SystemC 1.3

Languages for Embedded Systems

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Designing Big Digital Systems

Even Verilog or VHDL’s behavioral modeling is not high-level enough

People generally use C or C++

Standard Methodology for ICs

System-level designers write a C or C++ model

Written in a stylized, hardware-like form

Sometimes refined to be more hardware-like

C/C++ model simulated to verify functionality

Model given to Verilog/VHDL coders

Verilog or VHDL specification written

Models simulated together to test equivalence

Verilog/VHDL model synthesized

Designing Big Digital Systems

Every system company was doing this differently

Every system company used its own simulation library

“Throw the model over the wall” approach makes it easy to introduce errors

Problems:

System designers don’t know Verilog or VHDL

Verilog or VHDL coders don’t understand system design

Idea of SystemC

C and C++ are being used as ad-hoc modeling languages

Why not formalize their use?

Why not interpret them as hardware specification languages just as Verilog and VHDL were?

SystemC developed at my former employer Synopsys to do just this

What Is SystemC?

A subset of C++ that models/specifies synchronous digital hardware

A collection of simulation libraries that can be used to run a SystemC program

A compiler that translates the “synthesis subset” of SystemC into a netlist

What Is SystemC?

Language definition is publicly available

Libraries are freely distributed

Compiler is an expensive commercial product

See www.systemc.org for more information

Quick Overview

A SystemC program consists of module definitions plus a top-level function that starts the simulation

Modules contain processes (C++ methods) and instances of other modules

Ports on modules define their interface

Rich set of port data types (hardware modeling, etc.)

Signals in modules convey information between instances

Clocks are special signals that run periodically and can trigger clocked processes

Rich set of numeric types (fixed and arbitrary precision numbers)

Modules

Hierarchical entity

Similar to Verilog’s module

Actually a C++ class definition

Simulation involves

- Creating objects of this class
- They connect themselves together
- Processes in these objects (methods) are called by the scheduler to perform the simulation

Modules

```
SC_MODULE(mymod) {
    /* port definitions */
    /* signal definitions */
    /* clock  definitions */

    /* storage and state variables */

    /* process definitions */

    SC_CTOR(mymod) {
          /* Instances of processes and modules */
    }
};
```

Ports

Define the interface to each module

Channels through which data is communicated

Port consists of a direction

input	sc_in
output	sc_out
bidirectional	sc_inout

and any C++ or SystemC type

Ports

```
SC_MODULE(mymod) {
  sc_in<bool> load, read;
  sc_inout<int> data;
  sc_out<bool> full;

  /* rest of the module */
};
```

Signals

Convey information between modules within a module

Directionless: module ports define direction of data transfer

Type may be any C++ or built-in type

Signals

```
SC_MODULE(mymod) {
  /* ... */
  /* signal definitions */
  sc_signal<sc_uint<32> > s1, s2;
  sc_signal<bool> reset;

  /* ... */
  SC_CTOR(mymod) {
    /* Instances of modules that connect to the signals */
  }
};
```

Instances of Modules

Each instance is a pointer to an object in the module

```
SC_MODULE(mod1) { ... };
SC_MODULE(mod2) { ... };
SC_MODULE(foo) {
  mod1* m1;
  mod2* m2;
  sc_signal<int> a, b, c;
  SC_CTOR(foo) {
    m1 = new mod1("i1");  (*m1)(a, b, c);
    m2 = new mod2("i2");  (*m2)(c, b);
  }
};
```

Connect instance’s ports to signals

Processes

Only thing in SystemC that actually does anything

Procedural code with the ability to suspend and resume

Methods of each module class

Like Verilog’s initial blocks

Three Types of Processes

METHOD: Models combinational logic

THREAD: Models testbenches

CTHREAD: Models synchronous FSMs

METHOD Processes

Triggered in response to changes on inputs

Cannot store control state between invocations

Designed to model blocks of combinational logic

METHOD Processes

```
SC_MODULE(onemethod) {
  sc_in<bool> in;
  sc_out<bool> out;

  void inverter();

  SC_CTOR(onemethod) {

    SC_METHOD(inverter);
    sensitive(in);

  }
};
```

Process is simply a method of this class

Create an instance of this process

Trigger when **`in`** changes

METHOD Processes

Invoked once every time input “in” changes

Should not save state between invocations

Runs to completion: should not contain infinite loops

Not preempted

```
void onemethod::inverter()
  bool internal;
  internal = in;
  out =  internal;
```

Read a value from a port

Write a value to an output

THREAD Processes

Triggered in response to changes on inputs

Can suspend itself and be reactivated

Method calls wait to relinquish control

Scheduler runs it again later

Designed to model just about anything

THREAD Processes

```
SC_MODULE(onemethod) {
  sc_in<bool> in;
  sc_out<bool> out;

  void toggler();

  SC_CTOR(onemethod) {

    SC_THREAD(toggler);
    sensitive << in;
  }

};
```

Process a method of the class

Create an instance of the process

Alernate sensitivity list notation

THREAD Processes

Reawakened whenever an input changes

State saved between invocations

Infinite loops should contain a **`wait()`**

```
void onemethod::toggler() {
  bool last = false;
  for (;;) {
    last = in; out = last; wait();
    last =  in; out = last; wait();
  }
}
```

Relinquish control until the next change of signal on this process's sensitivity list

CTHREAD Processes

Triggered in response to a single clock edge

Can suspend itself and be reactivated

Method calls wait to relinquish control

Scheduler runs it again later

Designed to model clocked digital hardware

CTHREAD Processes

```
SC_MODULE(onemethod) {
  sc_in_clk clock;
  sc_in<bool> trigger, in;
  sc_out<bool> out;

  void toggler();

  SC_CTOR(onemethod) {
    SC_CTHREAD(toggler, clock.pos());

  }

};
```

Instance of this process created and relevant clock edge assigned

CTHREAD Processes

Reawakened at the edge of the clock

State saved between invocations

Infinite loops should contain a wait()

```
void onemethod::toggler() {
  bool last = false;
  for (;;) {
    wait_until(trigger.delayed() == true);
    last = in; out = last;
    wait();
    last =  in; out = last;
    wait();
  }
}
```

Relinquish control until the next clock cycle in which the trigger input is 1

Relinquish control until the next clock cycle

A CTHREAD for Complex Multiply

```
struct complex_mult : sc_module {
  sc_in<int>  a, b, c, d;
  sc_out<int> x, y;
  sc_in_clk   clock;

  void do_mult() {
    for (;;) {
      x = a * c - b * d;
      wait();
      y = a * d + b * c;
      wait();
    }
  }

  SC_CTOR(complex_mult) {
    SC_CTHREAD(do_mult, clock.pos());
  }
};
```

Watching

A CTHREAD process can be given reset-like behavior

```
SC_MODULE(onemethod) {
  sc_in_clk clock;
  sc_in<bool> reset, in;

  void toggler();

  SC_CTOR(onemethod) {
    SC_CTHREAD(toggler, clock.pos());
    watching(reset.delayed() == true);
  }
};
```

Process will be restarted from the beginning when reset is true

Local Watching

It’s hard, but the SystemC designers managed to put a more flexible version of abort in the language

Ugly syntax because they had to live with C++

Only for SC_CTHREAD processes

Local Watching

```
void mymodule::myprocess() {

  W_BEGIN
    watching(reset.delayed() == true);
  W_DO
    /* do something */
  W_ESCAPE
    /* code to handle the reset */
  W_END

}
```

SystemC Types

SystemC programs may use any C++ type along with any of the built-in ones for modeling systems

SystemC Built-in Types

- c_bit, sc_logic

  Two- and four-valued single bit

- sc_int, sc_unint

  1 to 64-bit signed and unsigned integers

- sc_bigint, sc_biguint

  arbitrary (fi xed) width signed and unsigned integers

- sc_bv, sc_lv

  arbitrary width two- and four-valued vectors

- sc_fi xed, sc_ ufi xed

  signed and unsigned fi xed point numbers

Numeric Types

- Integers

  Precise

  Manipulation is fast and cheap

  Poor for modeling continuous real-world behavior

Fixed and Floating Point Types

- Floating-point numbers

  Less precise

  Better approximation to real numbers

  Good for modeling continuous behavior

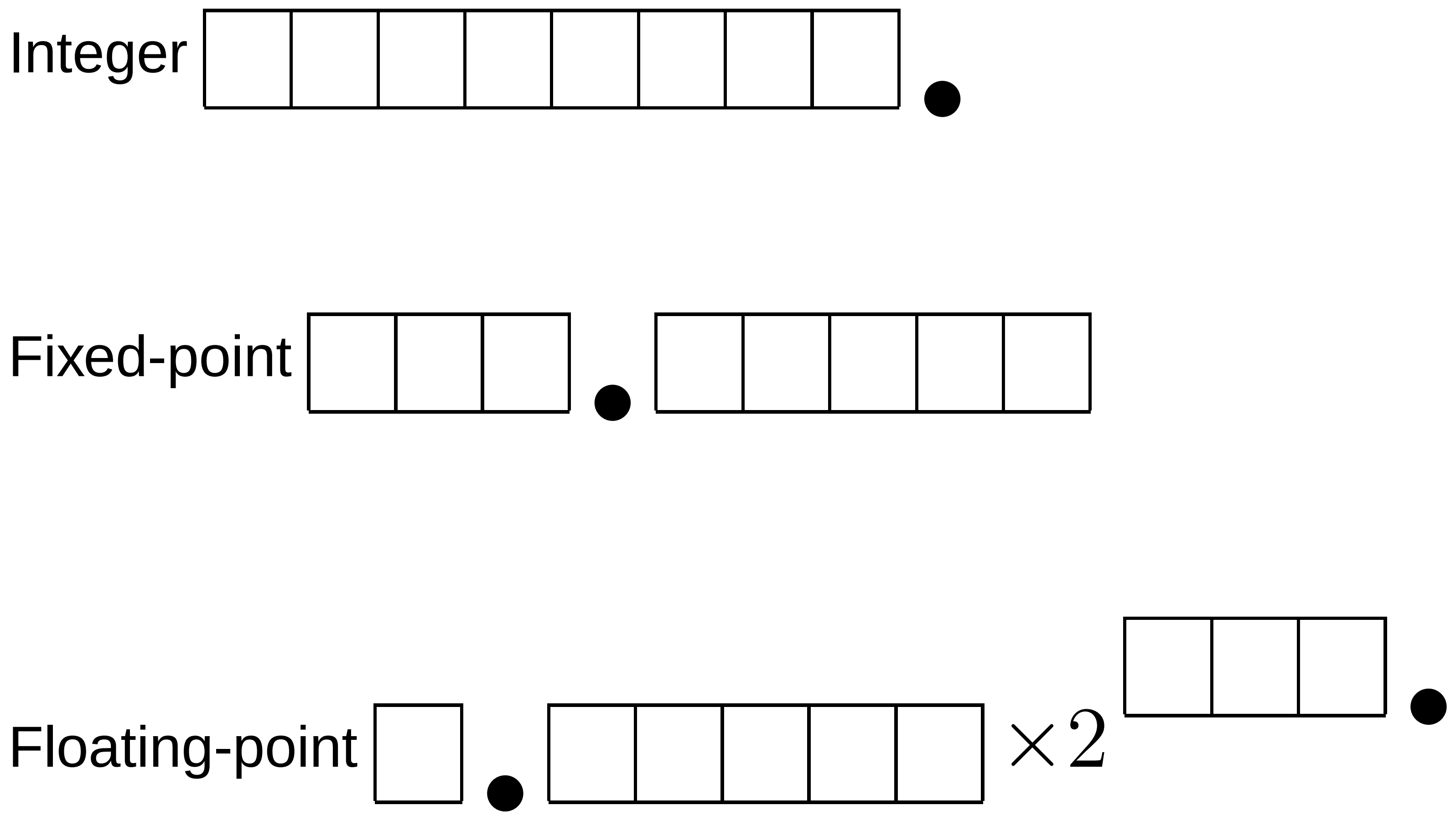
  Manipulation is slow and expensive

- Fixed-point numbers

  Worst of both worlds

  Used in many signal processing applications

Integers, Floating-point, Fixed-point



Using Fixed-Point Numbers

High-level models usually use floating-point for convenience

Fixed-point usually used in hardware implementation because they are much cheaper

Problem: the behavior of the two are different

How do you make sure your algorithm still works after it has been converted from floating-point to fixed-point?

SystemC’s fixed-point number classes facilitate simulating algorithms with fixed-point numbers

SystemC's Fixed-Point Types

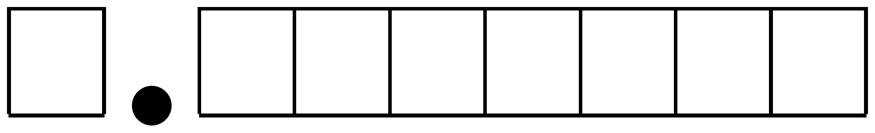
```
sc_fixed<8, 1, SC_RND, SC_SAT> fpn;
```

8 is the total number of bits in the type

1 is the number of bits to the left of the decimal point

SC_RND defines rounding behavior

SC_SAT defines saturation behavior



Rounding

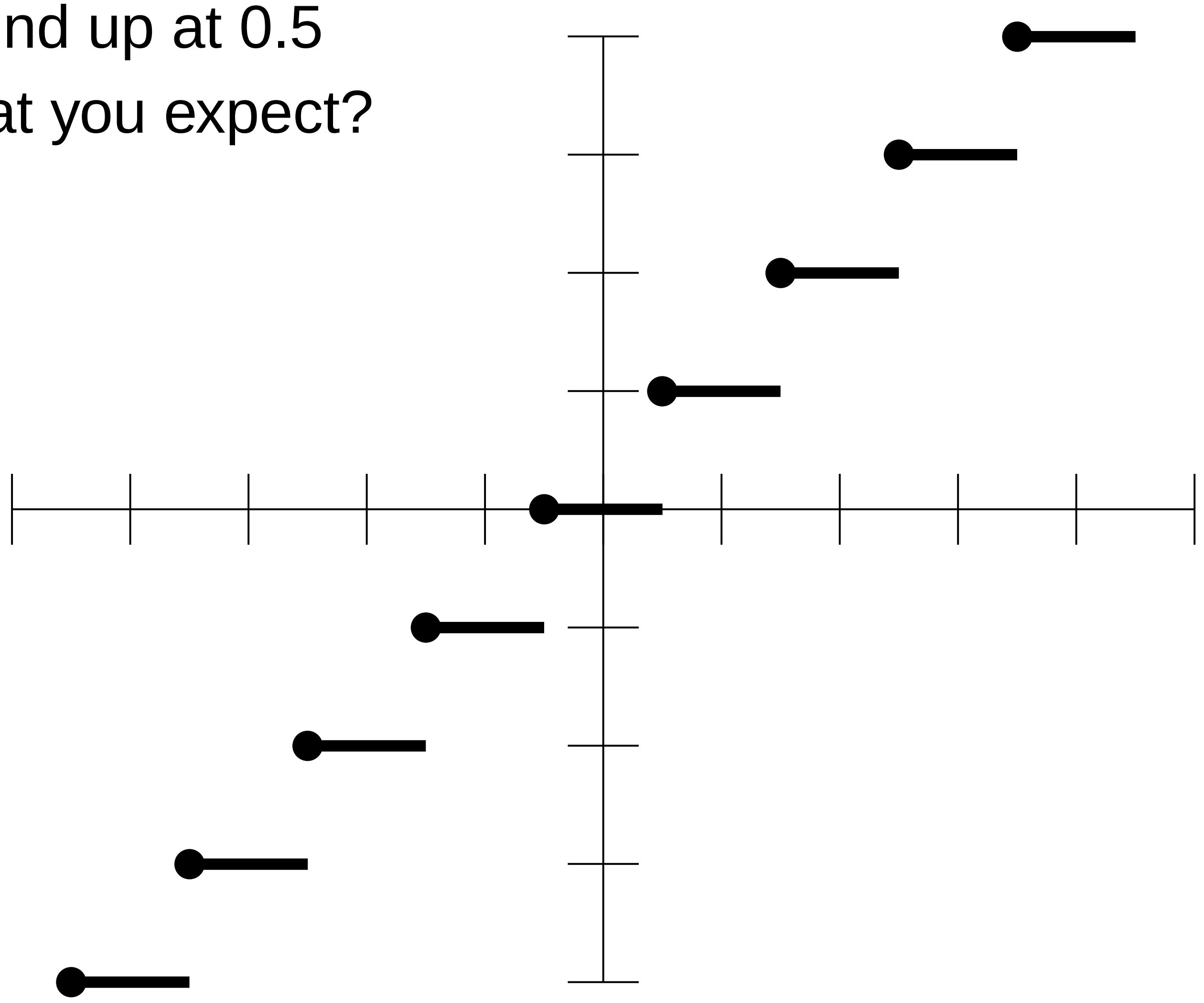
What happens when your result doesn’t land exactly on a representable number?

Rounding mode makes the choice

SC_RND

Round up at 0.5

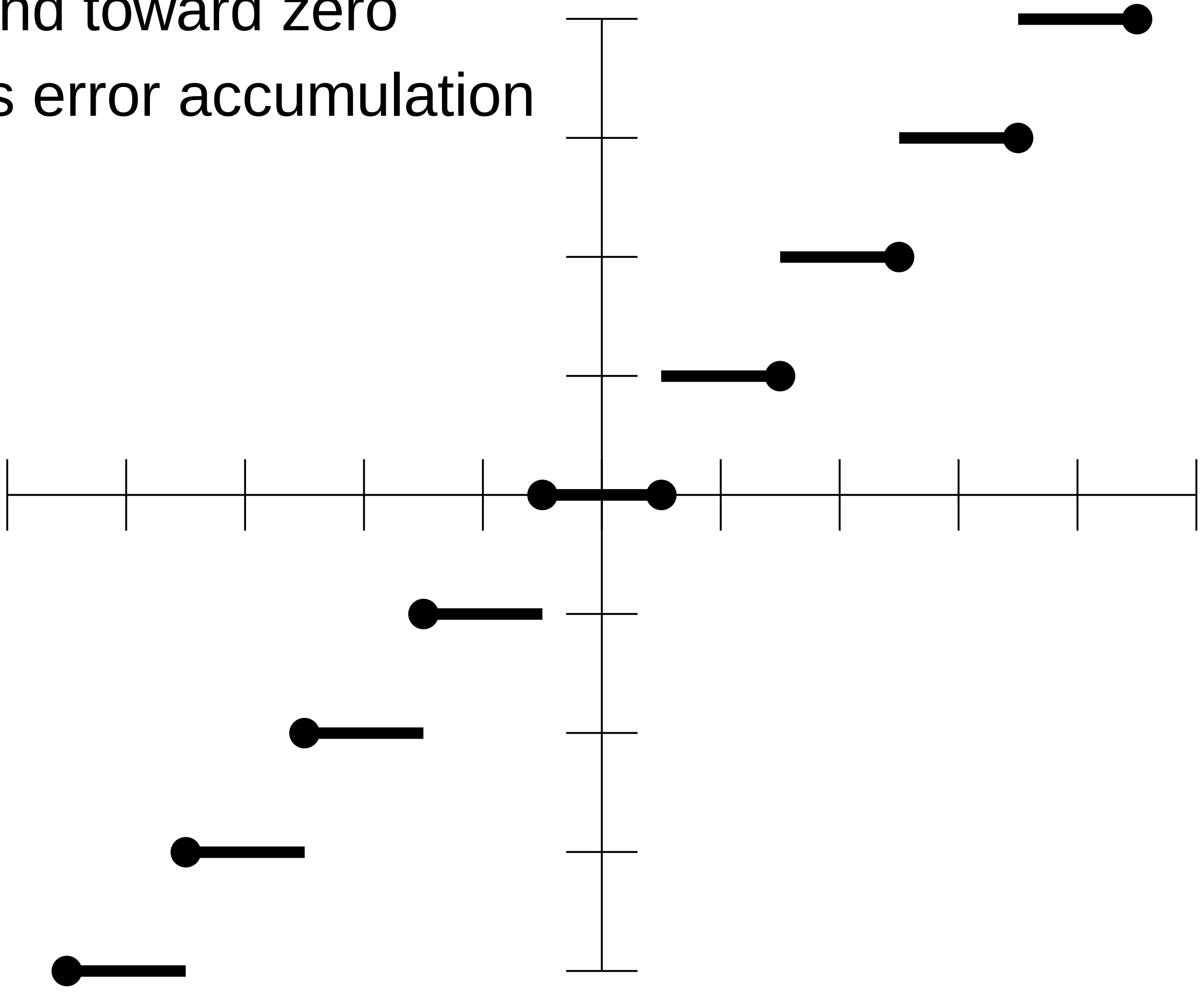
What you expect?



SC_RND_ZERO

Round toward zero

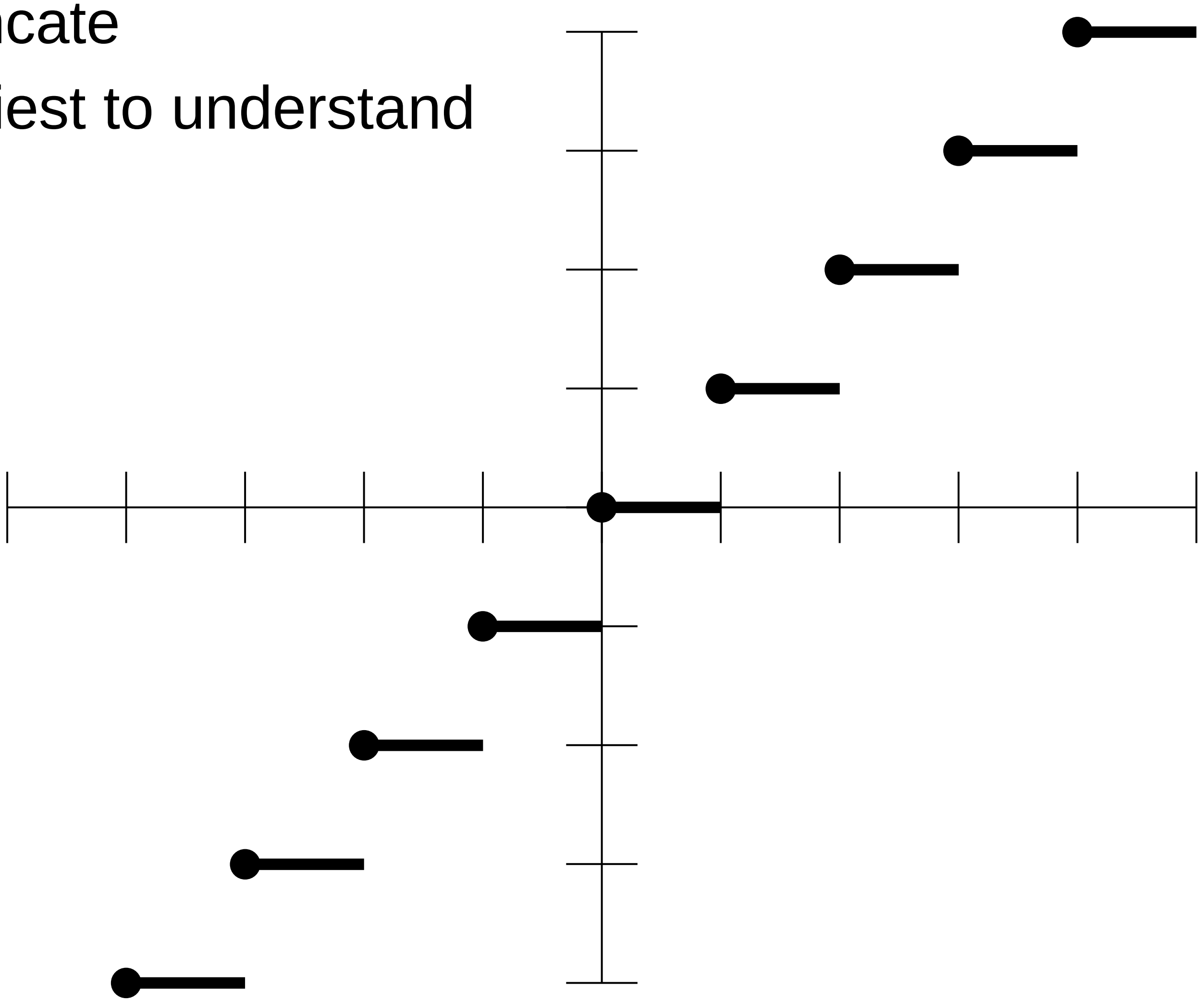
Less error accumulation



SC_TRN

Truncate

Easiest to understand



Overflow

What happens if the result is too positive or too negative to fit in the result?

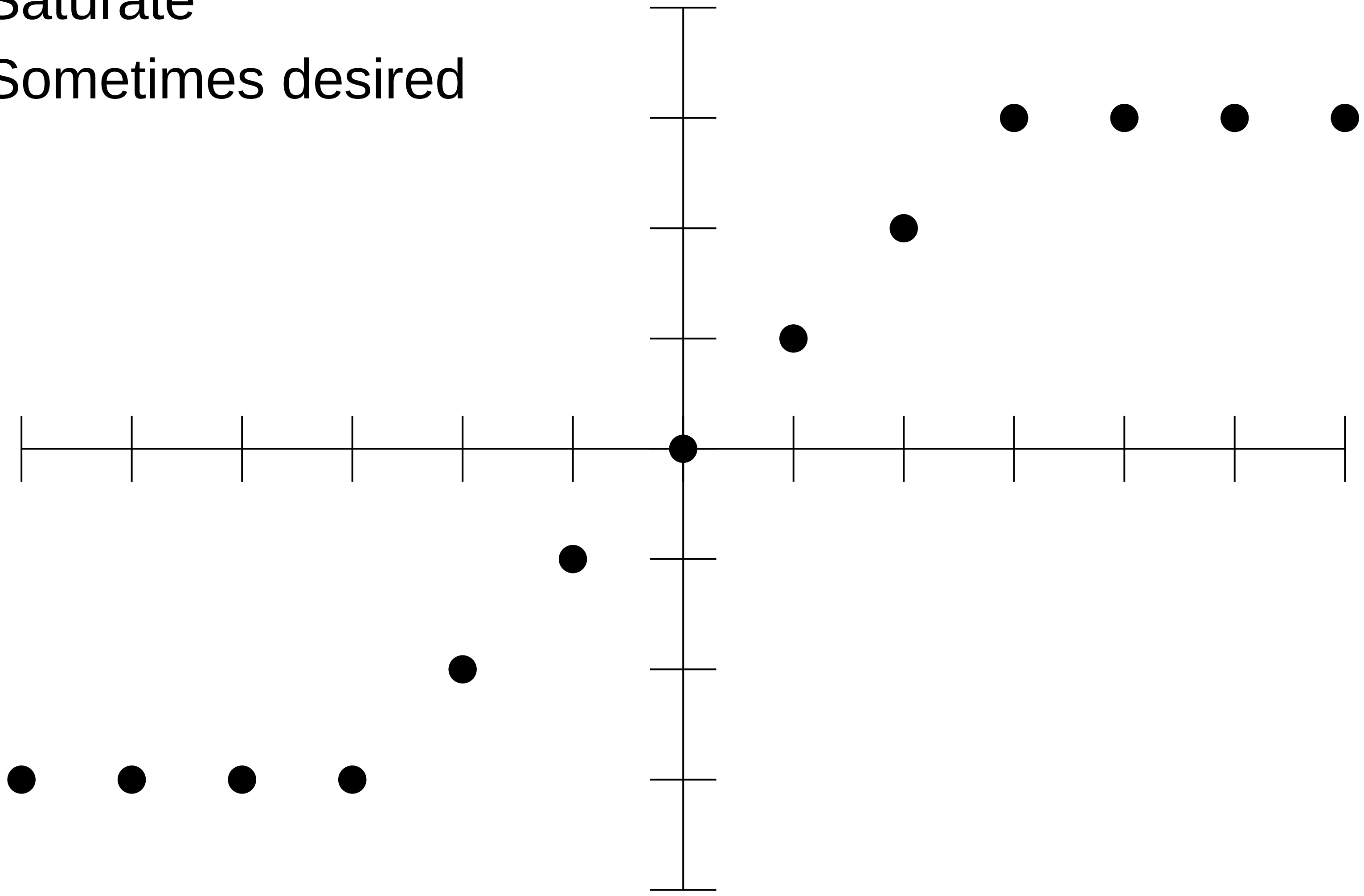
Saturation? Wrap-around?

Different behavior appropriate for different applications

SC_SAT

Saturate

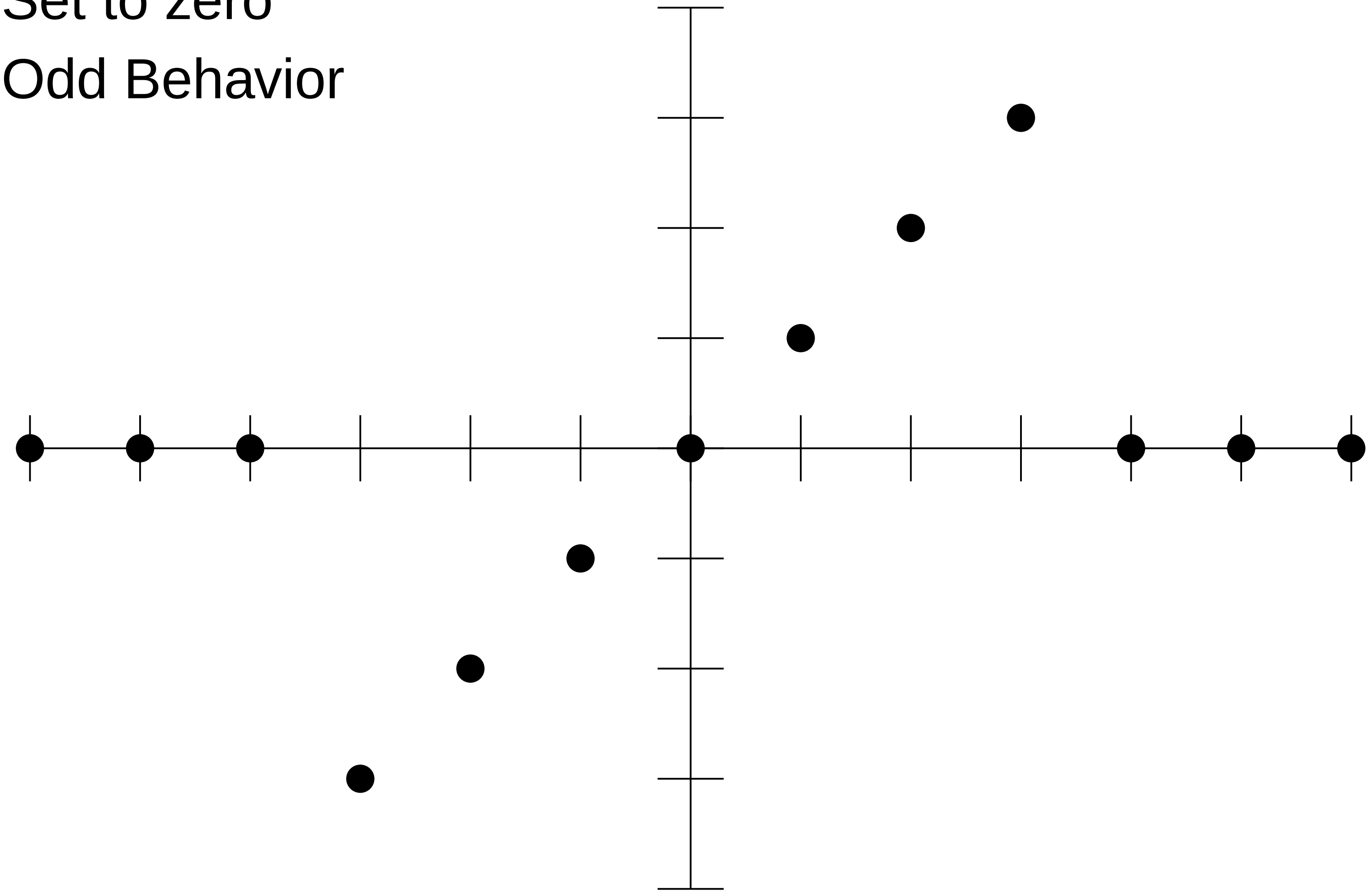
Sometimes desired



SC_SAT_ZERO

Set to zero

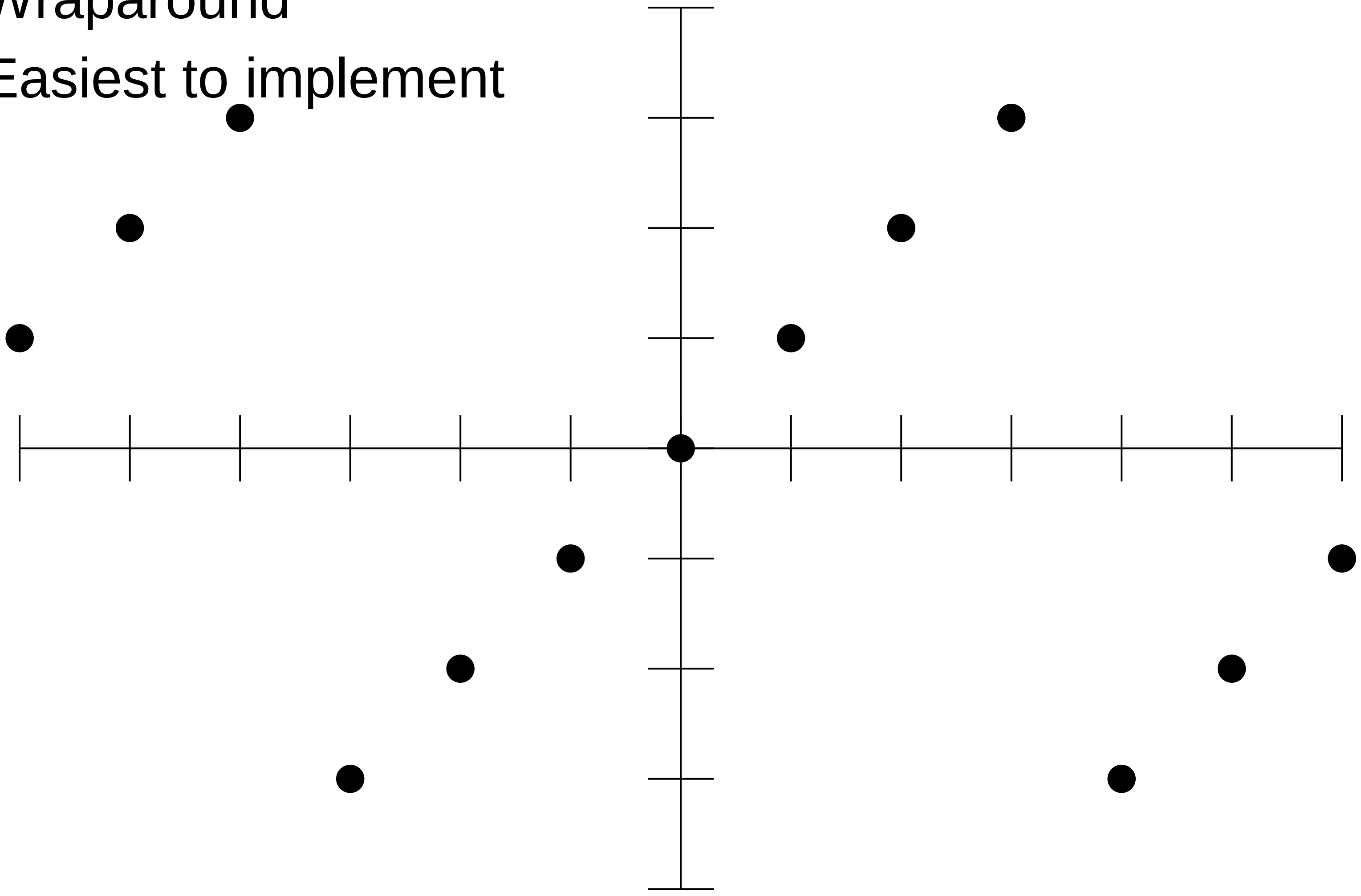
Odd Behavior



SC_WRAP

Wraparound

Easiest to implement



SystemC Semantics

Cycle-based simulation semantics

Resembles Verilog, but does not allow the modeling of delays

Designed to simulate quickly and resemble most synchronous digital logic

Clocks

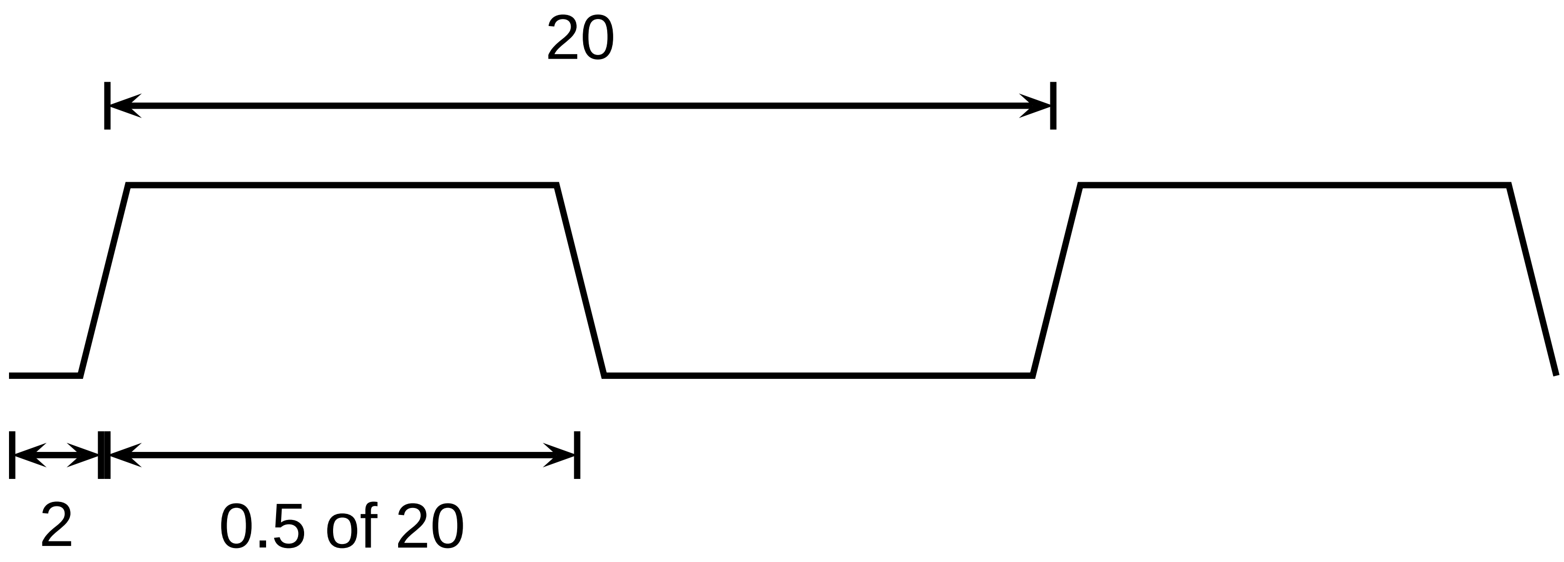
The only thing in SystemC that has a notion of real time

Only interesting part is relative sequencing among multiple clocks

Triggers SC_CTHREAD processes or others if they decided to become sensitive to clocks

Clocks

```
sc_clock clock1("myclock", 20, 0.5, 2, false);
```



SystemC 1.0 Scheduler

Assign clocks new values

Repeat until stable

- Update the outputs of triggered SC_CTHREAD processes
- Run all SC_METHOD and SC_THREAD processes whose inputs have changed

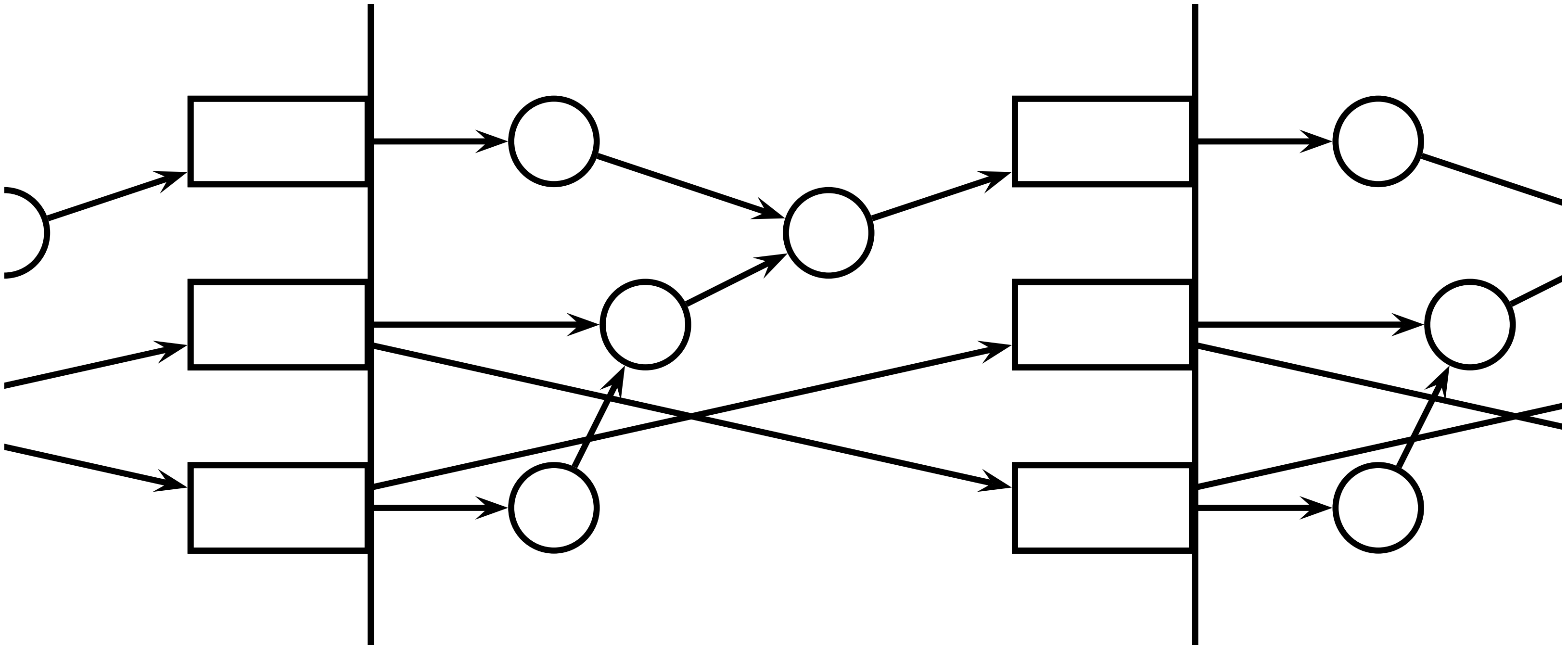
Execute all triggered SC_CTHREAD methods. Their outputs are saved until next time

Scheduling

Clock updates outputs of SC_CTHREADs

SC_METHODs and SC_THREADs respond to this change and settle down

Bodies of SC_CTHREADs compute the next state



Why Clock Outputs?

Why not allow Mealy-machine-like behavior in FSMs?

Difficult to build large, fast systems predictably

Easier when timing worries are per-FSM

Synthesis tool assumes all inputs arrive at the beginning of the clock period and do not have to be ready

Alternative would require knowledge of inter-FSM timing

Implementing SystemC

Main trick is implementing SC_THREAD and SC_CTHREAD's ability to call wait()

Implementations use a lightweight threads package

```
/* ... */
wait();
/* ... */
```

Instructs thread package to save current processor state (register, stack, PC, etc.) so this method can be resumed later

Implementing SystemC

Other trick is wait_until()

```
wait_until(continue.delayed() == true);
```

Expression builds an object that can check the condition

Instead of context switching back to the process, scheduler calls this object and only runs the process if the condition holds

Determinism in SystemC

Easy to write deterministic programs in SystemC

- Don’t share variables among processes
- Communicate through signals
- Don’t try to store state in SC_METHODs

Possible to introduce nondeterminism

- Share variables among SC_CTHREADs: They are executed in nondeterministic order
- Hide state in SC_METHODs: No control over how many times they are invoked
- Use nondeterministic features of C/C++

Synthesis Subset of SystemC

At least two

“Behavioral” Subset

- Implicit state machines permitted
- Resource sharing, binding, and allocation done automatically
- System determines how many adders you have

Register-transfer-level Subset

- More like Verilog
- You write a “+”, you get an adder
- State machines must be listed explicitly

Do People Use SystemC?

Not as many as use Verilog or VHDL

Growing in popularity

People recognize advantage of being able to share models

Most companies were doing something like it already

Use someone else’s free libraries? Why not?

Conclusions

C++ dialect for modeling digital systems

Provides a simple form of concurrency:

Cooperative multitasking

Modules

Instances of other modules

Processes

Conclusions

SC_METHOD

- Designed for modeling purely functional behavior
- Sensitive to changes on inputs
- Does not save state between invocations

SC_THREAD

- Designed to model anything
- Sensitive to changes
- May save variable, control state between invocations

Conclusions

SC_CTHREAD

- Models clocked digital logic
- Sensitive to clock edges
- May save variable, control state between invocations

Conclusions

Perhaps even more flawed than Verilog

Verilog was a hardware modeling language forced into specifying hardware

SystemC forces C++, a software specification language, into modeling and specifying hardware

SystemC 2.0 quite a change: moved to a more flexible, event-driven modeling style. Modeling, not synthesis the main focus.

Will it work? Time will tell.