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Imperative model of computation

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Models of computation considered in this course

Communication/ local computations	Shared memory	Message passing Synchronous | Asynchronous	
Undefined components	Plain text, use cases | (Message) sequence charts		
Communicating finite state machines	StateCharts		SDL
Data flow			Kahn networks, SDF
Petri nets		C/E nets, P/T nets, …	
Discrete event (DE) model (discussed later)	VHDL*, Verilog*, SystemC*, …	Only experimental systems, e.g. distributed DE in Ptolemy	
Imperative (Von Neumann) model	C, C++, Java	C, C++, Java with libraries CSP, ADA |	

* Classification based on semantic model

Imperative (von-Neumann) model

The von-Neumann model reflects the principles of operation of standard computers:

- Sequential execution of instructions (total order of instructions)

- Possible branches
- Visibility of memory locations and addresses

Example languages

- Machine languages (binary)
- Assembly languages (mnemonics)
- Imperative languages providing limited abstraction of machine languages (C, C++, Java, ….)

Threads/processes

Threads/processes

- Initially available only as entities managed by OS
- In most cases:
  - Context switching between threads/processes, frequently based on pre-emption
- Made available to programmer as well
  - ☞ Partitioning of applications into threads (same address space)
- Languages initially not designed for communication, but synchronization and communication is needed!

Problems with imperative languages and shared memory

- Access to shared memory leads to anomalies, that have to be pruned away by mutexes, semaphores, monitors

- Potential deadlocks
- Access to shared, protected resources leads to priority inversion (☞ chapter 4)
- Termination in general undecidable
- Timing cannot be specified and not guaranteed

Synchronous message passing: CSP

- CSP (communicating sequential processes) [Hoare, 1985], Rendez-vous-based communication: Example:

```
process A                 process B
..                        ..
var a ...                 var b ...
  a:=3;                     ...
  c!a; -- output            c?b; -- input
end                       end
```

Determinate!

Synchronous message passing: Ada

Named After Ada Lovelace (said to be the 1st female programmer).

US Department of Defense (DoD) wanted to avoid multitude of programming languages

☞Definition of requirements

☞Selection of a language from a set of competing designs (selected design based on PASCAL)

Ada' 95 is object-oriented extension of original Ada.

Synchronous message passing: Ada-rendez-vous

```
task screen_out is
 entry call_ch(val:character;  x, y: integer);
 entry call_int(z, x, y: integer);
end screen_out;
task body  screen_out is
...
 select
  accept call_ch …  do ..
  end call_ch;
 or
  accept call_int … do ..
  end call_int;
 end select;
```

Sending a message:

```
begin
 screen_out.call_ch('Z',10,20);
 exception
  when tasking_error =>
              (exception handling)
end;
```

Java

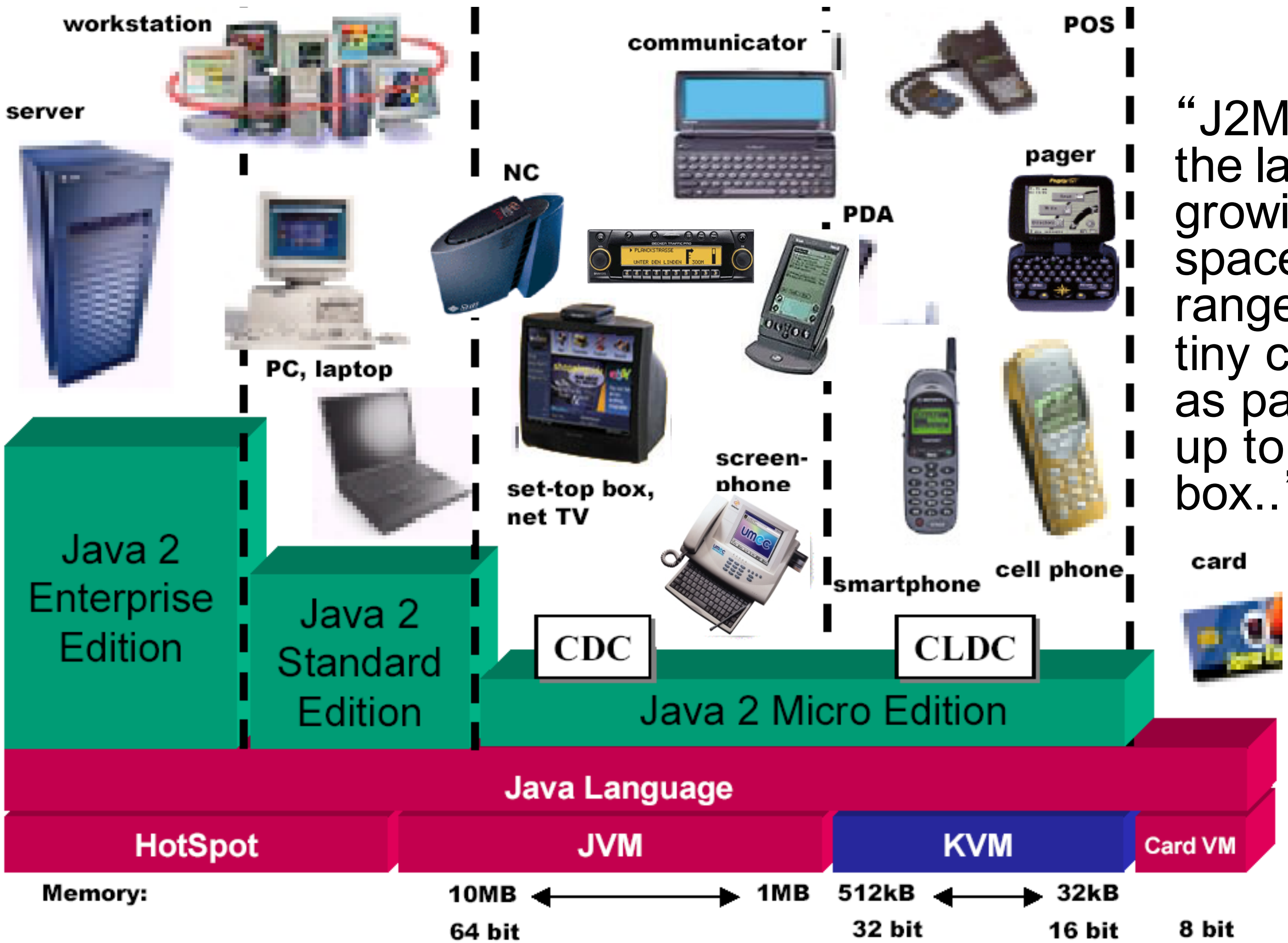
Potential benefits:

- Clean and safe language
- Supports multi-threading (no OS required?)
- Platform independence (relevant for telecommunications)

Problems:

- Size of Java run-time libraries? Memory requirements.
- Access to special hardware features
- Garbage collection time
- Non-deterministic dispatcher
- Performance problems
- Checking of real-time constraints

Overview over Java 2 Editions



"J2ME … addresses the large, rapidly growing consumer space, which covers a range of devices from tiny commodities, such as pagers, all the way up to the TV set-top box.."

Based on http://java.sun.com/products/cldc/wp/KVMwp.pdf

Lee's conclusion

Nontrivial software written with threads, semaphores, and mutexes is incomprehensible to humans.

….

Succinct Problem Statement

Threads are wildly nondeterministic.

The programmer's job is to prune away the nondeterminism by imposing constraints on execution order (e.g., mutexes).

Improve threads?

Or replace them?

[Edward Lee (UC Berkeley), Artemis Conference, Graz, 2007]

Lifting Level of Abstraction

Model-Based Design

(e.g., Simulink, UML)

Automatic program synthesis: No more programming

High-level languages:
Programming to the application

The "assembly age":
Programming to the platform

Code generation from specifications:
still mostly a dream

It is not yet feasible to abstract algorithms.

Compilation:
perhaps "the" success story of computer science

It is feasible to abstract the platform.

Comparison of models

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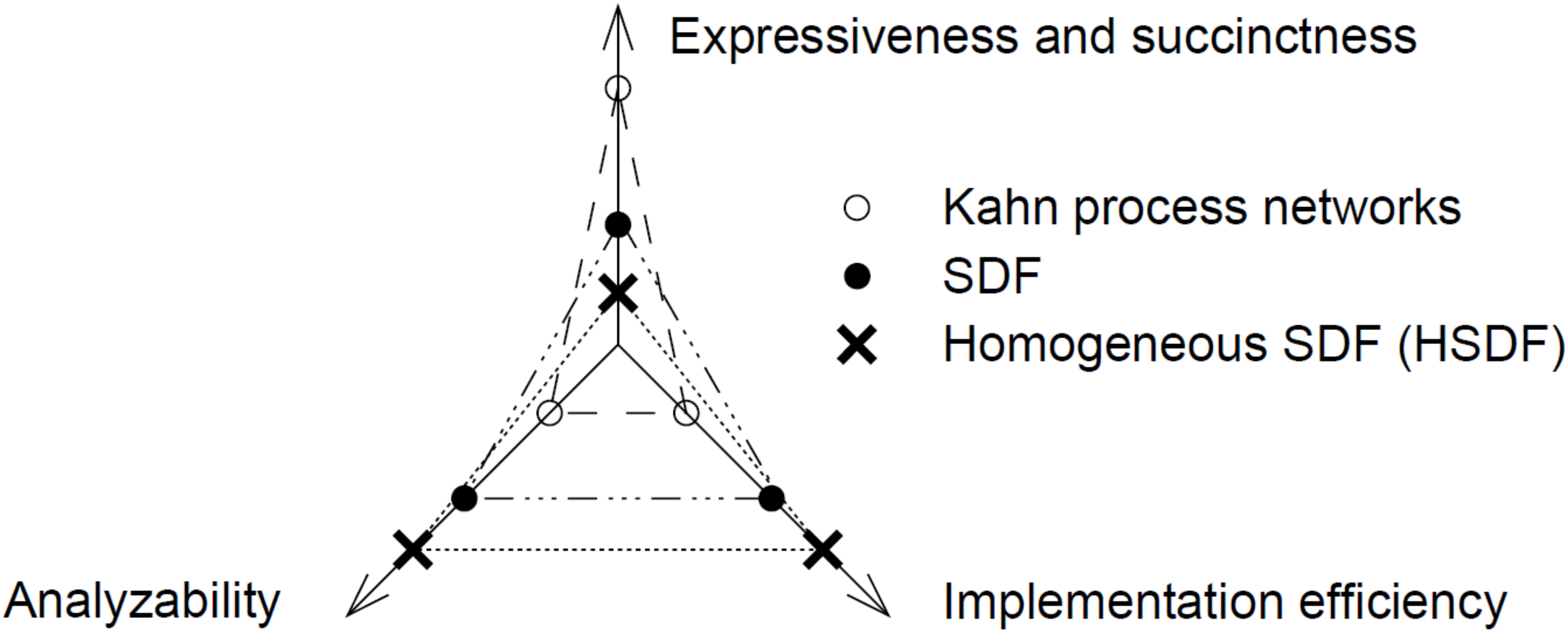
Classification by Stuijk

- **Expressiveness** and **succinctness** indicate, which systems can be modeled and how compact the are.
- **Analyzability** relates to the availability of scheduling algorithms and the need for run-time support.
- **Implementation efficiency** is influenced by the required scheduling policy and the code size.

The expressiveness/analyzability conflict



[S. Stuijk, 2007]

Properties of processes/threads (1)

- **Number of processes/threads**
  static;
  dynamic (dynamically changed hardware architecture?)

- **Nesting:**
  - Nested declaration of processes

    process {
      process {
        process {
    }}}
  - or all declared at the same level

    process { … }
    process { … }
    process { … }

Properties of processes/threads (2)

- Different techniques for **process creation**
  - **Elaboration in the source (c.f. ADA)**

```
declare
   process P1 …
```

  - **explicit fork and join (c.f. Unix)**

```
id = fork();
```

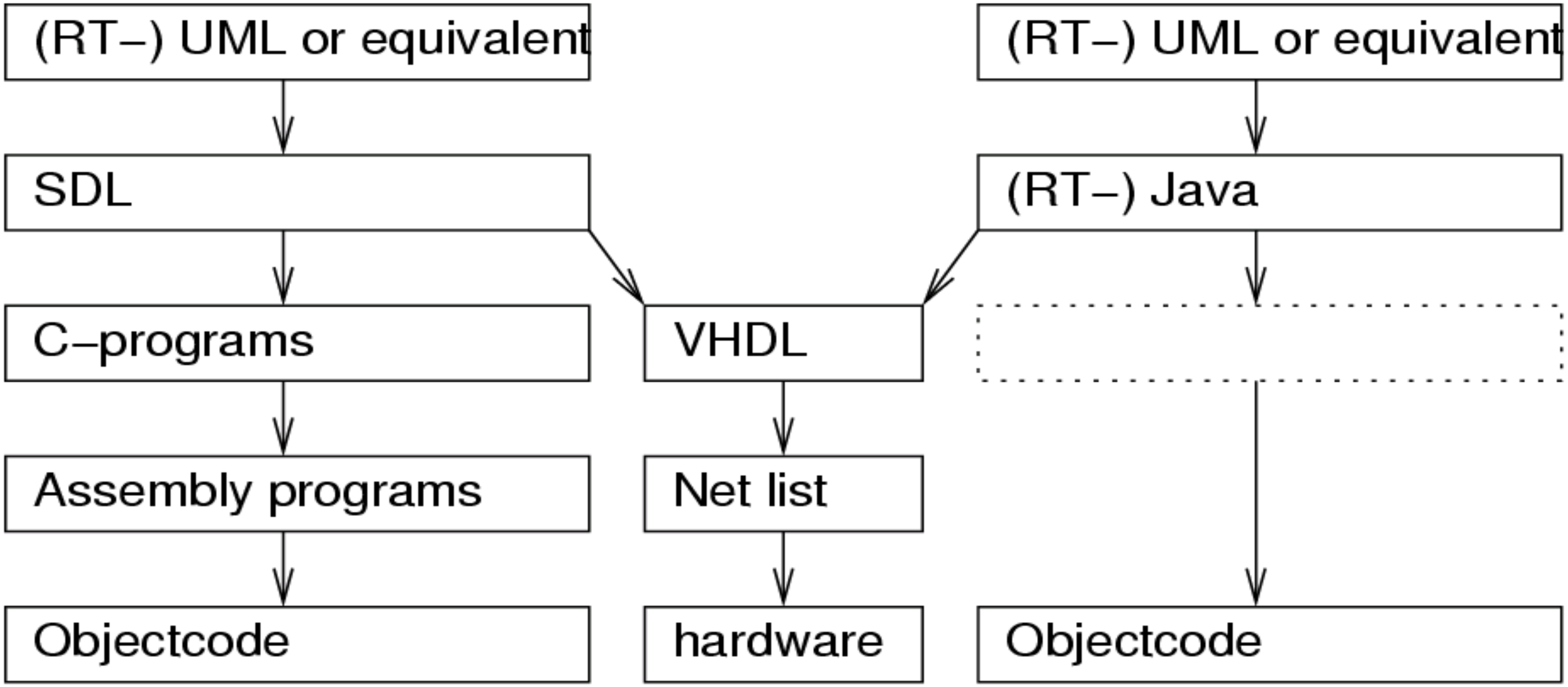
  - **process creation calls**

```
id = create_process(P1);
```

E.g.: StateCharts comprises a static number of processes, nested declaration of processes, and process creation through elaboration in the source.

How to cope with MoC and language problems in practice?

Mixed approaches:



Transformations between models

- Transformations between models are possible, e.g.
  - Frequent transformation into sequential code
  - Transformations between restricted Petri nets and SDF
- Transformations should be based on the precise description of the semantics
  (e.g. Chen, Sztipanovits et al., DATE, 2007)

Mixing models of computation: Ptolemy

Ptolemy (UC Berkeley) is an environment for simulating multiple models of computation.

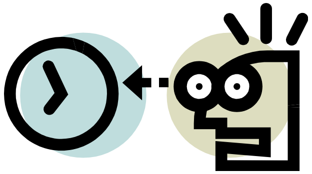
http://ptolemy.berkeley.edu/

(http://ptolemy.berkeley.edu/ptolemyII/ptII8.0/ptII8.0.1/doc/index.htm)

Available examples are restricted to a subset of the supported models of computation.

UML (Unified Modeling Language) for embedded systems?

Initially not designed for real-time.



Initially lacking features:

- Partitioning of software into tasks and processes
- specifying timing
- specification of hardware components

Projects on defining profiles for embedded/real-time systems

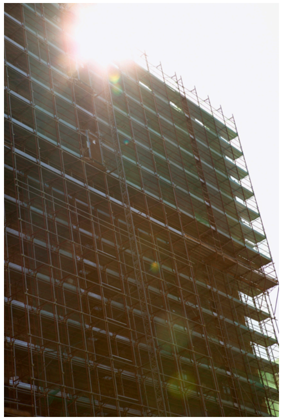
- Schedulability, Performance and Timing Analysis
- SysML (System Modeling Language)
- UML Profile for SoC
- Modeling and Analysis of Real-Time Embedded Systems
- UML/SystemC, …

Profiles may be incompatible

Modeling levels

Levels, at which modeling can be done:

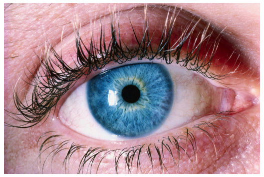
- System level
- Algorithmic level: just the algorithm
- Processor/memory/switch (PMS) level
- Instruction set architecture (ISA) level: function only
- Transaction level modeling (TML): memory reads & writes are just "transactions" (not cycle accurate)
- Register-transfer level: registers, muxes, adders, … (cycle accurate, bit accurate)
- Gate-level: gates
- Layout level



Tradeoff between accuracy and simulation speed

What's the bottom line?

- The prevailing technique for writing embedded SW has inherent problems; some of the difficulties of writing embedded SW are not resulting from design constraints, but from the modeling.
- However, there is no ideal modeling technique.
- The choice of the technique depends on the application.
- Check code generation from non-imperative models
- There is a tradeoff between the power of a modeling technique and its analyzability.
- It may be necessary to combine modeling techniques.
- **In any case, open your eyes & think about the model before you write down your spec! Be aware of pitfalls.**



- You may be forced, to use imperative models, but you can still implement, for example, finite state machines or KPNs in Java.