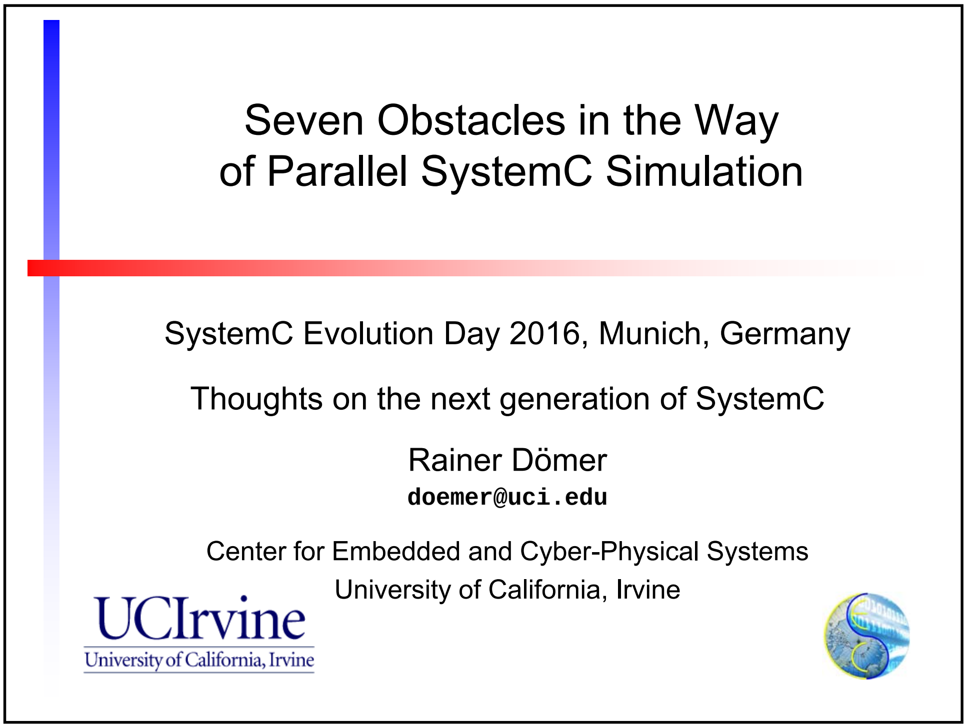


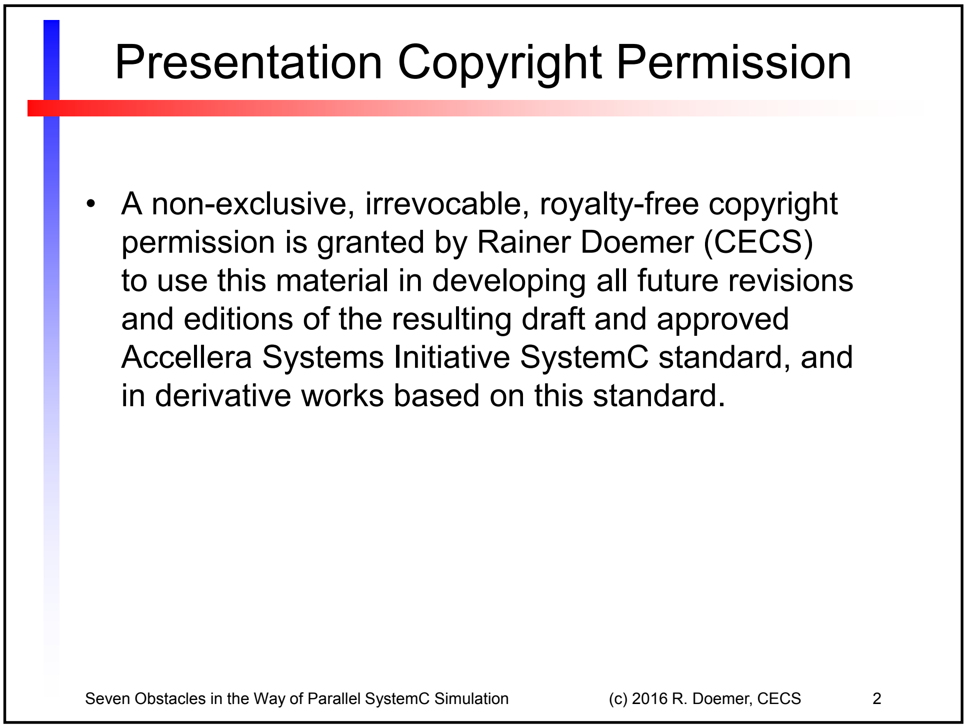
Seven Obstacles in the Way of Parallel SystemC Simulation

SystemC Evolution Day 2016, Munich, Germany

Thoughts on the next generation of SystemC

Rainer Dömer
`doemer@uci.edu`

Center for Embedded and Cyber-Physical Systems
University of California, Irvine



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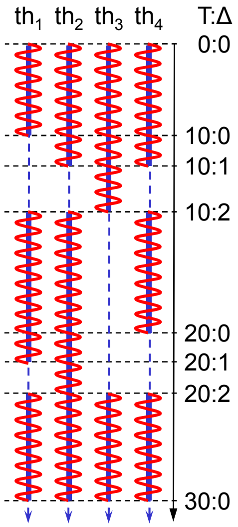
Goals

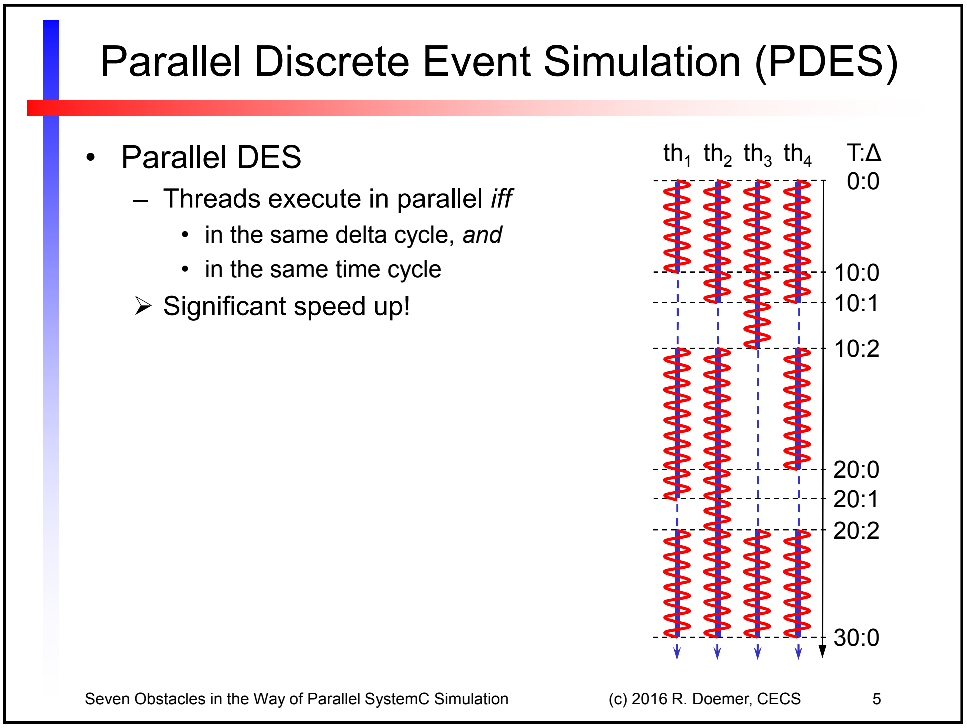
- Truly parallel simulation of SystemC models
  - – High speed due to parallel execution on multi/many core hosts
  - – Compliant to the IEEE 1666 standard
- Identify the main obstacles in the way of standard-compliant parallel SystemC
  - – And propose potential solutions
- Technical review and evaluation of
  - – Standard SystemC® Language Reference Manual
    - IEEE Std 1666™-2011 (Revision of IEEE Std 1666-2005)
  - – Accellera open source proof-of-concept library (v2.3.1)

➢ Warning: Controversial Content Ahead!
  - – Evolve SystemC to true parallelism (major revision)
  - – Let's have a good discussion!

Discrete Event Simulation (DES)

- Traditional DES
  - – Concurrent threads of execution
  - – Managed by a central scheduler
  - – Driven by events and time advances
    - Delta-cycle
    - Time-cycle
  - ➢ Partial temporal order with barriers
- Sequential Reference Simulator
  - – SystemC standard IEEE 1666-2011
  - ➢ A single thread is active at any time
  - ➢ Cannot exploit parallelism
  - ➢ Cannot utilize multiple cores





Parallel Discrete Event Simulation (PDES)

- Parallel DES
  - – Threads execute in parallel *iff*
    - in the same delta cycle, *and*
    - in the same time cycle
  - ➢ Significant speed up!

Obstacle 1: Co-Routine Semantics

- Fact: IEEE 1666-2011 requires *co-operative multitasking*
  - ➢ Quotes from Section “4.2.1.2 Evaluation phase” (pages 17, 18):

> Since process instances execute without interruption, only a single process instance can be running at any one time, […]. A process shall not pre-empt or interrupt the execution of another process. This is known as *co-routine* semantics or *co-operative multitasking*.
> […]
> The scheduler is not pre-emptive. An application can assume that a method process will execute in its entirety without interruption, and a thread or clocked thread process will execute the code between two consecutive calls to function **wait** without interruption.

- Problem: Uninterrupted execution guarantee

> An implementation running on a machine that provides hardware support for concurrent processes may permit two or more processes to run concurrently, provided that the behavior appears identical to the co-routine semantics defined in this subclause. In other words, the implementation would be obliged to analyze any dependencies between processes and to constrain their execution to match the co-routine semantics.

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- Parallel DES
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    - in the same delta cycle, *and*
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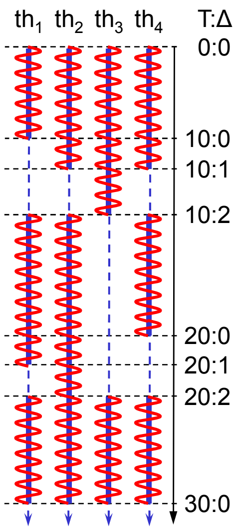
➢ SystemC LRM Requirement:
“The scheduler is not pre-emptive.”

```
int x;  // global variable

void thread1()       void thread42()
{ x = 0;             { x = 7;
  x = x + 1;           x = x * 6;
  cout << x;           cout << x;
}                    }
```

- ➢ SystemC: guaranteed safe!
- ➢ PDES: not safe! (race condition)



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- Proposal: Explicitly allow parallel execution, preemption
  - – Process instances at the same time (t,δ) may execute in parallel
    - Model designer must write thread safe code, avoid race conditions
    - ➢ Parallel systems, parallel models, parallel programming

Obstacle 2: Simulator State

- Fact: Discrete Event Simulation (DES) is presumed
  - ➢ Example from IEEE 1666-2011, page 31: `sysc/kernel/sc_simcontext.h`

```
[...]
bool sc_pending_activity_at_current_time();
bool sc_pending_activity_at_future_time();
bool sc_pending_activity();
bool sc_time_to_pending_activity();
[...]
```

- Problem: Parallel Discrete Event Simulation (PDES) is different from sequential DES
  - – After elaboration, there may be *multiple running threads*
  - – Scheduling may happen while some threads are still running
- Proposal: Carefully review simulator state primitives and revise as needed for PDES
  - ➢ Adapt the functions and APIs for parallel execution semantics
  - ➢ The general notion of *shared state* needs attention…

Obstacle 2: Simulator State

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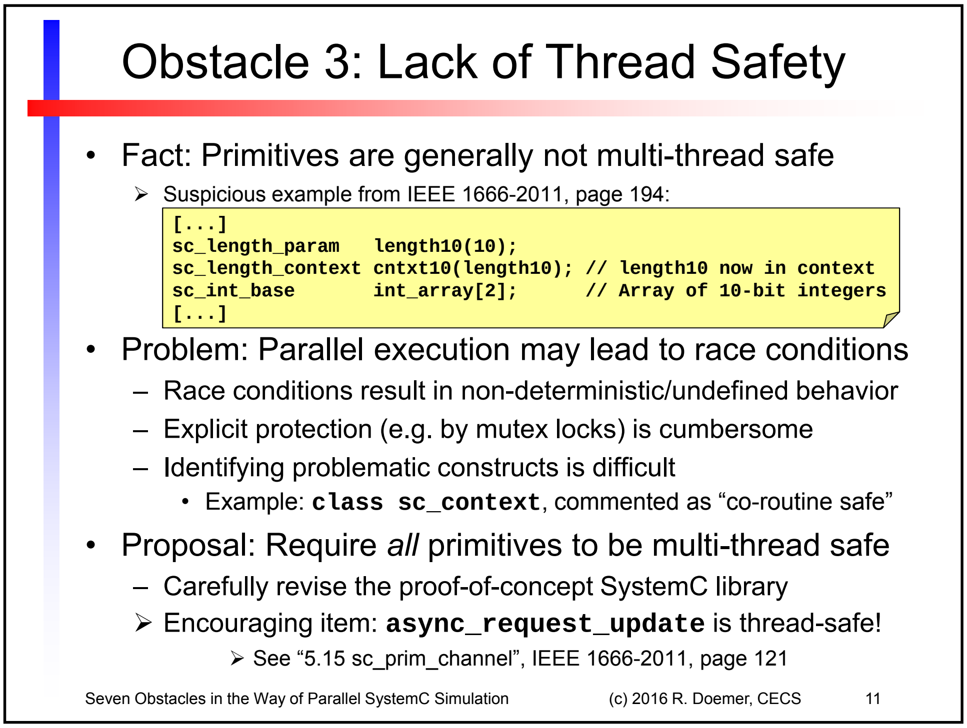
- Problem: Parallel Discrete Event Simulation (PDES) is different from sequential DES
- Proposal: Carefully review simulator state primitives and revise as needed for PDES
  - ➢ The general notion of *shared state* needs attention
  - ➢ Special consideration for very strict semantics, e.g. debugging: Quote from IEEE 1666-2011, Section "4.2.1.2 Evaluation phase" (page 17):

> The order in which process instances are selected from the set of runnable processes is implementation defined. However, if a specific version of a specific implementation runs a specific application using a specific input data set, the order of process execution shall not vary from run to run.

  - ➢ Strict DES can remain valid as a special case of PDES
    - ➢ While PDES typically runs up to n threads in parallel, where n = number of cores on the host, we can set n = 1 to mimic the classic DES case

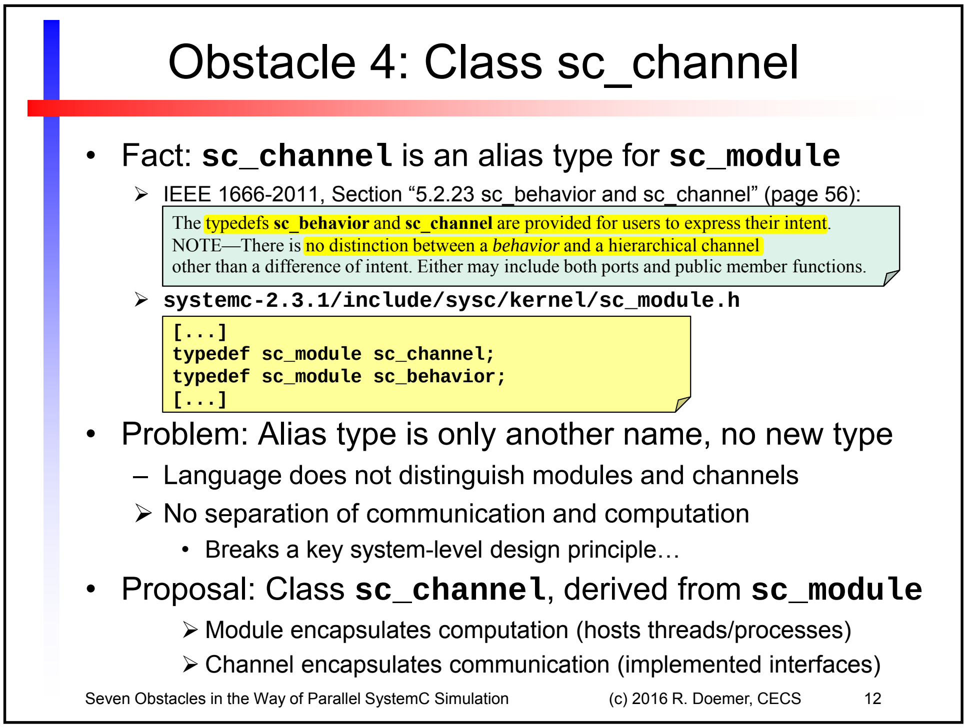


Obstacle 3: Lack of Thread Safety

- Fact: Primitives are generally not multi-thread safe
  - ➢ Suspicious example from IEEE 1666-2011, page 194:

```
[...]
sc_length_param   length10(10);
sc_length_context cntxt10(length10); // length10 now in context
sc_int_base       int_array[2];      // Array of 10-bit integers
[...]
```

- Problem: Parallel execution may lead to race conditions
  - – Race conditions result in non-deterministic/undefined behavior
  - – Explicit protection (e.g. by mutex locks) is cumbersome
  - – Identifying problematic constructs is difficult
    - Example: **`class sc_context`**, commented as “co-routine safe”
- Proposal: Require *all* primitives to be multi-thread safe
  - – Carefully revise the proof-of-concept SystemC library
  - ➢ Encouraging item: **`async_request_update`** is thread-safe!
    - ➢ See “5.15 sc_prim_channel”, IEEE 1666-2011, page 121



Obstacle 4: Class sc_channel

- Fact: **`sc_channel`** is an alias type for **`sc_module`**
  - ➢ IEEE 1666-2011, Section “5.2.23 sc_behavior and sc_channel” (page 56):

> The typedefs **sc_behavior** and **sc_channel** are provided for users to express their intent.
> NOTE—There is no distinction between a *behavior* and a hierarchical channel
> other than a difference of intent. Either may include both ports and public member functions.

  - ➢ **`systemc-2.3.1/include/sysc/kernel/sc_module.h`**

```
[...]
typedef sc_module sc_channel;
typedef sc_module sc_behavior;
[...]
```

- Problem: Alias type is only another name, no new type
  - – Language does not distinguish modules and channels
  - ➢ No separation of communication and computation
    - Breaks a key system-level design principle…
- Proposal: Class **`sc_channel`**, derived from **`sc_module`**
  - ➢ Module encapsulates computation (hosts threads/processes)
  - ➢ Channel encapsulates communication (implemented interfaces)

Obstacle 4: Class sc_channel

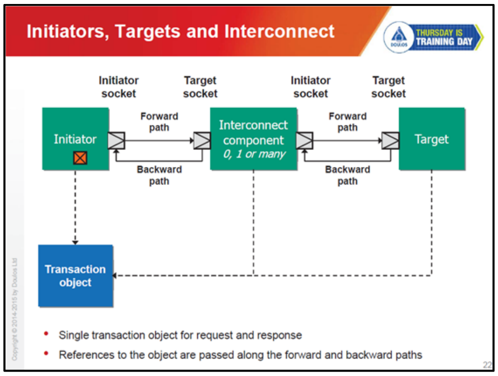
- Proposal: Class **`sc_channel`**, derived from **`sc_module`**
  - ➢ Module encapsulates computation (hosts threads/processes)
  - ➢ Channel encapsulates communication (implemented interfaces)
- ➢ Q: Why do we need channels? A: Thread safe communication!
- – Example: Blocking write in primitive channel **`sc_fifo.h`**

```
template <class T> inline
void sc_fifo<T>::write( const T& val_ )
{   sc_stacked_lock l(m_mutex);  // lock the channel mutex
    while( num_free() == 0 ) {
        sc_core::wait( m_data_read_event );
    }
    m_num_written ++;
    buf_write( val_ );
    request_update();
}
```

  - ➢ Race condition between **`num_free`** and **`m_num_written`**
  - ➢ Prevented by locking **`m_mutex`** of this channel instance
- – Channel acts as a *monitor* for multi-thread safe communication

Obstacle 5: TLM-2.0

- Fact: Channel concept has disappeared
  - ➢ *"The Definitive Guide to SystemC: TLM-2.0 and the IEEE 1666-2011 Standard"*, Presentation by David Black, Doulos, at DAC'15 Training Day
- Problem: Where is the channel?



Initiators, Targets and Interconnect

- Single transaction object for request and response
- References to the object are passed along the forward and backward paths

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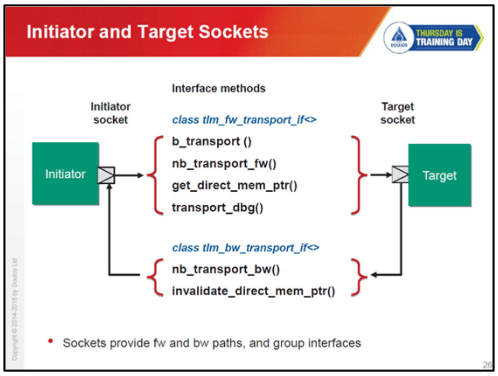
- Problem: Where is the channel?
  - Interface methods are well-defined, but not contained
  - Separation of concerns *"Computation ≠ Communication"* principle is broken



Initiator and Target Sockets

- Sockets provide fw and bw paths, and group interfaces

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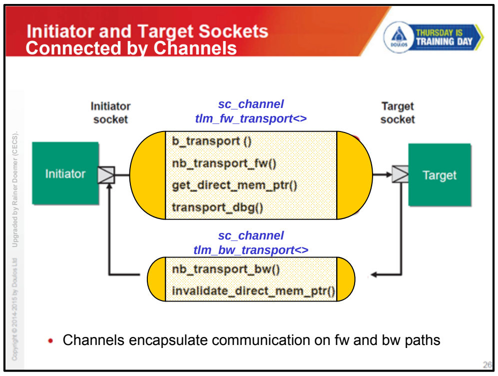
- Problem: Where is the channel?
  - Interface methods are well-defined, but not contained
  - Separation of concerns *"Computation ≠ Communication"* principle is broken
  - Proposal: Encapsulate communication methods in channels



Initiator and Target Sockets Connected by Channels

- Channels encapsulate communication on fw and bw paths

Obstacle 6: Sequential Mindset

- Fact: SC_METHOD is preferred over SC_THREAD, context switches are considered overhead
  - ➢ IEEE 1666-2011, Section 5.2.11 on threads (page 44):

> Each thread or clocked thread process requires its own execution stack.
> As a result, context switching between thread processes may impose a simulation overhead when compared with method processes.

- Problem: Sequential modeling is encouraged
  - – However, systems are parallel by nature, so should be models
  - – Avoiding context switches is the wrong optimization criterion
- Proposal: Use actual threads, eliminate **`SC_METHOD`**, identify dependencies among threads
  - ➢ Promote parallel mindset, with true thread-level parallelism
    - Speed due to parallel execution, not due to fewer context switches
  - ➢ Explicitly express task relations (use **`e.notify()`**, **`wait(e)`**)
    - Synchronize, communicate through events and channels

Obstacle 7: Temporal Decoupling

- Fact: TD is designed to speed up sequential DES
  - ➢ IEEE 1666-2011, Section 12.1 on "TLM-2.0 global quantum" (page 453):

> Temporal decoupling permits SystemC processes to run ahead of simulation time for an amount of time known as the time quantum and is associated with the loosely-timed coding style.
> Temporal decoupling permits a significant simulation speed improvement by reducing the number of context switches and events.

  - – Abstraction trades off accuracy for higher simulation speed
- Problem: PDES is a different foundation than DES
  - – TD design assumptions are not necessarily true for PDES
  - – Global time quantum is a technical obstacle (race condition)
- Proposal: Reevaluate costs/benefits, redesign if needed
  - – Analyze TD idea for PDES, adopt advantages, drop drawbacks
    - Avoid **`tlm_global_quantum`**, promote **`wait(time)`**
  - – Consider the use of a compiler to optimize scheduling, timing
    - Out-of-Order PDES is one solution (fully automatic, accurate)

Concluding Remarks

- Towards *standard-compliant parallel* SystemC
  - Higher simulation speed on multi/many core hosts
- Overcome the identified IEEE 1666-2011 obstacles
  - Move up from DES to PDES
  - Adopt a parallel mindset, expose and exploit parallelism
  - Apply the principle of separation of concerns
    - Modules encapsulate computation
    - Channels encapsulate communication
  - Simulate models faster with parallel execution semantics
- ➢ SystemC must evolve in a major revision (3.x)
  - C++11 already has built-in support for multithreading
  - SystemC must embrace true parallelism
    - Otherwise it will go down the same path as the dinosaurs…

Acknowledgments

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  - Ajit Dingankar
  - Philipp Hartmann

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    - …for not kicking me off the stage! ☺