Models of Computation and Modeling Languages

1. System Specification
2. System Modeling and Formal Models
3. Models of Computation: What’s that?
4. Concurrency
5. Communication & Synchronisation
6. Common Models of Computation

From Specifications to Implementations

☞ Specification: A description of basic requirements and properties of a system

• The designer gets a specification as an input and, finally, has to produce an implementation. This is usually done as a sequence of refinement steps.

• Specifications can be:
  - informal (natural language) or
  - more detailed and unambiguous (based on a formal notation)

System Specifications

☞ A specification captures:
  - The basic required behaviour of the system
    - E.g. as a relation between inputs and outputs
  - Other (non-functional) requirements
    - time constraints
    - power/energy constraints
    - safety requirements
    - environmental aspects
    - cost, weight, etc.

System Model

☞ As an early step in the design flow, a system model is produced (see Fö 1&2, slide 38).

☞ The model is a description of certain aspects/properties of the system. Models are abstract, in the sense that they omit details and concentrate on aspects that are significant for the design process.
System Model (cont'd)

Models are formulated using modeling languages

- **Modeling language:**
  - well-suited to expressing the basic system properties and basic aspects of system behaviour in a succinct and clear manner
  - lends itself well to the, preferably automatic, checking of requirements and synthesis of implementations.

Depending on the particularities of the system, an adequate modeling language has to be chosen.

The language has to contain the appropriate language constructs in order to express the system’s functionality and requirements.

System Model (cont'd)

What do we want to do with the model of an embedded system?

1. To validate the system description in order to check that the specified functionality is the desired one and the requirements are stated correctly:
   - by formal verification
   - by simulation
2. To synthesise efficient implementations

Semantics of System Models

- We would like modeling languages to have well defined semantics ⇒ models are unambiguous.

  - The semantics is the set of rules which associate a meaning (interpretation) to syntactical constructs (combination of symbols) of the language.
  
    - The semantics of the language is based on the underlying model of computation.

    It depends on this underlying model of computation what kind of systems can be described with the language.
    The model of computation decides on the expressiveness of the language.
Semantics of System Models (cont’d)

Do we want large expressiveness (we can describe anything we want)?

Not exactly!

- Large expressive power: imperative model (e.g. unrestricted use of C or Java):
  - Can specify “anything”.
  - No formal reasoning possible (or extremely complex).
- Limited expressive power, based on well chosen computation model:
  - Only particular systems can be specified.
  - Formal reasoning is possible.
  - Efficient (possibly automatic) synthesis.

Models of Computation

☞ The model of computation deals with the set of theoretical choices that build the execution model of the language.

- A design is represented as a set of components, which can be considered as isolated monolithic modules (often called processes or tasks), interacting with each other and with the environment.

The model of computation defines the behavior and interaction mechanisms of these modules.

Models of Computation (cont’d)

- Models of computation usually refer to:
  - how each module (process or task) performs internal computation
  - how the modules transfer information between them
  - how they relate in terms of concurrency
- Some models of computation do not refer to aspects related to the internal computation of the modules, but only to module interaction and concurrency.

Models of Computation (cont’d)

The main aspects we are interested in:

- Concurrency
- Communication & Synchronization
- Time
- Hierarchy
Concurrent

A system consists of several activities (processes or tasks) which potentially can be executed in parallel. Such activities are called concurrent.

How to express concurrency?
This is one aspect in which computational models differ!

- Data-driven concurrency
- Control-driven concurrency

Data-driven Concurrency

The system is modelled as a set of processes without any explicit specification of the ordering of executions.

The execution order of processes (and, implicitly, the potential of parallelism) is fixed solely by data dependencies

- Typical for many DSP applications (see e.g. later, Fö 4, when we discuss about dataflow models)

Control-driven Concurrency

The execution order of processes is given explicitly in the system model.

Explicit constructs are used to specify sequential execution and concurrency.

Process p1( in int a, out int x, out int y) {
    
} // p1
Process p2( in int a, out int x) { 
    
} // p2
Process p3( in int a, out int x) { 
    
} // p3
Process p4( in int a, in int b, out int x) { 
    
} // p4
channel int I, O, C1, C2, C3, C4;
p1(I, C1, C2);
p2(C1, C3);
p3(C2, C4);
p4(C3, C4, O);
It doesn’t matter in which order I have written this.
Control-driven Concurrency (cont’d)

- This example is in ESTEREL (see Fö 6 synchronous/reactive languages).
- p1 is started first and has to finish before the starting of p2 and p3.
- p2 and p3 are started in parallel.
- both p2 and p3 have to finish before p4 is started.

run p1;
[run p2 || run p3];
run p4

Here, the order in which we write is essential!

Communication

- Processes have to communicate in order to exchange information.
- Various communication mechanisms are used in the different computation models
  - shared memory
  - message passing
    - blocking
    - non-blocking

Shared Memory Communication

- Each sending process writes to shared variables which can be read by a receiving process.

```plaintext
shared memory

process p1
  int a;
  X = a+1;

process p2
  int b;
  b = X;

int X;
```

Private variables:
- a: local to p1
- b: local to p2

Shared variable:
- X

Message-passing Communication

- Data (messages) are passed over an abstract communication medium called channel.

```plaintext
Abstract channel C

process p1
  int a;
  C.send(a+1);

process p2
  int b;
  b = C.receive();
```

- This communication model is adequate for modeling of distributed systems.
Message-passing Communication (cont’d)

**Blocking communication**

A process which communicates over the channel blocks itself (suspends) until the other process is ready for the data transfer.

The two processes have to synchronize before data transfer can be initiated.

**Non-blocking communication**

Processes do not have to synchronize for communication.

But

Additional storage (buffer) has to be associated with the channel if no messages are to be lost!

- The sending process places the message into the buffer and continues execution.
- The receiving process reads the message from the channel whenever it is ready to do it.

Synchronization

- Synchronization cannot be separated from communication.
- Any interaction between processes implies a certain degree of communication and synchronization.
- Synchronization: One process is suspended until another one reaches a certain point in its execution.
  - Control-dependent synchronization
  - Data-dependent synchronization

Control-dependent Synchronization

Our example illustrating Control driven concurrency (slide 16):

```plaintext
module p1:
  end module

module p2:
  end module

module p3:
  end module

module p4:
  end module

run p1;
(run p2 || run p3);
run p4
```

- With control-dependent synchronization the control structure is responsible for synchronization
- In the example we have several synchronization points specified:
  - Between completion of p1 and starting of p2 and p3;
  - Between completion of p2 and p3, and starting of p4.
Data-dependent Synchronization

Communication mechanisms implicitly imply synchronization.

- Shared memory based synchronization

```
int X;
```

- Process p1
  - X = ...;
  - wait until X = ...;
  - ...

- Process p2
  - wait until X is modified;
  - ...

Data-dependent Synchronization (cont’d)

- Synchronization by message passing

  - Blocking communication with messages, automatically implies the synchronization between sender and receiver (slide 20).

And don’t forget: Time!

- How is time handled?

  This makes a great difference between computation models!

Common Models of Computation

In the following lectures we will analyze some of the models of computation commonly used to describe embedded systems:

- Dataflow Models
- Petri Nets
- Discrete Event
- (Synchronous) Finite State Machines
- Synchronous/Reactive Languages
- Timed & Hybrid Automata
Summary

- Design can be viewed as a sequence of refinement steps leading from specification to implementation.
- System models are formulated using modeling languages.
- We would like the modeling language to have a well defined semantics.
- The semantics of the system modeling language is based on an underlying model of computation.

Summary (cont’d)

- The key aspects of “how difficult it is to write the model?” and “what we can do with the model?”, are depending on the particular model of computation.
  The basic trade-off is expressiveness vs. the power of formal reasoning and efficient (possibly automatic) synthesis.
- The main aspects of a computation model we are interested in are: concurrency, communication&synchronisation, time, and hierarchy.
- In the following, we will study six of the most representative models of computation for the embedded systems area.