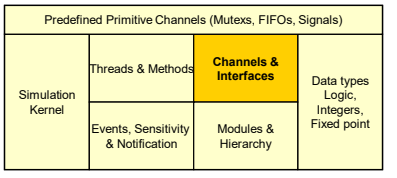
Plan

- Ch1 – Overview of SystemC
- Ch2 – Data Types
- Ch3 – Modules
- Ch4 – Notion of Time
- Ch5 – Concurrency
- Ch6 – Predefined Channels
- Ch7 – Structure
- Ch8 – Communication
- Ch9 – Custom Channels and Data
- Ch10 – Transaction Level Modeling

Custom Channels and Data

- Custom Primitive Channel
- Custom Data Type
- Custom Hierarchical Channel
- Adaptor / Transactor

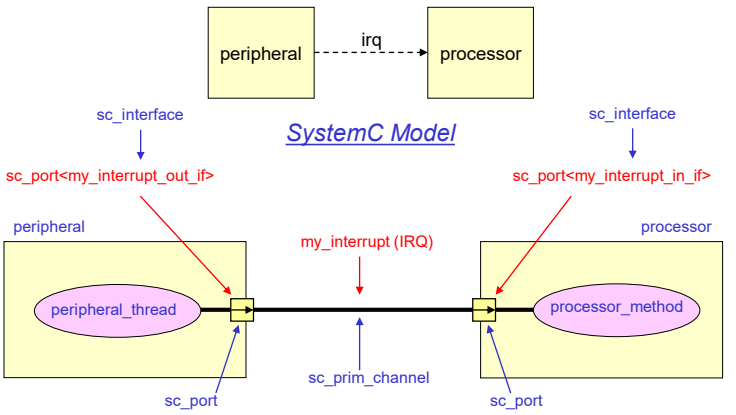


Review of Interface & Channels

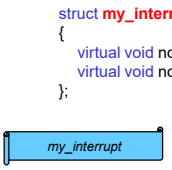
- Interface
  - makes a channel usable with ports
  - enables the separation of communication from processing
- Primitive Channel
  - inherits from sc_prim_channel (Chapter 6)
  - no hierarchy, no port
  - no SC_METHODs or SC_THREADs
  - ability to implement the evaluate-update paradigm
  - simple and fast communications
  - built-in channel (sc_fifo, sc_mutex, sc_semaphore, sc_signal)
- Hierarchical Channel
  - inherits from sc_channel
  - accesses ports
  - contains process(es), hierarchy
  - complex communications buses (PCI, AMBA AXI …)
- Channels are important
  - suitable channels enable safe communication between processes
  - channels with ports clarify the relationships of communication from processing

Custom Primitive Channel

- Problem : connect an event or interrupt between 2 modules
  - OK for 2 processes … (Chapter 6 – Concurrency)
  - side effect : we can use sc_signal<bool> !

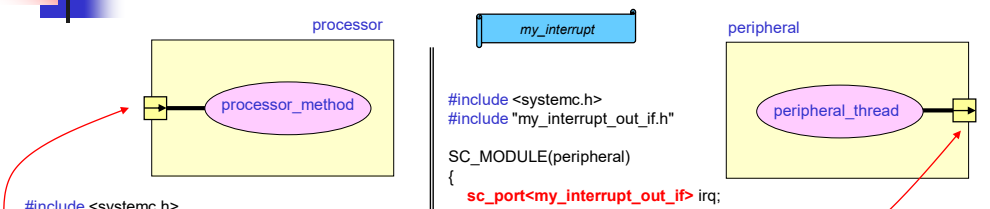


Interrupt Example
Define Primitive Channel




```
struct my_interrupt_out_if: public sc_interface
{
   virtual void notify() = 0;
   virtual void notify(sc_time t) = 0;
};

struct my_interrupt_in_if: public sc_interface
{
   virtual const sc_event& default_event() const = 0;
};

struct my_interrupt
   : public sc_prim_channel, public my_interrupt_in_if, public my_interrupt_out_if
{
   // Constructors
   explicit my_interrupt() : sc_prim_channel(sc_gen_unique_name("my_interrupt"))
   {}
   explicit my_interrupt(sc_module_name nm) : sc_prim_channel(nm)
   {}

   void notify()
      { m_interrupt.notify(); }
   void notify(sc_time t)
      {m_interrupt.notify(t); }
   const sc_event& default_event() const
      {return m_interrupt; }

private:
   sc_event m_interrupt;
   // Copy constructor so compiler won't create one
   my_interrupt( const my_interrupt& );
};
```


Interrupt Example
Modules




```
#include <systemc.h>
#include "my_interrupt_in_if.h"

SC_MODULE(processor)
{
   sc_port<my_interrupt_in_if> irq;

   SC_CTOR(processor)
   {
      SC_METHOD(processor_method);
         sensitive << irq.default_event();
         dont_initialize();
   }

   void processor_method(void)
   {
      cout << name() << " : Received IRQ event at ";
      cout << sc_time_stamp() << endl;
   };
```

```
#include <systemc.h>
#include "my_interrupt_out_if.h"

SC_MODULE(peripheral)
{
   sc_port<my_interrupt_out_if> irq;

   SC_CTOR(peripheral)
   {
      SC_THREAD(peripheral_thread);
   }

   void peripheral_thread(void)
   {
      wait(1,SC_NS);
      for (unsigned i=0; i!=5; i++)
      {
            cout << name() << " : Sending IRQ event at ";
            cout << sc_time_stamp() << endl;
            irq->notify(SC_ZERO_TIME);
            wait(5,SC_NS);
      }
   }
};
```

Interrupt Example Simulation

test_interrupt.h

```
#include <systemc.h>
#include "processor.h"
#include "peripheral.h"
#include "my_interrupt.h"
#include "my_interrupt_in_if.h"
#include "my_interrupt_out_if.h"

SC_MODULE(test_interrupt)
{
  my_interrupt* irq;
  processor* processor_i;
  peripheral* peripheral_i;

  SC_HAS_PROCESS(test_interrupt);
  test_interrupt(sc_module_name nm);
};
```

test_interrupt.cpp

```
#include "test_interrupt.h"

test_interrupt::test_interrupt(sc_module_name nm)
{
    irq = new my_interrupt();
    processor_i = new processor("processor_i");
    peripheral_i = new peripheral("peripheral_i");
    processor_i->irq(*irq);
    peripheral_i->irq(*irq);
}
```

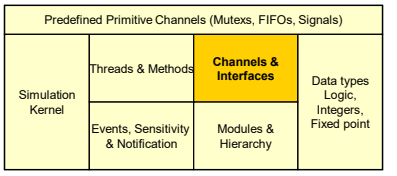
main.cpp

```
#include <systemc.h>
#include "test_interrupt.h"

int sc_main(int argc, char* argv[])
{
    cout << "INFO: Elaborating " << endl;
    test_interrupt interrupt_i("interrupt_i");
    cout << "INFO: Simulating " << endl;
    sc_start();
    cout << "INFO: Post-processing " << endl;

    return 0;
}
```

```
INFO: Elaborating
INFO: Simulating
interrupt_i.peripheral_i : Sending IRQ event at 1 ns
interrupt_i.processor_i : Received IRQ event at 1 ns
interrupt_i.peripheral_i : Sending IRQ event at 6 ns
interrupt_i.processor_i : Received IRQ event at 6 ns
interrupt_i.peripheral_i : Sending IRQ event at 11 ns
interrupt_i.processor_i : Received IRQ event at 11 ns
interrupt_i.peripheral_i : Sending IRQ event at 16 ns
interrupt_i.processor_i : Received IRQ event at 16 ns
interrupt_i.peripheral_i : Sending IRQ event at 21 ns
interrupt_i.processor_i : Received IRQ event at 21 ns
INFO: Post-processing
```

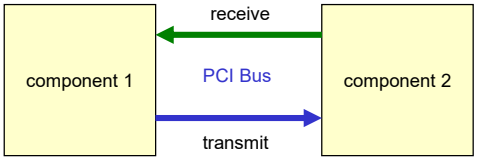

Custom Channels and Data

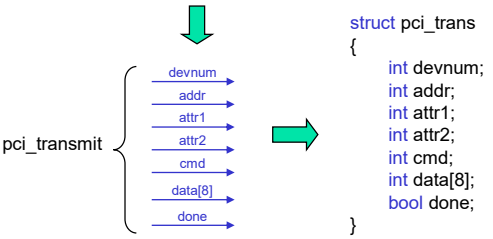
- Custom Primitive Channel
- Custom Data Type
- Custom Hierarchical Channel
- Adaptor / Transactor



PCIX Bus Example Model

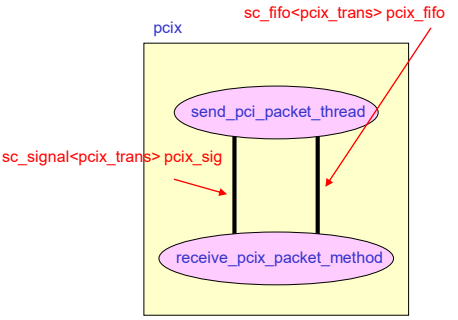
- Transmit a packet on the PCI-X Bus






```
struct pci_trans
{
    int devnum;
    int addr;
    int attr1;
    int attr2;
    int cmd;
    int data[8];
    bool done;
}
```

SystemC Model



PCIX Bus Example Structure Declaration (Header File)

pcix_trans.h

```
struct pcix_trans
{
   int  devnum;
   int  addr;
   int  attr1;
   int  attr2;
   int  cmnd;
   int  data[8];
   bool done;

   // Constructors
   pcix_trans()
      : devnum(-1), addr(-1), cmnd(-1),
        attr1(-1), attr2(-1), done(false)
   {
      for (unsigned i=0; i!=8; i++) data[i] = 0;
   }

   pcix_trans(int _devnum, int  _addr,
              int _attr1, int  _attr2, int _cmnd, int* _data,
              int _done)
      : devnum(_devnum), addr(_addr), cmnd(_cmnd)
        ,attr1(_attr1), attr2(_attr2), done(_done)
   {
      for (unsigned i=0; i!=8; i++) data[i] = _data[i];
   }

   // Required by sc_signal<> and sc_fifo<>
   pcix_trans& operator= (const pcix_trans& rhs);

   // Required by sc_signal<>
   bool operator== (const pcix_trans& rhs) const;
};

// Stream operator to output a PCIX transaction packet to terminal
ostream& operator<<(ostream& file, const pcix_trans& trans);

// Trace a PCIX transaction packet in case it is used in an sc_signal
void sc_trace(sc_trace_file*& tf, const pcix_trans& trans, sc_string nm);
```

pci_datatype

PCI signals

PCIX Bus Example
Structure Declaration (Body File)

```
//********** Member Functions **********
// Required by sc_signal<> and sc_fifo<>
pcix_trans& pcix_trans::operator= (const pcix_trans& rhs)
{
   devnum = rhs.devnum;
   addr   = rhs.addr;
   attr1  = rhs.attr1;
   attr2  = rhs.attr2;
   cmnd   = rhs.cmnd;
   for (unsigned i=0; i!=8; i++)
      data[i] = rhs.data[i];
   done   = rhs.done;
   return *this;
}

// Required by sc_signal<>
bool pcix_trans::operator== (const pcix_trans& rhs) const
{
   return (
      devnum  == rhs.devnum  && addr   == rhs.addr   &&
      attr1   == rhs.attr1   && attr2  == rhs.attr2  &&
      cmnd    == rhs.cmnd    && data[0] == rhs.data[0] &&
      data[1] == rhs.data[1] && data[2] == rhs.data[2] &&
      data[3] == rhs.data[3] && data[4] == rhs.data[4] &&
      data[5] == rhs.data[5] && data[6] == rhs.data[6] &&
      data[7] == rhs.data[7] && done   == rhs.done
      );
}
```

pci_datatype

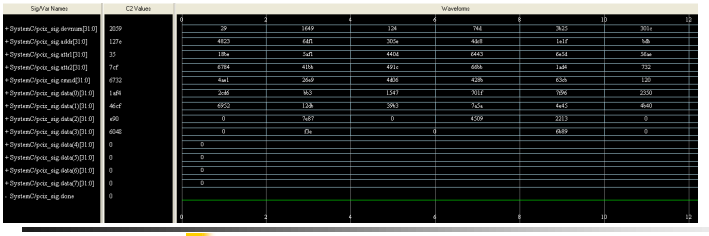
```
//********** Non-Member Functions **********
// Print a PCIX transaction packet out to a stream (usually just the terminal
// window), in a nice-looking format
ostream& operator<<(ostream& os, const pcix_trans& trans)
{
   os << "{" << endl
      << " cmnd: " << trans.cmnd  << ", "
      << "attr1:" << trans.attr1  << ", "
      …
      <<      "." << trans.data[4] << "."
      << "," << endl
      << " done:"  << (trans.done?"true":"false")  << endl
      << "}";
   return os;
}

// trace function, only required if actually used
void sc_trace(sc_trace_file*& tf, const pcix_trans& trans, sc_string nm)
{
   sc_trace(tf, trans.devnum,   nm + ".devnum");
   sc_trace(tf, trans.addr,     nm + ".addr");
   sc_trace(tf, trans.attr1,    nm + ".attr1");
   sc_trace(tf, trans.attr2,    nm + ".attr2");
   sc_trace(tf, trans.cmnd,     nm + ".cmnd");
   sc_trace(tf, trans.data[0],  nm + ".data[0]");
   …
   sc_trace(tf, trans.data[7],  nm + ".data[7]");
   sc_trace(tf, trans.done,     nm + ".done");
}
```


PCIX Bus Example
Simulation

```
SC_MODULE(pcix)
{
   sc_signal<pcix_trans> pcix_sig;
   sc_fifo<pcix_trans> pcix_fifo;

   SC_CTOR(pcix)
   {
      SC_THREAD(send_pcix_packet_thread);
      SC_METHOD(receive_pcix_packet_method);
         sensitive << pcix_sig;
         dont_initialize();
   }

   void send_pcix_packet_thread(void);
   void receive_pcix_packet_method(void);
};
```

pci_datatype

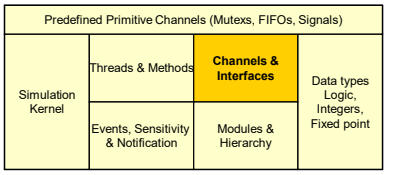
Wave of Signal



```
Elaborating ...
Simulating ...
0 s New PCIX transaction {
 cmnd: 19169, attr1:6334, attr2:26500,
 devnum:41, addr:18467,
 data: 11478.26962.0.0.0.0.0.0,
 done:false
}
2 ns New PCIX transaction {
 cmnd: 9961, attr1:23281, attr2:16827,
 devnum:5705, addr:28145,
 data: 2995.4827.32391.3902.0.0.0.0,
 done:false
}
4 ns New PCIX transaction {
 cmnd: 19718, attr1:17421, attr2:18716,
 devnum:292, addr:12382,
 data: 5447.14771.0.0.0.0.0.0,
 done:false
}
6 ns New PCIX transaction {
 cmnd: 17035, attr1:25667, attr2:26299,
 devnum:1869, addr:19912,
 data: 28703.31322.17673.0.0.0.0.0,
 done:false
}
8 ns New PCIX transaction {
 cmnd: 25547, attr1:28253, attr2:6868,
 devnum:15141, addr:7711,
 data: 32662.20037.8723.27529.0.0.0.0,
 done:false
}
…
```

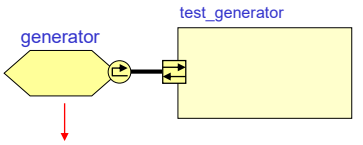
Custom Channels and Data

- Custom Primitive Channel
- Custom Data Type
- Custom Hierarchical Channel
- Adaptor / Transactor



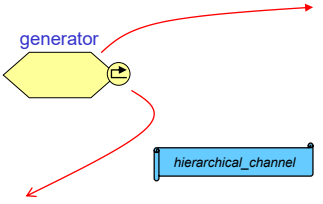
Hierarchical Channel

- To model complex buses
- inherit from sc_channel
  - sc_channel is just a sc_module
- Body of sc_channel
  - Ports
  - Member channel instances (sub-channel)
  - Member data instance
  - Constructor
  - Destructor
  - Process member functions (processes)
  - Helper functions




```
struct generator : public sc_channel, public generator_if
{
    …
};
```

Example : Generator Channel Declaration

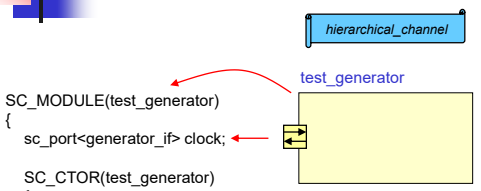



```
struct generator_if: public sc_interface
{
   virtual const sc_event& default_event() const = 0;
   virtual const sc_event& posedge_event() const = 0;
   virtual const int getTickNumber() const = 0;
};
```

```
struct generator : public sc_channel, public generator_if
{
   SC_HAS_PROCESS(generator);

   // Constructors
   explicit generator() : sc_channel(sc_gen_unique_name("generator"))
       , m_period(sc_get_default_time_unit()), m_tick(0)
   {
       SC_METHOD(generator_method);
           sensitive << m_clk;
   }
   explicit generator(sc_module_name nm, sc_time _period) : sc_channel(nm)
       , m_period(_period), m_tick(0)
   …

  // User methods
  const sc_event& default_event() const { return m_clk }
  const sc_event& posedge_event() const { return m_clk }
  const int getTickNumber() const { return m_tick }

  // Processes
  void generator_method();

private:
  sc_event m_clk;
  sc_time  m_period;
  int m_tick;

  // Copy constructor so compiler won't create one
  generator( const generator& );
};
```

```
void generator::generator_method(void)
{
    m_tick++;
    m_clk.notify(m_period);
}
```


Example : Generator Channel Simulation



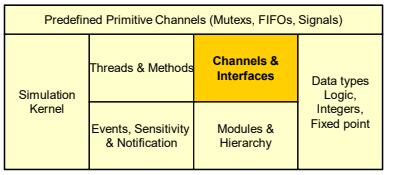

```
SC_MODULE(test_generator)
{
   sc_port<generator_if> clock;

   SC_CTOR(test_generator)
   {
      SC_METHOD(test_method);
         sensitive << clock;
         dont_initialize();
   }

   void test_method(void)
   {
      cout << clock->getTickNumber() << " : Received a tick at ";
      cout << sc_time_stamp() << "." << endl;
   }
};
```

```
int sc_main(int argc, char* argv[])
{
  cout << "INFO: Elaborating ..." << endl;
  sc_set_time_resolution(100,SC_PS);

  sc_time period(2,SC_NS);
  generator clock("clock", period);
  test_generator test_generator_i("test_generator_i");
  test_generator_i.clock(clock);

  cout << "INFO: Simulating " << endl;
  sc_start(20, SC_NS);
  cout << "INFO: Post-processing ... " << endl;
  return 0;
}
```

```
INFO: Elaborating ...
INFO: Simulating
1 : Received a tick at 2 ns.
2 : Received a tick at 4 ns.
3 : Received a tick at 6 ns.
4 : Received a tick at 8 ns.
5 : Received a tick at 10 ns.
6 : Received a tick at 12 ns.
7 : Received a tick at 14 ns.
8 : Received a tick at 16 ns.
9 : Received a tick at 18 ns.
INFO: Post-processing ...
```

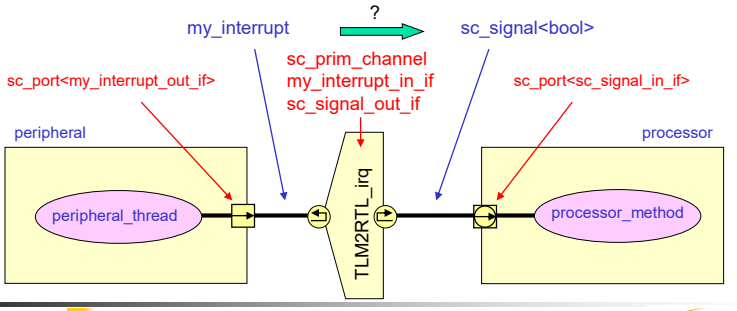
Custom Channels and Data

- Custom Primitive Channel
- Custom Data Type
- Custom Hierarchical Channel
- Adaptor / Transactor



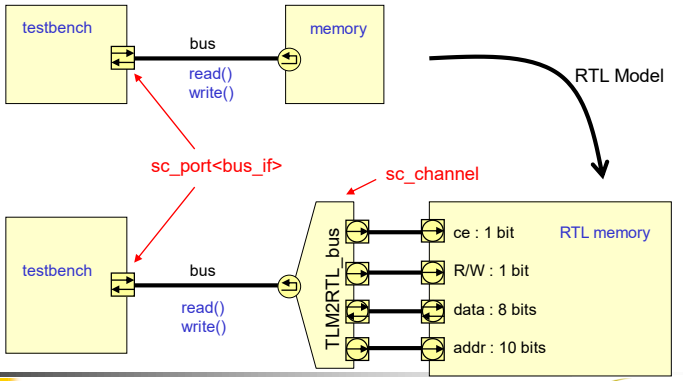
Adaptator

- Custom Primitive Channel (sc_prim_channel)
- Translates between modules with different interfaces
- Moving between different abstractions
  - communication at the TLM Level
  - communication at the RTL Level (Pin accurate level)



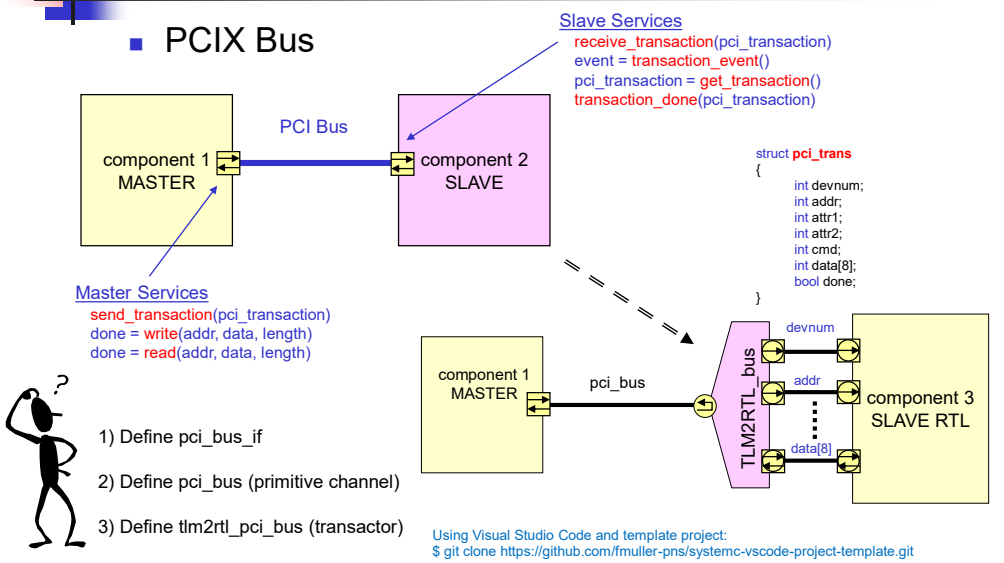
Transactor

- Custom Hierarchical Channel (sc_channel)
- Translates between modules with different interfaces
- Moving between different abstractions
  - testbench at the TLM Level
  - memory IP at th RTL Level (Pin accurate level)



Exercise

- PCIX Bus



Using Visual Studio Code and template project:
$ git clone https://github.com/fmuller-pns/systemc-vscode-project-template.git