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fakultät für informatik
informatik 12

FSMs & message passing: SDL

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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	Scoreboarding + Tomasulo Algorithm (☞ Comp.Archict.)		Kahn networks, SDF
Petri nets		C/E nets, P/T nets, …	
Discrete event (DE) model	VHDL*, Verilog*, SystemC*, …	Only experimental systems, e.g. distributed DE in Ptolemy	
Von Neumann model	C, C++, Java	C, C++, Java with libraries CSP, ADA	

* Based on implementation of VHDL, Verilog..

SDL

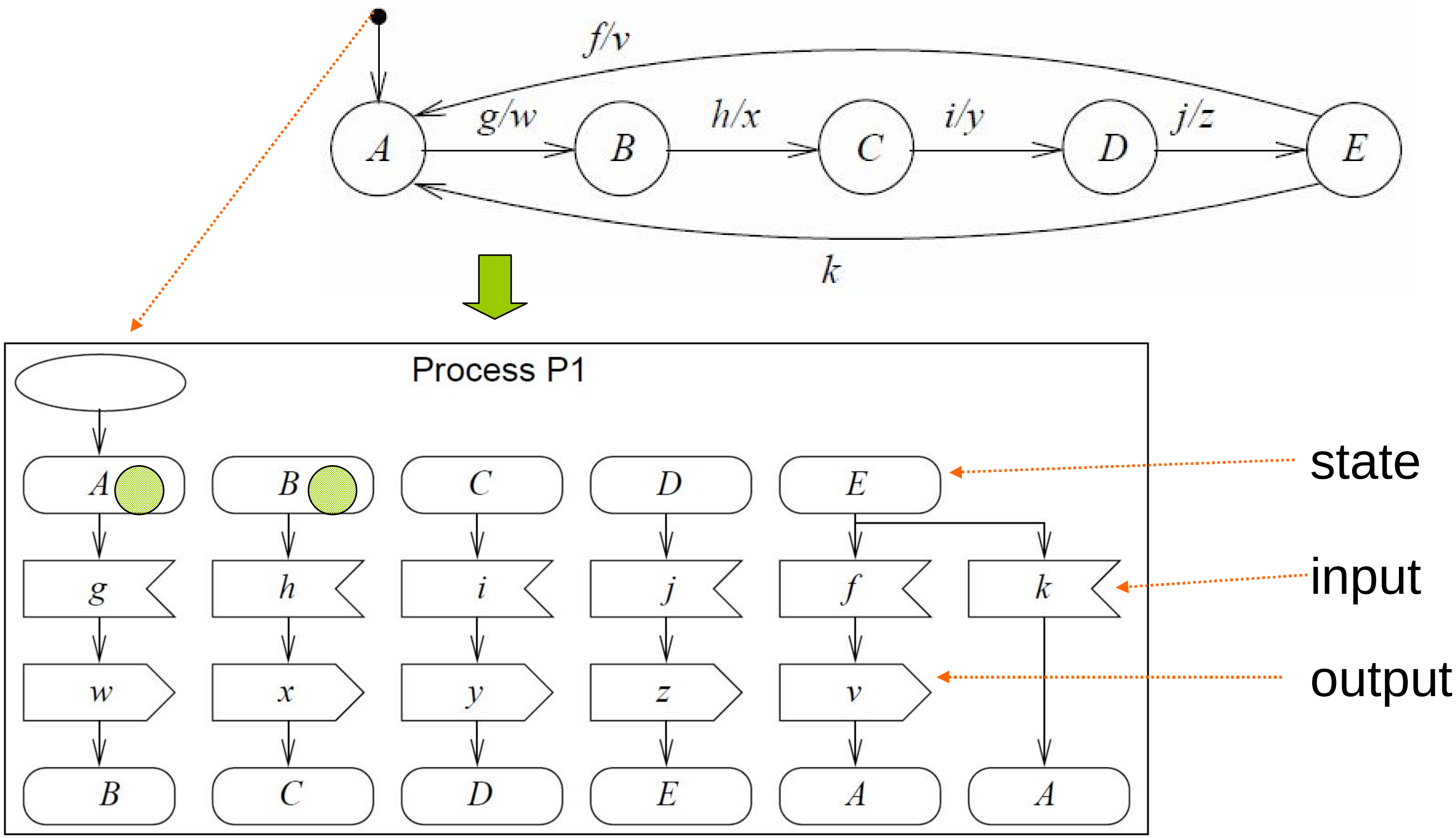
- SDL used here as a (prominent) example of a model of computation based on **asynchronous message passing communication**.

☞ SDL is appropriate also for distributed systems.

- Just like StateCharts, it is based on the CFSM model of computation; each FSM is called a **process**.

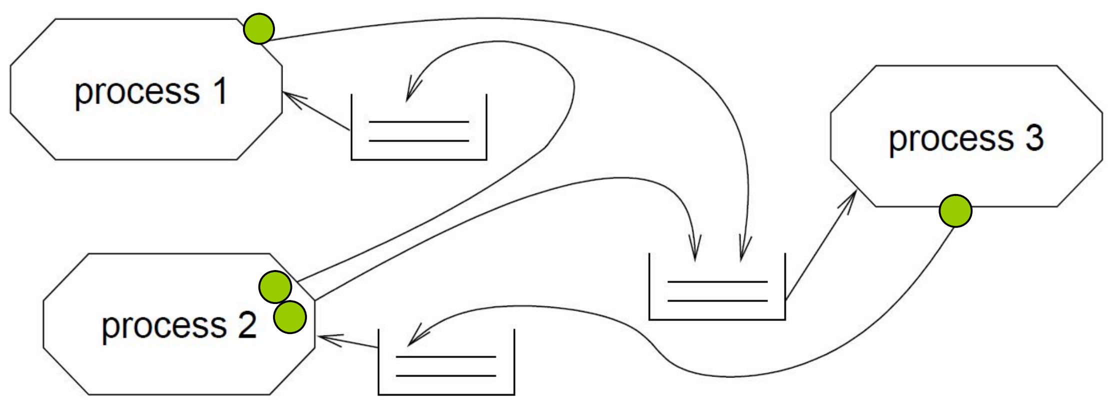
- Provides textual and graphical formats to please all users.

SDL-representation of FSMs/processes



Communication among SDL-FSMs

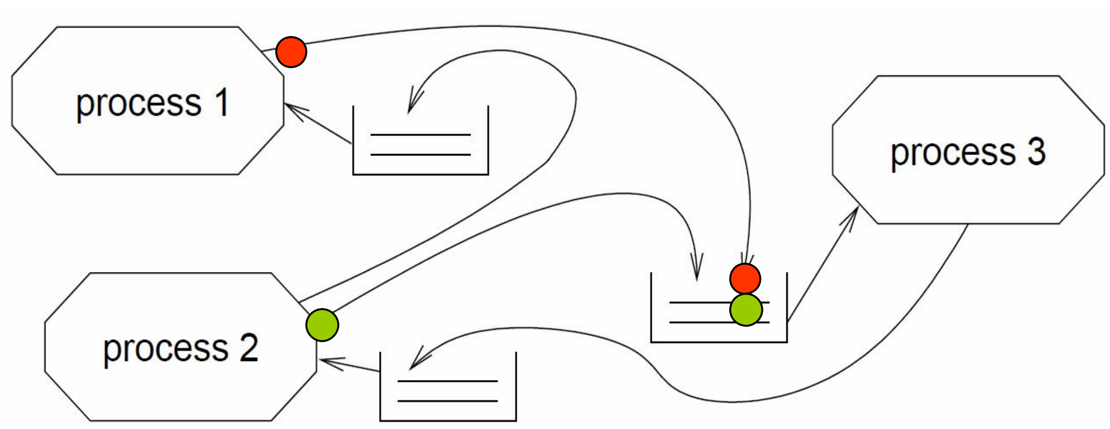
Communication is based on message-passing of *signals* (=inputs+outputs), assuming a **potentially indefinitely large FIFO-queue**.



- Each process fetches next signal from FIFO,
- checks if signal enables transition,
- if yes: transition takes place,
- if no: signal is ignored (exception: SAVE-mechanism).
- Implementation requires bound for the maximum length of FIFOs

Determinate?

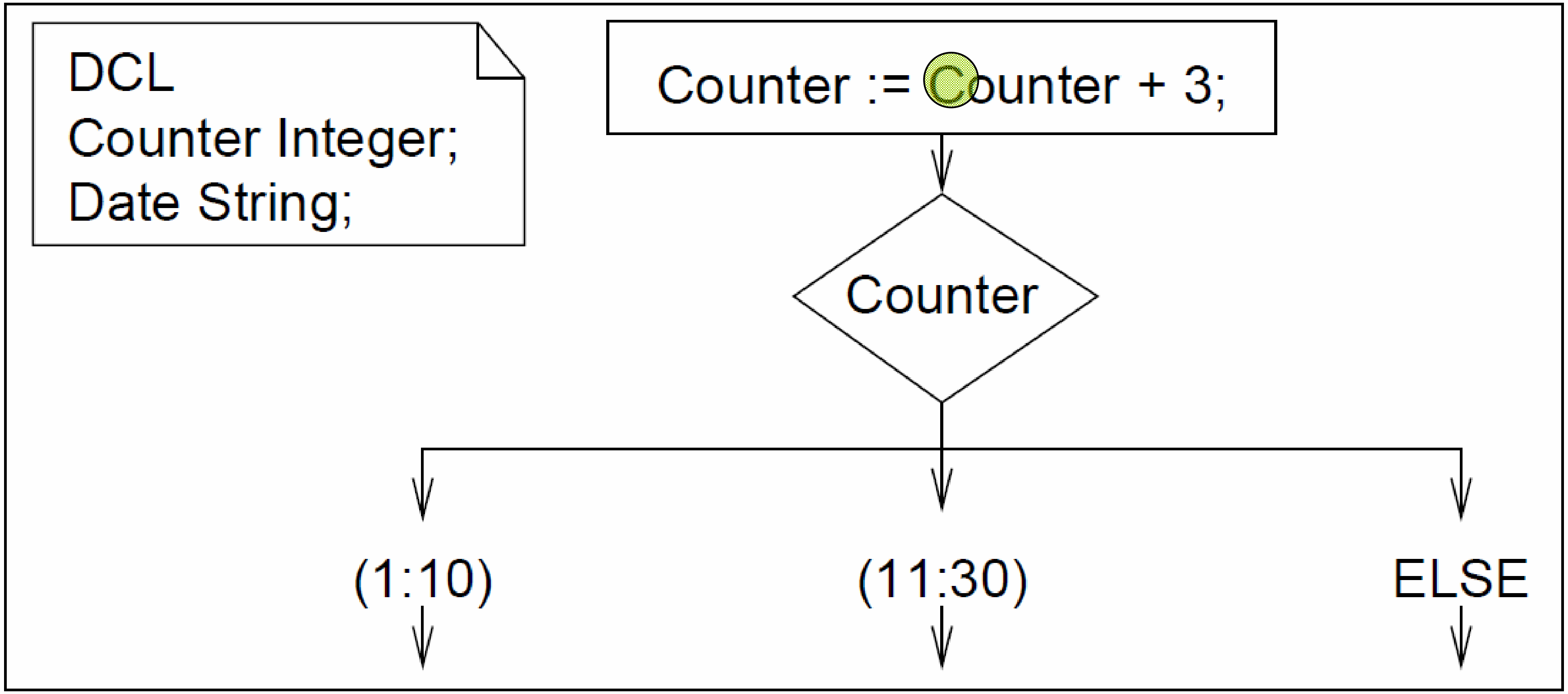
Let signals be arriving at FIFO at the same time:
☞Order in which they are stored, is unknown:



All orders are legal: ☞simulators can show different behaviors for the same input, all of which are correct.

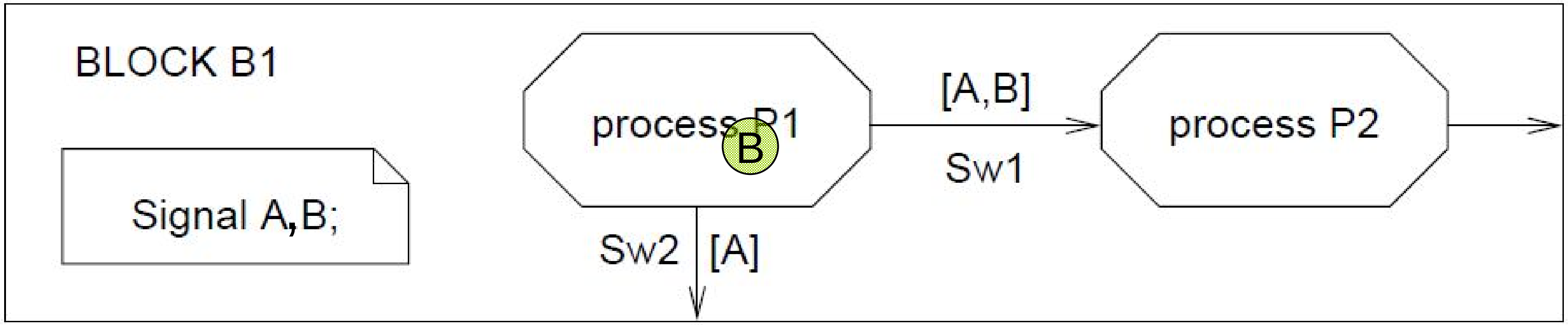
Operations on data

Variables can be declared locally for processes.
Their type can be predefined or defined in SDL itself.
SDL supports abstract data types (ADTs). Examples:



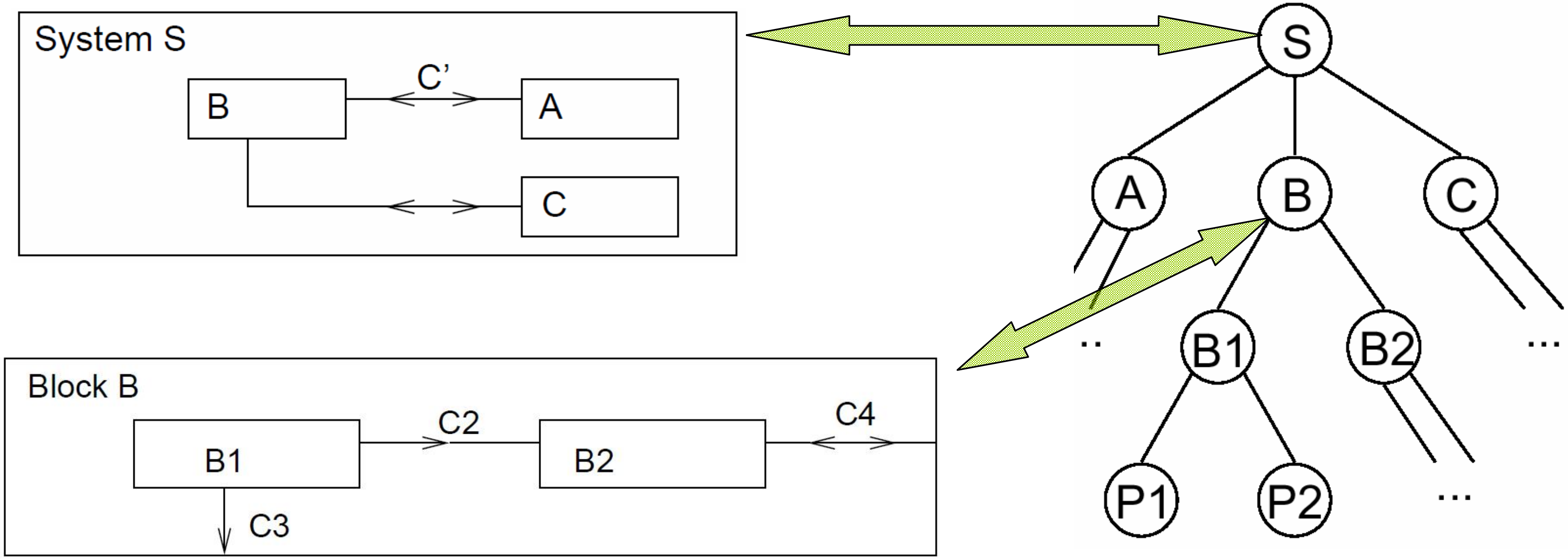
Process interaction diagrams

Interaction between processes can be described in process interaction diagrams (special case of block diagrams).
In addition to processes, these diagrams contain channels and declarations of local signals.
Example:



Hierarchy in SDL

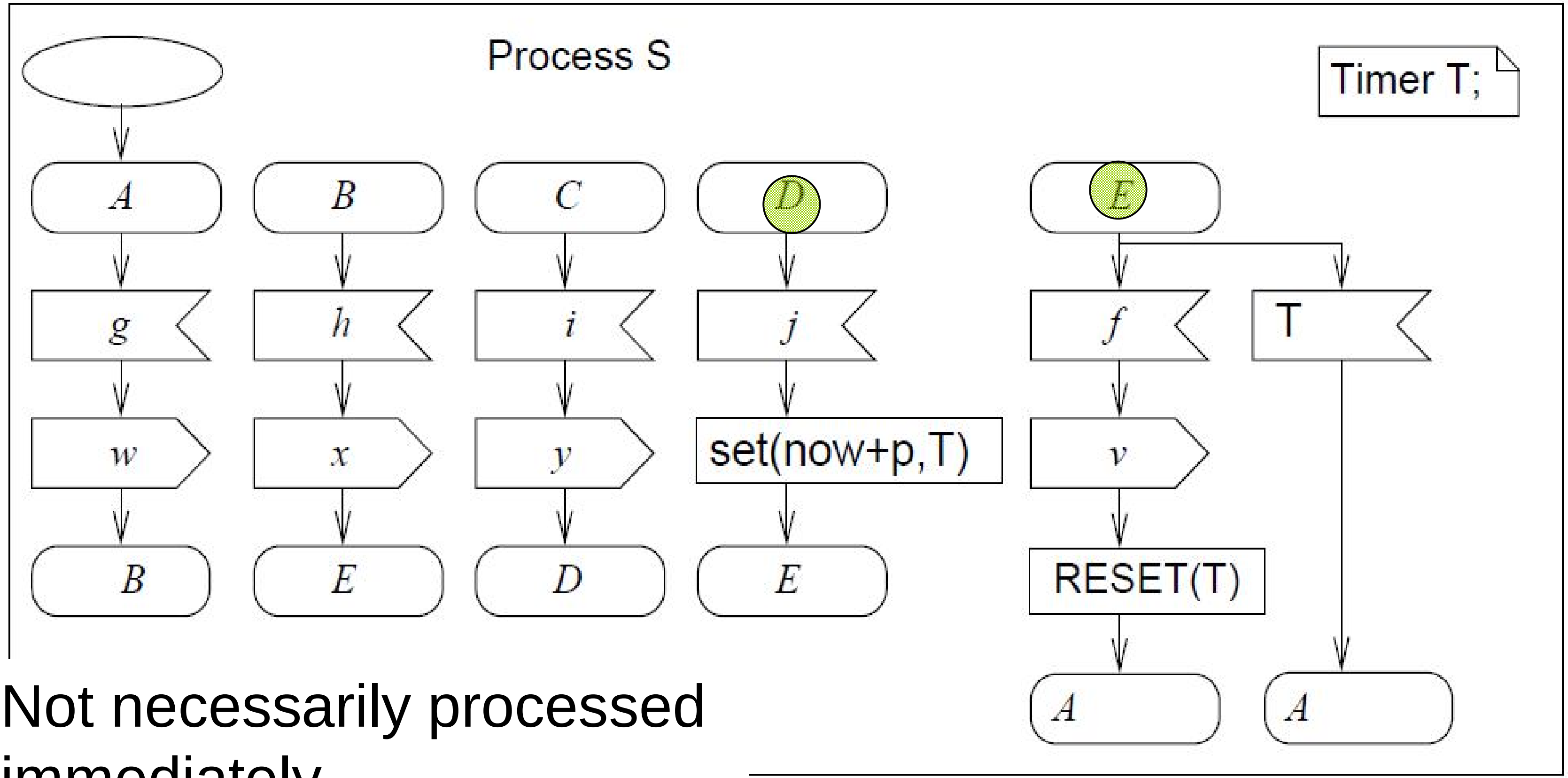
Process interaction diagrams can be included in **blocks.** The root block is called **system.**



Processes cannot contain other processes, unlike in StateCharts.

Timers

Timers can be declared locally. Elapsed timers put signal into queue. RESET removes timer (also from FIFO-queue).



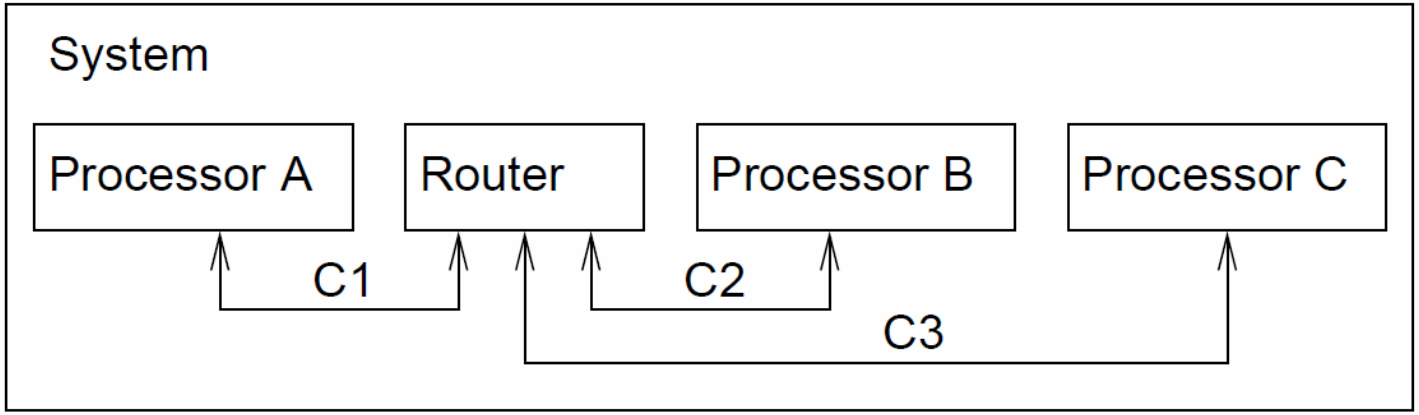
Not necessarily processed immediately.

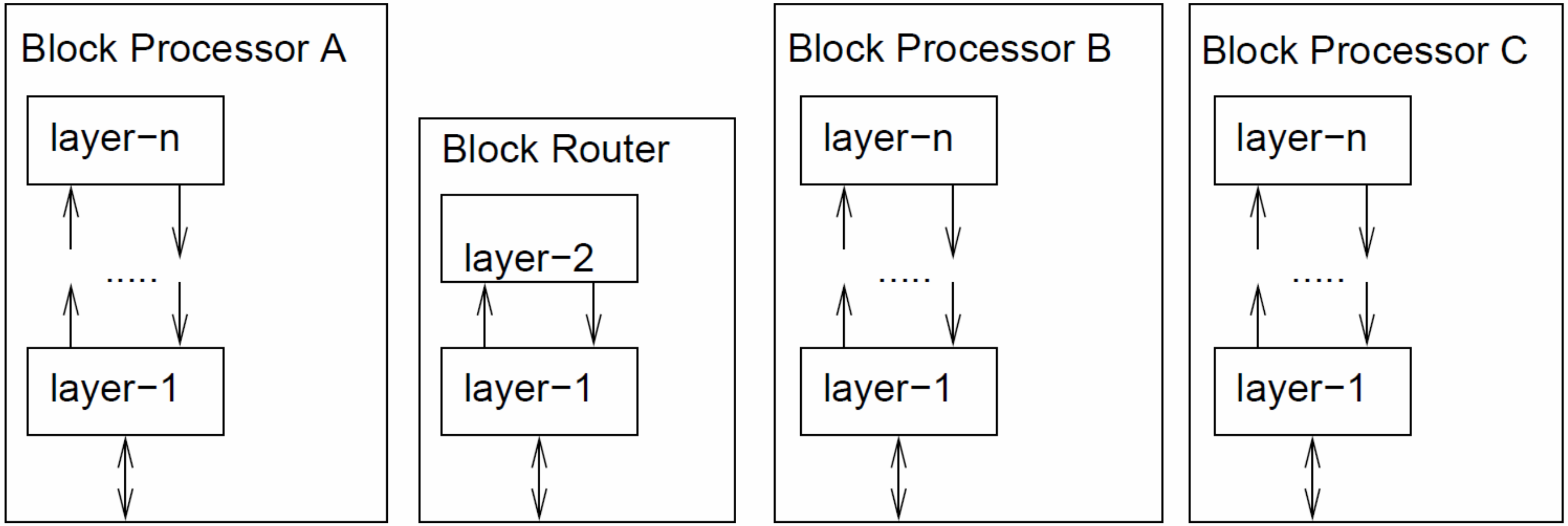
Additional language elements

SDL includes a number of additional language elements, like

- procedures
- creation and termination of processes
- advanced description of data
- More features added for SDL-2000

Application: description of network protocols



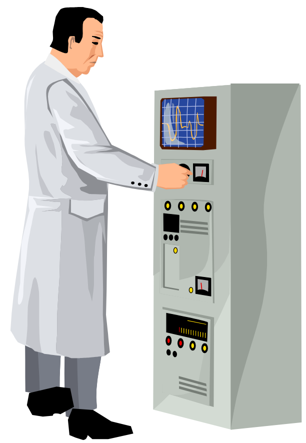


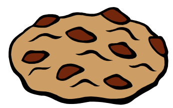
Larger example: vending machine

Machine° selling pretzels, (potato) chips, cookies, and doughnuts:

accepts nickels, dime, quarters, and half-dollar coins.

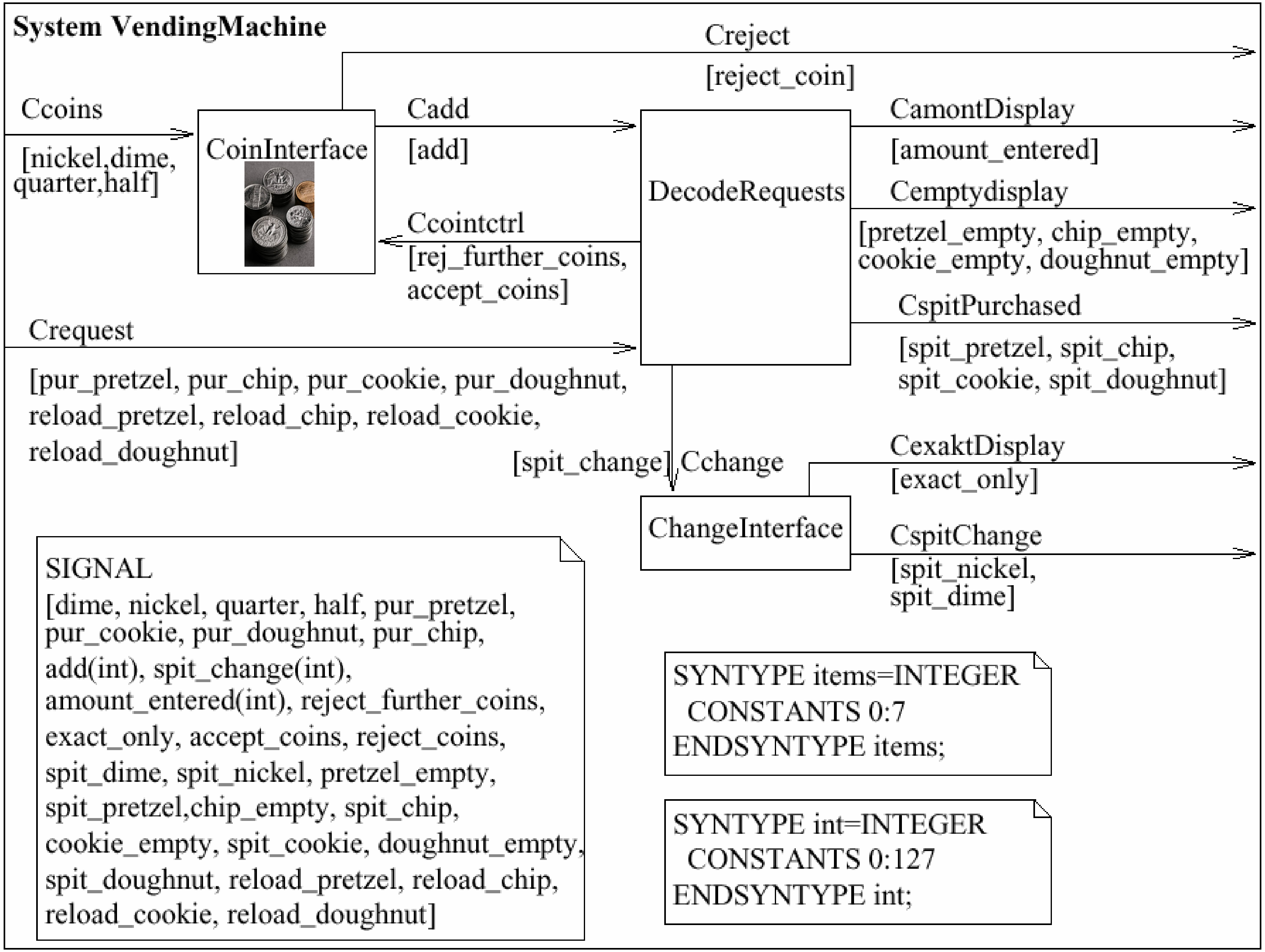
Not a distributed application.



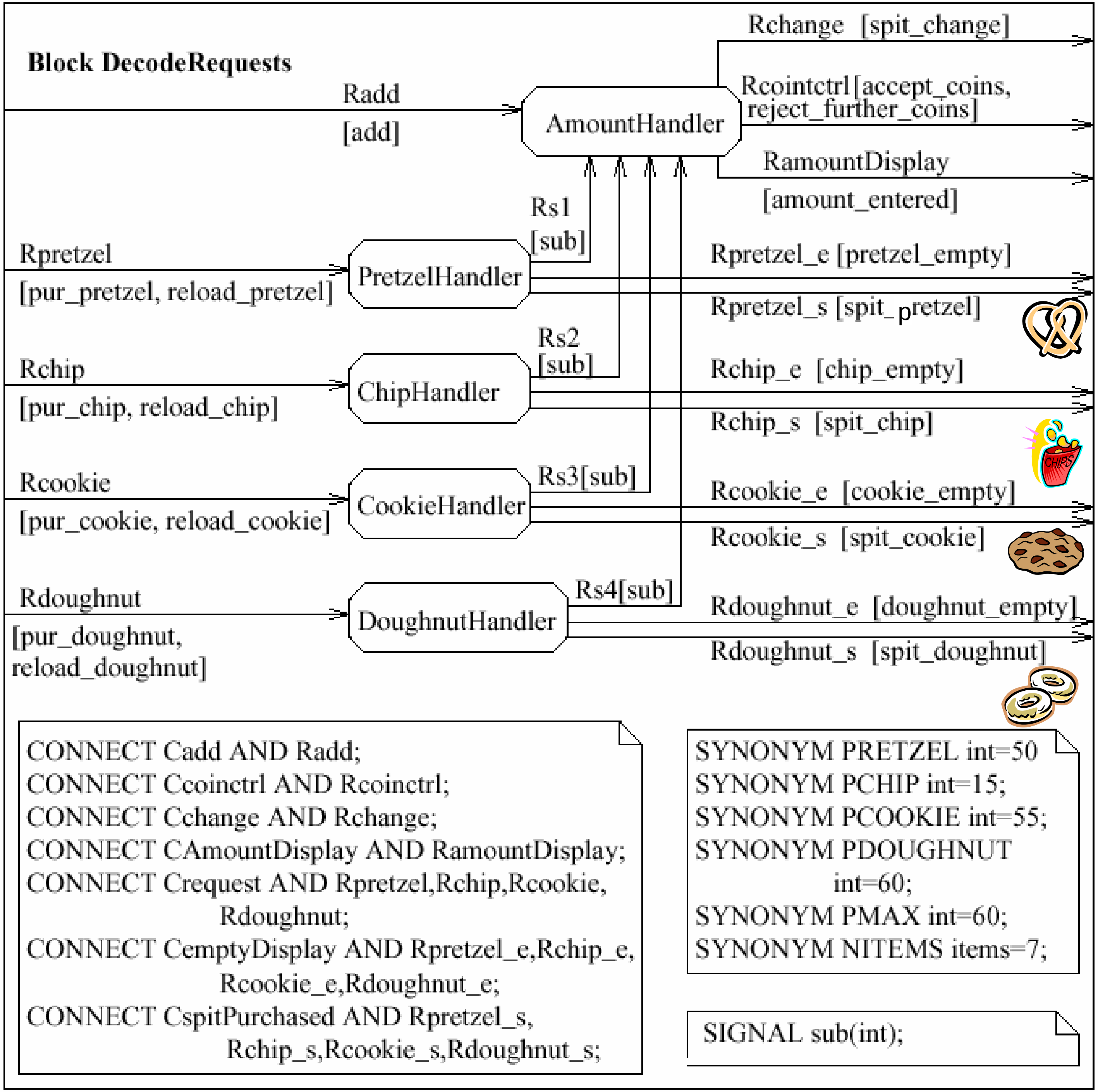


° [J.M. Bergé, O. Levia, J. Roullard: High-Level System Modeling, Kluwer Academic Publishers, 1995]

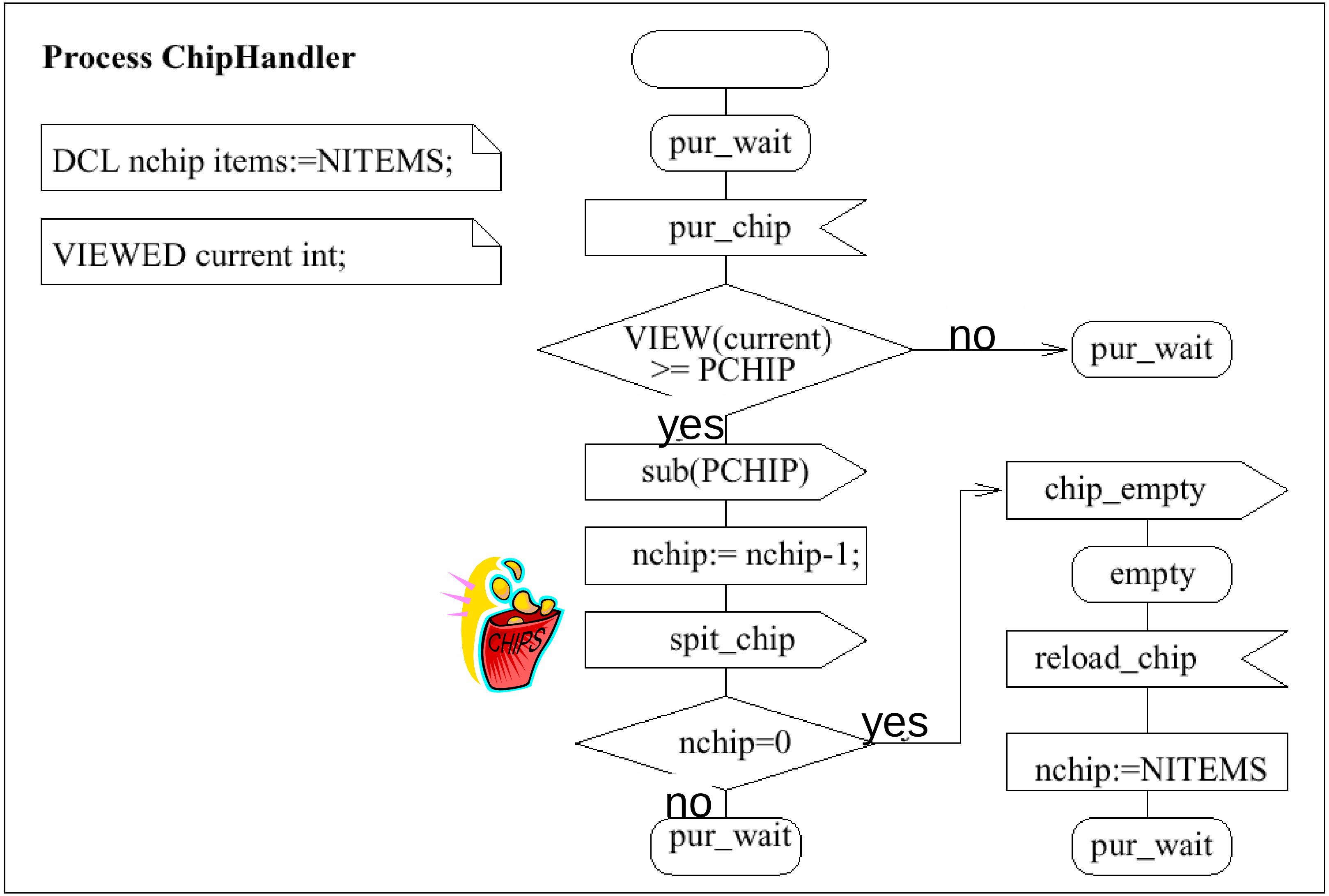
Overall view of vending machine



Decode Requests



ChipHandler



History

- Dates back to early 1970s,
- Formal semantics defined in the late 1980s,
- Defined by ITU (International Telecommunication Union):
  Z.100 recommendation in 1980
  Updates in 1984, 1988, 1992, 1996 and 1999
- SDL-2000 a significant update (not well accepted)
- Becoming less popular

Evaluation & summary

- FSM model for the components,
- Non-blocking message passing for communication,
- Implementation requires bound for the maximum length of FIFOs; may be very difficult to compute,
- Excellent for distributed applications (used for ISDN),
- Commercial tools available (see http://www.sdl-forum.org)
- Not necessarily determinate
- Timer concept adequate just for soft deadlines,
- Limited way of using hierarchies,
- Limited programming language support,
- No description of non-functional properties,
- Examples: small network + vending machine

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Data flow models

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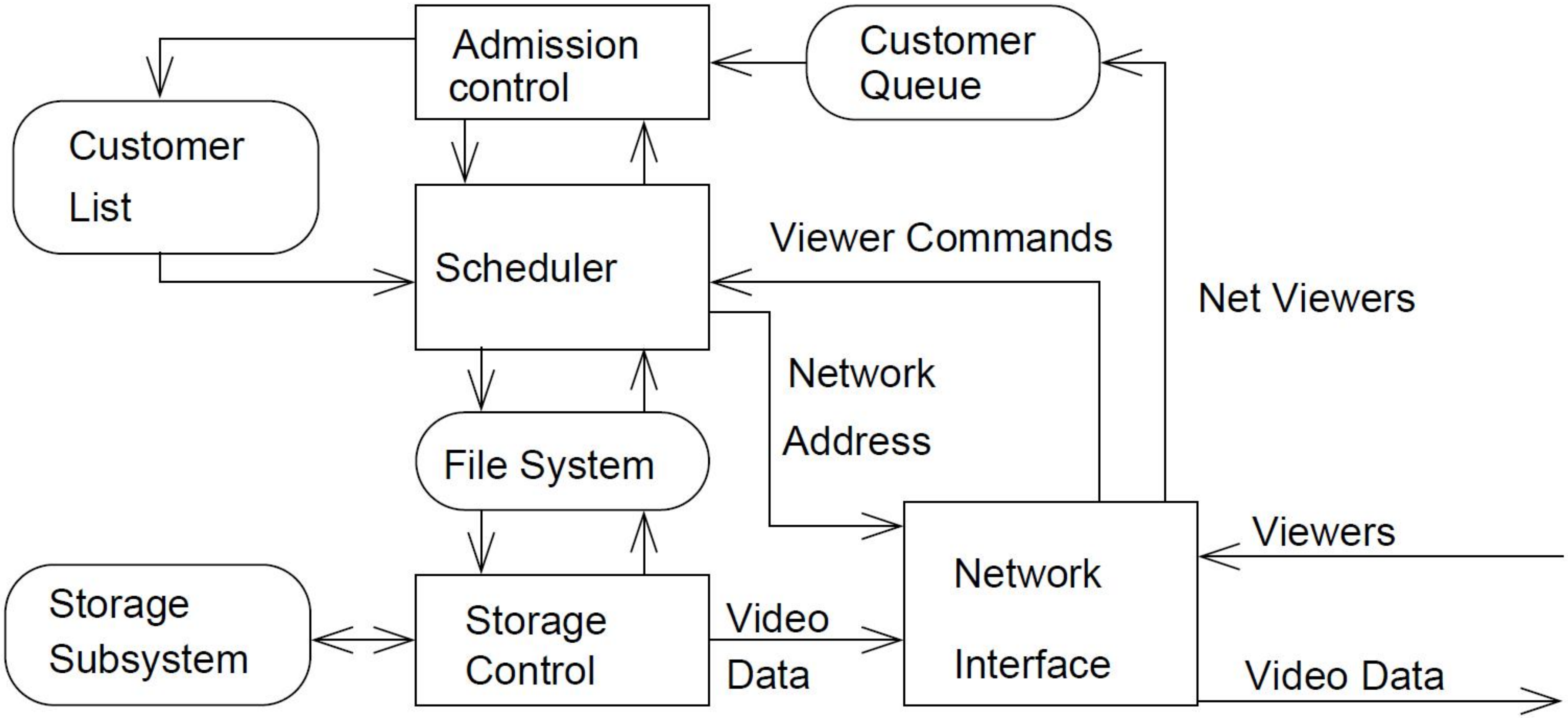
Data flow as a "natural" model of applications

Example: Video on demand system



www.ece.ubc.ca/~irenek/techpaps/vod/vod.html

Data flow modeling

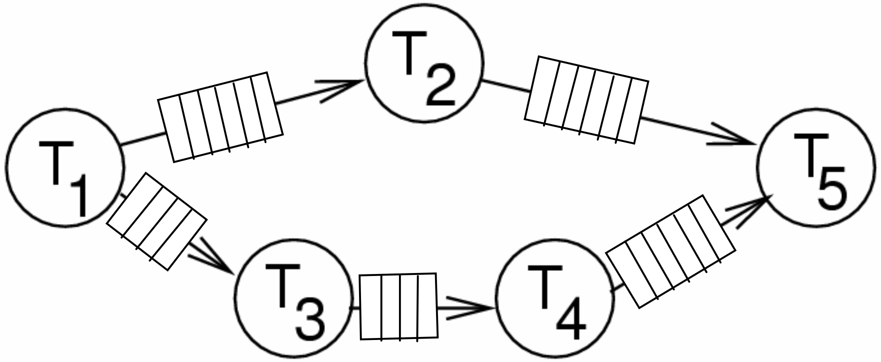
Definition: Data flow modeling is … "*the process of identifying, modeling and documenting how data moves around an information system.*
Data flow modeling examines

- *processes (activities that transform data from one form to another),*
- *data stores (the holding areas for data),*
- *external entities (what sends data into a system or receives data from a system, and*
- *data flows (routes by which data can flow)*".

[Wikipedia: Structured systems analysis and design method. *http://en.wikipedia.org/wiki/Structured Systems Analysis and Design Methodology,* 2010 (formatting added)].

Kahn process networks (KPN)

- Each component is modeled as a program/task/process, (underlying FSM is inconvenient: possibly many states)
- Communication is by FIFOs; no overflow considered
  ☞ writes never have to wait,
  ☞ reads wait if FIFO is empty.



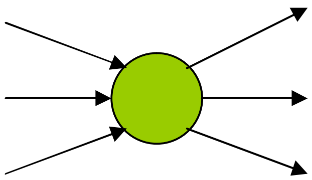
- Only one sender and one receiver per FIFO
  ☞ no SDL-like conflicts at FIFOs

Example

```
Process f(in int u, in int v, out int w){
  int i; bool b = true;
  for (;;) {
   i= b ? read(u) : read(v);
                    //read returns next token in FIFO, waits if empty
   send (i,w);    //writes a token into a FIFO w/o blocking
   b = !b;
   }
```

Properties of Kahn process networks

- Communication is only via channels (no shared variables)
- Mapping from ≥1 input channel to ≥1 output channel possible;

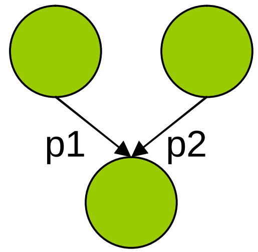


- Channels transmit information within an unpredictable but finite amount of time;
- In general, execution times are unknown.

Key beauty of KPNs (1)

- A process cannot check for available data before attempting a read (wait).

  ~~if nonempty(p1) then read(p1)~~
  ~~else if nonempty(p2) then read(p2);~~



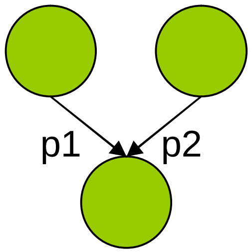
- A process cannot wait for data for >1 port at a time.

  ~~read(p1|p2);~~

☞ Processes have to commit to wait for data **from a particular port**;

Key beauty of KPNs (2)

- Therefore, the order of reads does not depend on the arrival time (but may depend on data).
- Therefore, Kahn process networks are determinate (!); for a given input, the result will always the same, regardless of the speed of the nodes.
- Many applications in embedded system design: Any combination of fast and slow simulation & hardware prototypes always gives the same result.



Computational power and analyzability

- It is a challenge to schedule KPNs without accumulating tokens
- KPNs are Turing-complete (anything which can be computed can be computed by a KPN)
- KPNs are computationally powerful, but difficult to analyze (e.g. what's the maximum buffer size?)
- Number of processes is static (cannot change)

More information about KPNs

- http://ls12-www.cs.tu-dortmund.de/teaching/download/levi/index.html: Animation
- http://en.wikipedia.org/wiki/Kahn_process_networks
- See also S. Edwards: http://www.cs.columbia.edu/~sedwards/classes/2001/w4995-02/presentations/dataflow.ppt

SDF

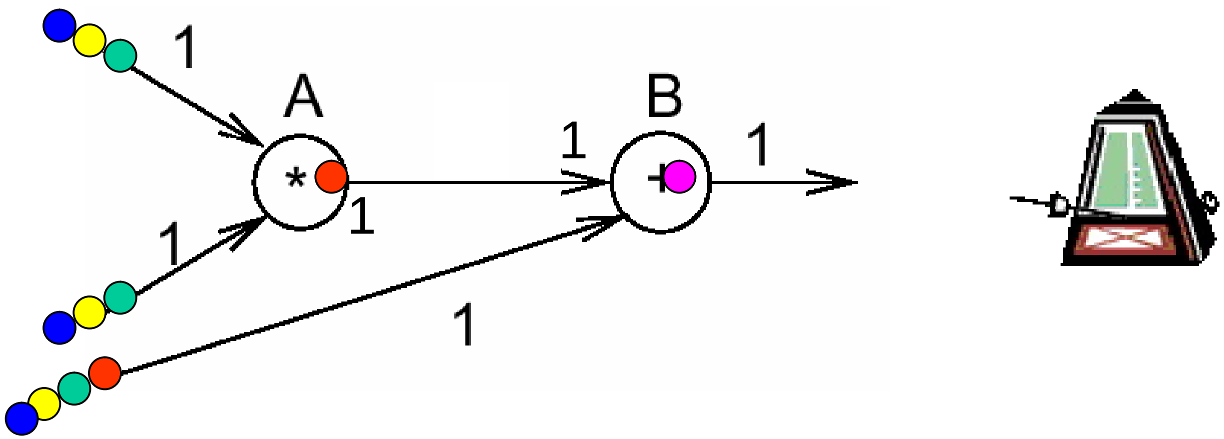
Less computationally powerful, but easier to analyze:

Synchronous data flow (SDF).

- **Synchronous**
  = global clock controlling “firing” of nodes
- Again using ***a***synchronous message passing
  = tasks do not have to wait until output is accepted.

(Homogeneous-) Synchronous data flow (SDF)

- Nodes are called ***actors.***
- Actors are ***ready***, if the necessary number of input tokens exists and if enough buffer space at the output exists
- Ready actors ***can fire*** (be executed).

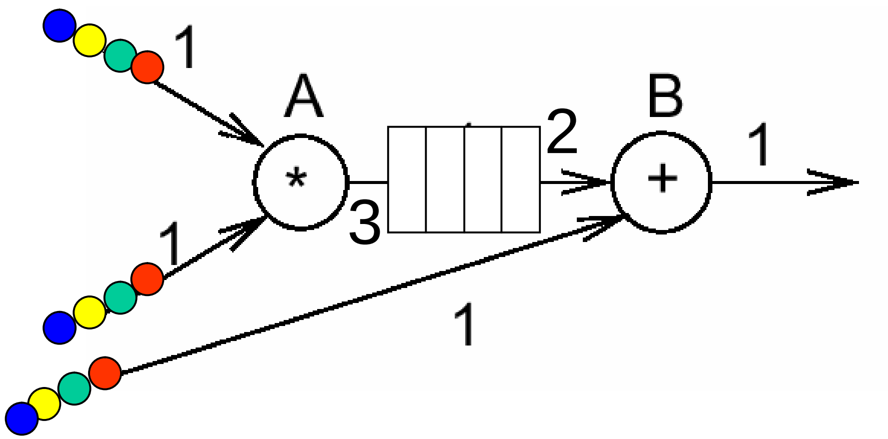


- Execution takes a ***fixed, known time***.

Actually, this is a case of ***homogeneous*** synchronous data flow models (HSDF): # of tokens per firing the same. ☞

(Non-homogeneous-) Synchronous data flow (SDF) (1)

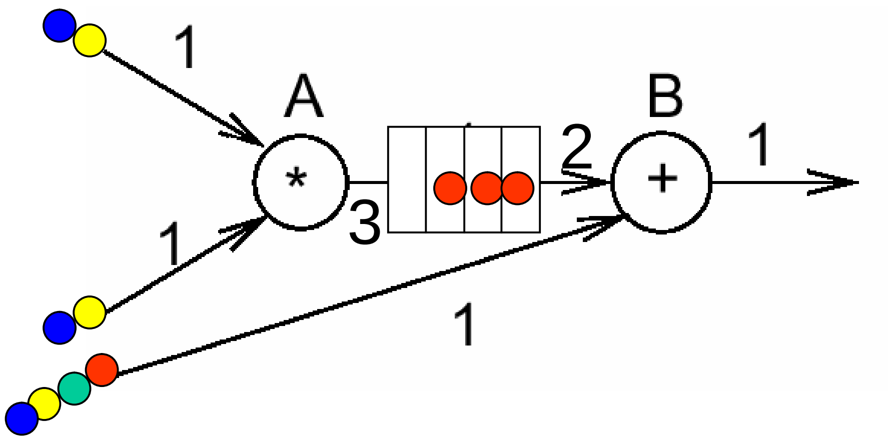
In the general case, a number of tokens can be produced/ consumed per firing



A ready, can fire (does not have to)

(Non-homogeneous-) Synchronous data flow (SDF) (2)

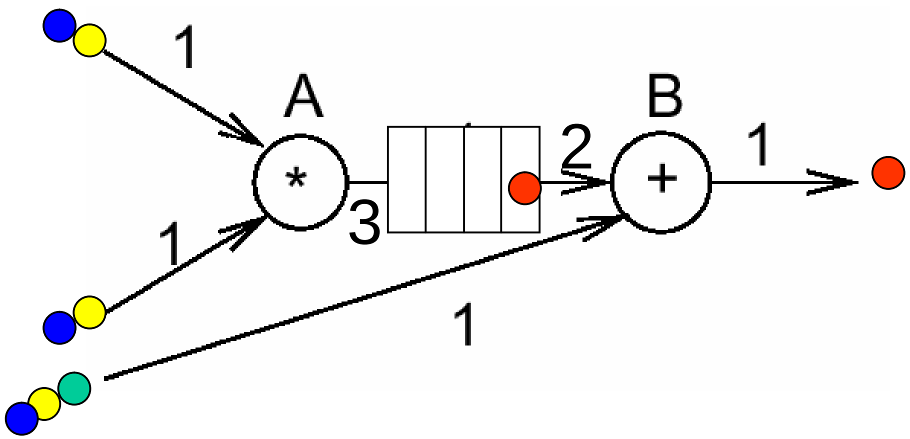
In the general case, a number of tokens can be produced/ consumed per firing



B ready, can fire

(Non-homogeneous-) Synchronous data flow (SDF) (3)

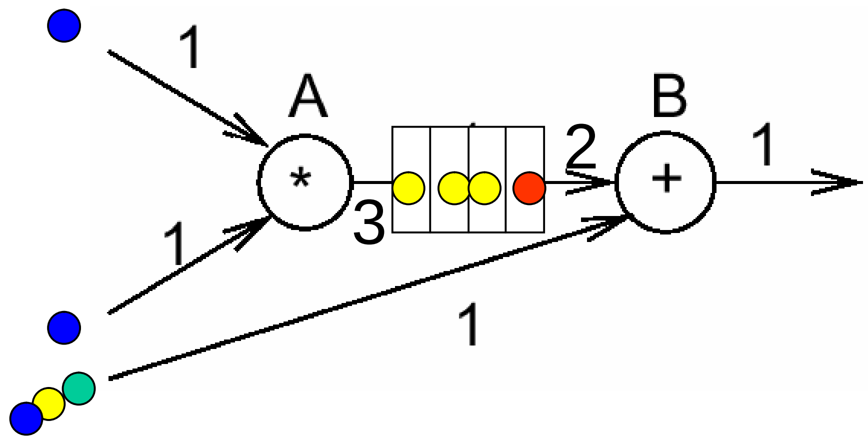
In the general case, a number of tokens can be produced/ consumed per firing



A ready, can fire

(Non-homogeneous-) Synchronous data flow (SDF) (4)

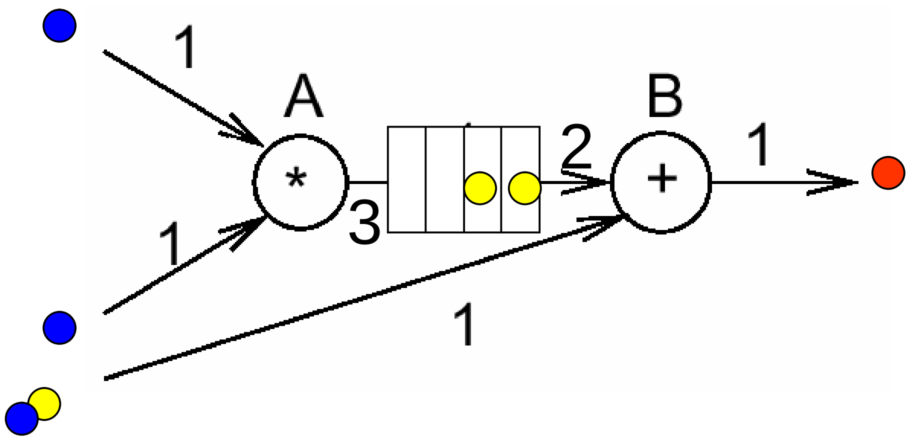
In the general case, a number of tokens can be produced/ consumed per firing



B ready, can fire

(Non-homogeneous-) Synchronous data flow (SDF) (5)

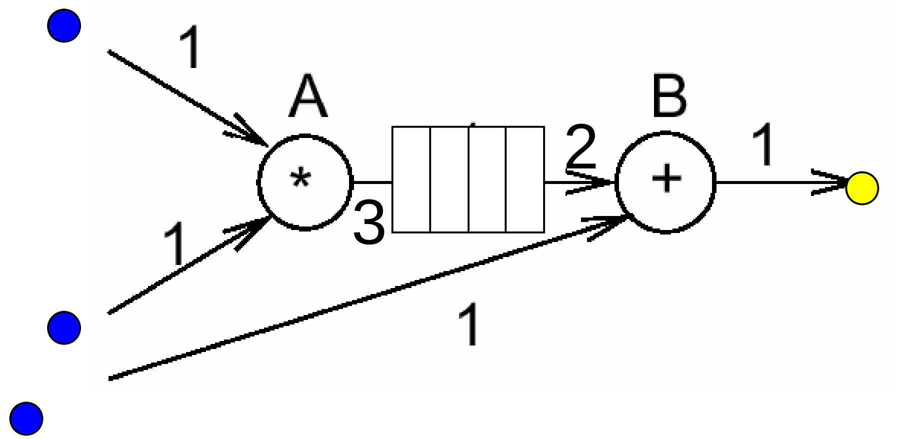
In the general case, a number of tokens can be produced/ consumed per firing



B ready, can fire

(Non-homogeneous-) Synchronous data flow (SDF) (6)

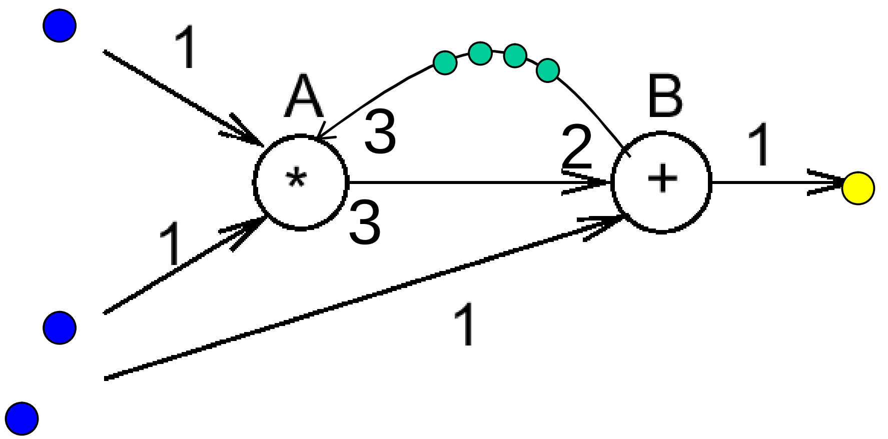
In the general case, a number of tokens can be produced/ consumed per firing



1 period complete, A ready, can fire

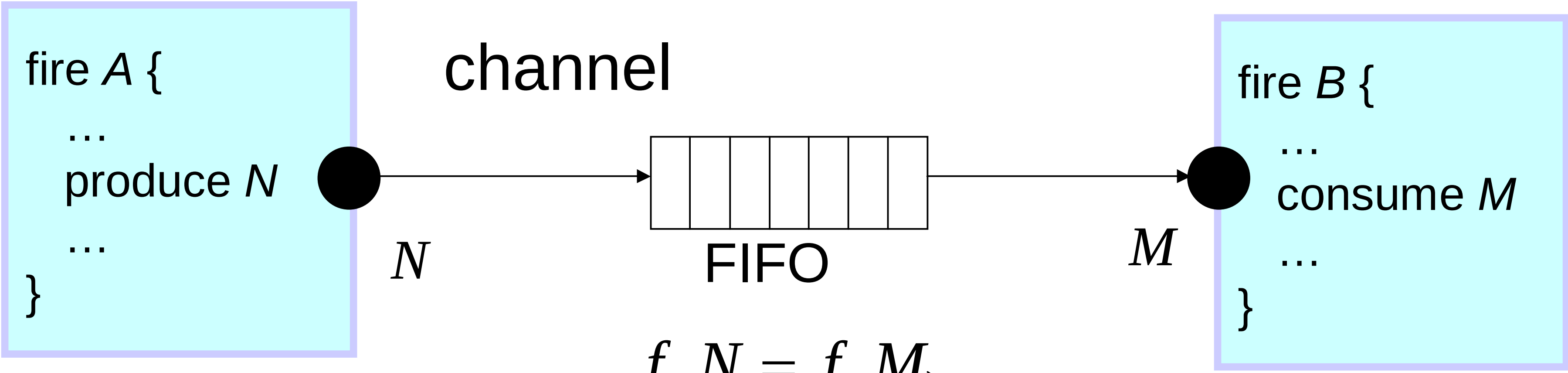
Actual modeling of buffer capacity

The capacity of buffers can be modeled easier:
as a ***backward*** edge where (initial number of tokens = buffer capacity).



Firing rate depends on # of tokens …

Multi-rate models & balance equations (one for each channel)



$$f_A N = f_B M$$

number of tokens produced

number of firings per "iteration"

number of tokens consumed

Decidable:

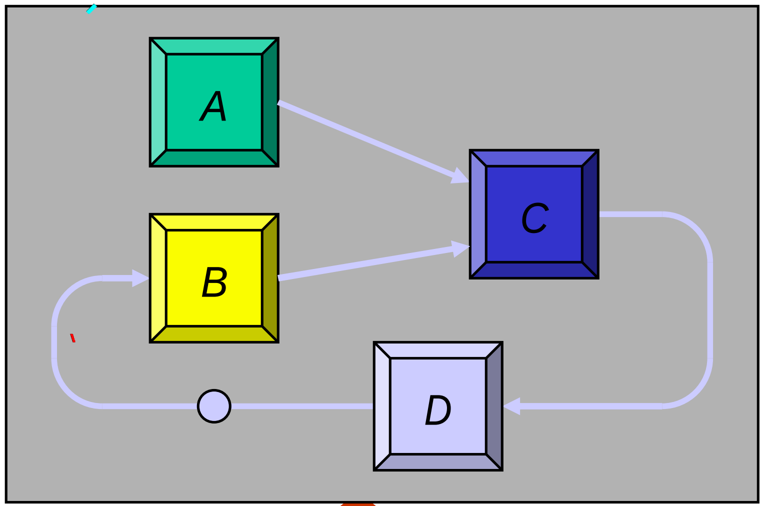
- buffer memory requirements
- deadlock

Schedulable statically

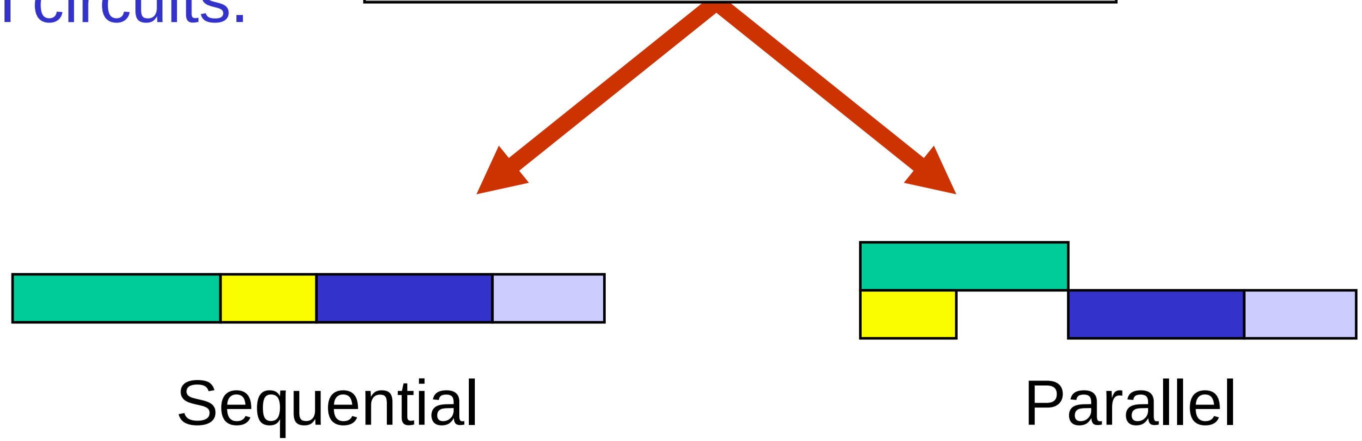
Adopted from: ptolemy.eecs.berkeley.edu/presentations/03/streamingEAL.ppt

Parallel Scheduling of SDF Models

SDF is suitable for automated mapping onto parallel processors and synthesis of parallel circuits.

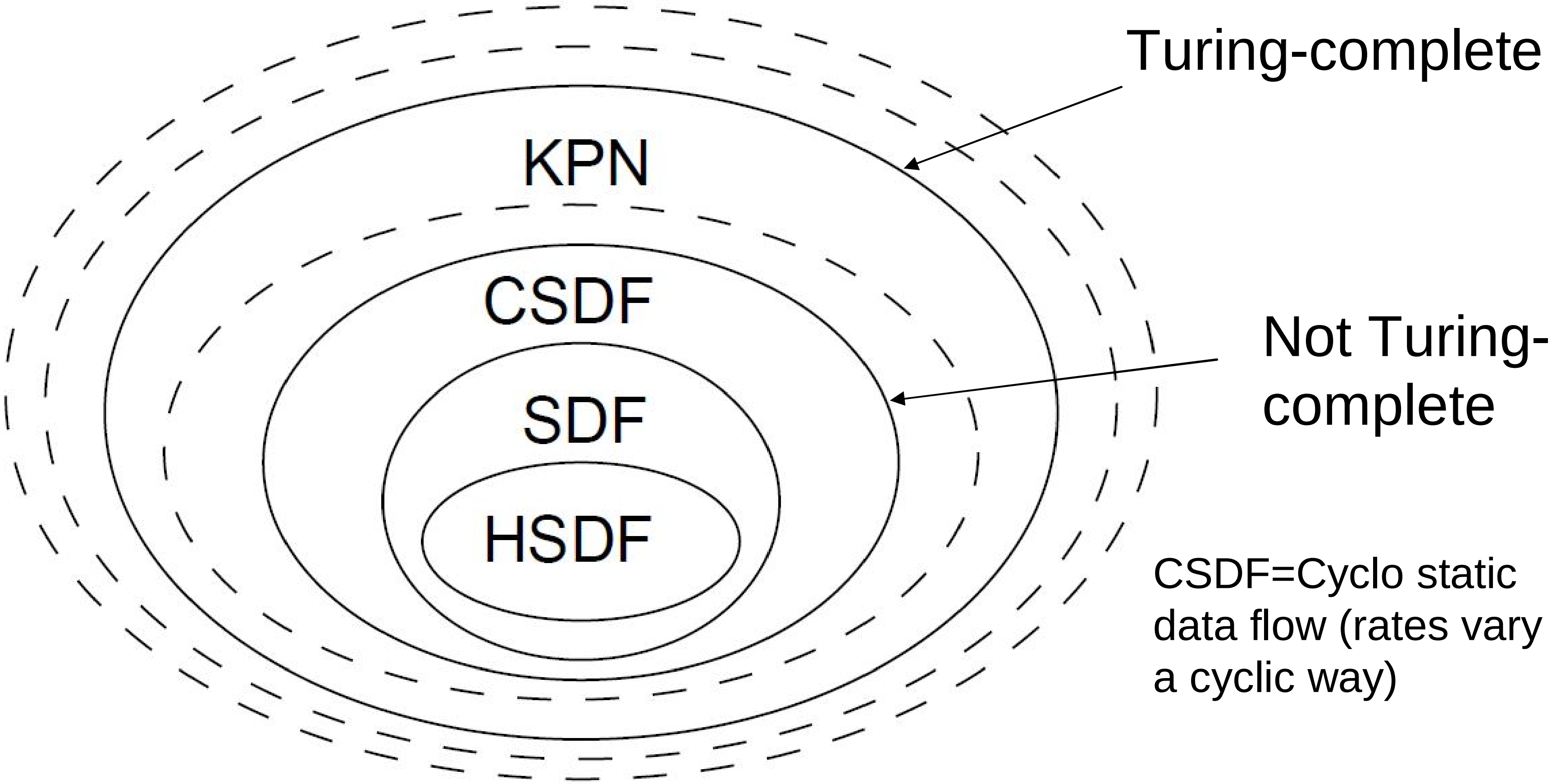


Many scheduling optimization problems can be formulated.



Source: ptolemy.eecs.berkeley.edu/presentations/03/streamingEAL.ppt

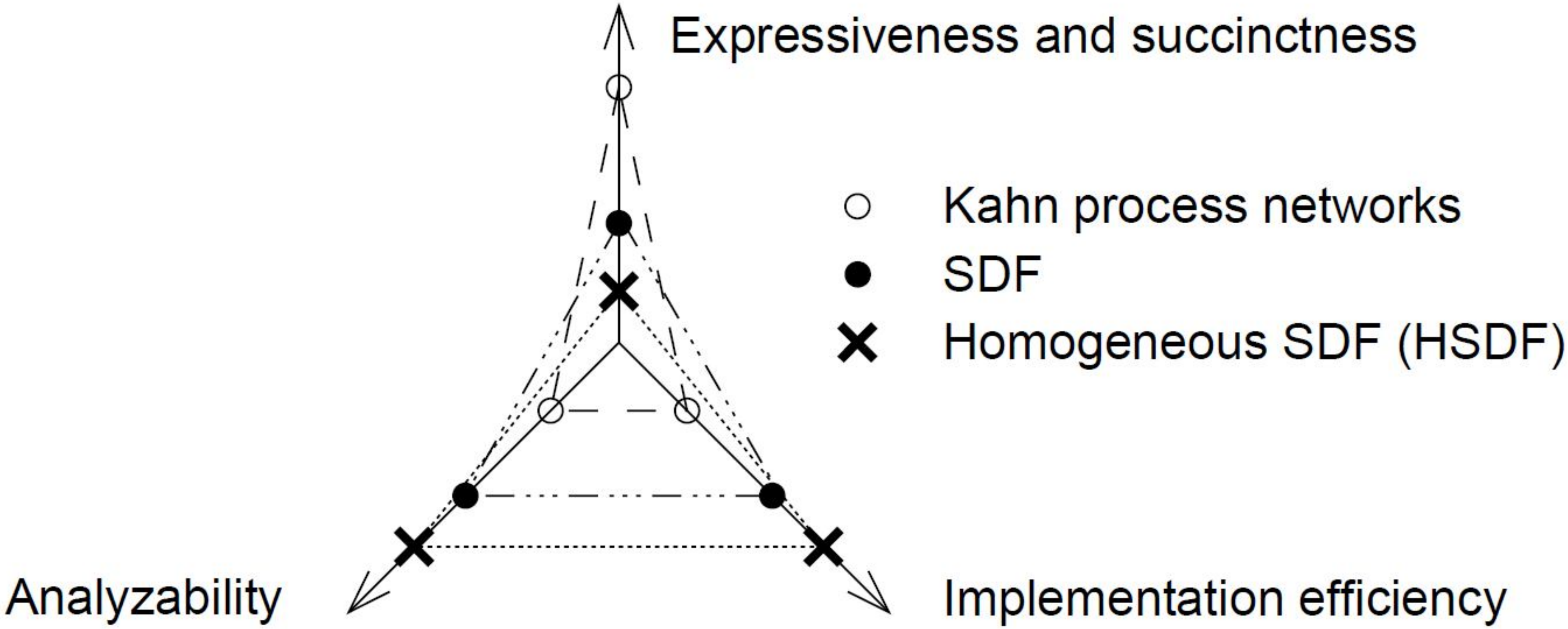
Expressiveness of data flow MoCs



CSDF=Cyclo static data flow (rates vary in a cyclic way)

[S. Stuijk, 2007]

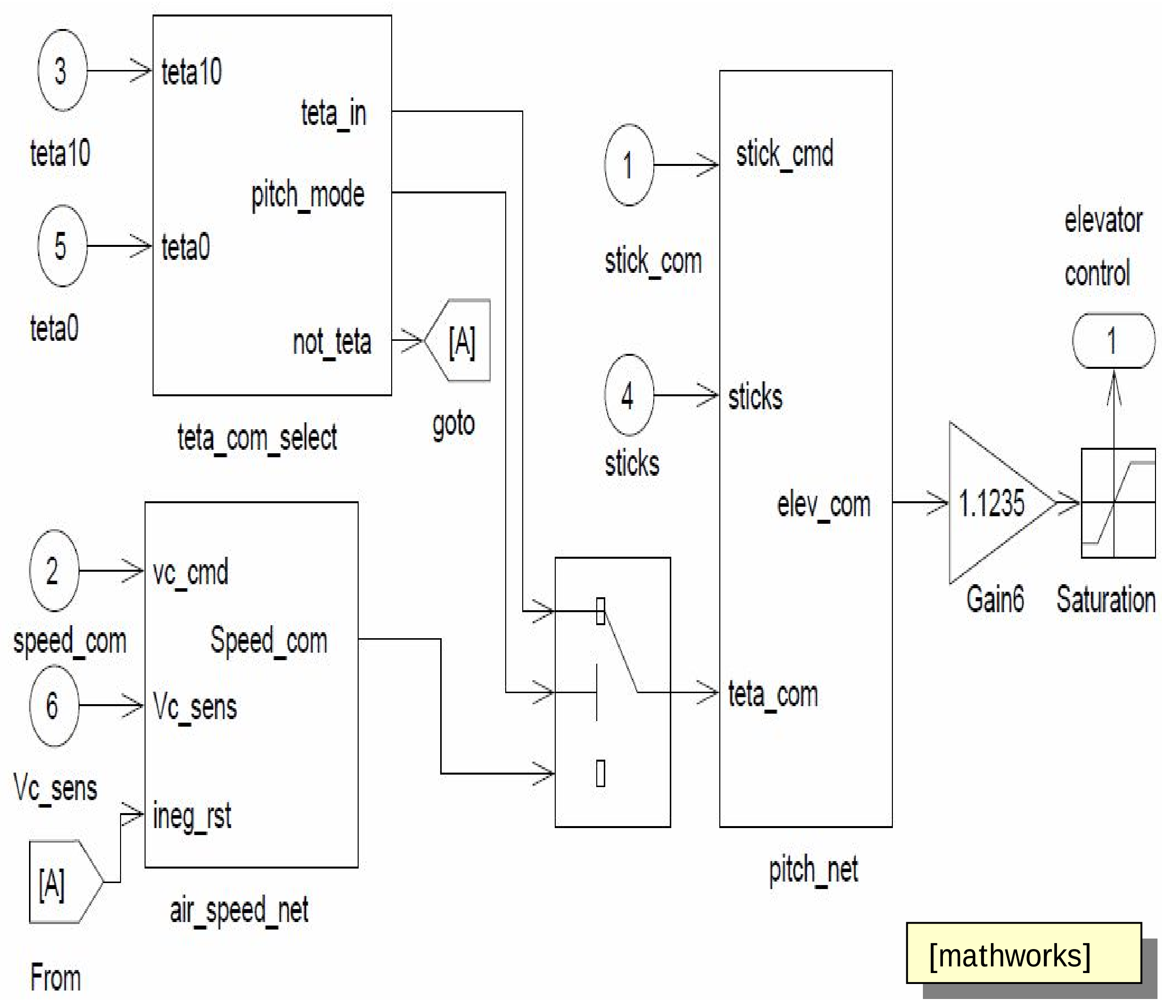
The expressiveness/analyzability conflict



[S. Stuijk, 2007]

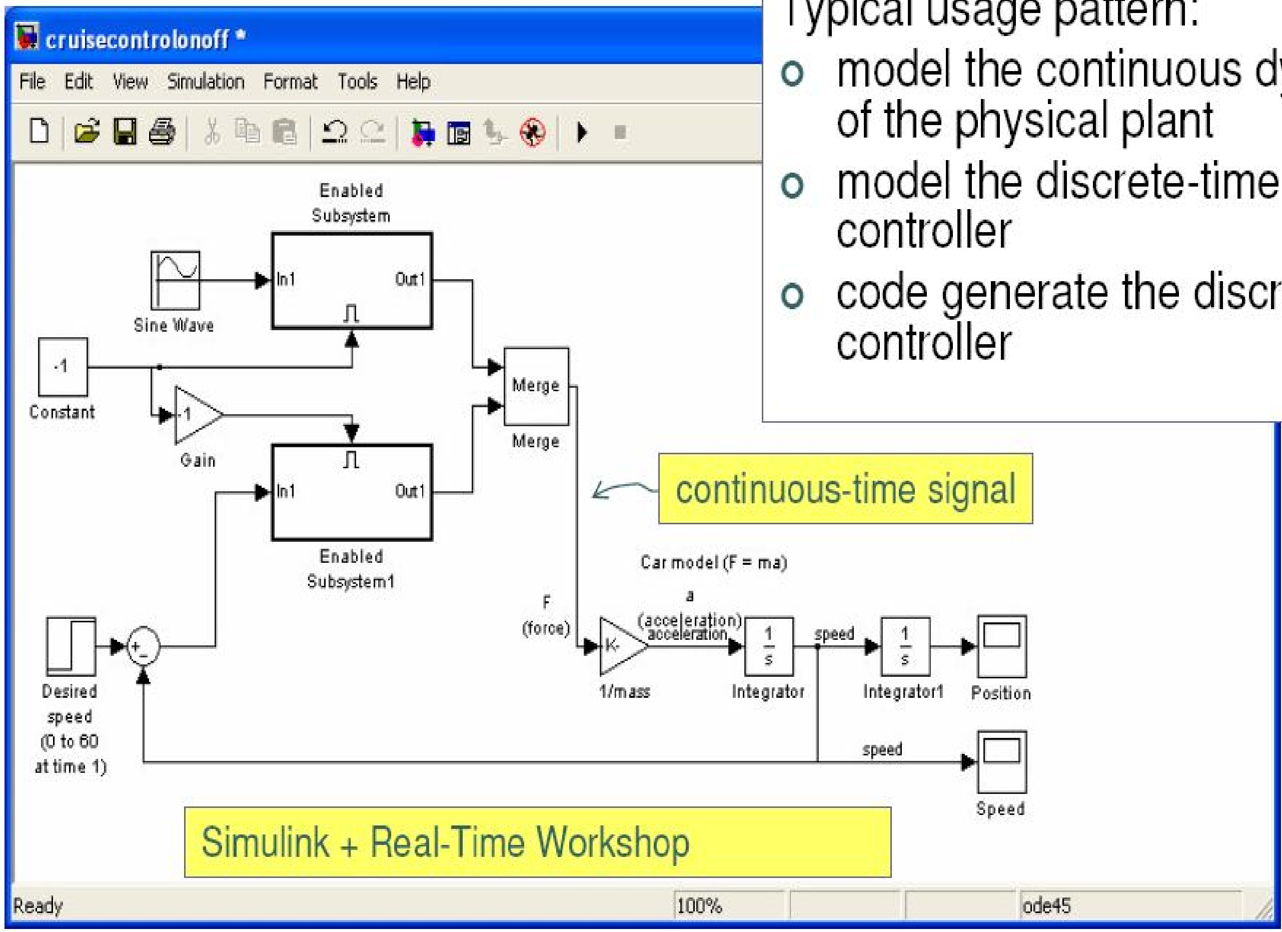
Similar MoC: Simulink

- example -



Semantics? *"Simulink uses an idealized timing model for block execution and communication. Both happen infinitely fast at exact points in simulated time. Thereafter, simulated time is advanced by exact time steps. All values on edges are constant in between time steps.*" [Nicolae Marian, Yue Ma]

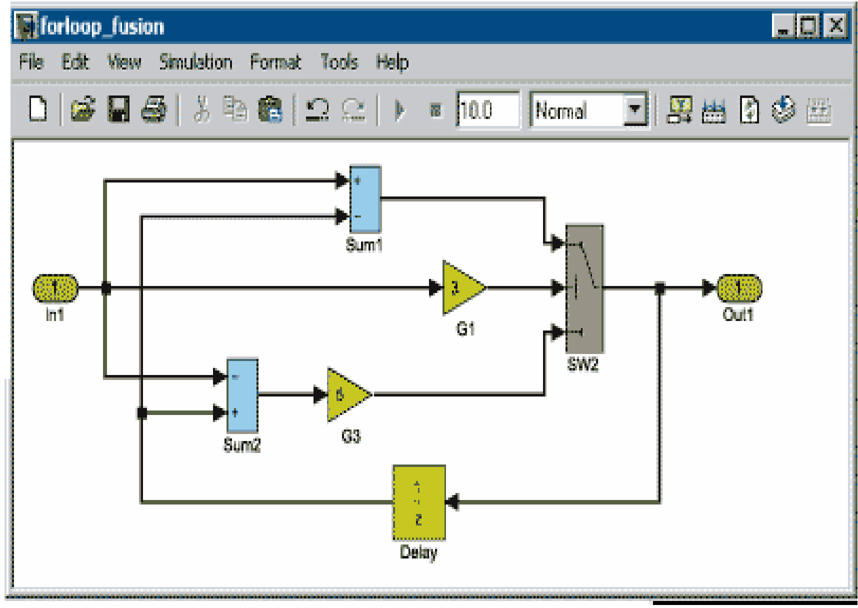
Threads are Not the Only Possibility: 6th example: Continuous-Time Languages



Typical usage pattern:

- model the continuous dynamics of the physical plant
- model the discrete-time controller
- code generate the discrete-time controller

Starting point for “model-based design”



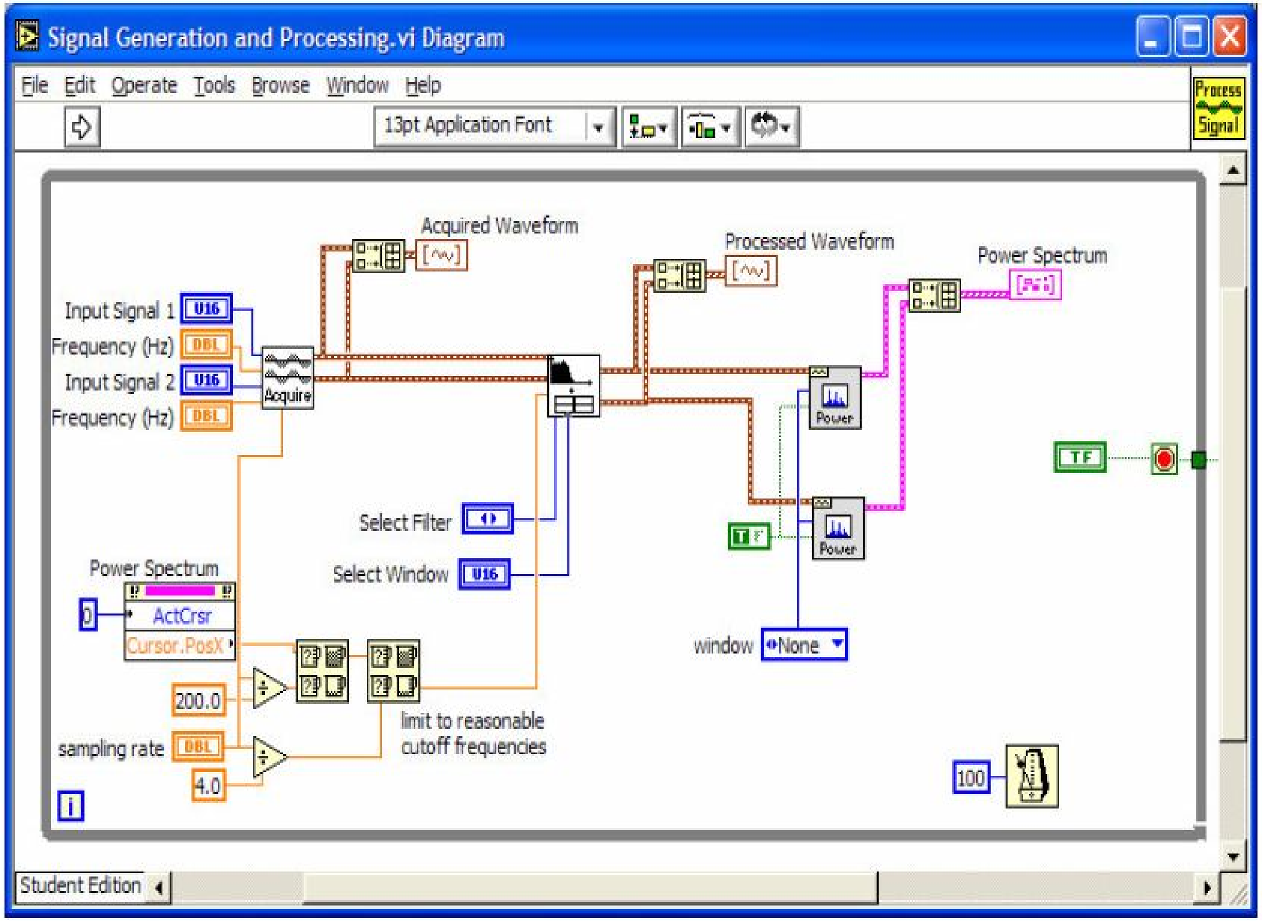

```
/* Switch: '<Root>/SW2' incorporates:
 *   Sum: '<Root>/Sum1'
 *   Gain: '<Root>/G1'
 *   Sum: '<Root>/Sum2'
 *   Gain: '<Root>/G3'
 */
for(i1=0; i1<10; i1++) {
  if(rtU.In1[i1] * 3.0 >= 0.0) {
    rtb_SW2_c[i1] = rtU.In1[i1] - rtDWork.Delay_DSTATE[i1];
  } else {
    rtb_SW2_c[i1] = (rtDWork.Delay_DSTATE[i1] - rtU.In1[i1]) * 5.0;
  }

  /* Outport: '<Root>/Out1' */
  rtY.Out1[i1] = rtb_SW2_c[i1];

  /* Update for UnitDelay: '<Root>/Delay' */
  rtDWork.Delay_DSTATE[i1] = rtb_SW2_c[i1];
}
```

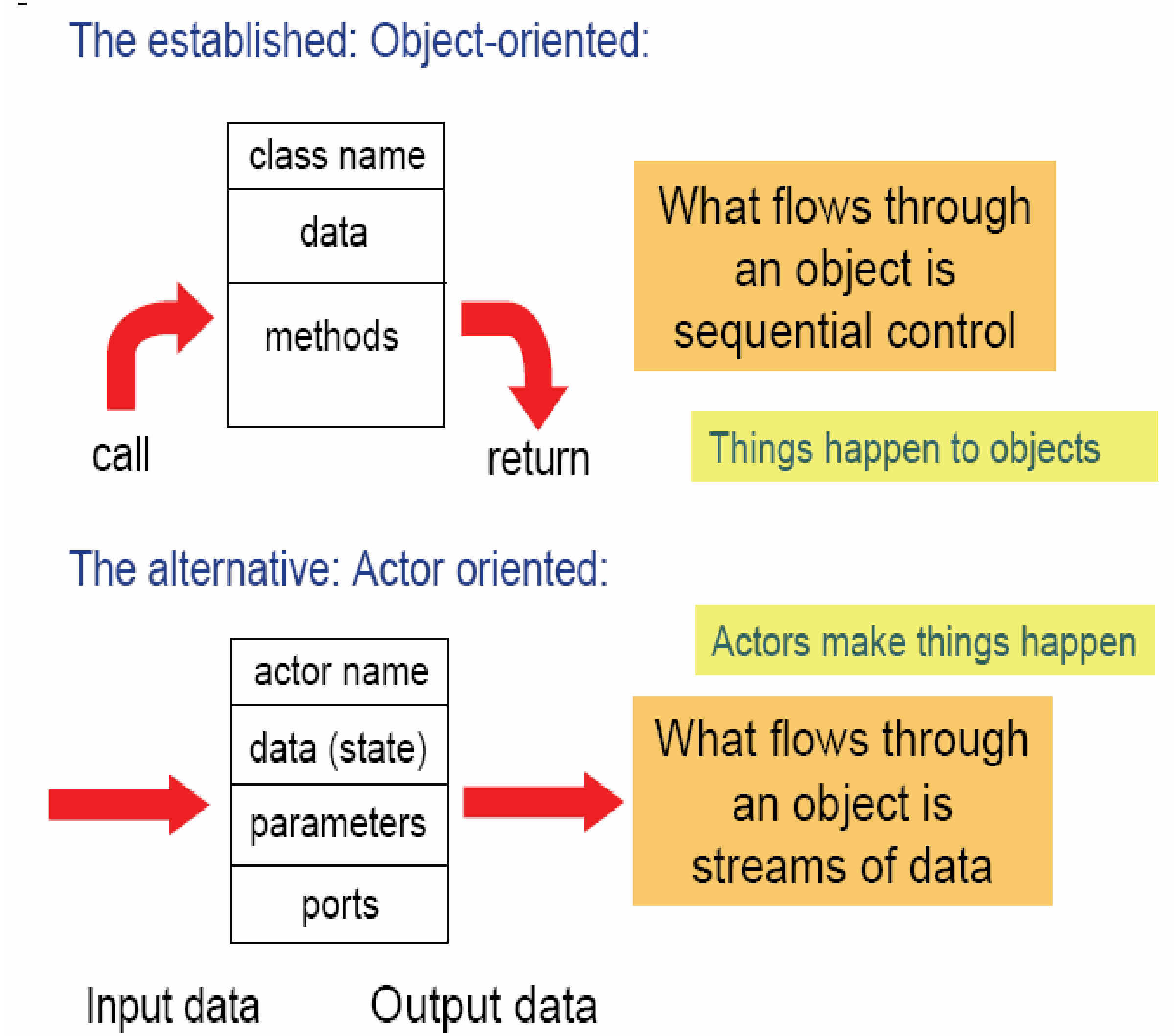
Code automatically generated

Threads are Not the Only Possibility: 5th example: Instrumentation Languages



e.g. LabVIEW, Structured dataflow model of computation

Actor languages



© E. Lee, Berkeley

Summary

Data flow model of computation

- Motivation, definition
- Kahn process networks (KPNs)
- (H/C)SDF
- Visual programming languages
  - Simulink, Real Time Workshop, LabVIEW