



Universal Verification Methodology (UVM) 1.1 User's Guide

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Notices

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The UVM *1.1 Class Reference* represents the foundation used to create the UVM 1.1 User's Guide. This guide is a way to apply the UVM *1.1 Class Reference*, but is not the only way. Accellera believes standards are an important ingredient to foster innovation and continues to encourage industry innovation based on its standards.

Suggestions for improvements to the UVM 1.1 User's Guide are welcome. They should be sent to the VIP email reflector

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1. Overview

This chapter describes:

- How to use the Universal Verification Methodology (UVM) for creating SystemVerilog testbenches.
- The recommended architecture of a verification component.

1.1 Introduction to UVM

The following subsections describe the UVM basics.

1.1.1 Coverage-Driven Verification (CDV)

UVM provides the best framework to achieve coverage-driven verification (CDV). CDV combines automatic test generation, self-checking testbenches, and coverage metrics to significantly reduce the time spent verifying a design. The purpose of CDV is to:

- Eliminate the effort and time spent creating hundreds of tests.
- Ensure thorough verification using up-front goal setting.
- Receive early error notifications and deploy run-time checking and error analysis to simplify debugging.

The CDV flow is different than the traditional directed-testing flow. With CDV, you start by setting verification goals using an organized planning process. You then create a smart testbench that generates legal stimuli and sends it to the DUT. Coverage monitors are added to the environment to measure progress and identify non-exercised functionality. Checkers are added to identify undesired DUT behavior. Simulations are launched after both the coverage model and testbench have been implemented. Verification then can be achieved.

Using CDV, you can thoroughly verify your design by changing testbench parameters or changing the randomization seed. Test constraints can be added on top of the smart infrastructure to tune the simulation to meet verification goals sooner. Ranking technology allows you to identify the tests and seeds that contribute to the verification goals, and to remove redundant tests from a test-suite regression.

CDV environments support both directed and constrained-random testing. However, the preferred approach is to let constrained-random testing do most of the work before devoting effort to writing time-consuming, deterministic tests to reach specific scenarios that are too difficult to reach randomly.

Significant efficiency and visibility into the verification process can be achieved by proper planning. Creating an executable plan with concrete metrics enables you to accurately measure progress and thoroughness throughout the design and verification project. By using this method, sources of coverage can be planned, observed, ranked, and reported at the feature level. Using an abstracted, feature-based approach (and not relying on implementation details) enables you to have a more readable, scalable, and reusable verification plan.

1.1.2 Testbenches and Environments

An UVM testbench is composed of reusable verification environments called *verification components*. A verification component is an encapsulated, ready-to-use, configurable verification environment for an interface protocol, a design submodule, or a full system. Each verification component follows a consistent architecture and consists of a complete set of elements for stimulating, checking, and collecting coverage

information for a specific protocol or design. The verification component is applied to the device under test (DUT) to verify your implementation of the protocol or design architecture.

[Figure 1](#) shows an example of a verification environment with three interface verification components. These verification components might be stored in a company repository and reused for multiple verification environments. The interface verification component is instantiated and configured for a desired operational mode. The verification environment also contains a multi-channel sequence mechanism (that is, virtual sequencer) which synchronizes the timing and the data between the different interfaces and allows fine control of the test environment for a particular test.

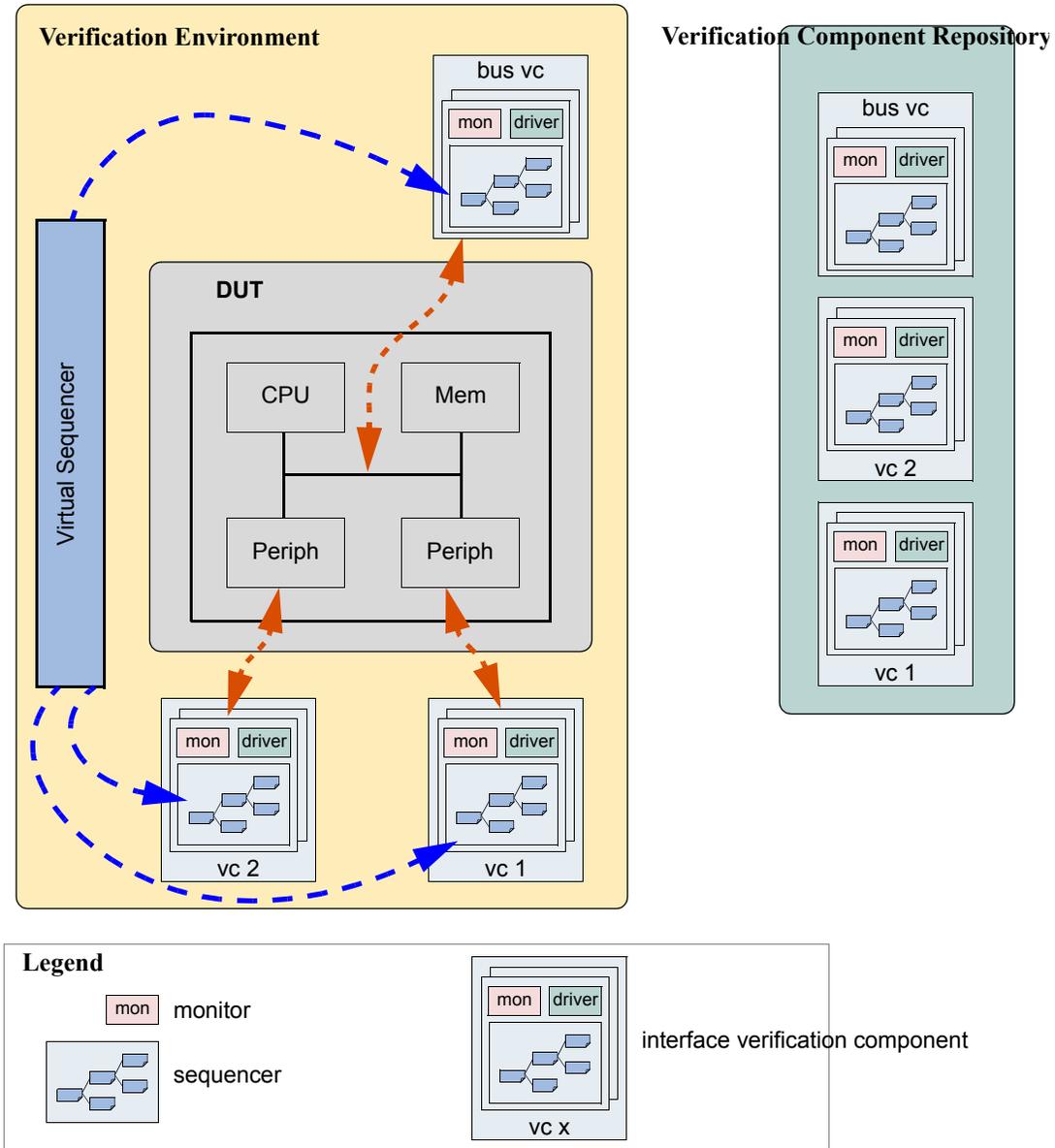


Figure 1—Verification Environment Example

1.2 Verification Component Overview

The following subsections describe the components of a verification component.

1.2.1 Data Item (Transaction)

Data items represent the input to the device under test (DUT). Examples include networking packets, bus transactions, and instructions. The fields and attributes of a data item are derived from the data item's specification. For example, the Ethernet protocol specification defines valid values and attributes for an Ethernet data packet. In a typical test, many data items are generated and sent to the DUT. By intelligently randomizing data item fields using SystemVerilog constraints, you can create a large number of meaningful tests and maximize coverage.

1.2.2 Driver (BFM)

A driver is an active entity that emulates logic that drives the DUT. A typical driver repeatedly receives a data item and drives it to the DUT by sampling and driving the DUT signals. (If you have created a verification environment in the past, you probably have implemented driver functionality.) For example, a driver controls the read/write signal, address bus, and data bus for a number of clocks cycles to perform a write transfer.

1.2.3 Sequencer

A sequencer is an advanced stimulus generator that controls the items that are provided to the driver for execution. By default, a sequencer behaves similarly to a simple stimulus generator and returns a random data item upon request from the driver. This default behavior allows you to add constraints to the data item class in order to control the distribution of randomized values. Unlike generators that randomize arrays of transactions or one transaction at a time, a sequencer captures important randomization requirements out-of-the-box. A partial list of the sequencer's built-in capabilities includes:

- Ability to react to the current state of the DUT for every data item generated.
- Captures the order between data items in user-defined sequences, which forms a more structured and meaningful stimulus pattern.
- Enables time modeling in reusable scenarios.
- Supports declarative and procedural constraints for the same scenario.
- Allows system-level synchronization and control of multiple interfaces.

For more information about creating and using sequencers, refer to the UVM *1.1 Class Reference* and to [Section 3.10](#), and [Section 4.8.2](#).

Sequencers also can be layered on top of each other to model protocol layering. Refer to [Section 6.5.2.5](#) for more information.

1.2.4 Monitor

A monitor is a passive entity that samples DUT signals but does not drive them. Monitors collect coverage information and perform checking. Even though reusable drivers and sequencers drive bus traffic, they are not used for coverage and checking. Monitors are used instead. A monitor:

- Collects transactions (data items). A monitor extracts signal information from a bus and translates the information into a transaction that can be made available to other components and to the test writer.
- Extracts events. The monitor detects the availability of information (such as a transaction), structures the data, and emits an event to notify other components of the availability of the transaction. A monitor also captures status information so it is available to other components and to the test writer.
- Performs checking and coverage.

Checking typically consists of protocol and data checkers to verify that the DUT output meets the protocol specification.

Coverage also is collected in the monitor.
- Optionally prints trace information.

A bus monitor handles all the signals and transactions on a bus, while an agent monitor handles only signals and transactions relevant to a specific agent.

Typically, drivers and monitors are built as separate entities (even though they may use the same signals) so they can work independently of each other. However, you can reuse code that is common between a driver and a monitor to save time.

Do not have monitors depend on drivers for information so that an agent can operate passively when only the monitor is present.

1.2.5 Agent

Sequencers, drivers, and monitors can be reused independently, but this requires the environment integrator to learn the names, roles, configuration, and hookup of each of these entities. To reduce the amount of work and knowledge required by the test writer, UVM recommends that environment developers create a more abstract container called an agent. Agents can emulate and verify DUT devices. They encapsulate a driver, sequencer, and monitor. Verification components can contain more than one agent. Some agents (for example, master or transmit agents) initiate transactions to the DUT, while other agents (slave or receive agents) react to transaction requests. Agents should be configurable so that they can be either active or passive. Active agents emulate devices and drive transactions according to test directives. Passive agents only monitor DUT activity.

1.2.6 Environment

The environment (`env`) is the top-level component of the verification component. It contains one or more agents, as well as other components such as a bus monitor. The `env` contains configuration properties that enable you to customize the topology and behavior and make it reusable. For example, active agents can be changed into passive agents when the verification environment is reused in system verification. [Figure 2](#) illustrates the structure of a reusable verification environment. Notice that a verification component may contain an environment-level monitor. This bus-level monitor performs checking and coverage for activities that are not necessarily related to a single agent. An agent's monitors can leverage data and events collected by the global monitor.

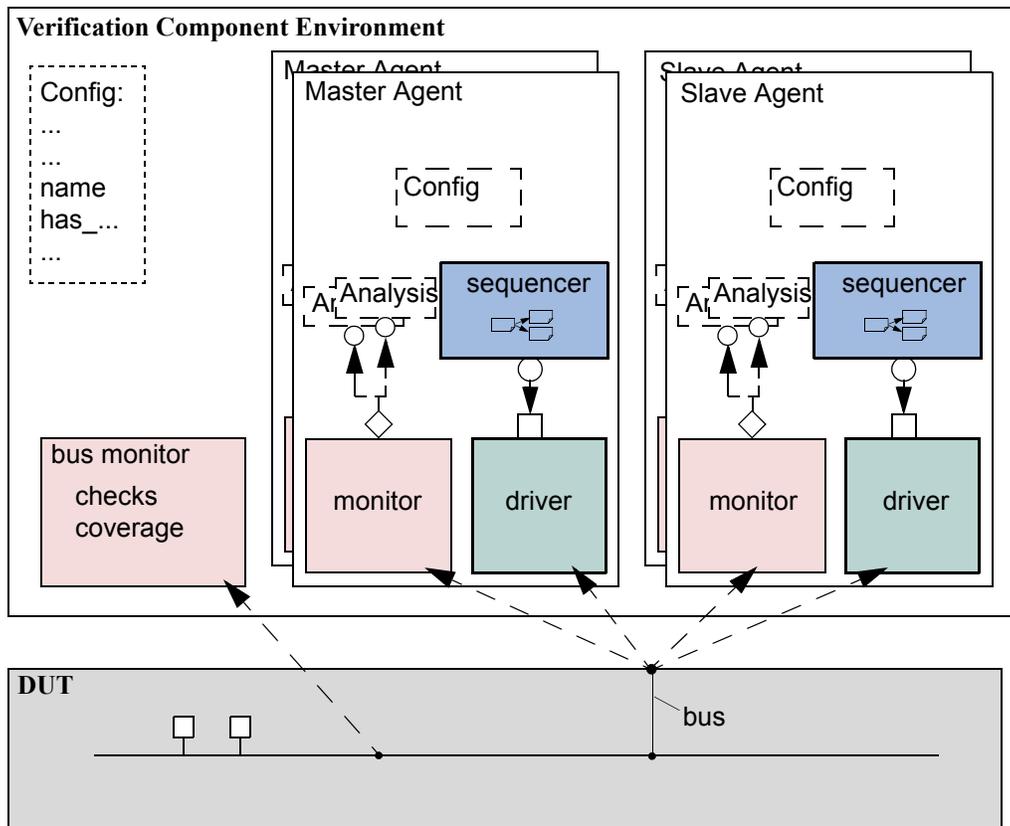


Figure 2—Typical Verification Component Environment

The environment class (`uvm_env`) is architected to provide a flexible, reusable, and extendable verification component. The main function of the environment class is to model behavior by generating constrained-random traffic, monitoring DUT responses, checking the validity of the protocol activity, and collecting coverage.

You can use derivation to specialize the existing classes to their specific protocol. This manual describes the process and infrastructure that UVM provides to replace existing component behavior with IP-specific behavior.

1.3 The UVM Class Library

The UVM Class Library provides all the building blocks you need to quickly develop well-constructed, reusable, verification components and test environments (see [Figure 3](#)). The library consists of base classes, utilities, and macros. Components may be encapsulated and instantiated hierarchically and are controlled through an extendable set of phases to initialize, run, and complete each test. These phases are defined in the base class library but can be extended to meet specific project needs. See the *UVM 1.1 Class Reference* for more information.

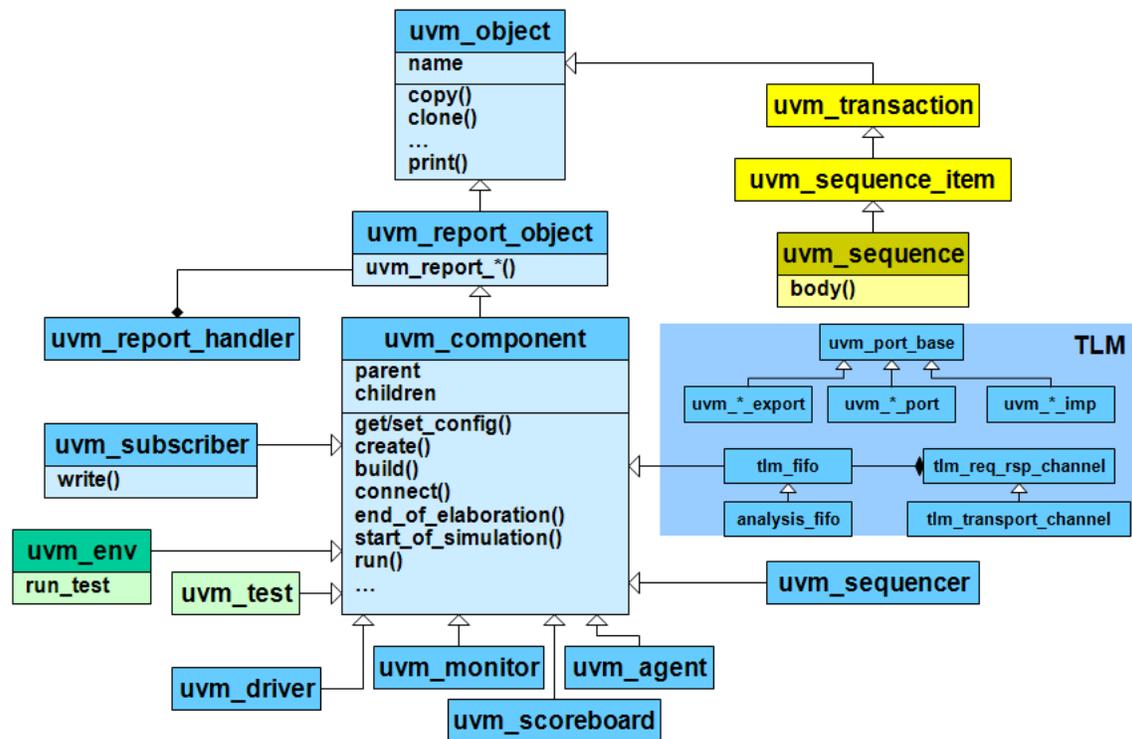


Figure 3—(Partial) UVM Class Hierarchy

The advantages of using the UVM Class Library include:

- a) A robust set of built-in features—The UVM Class Library provides many features that are required for verification, including complete implementation of printing, copying, test phases, factory methods, and more.
- b) Correctly-implemented UVM concepts—Each component in the block diagram in [Figure 2](#) is derived from a corresponding UVM Class Library component. [Figure 4](#) shows the same diagram using the derived UVM Class Library base classes. Using these base-class elements increases the readability of your code since each component’s role is predetermined by its parent class.

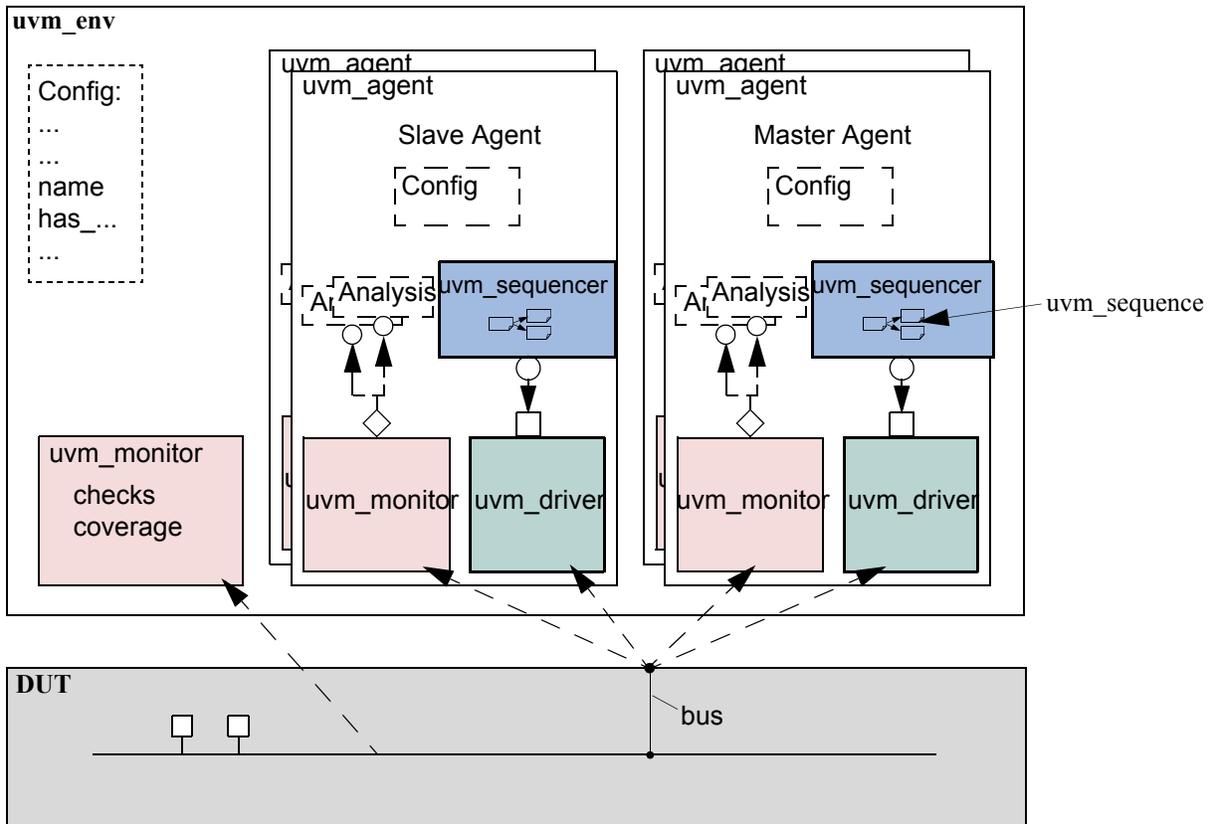


Figure 4—Typical UVM Environment using Library Classes

1.4 Other UVM Facilities

The UVM Class Library also provides various utilities to simplify the development and use of verification environments. These utilities support debugging by providing a user-controllable messaging utility. They support development by providing a standard communication infrastructure between verification components (TLM) and flexible verification environment construction (UVM factory).

The UVM Class Library provides global messaging facilities that can be used for failure reporting and general reporting purposes. Both messages and reporting are important aspects of ease of use.

1.4.1 UVM Factory

The factory method is a classic software design pattern that is used to create generic code, deferring to run time the exact specification of the object that will be created. In functional verification, introducing class variations is frequently needed. For example, in many tests you might want to derive from the generic data item definition and add more constraints or fields to it; or you might want to use the new derived class in the entire environment or only in a single interface; or perhaps you must modify the way data is sent to the DUT by deriving a new driver. The factory allows you to substitute the verification component without having to provide a derived version of the parent component as well.

The UVM Class Library provides a built-in central factory that allows:

- Controlling object allocation in the entire environment or for specific objects.
- Modifying stimulus data items as well as infrastructure components (for example, a driver).

Using the UVM built-in factory reduces the effort of creating an advanced factory or implementing factory methods in class definitions. It facilitates reuse and adjustment of predefined verification IP in the end-user's environment. One of the biggest advantages of the factory is that it is transparent to the test writer and reduces the object-oriented expertise required from both developers and users.

1.4.2 Transaction-Level Modeling (TLM)

UVM components communicate via standard TLM interfaces, which improves reuse. Using a SystemVerilog implementation of TLM in UVM, a component may communicate via its interface to any other component that implements that interface. Each TLM interface consists of one or more methods used to transport data. TLM specifies the required behavior (semantic) of each method, but does not define their implementation. Classes inheriting a TLM interface must provide an implementation that meets the specified semantic. Thus, one component may be connected at the transaction level to others that are implemented at multiple levels of abstraction. The common semantics of TLM communication permit components to be swapped in and out without affecting the rest of the environment.

2. Transaction-Level Modeling (TLM)

2.1 Overview

One of the keys to verification productivity is to think about the problem at a level of abstraction that makes sense. When verifying a DUT that handles packets flowing back and forth, or processes instructions, or performs other types of functionality, you must create a verification environment that supports the appropriate abstraction level. While the actual interface to the DUT ultimately is represented by signal-level activity, experience has shown that it is necessary to manage most of the verification tasks, such as generating stimulus and collecting coverage data, at the transaction level, which is the natural way engineers tend to think of the activity of a system.

UVM provides a set of transaction-level communication interfaces and channels that you can use to connect components at the transaction level. The use of TLM interfaces isolates each component from changes in other components throughout the environment. When coupled with the phased, flexible build infrastructure in UVM, TLM promotes reuse by allowing any component to be swapped for another, as long as they have the same interfaces. This concept also allows UVM verification environments to be assembled with a transaction-level model of the DUT, and the environment to be reused as the design is refined to RTL. All that is required is to replace the transaction-level model with a thin layer of compatible components to convert between the transaction-level activity and the pin-level activity at the DUT.

The well-defined semantics of TLM interfaces between components also provide the ideal platform for implementing mixed-language verification environments. In addition, TLM provides the basis for easily encapsulating components into reusable components, called *verification components*, to maximize reuse and minimize the time and effort required to build a verification environment.

This chapter discusses the essential elements of transaction-level communication in UVM, and illustrates the mechanics of how to assemble transaction-level components into a verification environment. Later in this document we will discuss additional concerns in order to address a wider set of verification issues. For now, it is important to understand these foundational concepts first.

2.2 TLM, TLM-1, and TLM-2.0

TLM, transaction-level modeling, is a modeling style for building highly abstract models of components and systems. It relies on transactions (see [Section 2.3, Basics](#)), objects that contain arbitrary, protocol-specific data to abstractly represent lower-level activity. In practice, TLM refers to a family of abstraction levels beginning with cycle-accurate modeling, the most abstract level, and extending upwards in abstraction as far as the eye can see. Common transaction-level abstractions today include: cycle-accurate, approximately-timed, loosely-timed, untimed, and token-level.

The acronym TLM also refers to a system of code elements used to create transaction-level models. TLM-1 and TLM-2.0 are two TLM modeling systems which have been developed as industry standards for building transaction-level models. Both were built in SystemC and standardized within the TLM Working Group of the Open SystemC Initiative (OSCI). TLM-1 achieved standardization in 2005 and TLM-2.0 became a standard in 2009.

TLM-1 and TLM-2.0 share a common heritage and many of the same people who developed TLM-1 also worked on TLM-2.0. Otherwise, they are quite different things. TLM-1 is a message passing system. Interfaces are either untimed or rely on the target for timing. None of the interfaces provide for explicit timing annotations. TLM-2.0, while still enabling transfer of data and synchronization between independent processes, is mainly designed for high performance modeling of memory-mapped bus-based systems. A subset of both these facilities has been implemented in SystemVerilog and is available as part of UVM.

2.2.1 TLM-1 Implementation

The following subsections specify how TLM-1 is to be implemented in SystemVerilog.

- [Section 2.4, Encapsulation and Hierarchy](#)
- [Section 2.5, Analysis Communication](#)

2.2.2 TLM-2.0 Implementation

The following subsections specify how TLM-2.0 is to be implemented in SystemVerilog.

- [Section 2.6, Generic Payload](#)
- [Section 2.7, Core Interfaces and Ports](#)
- [Section 2.8, Blocking Transport](#)
- [Section 2.9, Nonblocking Transport](#)
- [Section 2.10, Sockets](#)
- [Section 2.11, Time](#)
- [Section 2.12, Use Models](#)

2.3 Basics

Before you can fully understand how to model verification at the transaction level, you must understand what a transaction is.

2.3.1 Transactions

In UVM, a transaction is a class object, `uvm_transaction` (extended from `uvm_object`), that includes whatever information is needed to model a unit of communication between two components. In the most basic example, a simple bus protocol transaction would be modeled as follows:

```
class simple_trans extends uvm_transaction;
    rand data_t data;
    rand addr_t addr;
    rand enum {WRITE,READ} kind;
    constraint c1 { addr < 16'h2000; }
    ...
endclass
```

The transaction object includes variables, constraints, and other fields and methods necessary for generating and operating on the transaction. Obviously, there is often more than just this information that is required to fully specify a bus transaction. The amount and detail of the information encapsulated in a transaction is an indication of the abstraction level of the model. For example, the `simple_trans` transaction above could be extended to include more information, such as the number of wait states to inject, the size of the transfer, or any number of other properties. The transaction could also be extended to include additional constraints. It is also possible to define higher-level transactions that include some number of lower-level transactions. Transactions can thus be composed, decomposed, extended, layered, and otherwise manipulated to model whatever communication is necessary at any level of abstraction.

2.3.2 Transaction-Level Communication

Transaction-level interfaces define a set of methods that use transaction objects as arguments. A TLM *port* defines the set of methods (the application programming interface (API)) to be used for a particular connection, while a TLM *export* supplies the implementation of those methods. Connecting a port to an export allows the implementation to be executed when the port method is called.

2.3.3 Basic TLM Communication

The most basic transaction-level operation allows one component to *put* a transaction to another. Consider [Figure 5](#).

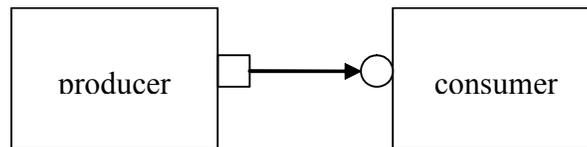


Figure 5—Simple Producer/Consumer

The square box on the producer indicates a port and the circle on the consumer indicates the export. The producer generates transactions and sends them out its `put_port`:

```
class producer extends uvm_component;
  uvm_blocking_put_port #(simple_trans) put_port; // 1 parameter
  function new( string name, uvm_component parent);
    put_port = new("put_port", this);
    ...
  endfunction
  virtual task run();
    simple_trans t;
    for(int i = 0; i < N; i++) begin
      // Generate t.
      put_port.put(t);
    end
  endtask
endclass
```

NOTE—The `uvm_*_port` is parameterized by the transaction type that will be communicated. This may either be specified directly or it may be a parameter of the parent component.

The actual implementation of the `put ()` call is supplied by the consumer.

```
class consumer extends uvm_component;
  uvm_blocking_put_imp #(simple_trans, consumer) put_export; // 2 parameters
  ...
  task put(simple_trans t);
    case(t.kind)
      READ: // Do read.
      WRITE: // Do write.
    endcase
  endtask
endclass
```

NOTE—The `uvm_*_imp` takes two parameters: the type of the transaction and the type of the object that declares the method implementation.

NOTE—The semantics of the `put` operation are defined by TLM. In this case, the `put()` call in the producer will block until the consumer's `put` implementation is complete. Other than that, the operation of `producer` is completely independent of the `put` implementation (`uvm_put_imp`). In fact, `consumer` could be replaced by another component that also implements `put` and `producer` will continue to work in exactly the same way. The modularity provided by TLM fosters an environment in which components may be easily reused since the interfaces are well defined.

The converse operation to `put` is `get`. Consider [Figure 6](#).

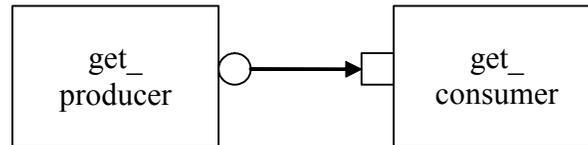


Figure 6—Consumer gets from Producer

In this case, the consumer requests transactions from the producer via its `get` port:

```

class get_consumer extends uvm_component;
  uvm_blocking_get_port #(simple_trans) get_port;
  function new( string name, uvm_component parent);
    get_port = new("get_port", this);
    ...
  endfunction
  virtual task run();
    simple_trans t;
    for(int i = 0; i < N; i++) begin
      // Generate t.
      get_port.get(t);
    end
  endtask

```

The `get()` implementation is supplied by the producer.

```

class get_producer extends uvm_component;
  uvm_blocking_get_imp #(simple_trans, get_producer) get_export;
  ...
  task get(output simple_trans t);
    simple_trans tmp = new();
    // Assign values to tmp.
    t = tmp;
  endtask
endclass

```

As with `put()` above, the `get_consumer`'s `get()` call will block until the `get_producer`'s method completes. In TLM terms, `put()` and `get()` are *blocking* methods.

NOTE—In both these examples, there is a single process running, with control passing from the port to the export and back again. The direction of data flow (from producer to consumer) is the same in both examples.

2.3.4 Communicating between Processes

In the basic `put` example above, the consumer will be active only when its `put()` method is called. In many cases, it may be necessary for components to operate independently, where the producer is creating transactions in one process while the consumer needs to operate on those transactions in another. UVM

provides the `uvm_tlm_fifo` channel to facilitate such communication. The `uvm_tlm_fifo` implements all of the TLM interface methods, so the producer puts the transaction into the `uvm_tlm_fifo`, while the consumer independently gets the transaction from the fifo, as shown in [Figure 7](#).

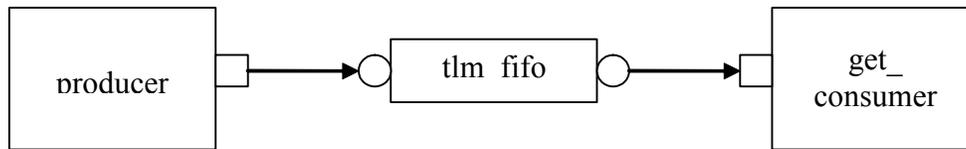


Figure 7—Using a `uvm_tlm_fifo`

When the producer puts a transaction into the fifo, it will block if the fifo is full, otherwise it will put the object into the fifo and return immediately. The `get` operation will return immediately if a transaction is available (and will then be removed from the fifo), otherwise it will block until a transaction is available. Thus, two consecutive `get()` calls will yield different transactions to the consumer. The related `peek()` method returns a copy of the available transaction without removing it. Two consecutive `peek()` calls will return copies of the same transaction.

2.3.5 Blocking versus Nonblocking

The interfaces that we have looked at so far are blocking—the tasks block execution until they complete; they are not allowed to fail. There is no mechanism for any blocking call to terminate abnormally or otherwise alter the flow of control. They simply wait until the request is satisfied. In a timed system, this means that time may pass between the time the call was initiated and the time it returns.

In contrast, a *nonblocking* call returns immediately. The semantics of a nonblocking call guarantee that the call returns in the same delta cycle in which it was issued, that is, without consuming any time, not even a single delta cycle. In UVM, nonblocking calls are modeled as functions.

```

class consumer extends uvm_component;
  uvm_get_port #(simple_trans) get_port;
  task run;
  ...
  for(int i=0; i<10; i++)
    if(get_port.try_get(t))
      //Do something with t.
  ...
endtask
endclass
  
```

If a transaction exists, it will be returned in the argument and the function call itself will return `TRUE`. If no transaction exists, the function will return `FALSE`. Similarly, with `try_peek()`. The `try_put()` method returns `TRUE` if the transaction is sent.

2.3.6 Connecting Transaction-Level Components

With ports and exports defined for transaction-level components, the actual connection between them is accomplished via the `connect()` method in the parent (component or env), with an argument that is the object (port or export) to which it will be connected. In a verification environment, the series of

`connect()` calls between ports and exports establishes a netlist of peer-to-peer and hierarchical connections, ultimately terminating at an implementation of the agreed-upon interface. The resolution of these connections causes the collapsing of the netlist, which results in the initiator's port being assigned to the target's implementation. Thus, when a component calls

```
put_port.put(t);
```

the connection means that it actually calls

```
target.put_export.put(t);
```

where `target` is the connected component.

2.3.7 Peer-to-Peer connections

When connecting components at the same level of hierarchy, ports are always connected to exports. All `connect()` calls between components are done in the parent's `connect()` method.

```
class my_env extends uvm_env;
...
virtual function void connect();
    // component.port.connect(target.export);
    producer.blocking_put_port.connect(fifo.put_export);
    get_consumer.get_port.connect(fifo.get_export);
    ...
endfunction
endclass
```

2.3.8 Port/Export Compatibility

Another advantage of TLM communication in UVM is that all TLM connections are checked for compatibility before the test runs. In order for a connection to be valid, the export must provide implementations for *at least* the set of methods defined by the port and the transaction type parameter for the two must be identical. For example, a `blocking_put_port`, which requires an implementation of `put()` may be connected to either a `blocking_put_export` or a `put_export`. Both exports supply an implementation of `put()`, although the `put_export` also supplies implementations of `try_put()` and `can_put()`.

2.4 Encapsulation and Hierarchy

The use of TLM interfaces isolates each component in a verification environment from the others. The environment instantiates a component and connects its ports/exports to its neighbor(s), independent of any further knowledge of the specific implementation. Smaller components may be grouped hierarchically to form larger components (see [Chapter 3](#)). Access to child components is achieved by making their interfaces visible at the parent level. At this level, the parent simply looks like a single component with a set of interfaces on it, regardless of its internal implementation.

2.4.1 Hierarchical Connections

Making connections across hierarchical boundaries involves some additional issues, which are discussed in this section. Consider the hierarchical design shown in [Figure 8](#).

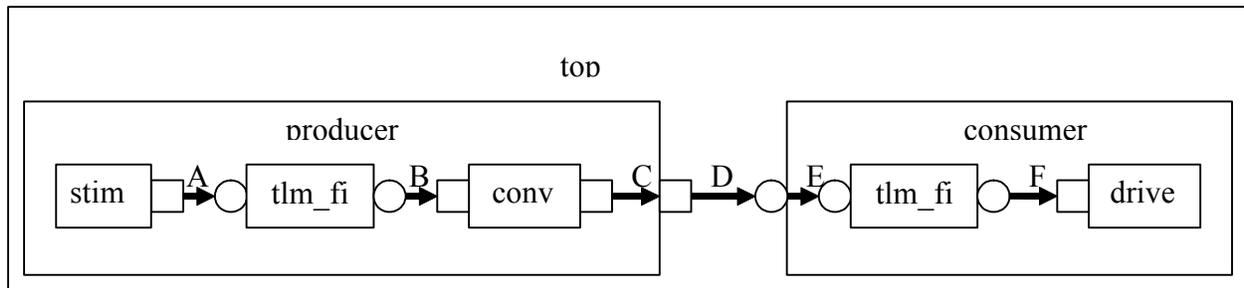


Figure 8—Hierarchy in TLM

The hierarchy of this design contains two components, `producer` and `consumer`. `producer` contains three components, `stim`, `t1m_fi`, and `conv`. `consumer` contains two components, `t1m_fi` and `drive`. Notice that, from the perspective of `top`, the `producer` and `consumer` appear identical to those in [Figure 5](#), in which the `producer`'s `put_port` is connected to the `consumer`'s `put_export`. The two fifos are both unique instances of the same `uvm_t1m_fifo` component.

In [Figure 8](#), connections A, B, D, and F are standard peer-to-peer connections as discussed above. As an example, connection A would be coded in the `producer`'s `connect()` method as:

```
gen.put_port.connect(fifo.put_export);
```

Connections C and E are of a different sort than what have been shown. Connection C is a port-to-port connection, and connection E is an export-to-export connection. These two kinds of connections are necessary to complete hierarchical connections. Connection C *imports* a port from the outer component to the inner component. Connection E *exports* an export upwards in the hierarchy from the inner component to the outer one. Ultimately, every transaction-level connection must resolve so that a port is connected to an export. However, the port and export terminals do not need to be at the same place in the hierarchy. We use port-to-port and export-to-export connections to bring connectors to a hierarchical boundary to be accessed at the next-higher level of hierarchy.

For connection E, the implementation resides in the `fifo` and is exported up to the interface of `consumer`. All export-to-export connections in a parent component are of the form

```
export.connect(subcomponent.export)
```

so connection E would be coded as:

```
class consumer extends uvm_component;
    uvm_put_export #(trans) put_export;
    uvm_t1m_fifo #(trans) fifo;
    ...
    function void connect();
        put_export.connect(fifo.put_export); // E
        bfm.get_port.connect(fifo.get_export); // F
    endfunction
    ...
endclass
```

Conversely, port-to-port connections are of the form:

```
subcomponent.port.connect(port);
```

so connection C would be coded as:

```
class producer extends uvm_component;
  uvm_put_port #(trans) put_port;
  conv c;
  ...
function void connect();
  c.put_port.connect(put_port);
  ...
endfunction
```

2.4.2 Connection Types

[Table 1](#) summarizes connection types and elaboration functions.

Table 1—TLM Connection Types

Connection type	connect() form
port-to-export	<code>comp1.port.connect(comp2.export);</code>
port-to-port	<code>subcomponent.port.connect(port);</code>
export-to-export	<code>export.connect(subcomponent.export);</code>

NOTE—The argument to the `port.connect()` method may be either an export or a port, depending on the nature of the connection (that is, peer-to-peer or hierarchical). The argument to `export.connect()` is always an export of a child component.

2.5 Analysis Communication

The put/get communication as described above allows verification components to be created that model the “operational” behavior of a system. Each component is responsible for communicating through its TLM interface(s) with other components in the system in order to stimulate activity in the DUT and/or respond its behavior. In any reasonably complex verification environment, however, particularly where randomization is applied, a collected transaction should be distributed to the rest of the environment for end-to-end checking (scoreboard), or additional coverage collection.

The key distinction between the two types of TLM communication is that the put/get ports typically require a corresponding export to supply the implementation. For analysis, however, the emphasis is on a particular component, such as a monitor, being able to produce a stream of transactions, regardless of whether there is a target actually connected to it. Modular analysis components are then connected to the `analysis_port`, each of which processes the transaction stream in a particular way.

2.5.1 Analysis Ports

The `uvm_analysis_port` (represented as a diamond on the monitor in [Figure 9](#)) is a specialized TLM port whose interface consists of a single function, `write()`. The analysis port contains a list of `analysis_exports` that are connected to it. When the component calls `analysis_port.write()`, the `analysis_port` cycles through the list and calls the `write()` method of each connected export. If nothing is connected, the `write()` call simply returns. Thus, an analysis port may be connected to zero,

one, or many analysis exports, but the operation of the component that writes to the analysis port does not depend on the number of exports connected. Because `write()` is a `void` function, the call will always complete in the same delta cycle, regardless of how many components (for example, scoreboards, coverage collectors, and so on) are connected.

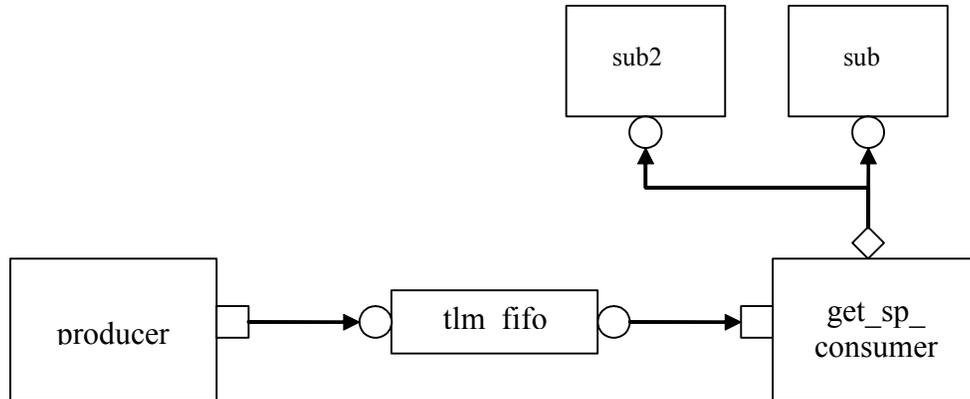


Figure 9—Analysis Communication

```

class get_ap_consumer extends get_consumer;
  uvm_analysis_port #(my_trans) ap;
  function new(...);
    super.new()
    ap = new("analysis_port", this);
    ...
  endfunction
  task run;
    ...
    for(int i=0; i<10; i++)
      if(get_port.try_get(t)) begin
        //Do something with t.
        ap.write(t); // Write transaction.
        ...
      end
    endtask
  
```

In the parent environment, the analysis port gets connected to the analysis export of the desired components, such as coverage collectors and scoreboards.

2.5.2 Analysis Exports

As with other TLM connections, it is up to each component connected to an analysis port to provide an implementation of `write()` via an `analysis_export`. The `uvm_subscriber` base component can be used to simplify this operation, so a typical analysis component would extend `uvm_subscriber` as:

```

class sub1 #(type T = simple_trans) extends uvm_subscriber #(T);
  ...
  function void write(T t);
    // Record coverage information of t.
  endfunction
endclass
  
```

As with `put()` and `get()` described above, the TLM connection between an analysis port and export, allows the export to supply the implementation of `write()`. If multiple exports are connected to an analysis port, the port will call the `write()` of each export, in order. Since all implementations of `write()` must be functions, the analysis port's `write()` function completes immediately, regardless of how many exports are connected to it.

```
class my_env extends uvm_env;
  get_ap_component g;
  sub1 s1;
  sub2 s2;
  ...
  function void connect();
    g.ap.connect(s1.analysis_export);
    g.ap.connect(s2.analysis_export);
    ...
  endfunction
endclass
```

When multiple subscribers are connected to an `analysis_port`, each is passed a pointer to the same transaction object, the argument to the `write()` call. Each `write()` implementation must make a local copy of the transaction and then operate on the copy to avoid corrupting the transaction contents for any other subscriber that may have received the same pointer.

UVM also includes an `analysis_fifo`, which is a `uvm_tlm_fifo` that also includes an analysis export, to allow blocking components access to the analysis transaction stream. The `analysis_fifo` is unbounded, so the monitor's `write()` call is guaranteed to succeed immediately. The analysis component may then get the transactions from the `analysis_fifo` at its leisure.

2.6 Generic Payload

TLM-2.0 defines a base object, called the *generic payload*, for moving data between components. In SystemC, this is the primary transaction vehicle. In SystemVerilog, this is the default transaction type, but it is not the only type that can be used (as will be explained more fully in [Section 2.7](#)).

2.6.1 Attributes

Each attribute in the SystemC version has a corresponding member in the SystemVerilog generic payload.

```
protected rand bit [63:0] m_address;
protected rand uvm_tlm_command_e m_command;
protected rand byte m_data[];
protected rand int unsigned m_length;
protected rand uvm_tlm_response_status_e m_response_status;
protected rand bit m_dmi;
protected rand byte m_byte_enable[];
protected rand int unsigned m_byte_enable_length;
protected rand int unsigned m_streaming_width;
```

The data types of most members translate directly into SystemVerilog. `bool` and `unsigned int` in SystemC become `bit` and `int unsigned` in SystemVerilog. `m_data` and `m_byte_enable`, which are defined as type `char*` in SystemC, are defined as dynamic arrays of bytes. `uvm_tlm_command_e` and `uvm_tlm_response_status_e` are enumerated types. They are defined as:

```

typedef enum
{
    TLM_READ_COMMAND,
    TLM_WRITE_COMMAND,
    TLM_IGNORE_COMMAND
} uvm_tlm_command_e;

typedef enum
{
    TLM_OK_RESPONSE = 1,
    TLM_INCOMPLETE_RESPONSE = 0,
    TLM_GENERIC_ERROR_RESPONSE = -1,
    TLM_ADDRESS_ERROR_RESPONSE = -2,
    TLM_COMMAND_ERROR_RESPONSE = -3,
    TLM_BURST_ERROR_RESPONSE = -4,
    TLM_BYTE_ENABLE_ERROR_RESPONSE = -5
} uvm_tlm_response_status_e;

```

All of the members of the generic payload have the rand qualifier. This enables instances of the generic payload to be randomized. SystemVerilog allows arrays, including dynamic arrays to be randomized. See subclause 18.4 of IEEE Std. 1800-2009, the SystemVerilog LRM, for more details.

2.6.2 Accessors

In SystemC, all of the attributes are private and are accessed through accessor methods. In SystemVerilog, this means all members are protected and similarly accessed through accessor methods.

```

virtual function uvm_tlm_command_e get_command();
virtual function void set_command(uvm_tlm_command_e command);
virtual function bit is_read();
virtual function void set_read();
virtual function bit is_write();
virtual function void set_write();
virtual function void set_address(bit [63:0] addr);
virtual function bit[63:0] get_address();
virtual function void get_data (output byte p []);
virtual function void set_data_ptr(ref byte p []);
virtual function int unsigned get_data_length();
virtual function void set_data_length(int unsigned length);
virtual function int unsigned get_streaming_width();
virtual function void set_streaming_width(int unsigned width);
virtual function void get_byte_enable(output byte p[]);
virtual function void set_byte_enable(ref byte p[]);
virtual function int unsigned get_byte_enable_length();
virtual function void set_byte_enable_length(int unsigned length);
virtual function void set_dmi_allowed(bit dmi);
virtual function bit is_dmi_allowed();
virtual function uvm_tlm_response_status_e get_response_status();
virtual function void set_response_status(uvm_tlm_response_status_e status);
virtual function bit is_response_ok();
virtual function bit is_response_error();
virtual function string get_response_string();

```

The accessor functions let you set and get each of the members of the generic payload. All of the accessor methods are virtual. This implies a slightly different use model for the generic payload than in SystemC. The way the generic payload is defined in SystemC does not encourage you to create new transaction types

derived from `uvm_tlm_generic_payload`. Instead, you would use the extensions mechanism (see [Section 2.6.3](#)). Thus, in SystemC, none of the accessors are virtual.

In SystemVerilog, an important use model is to add randomization constraints to a transaction type. This is most often done with inheritance—take a derived object and add constraints to a base class. These constraints can further be modified or extended by deriving a new class, and so on. To support this use model, the accessor functions are virtual, and the members are protected and not local.

2.6.3 Extensions

The generic payload extension mechanism is very similar to the one used in SystemC; minor differences exist simply due to the lack of function templates in SystemVerilog. Extensions are used to attach additional application-specific or bus-specific information to the generic bus transaction described in the generic payload.

An *extension* is an instance of a user-defined container class based on the `uvm_tlm_extension` class. The set of extensions for any particular generic payload object are stored in that generic payload object instance. A generic payload object may have only one extension of a specific extension container type.

Each extension container type is derived from the `uvm_tlm_extension` class and contains any additional information required by the user:

```
class gp_Xs_ext extends uvm_tlm_extension#(gp_Xs_ext);
    byte Xmask[];

    `uvm_object_new
    `uvm_object_utils_begin(gp_Xs_ext)
        `uvm_field_int_array(Xmask, UVM_ALL_ON)
    `uvm_object_utils_end
endclass
```

To add an extension to a generic payload object, allocate an instance of the extension container class and attach it to the generic payload object using the `set_extension()` method:

```
gp_Xs_ext Xs = new();
gp.set_extension(Xs);
```

The static function `ID()` in the user-defined extension container class can be used as an argument to the function `get_extension` method to retrieve the extension (if any) of the corresponding container type—if it is attached to the generic payload object.

```
gp_Xs_ext Xs;
$cast(Xs, gp.get_extension(gp_Xs_ext::ID));
```

The following methods are also available in the generic payload for managing extensions.

```
function int get_num_extensions();
function void clear_extension();
function void clear_extensions();
```

`clear_extension()` removes any extension of a specified type. `clear_extensions()` removes all extension containers from the generic payload.

2.7 Core Interfaces and Ports

In the SystemVerilog implementation of TLM-2.0, we have provided only the basic transport interfaces. They are defined in the `uvm_tlm_if#()` class:

```
class uvm_tlm_if #(type T=uvm_tlm_generic_payload, type P=uvm_tlm_phase_e);
endclass
```

The interface class is parameterized with the type of the transaction object that will be transported across the interface and the type of the phase enum. The default transaction type is the generic payload. The default phase enum is:

```
typedef enum
{
    UNINITIALIZED_PHASE,
    BEGIN_REQ,
    END_REQ,
    BEGIN_RESP,
    END_RESP
} uvm_tlm_phase_e;
```

Each of the interface methods take a handle to the transaction to be transported and a handle to a timescale-independent time value object. In addition, the nonblocking interfaces take a reference argument for the phase.

```
virtual function uvm_tlm_sync_e nb_transport_fw(T t, ref P p, input
    uvm_tlm_time delay);
virtual function uvm_tlm_sync_e nb_transport_bw(T t, ref P p, input
    uvm_tlm_time delay);
virtual task b_transport(T t, uvm_tlm_time delay);
```

In SystemC, the transaction argument is of type `T&`. Passing a handle to a class in SystemVerilog most closely represents the semantics of `T&` in SystemC. One implication in SystemVerilog is transaction types cannot be scalars. If the transaction argument was qualified with `ref`, indicating it was a reference argument, then it would be possible to use scalar types for transactions. However, that would also mean downstream components could change the handle to a transaction. This violates the required semantics in TLM-2.0 as stated in rule 4.1.2.5-b of the TLM-2.0 LRM, which is quoted here.

“If there are multiple calls to `nb_transport` associated with a given transaction instance, one and the same transaction object shall be passed as an argument to every such call. In other words, a given transaction instance shall be represented by a single transaction object.”

The `phase` and `delay` arguments may change value. These are also references in SystemC; e.g., `P&` and `sc_time&`. However, `phase` is a scalar, not a class, so the best translation is to use the `ref` qualifier to ensure the same object is used throughout the call sequence.

The `uvm_tlm_time` argument, which is present on all the interfaces, represents time. In the SystemC TLM-2.0 specification, this argument is reference to an `sc_time` variable, which lets the value change on either side. This was translated to a class object in SystemVerilog in order to manage timescales in different processes. Times passed through function calls are not automatically scaled. See also: [Section 2.11](#).

An important difference between TLM-1 and TLM-2.0 is the TLM-2.0 interfaces pass transactions by reference and not by value. In SystemC, transactions in TLM-1 were passed as `const` references and in TLM-2.0 just as references. This allows the transaction object to be modified without copying the entire transaction. The result is much higher performance characteristics as a lot of copying is avoided. Another result is any object that has a handle to a transaction may modify it. However, to adhere to the semantics of

the TLM-2.0 interfaces, these modifications must be made within certain rules and in concert with notifications made via the return enum in the nb_* interfaces and the phase argument.

2.8 Blocking Transport

The blocking transport is implemented using one interfaces:

```
task b_transport(T t, uvm_tlm_time delay);
```

The b_transport task transports a transaction from the initiator to the target in a blocking fashion. The call to b_transport by the initiator marks the first timing point in the execution of the transaction. That first timing point may be offset from the current simulation by the delay value specified in the delay argument. The return from b_transport by the target marks the final timing point in the execution of the transaction. That last timing point may be offset from the current simulation time by the delay value specified in the delay argument. Once the task returns, the transaction has been completed by the target. Any indication of success or failure must be annotated in the transaction object by the target.

The initiator may read or modify the transaction object before the call to b_transport and after its return, but not while the call to b_transport is still active. The target may modify the transaction object only while the b_transport call is active and must not keep a reference to it after the task return. The initiator is responsible for allocating the transaction object before the call to b_transport. The same transaction object may be reused across b_transport calls.

2.9 Nonblocking Transport

The blocking transport is implemented using two interfaces:

```
function uvm_tlm_sync_e nb_transport_fw(T t, ref P p, input uvm_tlm_time
    delay);
function uvm_tlm_sync_e nb_transport_bw(T t, ref P p, input uvm_tlm_time
    delay);
```

nb_transport_fw transports a transaction in the forward direction, that is from the initiator to the target (the forward path). nb_transport_bw does the reverse, it transports a transaction from the target back to the initiator (the backward path). An initiator and target will use the forward and backward paths to update each other on the progress of the transaction execution. Typically, nb_transport_fw is called by the initiator whenever the protocol state machine in the initiator changes state and nb_transport_bw is called by the target whenever the protocol state machine in the target changes state.

The nb_* interfaces each return an enum uvm_tlm_sync_e. The possible enum values and their meanings are shown in [Table 2](#).

Table 2—uvm_tlm_sync_e enum Description

Enum value	Interpretation
UVM_TLM_ACCEPTED	Transaction has been accepted. Neither the transaction object, the phase nor the delay arguments have been modified.

Table 2—uvm_tlm_sync_e enum Description (Continued)

Enum value	Interpretation
UVM_TLM_UPDATED	Transaction has been modified. The transaction object, the phase or the delay arguments may have been modified.
UVM_TLM_COMPLETED	Transaction execution has completed. The transaction object, the phase or the delay arguments may have been modified. There will be no further transport calls associated with this transaction.

The `P` argument of `nb_transport_fw` and `nb_transport_bw` represents the transaction phase. This can be a user-defined type that is specific to a particular protocol. The default type is `uvm_tlm_phase_e`, whose values are shown in [Table 3](#). These can be used to implement the *Base Protocol*.

Table 3—uvm_tlm_phase_e Description

Enum value	Interpretation
UNINITIALIZED_PHASE	Phase has not yet begun
BEGIN_REQ	Request has begun
END_REQ	Request has completed
BEGIN_RESP	Response has begun
END_RESP	Response has terminated

The first call to `nb_transport_fw` by the initiator marks the first timing point in the transaction execution. Subsequent calls to `nb_transport_fw` and `nb_transport_bw` mark additional timing points in the transaction execution. The last timing point is marked by a return from `nb_transport_fw` or `nb_transport_bw` with `UVM_TLM_COMPLETED`. All timing points may be offset from the current simulation time by the delay value specified in the `delay` argument. An `nb_transport_fw` call on the forward path shall under no circumstances directly or indirectly make a call to `nb_transport_bw` on the backward path, and vice versa.

The value of the `phase` argument represents the current state of the protocol state machine. Any change in the value of the transaction object should be accompanied by a change in the value of `phase`. When using the Base Protocol, successive calls to `nb_transport_fw` or `nb_transport_bw` with the same phase value are not permitted.

The initiator may modify the transaction object, the phase and the delay arguments immediately before calls to `nb_transport_fw` and before it returns from `nb_transport_bw` only. The target may modify the transaction object, the phase and the delay arguments immediately before calls to `nb_transport_bw` and before it returns from `nb_transport_fw` only. The transaction object, phase and delay arguments may not be otherwise modified by the initiator or target.

The initiator is responsible for allocating the transaction object before the first call to `nb_transport_fw`. The same transaction object is used by all of the forward and backward calls during its execution. That

transaction object is alive for the entire duration of the transaction until the final timing point. The same transaction object may be reused across different transaction execution that do not overlap in time.

2.10 Sockets

In TLM-1, the primary means of making a connection between two processes is through ports and exports, whereas in TLM-2.0 this done through sockets. A *socket* is like a port or export; in fact, it is derived from the same base class as ports and export, namely `uvm_port_base`. However, unlike a port or export a socket provides both a forward and backward path. Thus, you can enable asynchronous (pipelined) bi-directional communication by connecting sockets together. To enable this, a socket contains both a port and an export.

Components that initiate transactions are called initiators and components that receive transactions sent by an initiator are called targets. Initiators have initiator sockets and targets have target sockets. Initiator sockets can only connect to target sockets; target sockets can only connect to initiator sockets.

[Figure 10](#) shows the diagramming of socket connections. The socket symbol is a box with an isosceles triangle with its point indicating the data and control flow direction of the forward path. The backward path is indicated by an arrow connecting the target socket back to the initiator socket. Section 3.4 of the TLM-2.0 LRM fully explains sockets, initiators, targets, and interconnect components.

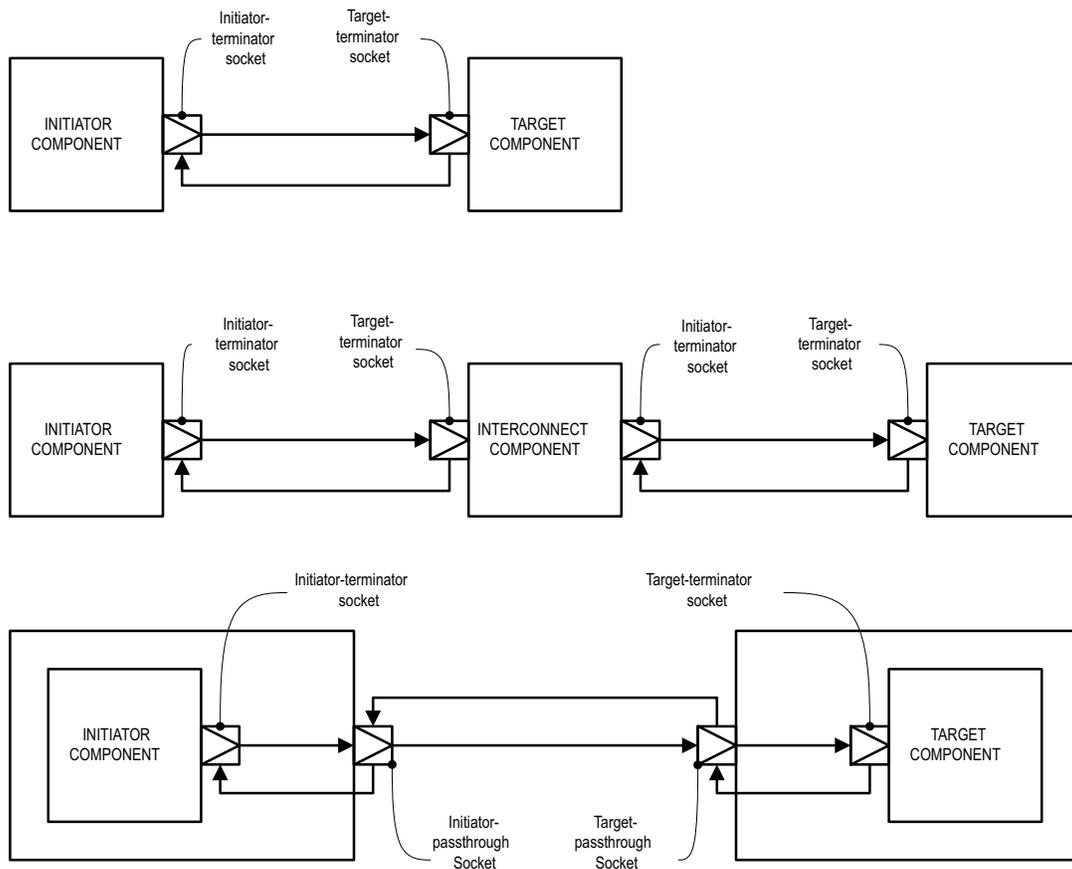


Figure 10—Socket Connections

Sockets come in several flavors: Each socket is an initiator or a target, a passthrough, or a terminator. Furthermore, any particular socket implements either blocking interfaces or nonblocking interfaces. Terminator sockets are used on initiators and targets as well as interconnect components as shown in [Figure 10](#). Passthrough sockets are used to enable connections to cross hierarchical boundaries.

The cross product of {initiator, target} X {terminator, passthrough} X {blocking, nonblocking} yields eight different kinds of sockets. The class definitions for these sockets are as follows:

```
class uvm_tlm_nb_passthrough_initiator_socket #(type
    T=uvm_tlm_generic_payload,
                                     type P=uvm_tlm_phase_e)
    extends uvm_tlm_nb_passthrough_initiator_socket_base #(T,P);

class uvm_tlm_nb_passthrough_target_socket #(type T=uvm_tlm_generic_payload,
                                     type P=uvm_tlm_phase_e)
    extends uvm_tlm_nb_passthrough_target_socket_base #(T,P);

class uvm_tlm_b_passthrough_initiator_socket #(type
    T=uvm_tlm_generic_payload)
    extends uvm_tlm_b_passthrough_initiator_socket_base #(T);

class uvm_tlm_b_passthrough_target_socket #(type T=uvm_tlm_generic_payload)
    extends uvm_tlm_b_passthrough_target_socket_base #(T);

class uvm_tlm_b_target_socket #(type T=uvm_tlm_generic_payload,
    type IMP=int)
    extends uvm_tlm_b_target_socket_base #(T);

class uvm_tlm_b_initiator_socket #(type T=uvm_tlm_generic_payload)
    extends uvm_tlm_b_initiator_socket_base #(T);

class uvm_tlm_nb_target_socket #(type T=uvm_tlm_generic_payload,
    type P=uvm_tlm_phase_e,
    type IMP=int)
    extends uvm_tlm_nb_target_socket_base #(T,P);

class uvm_tlm_nb_initiator_socket #(type T=uvm_tlm_generic_payload,
    type P=uvm_tlm_phase_e,
    type IMP=int)
    extends uvm_tlm_nb_initiator_socket_base #(T,P);
```

[Table 4](#) shows the different kinds of sockets and how they are constructed.

Table 4—Socket Construction

Socket	Blocking	Nonblocking
initiator	IS-A forward port	IS-A forward port; HAS-A backward imp
target	IS-A forward imp	IS-A forward imp; HAS-A backward port
passthrough initiator	IS-A forward port	IS-A forward port; HAS-A backward export
passthrough target	IS-A forward export	IS-A forward port; HAS-A backward export

IS-A and HAS-A are types of object relationships. IS-A refers to the inheritance relationship and HAS-A refers to the ownership relationship. For example, if you say D is a B, it means D is derived from base B. If you say object A HAS-A B, it means B is a member of A.

Each `<socket_type>::connect()` calls `super.connect()`, which performs all the connection mechanics. For the nonblocking sockets which have a secondary port/export for the backward path, `connect()` is called on the secondary port/export to form a backward connection.

Each socket type provides an implementation of the `connect()` method. Connection is defined polymorphically using the base class type as the argument.

```
function void connect(this_type provider);
```

where `this_type` is defined in `uvm_port_base` as:

```
uvm_port_base #(IF) this_type;
```

Further, IF is defined by `uvm_tlm_if#(T,P)`. Thus, compile-time interface type checking is achieved. However, this is not sufficient type checking. Additionally, each implementation of `connect()` in each socket type does run-time type checking to ensure it is connected to allowable socket types. For example, an initiator socket can connect to an initiator passthrough socket, a target passthrough socket, or a target socket. It cannot connect to another initiator socket. These kinds of checks are performed for each socket type.

2.11 Time

Integers are not sufficient on their own to represent time without any ambiguity; you need to know the scale of that integer value, which is conveyed outside of the integer. In SystemVerilog, this is based on the timescale that was active when the code was compiled. SystemVerilog properly scales time literals, but not integer values because it does not know the difference between an integer that carries an integer value and an integer that carries a time value. `time` variables are simply 64-bit integers, they are not scaled back and forth to the underlying precision. Here is a short example that illustrates part of the problem.

```
`timescale 1ns/1ps
module m();

    time t;

    initial begin
        #1.5;
        $write("T=%f ns (Now should be 1.5)\n", $realtime());
        t = 1.5;
        #t; // 1.5 will be rounded to 2
        $write("T=%f ns (Now should be 3.0)\n", $realtime());
        #10ps;
        $write("T=%f ns (Now should be 3.010)\n", $realtime());
        t = 10ps; // 0.010 will be converted to int (0)
        #t;
        $write("T=%f ns (Now should be 3.020)\n", $realtime());
    end
endmodule
```

yields

```
T=1.500000 ns (Now should be 1.5)
T=3.500000 ns (Now should be 3.0)
```

```
T=3.510000 ns (Now should be 3.010)
T=3.510000 ns (Now should be 3.020)
```

Within SystemVerilog, we have to worry about different time scales and precision. Because each endpoint in a socket could be coded in different packages and, thus, be executing under different timescale directives, a simple integer cannot be used to exchange time information across a socket.

For example,

```
`timescale 1ns/1ps

package a_pkg;
  class a;
    function void f(inout time t);
      t += 10ns;
    endfunction
  endclass

endpackage

`timescale 1ps/1ps

program p;

  import a_pkg::*;
  time t = 0;

  initial begin
    a A = new;
    A.f(t);
    #t;
    $write("T=%0d ps (Should be 10,000)\n", $time());
  end
endprogram
```

yields

```
T=10 ps (Should be 10,000)
```

Scaling is needed every time you make a procedural call to code that may interpret a time value in a different timescale. Using the `uvm_tlm_time` type:

```
`timescale 1ns/1ps

package a_pkg;

  import uvm_pkg::*;

  class a;
    function void f(uvm_tlm_time t);
      t.incr(10ns, 1ns);
    endfunction
  endclass

endpackage

`timescale 1ps/1ps
```

```

program p;

    import uvm_pkg::*;
    import a_pkg::*;

    uvm_tlm_time t = new;

    initial begin
        a A = new;
        A.f(t);
        #(t.get_realttime(1ns));
        $write("T=%0d ps (Should be 10,000)\n", $time());
    end
endprogram

```

yields

```
T=10000 ps (Should be 10,000)
```

To solve these problems, the `uvm_tlm_time` class contains the scaling information so that as time information is passed between processes, which may be executing under different time scales, the time can be scaled properly in each environment.

2.12 Use Models

Since sockets are derived from `uvm_port_base`, they are created and connected in the same way as port and exports. You can create them in the build phase and connect them in the connect phase by calling `connect()`. Initiator and target termination sockets are the end points of any connection. There can be an arbitrary number of passthrough sockets in the path between the initiator and target.

Some socket types must be bound to imps—implementations of the transport tasks and functions. Blocking terminator sockets must be bound to an implementation of `b_transport()`, for example. Nonblocking initiator sockets must be bound to an implementation of `nb_transport_bw` and nonblocking target sockets must be bound to an implementation of `nb_transport_fw`. Typically, the task or function is implemented in the component where the socket is instantiated and the component type and instance are provided to complete the binding.

Consider, for example, a consumer component with a blocking target socket:

```

class consumer extends uvm_component;

    uvm_tlm_b_target_socket #(trans, consumer) target_socket;

    function new(string name, uvm_component parent);
        super.new(name, parent);
    endfunction

    function void build();
        target_socket = new("target_socket", this, this);
    endfunction

    task b_transport(ref trans t, ref time delay);
        #5;
        `uvm_info("consumer", t.convert2string());
    endtask
endclass

```

The interface task `b_transport` is implemented in the consumer component. The consumer component type is used in the declaration of the target socket, which informs the socket object of the type of the object containing the interface task, in this case `b_transport()`. When the socket is instantiated `this` is passed in twice, once as the parent, just like any other component instantiation, and again to identify the object that holds the implementation of `b_transport()`. Finally, in order to complete the binding, an implementation of `b_transport()` must be present in the consumer component.

Any component that has a blocking termination socket, nonblocking initiator socket, or nonblocking termination socket must provide implementations of the relevant components. This includes initiator and target components, as well as interconnect components that have these kinds of sockets. Components with passthrough sockets do not need to provide implementations of any sort. Of course, they must ultimately be connected to sockets that do provide the necessary implementations.

3. Developing Reusable Verification Components

This chapter describes the basic concepts and components that make up a typical verification environment. It also shows how to combine these components using a proven hierarchical architecture to create reusable verification components. The sections in this chapter follow the same order you should follow when developing a verification component:

- *Modeling Data Items for Generation*
- *Transaction-Level Components*
- *Creating the Driver*
- *Creating the Sequencer*
- *Creating the Monitor*
- *Instantiating Components*
- *Creating the Agent*
- *Creating the Environment*
- *Enabling Scenario Creation*
- *Managing End of Test*
- *Implementing Checks and Coverage*

NOTE—This chapter builds upon concepts described in [Chapter 1](#) and [Chapter 2](#).

3.1 Modeling Data Items for Generation

Data items:

- Are transaction objects used as stimulus to the device under test (DUT).
- Represent transactions that are processed by the verification environment.
- Are classes that you define (“user-defined” classes).
- Capture and measure transaction-level coverage and checking.

NOTE—The UVM Class Library provides the `uvm_sequence_item` base class. Every user-defined data item must be derived directly or indirectly from this base class.

To create a user-defined data item:

- a) Review your DUT's transaction specification and identify the application-specific properties, constraints, tasks, and functions.
- b) Derive a data item class from the `uvm_sequence_item` base class (or a derivative of it).
- c) Define a constructor for the data item.
- d) Add control fields (“knobs”) for the items identified in Step [\(a\)](#) to enable easier test writing.
- e) Use UVM field macros to enable printing, copying, comparing, and so on.

UVM has built-in automation for many service routines that a data item needs. For example, you can use:

- `print()` to print a data item.
- `copy()` to copy the contents of a data item.
- `compare()` to compare two similar objects.

UVM allows you to specify the automation needed for each field and to use a built-in, mature, and consistent implementation of these routines.

To assist in debugging and tracking transactions, the `uvm_transaction` base class includes the `m_transaction_id` field. In addition, the `uvm_sequence_item` base class (extended from

uvm_transaction) also includes the `m_sequence_id` field, allowing sequence items to be correlated to the sequence that generated them originally. This is necessary to allow the sequencer to route response transactions back to the correct sequence in bidirectional protocols.

The class `simple_item` in this example defines several random variables and class constraints. The UVM macros implement various utilities that operate on this class, such as copy, compare, print, and so on. In particular, the ``uvm_object_utils` macro registers the class type with the common factory.

```
1 class simple_item extends uvm_sequence_item;
2   rand int unsigned addr;
3   rand int unsigned data;
4   rand int unsigned delay;
5   constraint c1 { addr < 16'h2000; }
6   constraint c2 { data < 16'h1000; }
7   // UVM automation macros for general objects
8   `uvm_object_utils_begin(simple_item)
9     `uvm_field_int(addr, UVM_ALL_ON)
10    `uvm_field_int(data, UVM_ALL_ON)
11    `uvm_field_int(delay, UVM_ALL_ON)
12  `uvm_object_utils_end
13  // Constructor
14  function new (string name = "simple_item");
15    super.new(name);
16  endfunction : new
17 endclass : simple_item
```

[Line 1](#) Derive data items from `uvm_sequence_item` so they can be generated in a procedural sequence. See [Section 3.10.2](#) for more information.

[Line 5](#) and [Line 6](#) Add constraints to a data item definition in order to:

- Reflect specification rules. In this example, the address must be less than `16'h2000`.

- Specify the default distribution for generated traffic. For example, in a typical test most transactions should be legal.

[Line 7-Line 12](#) Use the UVM macros to automatically implement functions such as `copy()`, `compare()`, `print()`, `pack()`, and so on. Refer to “Macros” in the UVM *1.1 Class Reference* for information on the ``uvm_object_utils_begin`, ``uvm_object_utils_end`, ``uvm_field_*`, and their associated macros.

NOTE—UVM provides built-in macros to simplify development of the verification environment. The macros automate the implementation of functions defined in the base class, such as `copy()`, `compare()`, and `print()`, thus saving many lines of code. Use of these macros is optional, but recommended.

3.1.1 Inheritance and Constraint Layering

In order to meet verification goals, the verification component user might need to adjust the data-item generation by adding more constraints to a class definition. In SystemVerilog, this is done using inheritance. The following example shows a derived data item, `word_aligned_item`, which includes an additional constraint to select only word-aligned addresses.

```
class word_aligned_item extends simple_item;
  constraint word_aligned_addr { addr[1:0] == 2'b00; }
  `uvm_object_utils(word_aligned_item)
  // Constructor
  function new (string name = "word_aligned_item");
```

```

        super.new(name);
    endfunction : new
endclass : word_aligned_item

```

To enable this type of extensibility:

- The base class for the data item (`simple_item` in this chapter) should use virtual methods to allow derived classes to override functionality.
- Make sure constraint blocks are organized so that they are able to override or disable constraints for a random variable without having to rewrite a large block.
- Do not use the `protected` or `local` keyword to restrict access to properties that may be constrained by the user. This will limit your ability to constrain them with an inline constraint.

3.1.2 Defining Control Fields (“Knobs”)

The generation of all values of the input space is often impossible and usually not required. However, it is important to be able to generate a few samples from ranges or categories of values. In the `simple_item` example in [Section 3.1](#), the `delay` property could be randomized to anything between zero and the maximum unsigned integer. It is not necessary (nor practical) to cover the entire legal space, but it is important to try back-to-back items along with short, medium, and large delays between the items, and combinations of all of these. To do this, define control fields (often called “knobs”) to enable the test writer to control these variables. These same control knobs can also be used for coverage collection. For readability, use enumerated types to represent various generated categories.

Knobs Example

```

typedef enum {ZERO, SHORT, MEDIUM, LARGE, MAX} simple_item_delay_e;
class simple_item extends uvm_sequence_item;
    rand int unsigned addr;
    rand int unsigned data;
    rand int unsigned delay;
    rand simple_item_delay_e delay_kind; // Control field
    // UVM automation macros for general objects
    `uvm_object_utils_begin(simple_item)
        `uvm_field_int(addr, UVM_ALL_ON)
        `uvm_field_enum(simple_item_delay_e, delay_kind, UVM_ALL_ON)
    `uvm_object_utils_end
    constraint delay_order_c { solve delay_kind before delay; }
    constraint delay_c {
        (delay_kind == ZERO) -> delay == 0;
        (delay_kind == SHORT) -> delay inside { [1:10] };
        (delay_kind == MEDIUM) -> delay inside { [11:99] };
        (delay_kind == LARGE) -> delay inside { [100:999] };
        (delay_kind == MAX ) -> delay == 1000;
        delay >=0; delay <= 1000; }
endclass : simple_item

```

Using this method allows you to create more abstract tests. For example, you can specify distribution as:

```

constraint delay_kind_d {delay_kind dist {ZERO:=2, SHORT:=1,
    MEDIUM:=1, LONG:=1, MAX:=2};}

```

When creating data items, keep in mind what range of values are often used or which categories are of interest to that data item. Then add knobs to the data items to simplify control and coverage of these data item categories.

3.2 Transaction-Level Components

As discussed in [Chapter 2](#), TLM interfaces in UVM provide a consistent set of communication methods for sending and receiving transactions between components. The components themselves are instantiated and connected in the testbench, to perform the different operations required to verify a design. A simplified testbench is shown in [Figure 11](#).

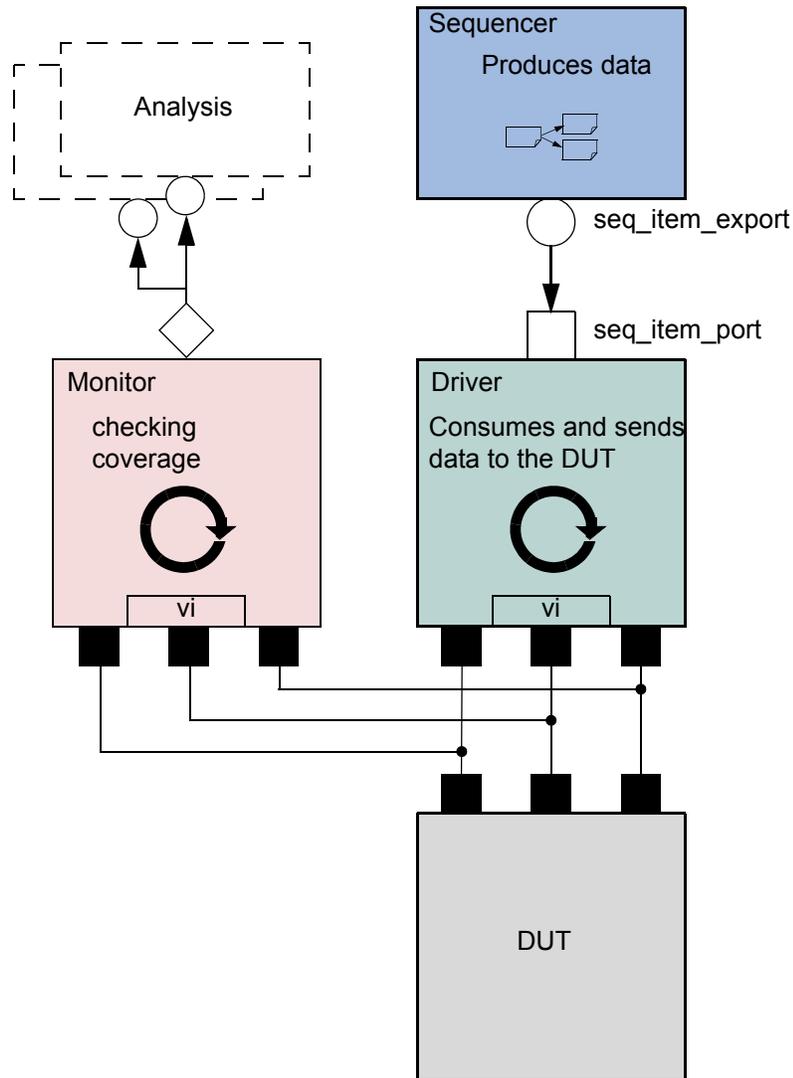


Figure 11—Simplified Transaction-Level Testbench

The basic components of a simple transaction-level verification environment are:

- A stimulus generator (sequencer) to create transaction-level traffic to the DUT.
- A driver to convert these transactions to signal-level stimulus at the DUT interface.
- A monitor to recognize signal-level activity on the DUT interface and convert it into transactions.
- An analysis component, such as a coverage collector or scoreboard, to analyze transactions.

As we shall see, the consistency and modularity of the TLM interfaces in UVM allow components to be reused as other components are replaced and/or encapsulated. Every component is characterized by its interfaces, regardless of its internal implementation (see [Figure 12](#)). This chapter discusses how to encapsulate these types of components into a proven architecture, a verification component, to improve reuse even further.

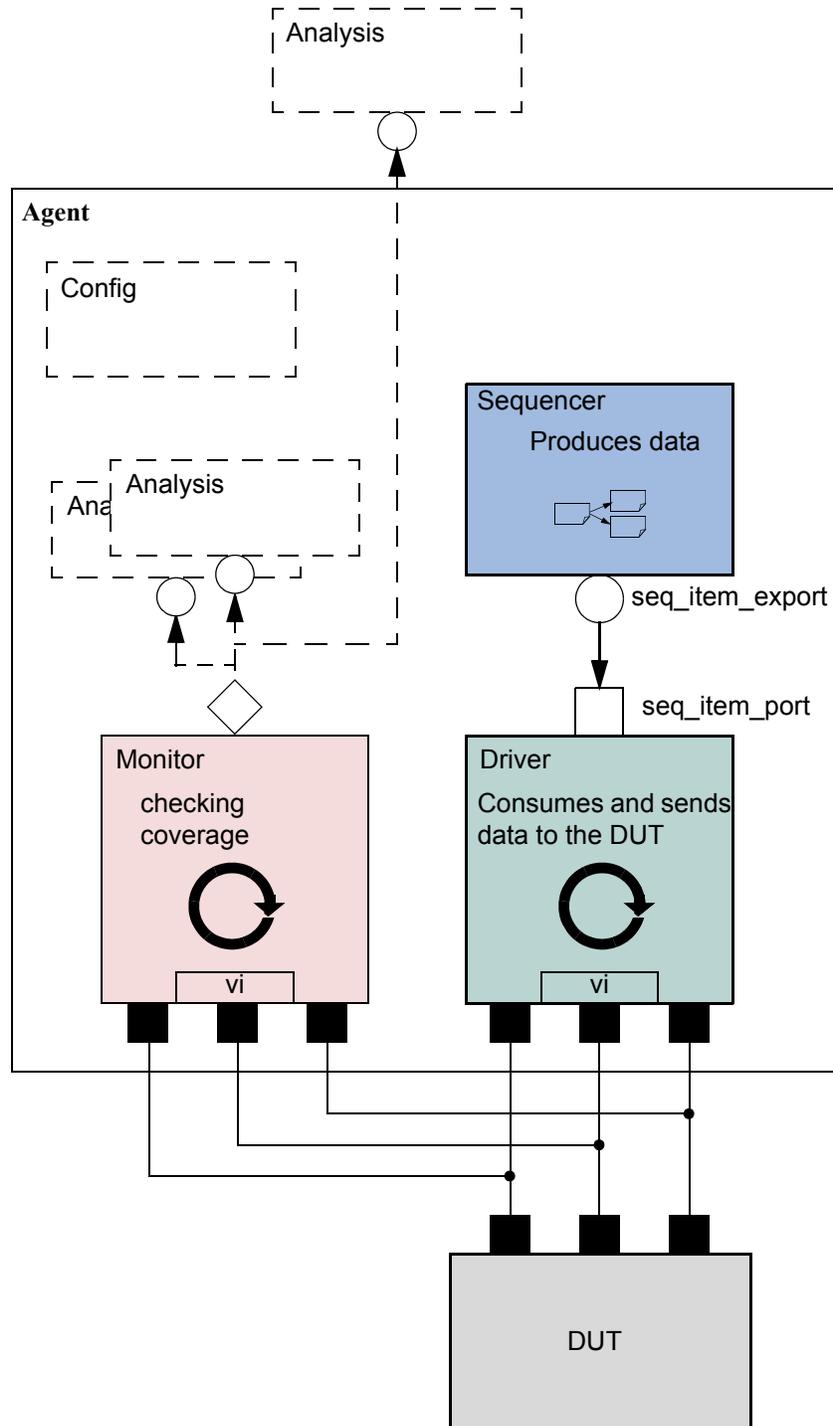


Figure 12—Highly Reusable Verification Component Agent

[Figure 12](#) shows the recommended grouping of individual components into a reusable interface-level verification component agent. Instead of reusing the low-level classes individually, the developer creates a component that encapsulates its sub-classes in a consistent way. Promoting a consistent architecture makes these components easier to learn, adopt, and configure.

3.3 Creating the Driver

The driver's role is to drive data items to the bus following the interface protocol. The driver obtains data items from the sequencer for execution. The UVM Class Library provides the `uvm_driver` base class, from which all driver classes should be extended, either directly or indirectly. The driver has a `run()` method that defines its operation, as well as a TLM port through which it communicates with the sequencer (see the example below). The driver may also implement one or more of the parallel run-time phases (`pre_reset` - `post_shutdown`) to refine its operation further.

To create a driver:

- a) Derive a driver from the `uvm_driver` base class.
- b) If desired, add UVM infrastructure macros for class properties to implement utilities for printing, copying, comparing, and so on.
- c) Obtain the next data item from the sequencer and execute it as outlined above.
- d) Declare a virtual interface in the driver to connect the driver to the DUT.

Refer to [Section 3.10.2](#) for a description of how a sequencer, driver, and sequences synchronize with each other to generate constrained random data.

The class `simple_driver` in the example below defines a driver class. The example derives `simple_driver` from `uvm_driver` (parameterized to use the `simple_item` transaction type) and uses the methods in the `seq_item_port` object to communicate with the sequencer. As always, include a constructor and the ``uvm_component_utils` macro to register the driver type with the common factory.

```
1 class simple_driver extends uvm_driver #(simple_item);
2   simple_item s_item;
3   virtual dut_if vif;
4   // UVM automation macros for general components
5   `uvm_component_utils(simple_driver)
6   // Constructor
7   function new (string name = "simple_driver", uvm_component parent);
8     super.new(name, parent);
9   endfunction : new
10  function void build_phase(uvm_phase phase);
11    string inst_name;
12    super.build_phase(phase);
13    if(!uvm_config_db#(virtual dut_if)::get(this,
14                                           "", "vif", vif))
15      `uvm_fatal("NOVIF",
16                {"virtual interface must be set for: ",
17                 get_full_name(), ".vif"});
18  endfunction : build_phase
19  task run_phase(uvm_phase phase);
20    forever begin
21      // Get the next data item from sequencer (may block).
22      seq_item_port.get_next_item(s_item);
23      // Execute the item.
24      drive_item(s_item);
```

```

25     seq_item_port.item_done(); // Consume the request.
26     end
27 endtask : run
28
29 task drive_item (input simple_item item);
30     ... // Add your logic here.
31 endtask : drive_item
32 endclass : simple_driver

```

[Line 1](#) Derive the driver.

[Line 5](#) Add UVM infrastructure macro.

[Line 13](#) Get the resource that defines the virtual interface

[Line 22](#) Call `get_next_item()` to get the next data item for execution from the sequencer.

[Line 25](#) Signal the sequencer that the execution of the current data item is done.

[Line 30](#) Add your application-specific logic here to execute the data item.

More flexibility exists on connecting the drivers and the sequencer. See [Section 3.5](#).

3.4 Creating the Sequencer

The sequencer generates stimulus data and passes it to a driver for execution. The UVM Class Library provides the `uvm_sequencer` base class, which is parameterized by the `request` and `response` item types. The `uvm_sequencer` base class contains all of the base functionality required to allow a sequence to communicate with a driver. The only time it is necessary to extend the `uvm_sequencer` class is if you need to add additional functionality, such as additional ports. The `uvm_sequencer` gets instantiated directly, with appropriate parameterization as shown in [Section 3.8.1](#), [Line 4](#). In the class definition, by default, the response type is the same as the request type. If a different response type is desired, the optional second parameter must be specified for the `uvm_sequencer` base type:

```
uvm_sequencer #(simple_item, simple_rsp) sequencer;
```

Refer to [Section 3.10.2](#) for a description of how a sequencer, driver, and sequences synchronize with each other to generate constrained-random data.

3.5 Connecting the Driver and Sequencer

The driver and the sequencer are connected via TLM, with the driver's `seq_item_port` connected to the sequencer's `seq_item_export` (see [Figure 13](#)). The sequencer produces data items to provide via the export. The driver consumes data items through its `seq_item_port` and, optionally, provides responses. The component that contains the instances of the driver and sequencer makes the connection between them. See [Section 3.8](#).

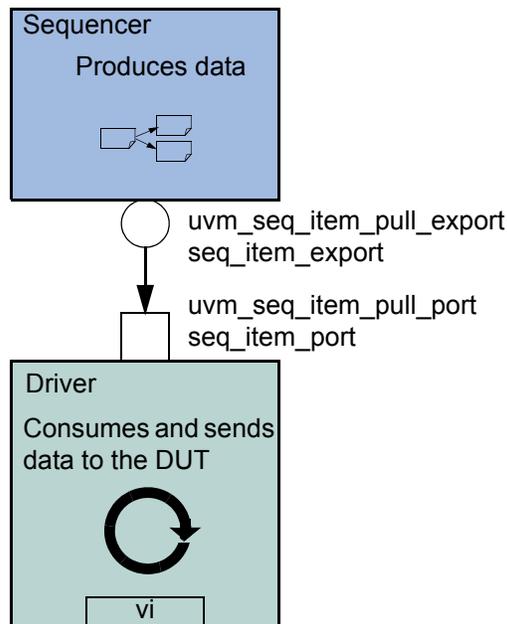


Figure 13—Sequencer-Driver Interaction

The `seq_item_port` in `uvm_driver` defines the set of methods used by the driver to obtain the next item in the sequence. An important part of this interaction is the driver’s ability to synchronize to the bus, and to interact with the sequencer to generate data items at the appropriate time. The sequencer implements the set of methods that allows flexible and modular interaction between the driver and the sequencer.

3.5.1 Basic Sequencer and Driver Interaction

Basic interaction between the driver and the sequencer is done using the tasks `get_next_item()` and `item_done()`. As demonstrated in the example in [Section 3.3](#), the driver uses `get_next_item()` to fetch the next randomized item to be sent. After sending it to the DUT, the driver signals the sequencer that the item was processed using `item_done()`. Typically, the main loop within a driver resembles the following pseudo code.

```
get_next_item(req);
// Send item following the protocol.
item_done();
```

NOTE—`get_next_item()` is blocking.

3.5.2 Querying for the Randomized Item

In addition to the `get_next_item()` task, the `uvm_seq_item_pull_port` class provides another task, `try_next_item()`. This task will return in the same simulation step if no data items are available for execution. You can use this task to have the driver execute some idle transactions, such as when the DUT has to be stimulated when there are no meaningful data to transmit. The following example shows a revised implementation of the `run()` task in the previous example (in [Section 3.3](#)), this time using `try_next_item()` to drive idle transactions as long as there is no real data item to execute:

```

task run_phase(uvm_phase phase);
  forever begin
    // Try the next data item from sequencer (does not block).
    seq_item_port.try_next_item(s_item);
    if (s_item == null) begin
      // No data item to execute, send an idle transaction.
      ...
    end
  else begin
    // Got a valid item from the sequencer, execute it.
    ...
    // Signal the sequencer; we are done.
    seq_item_port.item_done();
  end
end
endtask: run

```

3.5.3 Fetching Consecutive Randomized Items

In some protocols, such as pipelined protocols, the driver gets a few generated items to fill the pipeline before the first items were completely processed. In such cases, the driver calls `item_done()` without providing the response to the sequencer. In such scenarios the driver logic may look like the following pseudo code:

```

while the pipeline is not empty{
  get_next_item(req);
  fork;
  logic that sends item to the pipeline
  join_none;
  item_done();
  for each completed process call{
    ...
  }
}

```

3.5.4 Sending Processed Data back to the Sequencer

In some sequences, a generated value depends on the response to previously generated data. By default, the data items between the driver and the sequencer are copied by reference, which means that changes the driver makes to the data item will be visible inside the sequencer. In cases where the data item between the driver and the sequencer is copied by value, the driver needs to return the processed response back to the sequencer. Do this using the optional argument to `item_done()`.

```
seq_item_port.item_done(rsp);
```

using the `put_response()` method.

```
seq_item_port.put_response(rsp);
```

or using the built-in analysis port in `uvm_driver`.

```
rsp_port.write(rsp);
```

NOTE—Before providing the response, the response's sequence and transaction id must be set to correspond to the request transaction using `rsp.set_id_info(req)`.

NOTE—`put_response()` is a blocking method, so the sequence must do a corresponding `get_response(rsp)`.

With the basic functionality of driver-sequencer communication outlined above, the steps required to create a driver are straightforward.

3.5.5 Using TLM-Based Drivers

The `seq_item_port`, which is built into `uvm_driver`, is a bidirectional port. It also includes the standard TLM methods `get()` and `peek()` for requesting an item from the sequencer, and `put()` to provide a response. Thus, other components, which may not necessarily be derived from `uvm_driver`, may still connect to and communicate with the sequencer. As with the `seq_item_port`, the methods to use depend on the interaction desired.

```
// Pause sequencer operation while the driver operates on the transaction.
peek(req);
// Process req operation.
get(req);
// Allow sequencer to proceed immediately upon driver receiving transaction.
get(req);
// Process req operation.
```

The following also apply.

- `peek()` is a blocking method, so the driver may block waiting for an item to be returned.
- The `get()` operation notifies the sequencer to proceed to the next transaction. It returns the same transaction as the `peek()`, so the transaction may be ignored.

To provide a response using the `blocking_slave_port`, the driver would call:

```
seq_item_port.put(rsp);
```

The response may also be sent back using an `analysis_port` as well.

3.6 Creating the Monitor

The monitor is responsible for extracting signal information from the bus and translating it into events, structs, and status information. This information is available to other components and to the test writer via standard TLM interfaces and channels. The monitor should never rely on state information collected by other components, such as a driver, but it may need to rely on request-specific id information in order to properly set the sequence and transaction id information for the response.

The monitor functionality should be limited to basic monitoring that is always required. This can include protocol checking—which should be configurable so it can be enabled or disabled—and coverage collection. Additional high-level functionality, such as scoreboards, should be implemented separately on top of the monitor.

If you want to verify an abstract model or accelerate the pin-level functionality, you should separate the signal-level extraction, coverage, checking, and the transaction-level activities. An analysis port should allow communication between the sub-monitor components (see the *UVM 1.1 Class Reference*).

Monitor Example

The following example shows a simple monitor which has the following functions:

- The monitor collects bus information through a virtual interface (xmi).
- The collected data is used in coverage collection and checking.
- The collected data is exported on an analysis port (item_collected_port).

Actual code for collection is not shown in this example. A complete example can be found in the UBus example in `ubus_master_monitor.sv`.

```
class master_monitor extends uvm_monitor;
    virtual bus_if xmi; // SystemVerilog virtual interface
    bit checks_enable = 1; // Control checking in monitor and interface.
    bit coverage_enable = 1; // Control coverage in monitor and interface.
    uvm_analysis_port #(simple_item) item_collected_port;
    event cov_transaction; // Events needed to trigger covergroups
    protected simple_item trans_collected;
    `uvm_component_utils_begin(master_monitor)
        `uvm_field_int(checks_enable, UVM_ALL_ON)
        `uvm_field_int(coverage_enable, UVM_ALL_ON)
    `uvm_component_utils_end
    covergroup cov_trans @cov_transaction;
        option.per_instance = 1;
        ... // Coverage bins definition
    endgroup : cov_trans
    function new (string name, uvm_component parent);
        super.new(name, parent);
        cov_trans = new();
        cov_trans.set_inst_name({get_full_name(), ".cov_trans"});
        trans_collected = new();
        item_collected_port = new("item_collected_port", this);
    endfunction : new
    virtual task run_phase(uvm_phase phase);
        fork
            collect_transactions(); // Spawn collector task.
        join
    endtask : run
    virtual protected task collect_transactions();
        forever begin
            @(posedge xmi.sig_clock);
            ...// Collect the data from the bus into trans_collected.
            if (checks_enable)
                perform_transfer_checks();
            if (coverage_enable)
                perform_transfer_coverage();
            item_collected_port.write(trans_collected);
        end
    endtask : collect_transactions
    virtual protected function void perform_transfer_coverage();
        -> cov_transaction;
    endfunction : perform_transfer_coverage
    virtual protected function void perform_transfer_checks();
        ... // Perform data checks on trans_collected.
    endfunction : perform_transfer_checks
endclass : master_monitor
```

The collection is done in a task (`collect_transaction`) which is spawned at the beginning of the `run()` phase. It runs in an endless loop and collects the data as soon as the signals indicate that the data is available on the bus.

As soon as the data is available, it is sent to the analysis port (`item_collected_port`) for other components waiting for the information.

Coverage collection and checking are conditional because they can affect simulation run-time performance. If not needed, they can be turned off by setting `coverage_enable` or `checks_enable` to 0, using the configuration mechanism. For example:

```
uvm_config_db#(bit)::set(this, "*.master0.monitor", "checks_enable", 0);
```

If checking is enabled, the task calls the `perform_transfer_checks` function, which performs the necessary checks on the collected data (`trans_collected`). If coverage collection is enabled, the task emits the coverage sampling event (`cov_transaction`) which results in collecting the current values.

NOTE—SystemVerilog does not allow concurrent assertions in classes, so protocol checking can also be done using assertions in a SystemVerilog interface.

3.7 Instantiating Components

The isolation provided by object-oriented practices and TLM interfaces between components facilitate reuse in UVM enabling a great deal of flexibility in building environments. Because each component is independent of the others, a given component can be replaced by a new component with the same interfaces without having to change the parent's `connect()` method. This flexibility is accomplished through the use of the *factory* in UVM.

When instantiating components in UVM, rather than calling its constructor (in bold below),

```
class my_component extends uvm_component;
    my_driver driver;
    ...
    function build();
        driver = new("driver", this);
        ...
    endfunction
endclass
```

components are instantiated using the `create()` method.

```
class my_component extends uvm_component;
    my_driver driver;
    ...
    function build();
        driver = my_driver::type_id::create("driver", this);
        ...
    endfunction
endclass
```

The factory operation is explained in [Section 6.2](#). The `type_id::create()` method is a type-specific static method that returns an instance of the desired type (in this case, `my_driver`) from the factory. The arguments to `create()` are the same as the standard constructor arguments, a string name and a parent component. The use of the factory allows the developer to derive a new class extended from `my_driver` and cause the factory to return the extended type in place of `my_driver`. Thus, the parent component can use the new type without modifying the parent class.

For example, for a specific test, an environment user may want to change the driver. To change the driver for a specific test:

- a) Declare a new driver extended from the base component and add or modify functionality as desired.

```
class new_driver extends my_driver;
  ... // Add more functionality here.
endclass: new_driver
```

- b) In your test, environment, or testbench, override the type to be returned by the factory.

```
virtual function build();
  set_type_override_by_type(my_driver::get_type(),
    new_driver::get_type());
endfunction
```

The factory also allows a new type to be returned for the creation of a specific instance as well. In either case, because `new_driver` is an extension of `my_driver` and the TLM interfaces are the same, the connections defined in the parent remain unchanged.

3.8 Creating the Agent

An agent (see [Figure 14](#)) instantiates and connects together a driver, monitor, and sequencer using TLM connections as described in the preceding sections. To provide greater flexibility, the agent also contains configuration information and other parameters. As discussed in [Section 1.2.5](#), UVM recommends that the verification component developer create an agent that provides protocol-specific stimuli creation, checking, and coverage for a device. In a bus-based environment, an agent models either a master or a slave component.

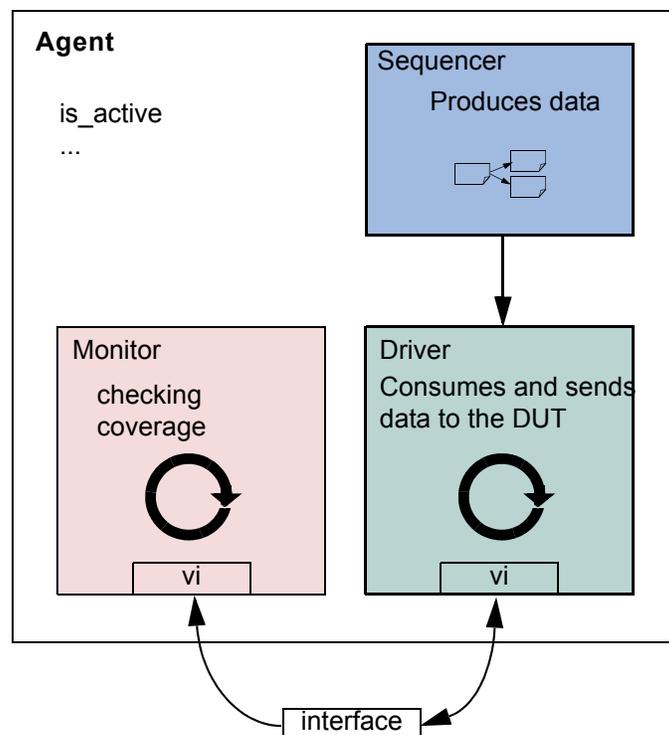


Figure 14—Agent

3.8.1 Operating Modes

An agent has two basic operating modes:

- Active mode, where the agent emulates a device in the system and drives DUT signals. This mode requires that the agent instantiate a driver and sequencer. A monitor also is instantiated for checking and coverage.
- Passive mode, where the agent does not instantiate a driver or sequencer and operates passively. Only the monitor is instantiated and configured. Use this mode when only checking and coverage collection is desired.

The class `simple_agent` in the example below instantiates a sequencer, a driver, and a monitor in the recommended way. Instead of using the constructor, the UVM `build()` phase is used to configure and construct the subcomponents of the agent. Unlike constructors, this virtual function can be overridden without any limitations. Also, instead of hard coding, the allocation `type_id::create()` is used to instantiate the subcomponents. The example in “To change the driver for a specific test:” in [Section 3.8](#) illustrates how you can override existing behavior using `extends`.

```
1 class simple_agent extends uvm_agent;
2   uvm_active_passive_enum is_active;
3   ... // Constructor and UVM automation macros
4   uvm_sequencer #(simple_item) sequencer;
5   simple_driver driver;
6   simple_monitor monitor;
7   // Use build() phase to create agents's subcomponents.
8   virtual function void build_phase(uvm_phase phase);
9     super.build_phase(phase)
10    monitor = simple_monitor::type_id::create("monitor",this);
11    if (is_active == UVM_ACTIVE) begin
12      // Build the sequencer and driver.
13      sequencer =
14        uvm_sequencer#(simple_item)::type_id::create("sequencer",this);
15      driver = simple_driver::type_id::create("driver",this);
16    end
17  endfunction : build_phase
18  virtual function void connect_phase(uvm_phase phase);
19    if(is_active == UVM_ACTIVE) begin
20      driver.seq_item_port.connect(sequencer.seq_item_export);
21    end
22  endfunction : connect_phase
23 endclass : simple_agent
```

NOTE—You should always call `super.build_phase()` (see [Line 9](#)) to update the given component's configuration overrides if the UVM automation macros were used. This is crucial to providing the capability for an enclosing component to be able to override settings of an instance of this component.

[Line 10](#) The monitor is created using `create()`.

[Line 11](#) - [Line 16](#) The `if` condition tests the `is_active` property to determine whether the driver and sequencer are created in this agent. If the agent is set to active (`is_active = UVM_ACTIVE`), the driver and sequencer are created using additional `create()` calls.

Both the sequencer and the driver follow the same creation pattern as the monitor.

This example shows the `is_active` flag as a configuration property for the agent. You can define any control flags that determine the component's topology. At the environment level, this could be a

num_masters integer, a num_slaves integer, or a has_bus_monitor flag. See [Chapter 7](#) for a complete interface verification component example that uses all the control fields previously mentioned.

NOTE—create() should always be called from the build_phase() method to create any multi-hierarchical component.

[Line 19 - Line 21](#) The if condition should be checked to see if the agent is active and, if so, the connection between the sequencer and driver is made using connect().

3.8.2 Connecting Components

The connect_phase() phase, which happens after the build is complete, should be used to connect the components inside the agent. See [Line 19 - Line 21](#) in the example in [Section 3.8.1](#).

3.9 Creating the Environment

Having covered the basic operation of transaction-level verification components in a typical environment above, this section describes how to assemble these components into a reusable environment (see [Figure 15](#)). By following the guidelines here, you can ensure that your environment will be architecturally correct, consistent with other verification components, and reusable. The following sections describe how to create and connect environment sub-components.

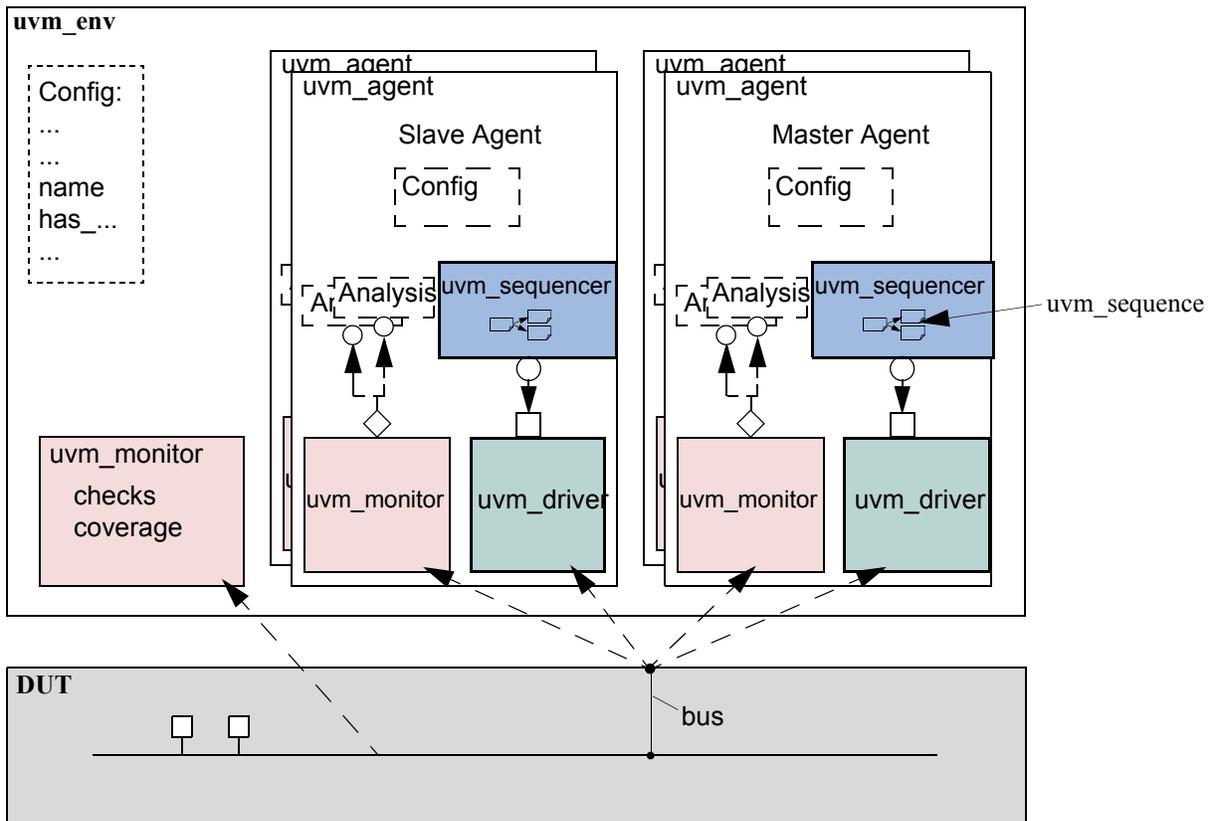


Figure 15—Typical UVM Environment Architecture

3.9.1 The Environment Class

The environment class is the top container of reusable components. It instantiates and configures all of its subcomponents. Most verification reuse occurs at the environment level where the user instantiates an environment class and configures it and its agents for specific verification tasks. For example, a user might need to change the number of masters and slaves in a new environment as shown below.

```
class ahb_env extends uvm_env;
  int num_masters;
  ahb_master_agent masters[];
  `uvm_component_utils_begin(ahb_env)
    `uvm_field_int(num_masters, UVM_ALL_ON)
  `uvm_component_utils_end
  virtual function void build_phase(phase);
  string inst_name;
  super.build_phase(phase);
  if(!uvm_config_db#(virtual ubus_if)::get(this, "",
                                           "vif", vif))
    `uvm_fatal("NOVIF", {"virtual interface must be set for: ",
                        get_full_name(), ".vif"});
  masters = new[num_masters];
  for(int i = 0; i < num_masters; i++) begin
    $sformat(inst_name, "masters[%0d]", i);
    masters[i] = ahb_master_agent::type_id::create(inst_name, this);
  end
  // Build slaves and other components.
endfunction
function new(string name, uvm_component parent);
  super.new(name, parent);
endfunction : new
endclass
```

NOTE—Similarly to the agent, `create` is used to allocate the environment sub-components. This allows introducing derivations of the sub-components later.

The user is not required to call `build_phase()` explicitly. The UVM Class Library will do this for all created components. Once all the components' `build()` functions are complete, the library will call each component's `connect()` function. Any connections between child components should be made in the `connect()` function of the parent component.

3.9.2 The UVM Configuration Mechanism

A verification component is created on a per-protocol basis for general-purpose protocol-related use. It may support various features or operation modes that are not required in a particular project. UVM provides a standard configuration mechanism which allows you to define the verification component's configuration to suit the current project's requirements. The verification component can get the configuration during run time or during the build process. Doing this during the build allows you to modify the environment object structure without touching multiple classes.

Properties that are registered as UVM fields using the `uvm_field_*` macros will be automatically updated by the component's `super.build_phase()` method. These properties can then be used to determine the `build_phase()` execution for the component.

It is not required to call a created component's `build_phase()` function. The UVM Class Library will do this automatically for all components that have not had their `build_phase()` function called explicitly by the user.

Connections among the created components is made in the `connect_phase()` function of the component. Since `connect_phase()` happens after `build_phase()`, the user can assume the environment topology is fully created. With the complete topology, the user can then make the necessary connections.

3.9.2.1 Making the Verification Component Reusable

There are times when you as the developer know the context in which the verification component you are developing will be used. In such cases you should take care to separate the requirements of the verification component's protocol from those of the project. It is strongly recommended that you use only the interface-protocol documentation in developing the verification component. Later, you can consult your project's documentation to see if there are some generic features which might be useful to implement. For example, you should be able to configure slave devices to reside at various locations within an address space.

As another example, when a few bits are defined as reserved in a protocol frame, they should stay reserved within the verification component. The verification logic that understands how a specific implementation uses these bits should be defined outside the global generic code.

As a developer, it is critical to identify these generic parameters and document them for the environment users.

3.9.2.2 How to Create a Configurable Attribute

Making an attribute configurable is part of the built-in automation that the UVM Class Library provides. Using the automation macros for `copy()`, `print()`, `compare()`, and so on, also introduces these attributes to the configuration mechanism. In the example in [Section 3.9.1](#), `num_master` is a configuration parameter that allows changing the master agent numbers as needed. Since the ``uvm_field_int` declaration is already provided for printing, there is no further action needed to allow the users to configure it.

For example, to get three master agents, you can specify:

```
uvm_config_db#(int)::set(this, "*.my_env", "num_masters", 3);
```

This can be done in procedural code within the testbench. For more information, see [Section 4.5](#).

The following also apply.

- The values of parameters are automatically updated in the `super.build()` phase. Make sure that you call `super.build()` before accessing these values.
- If you prefer not to use the automation macros, you can use `uvm_config_db#():get()` to fetch the configuration value of a parameter. You can also do this if you are concerned that the `num_masters` field was overridden and you want to re-fetch the original configuration value for it.
- A larger environment can integrate smaller ones and reconfigure their parameters to suit the needs of the parent environment. In this case, when there are contradicting configuration directives, the value set from the highest level in the hierarchy (i.e., the level that executed `build_phase()` first) takes precedence.

3.10 Enabling Scenario Creation

The environment user will need to create many test scenarios to verify a given DUT. Since the verification component developer is usually more familiar with the DUT's protocol, the developer should facilitate the test writing (done by the verification component's user) by doing the following:

- Place knobs in the data item class to simplify declarative test control.
- Create a library of interesting reusable sequences.

The environment user controls the environment-generated patterns configuring its sequencers. The user can:

- Add a sequence of transactions to a sequencer.
- Modify the sequencer to use specific sequences more often than others.
- Override the sequencer's main loop to start with a user-defined sequence instead.

In this section we describe how to create a library of reusable sequences and review their use. For more information on how to control environments, see [Section 4.7](#).

3.10.1 Declaring User-Defined Sequences

Sequences are made up of several data items, which together form an interesting scenario or pattern of data. Verification components can include a library of basic sequences (instead of single-data items), which test writers can invoke. This approach enhances reuse of common stimulus patterns and reduces the length of tests. In addition, a sequence can call upon other sequences, thereby creating more complex scenarios.

NOTE—The UVM Class Library provides the `uvm_sequence` base class. You should derive all sequence classes directly or indirectly from this class.

To create a user-defined sequence:

- a) Derive a sequence from the `uvm_sequence` base class and specify the request and response item type parameters. In the example below, only the request type is specified, `simple_item`. This will result in the response type also being of type `simple_item`.
- b) Use the ``uvm_object_utils` macro to register the sequence type with the factory.
- c) If the sequence requires access to the derived type-specific functionality of its associated sequencer, use the ``uvm_declare_p_sequencer` macro to declare the desired sequencer pointer.
- d) Implement the sequence's `body` task with the specific scenario you want the sequence to execute. In the `body` task, you can execute data items and other sequences using ``uvm_do` (see [Section 3.10.2.2.1](#)) and ``uvm_do_with` (see [Section 3.10.2.2.2](#)).

The class `simple_seq_do` in the following example defines a simple sequence. It is derived from `uvm_sequence` and uses the ``uvm_sequence_utils` macro to associate this sequence with `simple_sequencer` and declare the various utilities ``uvm_object_utils` would provide.

```
class simple_seq_do extends uvm_sequence #(simple_item);
  rand int count;
  constraint c1 { count >0; count <50; }
  // Constructor
  function new(string name="simple_seq_do");
    super.new(name);
  endfunction
  // UVM automation macros for sequences
  `uvm_object_utils(simple_seq_do)
  // The body() task is the actual logic of the sequence.
  virtual task body();
    repeat(count)
      `uvm_do(req)
  endtask : body
endclass : simple_seq_do
```

Once you define a sequence, it is registered with the factory and may be generated by the sequencer's default generation loop.

3.10.2 Generating Stimulus with Sequences and Sequence Items

Sequences allow you to define:

- Streams of data items sent to a DUT.
- Streams of actions performed on a DUT interface.

You can also use sequences to generate static lists of data items with no connection to a DUT interface.

3.10.2.1 Getting Started with Sequences

Previous sections discussed the basics of creating sequences and sequence items using the UVM Class Library. This section discusses how to generate stimulus using the sequence and sequence item macros provided in the class library.

[Figure 16](#) and [Figure 17](#) show the complete flow for sequence items and sequences when used with the `uvm_do` macros. The entire flow includes the allocation of an object based on factory settings for the registered type, which is referred to as “creation” in this section. After creation, comes the initialization of class properties. Although the balance of the object processing depends on whether the object is a sequence item or a sequence, the `pre_do()`, `mid_do()`, and `post_do()` callbacks of the parent sequence and randomization of the objects are also called, but at different points of processing for each object type as shown in the figures.

NOTE—You can use any of the macros with the SystemVerilog looping constructs.

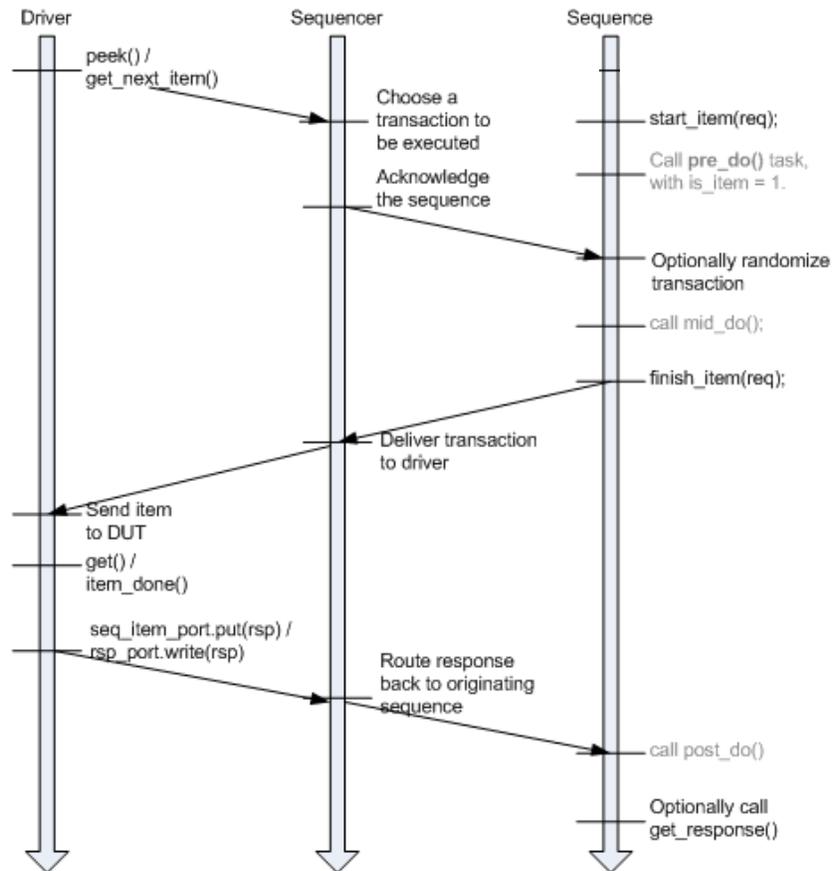
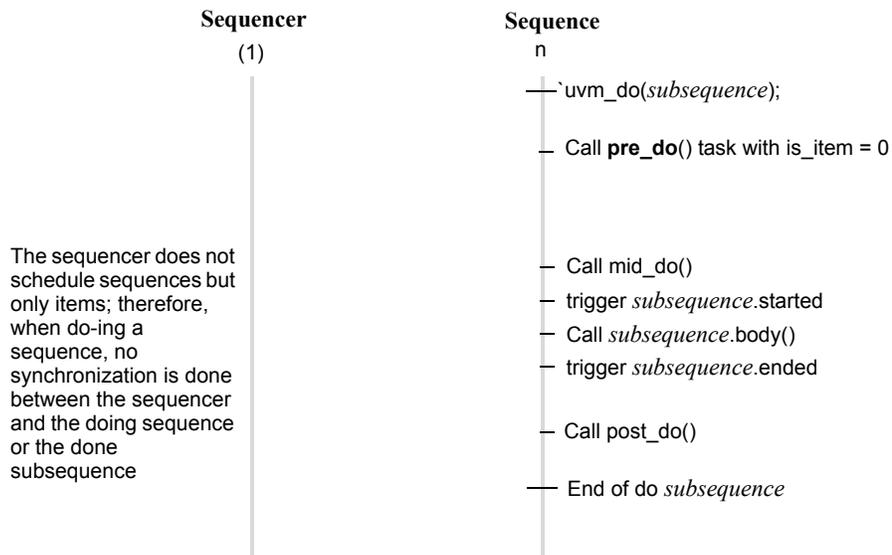


Figure 16—Sequence Item Flow in Pull Mode

The `\uvm_do` macro and all related macros provide a convenient set of calls to create, randomize, and send transaction items in a sequence. The `\uvm_do` macro delays randomization of the item until the driver has signaled that it is ready to receive it and the `pre_do` method has been executed. Other macro variations allow constraints to be applied to the randomization (`uvm_do_with`) or bypass the randomization altogether. The individual methods wrapped by `\uvm_do` in [Figure 16](#) may be called individually with no loss of functionality.

- a) Call `start_item()` to create the item via the factory.
- b) Optionally call `pre_do()` or some other functionality.
- c) Optionally randomize `item`.
- d) Optionally call `mid_do()` or some other functionality, if desired.
- e) Call `finish_item()`.
- f) Optionally call `post_do()` or some other functionality.
- g) Optionally call `get_response()`.



Note This flow does not depend on the driver interaction mode.

Figure 17—Subsequence Flow

3.10.2.2 Sequence and Sequence Item Macros

This section describes the sequence and sequence item macros, ``uvm_do` and ``uvm_do_with`.

3.10.2.2.1 `uvm_do

This macro takes as an argument a variable of type `uvm_sequence` or `uvm_sequence_item`. An object is created using the factory settings and assigned to the specified variable. Based on the processing in [Figure 16](#), when the driver requests an item from the sequencer, the item is randomized and provided to the driver.

The `simple_seq_do` sequence declaration in the example in [Section 3.10.1](#) is repeated here. The body of the sequence invokes an item of type `simple_item`, using the ``uvm_do` macro.

```

class simple_seq_do extends uvm_sequence #(simple_item);
... // Constructor and UVM automation macros
// See Section 4.8.2
virtual task body();
    `uvm_do(req)
endtask : body
endclass : simple_seq_do
  
```

Similarly, a sequence variable can be provided and will be processed as shown in [Figure 17](#). The following example declares another sequence (`simple_seq_sub_seqs`), which uses ``uvm_do` to execute a sequence of type `simple_seq_do`, which was defined earlier.

```

class simple_seq_sub_seqs extends uvm_sequence #(simple_item);
... // Constructor and UVM automation macros
// See Section 4.8.2
simple_seq_do seq_do;
  
```

```

    virtual task body();
        `uvm_do(seq_do)
    endtask : body
endclass : simple_seq_sub_seqs

```

3.10.2.2.2 `uvm_do_with

This macro is similar to ``uvm_do` ([Section 3.10.2.2.1](#)). The first argument is a variable of a type derived from `uvm_sequence_item`, which includes items and sequences. The second argument can be any valid inline constraints that would be legal if used in `arg1.randomize()` with inline constraints. This enables adding different inline constraints, while still using the same item or sequence variable.

Example

This sequence produces two data items with specific constraints on the values of `addr` and `data`.

```

class simple_seq_do_with extends uvm_sequence #(simple_item);
... // Constructor and UVM automation macros
// See Section 4.8.2
virtual task body();
    `uvm_do_with(req, { req.addr == 16'h0120; req.data == 16'h0444; } )
    `uvm_do_with(req, { req.addr == 16'h0124; req.data == 16'h0666; } )
endtask : body
endclass : simple_seq_do_with

```

If constraints are used simply to set parameters to specific values, as in the previous example, the macro can be replaced with a user-defined task.

```

class simple_seq_do_with extends uvm_sequence #(simple_item);
    task do_rw(int addr, int data);
        item= simple_item::type_id::create("item",,get_full_name());
        item.addr.rand_mode(0);
        item.data.rand_mode(0);
        item.addr = addr;
        item.data = data;
        start_item(item);
        randomize(item);
        finish_item(item);
    endtask

    virtual task body();
        repeat (num_trans)
            do_rw($urandom(), $urandom());
    endtask
    ...
endclass : simple_seq_do_with

```

3.10.3 Configuring the Sequencer's Default Sequence

Sequencers do not execute any sequences by default. In each phase, the sequencer will check for a resource corresponding to the specific phase to determine which sequence to start upon entering the phase. The resource is typically defined by the test.

```

uvm_config_db#(uvm_object_wrapper)::set(this,
    ".ubus_example_tb0.ubus0.masters[0].sequencer.main_phase",

```

```

        "default_sequence",
        loop_read_modify_write_seq::type_id::get());

```

In the previous example, the sequencer, upon entering the main phase, will create an instance of the `loop_read_modify_write_seq` sequence, randomize it, and start executing it. It is also possible to start a specific instance of a sequence:

```

lrmw_seq = loop_read_modify_write_seq::type_id::create("lrmw", ,
                                                    get_full_name());
// set parameters in lrmw_seq, if desired
uvm_config_db#(uvm_sequence_base)::set(this,
    ".ubus_example_tb0.ubus0.masters[0].sequencer.main_phase",
    "default_sequence", lrmw_seq);

```

By creating a specific instance of the sequence, the instance may be randomized and/or specific parameters set explicitly or constrained as needed. Upon entering the specified phase, the sequence instance will be started. The sequencer will not randomize the sequence instance.

3.10.4 Overriding Sequence Items and Sequences

In a user-defined `uvm_test`, e.g., `base_test_ubus_demo` (discussed in [Section 4.6.1](#)), you can configure the simulation environment to use a modified version of an existing sequence or a sequence item by using the common factory to create instances of sequence and sequence-item classes. See [Section 6.2](#) for more information.

To override any reference to a specific sequence or sequence-item type:

- a) Declare a user-defined sequence or sequence item class which derives from an appropriate base class. The following example shows the declaration of a basic sequence item of type `simple_item` and a derived item of type `word_aligned_item`.
- b) Invoke the appropriate `uvm_factory` override method, depending on whether you are doing a global or instance-specific override. For example, assume the `simple_seq_do` sequence is executed by a sequencer of type `simple_sequencer` (both defined in [Section 3.10.1](#)). You can choose to replace all processing of `simple_item` types with `word_aligned_item` types. This can be selected for all requests for `simple_item` types from the factory or for specific instances of `simple_item`. From within an UVM component, the user can execute the following:

```

// Affect all factory requests for type simple_item.
set_type_override_by_type(simple_item::get_type(),
    word_aligned_item::get_type());
// Affect requests for type simple_item only on a given sequencer.
set_inst_override_by_type("env0.agent0.sequencer.*",
    simple_item::get_type(), word_aligned_item::get_type());
// Alternatively, affect requests for type simple_item for all
// sequencers of a specific env.
set_inst_override_by_type("env0.*.sequencer.*",
    simple_item::get_type(),
    word_aligned_item::get_type());

```

- c) Use any of the sequence macros that allocate an object (as defined in [Section 3.10.2.2](#)), for example, the `~uvm_do` macro.

Since the sequence macros call the common factory to create the data item object, existing override requests will take effect and a `word_aligned_item` will be created instead of a `simple_item`.

3.11 Managing End of Test

UVM provides an objection mechanism to allow hierarchical status communication among components. There is a built-in objection for each phase, which provides a way for components and objects to synchronize their testing activity and indicate when it is safe to end the phase and, ultimately, the test.

In general, the process is for a component or sequence to raise a phase objection at the beginning of an activity that must be completed before the phase stops and to drop the objection at the end of that activity. Once all of the raised objections are dropped, the phase terminates.

In simulation, agents may have a meaningful agenda to be achieved before the test goals can be declared as done. For example, a master agent may need to complete all its read and write operations before the run phase should be allowed to stop. A reactive slave agent may not object to the end-of-test as it is merely serving requests as they appear without a well-defined agenda.

A typical use model of objections is for a sequence from an active agent to raise an objection when it is started as a root sequence (a sequence which has no parent sequence), and to drop the objection when it is finished as a root sequence. This would look like the following:

```
class interesting_sequence extends uvm_sequence#(data_item);
  task pre_body();
    // raise objection if started as a root sequence
    if(starting_phase != null)
      starting_phase.raise_objection(this);
    endtask
  task body();
    //do interesting activity
    ...
  endtask
  task post_body();
    // drop objection if started as a root sequence
    if(starting_phase != null)
      starting_phase.drop_objection(this);
    endtask
endclass
```

The `starting_phase` member is only set automatically if the sequence is started as the default sequence for a particular phase. Usually, such default phases are used to create “background traffic” on a particular interface and should, therefore, not raise an objection to the current phase, since they may never terminate and would thus prevent the phase from ending. If you wish to start a sequence explicitly and have it raise and lower the objection to manage the end of the current phase, the sequence should be started explicitly from the test during the desired phase:

```
class interesting_test extends uvm_test;
  task main_phase(uvm_phase phase);
    seq.starting_phase = phase;
    seq.start(foo_agent.sequencer); // blocking
  endtask
```

Since the `start()` call is blocking, the test could handle raising and dropping the objection directly, instead of relying on the sequence to do it.

```
class interesting_test extends uvm_test;
  task main_phase(uvm_phase phase);
    phase.raise_objection();
    seq.start(foo_agent.sequencer); // blocking
```

```

    phase.drop_objection();
endtask

```

Note—When the sequence is started explicitly, the `starting_phase` member is `null`, so the sequence will not raise or drop the phase objection.

When all objections are dropped, the currently running phase is ended. In practice, there are times in simulation when the “all objections dropped” condition is temporary. For example, concurrently running processes may need some additional cycles to convey the last transaction to a scoreboard.

To accommodate this, you may use the `phase_ready_to_end()` method to re-raise the phase objection if a transaction is currently in-flight.

Alternatively, you may set a drain time to inject a delay between the time a component’s total objection count reaches zero for the current phase and when the drop is passed to its parent. If any objections are re-raised during this delay, the drop is cancelled and the raise is not propagated further. While a drain time can be set at each level of the component hierarchy with the `adding` effect, typical usage would be to set a single drain time at the `env` or `test` level. If you require control over drain times beyond a simple time value (for example, waiting for a few clock cycles or other user-defined events), you can also use the `all_dropped` callback to calculate drain times more precisely. For more information on the `all_dropped` callback, refer to `uvm_objection` in the *UVM 1.1 Class Reference*.

Vertical reuse means building larger systems out of existing ones. What was once a top-level environment becomes a sub-environment of a large testbench. The objection mechanism allows sub-system environment developers to define a drain time per sub-system.

3.12 Implementing Checks and Coverage

Checks and coverage are crucial to a coverage-driven verification flow. SystemVerilog allows the usage shown in [Table 5](#) for `assert`, `cover`, and `covergroup` constructs.

NOTE—This overview is for concurrent assertions. Immediate assertions can be used in any procedural statement. Refer to the SystemVerilog IEEE1800 LRM for more information.

Table 5—SystemVerilog Checks and Coverage Construct Usage Overview

	class	interface	package	module	initial	always	generate	program
assert	no	yes	no	yes	yes	yes	yes	yes
cover	no	yes	yes	yes	yes	yes	yes	yes
covergroup	yes	yes	yes	yes	no	no	yes	yes

In a verification component, checks and coverage are defined in multiple locations depending on the category of functionality being analyzed. In [Figure 18](#), checks and coverage are depicted in the `uvm_monitor` and `interface`. The following sections describe how the `assert`, `cover`, and `covergroup` constructs are used in the Ubus verification component example (described in [Chapter 7](#)).

3.12.1 Implementing Checks and Coverage in Classes

Class checks and coverage should be implemented in the classes derived from `uvm_monitor`. The derived class of `uvm_monitor` is always present in the agent and, thus, will always contain the necessary checks and coverage. The bus monitor is created by default in an `env` and if the checks and coverage collection is enabled the bus monitor will perform these functions. The remainder of this section uses the master monitor as an example of how to implement class checks and coverage, but they apply to the bus monitor as well.

You can write class checks as procedural code or SystemVerilog immediate assertions.

Tip: Use immediate assertions for simple checks that can be written in a few lines of code and use functions for complex checks that require many lines of code. The reason is that, as the check becomes more complicated, so does the debugging of that check.

NOTE—Concurrent assertions are not allowed in SystemVerilog classes per the IEEE1800 LRM.

The following is a simple example of an assertion check. This assertion verifies the size field of the transfer is 1, 2, 4, or 8. Otherwise, the assertion fails.

```
function void ubus_master_monitor::check_transfer_size();
    check_transfer_size : assert (trans_collected.size == 1 ||
        trans_collected.size == 2 || trans_collected.size == 4 ||
        trans_collected.size == 8) else begin
        // Call DUT error: Invalid transfer size!
    end
endfunction : check_transfer_size
```

The following is a simple example of a function check. This function verifies the size field value matches the size of the data dynamic array. While this example is not complex, it illustrates a procedural-code example of a check.

```
function void ubus_master_monitor::check_transfer_data_size();
    if (trans_collected.size != trans_collected.data.size())
        // Call DUT error: Transfer size field / data size mismatch.
endfunction : check_transfer_data_size
```

The proper time to execute these checks depends on the implementation. You should determine when to make the call to the check functions shown above. For the above example, both checks should be executed after the transfer is collected by the monitor. Since these checks happen at the same instance in time, a wrapper function can be created so that only one call has to be made. This wrapper function follows.

```
function void ubus_master_monitor::perform_transfer_checks();
    check_transfer_size();
    check_transfer_data_size();
endfunction : perform_transfer_checks
```

The `perform_transfer_checks()` function is called procedurally after the item has been collected by the monitor.

Functional coverage is implemented using SystemVerilog covergroups. The details of the covergroup (that is, what to make coverpoints, when to sample coverage, and what bins to create) should be planned and decided before implementation begins.

The following is a simple example of a covergroup.

```

// Transfer collected beat covergroup.
covergroup cov_trans_beat @cov_transaction_beat;
  option.per_instance = 1;
  beat_addr : coverpoint addr {
    option.auto_bin_max = 16; }
  beat_dir : coverpoint trans_collected.read_write;
  beat_data : coverpoint data {
    option.auto_bin_max = 8; }
  beat_wait : coverpoint wait_state {
    bins waits[] = { [0:9] };
    bins others = { [10:$] }; }
  beat_addrXdir : cross beat_addr, beat_dir;
  beat_addrXdata : cross beat_addr, beat_data;
endgroup : cov_trans_beat

```

This embedded covergroup is defined inside a class derived from `uvm_monitor` and is sampled explicitly. For the above covergroup, you should assign the local variables that serve as coverpoints in a function, then sample the covergroup. This is done so that each transaction data beat of the transfer can be covered. This function is shown in the following example.

```

// perform_transfer_coverage
virtual protected function void perform_transfer_coverage();
  cov_trans.sample(); // another covergroup
  for (int unsigned i = 0; i < trans_collected.size; i++) begin
    addr = trans_collected.addr + i;
    data = trans_collected.data[i];
    wait_state = trans_collected.wait_state[i];
    cov_trans_beat.sample();
  end
endfunction : perform_transfer_coverage

```

This function covers several properties of the transfer and each element of the dynamic array data. SystemVerilog does not provide the ability to cover dynamic arrays. You should access each element individually and cover that value, if necessary. The `perform_transfer_coverage()` function would, like `perform_transfer_checks()`, be called procedurally after the item has been collected by the monitor.

3.12.2 Implementing Checks and Coverage in Interfaces

Interface checks are implemented as assertions. Assertions are added to check the signal activity for a protocol. The assertions related to the physical interface are placed in the `env`'s interface. For example, an assertion might check that an address is never X or Y during a valid transfer. Use `assert` as well as `assume` properties to express these interface checks.

An `assert` directive is used when the property expresses the behavior of the device under test. An `assume` directive is used when the property expresses the behavior of the environment that generates the stimulus to the DUT.

The mechanism to enable or disable the physical checks performed using assertions is discussed in [Chapter 3.12.3](#).

3.12.3 Controlling Checks and Coverage

You should provide a means to control whether the checks are enforced and the coverage is collected. You can use an UVM bit field for this purpose. The field can be controlled using the `uvm_config_db` interface. Refer to `uvm_config_db` in the *UVM 1.1 Class Reference* for more information. The following is an example of using the `checks_enable` bit to control the checks.

```
if (checks_enable)
    perform_transfer_checks();
```

If `checks_enable` is set to 0, the function that performs the checks is not called, thus disabling the checks. The following example shows how to turn off the checks for the `master0.monitor`.

```
uvm_config_db#(int)::set(this, "masters[0].monitor", "checks_enable", 0);
```

The same facilities exist for the `coverage_enable` field in the Ubus agent monitors and bus monitor.

4. Using Verification Components

This chapter covers the steps needed to build a testbench from a set of reusable verification components. UVM accelerates the development process and facilitates reuse. UVM users will have fewer hook-up and configuration steps and can exploit a library of reusable sequences to efficiently accomplish their verification goals.

In this chapter, a distinction is made between the environment integrator and the test writer who might have less knowledge about verification and wants to use UVM for creating tests. The test writer may skip the configuration sections and move directly into the test-creation sections.

The steps you need to perform to create a testbench from verification components are:

- a) Review the reusable verification component configuration parameters.
- b) Instantiate and configure reusable verification components.
- c) Create reusable sequences for interface verification components (optional).
- d) Add a virtual sequencer (optional).
- e) Add checking and functional coverage extensions.
- f) Create tests to achieve coverage goals.

Before reading this chapter make sure you read [Chapter 1](#). It is also recommended (but not required) that you read [Chapter 3](#) to get a deeper understanding of verification components.

4.1 Using a Verification Component

As illustrated in [Figure 1](#), the environment integrator instantiates and configures reusable components to build a desired testbench. The integrator also writes multiple tests to follow the verification plan in an organized way.

4.2 Testbench Class

The *testbench* is the container object that defines the testbench topology. The testbench instantiates the reusable verification IP and defines the default configuration of that IP as required by the application.

Instantiating individual verification components directly inside the tests has several drawbacks:

- The test writer must know how to configure the environment.
- Changes to the topology require updating multiple test files, which can turn into a big task.
- The tests are not reusable because they rely on a specific environment structure.

For these reasons, UVM recommends using a testbench class, derived from the `uvm_env` class. The testbench instantiates and configures the reusable components for the desired verification task. Multiple tests can instantiate the testbench class and determine the nature of traffic to generate and send for the selected configuration.

Figure 18 shows a typical verification environment that includes the test class containing the testbench class. Other verification components (or environments) are contained inside the testbench.

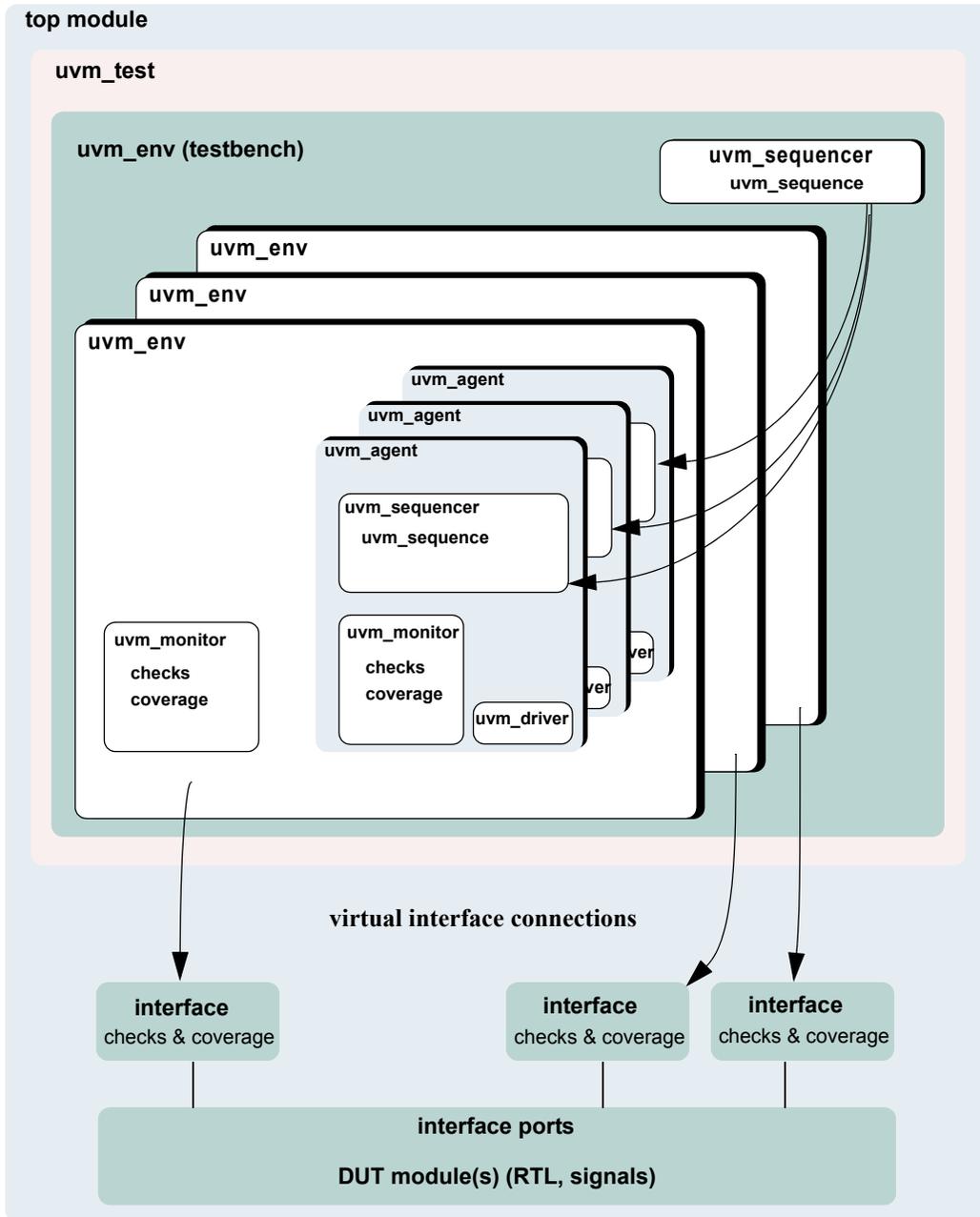


Figure 18—Verification Environment Class Diagram

4.3 Instantiating Verification Components

This section describes how you can use verification components to create a testbench that can be reused for multiple tests. The following example uses the verification IP in Chapter 7. This interface verification component can be used in many environments due to its configurability, but in this scenario it will be used in a simple configuration consisting of one master and one slave. The testbench sets the applicable topology overrides.

The following also apply.

- Examples for the `uvm_config_db::set` calls can be found within the `build_phase()` function.

```
class ubus_example_tb extends uvm_env;
  // Provide implementations of virtual methods such as get_type_name().
  `uvm_component_utils(ubus_example_tb)
  // UBus reusable environment
  ubus_env ubus0;
  // Scoreboard to check the memory operation of the slave
  ubus_example_scoreboard scoreboard0;
  // new()
  function new(string name, uvm_component parent);
    super.new(name, parent);
  endfunction : new
  // build()
  virtual function void build();
    super.build_phase(phase); // Configure before creating the
                              // subcomponents.
    uvm_config_db#(int)::set(this, "ubus0",
                              "num_masters", 1);
    uvm_config_db#(int)::set(this, ".ubus0",
                              "num_slaves", 1);
    ubus0 = ubus_env::type_id::create("ubus0", this);
    scoreboard0 =
    ubus_example_scoreboard::type_id::create("scoreboard0",
      this);
  endfunction : build_phase
  virtual function connect_phase();
    // Connect slave0 monitor to scoreboard.
    ubus0.slaves[0].monitor.item_collected_port.connect(
      scoreboard0.item_collected_export);
  endfunction : connect
  virtual function void end_of_elaboration();
    // Set up slave address map for ubus0 (basic default).
    ubus0.set_slave_address_map("slaves[0]", 0, 16'hffff);
  endfunction : end_of_elaboration
endclass : ubus_example_tb
```

Other configuration examples include:

- Set the `masters [0]` agent to be active:

```
uvm_config_db#(int)::set(this, "ubus0.masters[0]", "is_active",
  UVM_ACTIVE);
```
- Do not collect coverage for `masters [0]` agent:

```
uvm_config_db#(int)::set(this, "ubus0.masters[0].monitor",
  "coverage_enable", 0);
```
- Set all slaves (using a wildcard) to be passive:

```
uvm_config_db#(int)::set(this, "ubus0.slaves*", "is_active", UVM_PASSIVE);
```

Many test classes may instantiate the testbench class above, and configure it as needed. A test writer may use the testbench in its default configuration without having to understand all the details of how it is created and configured.

The `ubus_example_tb`'s `new()` constructor is not used for creating the testbench subcomponents because there are limitations on overriding `new()` in object-oriented languages such as SystemVerilog. Instead, use a virtual `build_phase()` function, which is a built-in UVM phase.

The `uvm_config_db::set` calls specify that the number of masters and slaves should both be 1. These configuration settings are used by the `ubus0` environment during the `ubus0 build_phase()`. This defines the topology of the `ubus0` environment, which is a child of the `ubus_example_tb`.

In a specific test, a user might want to extend the `ubus_env` and derive a new class from it. `create()` is used to instantiate the subcomponents (instead of the `new()` constructor) so the `ubus_env` or the scoreboard classes can be replaced with derivative classes without changing the testbench file. See [Section 6.2.3](#) for more information.

If the UVM field automation macros are used, `super.build_phase()` is called as the first line of the `ubus_example_tb`'s `build()` function. This updates the configuration fields of the `ubus_example_tb`.

`connect_phase()` is used to make the connection between the slave monitor and the scoreboard. The slave monitor contains a TLM analysis port which is connected to the TLM analysis export on the scoreboard. `connect_phase()` is a built-in UVM phase.

After the `build_phase()` and `connect_phase()` functions are complete, the user can make adjustments to run-time properties since the environment is completely elaborated (that is, created and connected). The `end_of_elaboration_phase()` function makes the environment aware of the address range to which the slave agent should respond.

The `ubus_example_tb` defines the topology needed for the Ubus demo tests. This object can be used as is or can be overridden from the test level, if necessary.

4.4 Test Class

The `uvm_test` class defines the test scenario for the testbench specified in the test. The test class enables configuration of the testbench and verification components, as well as utilities for command-line test selection. Although IP developers provide default values for topological and run-time configuration properties, use the configuration override mechanism provided by the UVM Class Library when you require configuration customization. You can provide user-defined sequences in a file or package, which is included or imported by the test class. A test provides data and sequence generation and inline constraints. Test files are typically associated with a single configuration. For usage examples of test classes, refer to [Section 4.6](#).

Tests in UVM are classes that are derived from an `uvm_test` class. Using classes allows inheritance and reuse of tests. Typically, you define a base test class that instantiates and configures the testbench (see [Section 4.6.1](#)), and then extend the base test to define scenario-specific configurations such as which sequences to run, coverage parameters, etc. The test instantiates the testbench just like any other verification component (see [Section 4.3](#))

4.5 Verification Component Configuration

4.5.1 Verification Component Configurable Parameters

Based on the protocols used in a device, the integrator instantiates the needed verification components and configures them for a desired operation mode. Some standard configuration parameters are recommended to address common verification needs. Other parameters are protocol- and implementation-specific.

Examples of standard configuration parameters:

- An agent can be configured for active or passive mode. In active mode, the agent drives traffic to the DUT. In passive mode, the agent passively checks and collects coverage for a device. A rule of thumb to follow is to use an active agent per device that needs to be emulated, and a passive agent for every RTL device that needs to be verified.
- The monitor collects coverage and checks a DUT interface by default. The user may disable these activities by the standard `checks_enable` and `coverage_enable` parameters.

Examples of user-defined parameters:

- The number of master agents and slave agents in an AHB verification component.
- The operation modes or speeds of a bus.

A verification component should support the standard configuration parameters and provide user-defined configuration parameters as needed. Refer to the verification component documentation for information about its user-defined parameters.

4.5.2 Verification Component Configuration Mechanism

UVM provides a configuration mechanism (see [Figure 19](#)) to allow integrators to configure an environment without needing to know the verification component implementation and hook-up scheme. The following are some examples.

```
uvm_config_db#(int)::set(this, "*.masters[0]", "master_id", 0);
uvm_config_db#(uvm_object_wrapper)::
    set(this, "*.ubus0.masters[0].sequencer.main_phase",
        "default_sequence", read_modify_write_seq::type_id::get());
uvm_config_db#(virtual ubus_if)::set(this, "ubus_example_tb0.*", "vif", vif);
uvm_resource_db#(myobject)::set("anyobject", "shared_config", data, this);
```

The `uvm_config_db` is a type-specific configuration mechanism, offering a robust facility for specifying hierarchical configuration values of desired parameters. It is built on top of the more general purpose `uvm_resource_db` which provides side-band (non-hierarchical) data sharing. The first example above shows how to set in integral value for the `master_id` field of all master components whose instance name ends with `masters[0]`. The second example shows how to tell the `masters[0].sequencer` to execute a sequence of type `read_modify_write_seq` upon entering the main phase. The third example shows how to define the virtual interface type that all components under `ubus_example_tb0` should use to set their `vif` variable. The last example shows how to store some shared resource to a location where any object anywhere in the verification hierarchy can access it. When the `uvm_resource_db::set()` call is made from a class, the last parameter should be `this` to allow debugging messages to show where the setting originated.

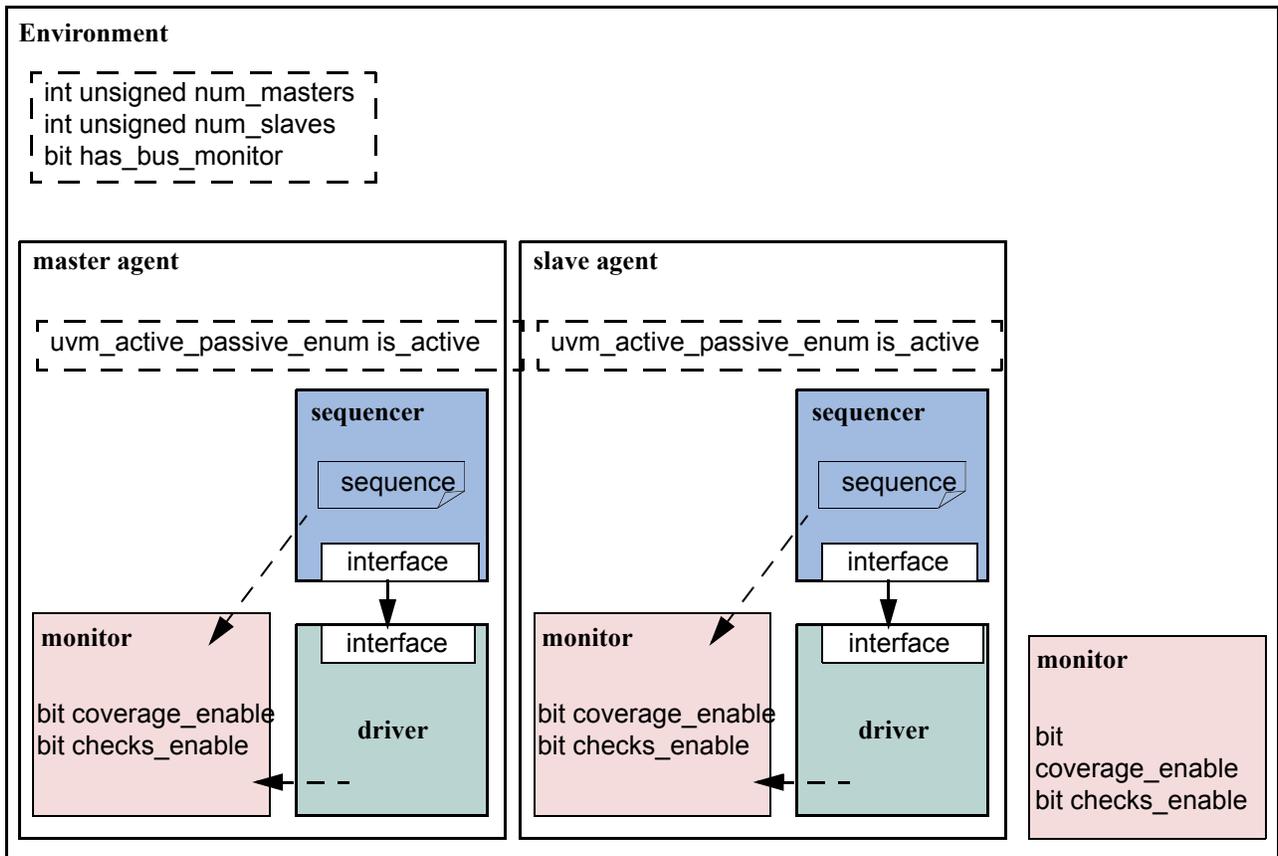


Figure 19—Standard Configuration Fields and Locations

4.5.3 Choosing between `uvm_resource_db` and `uvm_config_db`

The `uvm_config_db` and `uvm_resource_db` share the same underlying database. Because of this, it is possible to write to the database using `uvm_config_db::set()` and retrieve from the database using `uvm_resource_db::read_by_name()`. The primary reason for using one method over the other is whether or not a hierarchical context is important to the setting. For configuration properties that are related to hierarchical position, e.g., “set all of `coverage_enable` bits for all components in a specific agent”, `uvm_config_db` is the correct choice. `uvm_config_db` was architected to provide the required semantic for hierarchical configuration. Likewise, for cases where a configuration property is being shared without regard to hierarchical context, `uvm_resource_db` should be used.

4.5.4 Using a Configuration Class

Some verification components randomize configuration attributes inside a configuration class. Dependencies between these attributes are captured using constraints within the configuration object. In such cases, users can extend the configuration class to add new constraints or layer additional constraints on the class using inline constraints. Once configuration is randomized, the test writer can use `uvm_config_db::set()` to assign the configuration object to one or more environments within the testbench. Setting resources allows you to set the configuration to multiple environments in the testbench regardless of their location and impact the build process of the testbench.

4.6 Creating and Selecting a User-Defined Test

In UVM, a test is a class that encapsulates test-specific instructions written by the test writer. This section describes how to create and select a test. It also describes how to create a test family base class to verify a topology configuration.

4.6.1 Creating the Base Test

The following example shows a base test that uses the `ubus_example_tb` defined in [Section 4.3](#). This base test is a starting point for all derivative tests that will use the `ubus_example_tb`. The complete test class is shown here:

```
class ubus_example_base_test extends uvm_test;
    `uvm_component_utils(ubus_example_base_test)
    ubus_example_tb ubus_example_tb0;
    // The test's constructor
    function new (string name = "ubus_example_base_test",
        uvm_component parent = null);
        super.new(name, parent);
    endfunction

    // Update this component's properties and create the ubus_example_tb
    component.
    virtual function build_phase(); // Create the testbench.
        super.build_phase(phase);
        ubus_example_tb0 =
        ubus_example_tb::type_id::create("ubus_example_tb0", this);
    endfunction
endclass
```

The `build_phase()` function of the base test creates the `ubus_example_tb`. The UVM Class Library will execute the `build_phase()` function of the `ubus_example_base_test` for the user when cycling through the simulation phases of the components. This creates the testbench environment because each sub-component will create their own child components in their `build_phase()` functions.

All of the definitions in the base test are inherited by any test that derives from `ubus_example_base_test`. This means any derivative test will not have to build the testbench if the test calls `super.build_phase()`. Likewise, the `run_phase()` task behavior can be inherited, as well as all other run-time phases. If the current implementation does not meet your needs, you can redefine the `build_phase()`, `run_phase()`, and other run-time phase methods as needed because they are all virtual.

4.6.2 Creating Tests from a Test-Family Base Class

You can derive from the base test defined in [Section 4.6.1](#) to create tests that reuse the same topology. Since the testbench is created by the base test's `build_phase()` function, and the `run_phase()` task defines the run phase, the derivative tests can make minor adjustments. (For example, changing the default sequence executed by the agents in the environment.) The following is a simple test that inherits from `ubus_example_base_test`.

```
class test_read_modify_write extends ubus_example_base_test;
    `uvm_component_utils(test_read_modify_write)
```

```

// The test's constructor
function new (string name = "test_read_modify_write",
             uvm_component parent = null);
    super.new(name, parent);
endfunction
// Register configurations to control which
// sequence is executed by the sequencers.
virtual function void build_phase(uvm_phase phase);
    // Substitute the default sequence.
    uvm_config_db#(uvm_object_wrapper)::
        set(this, "ubus0.masters[0].sequencer.run_phase",
            "default_sequence", read_modify_write_seq::type_id::get());
    uvm_config_db#(uvm_object_wrapper)::
        set(this, "ubus0.slaves[0].sequencer.run_phase",
            "default_sequence", slave_memory_seq::type_id::get());
    super.build_phase(phase);
endfunction
endclass

```

This test changes the default sequence executed by the `masters[0]` agent and the `slaves[0]` agent. It is important to understand that `super.build_phase()`, through the base class, will create the testbench, `ubus_example_tb0`, and all its subcomponents. Therefore, any configuration that will affect the building of these components (such as how many masters to create) must be set before calling `super.build_phase()`. For this example, since the sequences don't get started until a later phase, they could be called after `super.build_phase()`.

This test relies on the `ubus_example_base_test` implementation of the `run_phase()` phase.

4.6.3 Test Selection

After you have declared a user-defined test (described in [Section 4.6.2](#)), invoke the global UVM `run_test()` task in the top-level module to select a test to be simulated. Its prototype is:

```
task run_test(string test_name="");
```

When a test name is provided to the `run_test()` task, the factory is called to create an instance of the test with that type name. Simulation then starts and cycles through the simulation phases.

The following example shows how the test type name `test_read_modify_write` (defined in [Section 4.6.2](#)) can be provided to the `run_test()` task. A test name is provided to `run_test()` via a simulator command-line argument. If the top module calls `run_test()` without an argument, the `+UVM_TESTNAME=test_name` simulator command-line argument is checked. If present, `run_test()` will use `test_name`. Using the simulator command-line argument avoids having to hardcode the test name in the `run_test()` task. For example, in the top-level module, call the `run_test()` as follows:

```

module tb_top;
    // DUT, interfaces, and all non-testbench code
    initial
        run_test();
endmodule

```

To select a test of type `test_read_modify_write` (described in [Section 4.6.2](#)) using simulator command-line option, use the following command:

```
% simulator-command other-options +UVM_TESTNAME=test_read_modify_write
```

If the test name provided to `run_test()` does not exist, the simulation will exit immediately via a call to `$fatal`. If this occurs, it is likely the name was typed incorrectly or the ``uvm_component_utils` macro was not used.

By using this method and only changing the `+UVM_TESTNAME` argument, you can run multiple tests without having to recompile or re-elaborate the design or testbench.

4.7 Creating Meaningful Tests

The previous sections show how test classes are put together. At this point, random traffic is created and sent to the DUT. The user can change the randomization seed to achieve new test patterns. To achieve verification goals in a systematic way, the user will need to control test generation to cover specific areas.

The user can control the test creation using these methods:

- Add constraints to control individual data items. This method provides basic functionality (see [Section 4.7.1](#)).
- Use UVM sequences to control the order of multiple data items. This method provides more flexibility and control (see [Section 4.8.2](#)).

4.7.1 Constraining Data Items

By default, sequencers repeatedly generate random data items. At this level, the test writer can control the number of generated data items and add constraints to data items to control their generated values.

To constrain data items:

- a) Identify the data item classes and their generated fields in the verification component.
- b) Create a derivation of the data item class that adds or overrides default constraints.
- c) In a test, adjust the environment (or a subset of it) to use the newly-defined data items.
- d) Run the simulation using a command-line option to specify the test name.

Data Item Example

```
typedef enum bit {BAD_PARITY, GOOD_PARITY} parity_e;
class uart_frame extends uvm_sequence_item;
    rand int unsigned transmit_delay;
    rand bit start_bit;
    rand bit [7:0] payload;
    rand bit [1:0] stop_bits;
    rand bit [3:0] error_bits;
    bit parity;
    // Control fields
    rand parity_e parity_type;
function new(input string name);
    super.new(name);
endfunction
// Optional field declarations and automation flags
`uvm_object_utils_begin(uart_frame)
    `uvm_field_int(start_bit, UVM_ALL_ON)
    `uvm_field_int(payload, UVM_ALL_ON)
    `uvm_field_int(parity, UVM_ALL_ON)
```

```

        `uvm_field_enum(parity_e, parity_type, UVM_ALL_ON + UVM_NOCOMPARE)
        `uvm_field_int(xmit_delay, UVM_ALL_ON + UVM_DEC + UVM_NOCOMPARE)
    `uvm_object_utils_end
// Specification section 1.2: the error bits value should be
// different than zero.
constraint error_bits_c {error_bits != 4'h0;}
// Default distribution constraints
constraint default_parity_type {parity_type dist {
    GOOD_PARITY:=90, BAD_PARITY:=10};}
// Utility functions
extern function bit calc_parity ( );
    ...
endfunction
endclass: uart_frame

```

The `uart_frame` is created by the `uart` environment developer.

4.7.2 Data Item Definitions

A few fields in the derived class come from the device specification. For example, a frame should have a payload that is sent to the DUT. Other fields are there to assist the test writer in controlling the generation. For example, the field `parity_type` is not being sent to the DUT, but it allows you to easily specify and control the parity distribution. Such control fields are called “knobs”. The verification component documentation should list the data item’s knobs, their roles, and legal range.

Data items have specification constraints. These constraints can come from the DUT specification to create legal data items. For example, a legal frame must have `error_bits_c` not equal to 0. A different type of constraint in the data items constrains the traffic generation. For example, in the constraint block `default_parity_type` (in the example in [Section 4.7.1](#)), the parity bit is constrained to be 90-percent legal (good parity) and 10-percent illegal (bad parity).

4.7.3 Creating a Test-Specific Frame

In tests, the user may wish to change the way data items are generated. For example, the test writer may wish to have short delays. This can be achieved by deriving a new data item class and adding constraints or other class members as needed.

```

// A derived data item example
// Test code
class short_delay_frame extends uart_frame;
    // This constraint further limits the delay values.
    constraint test1_txmit_delay {transmit_delay < 10;}
`uvm_object_utils(short_delay_frame)
function new(input string name="short_delay_frame");
    super.new(name);
endfunction
endclass: short_delay_frame

```

Deriving the new class is not enough to get the desired effect. You also need to have the environment use the new class (`short_delay_frame`) rather than the verification component frame. The UVM Class Library provides a mechanism that allows you to introduce the derived class to the environment.

```

class short_delay_test extends uvm_test;
  `uvm_component_utils(short_delay_test)
  uart_tb uart_tb0;
  function new (string name = "short_delay_test", uvm_component parent =
    null);
    super.new(name, parent);
  endfunction
  virtual function build_phase(uvm_phase phase);
    super.build_phase(phase);
    // Use short_delay_frame throughout the environment.
    factory.set_type_override_by_type(uart_frame::get_type(),
      short_delay_frame::get_type());
    uart_tb0 = uart_tb::type_id::create("uart_tb0", this);
  endfunction
  task run_phase(uvm_phase phase);
    uvm_top.print_topology();
  endtask
endclass

```

Calling the factory function `set_type_override_by_type()` (in bold above) instructs the environment to use short-delay frames.

At times, a user may want to send special traffic to one interface but keep sending the regular traffic to other interfaces. This can be achieved by using `set_inst_override_by_type()` inside an UVM component.

```

set_inst_override_by_type("uart_env0.master.sequencer.*",
  uart_frame::get_type(), short_delay_frame::get_type());

```

You can also use wildcards to override the instantiation of a few components.

```

set_inst_override_by_type("uart_env*.master.sequencer.*",
  uart_frame::get_type(), short_delay_frame::get_type());

```

4.8 Virtual Sequences

[Section 4.7](#) describes how to efficiently control a single-interface generation pattern. However, in a system-level environment, multiple components are generating stimuli in parallel. The user might want to coordinate timing and data between the multiple channels. Also, a user may want to define a reusable system-level scenario. Virtual sequences are associated with a virtual sequencer and are used to coordinate stimulus generation in a testbench hierarchy. In general, a virtual sequencer contains references to its subsequencers, that is, driver sequencers or other virtual sequencers in which it will invoke sequences. Virtual sequences can invoke other virtual sequences associated with its sequencer, as well as sequences in each of the subsequencers. However, virtual sequencers do not have their own data item and therefore do not execute data items on themselves. Virtual sequences can execute items on other sequencers that can execute items.

Virtual sequences enable centralized control over the activity of multiple verification components which are connected to the various interfaces of the DUT. By creating virtual sequences, you can easily reuse existing sequence libraries of the underlying interface components and block-level environments to create coordinated system-level scenarios.

In [Figure 20](#), the virtual sequencer invokes configuration sequences on the ethernet and cpu verification components. The configuration sequences are developed during block-level testing.

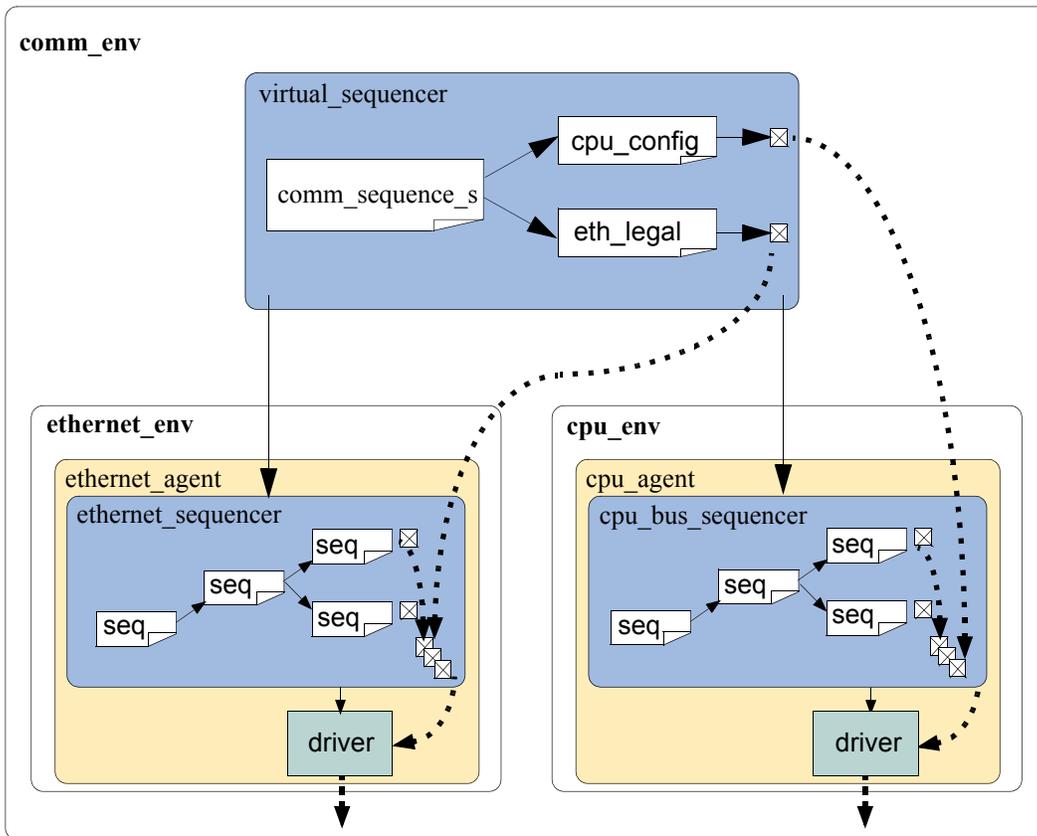


Figure 20—Virtual Sequence

There are three ways in which the virtual sequencer can interact with its subsequencers:

- “Business as usual”—Virtual subsequencers and subsequencers send transactions simultaneously.
- Disable subsequencers—Virtual sequencer is the only one driving.
- Using `grab()` and `ungrab()`—Virtual sequencer takes control of the underlying driver(s) for a limited time.

When using virtual sequences, most users disable the subsequencers and invoke sequences only from the virtual sequence. For more information, see [Section 4.8.3](#).

To invoke sequences, you can do one of the following:

- Use the appropriate `do` macro.
- Use the sequence `start()` method.

4.8.1 Creating a Virtual Sequencer

For high-level control of multiple sequencers from a single sequencer, use a sequencer that is not attached to a driver and does not process items itself. A sequencer acting in this role is referred to as a virtual sequencer.

To create a virtual sequencer that controls several subsequencers:

- Derive a virtual sequencer class from the `uvm_sequencer` class.

- b) Add references to the sequencers where the virtual sequences will coordinate the activity. These references will be assigned by a higher-level component (typically the testbench).

The following example declares a virtual sequencer with two subsequencers. Two interfaces called `eth` and `cpu` are created in the `build` function, which will be hooked up to the actual sub-sequencers.

```
class simple_virtual_sequencer extends uvm_sequencer;
    eth_sequencer eth_seqr;
    cpu_sequencer cpu_seqr;
    // Constructor
    function new(input string name="simple_virtual_sequencer",
        input uvm_component parent=null);
        super.new(name, parent);
    endfunction
    // UVM automation macros for sequencers
    `uvm_component_utils(simple_virtual_sequencer)
endclass: simple_virtual_sequencer
```

Subsequencers can be driver sequencers or other virtual sequencers. The connection of the actual subsequencer instances via reference is done later, as shown in [Section 4.8.4](#).

4.8.2 Creating a Virtual Sequence

Creating a virtual sequence is similar to creating a driver sequence, with the following differences:

- A virtual sequence use ``uvm_do_on` or ``uvm_do_on_with` to execute sequences on any of the subsequencers connected to the current virtual sequencer.
- A virtual sequence uses ``uvm_do` or ``uvm_do_with` to execute other virtual sequences of this sequencer. A virtual sequence cannot use ``uvm_do` or ``uvm_do_with` to execute items. Virtual sequencers do not have items associated with them, only sequences.

To create a virtual sequence:

- c) Declare a sequence class by deriving it from `uvm_sequence`, just like a driver sequence.
- d) Define a `body()` method that implements the desired logic of the sequence.
- e) Use the ``uvm_do_on` (or ``uvm_do_on_with`) macro to invoke sequences in the underlying subsequencers.
- f) Use the ``uvm_do` (or ``uvm_do_with`) macro to invoke other virtual sequences in the current virtual sequencer.

The following example shows a simple virtual sequence controlling two subsequencers: a `cpu` sequencer and an ethernet sequencer. Assume the `cpu` sequencer has a `cpu_config_seq` sequence in its library and the ethernet sequencer provides an `eth_large_payload_seq` sequence in its library. The following sequence example invokes these two sequencers, one after the other.

```
class simple_virt_seq extends uvm_sequence;
    ... // Constructor and UVM automation macros
    // A sequence from the cpu sequencer library
    cpu_config_seq conf_seq;
    // A sequence from the ethernet subsequencer library
    eth_large_payload_seq frame_seq;
    // A virtual sequence from this sequencer's library
    random_traffic_virt_seq rand_virt_seq;
```

```

virtual task body();
    // Invoke a sequence in the cpu sequencer.
    `uvm_do_on(conf_seq, p_sequencer.cpu_seqr)
    // Invoke a sequence in the ethernet sequencer.
    `uvm_do_on(frame_seq, p_sequencer.eth_seqr)
    // Invoke another virtual sequence in this sequencer.
    `uvm_do(rand_virt_seq)
endtask : body
endclass : simple_virt_seq

```

4.8.3 Controlling Other Sequencers

When using a virtual sequencer, you will need to consider how you want the subsequencers to behave in relation to the virtual sequence behavior being defined. There are three basic possibilities:

- a) Business as usual—You want the virtual sequencer and the subsequencers to generate traffic at the same time, using the built-in capability of the original subsequencers. The data items resulting from the subsequencers' default behavior—along with those injected by sequences invoked by the virtual sequencer—will be intermixed and executed in an arbitrary order by the driver. This is the default behavior, so there is no need to do anything to achieve this.
- b) Disable the subsequencers—Using the `set_config` routines, you can set the count property of the subsequencers to 0 and disable their default behavior. Recall that, by default, sequencers start their `uvm_random_sequence`, which uses the count property of the sequencer to determine how many sequences to execute.

The following code snippet disables the subsequencers in the example in [Section 4.8.4](#).

```

// Configuration: Disable sequencer sequences.
uvm_config_db#(int)::set(this, "*.cpu_seqr", "count", 0);
uvm_config_db#(int)::set(this, "*.eth_seqr", "count", 0);

```

- c) Use `grab()` and `ungrab()`—In this case, a virtual sequence can achieve full control over its subsequencers for a limited time and then let the original sequences continue working.

NOTE—Only (non-virtual) driver sequencers can be grabbed. Therefore, make sure a given sequencer is not a virtual sequencer before you attempt to grab it. The following example illustrates this using the functions `grab()` and `ungrab()` in the sequence consumer interface.

```

virtual task body();
    // Grab the cpu sequencer if not virtual.
    if (p_sequencer.cpu_seqr != null)
        p_sequencer.cpu_seqr.grab(this);
    // Execute a sequence.
    `uvm_do_on(conf_seq, p_sequencer.cpu_seqr)
    // Ungrab.
    if (p_sequencer.cpu_seqr != null)
        p_sequencer.cpu_seqr.ungrab(this);
endtask

```

NOTE—When grabbing several sequencers, make sure to use some convention to avoid deadlocks. For example, always grab in a standard order.

4.8.4 Connecting a Virtual Sequencer to Subsequencers

To connect a virtual sequencer to its subsequencers:

- a) Assign the sequencer references specified in the virtual sequencer to instances of the sequencers. This is a simple reference assignment and should be done only after all components are created.

```
v_sequencer.cpu_seqr = cpu_seqr;
v_sequencer.eth_seqr = eth_seqr;
```

- b) Perform the assignment in the `connect()` phase of the verification environment at the appropriate location in the verification environment hierarchy.

Alternatively, the sequencer pointer could be set as a resource during build, as shown with `eth_seqr` below.

The following more-complete example shows a top-level testbench, which instantiates the ethernet and `cpu` components and the virtual sequencer that controls the two. At the testbench level, the path to the sequencers inside the various components is known and that path is used to get a handle to them and connect them to the virtual sequencer.

```
class simple_tb extends uvm_env;
  cpu_env_c cpu0; // Reuse a cpu verification component.
  eth_env_c eth0; // Reuse an ethernet verification component.
  simple_virtual_sequencer v_sequencer;
  ... // Constructor and UVM automation macros
  virtual function void build_phase(uvm_phase phase);
    super.build_phase(phase);
    // Configuration: Set the default sequence for the virtual sequencer.
    uvm_config_db#(uvm_object_wrapper)::set(this,
                                             "v_sequencer.run_phase",
                                             "default_sequence",
                                             simple_virt_seq.type_id::get());

    // Build envs with subsequencers.
    cpu0 = cpu_env_c::type_id::create("cpu0", this);
    eth0 = eth_env_c::type_id::create("eth0", this);

    // Build the virtual sequencer.
    v_sequencer =
    simple_virtual_sequencer::type_id::create("v_sequencer",
                                             this);
  endfunction : build_phase
// Connect virtual sequencer to subsequencers.
  function void connect();
    v_sequencer.cpu_seqr = cpu0.master[0].sequencer;
    uvm_config_db#(uvm_sequencer)::set(this, "v_sequencer",
                                       "eth_seqr", eth0.tx_rx_agent.sequencer);
  endfunction : connect
endclass: simple_tb
```

4.9 Checking for DUT Correctness

Getting the device into desired states is a significant part of verification. The environment should verify valid responses from the DUT before a feature is declared verified. Two types of auto-checking mechanisms can be used:

- a) Assertions—Derived from the specification or from the implementation and ensure correct timing behavior. Assertions typically focus on signal-level activity.
- b) Data checkers—Ensure overall device correctness.

As was mentioned in [Section 1.2.4](#), checking and coverage should be done in the monitor regardless of the driving logic. Reusable assertions are part of reusable components. See [Chapter 3](#) for more information. Designers can also place assertions in the DUT RTL. Refer to your ABV documentation for more information.

4.10 Scoreboards

A crucial element of a self-checking environment is the scoreboard. Typically, a scoreboard verifies the proper operation of your design at a functional level. The responsibility of a scoreboard varies greatly depending on the implementation. This section will show an example of a scoreboard that verifies that a given UBus slave interface operates as a simple memory. While the memory operation is critical to the UBus demonstration environment, you should focus on the steps necessary to create and use a scoreboard in an environment so those steps can be repeated for any scoreboard application.

UBus Scoreboard Example

For the UBus demo environment, a scoreboard is necessary to verify the slave agent is operating as a simple memory. The data written to an address should be returned when that address is read. The desired topology is shown in [Figure 21](#).

In this example, the user has created a testbench with one UBus environment that contains the bus monitor, one active master agent, and one active slave agent. Every component in the UBus environment is created using the `build_phase()` methods defined by the IP developer.

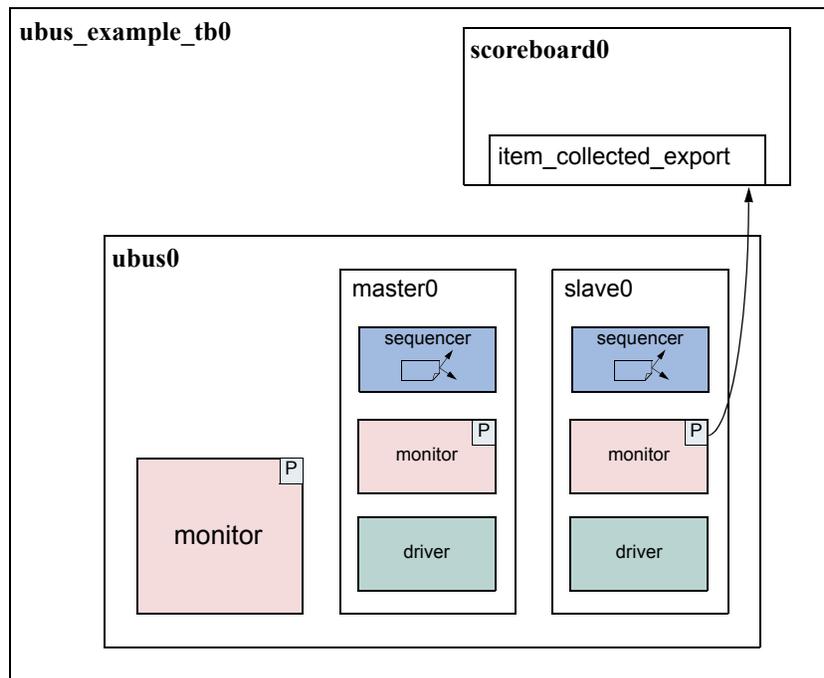


Figure 21—UBus Demo Environment

4.10.1 Creating the Scoreboard

Before the scoreboard can be added to the `ubus_example_tb`, the scoreboard component must be defined.

To define the scoreboard:

- a) Add the TLM export necessary to communicate with the environment monitor(s).

- b) Implement the necessary functions and tasks required by the TLM export.
- c) Define the action taken when the export is called.

4.10.2 Adding Exports to `uvm_scoreboard`

In the example shown in [Figure 21](#), the scoreboard requires only one port to communicate with the environment. Since the monitors in the environment have provided an analysis port `write()` interface via the TLM `uvm_analysis_port(s)`, the scoreboard will provide the TLM `uvm_analysis_imp`.

The `ubus_example_scoreboard` component derives from the `uvm_scoreboard` and declares and instantiates an `analysis_imp`. For more information on TLM interfaces, see “TLM Interfaces” in the *UVM 1.1 Class Reference*. The declaration and creation is done inside the constructor.

```

1 class ubus_example_scoreboard extends uvm_scoreboard;
2   uvm_analysis_imp #(ubus_transfer, ubus_example_scoreboard)
3     item_collected_export;
4   ...
5   function new (string name, uvm_component parent);
6     super.new(name, parent);
7   endfunction : new
8   function void build_phase(uvm_phase phase);
9     item_collected_export = new("item_collected_export", this);
10  endfunction
11  ...

```

[Line 2](#) declares the `uvm_analysis_export`. The first parameter, `ubus_transfer`, defines the `uvm_object` communicated via this TLM interface. The second parameter defines the type of this implementation’s parent. This is required so that the parent’s `write()` method can be called by the export.

[Line 9](#) creates the implementation instance. The constructor arguments define the name of this implementation instance and its parent.

4.10.3 Requirements of the TLM Implementation

Since the scoreboard provides an `uvm_analysis_imp`, the scoreboard must implement all interfaces required by that export. This means you must define the implementation for the `write` virtual function. For the `ubus_example_scoreboard`, `write()` has been defined as:

```

virtual function void write(ubus_transfer trans);
    if (!disable_scoreboard)
        memory_verify(trans);
endfunction : write

```

The `write()` implementation defines what happens when data is provided on this interface. In this case, if `disable_scoreboard` is 0, the `memory_verify()` function is called with the transaction as the argument.

4.10.4 Defining the Action Taken

When the write port is called via `write()`, the implementation of `write()` in the parent of the implementation is called. For more information, see “TLM Interfaces” in the *UVM 1.1 Class Reference*. As

seen in [Section 4.10.3](#), the `write()` function is defined to call the `memory_verify()` function if `disable_scoreboard` is set to 0.

The `memory_verify()` function makes the appropriate calls and comparisons needed to verify a memory operation. This function is not crucial to the communication of the scoreboard with the rest of the environment and not discussed here. The `ubus_example_scoreboard.sv` file shows the implementation.

4.10.5 Adding the Scoreboard to the Environment

Once the scoreboard is defined, the scoreboard can be added to the UBus demo testbench. First, declare the `ubus_example_scoreboard` inside the `ubus_example_tb` class.

```
ubus_example_scoreboard scoreboard0;
```

After the scoreboard is declared, you can construct the scoreboard inside the `build()` phase:

```
function ubus_example_tb::build_phase(uvm_phase phase);
    ...
    scoreboard0 = ubus_example_scoreboard::type_id::create("scoreboard0",
this);
    ...
endfunction
```

Here, the `scoreboard0` of type `ubus_example_scoreboard` is created using the `create()` function and given the name `scoreboard0`. It is then assigned the `ubus_example_tb` as its parent.

After the scoreboard is created, the `ubus_example_tb` can connect the port on the UBus environment `slaves[0]` monitor to the export on the scoreboard.

```
function ubus_example_tb::connect_phase(uvm_phase phase);
    ...
    ubus0.slaves[0].monitor.item_collected_port.connect(
scoreboard0.item_collected_export);
    ...
endfunction
```

This `ubus_example_tb`'s `connect()` function code makes the connection, using the TLM ports `connect()` interface, between the port in the monitor of the `slaves[0]` agent inside the `ubus0` environment and the implementation in the `ubus_example_scoreboard` called `scoreboard0`. For more information on the use of binding of TLM ports, see "TLM Interfaces" in the *UVM 1.1 Class Reference*.

4.10.6 Summary

The process for adding a scoreboard in this section can be applied to other scoreboard applications in terms of environment communication. To summarize:

- a) Create the scoreboard component.
 - 1) Add the necessary exports.
 - 2) Implement the required functions and tasks.
 - 3) Create the functions necessary to perform the implementation-specific functionality.
- b) Add the scoreboard to the environment.

- 1) Declare and instantiate the scoreboard component.
- 2) Connect the scoreboard implementation(s) to the environment ports of interest.

The UBus demo has a complete scoreboard example. See [Chapter 7](#) for more information.

4.11 Implementing a Coverage Model

To ensure thorough verification, you need observers to represent your verification goals. SystemVerilog provides a rich set of functional-coverage features.

4.11.1 Selecting a Coverage Method

No single coverage metric ensures completeness. There are two coverage methods:

- a) Explicit coverage—is user-defined coverage. The user specifies the coverage goals, the needed values, and collection time. As such, analyzing these goals is straightforward. Completing all your coverage goals means you have achieved 100% of your verification goals and verification has been completed. An example of such a metric is SystemVerilog functional coverage. The disadvantage of such metrics is that missing goals are not taken into account.
- b) Implicit coverage—is done with automatic metrics that are driven from the RTL or other metrics already existing in the code. Typically, creating an implicit coverage report is straightforward and does not require a lot of effort. For example, code coverage, expression coverage, and FSM (finite-state machine) coverage are types of implicit coverage. The disadvantage of implicit coverage is it is difficult to map the coverage requirements to the verification goals. It also is difficult to map coverage holes into unexecuted high-level features. In addition, implicit coverage is not complete, since it does not take into account high-level abstract events and does not create associations between parallel threads (that is, two or more events occurring simultaneously).

Starting with explicit coverage is recommended. You should build a coverage model that represents your high-level verification goals. Later, you can use implicit coverage as a “safety net” to check and balance the explicit coverage.

NOTE—Reaching 100% functional coverage with very low code-coverage typically means the functional coverage needs to be refined and enhanced.

4.11.2 Implementing a Functional Coverage Model

A verification component should come with a protocol-specific functional-coverage model. You may want to disable some coverage aspects that are not important or do not need to be verified. For example, you might not need to test all types of bus transactions in your system or you might want to remove that goal from the coverage logic that specifies all types of transactions as goals. You might also want to extend the functional-coverage model and create associations between the verification component coverage and other attributes in the system or other interface verification components. For example, you might want to ensure proper behavior when all types of transactions are sent and the FIFO in the system is full. This would translate into crossing the transaction type with the FIFO-status variable. This section describes how to implement this type of functional coverage model.

4.11.3 Enabling and Disabling Coverage

The verification IP developer should provide configuration properties that allow you to control the interesting aspects of the coverage (see [Section 3.12.3](#)). The VIP documentation will tell you what

properties can be set to affect coverage. The most basic of controls would determine whether coverage is collected at all. The UBus monitors demonstrate this level of control. If the you want to disable coverage before the environment is created, use the `uvm_config_db()` interface.

```
uvm_config_db#(int)::(this, "ubus0.masters[0].monitor", "coverage_enable", 0);
```

Once the environment is created, you can set this property directly.

```
ubus0.masters[0].monitor.coverage_enable = 0;
```

This is a simple SystemVerilog assignment to a class property (or variable).

5. Using the Register Layer Classes

5.1 Overview

The UVM *register layer classes* are used to create a high-level, object-oriented model for memory-mapped registers and memories in a design under verification (DUV). The UVM *register layer* defines several base classes that, when properly extended, abstract the read/write operations to registers and memories in a DUV. This abstraction mechanism allows the migration of verification environments and tests from block to system levels without any modifications. It also can move uniquely named fields between physical registers without requiring modifications in the verification environment or tests. Finally, UVM provides a register test sequence library containing predefined testcases you can use to verify the correct operation of registers and memories in a DUV.

A *register model* is typically composed of a hierarchy of blocks that map to the design hierarchy. Blocks can contain registers, register files and memories, as well as other blocks. The register layer classes support front-door and back-door access to provide redundant paths to the register and memory implementation, and verify the correctness of the decoding and access paths, as well as increased performance after the physical access paths have been verified. Designs with multiple physical interfaces, as well as registers, register files, and memories shared across multiple interfaces, are also supported.

Most of the UVM register layer classes must be specialized via extensions to provide an abstract view that corresponds to the actual registers and memories in a design. Due to the large number of registers in a design and the numerous small details involved in properly configuring the UVM register layer classes, this specialization is normally done by a model generator. Model generators work from a specification of the registers and memories in a design and thus are able to provide an up-to-date, correct-by-construction register model. Model generators are outside the scope of the UVM library.

[Figure 22](#) shows how a register model is used in a verification environment.

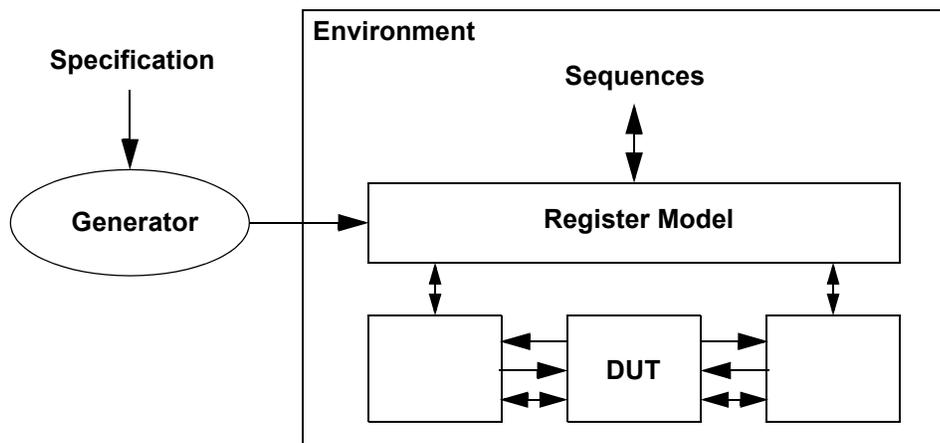


Figure 22—Register Model in an UVM Environment

5.2 Usage Model

A register model is an instance of a register block, which may contain any number of registers, register files, memories, and other blocks. Each register file contains any number of registers and other register files. Each register contains any number of fields, which mirror the values of the corresponding elements in hardware.

For each element in a register model—field, register, register file, memory or block—there is a class instance that abstracts the read and write operations on that element.

[Figure 23](#) shows the class collaboration diagram of the register model.

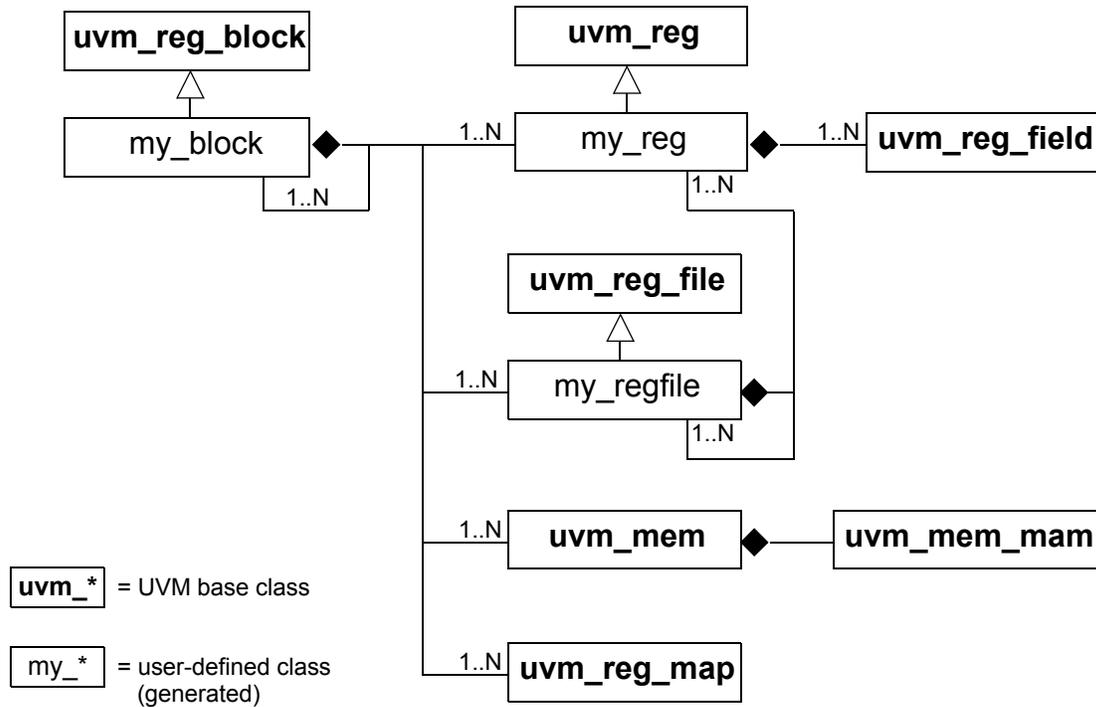


Figure 23—Register Model Class Collaboration

A *block* generally corresponds to a design component with its own host processor interface(s), address decoding, and memory-mapped registers and memories. If a memory is physically implemented externally to the block, but accessed through the block’s address space, then the memory is considered as part of the block register model.

All data values are modeled as fields. *Fields* represent a contiguous set of bits. Fields are wholly contained in a register. A register may span multiple addresses. The smallest register model that can be used is a block. A block may contain one register and no memories, or thousands of registers and gigabytes of memory. Repeated structures may be modelled as register arrays, register file arrays, or block arrays.

[Figure 24](#) shows the structure of a sample design block containing two registers, which have two and three fields respectively, an internal memory, and an external memory. [Figure 25](#) shows the structure of the corresponding register model.

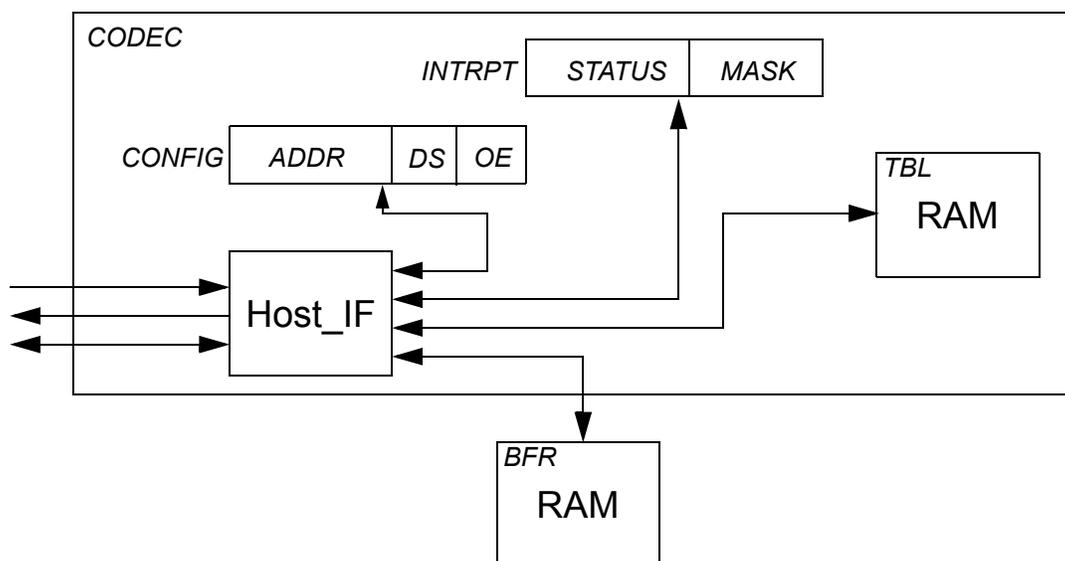


Figure 24—Design Structure of Registers, Fields, and Memories

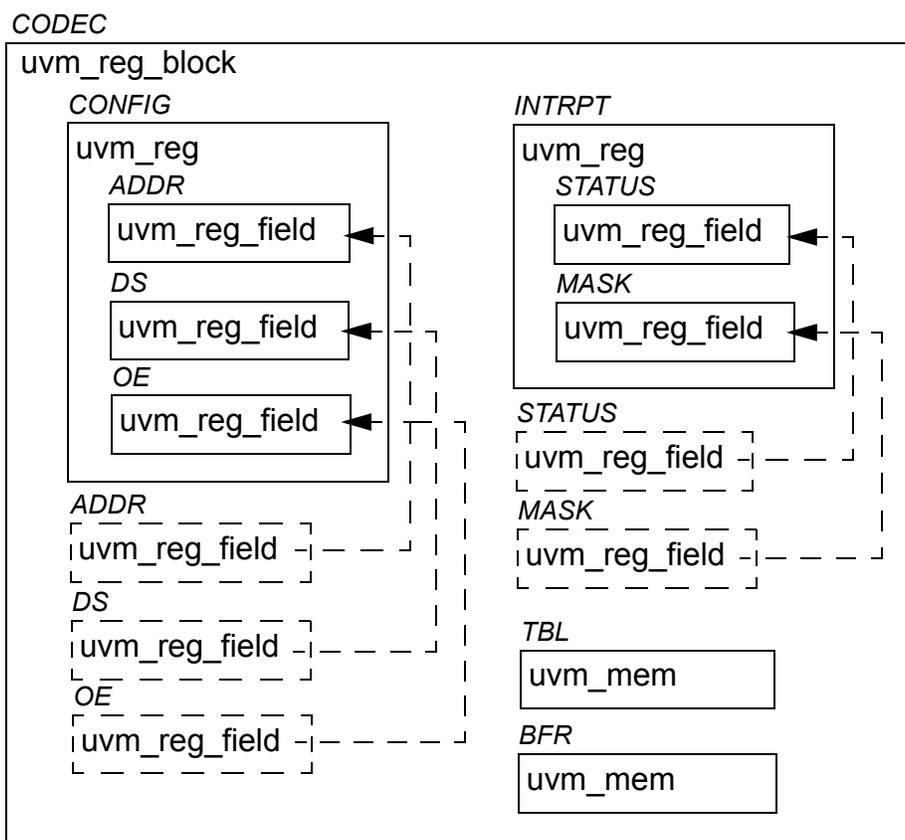


Figure 25—Register Model Structure

When using a register model, fields, registers, and memory locations are accessed through read and write methods in their corresponding abstraction class. It is the responsibility of the register model to turn these abstracted accesses into read and write cycles at the appropriate addresses via the appropriate bus driver. A register model user never needs to track the specific address or location of a field, register, or memory location, only its name.

For example, the field ADDR in the CONFIG register shown in [Figure 24](#) can be accessed through the register model shown in [Figure 25](#) using the CODEC.CONFIG.ADDR.read() method. Similarly, location 7 in the BFR memory can be accessed using the CODEC.BFR.write(7,value) method.

The location of fields within a physical register is somewhat arbitrary. If a field name is unique across all registers' fields within a block, it may also be accessed independently of their register location using an *alias handle* declared in the block. For example, the same ADDR field, being unique in name to all other fields in the CODEC block, may also be accessed using CODEC.ADDR.read(). Then, if ADDR is relocated from CONFIG to another register, any tests or environments that reference CODEC.ADDR will not be affected. Because a typical design has hundreds if not thousands of fields, the declaration and assignment of field aliases in a block are left as an optional feature in a register model generator.

5.2.1 Sub-register Access

When reading or writing a field using uvm_reg_field::read() or uvm_reg_field::write(), what actually happens depends on a lot of factors. If possible, only that field is read or written. Otherwise, the entire register containing that field is read or written, possibly causing unintended side effects to the other fields contained in that same register.

Consider the 128-bit register shown in [Figure 26](#). Assuming a 32-bit data bus with a little-endian layout, accessing this entire register requires four cycles at addresses 0x00, 0x04, 0x08, and 0x0C respectively. However, field D can be accessed using a single cycle at address 0x01. Since this field occupies an entire physical address, accessing it does not pose a challenge.

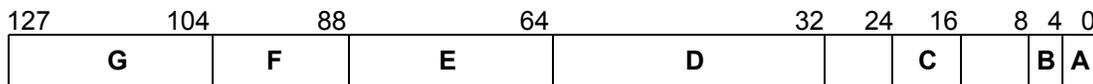


Figure 26—128-bit Register

Similarly, accessing field C can be done using a single access at address 0x00. However, this will also access fields B and A. Accessing field F requires two physical accesses, at addresses 0x02 and 0x03, but this would also access fields E and G at the same time. Accessing adjacent fields might not be an issue, but if the access has a side-effect on any of these fields, such as a clear-on-read field or writable field, this process will have unintended consequences.

When the underlying bus-protocol supports byte-enabling, field C (at address 0x00, lane #2) can be accessed without affecting the other fields at the same address. And since field F is byte-aligned, it can be accessed without side effects by accessing address 0x02, lane #3 and address 0x03, lane #0. However, fields B and A remain inaccessible without mutual side effects as they do not individually occupy an entire byte lane.

Thus, individual field access is supported for fields that are the sole occupant of one or more byte lane(s) if the containing register does not use a user-defined front-door and the underlying bus protocol supports byte enabling. A field may also be individually-accessible if the other fields in the same byte lanes are not

affected by read or write operations. Whether a field can be individually accessible (assuming the underlying protocol supports byte-enabling) is specified by the register model generator in the `uvm_reg_field::configure()` method.

For individual field access to actually occur, two conditions must be met: the field must be identified as being the sole occupant of its byte lane by the register model generator via the `uvm_reg_field::configure()` method and the bus protocol must report that it supports byte-enables via the `uvm_reg_adapter::supports_byte_enable` property.

Finally, individual field access is only supported for front-door accesses. When using back-door accesses, the entire register—and thus all the fields it contains—will always be accessed via a peek-modify-poke operation.

5.2.2 Mirroring

The register model maintains a mirror of what it thinks the current value of registers is inside the DUT. The mirrored value is not guaranteed to be correct because the only information the register model has is the read and write accesses to those registers. If the DUT internally modifies the content of any field or register through its normal operations (e.g., by setting a status bit or incrementing an accounting counter), the mirrored value becomes outdated.

The register model takes every opportunity to update its mirrored value. For every read operation, the mirror for the read register is updated. For every write operation, the new mirror value for the written register is predicted based on the access modes of the bits in the register (`read/write`, `read-only`, `write-1-to-clear`, etc.). Resetting a register model sets the mirror to the reset value specified in the model. A mirror is not a scoreboard, however; while a mirror can accurately predict the content of registers that are not updated by the design, it cannot determine if an updated value is correct or not.

You can update the mirror value of a register to the value stored in the DUT by using the `uvm_reg_field::mirror()`, `uvm_reg::mirror()`, or `uvm_reg_block::mirror()` methods. Updating the mirror for a field also updates the mirror for all the other fields in the same register. Updating the mirror for a block updates the mirror for all fields and registers it contains. Updating a mirror in a large block may take a lot of simulation time if physical read cycles are used; whereas, updating using back-door access usually takes zero-time.

You can write to mirrored values in the register model in zero-time by using the `uvm_reg_field::set()` or `uvm_reg::set()` methods. Once a mirror value has been overwritten, it no longer reflects the value in the corresponding field or register in the DUT. You can update the DUT to match the mirror values by using the `uvm_reg::update()` or `uvm_reg_block::update()` methods. If the new mirrored value matches the old mirrored value, the register is not updated, thus saving unnecessary bus cycles. Updating a block with its mirror updates all the fields and registers the block contains with their corresponding mirror values. Updating a large block may take a lot of simulation time if physical write cycles are used; whereas, updating using back-door access usually takes zero-time. It is recommended you use this update-from-mirror process when configuring the DUT to minimize the number of write operations performed.

To access a field or register's current mirror value in zero-time, use the `uvm_reg_field::get()` or `uvm_reg::get()` methods. However, if `uvm_reg_field::set()` or `uvm_reg::set()` is used to write a desired value to the DUT, `get()` only returns the desired value, modified according to the access mode for that field or register, until the actual write to the DUT has taken place via `update()`.

5.2.3 Memories are not Mirrored

Memories can be quite large, so they are usually modelled using a sparse-array approach. Only the locations that have been written to are stored and later read back. Any unused memory location is not modelled. Mirroring a memory would require that the same technique be used.

When verifying the correct operations of a memory, it is necessary to read and write all addresses. This negates the memory-saving characteristics of a sparse-array technique, as both the memory model of the DUT and the memory would mirror, become fully populated, and duplicate the same large amount of information.

Unlike bits in fields and registers, the behavior of bits in a memory is very simple: all bits of a memory can either be written to or not. A memory mirror would then be a ROM or RAM memory model—a model that is already being used in the DUT to model the memory being mirrored. The memory mirror can then be replaced by providing back-door access to the memory model.

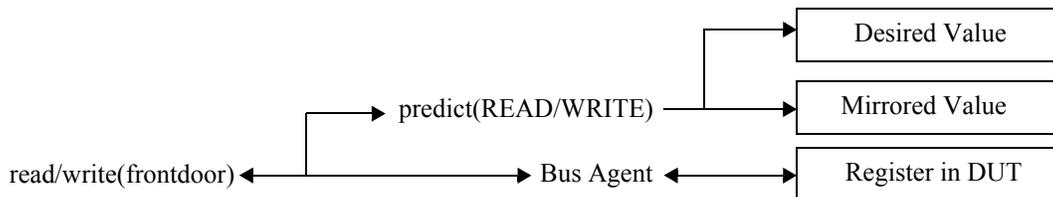
Therefore, using the `uvm_mem::peek()` or `uvm_mem::poke()` methods provide the exact same functionality as a memory mirror. Additionally, unlike a mirror based on observed read and write operations, using back-door accesses instead of a mirror always returns or sets the actual value of a memory location in the DUT.

5.3 Access API

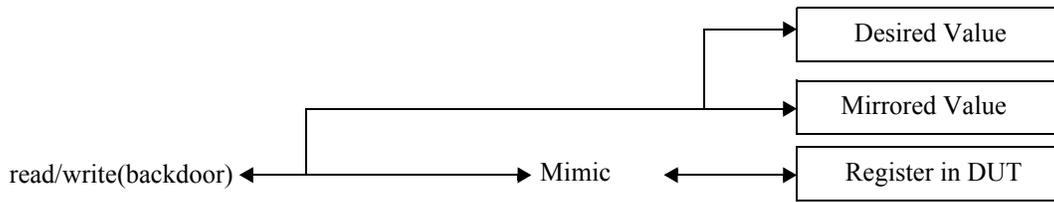
Register and fields have a variety of methods to get the current value of a register or field and modify it. It is important to use the correct API to obtain the desired result.

5.3.1 read / write

The normal access API are the `read()` and `write()` methods. When using the front-door (`path=BFM`), one or more physical transactions is executed on the DUT to read or write the register. The mirrored value is then updated to reflect the expected value in the DUT register after the observed transactions.

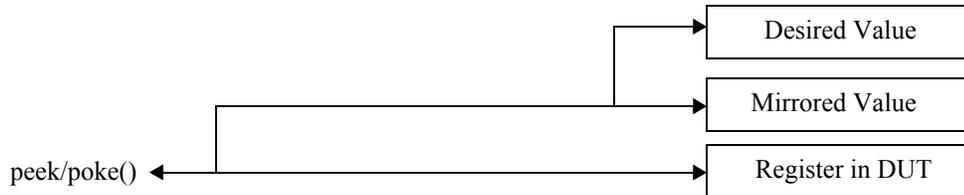


When using the back-door (`path=BACKDOOR`), peek or poke operations are executed on the DUT to read or write the register via the back-door mechanism, bypassing the physical interface. The behavior of the registers is mimicked as much as possible to duplicate the effect of reading or writing the same value via the front-door. For example, a read from a `clear-on-read` field causes 0's to be poked back into the field after the peek operation. The mirrored value is then updated to reflect the actual sampled or deposited value in the register after the observed transactions.



5.3.2 peek / poke

Using the `peek()` and `poke()` methods reads or writes directly to the register respectively, which bypasses the physical interface. The mirrored value is then updated to reflect the actual sampled or deposited value in the register after the observed transactions.



5.3.3 get / set

Using the `get()` and `set()` methods reads or writes directly to the desired mirrored value respectively, without accessing the DUT. The desired value can subsequently be uploaded into the DUT using the `update()` method.



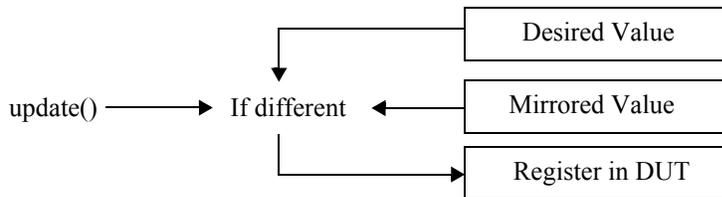
5.3.4 randomize

Using the `randomize()` method copies the randomized value in the `uvm_reg_field::value` property into the desired value of the mirror by the `post_randomize()` method. The desired value can subsequently be uploaded into the DUT using the `update()` method.



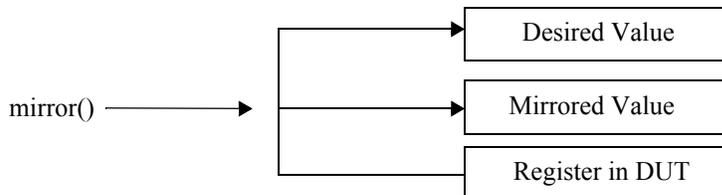
5.3.5 update

Using the `update()` method invokes the `write()` method if the desired value (previously modified using `set()` or `randomize()`) is different from the mirrored value. The mirrored value is then updated to reflect the expected value in the register after the executed transactions.



5.3.6 mirror

Using the `mirror()` method invokes the `read()` method to update the mirrored value based on the readback value. `mirror()` can also compare the readback value with the current mirrored value before updating it.



5.3.7 Concurrent Accesses

The register model can be accessed from multiple concurrent execution threads. However, it internally serializes the access to the same register to ensure predictability of the implicitly-updated mirrored value and of the other field values in the same register when a individual field is accessed.

A semaphore in each register ensures it can be read or written by only one process at a time. Any other process attempting access will block and not resume until after the current operation completes and after other processes that were blocked before it have completed their operations.

If a thread in the middle of executing a register operation is explicitly killed, it will be necessary to release the semaphore in the register it was accessing by calling the `uvm_reg::reset()` method.

5.4 Coverage Models

The UVM register library classes do not include any coverage models as a coverage model for a register will depend on the fields it contains and the layout of those fields, and a coverage model for a block will depend on the registers and memories it contains and the addresses where they are located. Since coverage model information is added to the UVM register library classes by the register model generator, that generator needs to include a suitable coverage model. Consequently, the UVM register library classes provide the necessary API for a coverage model to sample the relevant data into a coverage model.

Due to the significant memory and performance impact of including a coverage model in a large register model, the coverage model needs to handle the possibility that specific cover groups will not be instantiated or to turn off coverage measurement even if the cover groups are instantiated. Therefore, the UVM register library classes provide the necessary API to control the instantiation and sampling of various coverage models.

5.4.1 Predefined Coverage Identifiers

The UVM library has several predefined functional coverage model identifiers, as shown in [Table 6](#). Each symbolic value specifies a different type of coverage model. The symbolic values use a one-hot encoding. Therefore, multiple coverage models may be specified by OR'ing them. Additional symbolic values may be provided for vendor-specific and user-specific coverage models that fall outside of the pre-defined coverage model types. To avoid collisions with pre-defined UVM, vendor-defined, and user-defined coverage model identifiers, bits 0 through 7 are reserved for UVM, bits 8 through 15 are reserved for vendors, and bits 16 through 23 are reserved for users. Finally, bits 24 and above are reserved for future assignment.

Table 6—Pre-defined Functional Coverage Type Identifiers

Identifier	Description
<code>UVM_NO_COVERAGE</code>	No coverage models.
<code>UVM_CVR_REG_BITS</code>	Coverage models for the bits read or written in registers.
<code>UVM_CVR_ADDR_MAP</code>	Coverage models for the addresses read or written in an address map.
<code>UVM_CVR_FIELD_VALS</code>	Coverage models for the values of fields.
<code>UVM_CVR_ALL</code>	All coverage models.

5.4.2 Controlling Coverage Model Construction and Sampling

By default, coverage models are not included in a register model when it is instantiated. To be included, they must be enabled via the `uvm_reg::include_coverage()` method. It is recommended register-level coverage models are only included in unit-level environments; block-level coverage models may be included in block and system-level environments.

```
uvm_reg::include_coverage("", UVM_CVR_REG_BITS + UVM_CVR_FIELD_VALS);
```

Furthermore, the sampling for a coverage model is implicitly disabled by default. To turn the sampling for specific coverage models on or off, use the `uvm_reg_block::set_coverage()`, `uvm_reg::set_coverage()`, and `uvm_mem::set_coverage()` methods.

5.5 Constructing a Register Model

This section describes how to construct a UVM register model to represent different register and memory access and composition structures. The target audience for this section is generator writers. End users of the register model need not be familiar with the model construction process, only the final structure of the model.

5.5.1 Field Types

There is usually no need to construct field types. Fields are simple instantiations of the `uvm_reg_field` class. A field type may only be needed to specify field-level constraints, which could also be specified in the containing register.

A field type is constructed using a class extended from the `uvm_reg_field` class. There must be one class per unique field type. The name of the field type is created by the register model generator. The name of the field type class must be unique within the scope of its declaration. The field type class must include an appropriate invocation of the ``uvm_object_utils()` macro.

```
class my_fld_type extends uvm_reg_field;
  `uvm_object_utils(my_fld_type)
endclass
```

Field types are instantiated in the `build()` method of the containing register types.

5.5.1.1 Class Properties and Constraints

A separate constraint block should be defined for each aspect being constrained—e.g., one to keep it valid, one to keep it reasonable—so they can be turned off individually. The name of a constraint block shall be indicative of its purpose. Constraints shall constrain the `value` class property. Additional state variables may be added to the field class if they facilitate the constraints.

```
class my_fld_type extends uvm_reg_field;
  constraint valid {
    value inside {0, 1, 2, 4, 8, 16, 32};
  };
endclass
```

To ensure state variable and constraint block names do not collide with other symbols in `uvm_reg_field` base class, it is recommended their names be in all UPPERCASE.

If the `post_randomize()` method is overridden, it must call `super.post_randomize()`.

5.5.1.2 Constructor

The constructor must be a valid `uvm_object` constructor. The constructor shall call the `uvm_reg_field::new()` method with appropriate argument values for the field type.

```
class my_fld_type extends uvm_reg_field;

  function new(name = "my_fld_type");
    super.new(name);
  endfunction

endclass
```

5.5.1.3 Predefined Field Access Policies

The access policy of a field is specified using the `uvm_reg_field::configure()` method, called from the `build()` method of the register that instantiates it.

[Table 7](#) shows the pre-defined access policies for `uvm_reg_field`. Unless otherwise stated, the effect of a read cycle on the current value is performed after the current value has been sampled for read-back. Additional field access policies may be defined using the `uvm_reg_field::define_access()` method and by modeling their behavior by extending the `uvm_reg_field` or `uvm_reg_cbs` classes.

Table 7—Pre-defined Field Access Policies

Access Policy	Description	Effect of a Write on Current Field Value	Effect of a Read on Current Field Value	Read-back Value
RO	Read Only	No effect.	No effect.	Current value
RW	Read, Write	Changed to written value.	No effect.	Current value
RC	Read Clears All	No effect.	Sets all bits to 0's.	Current value
RS	Read Sets All	No effect.	Sets all bits to 1's.	Current value
WRC	Write, Read Clears All	Changed to written value.	Sets all bits to 0's.	Current value
WRS	Write, Read Sets All	Changed to written value.	Sets all bits to 1's.	Current value
WC	Write Clears All	Sets all bits to 0's.	No effect.	Current value
WS	Write Sets All	Sets all bits to 1's.	No effect.	Current value
WSRC	Write Sets All, Read Clears All	Sets all bits to 1's.	Sets all bits to 0's.	Current value
WCRS	Write Clears All, Read Sets All	Sets all bits to 0's.	Sets all bits to 1's.	Current value
W1C	Write 1 to Clear	If the bit in the written value is a 1, the corresponding bit in the field is set to 0. Otherwise, the field bit is not affected.	No effect.	Current value
W1S	Write 1 to Set	If the bit in the written value is a 1, the corresponding bit in the field is set to 1. Otherwise, the field bit is not affected.	No effect.	Current value
W1T	Write 1 to Toggle	If the bit in the written value is a 1, the corresponding bit in the field is inverted. Otherwise, the field bit is not affected.	No effect.	Current value
W0C	Write 0 to Clear	If the bit in the written value is a 0, the corresponding bit in the field is set to 0. Otherwise, the field bit is not affected.	No effect.	Current value

Table 7—Pre-defined Field Access Policies (Continued)

Access Policy	Description	Effect of a Write on Current Field Value	Effect of a Read on Current Field Value	Read-back Value
W0S	Write 0 to Set	If the bit in the written value is a 0, the corresponding bit in the field is set to 1. Otherwise, the field bit is not affected.	No effect.	Current value
W0T	Write 0 to Toggle	If the bit in the written value is a 0, the corresponding bit in the field is inverted. Otherwise, the field bit is not affected.	No effect.	Current value
W1SRC	Write 1 to Set, Read Clears All	If the bit in the written value is a 1, the corresponding bit in the field is set to 1. Otherwise, the field bit is not affected.	Sets all bits to 0's.	Current value
W1CRS	Write 1 to Clear, Read Sets All	If the bit in the written value is a 1, the corresponding bit in the field is set to 0. Otherwise, the field bit is not affected.	Sets all bits to 1's.	Current value
W0SRC	Write 0 to Set, Read Clears All	If the bit in the written value is a 0, the corresponding bit in the field is set to 1. Otherwise, the field bit is not affected.	Sets all bits to 0's.	Current value
W0CRS	Write 0 to Clear, Read Sets All	If the bit in the written value is a 0, the corresponding bit in the field is set to 0. Otherwise, the field bit is not affected.	Sets all bits to 1's.	Current value
WO	Write Only	Changed to written value.	No effect.	Undefined
WOC	Write Only Clears All	Sets all bits to 0's.	No effect.	Undefined
WOS	Write Only Sets All	Sets all bits to 1's.	No effect.	Undefined
W1	Write Once	Changed to written value if this is the first write operation after a hard reset. Otherwise, has no effect.	No effect.	Current value
W01	Write Only, Once	Changed to written value if this is the first write operation after a hard reset. Otherwise, has no effect.	No effect.	Undefined

5.5.1.4 IP-XACT Field Access Mapping

[Table 8](#) — [Table 12](#) show the mapping between the IEEE 1685-2009 field access policies (as specified by the `fieldData` group, see section 6.10.9.2 of the IEEE 1685-2009 Standard) and the pre-defined access policies for `uvm_reg_field`. Several combinations of `access`, `modifiedWriteValue`, and `readAction` are specified as n/a because they do not make practical sense. However, they can always be modeled as user-defined fields if they are used in a design.

Table 8—IP-XACT Mapping for access==read-write

access == read-write				
modifiedWriteValue	readAction			
	Unspecified	clear	set	modify
Unspecified	RW	WRC	WRS	User-defined
oneToClear	W1C	n/a	W1CRS	User-defined
oneToSet	W1S	W1SRC	n/a	User-defined
oneToToggle	W1T	n/a	n/a	User-defined
zeroToClear	W0C	n/a	W0CRS	User-defined
zeroToSet	W0S	W0SRC	n/a	User-defined
zeroToToggle	W0T	n/a	n/a	User-defined
clear	WC	n/a	WCRS	User-defined
set	WS	WSRC	n/a	User-defined
modify	User-defined	User-defined	User-defined	User-defined

Table 9—IP-XACT Mapping for access==read-only

access == read-only				
modifiedWriteValue	readAction			
	Unspecified	clear	set	modify
Unspecified	RO	RC	RS	User-defined
All others	n/a	n/a	n/a	n/a

Table 10—IP-XACT Mapping for access==write-only

access == write-only				
modifiedWriteValue	readAction			
	Unspecified	clear	set	modify
Unspecified	WO	n/a	n/a	n/a
clear	W0C	n/a	n/a	n/a
set	W0S	n/a	n/a	n/a
All others	n/a	n/a	n/a	n/a

Table 11—IP-XACT Mapping for access==read-writeOnce

access == read-writeOnce				
modifiedWriteValue	readAction			
	Unspecified	clear	set	modify
Unspecified	W1	n/a	n/a	n/a
All others	n/a	n/a	n/a	n/a

Table 12—IP-XACT Mapping for access==writeOnce

access == writeOnce				
modifiedWriteValue	readAction			
	Unspecified	clear	set	modify
Unspecified	W01	n/a	n/a	n/a
All others	n/a	n/a	n/a	n/a

5.5.1.5 Reserved Fields

There is no pre-defined field access policy for reserved fields. That is because “reserved” is a documentation concept, not a behavioral specification. Reserved fields should be left unmodelled (where they will be assumed to be RO fields filled with 0’s), modelled using an access policy that corresponds to their actual hardware behavior or not be compared using `uvm_reg_field::set_compare(0)`.

If reserved fields are not to be used, they should be identified with the `NO_REG_TESTS` attribute and have a user-defined behavior extension that will issue an error message if they are used.

5.5.1.6 User-defined Field Access Policy

The UVM field abstraction class contains several predefined field access modes. The access modes are used, in combination with observed read and write operations, to determine the expected value of a field. Although most fields fall within one of the predefined access policies, it is possible to design a field that behaves predictably but differently from the predefined ones.

New access policy identifiers can similarly be defined to document the user-defined behavior of the field.

```
class protected_field extends uvm_reg_field;
    local static bit m_protected = define_access("Protected");
    ...
endclass
```

The behavior of the user-defined field access policy is implemented by extending the pre/post read/write virtual methods in the field abstraction class or in the field callback methods. For example, a protected field that can only be written if another field is set to a specific value can be modelled as shown below:

```
class protected_field extends uvm_reg_field;
    local uvm_reg_field protect_mode;
```

```

    virtual task pre_write(uvm_reg_item rw);
        // Prevent the write if protect mode is ON
        if (protect_mode.get()) begin
            rw.value = value;
        endtask
    endclass

```

You can modify the behavior of any field to the user-specified behavior by registering a callback extension with that field. First, define the callback class; then, register an instance of it with an instance of the field whose behavior you want to modify:

```

class protected_field_cb extends uvm_reg_cbs;
    local uvm_reg_field protect_mode;
    virtual task pre_write(uvm_reg_item rw);
        // Prevent the write if protect mode is ON
        if (protect_mode.get()) begin
            uvm_reg_field field;
            if ($cast(field,rw.element))
                rw.value = field.get();
        end
    endtask
endclass

protected_field_cb protect_cb = new("protect_cb",protect_mode)
uvm_callbacks#(my_field_t, uvm_reg_cbs)::add(my_field, protect_cb);

```

5.5.1.7 Field Usage vs. Field Behavior

The access mode of a field is used to specify the physical behavior of the field so the mirror can track, as best as it can, the value of the field. It is not designed to specify whether or not it is suitable or functionally correct to use the field in a particular fashion from the application's perspective.

For example, a configuration field could be designed to be written only once by the software after the design comes out of reset. If the design does not support dynamic reprovisioning, it may not be proper to subsequently modify the value of that configuration field. Whether the field should be specified as write-once (W1) depends on the hardware functionality. If the hardware does not prevent the subsequent write operation, the field should be specified as read-write as that would accurately reflect the actual behavior of the field.

To include usage assertions to specific fields (e.g., specifying a configuration field is never written to more than once despite the fact that doing so is physically possible), implement that check in an extension of the field abstraction class, but do not prevent the mirror from reflecting that value in the hardware.

```

class config_once_field extends uvm_reg_field;
    local bit m_written = 0;
    virtual task pre_write(uvm_reg_item rw);
        if (m_written)
            `uvm_error(field.get_full_name(), "...");
        m_written = 1;
    endtask: pre_write

    virtual function reset(string kind = "HARD");
        if (has_reset(kind))
            m_written = 0;
            super.reset(kind);
    endfunction
endclass

```

5.5.2 Register Types

A register type is constructed using a class extended from the `uvm_reg` class. There must be one class per unique register type. The name of the register type is created by the register model generator. The name of the register type class must be unique within the scope of its declaration. The register type class must include an appropriate invocation of the ``uvm_object_utils()` macro.

```
class my_reg_type extends uvm_reg;
  `uvm_object_utils(my_reg_type)
endclass
```

Register types are instantiated in the `build()` method of the block and register file types.

5.5.2.1 Class Properties and Constraints

The register type must contain a public class property for each field it contains. The name of the field class property shall be the name of the field. The field class property shall have the `rand` attribute. Field class properties may be arrays.

```
class my_reg_type extends uvm_reg;
  rand uvm_reg_field F1;
  rand uvm_reg_field F2[3];
endclass
```

To ensure field names do not collide with other symbols in the `uvm_reg` base class, it is recommended their names be in all UPPERCASE.

Constraints, if any, should be defined in separate blocks for each aspect being constrained. This allows them to be turned off individually. The name of a constraint block shall be indicative of its purpose. Constraints shall constrain the `value` class property of each field in the register. Additional state variables may be added to the register type class if they facilitate the constraints. If the `post_randomize()` method is overridden, it must call the `super.post_randomize()` method.

If a register has only one field, then you would not want to have to write:

```
R.randomize() with (value.value == 5);
```

Instead, instantiate a private dummy field and include a `rand` class property named `value` in the register class. A constraint shall keep the `value` class property equal to the field's `value` class property.

```
class my_reg_type extends uvm_reg;
  rand uvm_reg_data_t value;
  local rand uvm_reg_field _dummy;

  constraint _dummy_is_reg {
    _dummy.value == value;
  }
endclass
```

Then, randomizing an instance of the register looks like the more natural:

```
R.randomize() with (value == 5);
```

5.5.2.2 Constructor

The constructor must be a valid `uvm_object` constructor. The constructor shall call the `uvm_reg::new()` method with appropriate argument values for the register type.

```
class my_reg_type extends uvm_reg;
  function new(name = "my_reg_type");
    super.new(.name(name),
              .n_bits(32),
              .has_coverage(UVM_NO_COVERAGE));
  endfunction
endclass
```

5.5.2.3 Build() Method

A virtual `build()` function, with no arguments, shall be implemented.

The `build()` method shall instantiate all field class properties using the class factory. Because the register model is a `uvm_object` hierarchy, not a `uvm_component` hierarchy, no parent reference is specified and the full hierarchical name of the register type instance is specified as the context. The `build()` method shall call the `uvm_reg_field::configure()` method for all field class properties with the appropriate argument values for the field instance and specifying `this` as the field parent.

```
class my_reg_type extends uvm_reg;
  virtual function build();
    this.F1 = uvm_reg_field::type_id::create(.name("F1"),
                                              .parent(null),
                                              .contxt(get_full_name()));

    this.F1.configure(this, ...);

  endfunction
endclass
```

5.5.2.4 Additional Methods

Register model generators are free to add access methods to abstract common operations. For example, a read-modify-write method could be added to a register model:

```
class my_reg extends uvm_reg;
  ...
  task RMW(output uvm_status_e  status;
           input uvm_reg_data_t data;
           input uvm_reg_data_t mask; ...);
    uvm_reg_data_t tmp;
    read(status, tmp, ...);
    tmp &= ~mask;
    tmp |= data & mask;
    write(status, tmp, ...);
  endtask
endclass
```

Although allowed by UVM, such additional methods are not part of the standard. To avoid collisions with class members that may be added in the future, the name of these methods should be in UPPERCASE or be given a generator-specific prefix.

5.5.2.5 Coverage Model

A register-level coverage model is defined and instantiated in the register type class. It measures the coverage of read and write operations and field values on each instance of that register type. The `uvm_reg::sample()` or `uvm_reg::sample_values()` methods shall be used to trigger the sampling of a coverage point based on the data provided as argument or data gathered from the current state of the register type instance. The sampling of the coverage model shall only occur if sampling for the corresponding coverage model has been turned on, as reported by the `uvm_reg::get_coverage()` method.

```
class my_reg extends uvm_reg;
  protected uvm_reg_data_t m_current;
  protected uvm_reg_data_t m_data;
  protected bit            m_is_read;

  covergroup cg1;
    ...
  endgroup
  ...
  virtual function void sample(uvm_reg_data_t data,
                              uvm_reg_data_r byte_en,
                              bit            is_read,
                              uvm_reg_map    map);
    if (get_coverage(UVM_CVR_REG_BITS)) begin
      m_current = get();
      m_data    = data;
      m_is_read = is_read;
      cg1.sample();
    endif
  endfunction
endclass
```

All the coverage models that may be included in the register type shall be reported to the `uvm_reg` base class using the `uvm_reg::build_coverage()` method when `super.new()` is called or the `uvm_reg::add_coverage()` method. If no functional coverage models are included in the generated register type, `UVM_NO_COVERAGE` shall be specified. Register-level coverage groups shall only be instantiated in the constructor if the construction of the corresponding coverage model is enabled, as reported by the `uvm_reg::has_coverage()` method.

```
class my_reg_typ extends uvm_reg;
  ...
  covergroup cg1;
    ...
  endgroup

  covergroup cg_vendor;
    ...
  endgroup

  function new(string name = "my_reg_typ");
    super.new(name, 32, build_coverage(UVM_CVR_REG_BITS + VENDOR_CVR_REG));
    if (has_coverage(UVM_CVR_REG_BITS))
      cg1 = new();
    if (has_coverage(VENDOR_CVR_REG))
      cg_vendor = new();
  endfunction
endclass
```

```
...
endclass
```

The content, structure, and options of the coverage group is defined by the register model generator and is outside the scope of UVM.

5.5.3 Register File Types

A register file type is constructed using a class extended from the `uvm_reg_file` class. There must be one class per unique register file type. The name of the register file type is created by the register model generator. The name of the register file type class must be unique within the scope of its declaration. The register file type class must include an appropriate invocation of the ``uvm_object_utils()` macro.

```
class my_rf_type extends uvm_reg_file;
  `uvm_object_utils(my_rf_type)
endclass
```

Register file types are instantiated in the `build()` method of the block and register file types.

5.5.3.1 Class Properties

A register file type must contain a public class property for each register it contains. The name of the register class property shall be the name of the register. The type of the register class property shall be the name of the register type. Each register class property shall have the `rand` attribute. Register class properties may be arrays.

```
class my_rf_type extends uvm_reg_file;
  rand my_reg1_type R1;
  rand my_reg2_type R2[3];
endclass
```

Register files can contain other register files. A register file type must contain a public class property for each register file it contains. The name of the register file class property shall be the name of the register file. The type of the register file class property shall be the name of the register file type. The register file class property shall have the `rand` attribute. Register file class properties may be arrays.

```
class my_rf_type extends uvm_reg_file;
  rand my_regfile1_type RF1;
  rand my_regfile2_type RF2[3];
endclass
```

To ensure register and register file names do not collide with other symbols in the register file abstraction base class, it is recommended their name be in all UPPERCASE or prefixed with an underscore (`_`).

The register file type may contain a constraint block for each cross-register constraint group it contains. The name of the constraint block shall be indicative of its purpose. Constraints shall constraint the `uvm_reg_field::value` class property of the fields in the registers contained in the register file. Additional state variables may be added to the register field type if they facilitate the constraints.

5.5.3.2 Constructor

The constructor must be a valid `uvm_object` constructor. The constructor shall call the `uvm_reg::configure()` method with appropriate argument values for the register type.

```

class my_rf_type extends uvm_reg_file;
  function new(name = "my_rf_type");
    super.(name);
  endfunction
endclass

```

5.5.3.3 build() Method

A virtual `build()` function, with no arguments, shall be implemented.

The `build()` method shall instantiate all register and register file class properties using the class factory. The name of the register or register file instance shall be prefixed with the name of the enclosing register file instance. Because the register model is a `uvm_object` hierarchy, not a `uvm_component` hierarchy, no parent reference is specified and the full hierarchical name of the block parent of the register file type instance is specified as the context. The `build()` method shall call the `configure()` method for all register and register file class properties, specifying `get_block()` for the parent block and `this` for the parent register file. The `build()` method shall call the `build()` method for all register and register file class properties.

```

class my_rf_type extends uvm_reg_file;
  virtual function build();
    uvm_reg_block blk = get_block();

    this.RF1 = my_rf1_type::type_id::create(
      .name($sprintf("%s.rf1", get_name())),
      .parent(null),
      .contxt(blk.get_full_name()));
    this.RF1.configure(get_block(), this, ...);
    this.RF1.build();
    this.RF1.add_hdl_path();
  endfunction
endclass

```

5.5.3.4 map() Method

A virtual `map()` function, with `uvm_reg_map` and address offset arguments, shall be implemented. The `map()` method shall call `uvm_reg_map::add_reg()` for all register class properties, adding the value of the address offset argument to the offset of the register in the register file. The `map()` method shall call the `map()` method of all register file class properties, adding the value of the address offset argument to the offset of the register file base offset. The `map()` method may call the `add_hdl_path()` method for all register or register file class properties with appropriate argument values for the register or register file instance.

```

class my_rf_type extends uvm_reg_file;
  virtual function map(uvm_reg_map mp, uvm_reg_addr_t offset);
    mp.add_reg(this.R1, offset + 'h04, ...);
    mp.add_reg(this.R2, offset + 'h08, ...);
    this.RF1.map(mp, offset + 'h200);
  endfunction
endclass

```

5.5.3.5 set_offset() Method

A virtual `set_offset()` function, with a `uvm_reg_map` and address offset arguments, may also be implemented. The `set_offset()` method shall call the `set_offset()` method for all register and

register file class properties with appropriate argument values for the each instance, adding the value of the address offset argument to the offset of the register and register file base offset.

```
class my_rf_type extends uvm_reg_file;
  virtual function set_offset(uvm_reg_map mp, uvm_reg_addr_t offset);
    this.R1.set_offset(mp, offset + 'h04, ...);
    this.R2.set_offset(mp, offset + 'h08, ...);
    this.RF1.set_offset(mp, offset + 'h200);
  endfunction
endclass
```

5.5.4 Memory Types

A memory type is constructed using a class extended from the `uvm_mem` class. There must be one class per unique memory type. The name of the memory type is created by the register model generator. The name of the memory type class must be unique within the scope of its declaration. The memory type class must include an appropriate invocation of the ``uvm_object_utils()` macro.

```
class my_mem_type extends uvm_mem;
  `uvm_object_utils(my_mem_type)
endclass
```

Memory types are instantiated in the `build()` method of the block and register file types.

5.5.4.1 Class Properties

The memory type need not contain any class property.

5.5.4.2 Constructor

The constructor must be a valid `uvm_object` constructor. The constructor shall call the `uvm_mem::new()` method with appropriate argument values for the memory type.

```
class my_mem_type extends uvm_mem;
  function new(name = "my_mem_type");
    super.new(name, ...);
  endfunction
endclass
```

5.5.4.3 Coverage Model

A memory-level coverage model is defined and instantiated in the memory type class. It measures the coverage of the accessed offsets on each instance of that memory type. The `uvm_mem::sample()` method shall be used to trigger the sampling of a coverage point, based on the data provided as an argument or gathered from the current state of the memory type instance. The sampling of the coverage model shall only occur if sampling for the corresponding coverage model has been turned on, as reported by the `uvm_mem::get_coverage()` method.

```
class my_mem extends uvm_mem;
  local uvm_reg_addr_t m_offset;

  covergroup cg_addr;
    ...
  endgroup
  ...
endclass
```

```

    virtual function void sample(uvm_reg_addr_t offset,
                                bit is_read,
                                uvm_reg_map map);
    if (get_coveragen(UVM_CVR_ADDR_MAP)) begin
        m_offset = offset;
        cg_addr.sample();
    end
endfunction
endclass

```

All the coverage models that may be included in the memory type shall be reported to the `uvm_mem` base class using `uvm_mem::build_coverage()` when `super.new()` is called or using the `uvm_mem::add_coverage()` method. If no functional coverage models are included in the generated memory type, `UVM_NO_COVERAGE` shall be specified. Memory-level coverage groups shall only be instantiated in the constructor if the construction of the corresponding coverage model is enabled, as reported by the `uvm_mem::has_coverage()` method.

```

class my_mem extends uvm_mem;
    ...
    covergroup cg_addr;
        ...
    endgroup

    function new(string name = "my_mem");
        super.new(name, ..., build_coverage(UVM_CVR_ADDR_MAP));
        if (has_coverage(UVM_CVR_ADDR_MAP))
            cg_addr = new();
    endfunction: new
    ...
endclass : my_mem

```

The content, structure, and options of the coverage group is defined by the register model generator and is outside the scope of UVM.

5.5.5 Block Types

A block type is constructed using a class extended from the `uvm_reg_block` class. There must be one class per unique block type. The name of the block type is created by the register model generator. The name of the block type class must be unique within the scope of its declaration. The block type class must include an appropriate invocation of the ``uvm_object_utils()` macro.

```

class my_blk_type extends uvm_reg_block;
    `uvm_object_utils(my_blk_type)
endclass

```

Block types are instantiated in the `build()` method of other block types and in verification environments.

5.5.5.1 Class Properties

The block type must contain a class property for each named address map it contains. The name of the address map class property shall be the name of the address map. The type of the address map class property shall be `uvm_reg_map`. The address map class property shall not have the `rand` attribute. Address map class properties shall not be arrays.

```

class my_blk_type extends uvm_reg_block;

```

```

    uvm_reg_map AHB;
    uvm_reg_map WSH;
endclass

```

The block type must contain a class property for each register it contains. The name of the register class property shall be the name of the register. The type of the register class property shall be the name of the register type. The register class property shall have the `rand` attribute. Register class properties may be arrays.

```

class my_blk_type extends uvm_reg_block;
    rand my_r1_type R1;
    rand my_r2_type R2[3];
endclass

```

The block type must contain a class property for each register file it contains. The name of the register file class property shall be the name of the register file. The type of the register file class property shall be the name of the register file type. The register file class property shall have the `rand` attribute. Register file class properties may be arrays.

```

class my_blk_type extends uvm_reg_block;
    rand my_rf1_type RF1;
    rand my_rf2_type RF2[3];
endclass

```

The block type must contain a class property for each memory it contains. The name of the memory class property shall be the name of the memory. The type of the memory class property shall be the name of the memory type. The memory class property should not have the `rand` attribute. Memory class properties may be arrays.

```

class my_blk_type extends uvm_reg_block;
    my_mem1_type RAM1;
    my_mem2_type RAM2[3];
endclass

```

The block type must contain a class property for each sub-block it contains. The name of the sub-block class property shall be the name of the sub-block. The type of the sub-block class property shall be the name of the sub-block type. The sub-block class property shall have the `rand` attribute. Sub-block class properties may be arrays.

```

class my_blk_type extends uvm_reg_block;
    rand my_blk1_type BLK1;
    rand my_blk2_type BLK2[3];
endclass

```

To ensure register, register file, memory and block names do not collide with other symbols in `uvm_reg_block` base class, it is recommended their name be in all UPPERCASE or prefixed with an underscore (`_`).

Constraints, if any, should be defined in separate blocks for each aspect being constrained. This allows them to be turned off individually. The name of a constraint block shall be indicative of its purpose. Constraints shall constraint the `uvm_reg_field::value` class property of the fields in lower-level registers. Additional state variables may be added to the block type class if they facilitate the constraints. If the `post_randomize()` method is overridden, it must call the `super.post_randomize()` method.

5.5.5.2 Constructor

The constructor must be a valid `uvm_object` constructor. The constructor shall call the `uvm_reg_block::new()` method with appropriate argument values for the block type.

```
class my_blk_type extends uvm_reg_block;
    function new(name = "my_blk_type");
        super.new(.name(name), .has_coverage(UVM_NO_COVERAGE));
    endfunction
endclass
```

5.5.5.3 build() Method

A virtual `build()` function, with no arguments, shall be implemented.

The `build()` method shall instantiate all named address maps by calling the `uvm_reg_block::create_map()` method, specifying appropriate argument values for the address map in the block type. One of the named address maps shall be assigned to the `uvm_reg_block::default_map` class property.

```
class my_blk_type extends uvm_reg_block;
    virtual function build();
        this.AHB = create_map();
        this.WSH = create_map();
        this.default_map = this.AHB;
    endfunction
endclass
```

If the block does not contain any named address maps, the `build()` method shall instantiate an anonymous address map by calling the `uvm_reg_block::create_map()` method, specifying the name of the address map and other appropriate argument values for the block type, and assign those to the `uvm_reg_block::default_map` class property.

```
class my_blk_type extends uvm_reg_block;
    virtual function build();
        this.default_map = create_map(.name("default_map",
            .base_addr('h1000),
            .n_bytes(4),
            .endian(UVM_LITTLE_ENDIAN));
    endfunction
endclass
```

The `build()` method shall instantiate all register, register file, memory, and sub-block class properties using the class factory. Because the register model is a `uvm_object` hierarchy, not a `uvm_component` hierarchy, no parent reference is specified and the full hierarchical name of the block type instance is specified as the context. The `build()` method shall call the `configure()` method for all register, register file, memory, and sub-block class properties, specifying `this` as the block parent and `null` as the register file parent. The `build()` method shall call the `build()` method for all register, register file, and sub-block class properties. The `build()` method may call the `add_hdl_path()` method for any register, register file, memory, or sub-block class properties with the appropriate argument values for the register, register file, memory, or sub-block instance.

```
class my_blk_type extends uvm_reg_block;
```

```

    virtual function build();
        this.BLK1 = my_blk1_type::type_id::create("BLK1", null,
                                                get_full_name());
        this.BLK1.configure(this, ...);
        this.BLK1.build();
    endfunction
endclass

```

After a register or memory has been created, the `build()` method shall call the appropriate `uvm_reg_map::add_*()` method for all address maps where the register, register file, or memory is accessible, specifying its offset in that address map.

```

class my_blk_type extends uvm_reg_block;
    virtual function build();
        this.R1 = my_reg1_type::type_id::create("R1", null, get_full_name());
        this.R1.configure(this, ...);
        this.R1.build();
        this.default_map.add_reg(this.R1, `h04, ...);
    endfunction
endclass

```

After a register file has been built, the `build()` method shall call its `map()` method for all address maps where the register file is accessible, specifying its offset in that address map.

```

class my_rf_type extends uvm_reg_regfile;
    virtual function build();
        this.RF1 = my_rf1_type::type_id::create("RF1", null, get_full_name());
        this.RF1.build();
        this.RF1.map(this.default_map, `h200, ...);
    endfunction
endclass

```

After a sub-block has been built, for each address map in that sub-block, the `build()` method shall call the appropriate `uvm_reg_map::add_submap()` method for all address maps where the sub-block address map is accessible, specifying its offset in that upper address map.

```

class my_blk_type extends uvm_reg_block;
    virtual function build();
        this.BLK1.build();
        this.default_map.add_submap(this.BLK1.default_map, `h8000);
    endfunction
endclass

```

5.5.5.4 Coverage Model

A block-level coverage model is defined and instantiated in the block type class. It measures the coverage of the accessed offsets and field values on each instance of that block type. The `uvm_reg_block::sample()` or `uvm_reg_block::sample_values()` methods shall be used to trigger the sampling of a coverage point, based on the data provided as an argument or gathered from the current state of the block type instance. The sampling of the coverage model shall only occur if sampling for the corresponding coverage model has been turned on, as reported by the `uvm_reg_block::get_coverage()` method.

```

class my_blk extends uvm_reg_block;
    covergroup cg_vals;
        ...
    endgroup

```

```

...
virtual function void sample_values();
    super.sample_values();
    if (get_coverage(UVM_CVR_FIELD_VALS))
        cg_vals.sample();
endfunction
endclass : my_blk

```

All the coverage models that may be included in the block type shall be reported to the `uvm_reg_mem` base class using `uvm_reg_block::build_coverage()` when `super.new()` is called or using the `uvm_reg_block::add_coverage()` method. If no functional coverage models are included in the generated block type, `UVM_NO_COVERAGE` shall be specified. Block-level coverage groups shall only be instantiated in the constructor if the construction of the corresponding coverage model is enabled, as reported by the `uvm_reg_block::has_coverage()` method.

```

class my_blk extends uvm_reg_block;
    covergroup cg_vals;
    ...
endgroup
...
function new(string name = "my_blk");
    super.new(name, build_coverage(UVM_CVR_FIELD_VALS));
    if (has_coverage(UVM_CVR_FIELD_VALS))
        cg_vals = new();
endfunction: new
...
endclass : my_blk

```

The content, structure, and options of the coverage group is defined by the register model generator and is outside the scope of UVM.

5.5.6 Packaging a Register Model

The generator is free to structure the generated code into packages and files to facilitate compilation or reuse.

The following practices are recommended, but not required:

- a) Block types, and all the register, register file, and memory types they require, should be located in separate packages.
- b) Register, register file, and memory types shared by more than one block type should be located in separate packages.
- c) A header file, with all the required import statements to use the register model, should be generated.
- d) A lengthy `build()` method may be split into several, shorter sub-methods. The sub-methods shall be declared local and called by the `build()` method.

5.5.7 Maximum Data Size

By default, the maximum size of fields, registers, and memories is 64 bits. This limitation is implemented via the definition of the `uvm_reg_data_t` type.

```
typedef bit [63:0] uvm_reg_data_t;
```

The `uvm_reg_data_t` type is used in all methods and API that deal with data values to and from the register model. Smaller fields, registers, and memories are intrinsically supported by using the SystemVerilog automatic value extension and truncation.

The maximum data size may be reduced to save memory in large register models. It may also be increased to support larger fields, registers, or memory values. The size of data values may be specified at compile-time by defining the ``UVM_REG_DATA_WIDTH` macro.

```
% ... +define+UVM_REG_DATA_WIDTH=256 ...
```

It is recommended register model generator provide a warning message if the maximum data size need to be increased. It is also recommended the register model contain a static initializer check for the required minimum data size and issue a fatal error message when that is not set appropriately:

```
class my_blk extends uvm_reg_block;
    local static bit m_req_data_width = check_data_width(256);
    ...
endclass
```

5.6 Back-door Access

Back-door access to registers and memory locations is an important tool for efficiently verifying their correct operation.

A back-door access can uncover bugs that may be hidden because write and read cycles are performed using the same access path. For example, if the wrong memory is accessed or the data bits are reversed, whatever bug is introduced on the way in (during the write cycle) will be undone on the way out (during the read cycle).

A back-door improves the efficiency of verifying registers and memories since it can access registers and memory locations with little or no simulation time. Later, once the proper operation of the physical interface has been demonstrated, you can use back-door access to completely eliminate the simulation time required to configure the DUT (which can sometimes be a lengthy process).

A back-door access operates by directly accessing the simulation constructs that implement the register or memory model through a hierarchical path within the design hierarchy. The main challenges of implementing a back-door access are the identification and maintenance of that hierarchical path and the nature of the simulation constructs used to implement the register or memory model.

5.6.1 Back-door read/write vs. peek/poke

You can perform back-door access to registers and memory by calling the following read/write methods with their path argument as `UVM_BACKDOOR`:

- a) `uvm_reg_field::read()` or `uvm_reg_field::write()`
- b) `uvm_reg::read()` or `uvm_reg::write()`
- c) `uvm_mem::read()` or `uvm_mem::write()`

... or by calling the following peek/poke methods:

- d) `uvm_reg_field::peek()` or `uvm_reg_field::poke()`
- e) `uvm_reg::peek()` or `uvm_reg::poke()`
- f) `uvm_mem::peek()` or `uvm_mem::poke()`

The `peek()` methods return the raw value read using the back-door without modifying the content of the register or memory. Should the register content be modified upon a normal read operation, such as a `clear-on-read` field, it will not be modified. Therefore, reading using `peek()` methods may yield different results than reading through `read()` methods.

The `poke()` methods deposit the specified value directly in the register or memory. Should the register contain non-writable bits or bits that do not reflect the exact value written, such as `read-only` or `write-1-to-clear` fields, they will contain a different value than if the same value had been written through normal means. All field values, regardless of their access mode, will be forced to the poked value. Therefore, writing using `poke()` methods may yield different results than writing through the front-door.

When using the `read()` methods with a back-door access path, the behavior of the register or memory access mimics the same access performed using a front-door access. For example, reading a register containing a `clear-on-read` field will cause the field value to be cleared by poking 0's into it.

When using the `write()` method with a back-door access path, the behavior of the register or memory access mimics the same access performed using a front-door access. For example, writing to a `read-only` field using back-door access will cause the field value to be maintained by first peeking its current value then poking it back in instead of the specified value.

5.6.2 Hierarchical HDL Paths

To access a register or memory directly into the design, it is necessary to know how to get at it. The UVM register library can specify arbitrary hierarchical path components for blocks, register files, registers and memories that, when strung together, provide a unique hierarchical reference to a register or memory. For example, a register with a hierarchical path component defined as `X`, inside a block with a hierarchical path component defined as `Y`, inside a block with a hierarchical path component defined as `Z` has a full hierarchical path defined as `Z.Y.X`.

HDL path components are specific to the language used to model the DUT and the structure of the DUT model. They may be individual hierarchical scope names (e.g., `decoder`), partial dot-separated (`.`) hierarchical paths (e.g., `bus_if.decoder`) or empty (i.e., they do not contribute to the overall path). They can also be build-time string expressions, but must be string constants at run-time, where the value of the string must be a constant name or partial path: it cannot be an expression. Each path component must be empty or a valid path component: they cannot start or end with a dot separator (`.`). They need not be valid SystemVerilog path components, as they may be used to refer to hierarchical paths that cross language boundaries. HDL paths terminate at registers and memories.

Multiple HDL paths may be defined for the same block, register file, register or memory abstraction. This indicates the block, register file, register, or memory is duplicated in the model of the DUT. The value of a duplicated register or memory must be kept coherent across all copies.

For example, assuming the following register model hierarchy and HDL path components:

```
Block b1          "b1"
  Block b2       "b2_a", "b2_b"
    Register r1  "r1"
    Register r2  {"r2_1", "r2_0"}
  Block b3       ""
    Register r3  "r3.z", {"r3_1", "r3_0"}
```

The full hierarchical paths would be as follows:

```

Block b1          "b1"
  Block b2        "b1.b2_a", "b1.b2_b"
    Register r1   "b1.b2_a.r1", "b1.b2_b.r1"
    Register r2   {"b1.b2_a.r2_1", "b1.b2_a.r2_0"},
                  {"b1.b2_b.r2_1", "b1.b2_b.r2_0"}
  Block b3        n/a
    Register r3   "b1.r3.z", {"b1.r3_1", "b1.r3_0"}

```

HDL path components are specified using the following methods:

- `uvm_reg_block::configure()` and `uvm_reg_block::add_hdl_path()`
- `uvm_reg_file::configure()` and `uvm_reg_file::add_hdl_path()`
- `uvm_reg::configure()` and `uvm_reg::add_hdl_path_slice()`
- `uvm_mem::configure()` and `uvm_mem::add_hdl_path_slice()`

The HDL path for a register or memory may be a concatenation of simple names. This is used when the register is implemented or modelled as a concatenation of individual fields variables, or when the memory is implemented or modelled using vertical banking. When specifying a concatenation, the bits may be left unspecified if they are not physically implemented.

For example, the register with the implementation illustrated in [Figure 27](#) has its HDL path component specified using the following concatenation:

```

rg.add_hdl_path_slice("RDY", 15, 1);
rg.add_hdl_path_slice("ID", 6, 6);
rg.add_hdl_path_slice("COUNT", 0, 4);

```



Figure 27—Composite Register Structure

HDL paths are created by concatenating each path component from the root block to the leaf register or memory. However, if a block HDL path component is defined has a root HDL path component, the HDL path component of any blocks above it are ignored.

5.6.3 VPI-based Back-door Access

The UVM register library provides a default back-door access mechanism that uses the HDL path(s) returned by the `uvm_reg::get_full_hdl_path()` and `uvm_reg::get_full_hdl_path()` methods for the default design abstraction. Using standard SystemVerilog VPI routines, it samples or deposits values in the HDL constructs referenced by the resulting hierarchical HDL paths. If the HDL paths are valid hierarchical SystemVerilog variables, including indexing and slicing operators, this should work without any further requirements.

5.6.3.1 Including the DPI C Library

The implementation of the default back-door access mechanism requires the inclusion of some DPI C code. Please refer to the *supplementary UVM documentation* provided by your simulator vendor on how to compile and link the UVM C library.

5.6.3.2 Performance Issues with the VPI-based Back-door Access

Enabling the VPI functionality required by the default back-door access mechanism may disable performance optimizations normally done in your simulator. Please refer to the *supplementary UVM documentation* provided by your simulator vendor for additional or alternative steps that may be taken to improve the performance of your simulation.

5.6.4 User-defined Back-door Access

Should the DPI-based back-door access prove to be insufficient, a user-defined back-door access can be used instead. A user-defined back-door access is able to use any SystemVerilog constructs or tool-specific utility to access registers and memories. For example, if a memory or register is located in an encrypted model, a user-defined back-door may be used to peek and poke values directly into the encrypted model via a suitable API.

A user-defined register back-door is provided through an extension of the `uvm_reg_backdoor` class. A back-door write operation is implemented in the `uvm_reg_backdoor::write()` virtual method whereas a back-door read operation is implemented in the `uvm_reg_backdoor::read()` virtual method. This back-door access is then associated with a specific register through the `uvm_reg::set_backdoor()` method or with all the registers within a block using the `uvm_reg_block::set_backdoor()` method.

A user-defined memory back-door is provided through an extension of the `uvm_mem_backdoor` class. A back-door write operation is implemented in the `uvm_mem_backdoor::write()` virtual method whereas a back-door read operation is implemented in the `uvm_mem_backdoor::read()` virtual method. This back-door access is then associated with a specific memory through the `uvm_mem::set_backdoor()` method.

User-defined back-door access mechanisms may be defined by the register model generators. They are instantiated and associated with their corresponding block, register, or memory abstraction class in the implementation of their respective `build()` method. User-defined back-door access mechanisms may also be registered with their corresponding block, register, or memory after the register model construction, overriding any previously defined (or default) back-door access mechanisms. In the latter case, they are instantiated and associated with their corresponding block, register, or memory abstraction class in the implementation of the environment's `build()` method.

```
function void tb_env::build();
    super.build();
    ...
    begin
        my_mem_backdoor bkdr = new;
        regmodel.mem.set_backdoor(bkdr);
    end
endfunction: build
```

5.6.5 Back-door Access for Protected Memories

The content of memories may be protected using one or more protection schemes. They can vary from simple additional bits providing an Error Correction Code to full encryption of its content.

When performing back-door write operations, it is necessary to correctly protect the memory content to avoid errors when a physical interface subsequently reads these memory locations. It may also be useful or

necessary to have direct access to the protected form because these bits are created and used entirely within the design, and can only be accessed through back-door access. The back-door is the only way protected values can be checked and protection errors injected.

The `encode()` and `decode()` callback methods located in the `uvm_mem_backdoor_cbs` class are designed to handle such data protection. The `encode()` method is applied on the way in and the `decode()` method is applied on the way out. But, unlike regular callback methods, the decoding is done in the reverse order of registration. This allows multiple layers of data protections to be implemented in the same memory, each modelled using a single callback extension. The order of registration determines the order in which the various layers of protections are applied—then undone.

For example, ECC bits are located in additional memory bits within the same memory location as the data they protect; they must be generated and set for write accesses, and must be checked and masked when read.

```
class ecc_protected extends uvm_mem_backdoor_cbs;

    virtual function uvm_reg_data_t encode(uvm_reg_data_t data);
        // Append the ECC bits to the data to write
        data[35:32] = ecc::compute(data[31:0]);
        return data;
    endfunction

    virtual function uvm_reg_data_t decode(uvm_reg_data_t data);
        // Check and mask the ECC bits to the data to write
        if (data[35:32] != ecc::compute(data[31:0])) `uvm_error(...)
            return data[31:0];
    endfunction

endclass
```

Similarly, data written to an encrypted memory must be ciphered during write accesses and deciphered when read.

```
class encrypted_mem extends uvm_mem_backdoor_cbs;

    virtual function uvm_reg_data_t encode(uvm_reg_data_t data);
        return crypt::encrypt(data);
    endfunction

    virtual function uvm_reg_data_t decode(uvm_reg_data_t data);
        return crypt::decrypt(data);
    endfunction

endclass
```

5.6.6 Active Monitoring

The mirrored field values in a register model are updated when the fields are accessed through the register model based on the current mirrored value, the accessed data value, and the access policy of the field. They may also be updated based on observed read and write transactions on the bus interface if the register model is integrated with the bus monitor and explicit monitoring is enabled (see [Section 5.9.3](#)). Any changes to the field value performed by the design itself cannot be detected and then mirrored in the register model.

The back-door mechanism can be used to automatically update the mirror value of fields that are modified by the design itself by observing the SystemVerilog constructs which are used to store the field values. When a change of value is detected, the mirrored value can be similarly updated.

Because there is no standard value-change callback VPI or PLI functionality, the automatic update of a field can only be implemented using a user-defined back-door. The active monitoring of a register requires the implementation of the `uvm_reg_backdoor::is_auto_updated()` and `uvm_reg_backdoor::wait_for_change()` methods.

`uvm_reg_backdoor::is_auto_updated()` returns TRUE if the specified named field is actively monitored. All actively-monitored fields have their mirror value updated strictly and only through the active mirroring mechanism. Executed or observed transactions are not used to update their mirrored value.

The `uvm_reg_backdoor::wait_for_change()` task must return only when a change in any of the actively-monitored fields is observed. For each actively-monitored register, a thread calls this task to wait for any change in any of the fields in the register. As soon as it returns, their values are sampled and their mirror values updated. The implementation of that method should not simply wait for the active edge of the clock signal used to update the field values in the design; for optimal performance, the implementation of that method should only return when an actual change occurs.

```
class active_monitor_r1 extends uvm_reg_backdoor;

    virtual function bit is_auto_updated(string fld_name);
        case (fld_name)
            "f1": return 1;
            "f2": return 1;
        endcase
    endfunction

    virtual task wait_for_change();
        @($root.tb_top.dut.rf.f1 or $root.tb_top.dut.rf.f2);
    endtask
endclass
```

The active-monitoring thread must be started for each actively-monitored register by invoking the `uvm_reg_backdoor::start_update_thread()` method of its back-door access class once an instance of that back-door access class is created, as shown in the following example:

```
class add_active_monitors extends my_blk;

    virtual function build();
        super.build();
        begin
            active_monitor_r1 am_r1 = new;
            r1.set_backdoor(am_r1);
            am_r1.start_update_thread(r1);
        end
    endfunction
endclass
```

5.7 Special Registers

The UVM register library presumes all registers and memories are average registers and memories, they are accessible at a known, constant, unique physical address(es), their behavior is constant throughout the simulation regardless of the physical interface used to access them, and they contain a single value.

Designer creativity, the demands of the application, or implementation constraints often require special behaviors be implemented. Special register behavior can be modeled using any number of extension capabilities provided in the UVM register and field abstraction classes. Pre- and post-read/write callback objects, virtual callback methods, user-defined front-doors, and user-defined back-doors may be used to extend the behavior of the base library. And, if all else fails, it is always possible to override virtual methods that are used to access the register content, i.e., `read()`, `write()`, `peek()`, and `poke()`.

5.7.1 Pre-defined Special Registers

The UVM library pre-defines some commonly used special registers. A register model generator is free to provide a library of additional special register models and use them in its generated model.

5.7.1.1 Indirect Indexed Registers

Some registers are not directly accessible via a dedicated address. Indirect access of an array of such registers is accomplished by first writing an “index” register with a value that specifies the array’s offset, followed by a read or write of a “data” register to obtain or set the value for the register at that specified offset. The pre-defined `uvm_reg_indirect_data` class models the behavior the “data” register.

A “data” register type is defined by extending the `uvm_reg_indirect_data` register class. The “data” register must not contain any fields. The “index” and indirect register array must be built first, as the “index” registers and the register array are specified when the “data” register is configured using the `uvm_reg_indirect_data::configure()` method. The indirect register array, “index”, and “data” registers are added as members of the containing block. However, only the “index” and “data” registers are added to a map in the containing block. The registers in the indirect register array must be not added to the address map in the containing block because they have no dedicated address.

```
class my_blk_type extends uvm_reg_block;
  ind_idx_reg  IND_IDX;
  ind_data_reg IND_DATA;
  ind_reg      INDIRECT_REG[256];

  virtual function build();

  foreach (INDIRECT_REG[i]) begin
    string name = $sformatf("INDIRECT_REG[%0d]", i);
    INDIRECT_REG[i] =
      ind_reg::type_id::create(name, , get_full_name());
    INDIRECT_REG[i].configure(this, null, ...);
    INDIRECT_REG[i].build();
  end

  IND_IDX = ind_idx_reg::type_id::create("IND_IDX", , get_full_name());
  IND_IDX.configure(this, null, ...);
  IND_IDX.build();

  IND_DATA = ind_data_reg::type_id::create("IND_DATA", , get_full_name());
  IND_DATA.configure(IND_IDX, INDIRECT_REG, this, null);
  IND_DATA.build();

  default_map = create_map("", 0, 4, UVM_BIG_ENDIAN);
  default_map.add_reg(IND_IDX, 0);
  default_map.add_reg(IND_DATA, 4);
endfunction
endclass
```

The registers in the indirect register array cannot be accessed via a back-door access to the “data” register. Back-door access to the register array is provided by performing back-door accesses via the unmapped, indirect register itself.

If a different indirection mechanism is required, a user-defined register extension will be necessary.

5.7.1.2 FIFO (first-in, first-out) Registers

A FIFO register is not a register in the usual sense. It is a FIFO whose push and pop operations are mapped to write and read operations at a specific address. Writing to that address causes the data written to be pushed at the end of the FIFO. Reading from that address returns the data that is currently at the head of the FIFO and pops it. Whether the FIFO is full or empty is usually specified via status bits in another register.

To model a FIFO register, the register type shall be extended from the `uvm_reg_fifo` class. The maximum number of entries in the FIFO and the size of each entry is specified when calling `super.new()`.

```
class fifo_reg extends uvm_reg_fifo;

    function new(string name = "fifo_reg");
        super.new(name, 8, 32, UVM_NO_COVERAGE);
    endfunction: new

    `uvm_object_utils(fifo_reg)

endclass
```

Backdoor access to a FIFO register is not allowed.

5.7.2 Unmapped Registers and Memories

By default, the entire register or memory is assumed to be linearly mapped into the address space of the block that instantiates it. Each register or location in a memory thus corresponds to a unique address in the block. However, you can use different addressing mechanisms. For example, you could access a large memory in a limited address space using an indexing mechanism: the desired offset within the memory is written into a register, then the data at that memory offset is read or written by reading or writing another register. This memory is effectively unmapped: it does not appear in the linear address space used to access it. See [Section 5.7.1.1](#).

The number of possible access mechanisms is potentially infinite and only limited by the imagination, requirements, and constraints of designers. To support arbitrary access mechanisms, it is possible to replace the default linearly mapped access mechanism with any user-defined access mechanism.

5.7.2.1 User-defined Front-door Access

User-defined front-door access is made possible by extending the `uvm_reg_frontdoor` class and registering an instance of the class with specific registers or memories using the `uvm_reg::set_frontdoor()` or `uvm_mem::set_frontdoor()` method. The `uvm_reg_frontdoor` is a `uvm_sequence`. For each write or read operation, the register model creates a `uvm_reg_item` object representing the operation, assigns it to the `rw_info` property of registered front-door sequence, and calls its `start` method. Ultimately, the front-door’s body task is called, which must be implement to perform the actual operation.

```

class indexed_reg_frontdoor extends uvm_reg_frontdoor;
  local uvm_reg  m_idx_reg;
  local uvm_reg  m_data_reg;
  local bit [7:0] m_addr;

  function new(string name="indexed_reg_frontdoor_inst");
    super.new(name);
  endfunction

  function void configure(uvm_reg idx, uvm_reg data, bit [7:0] addr);
    m_idx  = idx;;
    m_data = data;
    m_addr = addr;
  endfunction: new

  virtual task body(uvm_reg_item rw);
    m_idx_reg.write(status, m_addr, ...);
    if (status != UVM_IS_OK)
      return;
    if (rw.kind == UVM_WRITE)
      m_data.write(rw.status, data, ...);
    else
      m_data.read(rw.status, data, ...);
  endtask

endclass

```

User-defined front-doors are instantiated and associated with their corresponding register or memory abstraction class in the `build()` method of the block or register file that instantiates them or the `build()` phase callback of the environment component where the register model is instantiated and built.

```

virtual function void build();
  foreach TABLE[i] begin
    indexed_reg_frontdoor idx_frtdr = new(INDEX, DATA, i);
    = idx_reg_frontdoor::type_id::create("idx_frtdr", ,get_full_name());
    idx_frtdr.configure(idx_reg, data_reg, i);
    regmodel.TABLE[i].set_frontdoor(idx_frtdr, default_map, ...);
  end
endfunction: build

```

A user-defined front-door is registered on a per-map basis, affecting the access of a register or memory through a specific physical interface. A different front-door mechanism (or the built-in one) can be used for other physical interfaces. For example, a memory could use the indexed addressing scheme described above for one physical interface but be mapped normally within the address map of another physical interface.

5.7.2.2 Mirroring Unmapped Registers

When using explicit or passive monitoring to update the mirror value in unmapped registers, it will be necessary to override the `uvm_reg::predict()` method of the register(s) used to access the unmapped registers, since the observed transactions will be using the address of those access registers, not the unmapped (unaddressable) registers that are ultimately accessed.

In the case of an indirect register, the `uvm_reg_indirect_data` class extends `predict` for you and serves as an example of how you do this for your custom unmapped registers.

```

function bit uvm_reg_indirect_data::predict (uvm_reg_data_t value, ...);
  if (m_idx.get() >= m_tbl.size()) begin

```

```

        `uvm_error("Index reg > than size of indirect register array")
        return 0;
    end
    return m_tbl[m_idx.get()].predict(value, ...);
endfunction

```

5.7.3 Aliased Registers

Aliased registers are registers that are accessible from multiple addresses in the same address map. They are different from shared registers as the latter are accessible from multiple address maps. Typically, the fields in aliased registers will have different behavior depending on the address used to access them. For example, the fields in a register may be readable and writable when accessed using one address, but read-only when accessed from another.

Modelling aliased registers in UVM involves more than simply mapping the same register at two different addresses. A UVM register model requires each instance of a `uvm_reg` class be mapped to a unique address in an address map. For aliased registers, this requires a register class instance for each address. All this enables using a specific register instance to access the aliased register via a specific address.

For example, the (incomplete) register model shown below models a register aliased at two addresses: ``h0100` and ``h0200`. Each alias is known under a different instance name, `Ra` and `Rb` respectively. To access the aliased register via address ``h0100`, the `Ra` instance would be used.

```

class my_blk extends uvm_reg_block;
    rand my_reg_Ra Ra;
    rand my_reg_Rb Rb;
    virtual function build();
        ...
        default_map.add_reg(Ra, `h0100);
        default_map.add_reg(Rb, `h0200);
    endfunction
endclass

```

Each register instance must be of a register type that models the behavior of the register and field it contains of its corresponding alias. For example, a register that contains a field that is RW when accessed via one address, but RO when accessed via another would require two register types: one with a RW field and another one with a RO field, and both using the same field names.

```

class my_reg_Ra extends uvm_reg;
    rand uvm_reg_field F1;
    ...
    virtual function void build();
        F1 = uvm_reg_field::type_id::create("F1");
        F1.configure(this, 8, 0, "RW", 0, 8'h0, 1, 1, 1);
    endfunction
    ...
endclass

class my_reg_Rb extends uvm_reg;
    uvm_reg_field F1;
    ...
    virtual function void build();
        F1 = uvm_reg_field::type_id::create("F1");
        F1.configure(this, 8, 0, "RO", 0, 8'h0, 1, 0, 1);
    endfunction

```

```

...
endclass

```

The aliasing functionality must be provided in a third class that links the two register type instances. The aliasing class can make use of the pre-defined register and field callback methods to implement the aliasing functionality. It may also make use of additional APIs or functionality created by the register model generator in the different register types that model each alias of the register. The aliasing class should be based on `uvm_object` to be factory-enabled. The required reference to the various register instance aliases shall be supplied via a `configure()` method.

```

class write_also_to_F extends uvm_reg_cbs;
  local uvm_reg_field m_toF;

  function new(uvm_reg_field toF);
    m_toF = toF;
  endfunction

  virtual function void post_predict(uvm_reg_field fld,
                                     uvm_reg_data_t value,
                                     uvm_predict_e kind,
                                     uvm_path_e path,
                                     uvm_reg_map map);
    if (kind != UVM_PREDICT_WRITE) return;

    void'(m_toF.predict(value, -1, UVM_PREDICT_WRITE, path, map));
  endfunction

endclass

class alias_RaRb extends uvm_object;
  protected reg_Ra m_Ra;
  protected reg_Rb m_Rb;

  `uvm_object_utils(alias_RaRb)

  function new(string name = "alias_RaRb");
    super.new(name);
  endfunction: new

  function void configure(reg_Ra Ra, reg_Rb Rb);
    write_also_to_F F2F;

    m_Ra = Ra;
    m_Rb = Rb;

    F2F = new(Rb.F1);
    uvm_reg_field_cb::add(Ra.F1, F2F);
  endfunction : configure
endclass : alias_RaRb

```

The register file or block containing the various register aliases shall also instantiate the aliasing class in its `build()` method and call the `configure()` method with appropriate arguments.

```

class my_blk extends uvm_reg_block;
  rand my_reg_Ra Ra;
  rand my_reg_Rb Rb;
  ...

```

```

virtual function build();
    default_map = create_map("", 0, 4, UVM_BIG_ENDIAN);

    Ra = reg_Ra::type_id::create("Ra", ,get_full_name());
    Ra.configure(this, null);
    Ra.build();

    Rb = reg_Rb::type_id::create("Rb", ,get_full_name());
    Rb.configure(this, null);
    Rb.build();

    default_map.add_reg(Ra, `h0100);
    default_map.add_reg(Rb, `h0200);

    begin
        alias_RaRb RaRb;

        RaRb = alias_RaRb::type_id::create("RaRb", ,get_full_name());
        RaRb.configure(Ra, Rb);
    end
endfunction
endclass

```

There are no pre-defined aliasing classes because the nature of the aliasing is highly variable, not just in how the fields provide different behaviors through the various aliases, but potentially in their layout as well.

5.7.4 Unimplemented Registers

A UVM register model can model registers that are specified, but have not yet been implemented in the DUV. This allows the verification environment and testcases to make use of these registers before they are available.

Because these registers are unimplemented, there is nothing to actually read or write inside the DUT. Since the mirror in a register abstraction class provides a faithful model of the expected behavior of that register, it can be used to provide a read back value. A yet-to-be-implemented register is thus modelled by writing to and reading from the mirror.

An unimplemented register can be modelled by providing a user-defined front- and back-door that access the mirrored value instead of performing bus transactions.

```

class not_yet_implemented_fd extends uvm_reg_frontdoor;
    ...
    virtual task body();
        uvm_reg R;

        $cast(R, rw_info.element);
        if (rw_info.kind == UVM_READ) rw_info.value[0] = R.get();

        R.predict(rw_info.value[0], -1,
            (rw_info.kind == UVM_READ) ?
                UVM_PREDICT_READ : UVM_PREDICT_WRITE,
            rw_info.path,
            rw_info.map);
    endtask
endclass

```

The user-defined front- and back-door shall be registered in the environment where the register model is instantiated and clearly identified as temporary work-arounds.

```
virtual function void connect();
...
if (get_parent() == null) begin
    not_yet_implemented_fd fd;
    `uvm_warning("NotYetImpl",
                "Working around yet-to-be-implemented registers");
    fd = new;
    regmodel.R2.set_frontdoor(fd);
end
endfunction
```

5.7.5 RO and WO Registers Sharing the Same Address

It is possible for a register containing only write-only fields (WO, WOC, WOS, and WO1) to share the same address with another register containing only read-only fields (RO, RC, and RS). The fields in each register are unrelated and can have different layouts.

This register structure is modelled by simply mapping both registers at the same address. Only one read-only register and one write-only register may be mapped at the same address. Once mapped, calling the `uvm_reg::read()` method on a write-only register or calling the `uvm_reg::write()` method on a read-only register will cause an error message to be issued, the operation will be aborted, and `UVM_NOT_OK` will be returned as the status. Back-door poke and peek are allowed on read-only and write-only registers respectively.

```
class block_B extends uvm_reg_block;
    rand reg_RO R;
    rand reg_WO W;
    ...
    virtual function void build();
        default_map = create_map("", 0, 4, UVM_BIG_ENDIAN);

        R = reg_RO::type_id::create("R");
        R.configure(this, null, "R_reg");
        R.build();

        W = reg_WO::type_id::create("W");
        W.configure(this, null, "W_reg");
        W.build();

        default_map.add_reg(R, 'h100, "RO");
        default_map.add_reg(W, 'h100, "WO");
    endfunction : build
    ...
endclass
```

5.8 Integrating a Register Model in a Verification Environment

Test sequences, whether pre-defined or user-defined ones, need a verification environment in which to execute. The register model needs to be an integral part of that verification environment to be used by the tests to access registers and memories in the DUT.

An environment must have a reference to the register model that corresponds to the DUT it verifies. It is recommended a class property named `regmodel` be used for that purpose. To enable vertical reuse of the environment, it must first check if its register model has been defined by a higher-level environment. If not, it must be allocated using the class factory, explicitly built by calling its `build()` method, then it calls the `uvm_reg_block::lock_model()` method. After creating any sub-block environments, their register models must then be specified by setting their respective `regmodel` class properties. All of this must be implemented in the environment's `build()` method.

```
class block_env extends uvm_env;
  block_reg_model regmodel;
  subblk_env      subblk;

  virtual function void build();
    if (regmodel == null) begin
      regmodel = block_reg_model::type_id::create("regmodel", this);
      regmodel.build();
      regmodel.lock_model();
    end
    subblk = subblk_env::type_id::create("subblk", this);
    subblk.regmodel = regmodel.subblk;
  endfunction
endclass
```

If HDL paths are used, the root HDL paths must be specified in the environment that instantiates the register model. The value of that root path will depend on the location of the model for the DUT within the complete simulation model.

```
class block_env extends uvm_env;
  block_reg_model regmodel;
  virtual function void build();
    if (regmodel == null) begin
      regmodel = block_reg_model::type_id::create("regmodel", this);
      regmodel.build();
      regmodel.set_hdl_path_root("tb_top.dut");
    end
  endfunction
endclass
```

5.9 Integrating a Register Model

A register model must be integrated with the bus agents that perform and monitor the actual read and write operations. The terms “bus driver”, “bus agent”, “bus interface” and “bus operations” are used to describe the components, protocol, and interface associated with the execution of read and write operations on the DUT. The integration may be established via a non-bus-based interface and protocol.

The integration with the bus agent must only be done on root blocks. Root blocks model the entire DUT and they are the only ones who have access to and knowledge of the externally-visible address maps. Lower-level register models will translate their read and write operations in terms of read and write operations at the root block level, using root-level addresses and bus protocols.

To that end, the integration process must be conditional to the register model being a root register model. This is accomplished by checking if the register model has a parent. If not, it is a root model and integration with the bus agent may proceed. All this must be implemented in the environment's `connect()` method.

```
class block_env extends uvm_env;
```

```

block_reg_model regmodel;
subblk_env      subblk;

virtual function void connect();
    if (regmodel.get_parent() == null) begin
        // Integrate register model with bus agent
        ...
    end
endfunction
endclass

```

There are three structural bus agent integration approaches for keeping the register model's mirror values in sync with the DUT: implicit prediction, explicit prediction, and passive.

Implicit prediction only requires the integration of the register model with one or more bus sequencers. Updates to the mirror are predicted automatically (i.e., implicitly) by the register model after the completion of each read, write, peek, or poke operation. This integration is the simplest and quickest, but it will fail to observe bus operations that did not originate from the register model (e.g., by a third-party bus agent) and thus fail to appropriately update the corresponding mirror values.

Explicit prediction requires the register model be integrated with both the bus sequencers and corresponding bus monitors. In this mode, implicit prediction is turned off and all updates to the mirror are predicted externally (i.e., explicitly) by a `uvm_reg_predictor` component, one for each bus interface. The predictor receives the bus operations observed by a connected bus monitor, determines the register being accessed by performing a reverse-lookup using the observed address, and then calls the found register's `predict` method explicitly to update the mirror. This integration requires more work, but it will observe all bus operations, whether they originated from the register model or a third-party bus agent, and thus appropriately update the corresponding mirror values.

Passive integration only requires the integration of the register model with the bus monitor as described above. All the monitoring of the register operations is performed externally to (i.e., explicitly) the register model. All bus operations, whether they originated from the register model or a third-party bus agent, are observed and thus appropriately reflected in the corresponding mirror values. Because the register model is not integrated with a bus sequencer, it cannot be used to read and write register and memories in the DUT, only to track and verify their current value.

5.9.1 Transaction Adapter

The first step in integrating a register model with a bus agent are the conversion functions between a generic read/write bus operation descriptor, `uvm_reg_bus_op`, used by the register model and the protocol-specific read/write transaction descriptor used by the bus agent.

The transaction adapter is implemented by extending the `uvm_reg_adapter` class and implementing the `reg2bus()` and `bus2reg()` methods. Being a `uvm_object`, the bus adapter must implement a suitable `uvm_object` constructor and use the ``uvm_object_utils()` macro to enable it for the class factory.

```

class reg2apb_adapter extends uvm_reg_adapter;

    `uvm_object_utils(reg2apb_adapter)

    function new(string name = "reg2apb_adapter");
        super.new(name);
    endfunction

```

```

virtual function uvm_sequence_item reg2bus(const ref uvm_reg_bus_op rw);
    apb_rw apb = apb_rw::type_id::create("apb_rw");
    apb.kind = (rw.kind == UVM_READ) ? apb_rw::READ : apb_rw::WRITE;
    apb.addr = rw.addr;
    apb.data = rw.data;
    return apb;
endfunction

virtual function void bus2reg(uvm_sequence_item bus_item,
                             ref uvm_reg_bus_op rw);

    apb_rw apb;
    if (!$cast(apb,bus_item)) begin
        `uvm_fatal("NOT_APB_TYPE",
                  "Provided bus_item is not of the correct type")
        return;
    end
    rw.kind = apb.kind ? UVM_READ : UVM_WRITE;
    rw.addr = apb.addr;
    rw.data = apb.data;
    rw.status = UVM_IS_OK;
endfunction
endclass

```

If the bus protocol supports byte lane enables (i.e., it is possible to read or write individual bytes in a multi-byte bus), the `supports_byte_enable` class property should be set to `TRUE` in the constructor. Similarly, the `provides_responses` class property should be set to `TRUE` if the bus driver returns responses, e.g., the result of a read operation, in a separate response descriptor:

```

class reg2apb_adapter extends uvm_reg_adapter;
    function new(string name = "");
        super.new(name);
        supports_byte_enables = 0;
        provides_responses     = 1;
    endfunction
endclass

```

Because this transaction adapter is specific to the bus agent, not the register model, it should be provided as part of a UVM-compliant bus UVC.

The transaction adapter is then instantiated in the `connect()` method of the environments corresponding to root register models:

```

class block_env extends uvm_env;
    block_reg_model regmodel;
    subblk_env      subblk;

    virtual function void connect();
        ...
        if (regmodel.get_parent() == null) begin
            reg2apb_adapter reg2apb =
                reg2apb_adapter::type_id::create("reg2apb",,get_full_name());
            ...
        end
    endfunction
endclass

```

5.9.2 Integrating Bus Sequencers

All integration approaches require a register model be configured with one or more bus sequencers. The register model becomes a property of a `uvm_reg_sequence` subtype that executes

- a) directly on a bus sequencer, if there is only one bus interface providing access to the DUT registers;
- b) as a virtual sequence, if there are one or more bus interfaces providing access to the DUT registers;
- c) as a register sequence running on a generic, bus-independent sequencer, which is layered on top of a downstream bus sequencer.

Note—To keep the code examples that follow succinct and focused on register model integration, we do not show obtaining handles via configuration or the resources database, or a priori sequence registration to a specific sequencer.

5.9.2.1 Register Sequence Running on the Bus Sequencer

The simplest approach is to run register sequences directly on the bus sequencer, competing directly with all other “native” bus sequences concurrently running on the bus sequencer. The register sequence will, via the register model, produce bus sequence stimulus using a preconfigured bus adapter. This approach is suitable for when the registers being accessed by the register sequence are accessible via a single bus interface, as shown in [Figure 28](#).

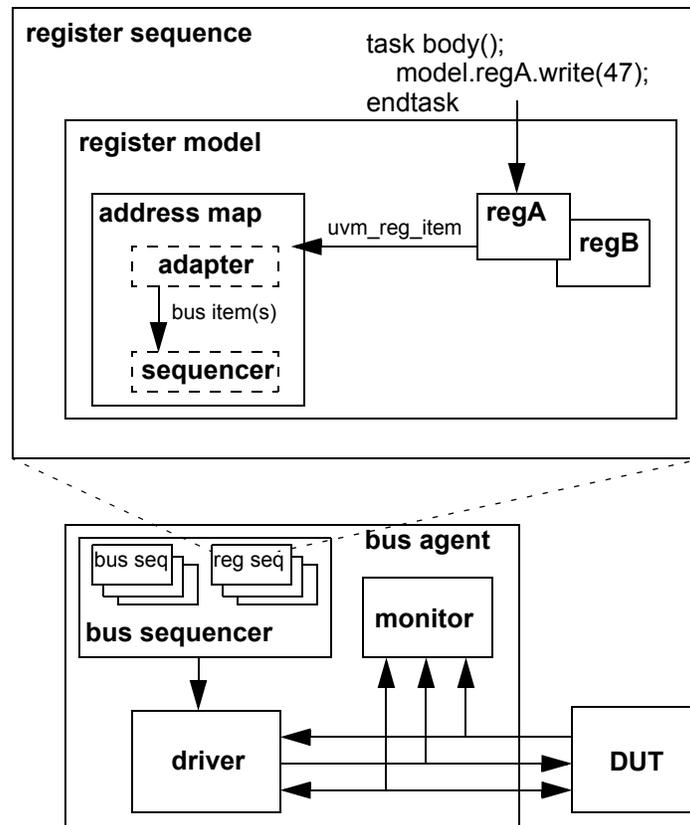


Figure 28—Register Sequence Running Directly on a Bus Sequencer

Implementing this approach is accomplished by registering the bus sequencer and corresponding transaction adapter with the appropriate address map in the register model. The model is registered with the user-

defined register sequence and the sequence started on the bus sequencer. As with any other running bus sequence, the register sequence's `is_relevant`, `pre_do`, `mid_do`, and `post_do` methods are called during execution of each bus item generated by the model. To gain exclusive access to the bus, the register sequence may also call `grab` or `lock` to prevent other bus sequences from running.

```
class block_env extends uvm_env;

    block_reg_model regmodel;
    apb_agent apb;

    virtual function void connect();
        if (regmodel.get_parent() == null) begin
            reg2apb_adapter reg2apb =
                reg2apb_adapter::type_id::create("reg2apb", ,get_full_name());
            regmodel.APB.set_sequencer(apb.sequencer, reg2apb);
            regmodel.set_auto_predict(1);
        end
        ...
    endfunction
    ...
endclass
```

The above example registers an APB bus sequencer and APB-specific bus adapter with the APB address map defined in top-level register model. If the register model defines only a single map, the map may be referenced via the handle `default_map`.

You define a register sequence by extending `uvm_reg_sequence` and defining the `body()` task to use the `model` property.

```
class my_reg_sequence extends uvm_reg_sequence;
    `uvm_object_utils(my_reg_sequence)

    block_reg_model model;

    virtual task body();
        uvm_status_e status;
        uvm_reg_data_t data;

        model.A.write(status, 'h33, .parent(this));
        if (status == UVM_NOT_OK)
            `uvm_error(...)
        model.A.read(status, data, .parent(this));
        if (data != 'h33)
            `uvm_error(...)
    endtask

endclass
```

The `uvm_reg_sequence` class parameterizes its base class. This allows you to splice in any user-defined `uvm_sequence` subtype if needed:

```
class VIP_sequence extends uvm_sequence #(VIP_base_item);
class my_reg_sequence extends uvm_reg_sequence (VIP_sequence);
```

Alternatively, you can promote the parameter to your register sequence, which allows the end-user to choose the super class:

```

class my_reg_sequence #(type BASE=uvm_sequence #(uvm_reg_item))
    extends uvm_reg_sequence #(BASE);

```

To run the register sequence, assign the sequence model property and start it on the bus sequencer:

```

class my_test extends uvm_test;
    block_env env;
    virtual function void run();
        my_reg_sequence seq = my_reg_sequence::type_id::create("seq",this);
        seq.start(env.apb.master);
    endfunction
endclass

```

5.9.2.2 Register Sequence Running as a Virtual Sequence

When the registers in the DUT become accessible via more than one physical bus interface, the same register sequence may instead be started as a virtual sequence as the sequencer used in each write/read call is not directly referenced. The register model routes the operation to the appropriate sequencer based on which map is in effect.

Consider a register model with two registers accessible via different bus interfaces, as shown in [Figure 29](#). As in the previous example in [Section 5.9.2.1](#), the sequence calls write and read on regA and regB without referring to a map or sequencer.

Note—Write and read calls have an optional map argument, but specifying a map explicitly would limit sequence reuse.

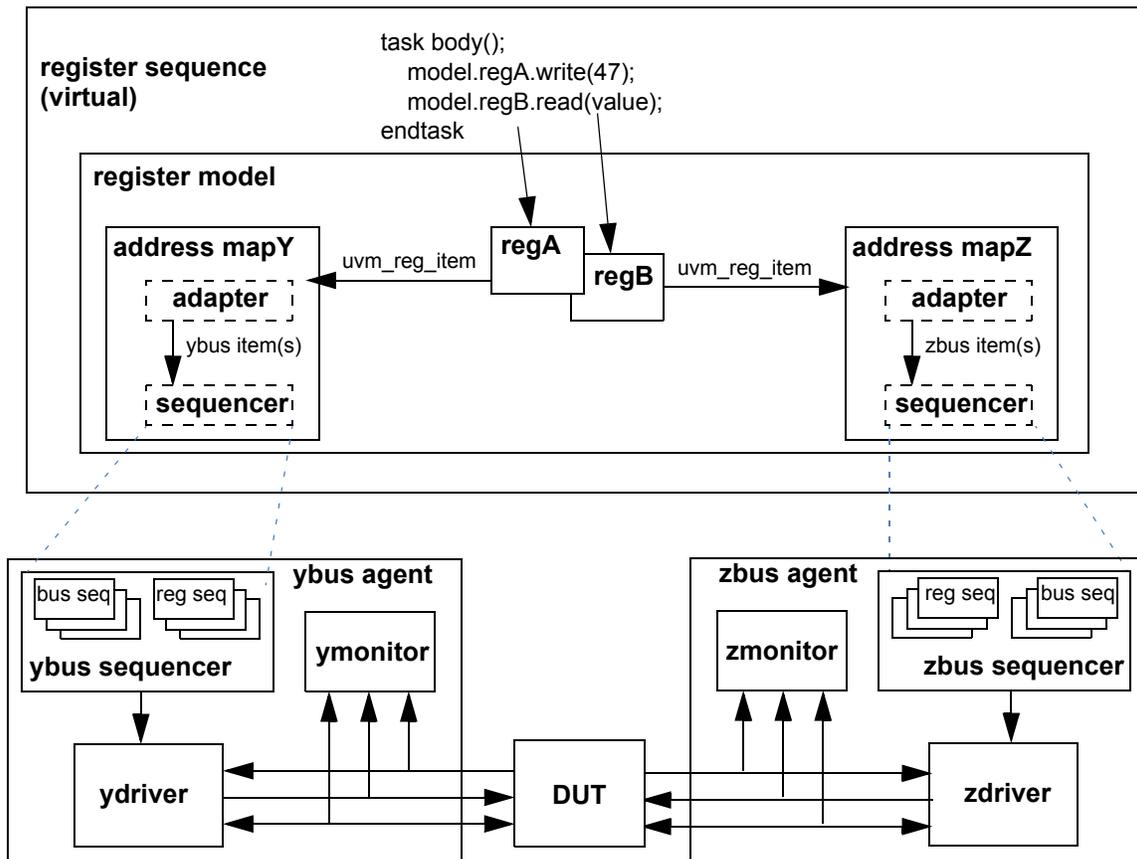


Figure 29—Register Sequence Running as a Virtual Sequence

The only difference between this and running directly on a bus sequencer is more than one sequencer/adapter pair is registered with the register model and the register sequence's `start` method is called without specifying a sequencer to run.

```
class block_env extends uvm_env;

    block_reg_model regmodel;
    apb_agent apb;
    wishbone_agent wsh;

    virtual function void connect();
        if (regmodel.get_parent() == null) begin
            reg2apb_adapter reg2apb =
                reg2apb_adapter::type_id::create("reg2apb", ,get_full_name());
            reg2wsh_adapter reg2wsh =
                reg2wsh_adapter::type_id::create("reg2wsh", ,get_full_name());
            regmodel.APB.set_sequencer(apb.sequencer, reg2apb);
            regmodel.WSH.set_sequencer(wsh.sequencer, reg2wsh);
            regmodel.set_auto_predict(1);
        end
        ...
    endfunction
    ...
endclass
```

A register model having more than one configured interface offers interesting timing possibilities. For example, if two registers are accessible via different busses, their accesses can be concurrent:

```
class my_reg_sequence extends uvm_reg_sequence;

    `uvm_object_utils(my_reg_sequence)

    block_reg_model model;

    virtual task body();
        uvm_status_e status;

        fork
            model.APB.write(status, 'h33, .parent(this));
            model.WSH.read(status, 'h66, .parent(this));
        join

    endtask

endclass
```

To run the register sequence, register the model and start it without specifying a particular sequencer:

```
class my_test extends uvm_test;

    block_env env;

    virtual function void run();
        my_reg_sequence seq = my_reg_sequence::type_id::create("seq", this);
        seq.start(null);
    endfunction

endclass
```

If you needed to grab a particular sequencer for corner-case testing and were not concerned about creating a dependency on a particular sequencer:

```
grab (regmodel .APB.get_sequencer ());
...
ungrab (regmode .APB.get_sequencer ());
```

5.9.2.3 Register Sequence Running on a Layered Register Sequencer

An alternative integration mechanism is to connect the register model with a register sequencer, then layer that register sequencer on top of the bus sequencer, as shown in [Figure 30](#). The register operations will “execute” as abstract sequence items on the register sequencer, allowing central, bus-independent control of the register sequences. However, this also prevents register sequences from competing directly with or having control over concurrently executing bus sequences (i.e., via `grab` and `ungrab`), mixing register and bus-specific sequences and sequence item execution within the same sequence, and being notified of bus-specific operations (via `pre_do`, `mid_do`, `post_do`, and `is_relevant`). This process also only works with a single bus interface, as all register operations are funneled through a single register sequence.

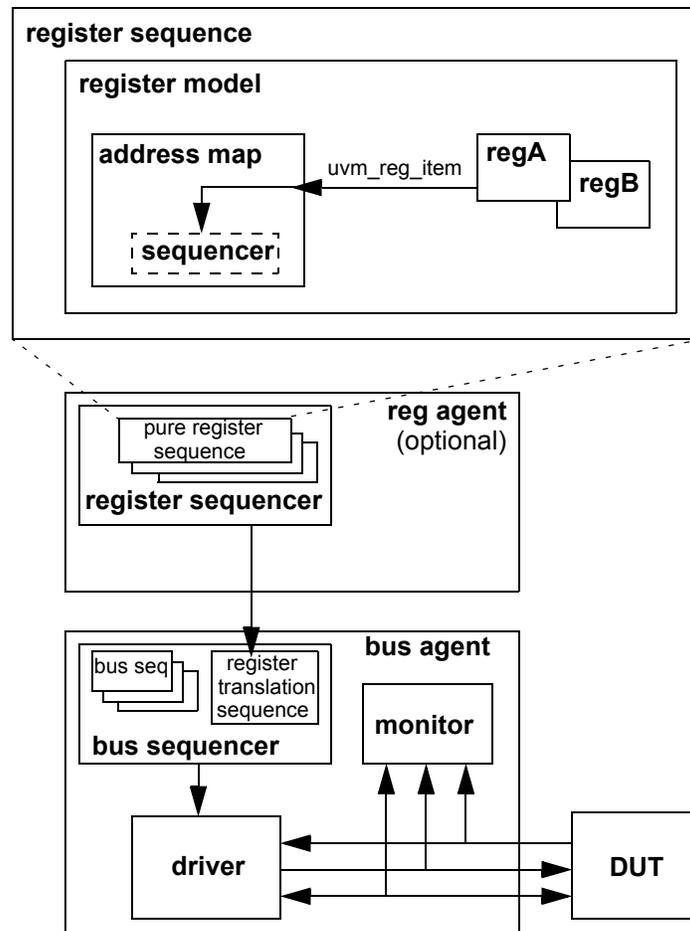


Figure 30—Register Sequence Running on a Layered Register Sequencer

In this scheme, you are effectively moving the built-in register-to-bus item conversion and bus item execution from the register model to an external translation sequence, which can be overridden to perform custom address translation or item conversions. The register model sends abstract `uvm_reg_item` descriptors to the register sequencer. It is the responsibility of the translation sequence running on the bus sequencer to get these abstract items and convert them to physical bus items and start them on the bus sequencer. The `uvm_reg_sequence` base class provides this functionality. It parameterizes its base class to enable it to run on bus-specific sequencers.

This is implemented in the `connect` phase by first registering a `uvm_reg_item` sequencer and null adapter with the address map corresponding to the bus being targeted. In a single-map model, the `default_map` is typically used.

You then create an instance of a translation sequence and configure it with the register sequencer handle and bus adapter. The pre-defined layering sequence `uvm_reg_sequence`, properly parameterized and configured, may be used in this step.

Then, in the `run` phase, you start the translation sequence on the bus sequencer.

```
// translation sequence type
typedef uvm_reg_sequence #(uvm_sequence #(apb_rw)) reg2apb_seq_t;

class block_env extends uvm_env;

    block_reg_model          regmodel;
    uvm_sequencer#(uvm_reg_item) reg_seqr;
    apb_agent                apb;
    reg2apb_seq_t            reg2apb_seq;

    virtual function void connect();
        if (regmodel.get_parent() == null) begin
            regmodel.default_map.set_sequencer(reg_seqr,null);
            reg2apb_seq = reg2apb_seq_t::type_id::create("reg2apb_seq",,
                                                         get_full_name());

            reg2apb_seq.reg_seqr = reg_seqr;
            reg2apb_seq.adapter =
                reg2apb_adapter::type_id::create("reg2apb",,
                                                  get_full_name());

            regmodel.set_auto_predict(1);
        end
    endfunction

    virtual task run();
        reg2apb_seq.start(apb.sequencer);
    endtask

endclass
```

To run a register sequence, you register the model and start it on the register sequencer:

```
class my_test extends uvm_test;

    block_env env;

    virtual function void run();
        my_reg_sequence seq = my_reg_sequence::type_id::create("seq",this);
        seq.start(env.reg_seqr);
    endfunction

endclass
```

endclass

5.9.3 Integrating the Register Model with a Bus Monitor

By default, the register model updates its mirror copy of the register values implicitly. Every time a register is read or written through the register model, its mirror value is updated. However, if other agents on the bus interface perform read and write transactions outside the context of the register model, the register model must learn of these bus operations to update its mirror accordingly.

Integration of a bus monitor (see [Figure 31](#)) to make predictions based on observed transactions is independent from how bus sequencers are integrated. All previously described bus sequencer integration approaches may employ explicit, bus monitor-based prediction.

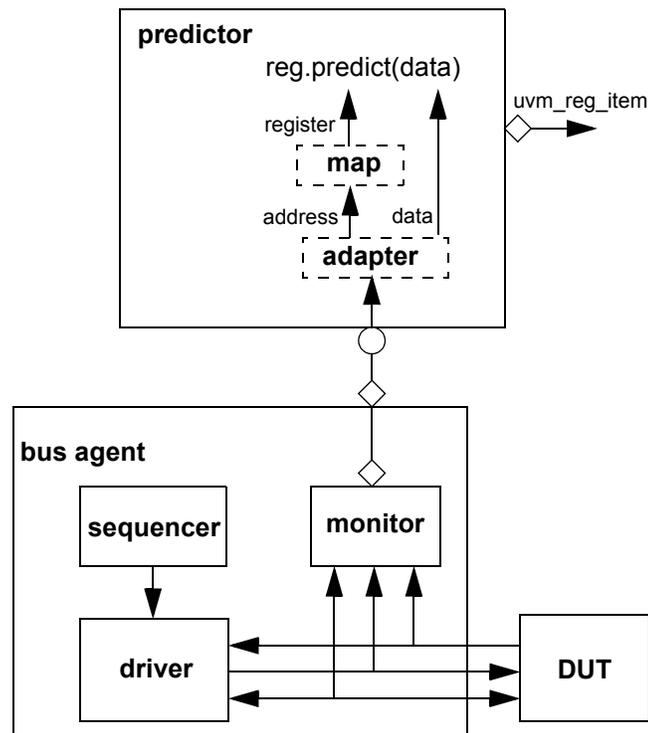


Figure 31—Integration with a Bus Monitor

The predictor accepts bus transactions from a connected bus monitor. It uses the preconfigured adapter to obtain the canonical address and data from the bus operation. The map is used to lookup the register object associated with that address. The register's `predict()` method is then called with the observed data to update the mirror value. If the register width is wider than the bus, the predictor will collect multiple observed bus operations before calling `predict()` with the register's full value. As a final step, a generic `uvm_reg_item` descriptor representing the abstract register operation is broadcast to subscribers of its analysis port.

Integration is accomplished by first instantiating a `uvm_reg_predictor` component, parameterized to the bus transaction type, and configuring it with the adapter and address map in the register model that corresponds to the bus being monitored. The `uvm_reg_predictor` component is then connected to the bus monitor's analysis port.

```
class block_env extends uvm_env;

    block_reg_model          regmodel;
    uvm_reg_predictor#(apb_rw) apb2reg_predictor;
    apb_agent                apb;

    virtual function void build();
        ...
        apb2reg_predictor = new("apb2reg_predictor", this);
    endfunction

    virtual function void connect();

        if (regmodel.get_parent() == null) begin
            reg2apb_adapter reg2apb =
                reg2apb_adapter::type_id::create("reg2apb", , get_full_name());
            ...
            apb2reg_predictor.map = regmodel.APB;
            apb2reg_predictor.adapter = reg2apb;
            regmodel.APB.set_auto_predict(0);
            apb.monitor.ap.connect(apb2reg_predictor.bus_in);
        end
        ...
    endfunction
    ...
endclass
```

When explicit prediction is employed, the implicit prediction must be turned off using `uvm_reg_map::set_auto_predict(0)`.

Note—For register models with a single address map, the name of the address map will be `default_map`.

5.10 Randomizing Field Values

A register model can specify constraints on field values. You can add additional constraints by extending the field, register, register file, or block abstraction class and substituting it in the register model using the factory or by using `randomize() with {}` when randomizing a field, register, register file, or block. When constraining a field value, the class property to be constrained is named `value`. This is *not* the class property that is eventually mirrored or updated and used by the `get()` and `set()` methods; it cannot be used for purposes other than random constraints.

```
ok = regmodel.r1.randomize() with { f1.value <= 'hF; };
```

Once randomized, the selected field values in a register or block may be automatically uploaded to the DUT by using the `uvm_reg::update()` or `uvm_reg_block::update()` method. This will upload any randomized value that is different from the current mirrored value to the DUT. If you override the `post_randomize()` method of a field abstraction class, you must call `super.post_randomize()` to ensure the randomized value is properly set into the mirror.

You can relax constraints specified in a register model by turning the corresponding constraint block OFF.

```
regmodel.r1.consistency.constraint_mode(0);
```

5.11 Pre-defined Sequences

Once a register model has been instantiated in an environment and integrated with the DUT, it is possible to execute any of the predefined register tests sequences to verify the proper operation of the registers and memories in the DUV. It is recommended you start with the simplest test—the hardware reset test—to debug the register model, the environment, the physical transactors, and the DUV to a level where it can be taken through more complicated tests. Some of the predefined test sequences require back-door access be available for registers or memories.

The predefined test sequences in [Table 13](#) are included in the register library. You can combine them in a higher-level virtual sequence to better verify your design. Test sequences are not applied to any block, register, or memory with the `NO_REG_TESTS` attribute defined. Refer to the *UVM 1.1 Class Reference* for more details on each pre-defined test sequence.

Table 13—Pre-defined Test Sequences

Sequence Name	Description	Attributes
<code>uvm_reg_hw_reset_seq</code>	Reads all the register in a block and check their value is the specified reset value.	Skip block or register if any of the following attributes are defined: <code>NO_REG_HW_RESET_TEST</code> <code>NO_REG_TESTS</code>
<code>uvm_reg_single_bit_bash_seq</code>	Sequentially writes 1's and 0's in each bit of the register, checking it is appropriately set or cleared, based on the field access policy specified for the field containing the target bit.	Skip register if any of the following attributes are defined: <code>NO_REG_BIT_BASH_TEST</code> <code>NO_REG_TESTS</code>
<code>uvm_reg_bit_bash_seq</code>	Executes the <code>uvm_reg_single_bit_bash_seq</code> sequence for all registers in a block and sub-blocks.	Skip block if any of the following attributes are defined: <code>NO_REG_BIT_BASH_TEST</code> <code>NO_REG_TESTS</code>
<code>uvm_reg_single_access_seq</code>	Requires the back-door be defined for the register. For each address map in which the register is accessible, writes the register then confirms the value was written using the back-door. Subsequently writes a value via the back-door and checks the corresponding value can be read through the address map.	Skip register if any of the following attributes are defined: <code>NO_REG_ACCESS_TEST</code> <code>NO_REG_TESTS</code>
<code>uvm_reg_access_seq</code>	Executes the <code>uvm_reg_single_access_seq</code> sequence for all registers in a block and sub-blocks.	Skip block if any of the following attributes are defined: <code>NO_REG_ACCESS_TEST</code> <code>NO_REG_TESTS</code>
<code>uvm_mem_single_walk_seq</code>	Write a walking pattern into the memory then checks it can be read back with the expected value.	Skip memory if any of the following attributes are defined: <code>NO_MEM_WALK_TEST</code> <code>NO_MEM_TESTS</code> <code>NO_REG_TESTS</code>

Table 13—Pre-defined Test Sequences (Continued)

Sequence Name	Description	Attributes
uvm_mem_walk_seq	Executes the uvm_mem_single_walk_seq sequence for all memories in a block and sub-blocks.	Skip block if any of the following attributes are defined: NO_MEM_WALK_TEST NO_MEM_TESTS NO_REG_TESTS
uvm_mem_single_access_seq	Requires the back-door be defined the memory. For each address map in which the memory is accessible, writes the memory locations for each memory then confirms the value was written using the back-door. Subsequently writes a value via the back-door and checks the corresponding value can be read through the address map.	Skip memory if any of the following attributes are defined: NO_MEM_ACCESS_TEST NO_MEM_TESTS NO_REG_TESTS
uvm_mem_access_seq	Executes the uvm_mem_single_access_seq sequence for all memories in a block and sub-blocks.	Skip block if any of the following attributes are defined: NO_MEM_ACCESS_TEST NO_MEM_TESTS NO_REG_TESTS
uvm_reg_shared_access_seq	Requires the register be mapped in multiple address maps. For each address map in which the register is accessible, writes the register via one map then confirms the value was written by reading it from all other address maps.	Skip register if any of the following attributes are defined: NO_SHARED_ACCESS_TEST NO_REG_TESTS
uvm_mem_shared_access_seq	Requires the memory be mapped in multiple address maps. For each address map in which the memory is accessible, writes each memory location via one map then confirms the value was written by reading it from all other address maps.	Skip memory if any of the following attributes are defined: NO_SHARED_ACCESS_TEST NO_MEM_TESTS NO_REG_TESTS
uvm_reg_mem_shared_access_seq	Executes the uvm_reg_shared_access_seq sequence for all registers in a block and sub-blocks. Executes the uvm_mem_shared_access_seq sequence for all memories in a block and sub-blocks.	Skip block if any of the following attributes are defined: NO_SHARED_ACCESS_TEST NO_MEM_TESTS NO_REG_TESTS
uvm_reg_mem_built_in_seq	Execute all the selected predefined block-level sequences. By default, all pre-defined block-level sequences are selected.	Applies attributes governing each predefined sequence, as defined above.
uvm_reg_mem_hdl_paths_seq	Verify the HDL path(s) specified for registers and memories are valid.	Skip register or memory if no HDL path(s) have been specified.

6. Advanced Topics

This chapter discusses UVM topics and capabilities of the UVM Class Library that are beyond the essential material covered in the previous chapters. Consult this chapter as needed.

6.1 The `uvm_component` Base Class

All the infrastructure components in an UVM verification environment, including environments and tests, are derived either directly or indirectly from the `uvm_component` class. User-defined classes derived from this class inherit built-in automation. Typically, you will derive your classes from the methodology classes, which are themselves extensions of `uvm_component`. However, understanding the `uvm_component` is important because many of the facilities that the methodology classes offer are derived from this class.

NOTE—The `uvm_threaded_component` class has been deprecated in UVM and is now simply a typedef for `uvm_component`.

The following sections describe some of the capabilities that are provided by the `uvm_component` base class and how to use them. The key pieces of functionality provided by the `uvm_component` base class include:

- Phasing and execution control
- Configuration methods
- Factory convenience methods
- Hierarchical reporting control.

6.2 The Built-In Factory and Overrides

6.2.1 About the Factory

UVM provides a built-in factory to allow components to create objects without specifying the exact class of the object being creating. The factory provides this capability with a static allocation function that you can use instead of the built-in `new` function. The function provided by the factory is:

```
type_name::type_id::create(string name, uvm_component parent)
```

Since the `create()` method is automatically type-specific, it may be used to create components or objects. When creating objects, the second argument, `parent`, is optional.

A component using the factory to create data objects would execute code like the following:

```
task mycomponent::run_phase(uvm_phase phase);
    mytype data; // Data must be mytype or derivative.
    data = mytype::type_id::create("data");
    $display("type of object is: %0s", data.get_type_name());
    ...
endtask
```

In the code above, the component requests an object from the factory that is of type `mytype` with an instance name of `data`.

When the factory creates this object, it will first search for an instance override that matches the full instance name of the object. If no instance-specific override is found, the factory will search for a type-wide override for the type `mytype`. If no type override is found then the type created will be of type `mytype`.

6.2.2 Factory Registration

You must tell the factory how to generate objects of specific types. In UVM, there are a number of ways to do this allocation.

- Use the ``uvm_object_utils(T)` or ``uvm_component_utils(T)` macro in a derivative `uvm_object` or `uvm_component` class declaration, respectively. These macros expand code which will register the given type with the factory. The argument `T` may be a parameterized type

```
`uvm_object_utils(packet)
`uvm_component_utils(my_driver)
```
- Use the ``uvm_object_registry(T,S)` or ``uvm_component_registry(T,S)` registration macros. These macros can appear anywhere in the declaration space of the class declaration of `T` and will associate the string `S` to the object type `T`. These macros are called by the corresponding `uvm_*_utils` macros, so you may only use them if you do not use the `uvm_*_utils` macros.

6.2.3 Component Overrides

A global factory allows you to substitute a predefined-component type with some other type that is specialized for your needs, without having to derive the container type. The factory can replace a component type within the component hierarchy without changing any other component in the hierarchy. You need to know how to use the factory, but not how the factory works.

NOTE—All type-override code should be executed in a parent prior to building the child(ren). This means that environment overrides should be specified in the test.

Two interfaces, `set_type_override_by_type` and `set_inst_override_by_type`, exist to replace default components. These interfaces will be examined one at a time.

To override a default component:

- a) Define a class that derives from the appropriate UVM base class.
- b) Execute the override (described in the following sections).
- c) Build the environment.

6.2.3.1 Type Overrides

The first component override replaces all components of the specified type with the new specified type. The prototype is.

```
set_type_override_by_type(orig_type, override_type, bit replace = 1);
```

The first argument (`orig_type`) is the type, obtained by calling the static `get_type()` method of the type (`orig_type:get_type()`). That type will be overridden by the second argument (`override_type:get_type()`). The third argument, `replace`, determines whether to replace an existing override (`replace = 1`). If this bit is 0 and an override of the given type does not exist, the override is registered with the factory. If this bit is 0 and an override of the given type does exist, the override is ignored.

If no overrides are specified, the environment will be constructed using default types. For example, the environment would be created using an `ubus_master_driver` type component inside `ubus_master_agent.build()`. The `set_type_override_by_type` interface allows you to override this behavior in order to have an `ubus_new_master_driver` for all instances of `ubus_master_driver`.

```
set_type_override_by_type(ubus_master_driver::get_type(),
    ubus_new_master_driver::get_type());
```

This overrides the default type (`ubus_master_driver`) to be the new type (`ubus_new_master_driver`). In this case, we have overridden the type that is created when the environment should create an `ubus_master_driver`. The complete hierarchy would now be built as shown in [Figure 32](#).

NOTE—While only one `ubus_master_driver` instance is replaced in this example, any and all `ubus_master_driver` instances would be replaced in an environment containing multiple `ubus_master_drivers`

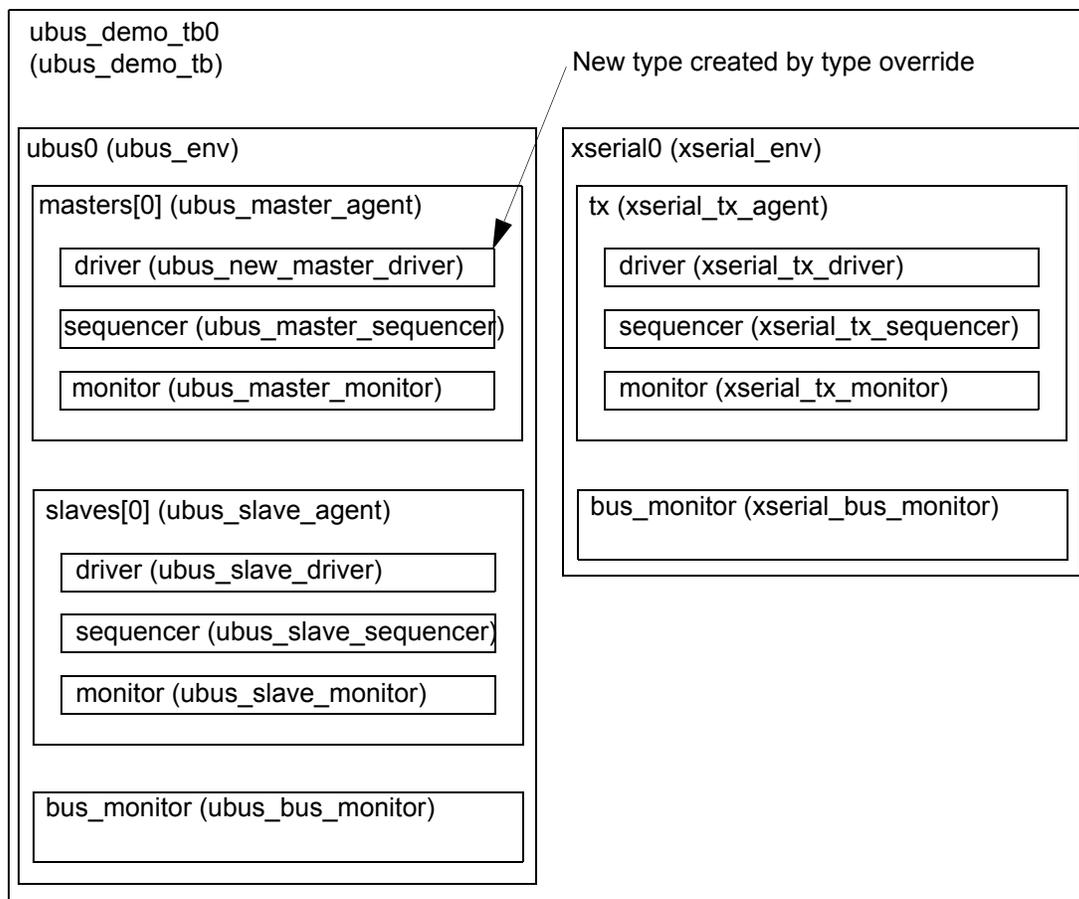


Figure 32—Hierarchy Created with `set_type_override()` Applied

6.2.3.2 Instance Overrides

The second component override replaces targeted components of the matching instance path with the new specified type. The prototype for `uvm_component` is

```
set_inst_override_by_type(string inst_path, orig_type, override_type);
```

The first argument, `inst_path`, is the relative component name of the instance override. It can be considered the “target” of the override. The second argument, `orig_type`, is the type to be overridden (specified by `orig_type::get_type()`) and replaced by the type specified by the last argument, `override_type` (also using `override_type::get_type()`).

Assume the `ubus_new_slave_monitor` has already been defined. Once the following code is executed, the environment will now create the new type, `ubus_new_slave_monitor`, for all instances that match the instance path.

```
set_inst_override_by_type("slaves[0].monitor",
    ubus_slave_monitor::get_type(), ubus_new_slave_monitor::get_type());
```

In this case, the type is overridden that is created when the environment should create an `ubus_slave_monitor` for only the `slaves[0].monitor` instance that matches the instance path in the override. The complete hierarchy would now be built as shown in [Figure 33](#). For illustration purposes, this hierarchy assumes both overrides have been executed.

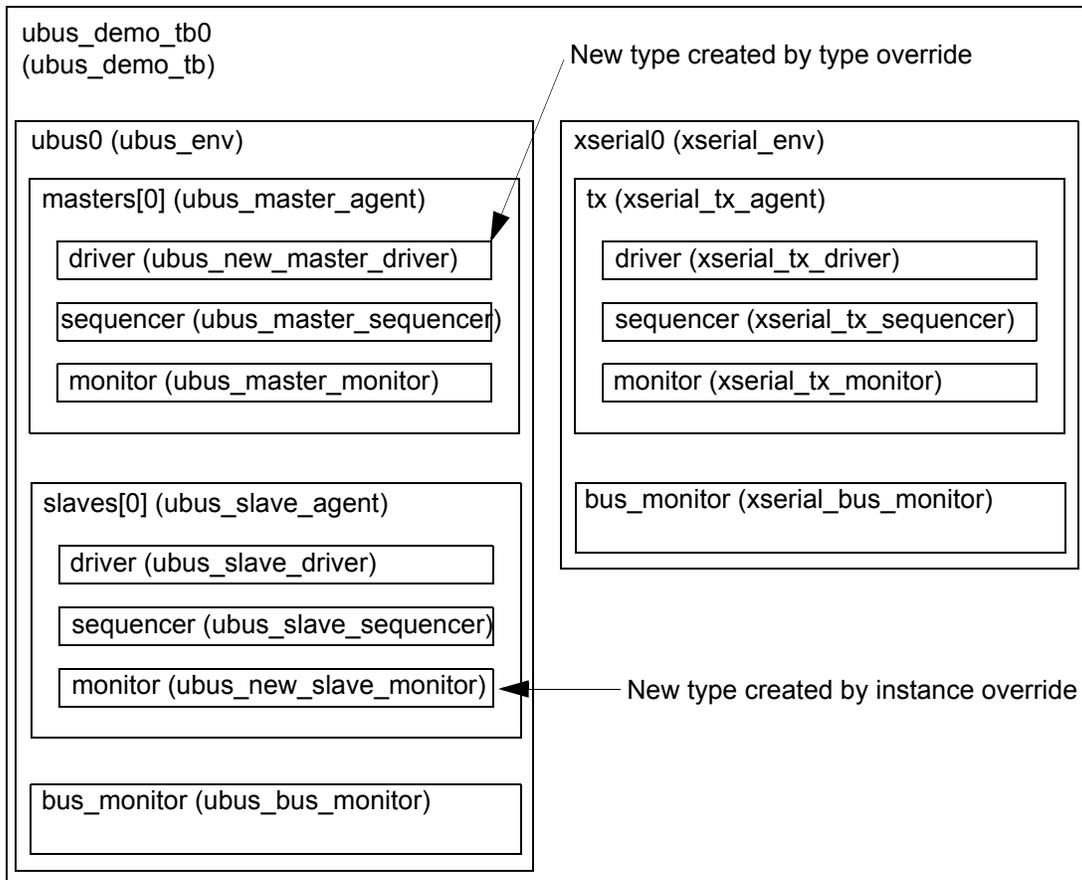


Figure 33—Hierarchy Created with both Overrides Applied

NOTE—Instance overrides are used in a first-match order. For each component, the first applicable instance override is used when the environment is constructed. If no instance overrides are found, then the type overrides are searched for any applicable type overrides. The ordering of the instance overrides in your code affects the application of the instance overrides. You should execute more-specific instance overrides first. For example,

```
set_inst_override_by_type("a.b.*", mytype::get_type(),
    newtype::get_type());
```

```
set_inst_override_by_Type("a.b.c", mytype::get_type(),
                          different_type::get_type());
```

will create `a.b.c` with `different_type`. All other objects under `a.b` of `mytype` are created using `newtype`. If you switch the order of the instance override calls then all of the objects under `a.b` will get `newtype` and the instance override `a.b.c` is ignored.

```
set_inst_override_by_type("a.b.c", mytype::get_type(),
                          different_type::get_type());
set_inst_override_by_type("a.b.*", mytype::get_type(),
                          newtype::get_type());
```

6.3 Callbacks

Callbacks are an optional facility end users can use to augment component behavior

6.3.1 Use Model

To provide a callback facility to end-users, the component developer needs to:

- a) Derive a callback class from the `uvm_callback` base. It should declare one or more methods that comprise the “callback interface”.
- b) Optionally, define a `typedef` to the `uvm_callbacks` pool typed to our specific component-callback combination.
- c) Define the component to iteratively invoke the registered implementations of each method defined in the callback class defined in Step [\(a\)](#) at the desired locations within a component main body of code. Whether a function or a task is used is determined by the ability of the component’s code or behavior to be suspended or not during its execution.

To use callbacks, the user needs to:

- d) Define a new callback class extending from the callback base class provided by the developer, overriding one or more of the available callback methods.
- e) Register one or more instances of the callback with the component(s) you wish to extend.

These steps are illustrated in the following simple example.

6.3.2 Example

The example below demonstrates callback usage. The component developer defines a driver component and a driver-specific callback class. The callback class defines the hooks available for users to override. The component using the callbacks (that is, calling the callback methods) also defines corresponding virtual methods for each callback hook. The end-user may then define either a callback or a driver subtype to extend driver’s behavior.

6.3.2.1 Developer Code

- a) Define a callback class extending from `uvm_callback`.
The callback class defines an application-specific interface consisting of one or more function or task prototypes. The signatures of each method have no restrictions. To be able to use the callback invocation macros, functions should return `void` or `bit` type.

In the example below, a new `bus_bfm_cb` class extending from `uvm_callback` is defined. The developer of the `bus_bfm` component decides to add two hooks for users, `trans_received` and `trans_executed`:

- 1) `trans_received`—the bus driver calls this after it first receives a new transaction item. It provides a handle to both itself and the new transaction. An additional argument determines whether to drop (1) or execute (0) the transaction.
- 2) `trans_executed`—the bus driver calls this after executing the transaction, passing in a handle to itself and the transaction, which may contain read data or other status information.

```
virtual class bus_driver_cb extends uvm_callback;
  virtual function void trans_received(bus_driver driver, bus_tr tr,
                                     ref bit drop);

      endfunction
  virtual task trans_executed(bus_driver driver, bus_tr tr);
      endtask
  function new(string name="bus_driver_cb");
      super.new(name);
  endfunction
endclass
```

- b) Define a typedef to the `uvm_callbacks` pool typed to our specific component-callback combination.

UVM callbacks are type-safe, meaning any attempt to register a callback to a component not designed for that callback simply will not compile. In exchange for this type-safety we must endure a bit of parameterized syntax as follows:

```
typedef uvm_callbacks #(bus_driver, bus_driver_cb) bus_driver_cb_pool;
```

The alias `bus_driver_cb_pool` can help both the component developer and the end-user produce more readable code.

- c) Embed the callback feature in the component that will use it.

The developer of the `bus_bfm` adds the `trans_received` and `trans_executed` virtual methods, with empty default implementations and utilizes some macros that implement the most common algorithms for executing all registered callbacks. With this in place, end-users can now customize component behavior in two ways:

- extend `bus_driver` and override one or more of the virtual methods `trans_received` or `trans_executed`. Then configure the factory to use the new type via a type or instance override.
- extend `bus_driver_cb` and override one or more of the virtual methods `trans_received` or `trans_executed`. Then register an instance of the new callback type with all or a specific instance of `bus_driver`. The latter requires access to the specific instance of the `bus_driver`.

```
class bus_driver extends uvm_driver;
  function new (string name, uvm_component parent=null);
      super.new(name,parent);
  endfunction
  `uvm_register_cb(bus_driver, bus_driver_cb)
  virtual function bit trans_received(bus_tr tr, ref bit drop);
      endfunction
  virtual task trans_executed(bus_tr tr);
      endtask
  virtual task run_phase(uvm_phase phase);
      super.run_phase(phase);
  forever begin
      bus_tr tr;
      bit drop = 0;
      seq_item_port.get_next_item(tr);
```

```

        `uvm_info("bus_tr received",tr.convert2string(), UVM_LOW)
        trans_received(tr, drop);
        `uvm_do_callbacks(bus_driver_cb, bus_driver,
            trans_received(this, tr, drop))
    if (drop) begin
        `uvm_info("bus_tr dropped",
            "user callback indicated DROPPED", UVM_HIGH)
        return;
    end
    #100;
    trans_executed(tt);
    `uvm_do_callbacks(bus_driver_cb, bus_driver,
        trans_executed(this, tr))
    `uvm_info("bus_tr executed", tr.convert2string(), UVM_LOW)
    seq_item_port.item_done(tr);
end // forever
endtask
endclass

```

The driver's put task, which implements the component's primary functionality, merely calls the virtual methods and callbacks at the appropriate times during execution.

6.3.2.2 End User Code

Using the callback feature of a component involves the following steps:

- a) Extend the developer-supplied callback class.

Define a new callback class that extends from the class provided by the component developer, implementing any or all of the methods of the callback interface.

In our example, we define both hooks, `trans_received` and `trans_executed`. For `trans_received`, we randomly choose whether to return 0 or 1. When 1, the `bus_driver` will "drop" the received transaction. For `trans_executed`, we delay #10 to prevent back-to-back transactions.

```

class my_bus_bfm_cb extends bus_bfm_cb;
    function new(string name="bus_bfm_cb_inst");
        super.new(name);
    endfunction
    `uvm_object_utils(my_bus_bfm_cb)
    virtual function bit trans_received(bus_bfm driver, bus_tr tr);
        `uvm_info_context("trans_received_cb",
            {" bus_bfm=",driver.get_full_name(),
            tr=",tr.convert2string() }, UVM_LOW, driver)
        return $urandom & 1;
    endfunction
    virtual task trans_executed(bus_bfm driver, bus_tr tr);
        `uvm_info("trans_executed_cb",
            {" bus_bfm=",driver.get_full_name(),
            tr=",tr.convert2string() }, UVM_LOW, driver)
        #10;
    endtask
endclass

```

- b) Create callback object(s) and register with component you wish to extend.

To keep the example simple and focus on callback usage, we do not show a complete or compliant UVM environment.

In the top module, we instantiate the `bus_bfm` and an instance of our custom callback class. To register the callback object with the driver, we first get a handle to the global callback pool for our

specific driver-callback combination. Luckily, the developer provided a convenient typedef in his Step [\(b\)](#) that makes our code a little more readable.

Then, we associate (register) the callback object with a driver using the callback pool's `add_cb` method. After calling `display_cbs` to show the registration was successful, we push several transactions into the driver. The output shows that the methods in our custom callback implementation are called for each transaction the driver receives.

```
module top;
    bus_tr          tr      = new;
    bus_bfm         driver = new("driver");
    my_bus_bfm_cb   cb      = new("cb");

    initial begin
        bd_cb::add(driver,cb);
        cbs.display_cbs();
        for (int i=1; i<=5; i++) begin
            tr.addr = i;
            tr.data = 6-i;
            driver.in.put(tr);
        end
    end
endmodule
```

- c) Instance-specific callback registrations can only be performed after the component instance exists. Therefore, those are typically done in the `build()` and `end_of_elaboration()` for extensions that need to apply for the entire duration of the test and in the `run()` method for extensions that need to apply for a specific portion of the testcase.

```
class error_test extends uvm_test;
    function new(name = "error_test", uvm_component parent = null);
        super.new(name, parent);
    endfunction

    virtual task run_phase(uvm_phase phase);
        cbs = new;
        #1000;
        bd_cb::add_by_name(cbs, "top.bfm");
        #100;
        bd_cb::delete(cbs);
    endtask
endclass
```

6.4 The Sequence Library

In UVM, it is possible to group similar sequences together into a *sequence library*. The `uvm_sequence_library` is an extension of the `uvm_sequence` base class.

```
class uvm_sequence_library #(type REQ=int, RSP=REQ)
    extends uvm_sequence#(REQ,RSP);
```

The `uvm_sequence_library` is a sequence that contains a list of registered sequence types. It can be configured to create and execute these sequences any number of times using one of several modes of operation, including a user-defined mode. When started (as any other sequence) the sequence library will randomly select and execute a sequence from its sequences queue, depending on the `selection_mode` chosen.

- UVM_SEQ_LIB_RAND: Randomly select from the queue.
- UVM_SEQ_LIB_RANDC: Randomly select from the queue without repeating until all sequences have executed.
- UVM_SEQ_LIB_ITEM: Execute a single item.
- UVM_SEQ_LIB_USER: Call the `select_sequence()` method, which the user may override, to generate an index into the queue to select a sequence to execute.

The selection mode may be set using the configuration database:

```
uvm_config_db#(uvm_sequence_lib_mode)::set(this, "<sequencer path>",
                                           "default_sequence.selection_mode",
                                           MODE);
```

To create a sequence library, declare your own extension of `uvm_sequence_library` and initialize it as follows:

```
class my_seq_lib extends uvm_sequence_library #(my_item);
  `uvm_object_utils(my_seq_lib)
  `uvm_sequence_library_utils(my_seq_lib)
  function new(string name="");
    super.new(name);
    init_sequence_library();
  endfunction
  ...
endclass
```

Individual sequence types may then be added to the sequence library, by type, using the ``uvm_add_to_seq_lib` macro:

```
class my_seq1 extends my_seq;
  `uvm_object_utils(my_seq1);
  `uvm_add_to_seq_lib(my_seq1, my_seq_lib)
  `uvm_add_to_seq_lib(my_seq1, my_other_seq_lib)
  ...
endclass
```

A sequence type may be added to more than one sequence library by having multiple ``uvm_add_to_seq_lib` calls in the sequence definition. The parameterization of the sequences and the sequence library must be compatible. The sequence library is then just started as any other sequence.

```
uvm_config_db#(ovm_object_wrapper)::set(this, "<sequencer path>.<phase>",
                                           "default_sequence",
                                           my_seq_lib::type_id::get());
```

6.5 Advanced Sequence Control

This section discusses advanced techniques for sequence control.

6.5.1 Implementing Complex Scenarios

This section highlights how to implement various complex scenarios.

6.5.1.1 Executing Multiple Sequences Concurrently

There are two ways you can create concurrently-executing sequences: the following subsections show an example of each method.

6.5.1.1.1 Using the `uvm_do` Macros with `fork/join`

In this example, the sequences are executed with `fork/join`. The simulator schedules which sequence requests interaction with the sequencer. The sequencer schedules which items are provided to the driver, arbitrating between the sequences that are willing to provide an item for execution and selects them one at a time. The `a` and `b` sequences are subsequences of the `fork_join_sequence`.

```
class fork_join_sequence extends uvm_sequence #(simple_item);
... // Constructor and UVM automation macros go here.
    // See Section 4.8.2
    a_seq a;
    b_seq b;
virtual task body();
    fork
        `uvm_do(a)
        `uvm_do(b)
    join
endtask : body
endclass : fork_join_sequence
```

6.5.1.1.2 Starting several Sequences in Parallel

In this example, the `concurrent_seq` sequence activates two sequences in parallel. It does not wait for the sequences to complete. Instead, it immediately finishes after activating the sequences. Also, the `a` and `b` sequences are started as root sequences.

```
class concurrent_seq extends uvm_sequence #(simple_item);
... // Constructor and UVM automation macros go here.
    // See Section 4.8.2
    a_seq a;
    b_seq b;
virtual task body();
    // Initialize the sequence variables with the factory.
    `uvm_create(a)
    `uvm_create(b)
    // Start each subsequence as a new thread.
    fork
        a.start(p_sequencer);
        b.start(p_sequencer);
    join
endtask : body
endclass : concurrent_seq
```

NOTE—The `sequence.start()` method allows the sequence to be started on any sequencer.

See `uvm_create` in the *UVM 1.1 Class Reference* for additional information.

6.5.1.1.3 Using the `pre_body()` and `post_body()` Callbacks

The UVM Class Library provides two additional callback tasks, `pre_body()` and `post_body()`, which are invoked before and after the sequence's `body()` task, respectively. These callbacks are invoked only when a sequence is started by its sequencer's `start_sequence()` task or the sequence's `start()` task.

Examples of using the `pre_body()` and `post_body()` callbacks include:

- Synchronization to some event before the `body()` task starts.
- Calling a cleanup task when the `body()` task ends.

The following example declares a new sequence type and implements its callback tasks.

```
class revised_seq extends fork_join_sequence;
    ... // Constructor and UVM automation macros go here.
        // See Section 4.8.2
    task pre_body();
        super.pre_body();
        // Wait until initialization is done.
        @p_sequencer.initialization_done;
    endtask : pre_body
    task post_body();
        super.post_body();
        do_cleanup();
    endtask : post_body
endclass : revised_seq
```

The `pre_body()` and `post_body()` callbacks are not invoked in a sequence that is executed by one of the ``uvm_do` macros.

NOTE—The `initialization_done` event declared in the sequencer can be accessed directly via the `p_sequencer` variable. The `p_sequencer` variable is available since the ``uvm_sequence_utils` macro was used. This prevents the user from having to declare a variable of the appropriate type and initialize it using `$cast`.

6.5.1.2 Interrupt Sequences

A DUT might include an interrupt option. Typically, an interrupt should be coupled with some response by the agent. Once the interrupt is serviced, activity prior to the interrupt should be resumed from the point where it was interrupted. Your verification environment can support interrupts using sequences.

To handle interrupts using sequences:

- a) Define an interrupt handler sequence that will do the following:
 - 1) Wait for the interrupt event to occur.
 - 2) Grab the sequencer for exclusive access.
 - 3) Execute the interrupt service operations using the proper items or sequences.
 - 4) Ungrab the sequencer.
- b) Start the interrupt-handler sequence in the sequencer or in the default sequence. (You can configure the sequencer to run the default sequence when the simulation begins.)

Example

Define an interrupt handler sequence.

```
// Upon an interrupt, grab the sequencer, and execute a
// read_status_seq sequence.
class interrupt_handler_seq extends uvm_sequence #(bus_transfer);
    ... // Constructor and UVM automation macros here
        // See Section 4.8.2
    read_status_seq interrupt_clear_seq;
    virtual task body();
        forever begin
            // Initialize the sequence variables with the factory.
```

```

        @p_sequencer.interrupt;
        grab(p_sequencer);
        `uvm_do(interrupt_clear_seq)
        ungrab(p_sequencer);
    end
    endtask : body
endclass : interrupt_handler_seq

```

Then, start the interrupt handler sequence in the sequencer. The example below does this in the sequencer itself at the run phase:

```

class my_sequencer extends uvm_sequencer;
    ... // Constructor and UVM automation macros here
        // See Section 4.8.2
    interrupt_handler_seq interrupt_seq;
    virtual task run_phase(uvm_phase phase);
        interrupt_seq =
            interrupt_handler_seq::type_id::create("interrupt_seq");
        fork
            interrupt_seq.start(this);
        join_none
        super.run();
    endtask : run
endclass : my_sequencer

```

NOTE—In this step, we cannot use any of the ``uvm_do` macros since they can be used only in sequences. Instead, we use utility functions in the sequencer itself to create an instance of the interrupt handler sequence through the common factory.

6.5.1.3 Controlling the Scheduling of Items

There might be several sequences doing items concurrently. However, the driver can handle only one item at a time. Therefore, the sequencer maintains a queue of `do` actions. When the driver requests an item, the sequencer chooses a single `do` action to perform from the `do` actions waiting in its queue. Therefore, when a sequence is doing an item, the `do` action is blocked until the sequencer is ready to choose it.

The scheduling algorithm works on a first-come-first-served basis. You can affect the algorithm using `grab()`, `ungrab()`, and `is_relevant()`.

If a sequence is grabbing the sequencer, then the sequencer will choose the first `do` action that satisfies the following conditions:

- It is done by the grabbing sequence or its descendants.
- The `is_relevant()` method of the sequence doing it returns 1.

If no sequence is grabbing the sequencer, then the sequencer will choose the first `do` action that satisfies the following condition:

The `is_relevant()` method of the sequence doing it returns 1.

If there is no `do` action to choose, then `get_next_item()` is blocked. The sequencer will try to choose again (that is, reactivate the scheduling algorithm) when one of the following happens:

- a) Another `do` action is added to the queue.
- b) A new sequence grabs the sequencer, or the current grabber ungrabs the sequencer.
- c) Any one of the blocked sequence's `wait_for_relevant()` task returns. See [Section 6.5.1.4](#) for more information.

When calling `try_next_item()`, if the sequencer does not succeed in choosing a do action before the time specified in `uvm_driver::wait_for_sequences()`, `uvm_driver::try_next_item()` returns with `NULL`.

6.5.1.4 Run-Time Control of Sequence Relevance

In some applications, it is useful to invoke sequences concurrently with other sequences and have them execute items under certain conditions. Such a sequence can therefore become relevant or irrelevant, based on the current conditions, which may include the state of the DUT, the state of other components in the verification environment, or both. To implement this, you can use the `is_relevant()` function. Its effect on scheduling is discussed in [Section 6.5.1.3](#).

If you are using `is_relevant()`, you must also implement the `wait_for_relevant()` task to prevent the sequencer from hanging under certain circumstances. The following example illustrates the use of both.

```
class flow_control_seq extends uvm_sequence #(bus_transfer);
... // Constructor and UVM automation macros go here.
    // See Section 4.8.2

    bit relevant_flag;
    function bit is_relevant();
        return(relevant_flag);
    endfunction

    // This task is started by the sequencer if none of the running
    // sequences is relevant. The task must return when the sequence
    // becomes relevant again.
    task wait_for_relevant();
        while(!is_relevant())
            @(relevant_flag); // Use the appropriate sensitivity list.
    endtask

    task monitor_credits();
        ...
        // Logic goes here to monitor available credits, setting
        // relevant_flag to 1 if enough credits exist to send
        // count frames, 0 otherwise.
    endtask : monitor_credits

    task send_frames();
        my_frame frame;
        repeat (count) `uvm_do(frame)
    endtask : send_frames

    virtual task body();
        fork
            monitor_credits();
            send_frames();
        join_any
    endtask : body
endclass : flow_control_seq
```

6.5.2 Protocol Layering

This section discusses the layering of protocols and how to implement it using sequences.

6.5.2.1 Introduction to Layering

Some verification environments require layering of data items of different protocols. Examples include TCP over IP and ATM over Sonet. Sequence layering and virtual sequences are two ways in which sequencers can be composed to create a layered protocol implementation.

6.5.2.2 Layering of Protocols

The classic example of protocol layering can be described by generic higher- and lower-levels (or layers) of a protocol. An array of bytes may be meaningless to the lower-level protocol, while in the higher-level protocol context, the array provides control and data messages to be processed appropriately.

For example, assume there are two sequencers. The low-layer sequencer drives `lower_layer_items`, defined as:

```
class lower_layer_item extends uvm_sequence_item;
  ... // Constructor and UVM automation macros go here.
      // See Section 4.8.2.
  bit[MAX_PL:0][DATA_SIZE-1:0] payload;
endclass : lower_layer_item
```

The low-level sequences base class is defined as:

```
class lower_layer_seq_base extends uvm_sequence #(lower_layer_item);
  ... // Constructor and UVM automation macros go here.
      // See Section 4.8.2
  lower_layer_item item;
  virtual task body();
  ...
  endtask : body
endclass : lower_layer_seq_base
```

In one case, you want to send `lower_layer_items` with random data. In another case, you want the data to come from a higher-layer data protocol. The higher-layer protocol in this example drives `lower_layer_items` which will be mapped to one or more `lower_layer_items`. Therefore, the high-level sequence base class is defined as:

```
class higher_layer_seq_base extends uvm_sequence #(higher_layer_item);
  ... // Constructor and UVM automation macros
      // See Section 4.8.2
  higher_layer_item item;
  virtual task body();
  ...
  endtask : body
endclass : higher_layer_seq_base
```

6.5.2.3 Layering and Sequences

Layering is best implemented with sequences. There are two ways to do layering using sequences: the following subsections show an example of each method.

6.5.2.3.1 Layering inside one Sequencer

For simple cases, you can layer inside one sequencer by generating a data item of the higher layer within a lower-layer sequence. Do this by creating another sequence kind for the lower-layer sequencer. For example:

```

class use_higher_level_item_seq extends lower_layer_base_seq;
... // Constructor and UVM automation macros go here.
    // See Section 4.8.2
higher_layer_item hli;
lower_layer_item lli;
task body();
    // Create a higher-level item.
    `uvm_create(hli)
    ... // Randomize it here.
    send_higher_level_item(hli);
endtask : body
task send_higher_level_item(higher_layer_item hli);
for(int i = 0 ; i< hli.length; i++) begin
    // Convert the higher-level item to lower-level items and send.
    `uvm_create(lli);
    ... // Slice and dice hli to form property values of lli.
    `uvm_send(lli)
end
endtask : send_higher_level_item
endclass: use_higher_level_item_seq

```

The `use_higher_level_item_seq` sequence generates a single `higher_layer_item` and sends it in chunks, in one or more `lower_layer_items`, until the data of the `higher_layer_item` is exhausted. See `uvm_create` in the *UVM 1.1 Class Reference* for more information.

6.5.2.3.2 Layering of Several Sequencers

This general approach to layering several sequencers uses multiple sequencers as shown in [Figure 34](#).

Taking the `higher_layer_item` and `lower_layer_item` example, there is a lower-layer sequence and a higher-layer sequence (complete with their sequencers). The lower-layer sequence pulls data from the higher-layer sequencer (or from the higher-layer driver).

Each sequencer can be encapsulated in a verification component so that layering can be done by connecting the verification components.

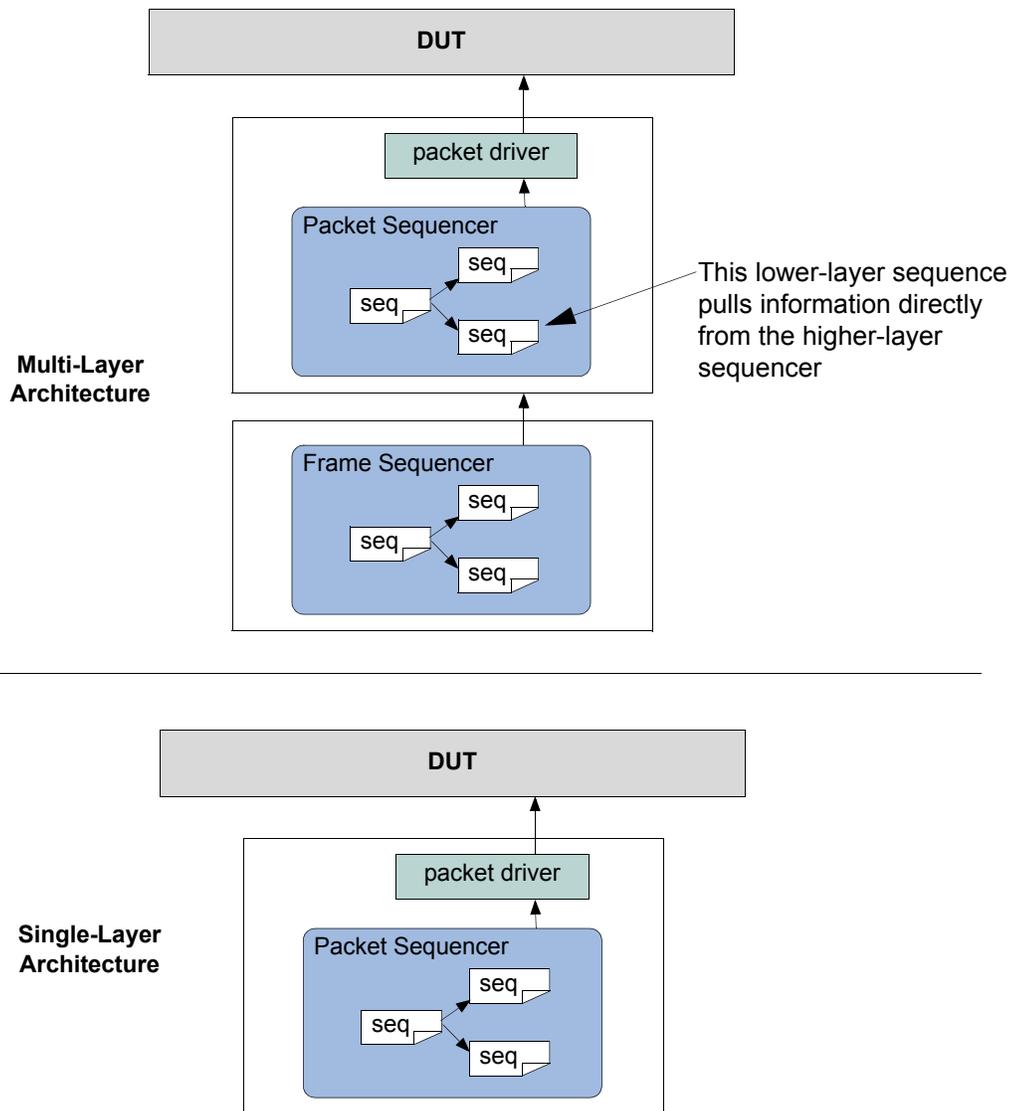


Figure 34—Layering Architecture

6.5.2.4 Styles of Layering

This section explores the various layering styles.

6.5.2.4.1 Basic Layering

The simplest general scenario of basic layering consists of:

- The driver accepts `layer1` items.
- The `layer1` items are constructed from `layer2` items in some way. The `layer2` items are, in turn, constructed from `layer3` items, and so on.
- For every `layerN` and `layerN+1`, there is a mechanism that takes `layerN+1` items and converts them into `layerN` items.

You can also have multiple kinds of `layer1` and `layer2` items. In different configurations, you might want to layer any kind of `layer2` item over any kind of `layer1` item (see [Figure 35](#)).

The remainder of this section describes possible variations and complications, depending on the particular protocol or on the desired test-writing flexibility.

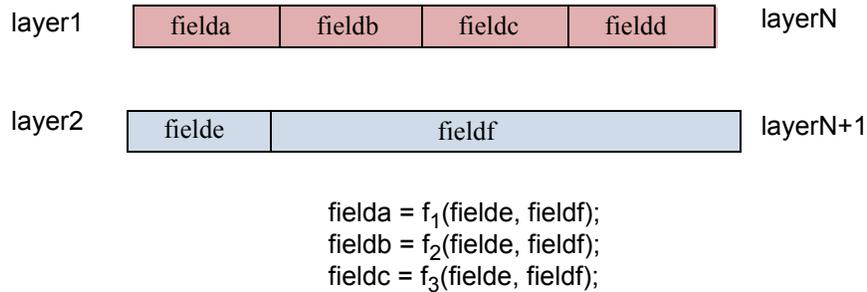


Figure 35—Protocol Layering

6.5.2.4.2 One-to-One, One-to-Many, Many-to-One, Many-to-Many

A conversion mechanism might need to cope with the following situations (see [Figure 36](#)):

- a) One-to-one—One high-layer item must be converted into one low-layer item.
- b) One-to-many—One large high-layer item must be broken into many low-layer items.
- c) Many-to-one—Many high-layer items must be combined into one large low-layer item (as in Sonet, for example).
- d) Many-to-many—Multiple higher-layer items must be taken in and converted into multiple lower-layer items. For example, high-layer packets are 10-bytes long, and low-layer packets are 3- to 35-bytes long. In this case, there could be remainders.

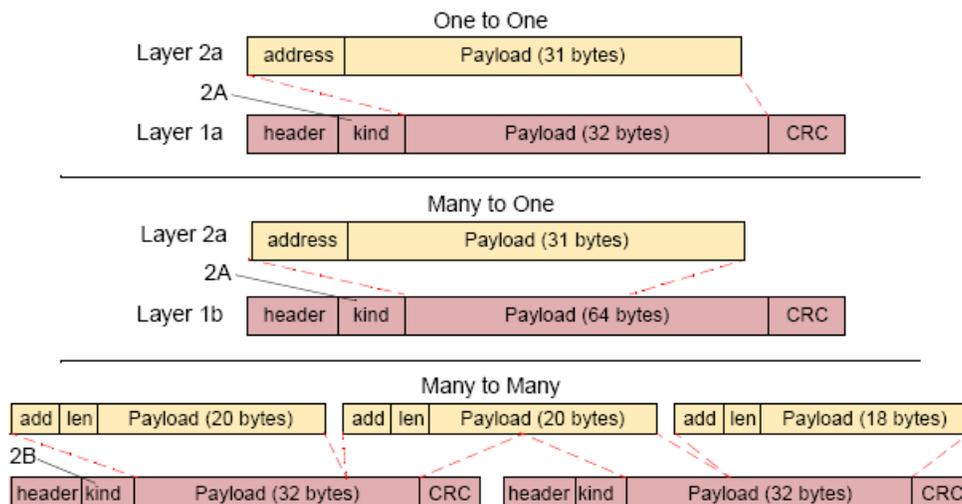


Figure 36—Layer Mapping

6.5.2.4.3 Different Configurations at Pre-Run Generation and Run Time

A system might need to support different modes of operation defined by topology, data type, or other application-specific requirements. For example, in one environment, you might have only `layer1` items. In another environment, `layer1` items would be dictated by `layer2` items. You might also want to decouple the layers further, for example, so `layer2` items could drive either `layer1` items or `layer1` cells (on another interface) or both.

At times, you might have a mix of inputs from multiple sources at run time. For example, you might want to have one low-layer sequencer send items that come from several high-layer sequencers.

6.5.2.4.4 Timing Control

In some configurations, the high-layer items drive the timing completely. When high-layer items are created, they are immediately converted into low-layer items.

In other configurations, the low-layer sequences pace the operation. When a low-layer `do` macro is executed, the corresponding high-layer item should appear in zero time.

Finally, there is a case where items are driven to the DUT according to the timing of the low-layer sequences, but the high-layer sequences are not reacting in zero time. Rather, if there is no data available from the high-layer sequences, then some default value (for example, a zero filler) is used instead. `uvm_driver::try_next_item()` would be used by the lower-level driver in this case.

6.5.2.4.5 Data Control

In some configurations, the high-layer items completely dictate which low-layer items reach the DUT. The low layer simply acts as a slave.

Often, however, both layers influence what reaches the DUT. For example, the high layer might influence the data in the payload while the low layer influences other attributes of the items reaching the DUT. In these cases, the choice of sequences for both layers is meaningful.

6.5.2.4.6 Controlling Sequences on Multiple Sequencers

In the most general case, you have a graph consisting of several sequencers, some of which may control sequence execution on other sequencers and some of which may generate items directly. Some low-layer “driver sequencers” are connected to the DUT, some higher-layer driver sequencers are layered above them, and some sequencers on top feed into all of the driver sequencers below.

In the example configuration shown in [Figure 37](#), a low-layer sequencer (L1B) gets input from multiple high-layer sequencers (two instances of L2A), as well as from a controlling sequencer.

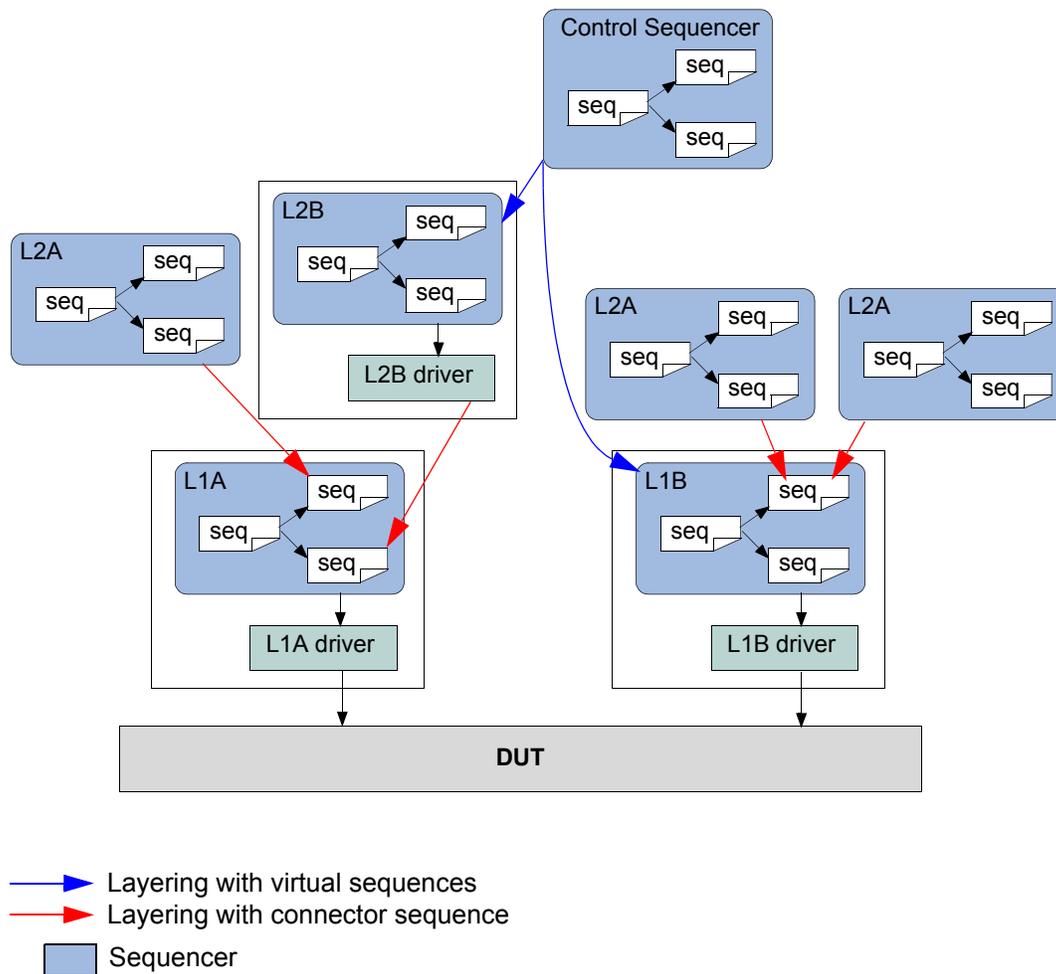


Figure 37—Most-General Case of using Virtual Sequencers

6.5.2.5 Using Layered Sequencers

Layered sequencers work as follows:

- Higher-layer sequencers operate as usual, generating upper-layer data items and sending them through the `seq_item_pull_export`. In most cases, you will not need to change the upper-layer sequencer or sequences that will be used in a layered application.
- The lower-layer sequencers connect to the higher-layer sequencer(s) from which information must be pulled. The pulled information (a higher-layer item) is put in a property of the sequence and is then used to constrain various properties in the lower-layer item(s). The actual connectivity between the layers is done in the same manner as the connection between a sequencer and a driver. To connect to the higher-layer sequencer, declare a corresponding `uvm_seq_item_pull_port` in the lower-layer sequencer (see [Section 6.5.2.6](#)). The connection itself is performed at the time the containing object's `connect()` method is invoked.
- The lower-layer sequencers send information to a lower-layer driver that interacts with a DUT's physical interface.

Assuming you already have created (or are reusing) upper-layer and lower-layer sequencers, follow these steps to create the layering:

- a) Create a lower-layer sequence which does the following:
 - 1) Repeatedly pulls upper-layer items from the upper-layer sequencer.
 - 2) Translates them to lower-layer items.
 - 3) Sends them to the lower-layer driver.

To preserve late generation of the upper-layer items, pull the upper-layer items from within the lower-sequence's `pre_do()` task. This ensures the upper-layer item will be randomized only when the lower-layer driver is ready to start processing the matching lower-layer items.

- b) Connect the lower-layer sequencer to the upper-layer sequencer using the same technique as when connecting a driver to a sequencer.
- c) Configure the lower-layer sequencer's default sequence to be the sequence you created in Step [\(a\)](#).

6.5.2.6 Layered Sequencers Examples

Assume you are reusing the upper- and lower-layer classes from components created earlier. The lower-layer components are likely to be encapsulated inside an agent modeling the interface protocol. This example shows how to achieve layering without introducing the recommended reuse structure to keep the code compact.

```
// Upper-layer classes
class upper_item extends uvm_sequence_item;
...
endclass : upper_item
class upper_sequencer extends uvm_sequencer #(upper_item);
...
endclass : upper_sequencer
// Lower-layer classes
class lower_item extends uvm_sequence_item;
...
endclass : lower_item
class lower_sequencer extends uvm_sequencer #(lower_item);
  uvm_seq_item_pull_port #(upper_item) upper_seq_item_port;
  ...
  function new (string name, uvm_component parent);
    super.new(name, parent);
    upper_seq_item_port = new("upper_seq_item_port",this);
  endfunction : new
  ...
endclass : lower_sequencer
class lower_driver extends uvm_driver #(lower_item);
...
endclass : lower_driver
```

Now create a lower-layer sequence that pulls upper-layer items and translates them to lower-layer items.

```
class higher_to_lower_seq extends uvm_sequence #(lower_item);
  ... // Constructor and UVM automation macros go here.
  // See Section 4.8.2
  upper_item u_item;
  lower_item l_item;
  virtual task body();
    forever begin
      `uvm_do_with(l_item,
        { ... }) // Constraints based on u_item
    end
  endtask : body
```

```

// In the pre_do task, pull an upper item from upper sequencer.
virtual task pre_do(bit is_item);
    p_sequencer.upper_seq_item_port.get_next_item(u_item);
endtask : pre_do

// In the post_do task, signal the upper sequencer we are done.
// And, if desired, update the upper-item properties for the
// upper-sequencer to use.
virtual function void post_do(uvm_sequence_item this_item);
    p_sequencer.upper_seq_item_port.item_done(this_item);
endfunction : post_do

endclass : higher_to_lower_seq

```

The following example illustrates connecting a lower-layer sequencer with an upper-layer sequencer.

NOTE—The lower-layer sequencer is likely to be encapsulated inside an interface verification component; therefore, it will be encapsulated in an env and an agent. This does not change the layering scheme, but changes the path to connect the sequencers to each other in the tb file. The connection to the upper sequencer to the lower sequencer will typically happen in the tb env, whereas the connection from lower sequencer to its driver will happen in the connect () phase of the agent.

```

// This code resides in an env class.
lower_driver    l_driver0;
lower_sequencer l_sequencer0;
upper_sequencer u_sequencer0;

function void build();
    super.build();
    // Make lower sequencer execute upper-to-lower translation sequence.
    set_config_string("l_sequencer0", "default_sequence",
        "higher_to_lower_seq");
    // Build the components.
    l_driver0 = lower_driver::type_id::create("l_driver0", this);
    l_sequencer0 = lower_sequencer::type_id::create("l_sequencer0", this);
    u_sequencer0 = upper_sequencer::type_id::create("u_sequencer0", this);
endfunction : build

// Connect the components.
function void connect();
    // Connect the upper and lower sequencers.
    l_sequencer0.upper_seq_item_port.connect(u_sequencer0.seq_item_export);
    // Connect the lower sequencer and driver.
    l_driver0.seq_item_port.connect(l_sequencer0.seq_item_export);
endfunction : connect

```

6.5.3 Generating the Item or Sequence in Advance

The various ``uvm_do*` macros perform several steps sequentially, including the allocation of an object (sequence or sequence item), synchronization with the driver (if needed), randomization, sending to the driver, and so on. The UVM Class Library provides additional macros that enable finer control of these various steps. This section describes these macros.

6.5.3.1 ``uvm_create`

This macro allocates an object using the common factory and initializes its properties. Its argument is a variable of type `uvm_sequence_item` or `uvm_sequence`. You can use the macro with SystemVerilog's `constraint_mode()` and `rand_mode()` functions to control subsequent randomization of the sequence or sequence item.

In the following example, `my_seq` is similar to previous sequences that have been discussed. The main differences involve the use of the ``uvm_create(item0)` call. After the macro call, the `rand_mode()` and `constraint_mode()` functions are used and some direct assignments to properties of `item0` occur. The manipulation of the `item0` object is possible since memory has been allocated for it, but randomization has not yet taken place. Subsequent sections will review the possible options for sending this pre-generated item to the driver.

```
class my_seq extends uvm_sequence #(my_item);
... // Constructor and UVM automation macros go here.
    // See Section 4.8.2
virtual task body();
    `uvm_create(req)
    req.addr.rand_mode(0); // Disables randomization of addr
    req.dcl.constraint_mode(0); // Disables constraint dcl
    req.addr = 27;
    ...
endtask : body
endclass: my_seq
```

You can also use a sequence variable as an argument to ``uvm_create`.

NOTE—You might need to disable a constraint to avoid a conflict.

6.5.3.2 `uvm_send

This macro processes the `uvm_sequence_item` or `uvm_sequence` class handle argument as shown in [Figure 16](#) and [Figure 17](#), without any allocation or randomization. Sequence items are placed in the sequencer's queue to await processing while subsequences are processed immediately. The parent `pre_do()`, `mid_do()`, and `post_do()` callbacks still occur as shown.

In the following example, we show the use of `uvm_create()` to pre-allocate a sequence item along with ``uvm_send`, which processes it as shown in [Figure 16](#), without allocation or randomization.

```
class my_seq2 extends uvm_sequence #(my_item);
... // Constructor and UVM automation macros go here.
    // See Section 4.8.2
virtual task body();
    `uvm_create(req)
    req.addr = 27;
    req.data = 4;
    // No randomization. Use a purely pre-generated item.
    `uvm_send(req)
endtask : body
endclass: my_seq2
```

Similarly, a sequence variable could be provided to the ``uvm_create` and ``uvm_send` calls above, in which case the sequence would be processed in the manner shown in [Figure 17](#), without allocation or randomization.

6.5.3.3 `uvm_rand_send, `uvm_rand_send_with

These macros are identical to ``uvm_send` (see [Section 6.5.3.2](#)), with the single difference of randomizing the given class handle before processing it. This enables you to adjust an object as required while still using class constraints with late randomization, that is, randomization on the cycle that the driver is requesting the item. ``uvm_rand_send()` takes just the object handle. ``uvm_rand_send_with()` takes an extra argument, which can be any valid inline constraints to be used for the randomization.

The following example shows the use of ``uvm_create` to pre-allocate a sequence item along with the ``uvm_rand_send*` macros, which process it as shown in [Figure 16](#), without allocation. The `rand_mode()` and `constraint_mode()` constructs are used to show fine-grain control on the randomization of an object.

```
class my_seq3 extends uvm_sequence #(my_item);
... // Constructor and UVM automation macros go here.
    // See Section 4.8.2
virtual task body();
    `uvm_create(req)
    req.addr.rand_mode(0);
    req.dcl.constraint_mode(0);
    req.addr = 27;
    // Randomize and process the item.
    `uvm_rand_send(req)

// Randomize and process again, this time with inline constraints.
    `uvm_rand_send_with(req, {data < 1000;})
endtask : body
endclass: my_seq3
```

6.5.4 Executing Sequences and Items on other Sequencers

In the preceding sections, all `uvm_do` macros (and their variants) execute the specified item or sequence on the current `p_sequencer`. To allow sequences to execute items or other sequences on specific sequencers, additional macro variants are included that allow specification of the desired sequencer.

``uvm_do_on`, ``uvm_do_on_with`, ``uvm_do_on_pri`, and ``uvm_do_on_pri_with`

All of these macros are exactly the same as their root versions, except they all take an additional argument (always the second argument) that is a reference to a specific sequencer.

```
`uvm_do_on(s_seq, that_sequencer);
`uvm_do_on_with(s_seq, that_sequencer, {s_seq.foo == 32'h3;})
```

6.6 Command Line Interface (CLI)

6.6.1 Introduction

The Command Line Processor class provides a general interface to the command line arguments that are provided for the given simulation. Not only can users retrieve the complete arguments using methods such as `~get_args()` and `~get_arg_matches()`, but they can also retrieve the suffixes of arguments using `~get_arg_values()`.

The `uvm_cmdline_processor` class also provides support for setting various UVM variables from the command line, such as components' verbosity and configuration settings for integral types and strings. Command line arguments that are in UPPERCASE should only have one setting to invocation. Command line arguments in lowercase can have multiple settings per invocation. All of this is further described in `uvm_cmdline_processor` in the *UVM 1.1 Class Reference*.

6.6.2 Getting Started

To start using the `uvm_cmdline_processor`, the user needs to first get access to the singleton instance of the `uvm_cmdline_processor`.

```
uvm_cmdline_processor cmdline_processor = uvm_cmdline_processor::get_inst();
```

A common use case involves using the `get_arg_value()` function to get the value of a specific argument, which is returned through an output argument. The total number of matches returned from this function usually is of interest when there are no matches and no default value. In this case, the user may generate an error. Similar to `$test$plusargs`, if the command line contains multiple matching arguments, the first value is returned.

```
string my_value = "default_value";  
int rc = cmdline_processor.get_arg_value("+abc=", my_value);
```

If the user knows the value is an integer, this string value may be further turned into an integer by calling the SystemVerilog function `atoi()` as follows.

```
int my_int_value = my_value.atoi();
```

If processing multiple values makes sense for a particular option (as opposed to just the first one found), use the `get_arg_values()` function instead, which returns a queue of all the matches.

```
string my_value_list[$];  
int rc = cmdline_processor.get_values("+abc=", my_value_list);
```

The `uvm_cmdline_processor` provides comprehensive access to the command line processing; see [Section 6.6.3](#) and the *UVM 1.1 Class Reference* for more details.

6.6.3 UVM-aware Command Line Processing

This section highlights how to select tests, set verbosity, and control other UVM facilities using the CLI.

6.6.3.1 Selecting Tests

The `uvm_cmdline_processor` is used to pass the `+UVM_TESTNAME` option to the `run_test()` routine to select which class will get constructed as the top-level testcase.

6.6.3.2 Setting Verbosity

The `uvm_cmdline_processor` looks for the `+UVM_VERBOSITY` option to change the verbosity for all UVM components. It is also possible to control the verbosity in a much more granular way by using the `+uvm_set_verbosity` option. The `+uvm_set_verbosity` option has a specific format that allows control over the phases where the verbosity change applies, and in the case of time-consuming phases, exactly what time it applies. Typically, verbosity is only turned up during time-consuming phases as the test approaches the time where an error occurs to help in debugging that error. The simulation will run faster if it is not burdened by generating debug messages earlier on where they are not required.

The `+uvm_set_verbosity` option is used as follows.

```
sim_cmd  
+uvm_set_verbosity=component_name,id,verbosity,phase_name,optional_time
```

In a similar fashion, the severity, and also the action taken, can be modified as follows.

```
sim_cmd +uvm_set_action=component_name,id,severity,action
sim_cmd +uvm_set_severity=component_name,id,current_severity,new_severity
```

6.6.3.3 Other UVM facilities that can be Controlled from the Command Line

[Table 14](#) shows other UVM options the user can set from the CLI.

Table 14—UVM CLI Options

Facility	Setting
Instance-specific factory override	+uvm_set_inst_override
Type-specific factory override	+uvm_set_type_override
Integer configuration	+uvm_set_config_int
String configuration	+uvm_set_config_string
Timeout	+UVM_TIMEOUT
Max quit count	+UVM_MAX_QUIT_COUNT
Objection mechanism debug	+UVM_OBJECTION_TRACE

Please see the UVM *1.1 Class Reference* for more examples of using the `uvm_cmdline_processor` class facilities.

7. UBus Verification Component Example

This chapter introduces the basic architecture of the UBus verification component. It also discusses an executable demo you can run to get hands-on experience in simulation. The UBus source code is provided as a further aid to understanding the verification component architecture. When developing your own simulation environment, you should follow the UBus structure and not its protocol-specific functionality.

All UBus verification component subcomponents inherit from some base class in the UVM Class Library, so make sure you have the *UVM 1.1 Class Reference* available while reading this chapter. It will be important to know, understand, and use the features of these base classes to fully appreciate the rich features you get—with very little added code—right out of the box.

You should also familiarize yourself with the UBus specification in [Chapter 8](#). While not a prerequisite, understanding the UBus protocol will help you distinguish UBus protocol-specific features from verification component protocol-independent architecture.

7.1 UBus Example

The UBus example constructs an verification environment consisting of a master and a slave. In the default test, the UBus slave communicates using the `slave_memory` sequence and the UBus master sequence `read_modify_write` validates the behavior of the UBus slave memory device. Instructions for running the UBus example can be found in the `readme.txt` file in the `examples/ubus/examples` directory of the UVM kit.

The output from the simulation below shows the UBus testbench topology containing an environment. The environment contains one active master and one active slave agent. The test runs the `read_modify_write` sequence, which activates the read byte sequence followed by the write byte sequence, followed by another read byte sequence. An assertion verifies the data read in the second read byte sequence is identical to the data written in the write byte sequence. The following output is generated when the test is simulated with `UVM_VERBOSITY = UVM_LOW`.

```
# UVM_INFO @ 0: reporter [RNTST] Running test test_read_modify_write...
# UVM_INFO test_lib.sv(55) @ 0: uvm_test_top [test_read_modify_write] Printing
  the test topology :
# -----
# Name                                Type                                Size  Value
# -----
# uvm_test_top                        test_read_modify_write             -     @459
#   ubus_example_tb0                  ubus_example_tb                    -     @478
#     scoreboard0                      ubus_example_scoreboard            -     @500
#       item_collected_export          uvm_analysis_imp                   -     @507
#       disable_scoreboard              integral                            1     'h0
#       num_writes                      integral                            32    'd0
#       num_init_reads                  integral                            32    'd0
#       num_uninit_reads                integral                            32    'd0
#       recording_detail                uvm_verbosity                      32    UVM_FULL
#   ubus0                              ubus_env                            -     @493
#     bus_monitor                      ubus_bus_monitor                   -     @517
#     masters[0]                       ubus_master_agent                  -     @546
#     slaves[0]                         ubus_slave_agent                   -     @557
#     has_bus_monitor                   integral                            1     'h1
#     num_masters                      integral                            32    'h1
#     num_slaves                        integral                            32    'h1
#     intf_checks_enable                integral                            1     'h1
#     intf_coverage_enable              integral                            1     'h1
```

```

#      recording_detail      uvm_verbosity      32      UVM_FULL
#      recording_detail      uvm_verbosity      32      UVM_FULL
# -----
#
# UVM_INFO ubus_example_scoreboard.sv(100) @ 110:
#   uvm_test_top.ubus_example_tb0.scoreboard0 [ubus_example_scoreboard] READ
#   to empty address...Updating address : 8764 with data : dd
# UVM_INFO ../sv/ubus_bus_monitor.sv(223) @ 110:
#   uvm_test_top.ubus_example_tb0.ubus0.bus_monitor [ubus_bus_monitor]
#   Transfer collected :
# -----
# Name                Type                Size  Value
# -----
# ubus_transfer_inst  ubus_transfer      -     @524
#   addr              integral            16    'h8764
#   read_write        ubus_read_write_enum 32    READ
#   size              integral            32    'h1
#   data              da(integral)        1     -
#     [0]             integral            8     'hdd
#   wait_state        da(integral)        0     -
#   error_pos         integral            32    'h0
#   transmit_delay    integral            32    'h0
#   master            string              10    masters[0]
#   slave             string              9     slaves[0]
#   begin_time        time                64    70
#   end_time          time                64    110
# -----
#
# UVM_INFO ubus_example_scoreboard.sv(89) @ 260:
#   uvm_test_top.ubus_example_tb0.scoreboard0 [ubus_example_scoreboard] WRITE
#   to existing address...Updating address : 8764 with data : de
# UVM_INFO ../sv/ubus_bus_monitor.sv(223) @ 260:
#   uvm_test_top.ubus_example_tb0.ubus0.bus_monitor [ubus_bus_monitor]
#   Transfer collected :
# -----
# Name                Type                Size  Value
# -----
# ubus_transfer_inst  ubus_transfer      -     @524
#   addr              integral            16    'h8764
#   read_write        ubus_read_write_enum 32    WRITE
#   size              integral            32    'h1
#   data              da(integral)        1     -
#     [0]             integral            8     'hde
#   wait_state        da(integral)        0     -
#   error_pos         integral            32    'h0
#   transmit_delay    integral            32    'h0
#   master            string              10    masters[0]
#   slave             string              9     slaves[0]
#   begin_time        time                64    220
#   end_time          time                64    260
# -----
#
# UVM_INFO ubus_example_scoreboard.sv(75) @ 330:
#   uvm_test_top.ubus_example_tb0.scoreboard0 [ubus_example_scoreboard] READ
#   to existing address...Checking address : 8764 with data : de
# UVM_INFO ../sv/ubus_bus_monitor.sv(223) @ 330:
#   uvm_test_top.ubus_example_tb0.ubus0.bus_monitor [ubus_bus_monitor]
#   Transfer collected :

```

```

# -----
# Name                Type                Size  Value
# -----
# ubus_transfer_inst  ubus_transfer          -    @524
#   addr              integral              16    'h8764
#   read_write        ubus_read_write_enum  32    READ
#   size              integral              32    'h1
#   data              da(integral)          1     -
#     [0]             integral              8     'hde
#   wait_state        da(integral)          0     -
#   error_pos         integral              32    'h0
#   transmit_delay    integral              32    'h0
#   master            string                10    masters[0]
#   slave             string                9     slaves[0]
#   begin_time        time                  64    290
#   end_time          time                  64    330
# -----
#
# UVM_INFO ../../../../src/base/uvm_objection.svh(1122) @ 380: reporter
#   [TEST_DONE] 'run' phase is ready to proceed to the 'extract' phase
# UVM_INFO ubus_example_scoreboard.sv(114) @ 380:
#   uvm_test_top.ubus_example_tb0.scoreboard0 [ubus_example_scoreboard]
#   Reporting scoreboard information...
# -----
# Name                Type                Size  Value
# -----
# scoreboard0         ubus_example_scoreboard -    @500
#   item_collected_export uvm_analysis_imp      -    @507
#   recording_detail   uvm_verbosity          32    UVM_FULL
#   disable_scoreboard integral              1     'h0
#   num_writes         integral              32    'd1
#   num_init_reads     integral              32    'd1
#   num_uninit_reads   integral              32    'd1
#   recording_detail   uvm_verbosity          32    UVM_FULL
# -----
#
# UVM_INFO test_lib.sv(70) @ 380: uvm_test_top [test_read_modify_write] ** UVM
#   TEST PASSED **
#
# --- UVM Report Summary ---
#
# ** Report counts by severity
# UVM_INFO :    11
# UVM_WARNING :    0
# UVM_ERROR :    0
# UVM_FATAL :    0
# ** Report counts by id
# [RNTST]      1
# [TEST_DONE]  1
# [test_read_modify_write]  2
# [ubus_bus_monitor]      3
# [ubus_example_scoreboard]  4
# ** Note: $finish : ../../../../src/base/uvm_root.svh(392)
#   Time: 380 ns  Iteration: 42  Instance: /ubus_tb_top

```

7.2 UBus Example Architecture

Figure 38 shows the testbench topology of the UBus simulation environment in the UBus example delivered with this release.

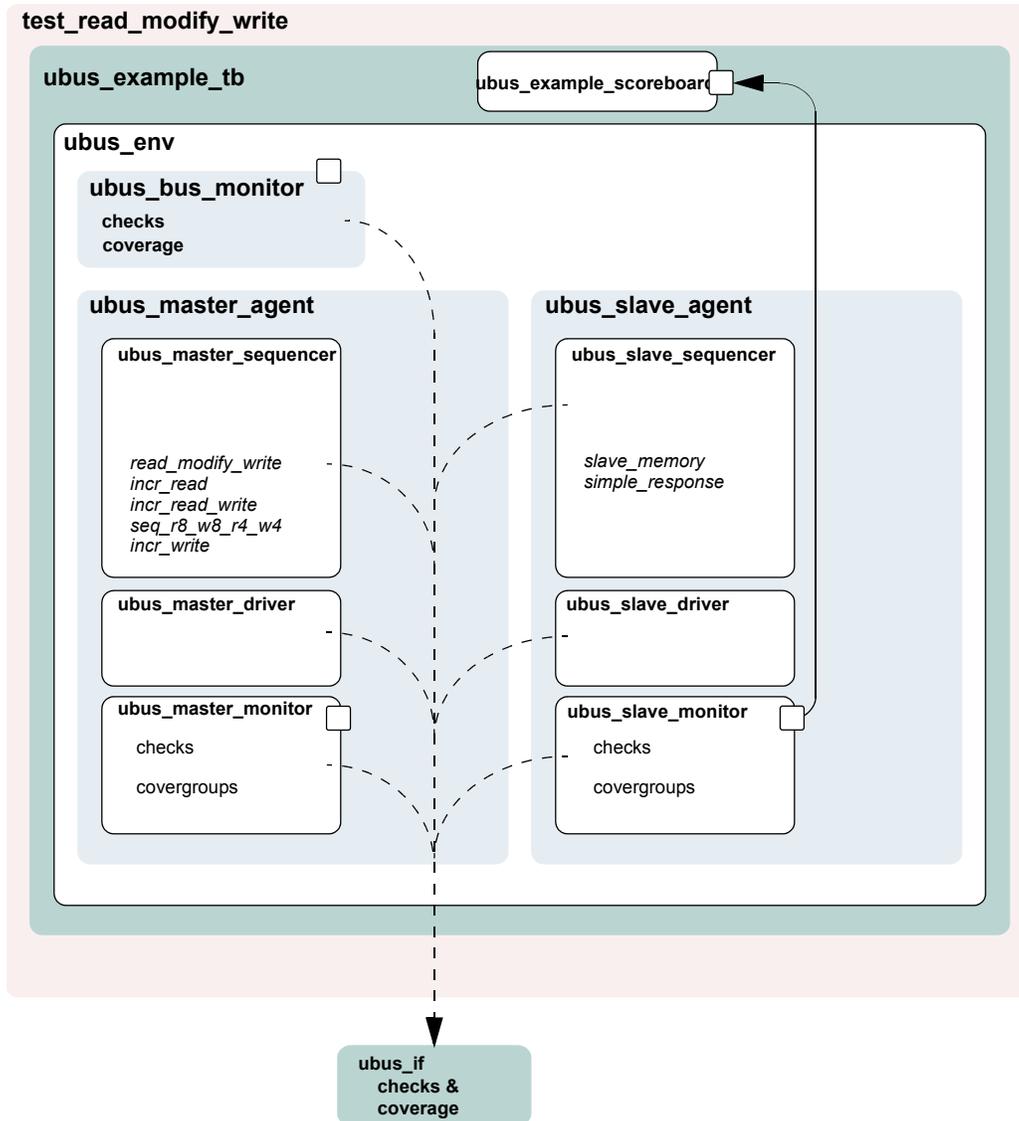


Figure 38—UBus Example Architecture

7.3 UBus Top Module

The UBus testbench is instantiated in a top-level module to create a class-based simulation environment. The example below uses an example DUT with UBus-specific content. The example is intentionally trivial so the focus is on the UBus verification component environment.

The top module contains the typical HDL constructs and a SystemVerilog interface. This interface is used to connect the class-based testbench to the DUT. The UBus environment inside the testbench uses a virtual

interface variable to refer to the SystemVerilog interface. The following example shows the UBus interface (xi0) and the example DUT connected together and passed to the components in the testbench via the resource database ([Line 16](#)). The `run_test()` command used to simulate the DUT and the testbench is covered in the next section.

Example: ubus_tb_top.sv

```
1 module ubus_tb_top;
2
3   import uvm_pkg::*;
4   import ubus_pkg::*;
5   `include "test_lib.sv"
6
7   ubus_if vif(); // SystemVerilog interface to the DUT
8
9   dut_dummy dut(
10     vif.sig_request[0],
11     ...
12     vif.sig_error
13   );
14
15   initial begin
16     uvm_config_db#(virtual ubus_if)::set(null,"ubus_example_tb0.*",
17                                           "vif",vif);
18     run_test();
19   end
20
21   initial begin
22     vif.sig_reset <= 1'b1;
23     vif.sig_clock <= 1'b1;
24     #51 vif.sig_reset = 1'b0;
25   end
26
27   //Generate clock.
28   always
29     #5 vif.sig_clock = ~vif.sig_clock;
30
31 endmodule
```

The UBus SystemVerilog interface is instantiated in the top-level testbench module. The interface uses generally-accepted naming conventions for its signals to allow easy mapping to any naming conventions employed by other implementations of the UBus protocol. The DUT pins connect directly to the signal inside the interface instance. Currently, the signals are simple non-directional variables that are driven either by the DUT or the class-based testbench environment via a virtual interface. The UBus interface contains concurrent assertions to perform physical checks. Refer to [Section 4.9](#) and [Section 7.12](#) for more information.

7.4 The Test

In UVM, the test is defined in a separate class, `test_read_modify_write`. It derives from `ubus_example_base_test` that, in turn, derives from `uvm_test`. The `ubus_example_base_test` test builds the `ubus_example_tb` object and manages the `run_phase()` phase of the test. Subsequent derived tests, such as `test_read_modify_write`, can leverage this functionality as shown in the example below.

All classes that use the ``uvm_component_utils` macros are registered with a common factory, `uvm_factory`. When the top module calls `run_test(test_name)`, the factory is called upon to create an instance of a test with type `test_name` and then simulation is started. When `run_test` is called without an argument, a `+UVM_TESTNAME=test_name` command-line option is checked and, if it exists, the test with that type name is created and executed. If neither are found, all constructed components will be cycled through their simulation phases. Refer to [Section 4.6](#) for more information.

Example: test_lib.sv

```

1  `include "ubus_example_tb.sv"
2
3  class ubus_example_base_test extends uvm_test;
4
5      `uvm_component_utils(ubus_example_base_test)
6
7      ubus_example_tb ubus_example_tb0; // UBus verification environment
8      uvm_table_printer printer;
9      bit test_pass = 1;
10
11     function new(string name = "ubus_example_base_test",
12         uvm_component parent=null);
13         super.new(name, parent);
14     endfunction
15     // UVM build_phase() phase
16     virtual function void build_phase();
17         super.build_phase();
18         // Enable transaction recording.
19         set_config_int("*", "recording_detail", UVM_FULL);
20         // Create the testbench.
21         ubus_example_tb0 =
22             ubus_example_tb::type_id::create("ubus_example_tb0",
23                 this);
24         // Create a specific-depth printer for printing the topology.
25         printer = new();
26         printer.knobs.depth = 3;
27     endfunction
28     // Built-in UVM phase
29     function void end_of_elaboration_phase();
30         // Set verbosity for the bus monitor.
31         ubus_example_tb0.ubus0.bus_monitor.set_report_verbosity_level
32             (UVM_FULL);
33         // Print the test topology.
34         `uvm_info(get_type_name(),
35             $psprintf("Printing the test topology :\n%s",
36                 this.sprint(printer)), UVM_LOW)
37     endfunction : end_of_elaboration_phase();
38     // UVM run_phase() phase
39     task run_phase();
40         // Set a drain time for the environment if desired.
41         uvm_test_done.set_drain_time(this, 50);
42     endtask: run
43
44     function void extract();
45         if(ubus_example_tb0.scoreboard0.sbd_error)
46             test_pass = 1'b0;
47     endfunction // void
48
49     function void report();

```

```

47     if(test_pass) begin
48         `uvm_info(get_type_name(), "*** UVM TEST PASSED ***", UVM_NONE)
49     end
50     else begin
51         `uvm_error(get_type_name(), "*** UVM TEST FAIL ***")
52     end
53 endfunction
54 endclass

```

[Line 1](#) Include the necessary file for the test. The testbench used in this example is the `ubus_example_tb` that contains, by default, the bus monitor, one master, and one slave. See [Section 7.5](#).

[Line 3](#) - [Line 5](#) All tests should derive from the `uvm_test` class and use the ``uvm_component_utils` or the ``uvm_component_utils_begin/`uvm_component_utils_end` macros. See the UVM *1.1 Class Reference* for more information.

[Line 7](#) Declare the testbench. It will be constructed by the `build_phase()` function of the test.

[Line 8](#) Declare a printer of type `uvm_table_printer`, which will be used later to print the topology. This is an optional feature. It is helpful in viewing the relationship of your topology defined in the configuration and the physical testbench created for simulation. Refer to the UVM *1.1 Class Reference* for different types of printers available.

[Line 16](#) - [Line 25](#) Specify the `build_phase()` function for the base test. As required, `build` first calls the `super.build_phase()` function in order to update any overridden fields. Then the `ubus_example_tb` is created using the `create()` function. The `build_phase()` function of the `ubus_example_tb` is executed by the UVM library phasing mechanism during `build_phase()`. The user is not required to explicitly call `ubus_example_tb0.build_phase()`.

[Line 27](#) - [Line 34](#) Specify the `end_of_elaboration_phase()` function for the base test. This function is called after all the component's `build_phase()` and `connect()` phases are executed. At this point, the test can assume that the complete testbench hierarchy is created and all testbench connections are made. The test topology is printed.

[Line 36](#) - [Line 39](#) Specify the `run_phase()` task for the base test. In this case, we set a drain time of 50 micro-seconds. Once all of the end-of-test objections were dropped, a 50 micro-second delay is introduced before the run phase it terminated.

Now that the base test is defined, a derived test will be examined. The following code is a continuation of the `test_lib.sv` file.

```

class test_read_modify_write extends ubus_example_base_test;
    `uvm_component_utils(test_read_modify_write)
    function new(string name = "test_read_modify_write",
        uvm_component parent=null);
        super.new(name,parent);
    endfunction
    virtual function void build_phase();
        // Set the default sequence for the master and slave.
        uvm_config_db#(uvm_object_wrapper)::set(this,
            "ubus_example_tb0.ubus0.masters[0].sequencer.main_phase",
            "default_sequence",
            read_modify_write_seq::type_id::get());
        uvm_config_db#(uvm_object_wrapper)::set(this,
            "ubus_example_tb0.ubus0.slaves[0].sequencer.run_phase",
            "default_sequence",

```

```

        slave_memory_seq::type_id::get());
    endfunction
endclass

```

The `build_phase()` function of the derivative test, `test_read_modify_write`, is of interest. The `build_phase()` function uses the resource database to set the master agent sequencer's default sequence for the `main()` phase to use the `read_modify_write_seq` sequence type. Similarly, it defines the slave agent sequencer's default sequence for the `run_phase()` phase to use the `slave_memory_seq` sequence type. Once these resources are set, `super.build_phase()` is called which creates the `ubus_example_tb0` as specified in the `ubus_example_base_test` build function.

The `run_phase()` task implementation is inherited by `test_read_modify_write` since this test derives from the `ubus_example_base_test`. Since that implementation is sufficient for this test, no action is required by you. This greatly simplifies this test.

7.5 Testbench Environment

This section discusses the testbench created in the *Example: test_lib.sv* in [Section 7.4](#). The code that creates the `ubus_example_tb` is repeated here.

```

ubus_example_tb0 = ubus_example_tb::type_id::create("ubus_example_tb0",
    this);

```

In general, testbenches can contain any number of envs (verification components) of any type: `ubus`, `pci`, `ahb`, `ethernet`, and so on. The UBus example creates a simple testbench consisting of a single UBus environment (verification component) with one master agent, slave agent, and bus monitor (see [Figure 39](#)).

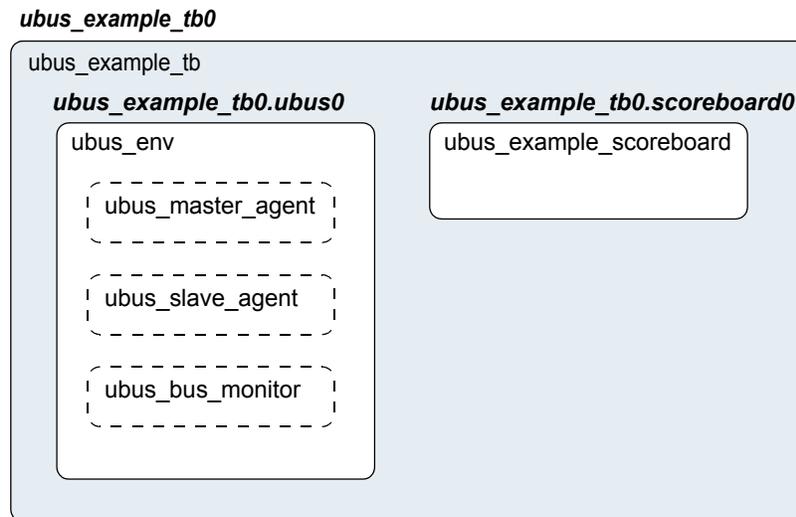


Figure 39—Testbench derived from `uvm_env`

The following code defines a class that specifies this configuration. The test will create an instance of this class.

Example: *ubus_example_tb.sv*

```
1 function void ubus_example_tb::build_phase();
2     super.build_phase();
3     uvm_config_db#(int)::set(this, ".ubus0",
4                             "num_masters", 1);
5     uvm_config_db#(int)::set(this, ".ubus0",
6                             "num_slaves", 1);
7     ubus0 = ubus_env::type_id::create("ubus0", this);
8     scoreboard0 = ubus_example_scoreboard::type_id::create("scoreboard0",
9                                                             this);
9 endfunction : build
10
11 function void ubus_example_tb::connect();
12     // Connect the slave0 monitor to scoreboard.
13     ubus0.slaves[0].monitor.item_collected_port.connect(
14         scoreboard0.item_collected_export);
15 endfunction : connect
16
17 function void end_of_elaboration_phase();
18     // Set up slave address map for ubus0 (basic default).
19     ubus0.set_slave_address_map("slaves[0]", 0, 16'hffff);
20 endfunction : end_of_elaboration
```

[Line 1](#) Declare the `build_phase()` function.

[Line 2](#) Call `super.build_phase()` in order to update any overridden fields. This is important because the test, which creates the testbench, may register overrides for the testbench. Calling `super.build_phase()` will ensure that those overrides are updated.

[Line 3](#) - [Line 5](#) The `set_config_int` calls are adjusting the `num_masters` and `num_slaves` configuration fields of the `ubus_env`. In this case, the `ubus0` instance of the `ubus_env` is being manipulated. [Line 3](#) instructs the `ubus0` instance of the `ubus_env` to contain one master agent. The `num_masters` property of the `ubus_env` specifies how many master agents should be created. The same is done for `num_slaves`.

[Line 7](#) Create the `ubus_env` instance named `ubus0`. The `create()` call specifies that an object of type `ubus_env` should be created with the instance name `ubus0`.

[Line 7](#) As with `ubus0`, the scoreboard is created.

[Line 11](#) Declare the `connect()` function.

[Line 12](#) Make the connections necessary for the `ubus0` environment and the `scoreboard0` between the analysis port on the `ubus0.slaves[0].monitor` and the analysis export on the `scoreboard0` instance.

[Line 17](#) Declare the `end_of_elaboration_phase()` built-in UVM phase.

[Line 19](#) Assign the slave address map for the `slaves[0]`. Since all components in the complete testbench have been created and connected prior to the start of `end_of_elaboration_phase()`, the slave instances are guaranteed to exist at this point.

7.6 UBus Environment

The `ubus_env` component contains any number of UBus master and slave agents. In this demo, the `ubus_env` (shown in [Figure 40](#)) is configured to contain just one master and one slave agent.

NOTE—The bus monitor is created by default.

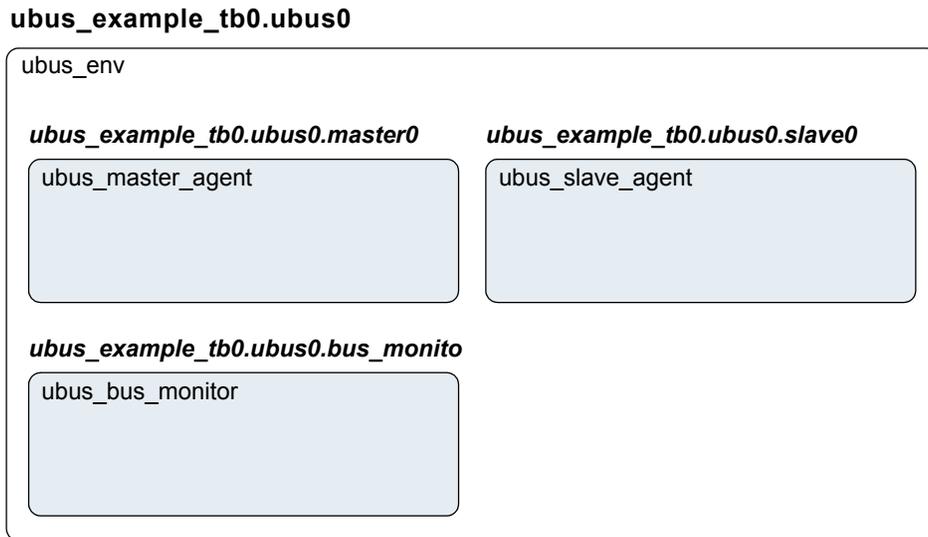


Figure 40—Instance of `ubus_env`

The `build_phase()` function of the `ubus_env` creates the master agents, slave agents, and the bus monitor. Three properties control whether these are created. The source code is shown here.

```
1 function void ubus_env::build_phase();
2     string inst_name;
3     super.build_phase();
4     if(!uvm_config_db#(virtual ubus_if)::get(this, "", "vif", vif))
5         `uvm_fatal("NOVIF", {"virtual interface must be set for:",
6             get_full_name(), ".vif"});
7
8     if(has_bus_monitor == 1) begin
9         bus_monitor = ubus_bus_monitor::type_id::create("bus_monitor",
10             this);
11     end
12     uvm_config_db#(int)::get(this, "", "num_masters", num_masters);
13     masters = new[num_masters];
14     for(int i = 0; i < num_masters; i++) begin
15         $sformat(inst_name, "masters[%0d]", i);
16         masters[i] = ubus_master_agent::type_id::create(inst_name, this);
17         uvm_config_db#(int)::set(this, {inst_name, "*"},
18             "master_id", i);
19     end
20     uvm_config_db#(int)::get(this, "", "num_slaves", num_slaves);
21     slaves = new[num_slaves];
22     for(int i = 0; i < num_slaves; i++) begin
23         $sformat(inst_name, "slaves[%0d]", i);
```

```

25     slaves[i] = ubus_slave_agent::type_id::create("ubus_slave_agent",
26         this);
27         inst_name));
28     end
29 endfunction: build

```

[Line 1](#) Declare the `build_phase()` function.

[Line 3](#) Call `super.build_phase()`. This guarantees that the configuration fields (`num_masters`, `num_slaves`, and `has_bus_monitor`) are updated per any resource settings.

[Line 4](#) Read the “vif” resource to get the virtual interface instance that was set in the top-level module. If no virtual interface has been set, issue a FATAL error.

[Line 8 - Line 10](#) Create the bus monitor if the `has_bus_monitor` control field is set to 1. The `create` function is used for creation.

[Line 11 - Line 19](#) The master’s dynamic array is sized per the `num_masters` control field, which is read from the resource database. This allows the `for` loop to populate the dynamic array according to the `num_masters` value. The instance name that is used for the master agent instance is built using `$sformat` so the instance names match the dynamic-array identifiers exactly. The iterator of the `for` loop is also used to set a resource value for the `master_id` properties of the master agent and all its children (through the use of the asterisk). This defines which request-grant pair is driven by the master agent.

[Line 20 - Line 28](#) As in the master-agent creation code above, this code creates the slave agents using `num_slaves` but does not set a resource for the slave agent.

7.7 UBus Master Agent

The `ubus_master_agent` (shown in [Figure 41](#)) and `ubus_slave_agent` are structured identically; the only difference is the protocol-specific function of its subcomponents.

The UBus master agent contains up to three subcomponents: the sequencer, driver, and monitor. By default, all three are created. However, the configuration can specify the agent as passive (`is_active=UVM_PASSIVE`), which disables the creation of the sequencer and driver. The `ubus_master_agent` is derived from `uvm_agent`.

ubus_example_tb0.ubus0.master0

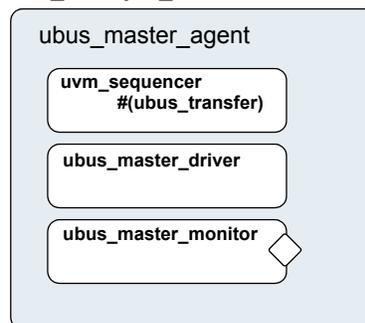


Figure 41—Instance of `ubus_master_agent`

The `build_phase()` function of the `ubus_master_agent` is specified to create the driver, sequencer, and the monitor. The `is_active` property controls whether the driver and sequencer are created.

```

1  function void ubus_master_agent::build_phase();
2      super.build_phase();
3      monitor = ubus_master_monitor::type_id::create("monitor", this);
4      if (is_active == UVM_ACTIVE) begin
5          sequencer =
6              uvm_sequencer#(ubus_transfer)::type_id::create("sequencer",
7                  this);
8          driver = ubus_master_driver::type_id::create("driver", this);
9      end
10 endfunction : build
11
12 function void ubus_master_agent::connect();
13     if (is_active == UVM_ACTIVE) begin
14         driver.seq_item_port.connect(sequencer0.seq_item_export);
15     end
16 endfunction

```

[Line 1](#) Declare the `build_phase()` function.

[Line 2](#) Call `super.build_phase()`. This guarantees that the configuration field (`is_active`) is updated per any overrides.

[Line 3](#) Create the monitor. The monitor is always created. Creation is not conditional on a control field.

[Line 4](#) - [Line 7](#) Create the sequencer and driver if the `is_active` control field is set to `UVM_ACTIVE`. The `create()` function is used for creation. Note the use of the base `uvm_sequencer`.

[Line 10](#) Declare the `connect()` function.

[Line 11](#) - [Line 13](#) Since the driver expects transactions from the sequencer, the interfaces in both components should be connected using the `connect()` function. The agent (which creates the monitor, sequencer, and driver) is responsible for connecting the interfaces of its children.

7.8 UBus Master Sequencer

This component controls the flow of sequence items to the driver (see [Figure 42](#)).

ubus_example_tb0.ubus0.master0.sequencer

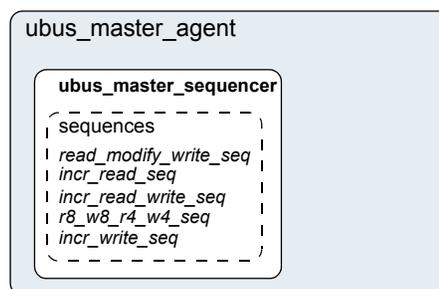


Figure 42—Instance of `ubus_master_sequencer`

The sequencer controls which sequence items are provided to the driver. The `uvm_sequencer` base class will automatically read the sequence resource set for each specific run-time phase and start an instance of that sequence by default.

7.9 UBus Driver

This component drives the UBus bus-signals interface by way of the `xmi` virtual interface property (see [Figure 43](#)). The `ubus_master_driver` fetches `ubus_transfer` transactions from the sequencer and processes them based on the physical-protocol definition. In the UBus example, the `seq_item_port` methods `get_next_item()` and `item_done()` are accessed to retrieve transactions from the sequencer.

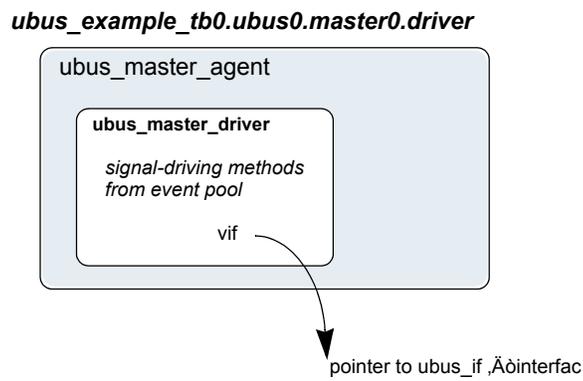


Figure 43—Instance of `ubus_master_driver`

The primary role of the driver is to drive (in a master) or respond (in a slave) on the UBus bus according to the signal-level protocol. This is done in the `run_phase()` task that is automatically invoked as part of UVM's built-in simulation phasing. For the master driver, the core routine is summarized as follows:

```

task ubus_master_driver::run_phase();
  ...
  @(negedge vif.sig_reset);

  forever begin // Repeat the following forever.
    @(posedge vif.sig_clock);
    seq_item_port.get_next_item(req); // Pull item from sequencer.
    ...
    drive_transfer(req); // Drive item onto signal-level bus.
    ...
    seq_item_port.item_done(); // Indicate we are done.
    seq_item_port.put_response(rsp); // Provide response
  end
endtask
  
```

Once the `sig_reset` signal is deasserted, the driver's run task runs forever until stopped by having all `run_phase` objections dropped. You are encouraged to study the UBus driver source code to gain a deeper understanding of the implementation specific to the UBus protocol.

7.10 UBus Agent Monitor

The UBus monitor collects `ubus_transfers` seen on the UBus signal-level interface (see [Figure 44](#)). If the checks and coverage are present, those corresponding functions are performed as well.

The primary role of the UBus master monitor is to sample the activity on the UBus master interface and collect the `ubus_transfer` transactions that pertain to its parent master agent only. The transactions that are collected are provided to the external world by way of a TLM analysis port. The monitor performs this duty in the run task that is automatically invoked as part of simulation phasing. The run task may fork other processes and call other functions or tasks in performance of its duties. The exact implementation is protocol- and programmer-dependent, but the entry point, the run task, is the same for all components.

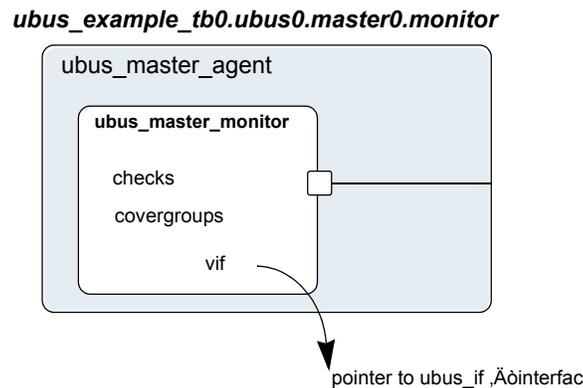


Figure 44—Instance of `ubus_master_monitor`

The monitor's functionality is contained in an infinite loop defined with the `run_phase()` task. Once all of the `run_phase` objections were dropped, the `run_phase()` tasks finish, allowing other simulation phases to complete, and the simulation itself to end.

The checks are responsible for enforcing protocol-specific checks, and the coverage is responsible for collecting functional coverage from the collected `ubus_transfers`.

7.11 UBus Bus Monitor

The UBus bus monitor collects `ubus_transfers` seen on the UBus signal-level interface and emits status updates via a state transaction, indicating different activity on the bus. The UBus bus monitor has class checks and collects coverage if checks and coverage collection is enabled. The UBus bus monitor is instantiated within the UBus environment.

The `ubus_env build_phase()` function has a control field called `has_bus_monitor`, which determines whether the `ubus_bus_monitor` is created or not. The bus monitor will be created by default since the default value for this control field is 1. You can use the `uvm_config_db` interface to override this value.

```
uvm_config_db#(int)::set(this, "ubus0", "has_bus_monitor", 0);
```

Here, the `ubus0` instance of `ubus_env` has its `has_bus_monitor` control field overridden to 0. Therefore, the `ubus_bus_monitor` in `ubus0` will not be present. The `build_phase()` function for the `ubus_env` that uses the `has_bus_monitor` control field can be found in [Section 7.6](#).

7.11.1 Collecting Transfers from the Bus

The UBus bus monitor populates the fields of `ubus_transfer`, including the master and slave, which indicate which master and slave are performing a transfer on the bus. These fields are required to ensure a slave responds to the appropriate address range when initiated by a master.

In the UBus protocol, each master on the bus has a dedicated request signal and a dedicated grant signal defined by the master agent's ID. To determine which master is performing a transfer on the bus, the UBus bus monitor checks which grant line is asserted.

To keep the UBus bus monitor example simple, an assumption has been made that the *n*th master connects to the *n*th request and grant lines. For example, `master[0]` is connected to `grant0`, `master[1]` is connected to `grant1`, and so on. Therefore, when the UBus bus monitor sees `grant0` is asserted, it assumes `master[0]` is performing the transfer on the bus.

To determine which slave should respond to the transfer on the bus, the UBus bus monitor needs to know the address range supported by each slave in the environment. The environment developer has created the user interface API, `ubus_env::set_slave_address_map()`, to set the address map for the slave as well as the bus monitor. The prototype for this function is

```
set_slave_address_map(string slave_name, int min_addr, int max_addr);
```

For each slave, call `set_slave_address_map()` with the minimum and maximum address values to which the slave should respond. This function sets the address map for the slave and provides information to the bus monitor about each slave and its address map.

Using the address map information for each slave and the address that is collected from the bus, the bus monitor determines which slave has responded to the transfer.

7.11.2 Number of Transfers

The bus monitor has a protected field property, `num_transactions`, which holds the number of transfers that were monitored on the bus.

7.11.3 Notifiers Emitted by the UBus Bus Monitor

The UBus bus monitor contains two analysis ports, which provide information on the different types of activity occurring on the UBus signal-level interface

- a) `state_port`—This port provides a `ubus_status` object which contains an enumerated `bus_state` property. The `bus_state` property reflects bus-state changes. For example, when the bus enters reset, the `bus_state` property is set to `RST_START` and the `ubus_status` object is written to the analysis port.
- b) `item_collected_port`—This port provides the UBus transfer that is collected from the signal interface after a transfer is complete. This collected transfer is written to the `item_collected_port` analysis port.

NOTE—Any component provided by the appropriate TLM interfaces can attach to these TLM ports and listen to the information provided.

7.11.4 Checks and Coverage

The UBus bus monitor performs protocol-specific checks using class checks and collects functional coverage from the collected `ubus_transfers`.

The UVM field `coverage_enable` and `checks_enable` are used to control whether coverage and checks, respectively, will be performed or not. Refer to [Section 4.11](#) for more information.

7.12 UBus Interface

The UBus interface is a named bundle of nets and variables such that the master agents, slave agents, and bus monitor can drive or monitor the signals in it. Any physical checks to be performed are placed in the interface. Refer to [Section 4.11](#).

Assertions are added to perform physical checks. The `ubus_env` field `intf_checks_enable` controls whether these checks are performed. Refer to [Section 4.11](#) for more information.

The code below is an example of a physical check for the UBus interface, which confirms a valid address is driven during the normal address phase. A concurrent assertion is added to the interface to perform the check and is labeled `assertAddrUnknown`. This assertion evaluates on every positive edge of `sig_clock` if `checks_enable` is true. The `checks_enable` bit is controlled by the `intf_checks_enable` field. If any bit of the address is found to be at an unknown value during the normal address phase, an error message is issued.

```
always @(posedge sig_clock)
begin
    assertAddrUnknown:assert property (
        disable iff(!checks_enable)
        (sig_grant |-> ! $isunknown(sig_addr))
    )
    else
        $error("ERR_ADDR_XZ\n Address went to X or Z during Address Phase");
end
```

8. UBus Specification

8.1 Introduction

8.1.1 Motivation

The motivation for the UBus specification is to provide an example of a simple bus standard for demonstration purposes and to illustrate the methodology required for a bus-based verification component. As such, the UBus specification is designed to demonstrate all of the important features of a typical modern bus standard while keeping complexity to a minimum.

8.1.2 Bus Overview

The UBus is a simple non-multiplexed, synchronous bus with no pipelining (to ensure simple drivers). The address bus is 16-bits wide and the data bus is byte-wide (so as to avoid alignment issues). Simple burst transfers are allowed and slaves are able to throttle data rates by inserting wait states.

The bus can have any number of masters and slaves (the number of masters is only limited by the arbitration implementation). Masters and slaves are collectively known as “bus agents”.

The transfer of data is split into three phases: *Arbitration Phase*, *Address Phase*, and *Data Phase*. Because no pipelining is allowed, these phases happen sequentially for each burst of data. The Arbitration and Address Phases each take exactly one clock cycle. The Data Phase may take one or more clock cycles.

8.2 Bus Description

8.2.1 Bus Signals

The list of bus signals (not including arbitration signals) is shown in [Table 15](#). All control signals are active high.

Table 15—Bus Signals

Signal Name	Width (bits)	Driven By	Purpose
clock	1	n/a	Master clock for bus
reset	1	n/a	Bus reset
start	1	arbiter	This signal is high during the Arbitration Phase and low during the Address and Data Phases
addr	16	master	Address of first byte of a transfer
size	2	master	Indicates how many bytes will be transfers: 00 => 1 byte 01 => 2 bytes 10 => 4 bytes 11 => 8 bytes
read	1	master	This signal is high for read transfers (write must be low)

Table 15—Bus Signals (Continued)

Signal Name	Width (bits)	Driven By	Purpose
write	1	master	This signal is high for write transfers (read must be low)
bip	1	master	Burst In Progress—driven high by master during Data Phase for all bytes, except the last byte of the burst. This signal, when combined with wait and error , can be used by the arbiter to determine if the bus will start a new transfer in the next clock cycle
data	8	master/slave	Data for reads and writes
wait	1	slave	High if slave needs master to wait for completion of transfer
error	1	slave	High if slave error condition applies to this transfer

8.2.2 Clocking

All bus agents operate synchronous to the rising edge of the *clock* signal with the exception of *gnt* signals (see [Section 8.3](#)).

8.2.3 Reset

The active high *reset* signal is synchronous to the rising edge of clock. *reset* shall be asserted during power up and shall remain asserted for a minimum of five rising edges of clock* after power and clock have stabilized. Thereafter, *reset* shall be de-asserted synchronous to a rising edge of clock.

reset may be asserted at any time during operation. In such cases, *reset* must be asserted for at least three clock cycles and must be both asserted and de-asserted synchronous to the rising edge of clock. The assertion of *reset* cancels any pending transfer at the first rising edge of clock where *reset* is asserted. Any bytes that have been transferred prior to assertion of *reset* are considered to have succeeded. Any byte that would have succeeded at the rising edge of clock where *reset* is first asserted is considered to have failed.

While *reset* is asserted, all agents should ignore all bus and arbitration signals. While *reset* is asserted, the arbiter should drive *start* and all *gnt* signals low. At the first rising edge of clock where *reset* is de-asserted, the arbiter should drive *start* high. Thereafter, the normal bus operation should occur.

8.3 Arbitration Phase

Each UBus shall have a single, central arbiter to perform arbitration and certain other central control functions.

The Arbitration Phase always lasts for one clock cycle. During the Arbitration Phase, the arbiter shall drive the *start* signal high. At all other times, the arbiter should drive the *start* signal low. The *start* signal can therefore be used by slaves to synchronize themselves with the start of each transfer. The arbiter shall always drive *start* high in the cycle following the last cycle of each Data Phase or in the cycle following a “no operation” (NOP) Address Phase (see [Section 8.4.1](#)). The last cycle of a Data Phase is defined as a Data Phase cycle in which the *error* signal is high, or both the *bip* and *wait* signals are low.

Each master on the bus has a dedicated *req* signal and *gnt* signal. The arbiter samples all *req* signals at each falling edge of clock where *start* is asserted and asserts a single *gnt* signal based on an unspecified priority system. At all falling edges of clock where *start* is not asserted, the arbiter shall drive all *gnt* signals low.

Thus, a master can see assertion of its *gnt* signal not only as an indication that it has been granted the bus, but also as an indication that it must start an Address Phase. It is not necessary for the master to check the *start* signal before starting its Address Phase.

Once a master is granted the bus, it must drive a transaction onto the bus immediately. No other master is allowed to drive the bus until the current master has completed its transaction.

NOTE—Only the arbiter is allowed to drive a NOP transfer. This means a master must drive a real transfer if it is granted the bus. Therefore, masters should not request the bus unless they can guarantee they will be ready to do a real transfer.

Arbitration signals shall be active high and shall be named according to a convention whereby the first part of the name is the root signal name (*req_* for the request signal; *gnt_* for the grant signal) and the second part of the name is the logical name or number of the master. Although the arbitration signals form part of the UBus specification, they are not considered to be “bus” signals as they are not connected to all agents on the bus.

It is up to individual implementations to choose an appropriate arbitration system. Arbiters might allocate different priorities to each master or might choose randomly with each master having equal priority.

8.4 Address Phase

The Address Phase lasts for a single clock cycle and always immediately follows the Arbitration Phase.

8.4.1 NOP Cycle

Where no master has requested the bus and the *start* signal is asserted at the falling edge of clock, no *gnt* signal is asserted at the start of the Address Phase and the arbiter itself is responsible for driving the bus to a “no operation” (NOP) state. It does this by driving the *addr* and *size* signals to all zeroes and both the *read* and *write* signals low. A NOP address phase has no associated data phase so the arbiter shall assert the *start* signal in the following clock cycle.

NOTE—This means the arbiter is connected to certain bus signals in addition to the arbitration signals and behaves as a “default master”.

8.4.2 Normal Address Phase

If, at the rising edge of clock, a master sees its *gnt* signal asserted, then it must drive a valid Address Phase in the following cycle. The master should also de-assert its *req* signal at this clock edge unless it has a further transfer pending.

During the Address Phase, the granted master should drive the *addr* and *size* signals to valid values and should drive either *read* or *write* (but not both) high. The address driven on *addr* represents the address of the first byte of a burst transfer. It is up to the slave to generate subsequent addresses during burst transfers.

The master shall only drive the *addr*, *size*, *read*, and *write* signals during the Address Phase. During the subsequent Data Phase, the master should not drive these signals.

8.5 Data Phase

The Data Phase may last for one or more clock cycles. The Data Phase follows immediately after the Address Phase (and is immediately followed by the Arbitration Phase).

8.5.1 Write Transfer

The master shall drive the first byte of data onto the bus on the clock cycle after driving a write Address Phase. If, at the end of this clock cycle, the slave has asserted the *wait* signal, then the master shall continue to drive the same data byte for a further clock cycle. The *data* signal may only change at the end of a cycle where *wait* is not asserted. Thus, the slave can insert as many wait states as it requires. The master shall drive the *bip* signal high throughout the Data Phase until the point where the final byte of the transfer is driven onto the bus, at which point it shall be driven low.

At the end of the transfer (the end of the cycle where both *bip* and *wait* are low) the master shall cease to drive all bus signals.

8.5.2 Error during Write Transfer

The slave shall drive the *error* throughout the Data Phase. If a slave encounters an error condition at any point during the Data Phase of a write transfer, it may signal this by asserting the *error* signal. To signal an error condition, the slave must drive the *error* signal high while driving the *wait* signal low. This indicates to the master that the associated byte of the transfer failed—any previous bytes in the burst are considered to have succeeded; any subsequent bytes in the burst are abandoned. The assertion of *error* always terminates the Data Phase even if *bip* is asserted simultaneously.

8.5.3 Read Transfer

On the clock cycle after the master drives a read Address Phase, the slave can take one of two actions: drive the first byte of data onto the bus while driving the *wait* signal low or drive the *wait* signal high to indicate it is not yet ready to drive data. Each byte of data is latched only by the master at the end of a cycle where *wait* is low—thus the slave can insert as many wait states as is required. The master shall drive the *bip* signal high throughout the Data Phase until the point where the master is ready to receive the final byte of the transfer, at which point it shall be driven low.

At the end of the transfer (the end of the cycle where both *bip* and *wait* are low) the master shall cease to drive all bus signals.

8.5.4 Error during Read Transfer

The slave shall drive the *error* throughout the Data Phase. If a slave encounters an error condition at any point during a read transfer, it may signal this by asserting the *error* signal. To signal an error condition, the slave must drive the *error* signal high while driving the *wait* signal low. This indicates to the master that the associated byte of the transfer failed—any previous bytes in the burst are considered to have succeeded; any subsequent bytes in the burst are abandoned. The assertion of *error* always terminates the Data Phase even if *bip* is asserted simultaneously.

8.6 How Data is Driven

[Table 16](#) specifies how data is driven in the UBus specification.

Table 16—What Drives What When

Signal Name	Arbitration Phase	Address Phase	Data Phase
start	Driven to 1 by arbiter	Driven to 0 by arbiter	Driven to 0 by arbiter
addr	Not driven	Driven by master (or to 0 by arbiter for NOP)	Not driven
size	Not driven	Driven by master (or to 0 by arbiter for NOP)	Not driven
read	Not driven	Driven by master (or to 0 by arbiter for NOP)	Not driven
write	Not driven	Driven by master (or to 0 by arbiter for NOP)	Not driven
bip	Not driven	Not driven	Driven to 1 by master for all but last byte of transfer
data	Not driven	Not driven	Driven by master during writes . Driven by slave during reads in cycles where wait is low; otherwise, don't care (may be driven to unknown state or not driven at all)
wait	Not driven	Not driven	Driven by slave
error	Not driven	Not driven	Driven by slave

8.7 Optional Pipelining Scheme

As previously stated, the UBus standard does not normally support pipelining. However, pipelining can optionally be implemented.

NOTE—All agents (including arbitration) on a bus must agree either to pipeline or not to pipeline. Mixing pipelined and non-pipelined agents on the same bus is not supported.

Because pipelining overlaps the Arbitration, Address, and Data Phases, two levels of pipelining are provided; i.e., there are a total of three transfers in progress at any one time.

NOTE—Pipelining results in different bus agents driving the same signals in consecutive clock cycles. As such, there is no period where the signal is not driven as part of a change of sequencers. As a result, care is necessary in the physical design of the bus to ensure that bus contention does not occur. A multiplexed approach will be required (in the form of either a ring or a star).

8.7.1 Pipelined Arbitration Phase

In a pipelined system, the Arbitration Phase is performed in parallel with the Address and Data Phases. Arbitration is carried out in every clock cycle regardless of whether this is necessary or not. This is because the arbiter cannot predict whether the next clock cycle will mark the start of a new Address Phase.

The Arbiter asserts the *start* signal in the clock cycle after the end of each Data Phase as in the non-pipelined system. However, this *start* signal marks the start of all three Phases in parallel.

The end of a Data Phase can be recognized by either assertion of *error* or de-assertion of both *bip* and *wait*.

8.7.2 Pipelined Address Phase

A master that has its *gnt* signal asserted at the clock edge where a Data Phase completes is granted the Address Phase of the bus. It must immediately start driving an Address Phase. Unlike in the non-pipelined bus, where the Address Phase lasts a single clock cycle, the Address Phase in a pipelined bus lasts until the end of the next Data Phase.

Where no master requests the bus and, therefore, no master is granted the bus, the arbiter is responsible for driving NOP until the end of the next Data Phase.

8.7.3 Pipelined Data Phase

The Data Phase of a pipelined bus is similar to that of a non-pipelined bus. Where the arbiter drives a NOP for the preceding Address Phase, the master must drive *error*, *bip*, and *wait* low during the Data Phase (which will last for a single clock cycle in this case).

8.8 Example Timing Diagrams

[Figure 45](#) and [Figure 46](#) show sample timing diagrams.

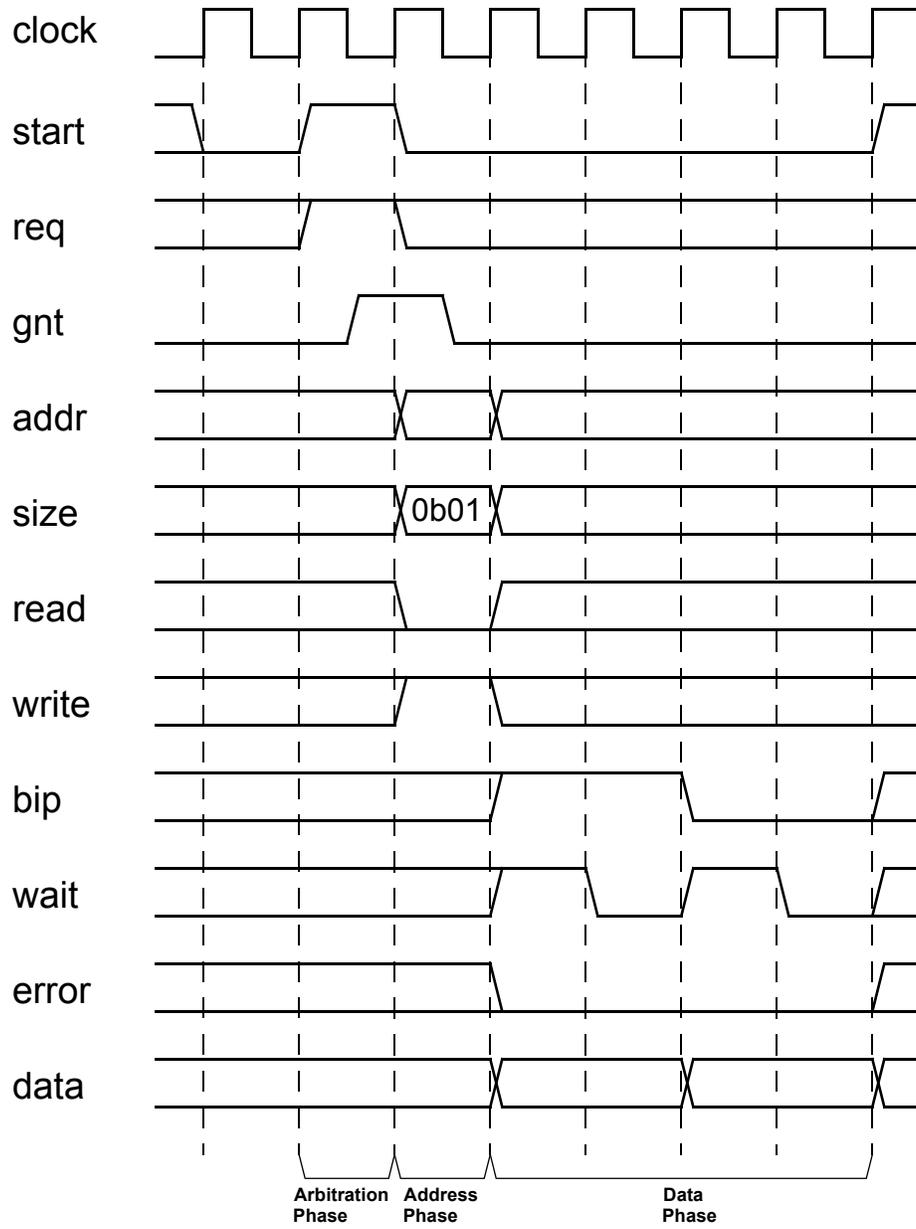


Figure 45—Example Write Waveform

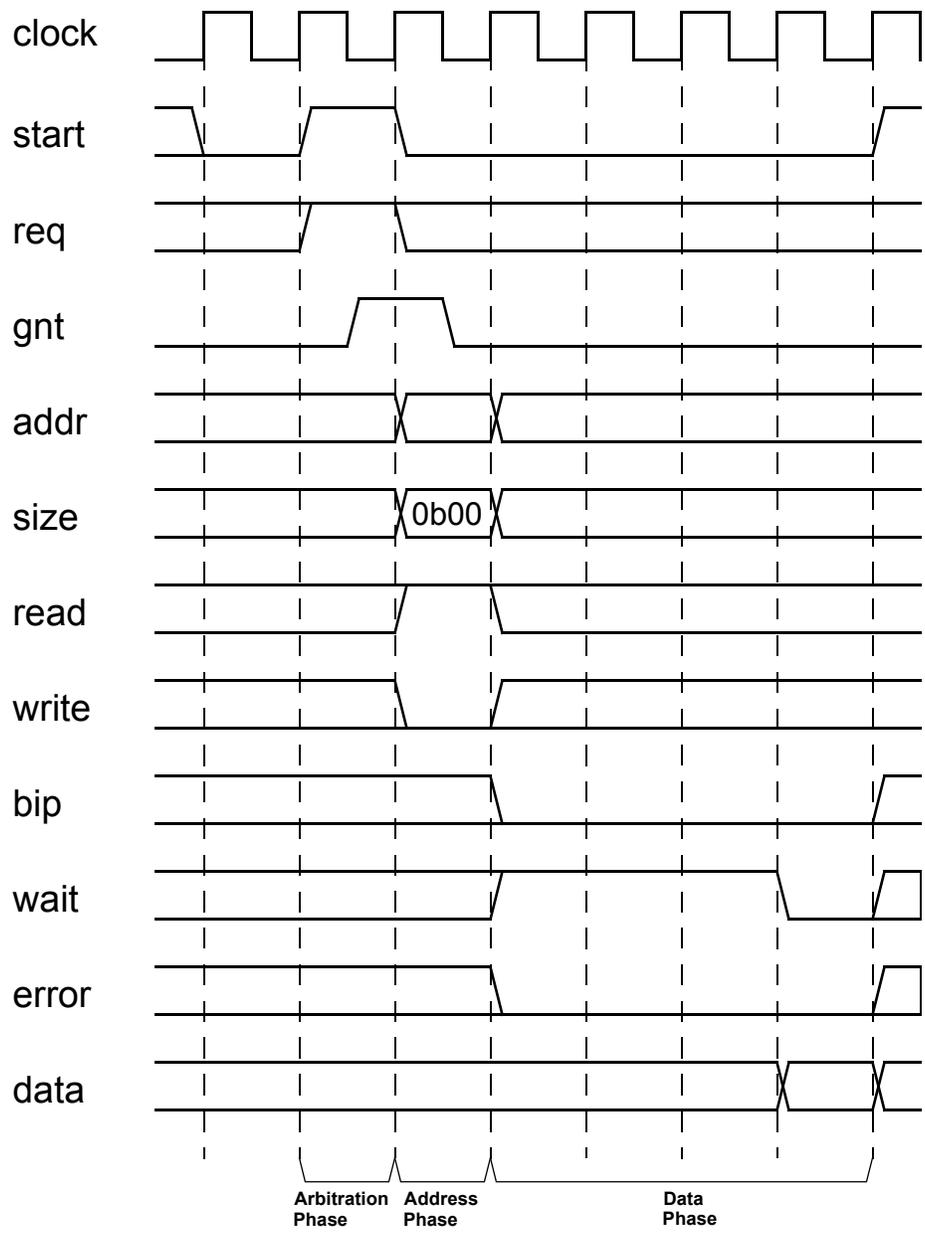


Figure 46—Example Read Waveform

Appendix A

(informative)

Sequence Library

A.1 Creating the Sequencer

The sequencer generates stimulus data and passes it to a driver for execution. The UVM Class Library provides the `uvm_sequencer` base class, which is parameterized by the request and response item types. You should derive all sequencer classes directly or indirectly from this class.

To create a sequencer:

- a) Derive a sequencer from the `uvm_sequencer` base class and specify the request and response type parameters.
- b) Use ``uvm_sequencer_utils` and ``uvm_update_sequence_lib_and_item` to indicate the generated data item type and field desired automation.

This is all that is required to define baseline behavior for a sequencer. Refer to [Section 3.10.2.1](#) for a description of how a sequencer, driver, and sequences synchronize with each other to generate constrained-random data.

The class `simple_sequencer` in the example below defines a sequencer class. The example derives it from `uvm_sequencer` and parameterizes it to use the `simple_item` type.

```
class simple_sequencer extends uvm_sequencer #(simple_item);
  // UVM automation macro for sequencers
  `uvm_sequencer_utils(simple_sequencer)
  // Constructor
  function new (string name="simple_sequencer", uvm_component parent);
    super.new(name, parent);
    `uvm_update_sequence_lib_and_item(simple_item)
  endfunction : new
endclass : simple_sequencer
```

The following also apply.

- In the class definition, by default, the response type is the same as the request type. If a different response type is desired, the optional second parameter must be specified for the `uvm_sequencer` base type:

```
class simple_sequencer extends uvm_sequencer #(simple_item, simple_rsp);
```

- The ``uvm_component_utils` macro should not be used here because its functionality is embedded in ``uvm_sequencer_utils`. Instead of using the ``uvm_component_utils`, use ``uvm_sequencer_utils`, as well as the regular general automation this macro provides sequencer-specific infrastructure. Refer to “Macros” in the UVM *1.1 Class Reference* for more information.
- Call ``uvm_update_sequence_lib_and_item` from the constructor of your sequencer class. This macro registers all the sequence types that are associated with the current sequencer and indicates the sequencer's generated transaction type as a parameter. Refer to “Macros” in the UVM *1.1 Class Reference* for more information.

A.2 Enabling Scenario Creation

The environment user will need to create many test scenarios to verify a given DUT. Since the verification component developer is usually more familiar with the DUT's protocol, the developer should facilitate the test writing (done by the verification component's user) by doing the following:

- Place knobs in the data item class to simplify declarative test control.
- Create a library of interesting reusable sequences.

The environment user controls the environment-generated patterns configuring its sequencers. The user can:

- Add a sequence of transactions to a sequencer.
- Modify the sequencer to use specific sequences more often than others.
- Override the sequencer's main loop to start with a user-defined sequence instead.

In this section we describe how to create a library of reusable sequences and review their use. For more information on how to control environments, see [Section 4.7](#).

A.2.1 Declaring User-Defined Sequences

Sequences are made up of several data items, which together form an interesting scenario or pattern of data. Verification components can include a library of basic sequences (instead of single-data items), which test writers can invoke. This approach enhances reuse of common stimulus patterns and reduces the length of tests. In addition, a sequence can call upon other sequences, thereby creating more complex scenarios.

NOTE—The UVM Class Library provides the `uvm_sequence` base class. You should derive all sequence classes directly or indirectly from this class.

To create a user-defined sequence:

- Derive a sequence from the `uvm_sequence` base class and specify the request and response item type parameters. In the example below, only the request type is specified, `simple_item`. This will result in the response type also being of type `simple_item`.
- Use the ``uvm_sequence_utils` macro to associate the sequence with the relevant sequencer type and to declare the various automation utilities. This macro also provides a `p_sequencer` variable that is of the type specified by the second argument of the macro. This allows access to derived type-specific sequencer properties.
- Implement the sequence's `body` task with the specific scenario you want the sequence to execute. In the `body` task, you can execute data items and other sequences using ``uvm_do` (see [Section 3.10.2.2.1](#)) and ``uvm_do_with` (see [Section 3.10.2.2.2](#)).

The class `simple_seq_do` in the following example defines a simple sequence. It is derived from `uvm_sequence` and uses the ``uvm_sequence_utils` macro to associate this sequence with `simple_sequencer` and declare the various utilities ``uvm_object_utils` would provide.

```
class simple_seq_do extends uvm_sequence #(simple_item);
  rand int count;
  constraint c1 { count >0; count <50; }
  // Constructor
  function new(string name="simple_seq_do");
    super.new(name);
  endfunction
  // UVM automation macros for sequences
  `uvm_sequence_utils(simple_seq_do, simple_sequencer)
  // The body() task is the actual logic of the sequence.
  virtual task body();
```

```

repeat(count)
  `uvm_do(req)
endtask : body
endclass : simple_seq_do

```

Once you define a sequence, it is registered inside its sequencer and may be generated by the sequencer's default generation loop. The ``uvm_sequence_utils` macro creates the necessary infrastructure to associate this sequence with the relevant sequencer type and declares the various automation utilities. This macro is similar to the ``uvm_object_utils` macro (and its variations), except it takes a second argument, which is the sequencer type name this sequence is associated with.

NOTE—Do not use the ``uvm_object_utils` macro when using the ``uvm_sequence_utils` macro. The functionality of ``uvm_object_utils` is included in ``uvm_sequence_utils`.

A.2.2 Configuring the Sequencer's Default Sequence

Sequencers execute an `uvm_random_sequence` object by default. The sequencer has a string property named `default_sequence` which can be set to a user-defined sequence-type name. This sequence is used as the default sequence for the instance of the sequencer.

To override the default sequence:

- a) Declare a user-defined sequence class which derives from an appropriate base sequence class. The example in [Section A.2.1](#) provides a declaration example of a sequence named `simple_seq_do`.
- b) Configure the `default_sequence` property for a specific sequencer or a group of sequencers. Typically, this is done inside the test class before creating the component that includes the relevant sequencer(s). For example,

```

set_config_string("*.master0.sequencer", "default_sequence",
  "simple_seq_do");

```

The first argument utilizes a wildcard mechanism. Here, any instance name containing `.master0.sequencer` will have its `default_sequence` property (if it exists) set to the value `simple_seq_do`.

A.2.3 Building a Reusable Sequence Library

A reusable sequence library is a set of user-defined sequences. Creating a verification component reusable sequence library is an efficient way to facilitate reuse. The environment developer can create a meaningful set of sequences to be leveraged by the test writer. Such sequence libraries avoid code duplication in tests, making them more maintainable, readable, and concise.

Tips

- Try to think of interesting protocol scenarios that many test writers can use.
- Since some users may not want to use the reusable sequence library (because the sequences may not match the design requirements of the user), do not include your reusable sequence library within the verification component files. Leave it to the user to decide whether to use them.

A.2.4 Using Sequences

Constraint layering is an efficient way of uncovering bugs in your DUT. Having the constraint solver randomly select values ensures a non-biased sampling of the legal input space. However, constraint layering

does not allow a user to control the order between consecutive data items. Many high-level scenarios can only be captured using a stream of ordered transactions. For example, simply randomizing bus transactions is unlikely to produce a legal scenario for your device. UVM sequences are library base classes that allow you to create meaningful ordered scenarios. This section describes UVM sequencers and sequences.

A.2.4.1 Important Randomization Concepts and Sequence Requirements

The previous section described the sequencer as a generator that can generate data items in a loop. While this is the default behavior, the sequencer actually generates sequences. User-defined sequences can be added to the sequencer's sequence library and randomly executed. If no user-defined sequences are added, then the only executed sequence is the built-in sequence called `simple_sequence` that executes a single data item.

[Section A.2.4.2](#) shows how you can use the configuration mechanism to modify the count to adjust the sequence generated pattern. Subsequent sections introduce other advanced ways to control the sequencer, including:

- Creating and adding a new sequence to be executed.
- Changing the distribution of executed sequences.
- Adjust the sequencer to start from a sequence other than the pre-defined random sequence.

A.2.4.2 Controlling the Number of Sequences Created by `uvm_random_sequence`

The default number of generated sequences is a random number between 0 and `uvm_sequencer::max_random_count`. The user can modify the number of generated sequences (`count`). Use the configuration mechanism to change the value of `count`. For example, to generate and send 10 sequences, use:

```
set_config_int("*.cpu_seqr", "count", 10);
```

You can disable a sequencer from generating any sequences by setting the `count` to 0.

```
set_config_int("*.cpu_seqr", "count", 0);
```

NOTE—Having more data items than `count` is not necessarily a bug. The sequencer does not generate data items directly. By default, it generates `count` number of simple sequences that translate into `count` number of items. The sequencer has more built-in capabilities, which are described in [Section A.2.4.3](#).

A.2.4.3 Creating and Adding a New Sequence

To create a user-defined sequence:

- a) Derive a sequence from the `uvm_sequence` base class.
- b) Use the ``uvm_sequence_utils` macro to associate the sequence with the relevant sequencer type and to declare the various automation utilities. This macro is similar to the ``uvm_object_utils` macro (and its variations), except it takes another argument, which is the sequencer type name this sequence is associated with. This macro also provides a `p_sequencer` variable that is of the type specified by the second argument of the macro. This allows access to derived type-specific sequencer properties.
- c) Implement the sequence's body task with the specific scenario you want the sequence to execute. In the body, you can execute data items and other sequences using ``uvm_do` (see [Section 3.10.2.2.1](#)) and ``uvm_do_with` (see [Section 3.10.2.2.2](#)).

Example

The class `retry_seq` in this example a new sequence. It is derived from `uvm_sequence` and uses the ``uvm_sequence_utils` macro to associate this sequence with `uart_tx_sequencer` and to declare the various utilities ``uvm_object_utils` provides.

```
// Send one BAD_PARITY frame followed by a GOOD_PARITY
// frame with the same payload.
class retry_seq extends uvm_sequence #(uart_frame);
    rand bit [7:0] pload; // Randomizable sequence parameter
    ...
    // UVM automation for sequences
    `uvm_sequence_utils_begin(retry_seq, uart_tx_sequencer)
    `uvm_field_object(frame, UVM_ALL_ON)
    `uvm_field_int(pload, UVM_ALL_ON)
    `uvm_sequence_utils_end
    // Constructor
    function new(string name="retry_seq");
        super.new(name);
    endfunction
    task body ( ); // Sequence behavior
        `uvm_do_with(req, {req.payload == pload; req.parity == BAD_PARITY;} )
        `uvm_do_with(req, {req.payload == pload; req.parity == GOOD_PARITY;} )
    endtask : body
endclass: retry_seq
```

Sequences can have parameters which can be randomized (e.g., `pload` in this example). Use constraints to control the randomization of these parameters. Then use the randomized parameters within the `body ()` task to guide the sequencer's behavior.

The `body` task defines the main behavior of a sequence. Since it is a task, you can use any procedural code, loops, fork and join, wait for events, and so on.

The ``uvm_do_with` macro randomizes and executes an item with inline constraints. The ``uvm_do_with` also sends the data item to the driver, which sends it to the DUT. The execution of the `body` task is blocked until the driver has sent the item to the DUT. Use the ``uvm_do` macro to randomize the item without inline constraints.

In the example above, when the `retry` sequence is executed, it will randomize the payload, send a frame with the generated payload having illegal parity, and follow it with a frame with a similar payload but with legal parity.

A sequencer type is provided as the second parameter to the ``uvm_sequence_utils` macro, which means that this sequence is added to the sequencer pool and could be randomly executed by the default random sequence. Since the sequencer type is provided, the `p_sequencer` variable can be declared the appropriate type and initialized.

A.2.4.4 Describing Nested Sequences

You can define more abstract sequences using existing sequences. Doing so provides additional reuse and makes it easier to maintain the test suite. For example, after defining the configuration sequence per device in a block-level testbench, the user may define a system-level configuration sequence which is a combination of the already-defined sequences.

Executing (doing) a sequence is similar to doing a data item. For example:

```

// Call retry sequence wrapped with random frames.
class rand_retry_seq extends uvm_sequence #(uart_frame);
  // Constructor, and so on
  ...
  `uvm_sequence_utils(rand_retry_rand_seq, uart_tx_sequencer)
  retry_seq retry_sequence; // Variable of a previously declared sequence
  task body (); // Sequence behavior
    `uvm_do (req)
    `uvm_do_with(retry_sequence, {retry_sequence.pload inside {[0:31]}};)
    `uvm_do(req)
  endtask
endclass

```

The `rand_retry_seq` has a field called `retry_sequence`. `retry_seq` is a user-predefined sequence.

The `body()` task is doing this sequence and layering inline constraints from above. This layering from above is one of many advantages that UVM sequences have.

A.2.4.5 Adjusting the Sequencer

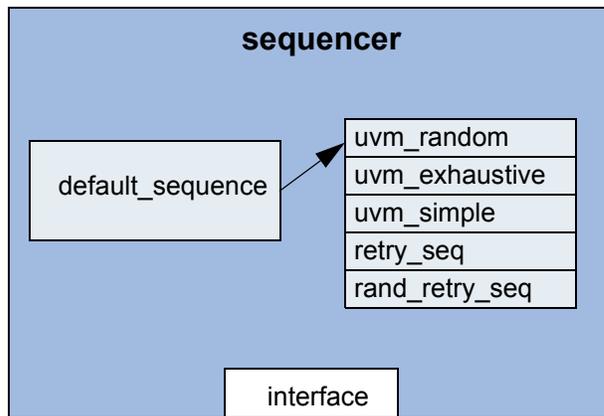
The sequencer has a string property named `default_sequence` which can be set to a user-defined sequence type. This sequence type is used as the default sequence for the current instance of the sequencer (see [Figure A1](#)).

To override the default sequence:

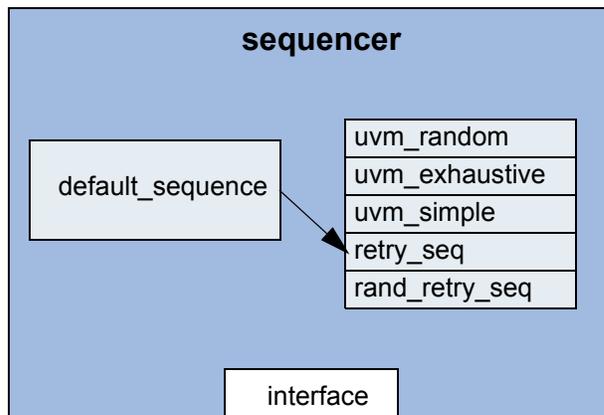
- a) Declare a user-defined sequence class which derives from an appropriate base sequence class.
- b) Configure the `default_sequence` property for a specific sequencer or a group of sequencers. This is typically done inside the test class, before creating the component that includes the relevant sequencer(s). For example,

```
set_config_string("*.master0.sequencer", "default_sequence", "retry_seq");
```

The first argument uses a wildcard to match any instance name containing `.master0.sequencer` to set the `default_sequence` property (if it exists) to the value `retry_seq`.



In default mode, the sequencer executes the random sequence, which randomly selects sequences and executes them



Setting `default_sequence` to `"retry_seq"` using `set_config_string("*.sequencer", "default_sequence", "retry_seq");` causes the sequencer to execute the `"retry_seq"` sequence

Figure A1—Sequencer with a Sequence Library

A.2.4.6 Sequence Libraries and Reuse

Use of sequences is an important part of verification component reuse. The environment developer who knows and understands the verification component protocol specifications can create interesting parameterized reusable sequences. This library of sequences enables the environment user to leverage interesting scenarios to achieve coverage goals more quickly. Check to see if your verification component's sequencer comes with a library of sequences. The example below shows a printout of a `sequencer.print()` command.

```

-----
Name           Type           Size   Value
-----
sequencer      uart_tx_sequencer-  @1011
default_sequence string         19    uvm_random_sequence
sequences      da(string)      4     -
  [0]          string         19    uvm_random_sequence
  [1]          string         23    uvm_exhaustive_sequence
  [2]          string         19    uvm_simple_sequence
  [3]          string          9     retry_seq
  [4]          string         14    rand_retry_seq
count          integral       32    -1
max_random_count integral       32    'd10
max_random_depth integral       32    'd4

```

The default sequence of this sequencer is `uvm_random_sequence`, which means sequences will be randomly generated in a loop by default.

This sequencer has five sequences associated with it. Three sequences are built-in sequences (`uvm_random_sequence`, `uvm_exhaustive_sequence`, and `uvm_simple_sequence`), and two are user-defined (`retry_seq` and `rand_retry_seq`).

The built-in exhaustive sequence is similar to random sequence. It randomly selects and executes once each sequence from the sequencer's sequence library, excluding `uvm_random_sequence` and `uvm_exhaustive_sequence`. If `count` equals 0, the sequencer will not automatically start a sequence. If desired, the user may start a sequence manually. This operation typically is used for virtual sequencers. If `count` is not equal to 0, the sequencer automatically starts the default sequence, which may use the `count` variable.

The exhaustive sequence does not use the `count` variable. However, the subsequences started by the exhaustive sequence may use `count`.

The value of `count` in this sequencer is -1, which means the number of generated sequences will be between 0 and `max_random_count` (10, the default value, in this example).

For more information about sequences, refer to [Section 6.5](#).

A.2.4.7 Directed-Test Style Interface

The sequence style discussed in [Section A.2.4](#) is the recommended way to create tests. Focus on creating reusable sequences you can use across many tests, instead of placing stimulus scenarios directly inside the test. Each sequencer is preloaded with the default traffic that will be generated at run time and sent to the DUT. Inside the tests, the test writer needs to touch only the sequencers that need to be modified.

Some test writers, however, are accustomed to writing directed tests. In directed tests, you write procedural code in which you explicitly request each interface to generate and send items. While directed tests are not the recommended test-creation style, UVM support this method using the sequencer's `execute_item()` task. Before using directed tests, consider their disadvantages compared to the UVM-recommended test-creation method:

- Directed tests require more code to write and maintain. This becomes critical in system-level environments.
- In directed tests, the high-level intention of the code is not as clear or as easy to read and understand. In the recommended method, the code is focused on test-specific needs and other system-related

aspects are present by default. For example, the arbitration logic for slaves that service requests does not need to be coded in every test.

- Directed tests are less reusable because they contain specific and un reusable information.
- In the recommended method, tests are random by default. All declared sequences are candidates for execution by default. You must explicitly exclude a sequence from being executed. This prevents the problem of missing sequences and creates a more random pattern that can expose unanticipated bugs.
- In the recommended method for many protocols, you should never have to touch the high-level sequence, which serves as a template for other sub-sequences to be executed in a certain order.

The following code is an example of a directed test.

```
class directed_test extends ubus_example_base_test;
    `uvm_component_utils(directed_test)
    ubus_example_tb ubus_example_tb0;
    function new (string name = "directed_test",
        uvm_component parent = null);
        super.new(name, parent);
    endfunction
    virtual function void build();
        super.build();
        set_config_int("*.sequencer", "count", 0);
        // Create the testbench.
        ubus_example_tb0 =
        ubus_example_tb::type_id::create("ubus_example_tb0", this);
    endfunction
    virtual task run();
        bit success; simple_item item;
        #10;
        item = new();
        success = item.randomize();
        tb.ahb.masters[1].sequencer.execute_item(item);
        success = item.randomize() with { addr < 32'h0123; };
        tb.ahb.masters[1].sequencer.execute_item(item);
    endtask
endclass
```

The following also apply.

- a) The `execute_item()` task can execute a data item or a sequence. It blocks until the item or the sequence is executed by the sequencer. You can use regular SystemVerilog constructs such as `fork/join` to model concurrency.
- b) The default activity in the sequencers is disabled by setting the count parameters of all sequencers to 0. The `execute_item()` task is used to send traffic in a deterministic way.
- c) Using default random activity is a good practice. It is straightforward and a good investment. The use of `execute_item()` should be minimized and limited to specific scenarios.

A.2.5 Creating a Virtual Sequencer

For high-level control of multiple sequencers from a single sequencer, use a sequencer that is not attached to a driver and does not process items itself. A sequencer acting in this role is referred to as a virtual sequencer.

To create a virtual sequencer that controls several subsequencers:

- a) Derive a virtual sequencer class from the `uvm_sequencer` class.

- b) Add references to the sequencers where the virtual sequences will coordinate the activity. These references will be assigned by a higher-level component (typically the testbench).

The following example declares a virtual sequencer with two subsequencers. Two interfaces called `eth` and `cpu` are created in the `build` function, which will be hooked up to the actual sub-sequencers.

```
class simple_virtual_sequencer extends uvm_sequencer;
    eth_sequencer eth_seqr;
    cpu_sequencer cpu_seqr;
    // Constructor
    function new(input string name="simple_virtual_sequencer",
        input uvm_component parent=null);
        super.new(name, parent);
        // Automation macro for virtual sequencer (no data item)
        `uvm_update_sequence_lib
    endfunction
    // UVM automation macros for sequencers
    `uvm_sequencer_utils(simple_virtual_sequencer)
endclass: simple_virtual_sequencer
```

NOTE—The ``uvm_update_sequence_lib` macro is used in the constructor when defining a virtual sequencer. This is different than (non-virtual) driver sequencers, which have an associated data item type. When this macro is used, the `uvm_simple_sequence` is not added to the sequencer's sequence library. This is important because the simple sequence only does items and a virtual sequencer is not connected to a driver that can process the items. For driver sequencers, use the ``uvm_update_sequence_lib_and_item` macro. See [Section 3.4](#) for more information.

Subsequencers can be driver sequencers or other virtual sequencers. The connection of the actual subsequencer instances via reference is done later, as shown in [Section 4.8.4](#).