresponding instance from the ICL.