The Ptolemy Project

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Sponsors

DARPA
MICRO
The Alta Group of Cadence
Hewlett Packard
Hitachi
Hughes
LG Electronics
NEC
Philips
Rockwell
SRC

Types of Computational Systems

Transformational

- transform a body of input data into a body of output data

Interactive

- interact with the environment at their own speed

Reactive

- react continuously at the speed of the environment

This project focuses on design of reactive systems

- real-time
- embedded
- concurrent
- network-aware
- adaptive

Adaptive Systems

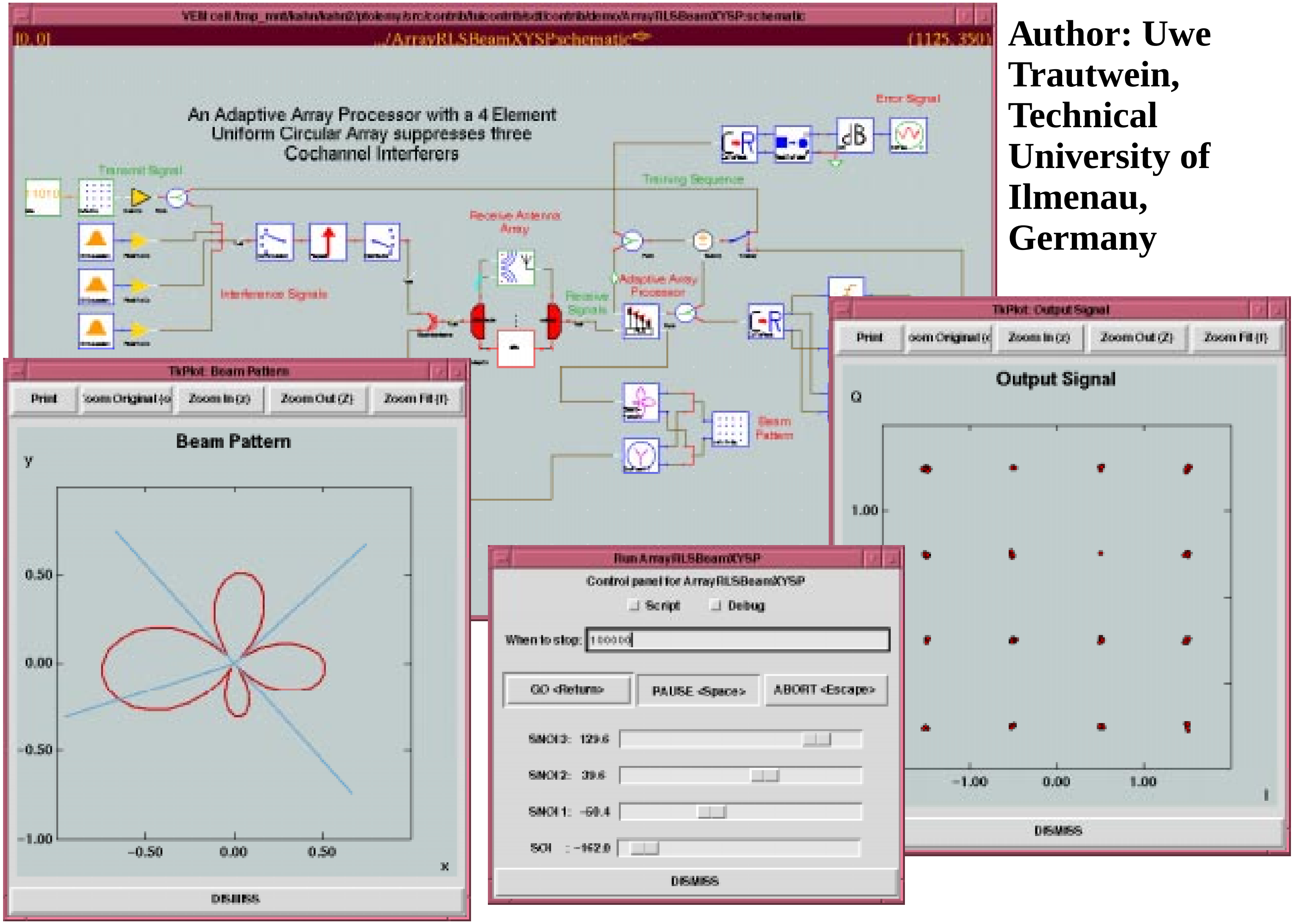
Classical adaptive signal processing

- **system identification**
- **interference nulling**
- **reversing distortion**

Resource adaptive signal processing

- **conserving power**
- **meeting changing latency and QOS requirements**
- **using available sensor data**
- **using network resources (memory, cycles, bandwidth)**

Interactive, High-Level Simulation and Specification

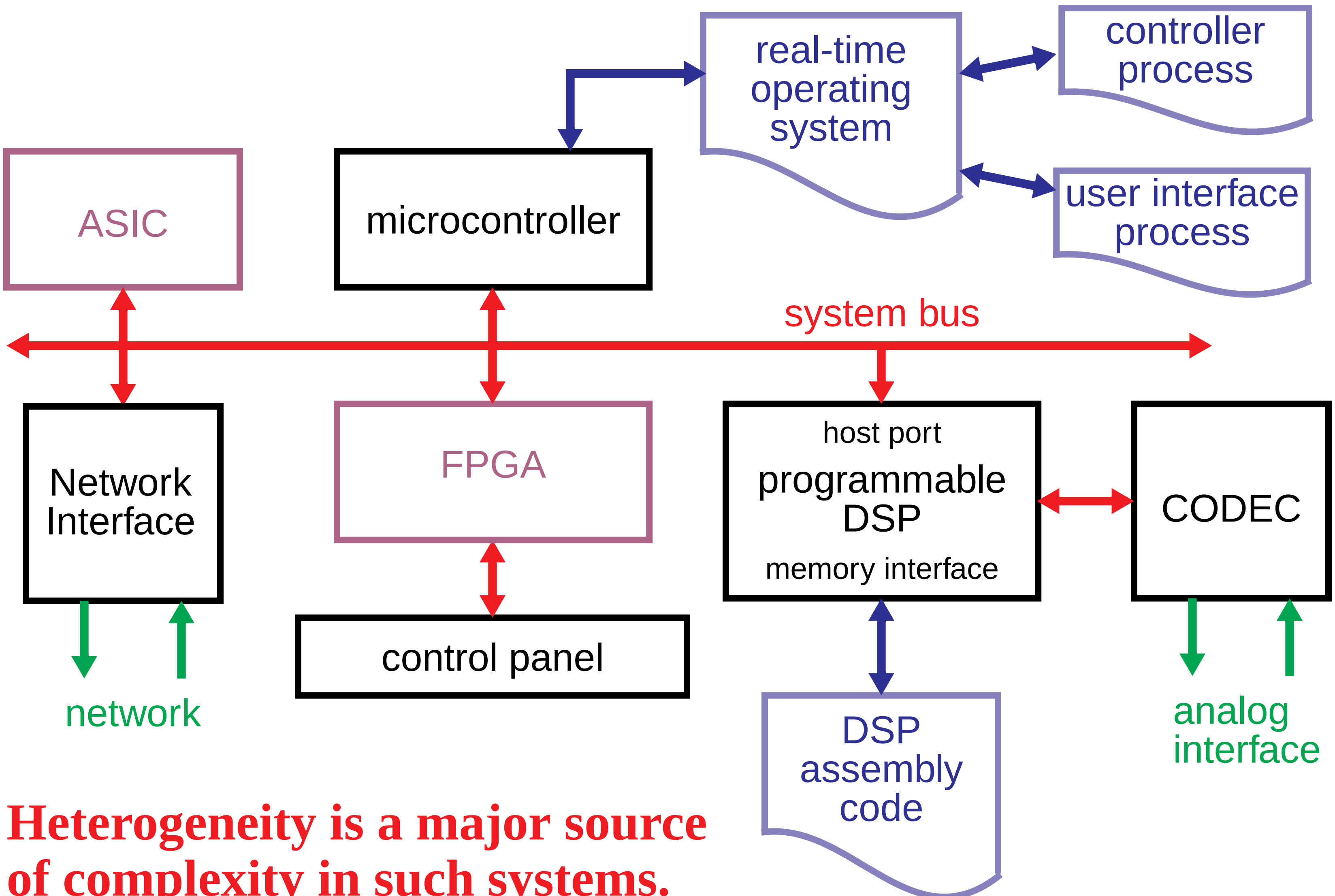


Author: Uwe Trautwein, Technical University of Ilmenau, Germany

Properties of Such Specifications

- **Modular**
  - Large designs are composed of smaller designs
  - Modules encapsulate specialized expertise
- **Hierarchical**
  - Composite designs themselves become modules
  - Modules may be very complicated
- **Concurrent**
  - Modules logically operate simultaneously
  - Implementations may be sequential or parallel or distributed
- **Abstract**
  - The interaction of modules occurs within a “model of computation”
  - Many interesting and useful MoCs have emerged

Typical Implementation



Heterogeneity is a major source of complexity in such systems.

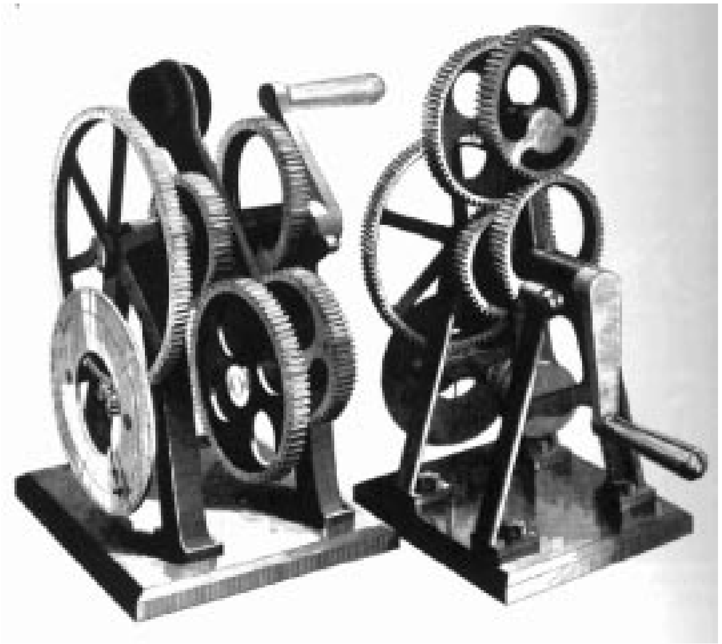
Two Approaches to the Design of Such Systems

- **The grand-unified approach**
  - **Find a common representation language for all components**
  - **Develop techniques to synthesize diverse implementations from this**
- **The heterogeneous approach**
  - **Find domain-specific *models of computation* (MoC)**
  - **Hierarchically mix and match MoCs to define a system**
  - **Retargettable synthesis techniques from MoCs to diverse implementations**

The Ptolemy project is pursuing the latter approach

- **Domain specific MoCs match the applications better**
- **Choice of MoC can profoundly affect system architecture**
- **Choice of MoC can limit implementation options**
- **Synthesis from specialized MoCs is easier than from GULs.**

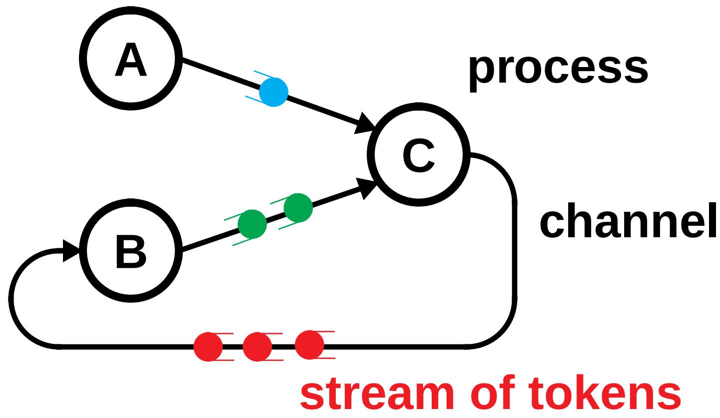
Some Concurrent Models of Computation



- Gears
- Threads
- Petri nets
- Synchronous dataflow
- Dynamic dataflow
- Process networks
- Concrete data structures
- Discrete-events
- Synchronous/Reactive languages
- Communicating sequential processes
- Hierarchical communicating finite state machines

Example — Process Networks

Note: Dataflow is
a special case.



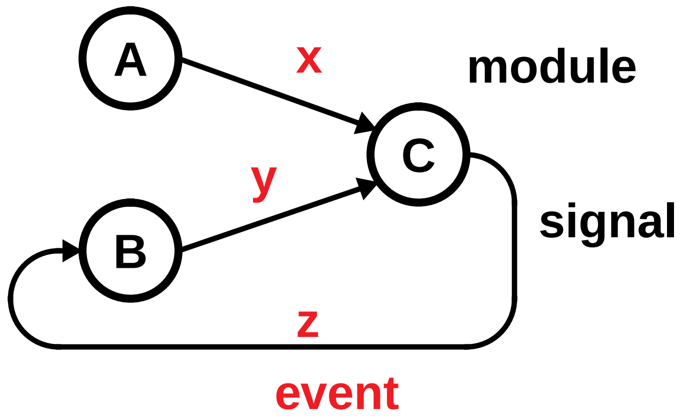
Strengths:

- Good match for signal processing
- Loose synchronization (distributable)
- Determinate
- Maps easily to threads
- Dataflow special cases map well to hardware and embedded software

Weakness:

- Control-intensive systems are hard to specify

Example — Synchronous/Reactive Models



A discrete model of time progresses as a sequence of "ticks." At a tick, the signals are defined by a fixed point equation:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} f_{A,t}(1) \\ f_{B,t}(z) \\ f_{C,t}(x, y) \end{bmatrix}$$

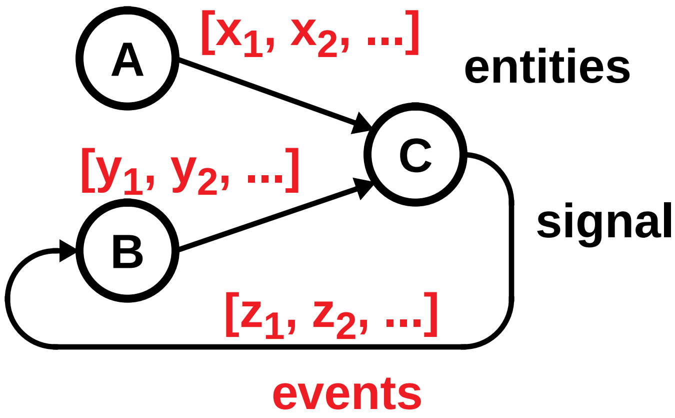
Strengths:

- Good match for control-intensive systems
- Tightly synchronized
- Determinate
- Maps well to hardware and software

Weaknesses:

- Computation-intensive systems are overspecified
- Modularity is compromised

Example — Discrete-Event Models



Events occur at discrete points on a time line that is usually a continuum. The entities react to events in chronological order.

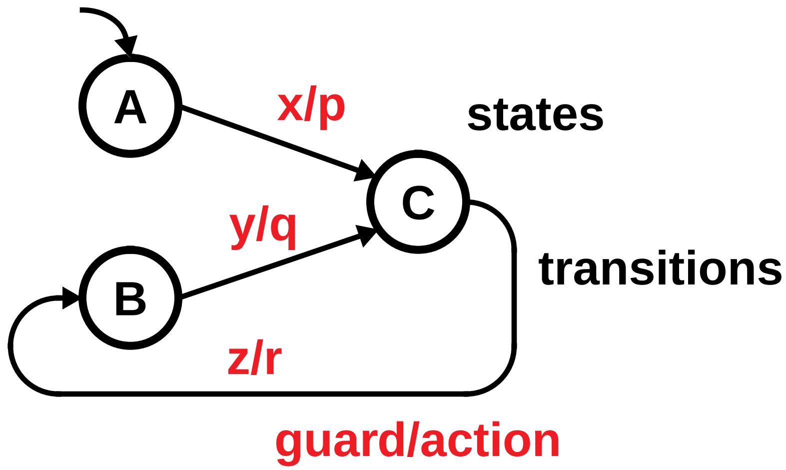
Strengths:

- Natural description of hardware
- Global synchronization
- Can be made determinate (often is not, however)

Weaknesses:

- Expensive to implement in software
- May over-specify and/or over-model systems (global time)

Sequential Example — Finite State Machines



Guards determine when a transition may be made from one state to another, in terms of events that are visible, and outputs assert other events.

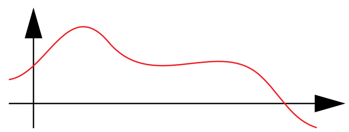
Strengths:

- Natural description of sequential control
- Behavior is decidable
- Can be made determinate (often is not, however)
- Good match to hardware or software implementation

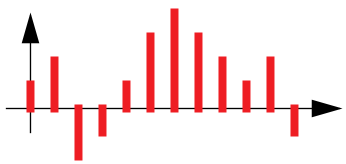
Weaknesses:

- Awkward to specify numeric computation
- Size of the state space can get large

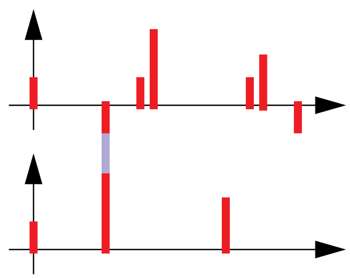
Essential Differences — Models of Time

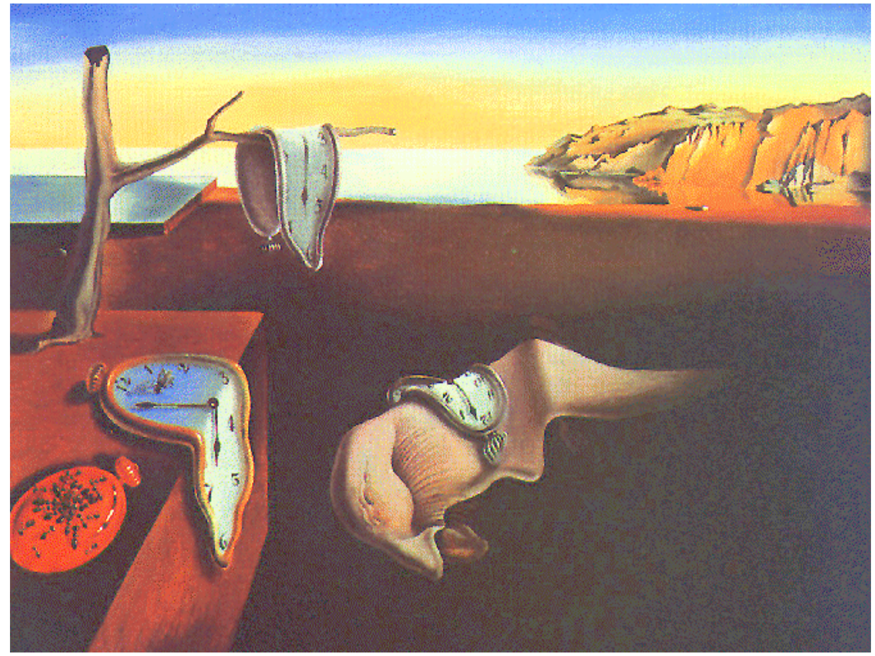


continuous time



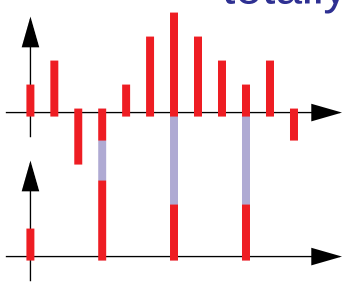
discrete time



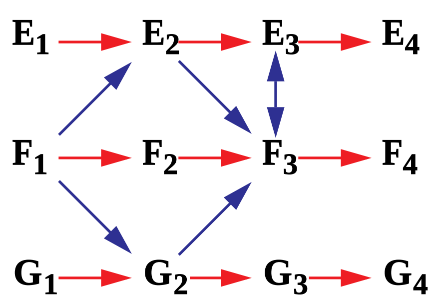


Salvador Dali, ***The Persistence of Memory***, 1931

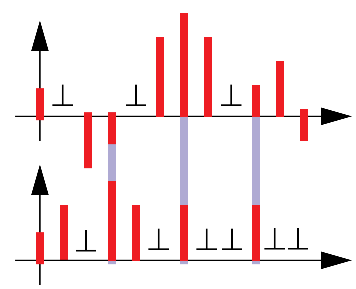
totally-ordered discrete events



multirate discrete time



partially-ordered discrete events



synchronous/reactive

Key Issues in these Models of Computation

- Maintaining determinacy.
- Supporting nondeterminacy.
- Bounding the queueing on channels.
- Scheduling processes.
- Synthesis: mapping to hardware/software implementations.
- Providing scalable visual syntaxes.
- Resolving circular dependencies.
- Modeling causality.
- Achieving fast simulations.
- Supporting modularity (gray box model for modules).
- Composing multiple models of computation.

Validation methods

- **By construction**
  - property is inherent.
- **By verification**
  - theorem proving or algorithm.
- **By simulation**
  - check behavior for all inputs.
- **By testing**
  - observation of a prototype.
- **By intuition**
  - property is true, I think.
- **By assertion**
  - property is true. That's an order.

Meret Oppenheim, *Object*, 1936

It is generally better to be higher in this list

The following objectives are at odds with one another:

- **Expressiveness**
- **Generality**

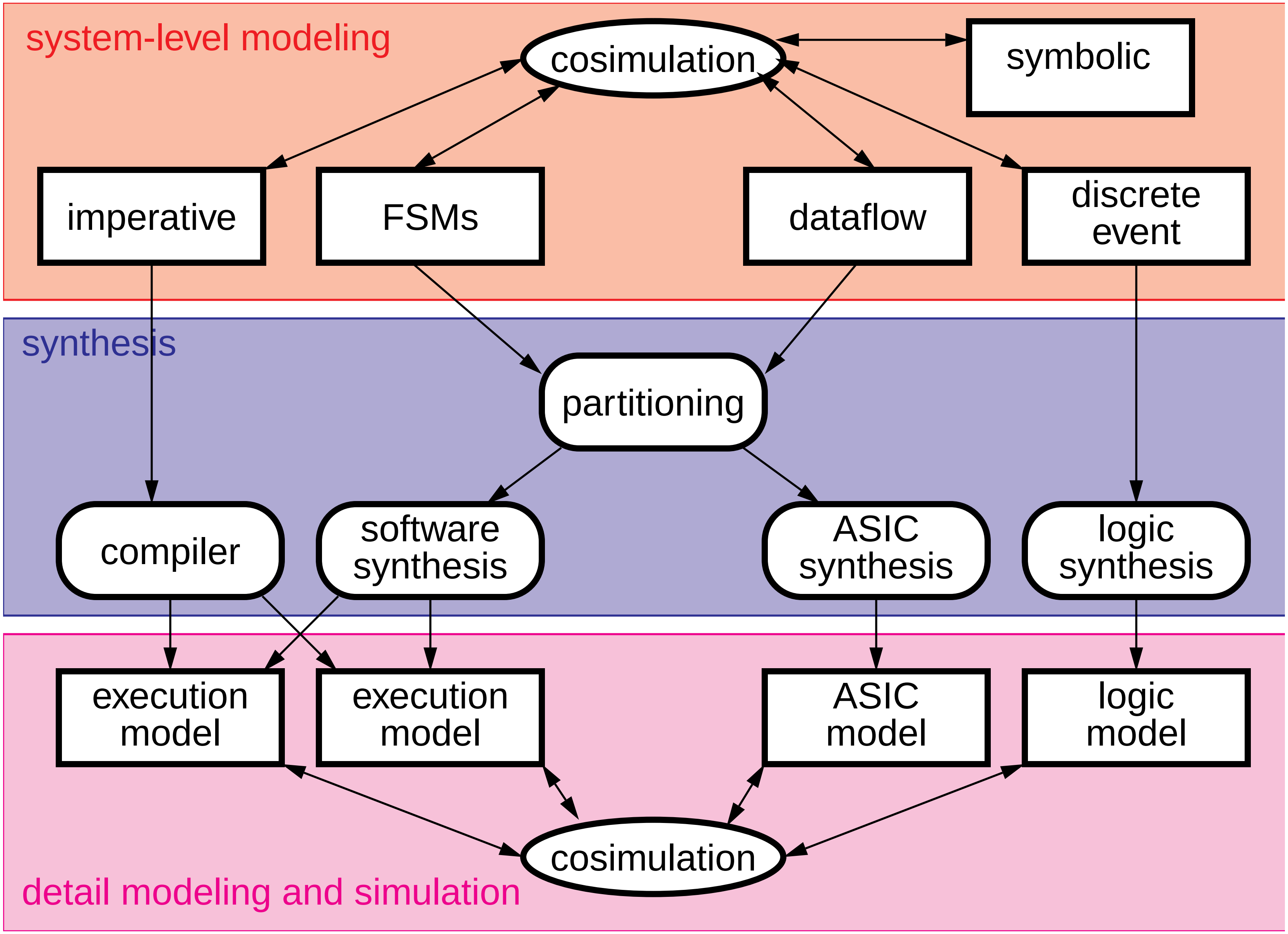
vs.

- **Verifiability**
- **Compilability/Synthesizability**

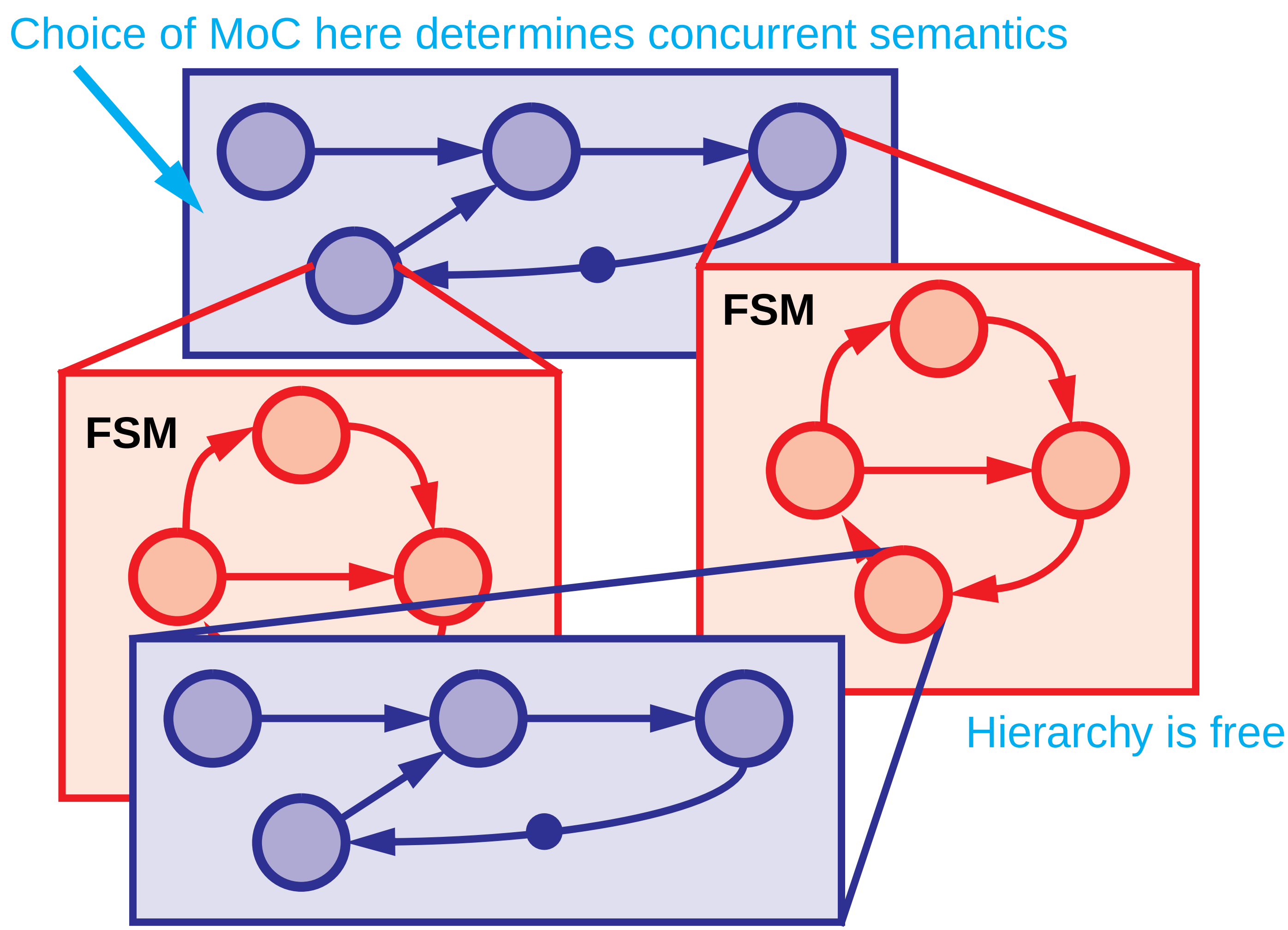
The Conclusion?

Heterogeneous modeling.

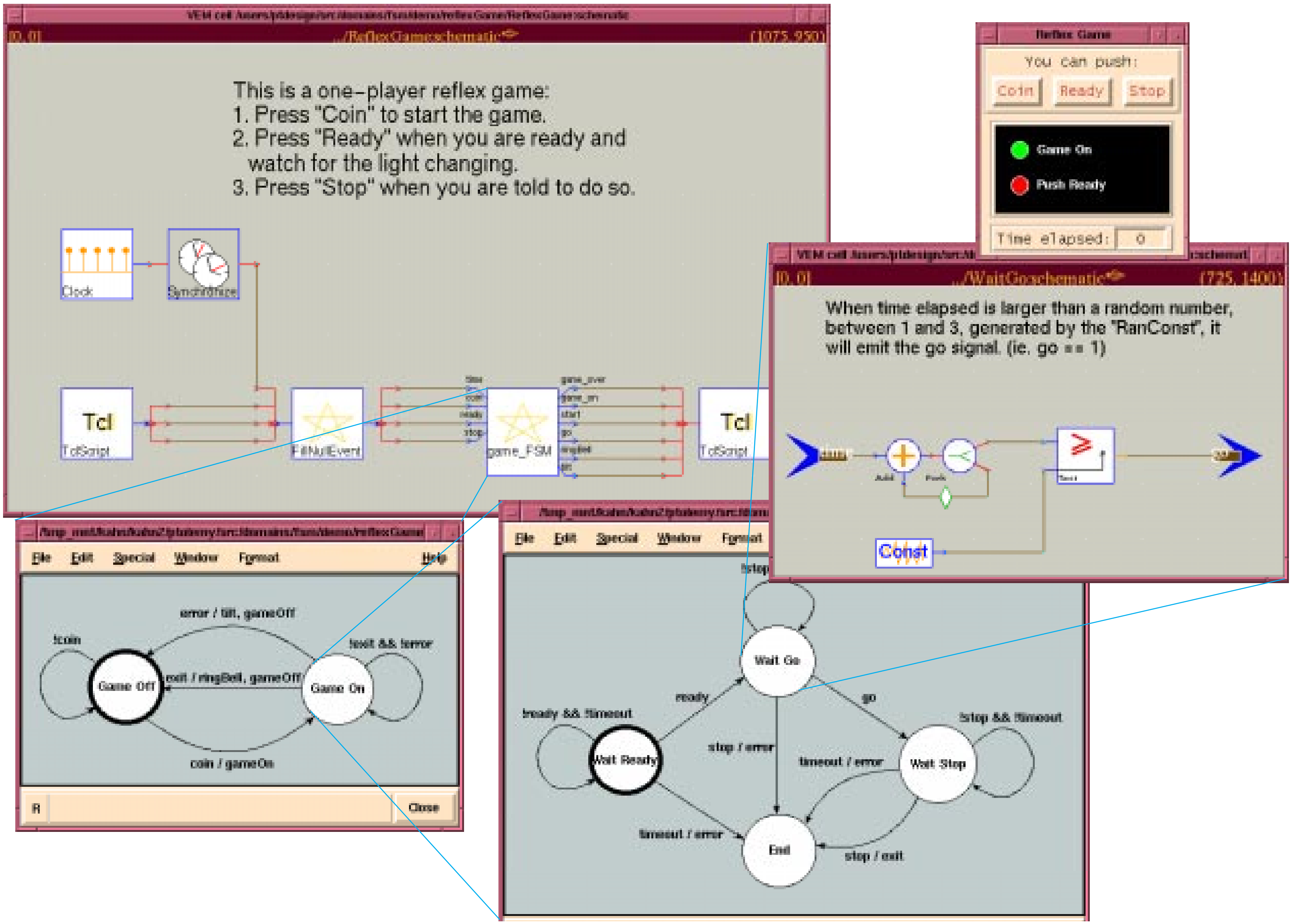
A Mixed Design Flow



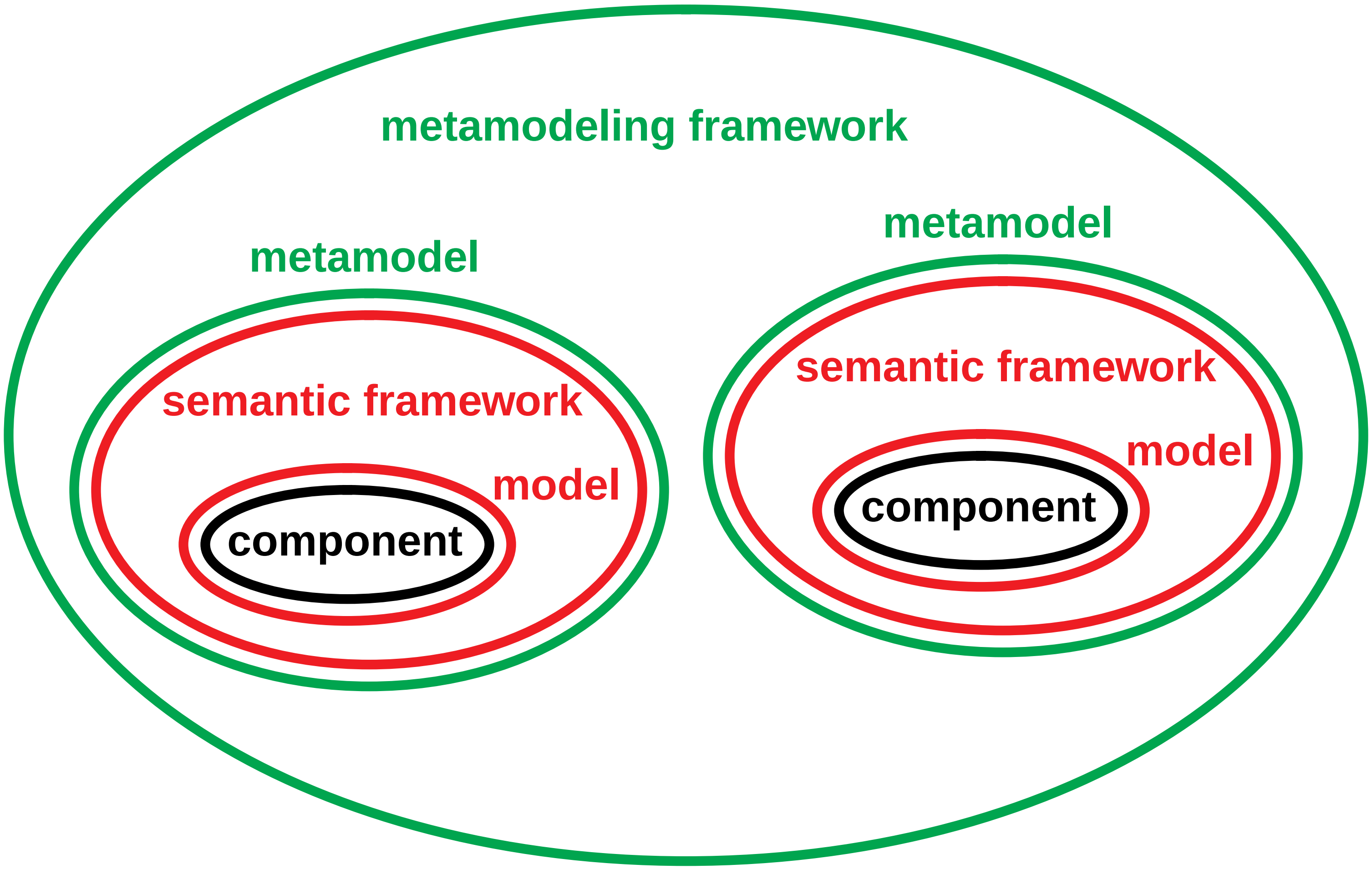
An Example of Hiearchical Heterogeneity: *Charts



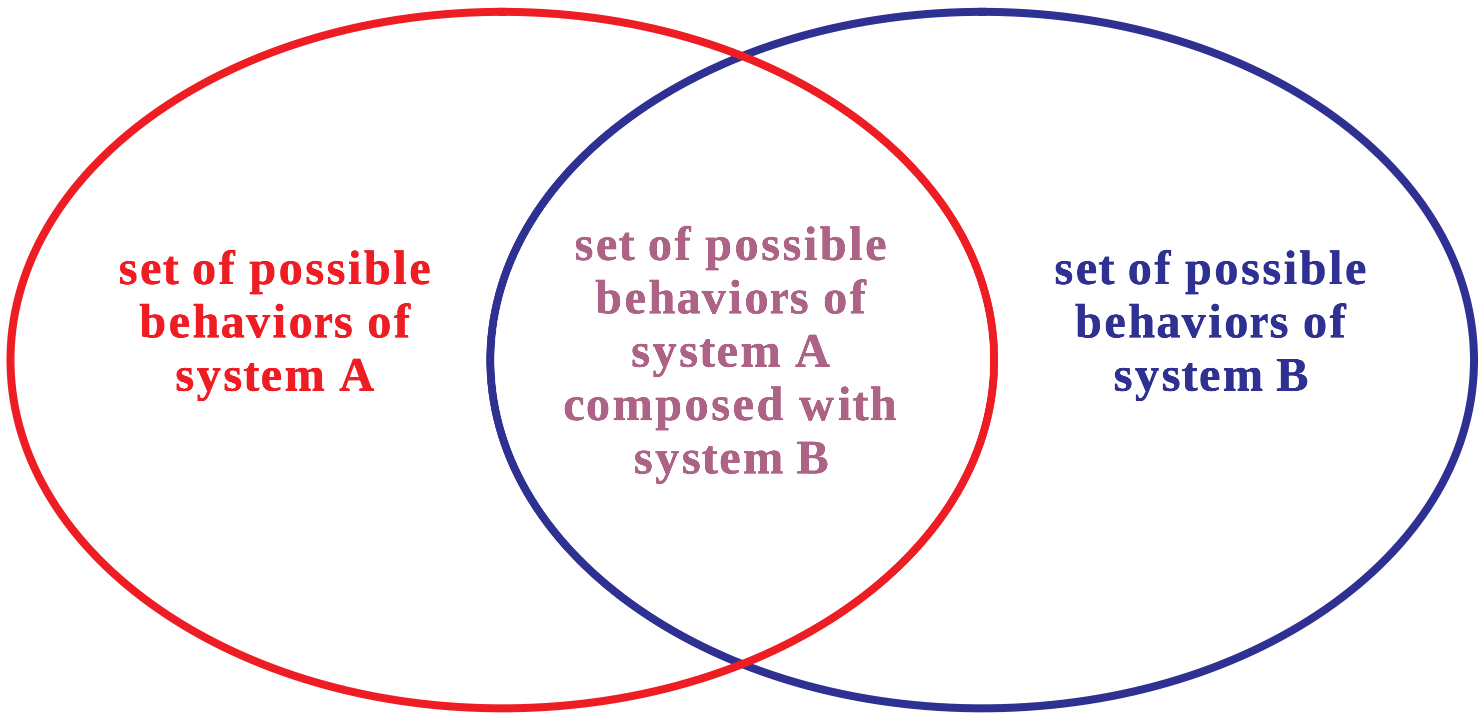
Example: DE, Dataflow, and FSMs



Metamodeling



Constraint-Based Metamodeling Frameworks



These sets might be deterministic or random, exact or approximate.

Uses for Metamodeling

- **Heterogeneous mixtures of semantic frameworks**
  - **heterogeneous systems**
  - **multiple views of the same system**
- **Design analysis**
  - **check aspects of correctness**
  - **discover opportunities for optimization**
- **Design refinement**
  - **the set of all possible design refinements gives the concretization operator**
- **Run-time modeling**
  - **reflection**
  - **model discovery and adaptation**
  - **model-driven control**

Ptolemy Software as a Tool and as a Laboratory

Ptolemy software is
- Extensible
- Publicly available
- An open architecture
- Object-oriented

Allows for experiments with:
- Models of computation
- Heterogeneous design
- Domain-specific tools
- Design methodology
- Software synthesis
- Hardware synthesis
- Cosimulation
- Cosynthesis
- Visual syntaxes (Tycho)

Modular Deployable Design Tools

Past design software:

- Monolithic
- Huge
- Back-room use

Future design software:

- Modular
- Deployable
- In-the-field evolution

Initial Strategy

Toolkit approach to design, creating an environment that is

- **safe (no core dumps)**
- **extensible**
- **distributable**
- **concurrent**
- **portable**

Deployed designs must minimize the use of

- **C, C++**
- **Thus, most of the existing Ptolemy kernel**

Initial Languages

In addition to satisfying all the above,

Tcl/Tk/Itcl

- **scripting language**
- **high-level, object-oriented**
- **universal, communicable data type (strings)**
- **extensive graphical user interface toolkits**

Java

- **faster (we have measured up to 8x)**
- **lower-level, object-oriented**
- **modularity built in**
- **concurrent (threads), although at a very low level**

Tycho

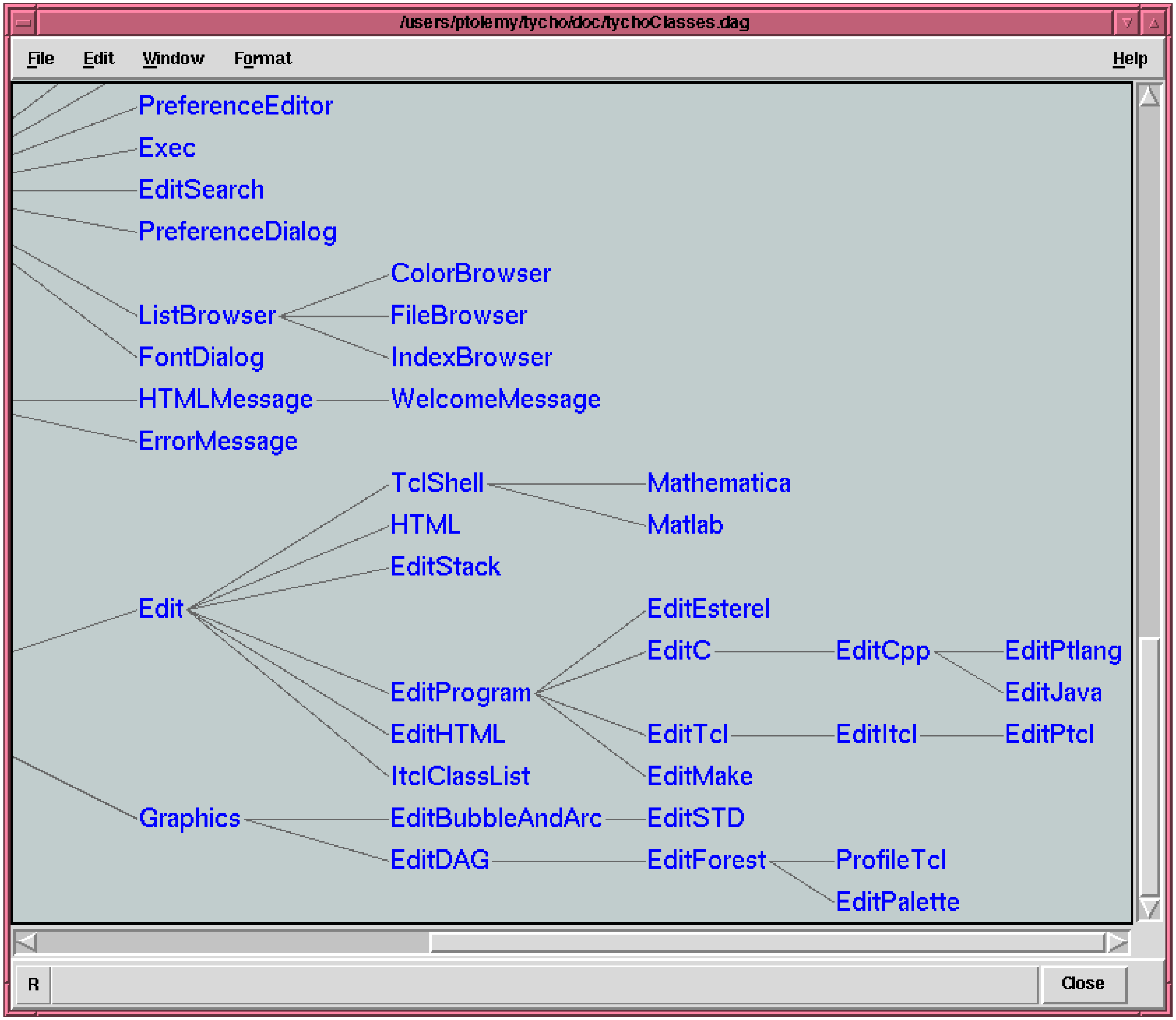
Modular Itcl class library

- **system control**
- **configuration**
- **user interface**

Current facilities:

- **context-sensitive text editors**
- **scripting shells (Tcl, Matlab, Mathematica)**
- **graphics toolkit (the Tycho Slate)**
- **integrated, interactive, HTML documentation**
- **preferences manager, version control, widget library**

A Portion of the Class Hierarchy (displayed in Tycho)



The Tycho Slate

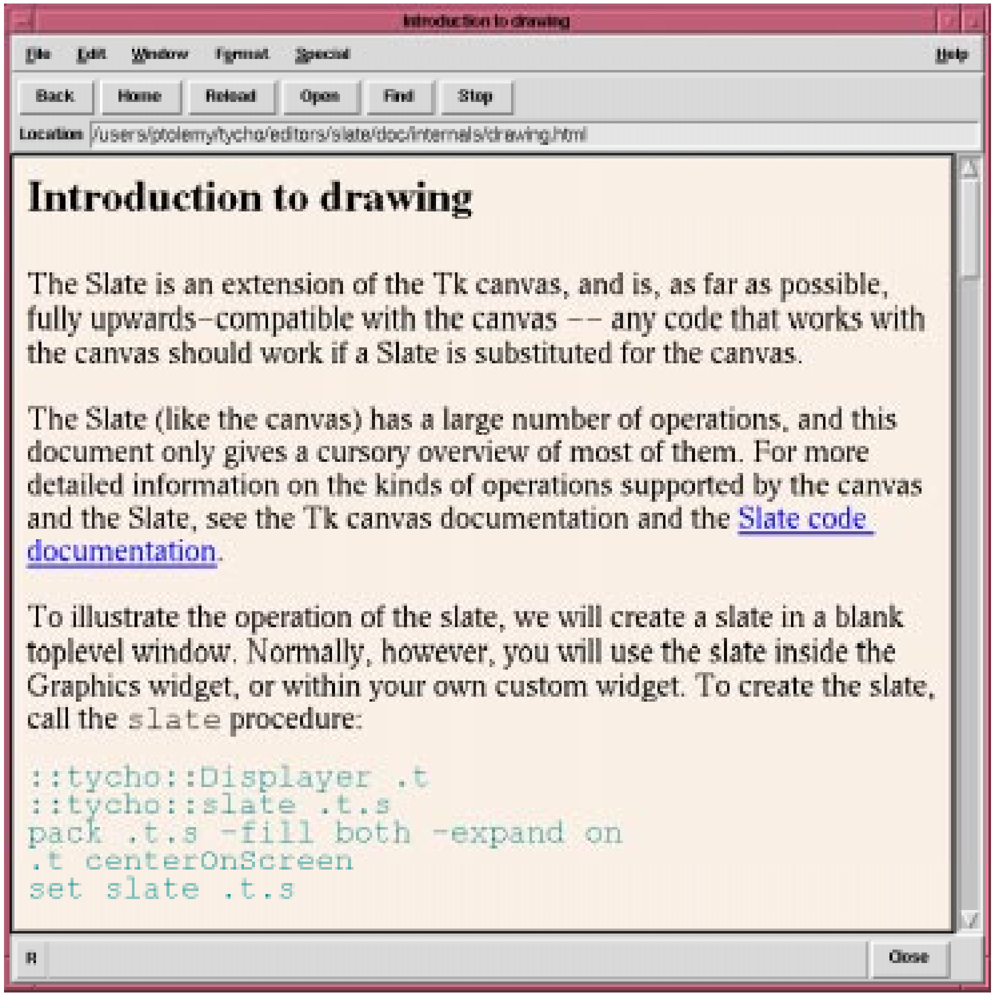
Extends the Tk canvas supporting

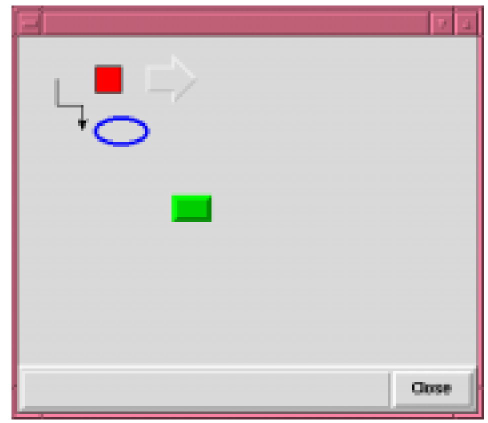
- creating complex items,
- re-using common patterns of user interaction.

There are two key uses of the Slate:

- As a higher-level canvas for building graphical displays and editors. The Slate is used this way within the Graphics class and subclasses.
- As a toolbox for rapidly building custom widgets. The Slate is used this way to create some of the custom widgets used in Ptolemy C-code-generated systems.

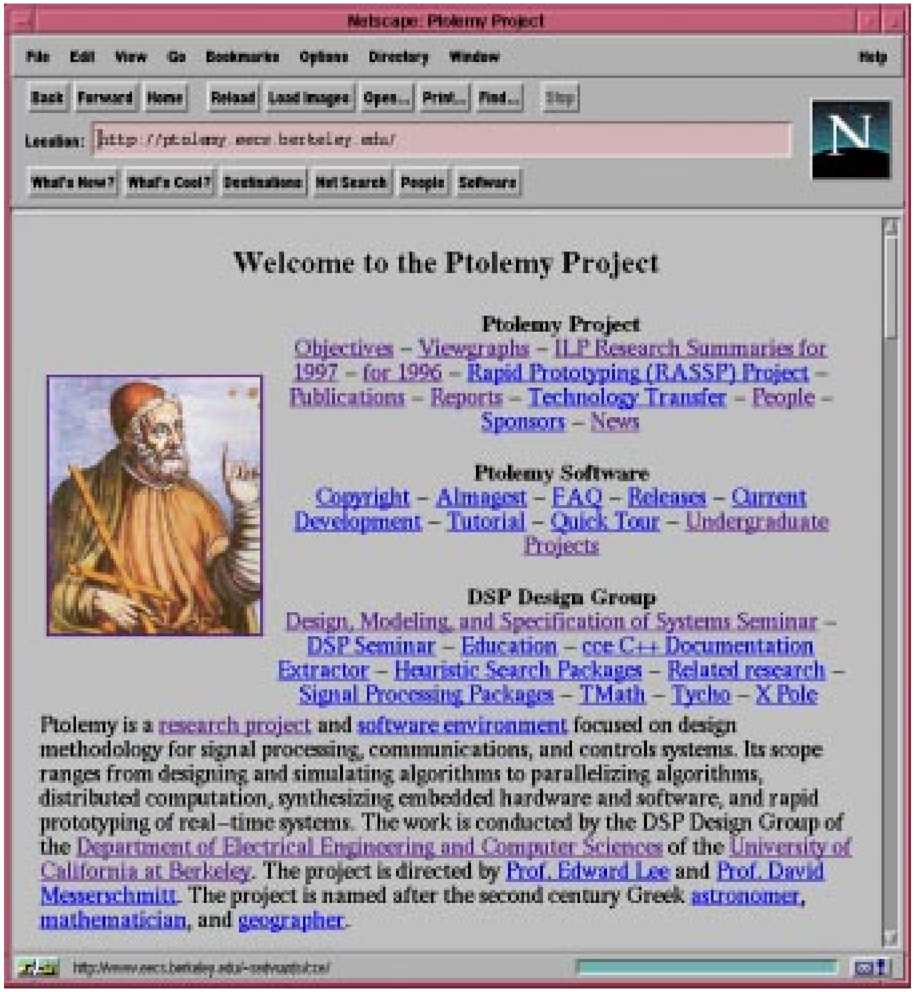
Integrated, Interactive Documentation





In the above example, clicking on the Tcl code at the bottom executes the code, creating the example slate on the right.

Further Information



- Software distribution
- Small demonstration version
- Project overview
- *The Almagest* (the manual)
- Current projects summary
- Project publications
- Keyword searching
- Project participants
- Sponsors
- Copy of the FAQ
- Newsgroup info
- Mailing lists info

http://ptolemy.eecs.berkeley.edu