The Ptolemy Project

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Mission

Ptolemy is a research project and software environment focused on the design and modeling of reactive systems, providing high-level support for signal processing, communications, and real-time control. The key underlying principle in the project is the use of multiple models of computation in a hierarchical heterogeneous design and modeling environment.

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Organizational

Staff

Diane Chang, administrative assistant
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Mary Stewart, programmer analyst

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Tom Lane (SSS)
Thomas M. Parks (Lincoln Labs)
José Luis Pino (Hewlett Packard)

Sponsors

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

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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**
- **heterogeneous**

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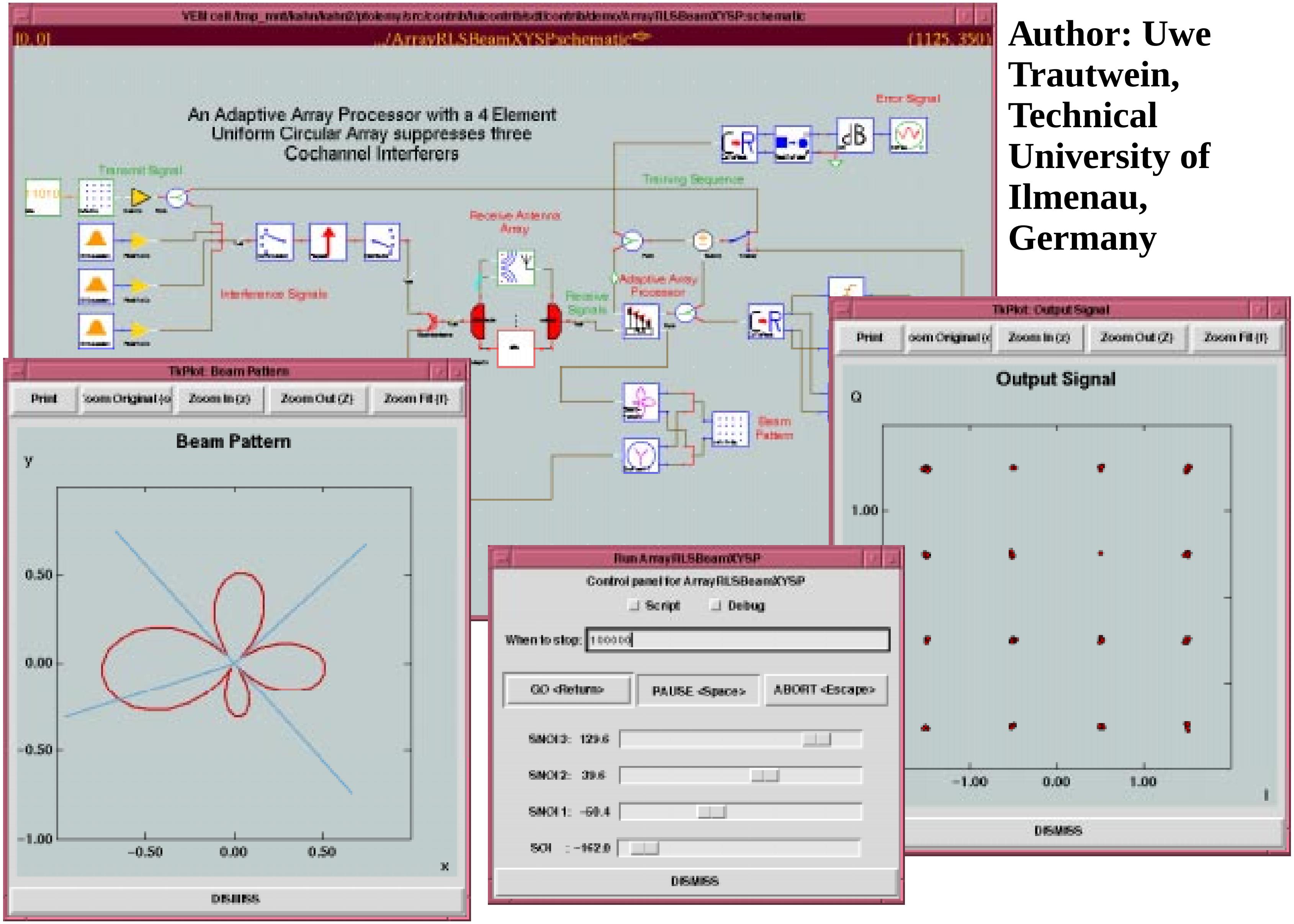
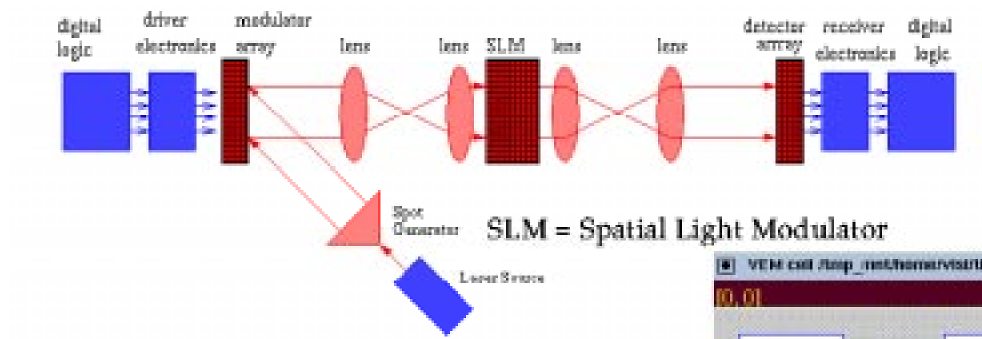
Interactive, High-Level Simulation and Specification

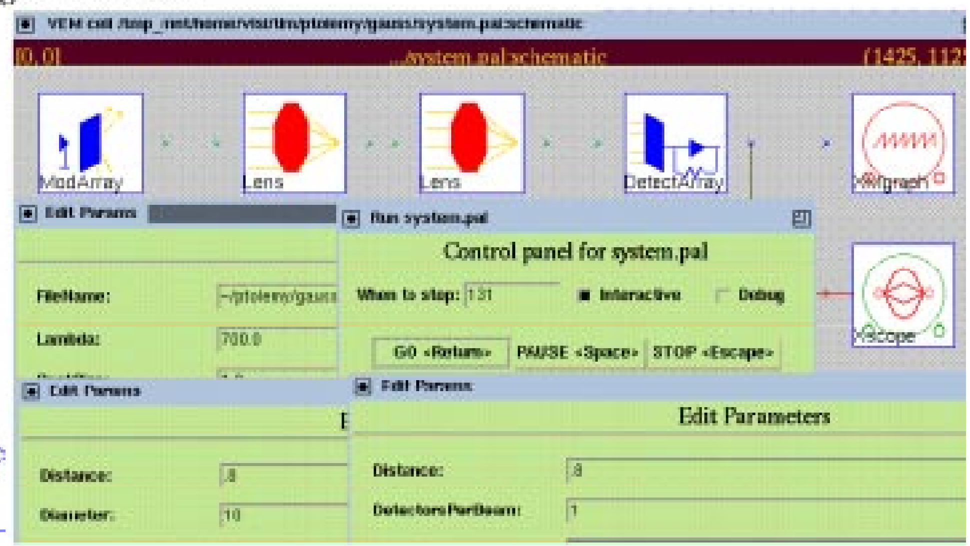


Author: Uwe Trautwein, Technical University of Ilmenau, Germany

Encapsulating Domain-Specific Expertise

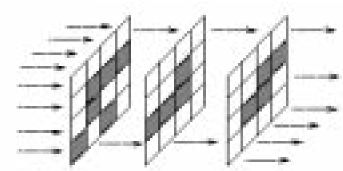
Computer Aided Design and Simulation of Free Space Optoelectronic Information Processing Systems, S.P. Levitan *et al.*, Univ. of Pittsburgh.

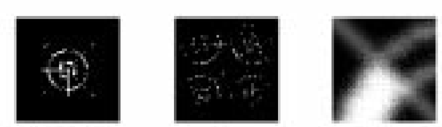




$$P_{optic}(V) = P_{in}\left(1 - \frac{k(V)}{1 + \frac{P_{in}}{A \cdot I_d(V)}}\right)$$

$$V_d(s) = \frac{R_f}{1 + \left(\frac{R_f C_f}{A}\right)s} \cdot P_{optic}(s)$$





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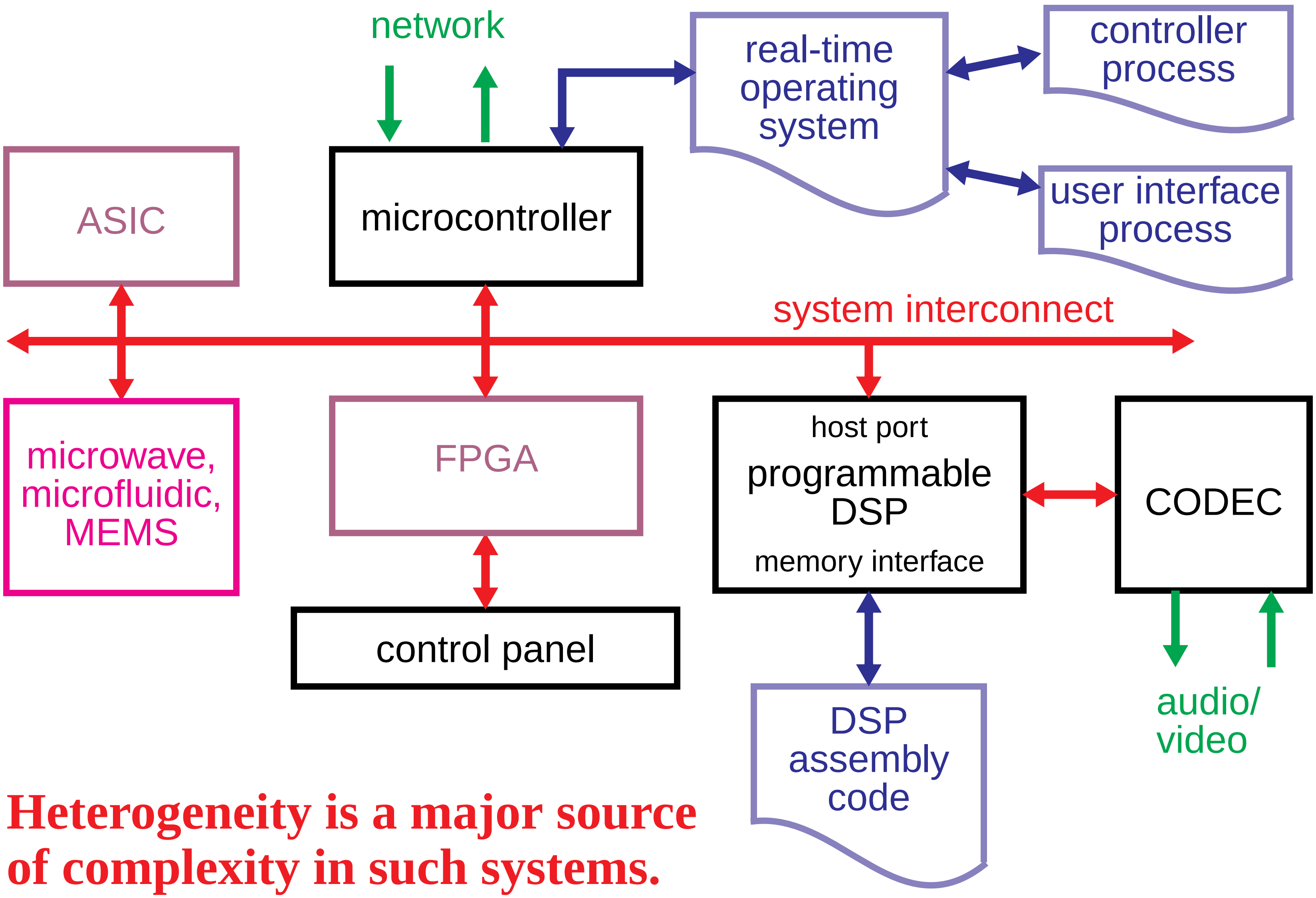
Properties of Such Specifications

- **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
- **Domain Specific**
  - Expertise encapsulated in MoCs and libraries of modules.

Heterogeneous Implementation Architectures



Heterogeneity is a major source of complexity in such systems.

Two Approaches to the Design of Such Systems

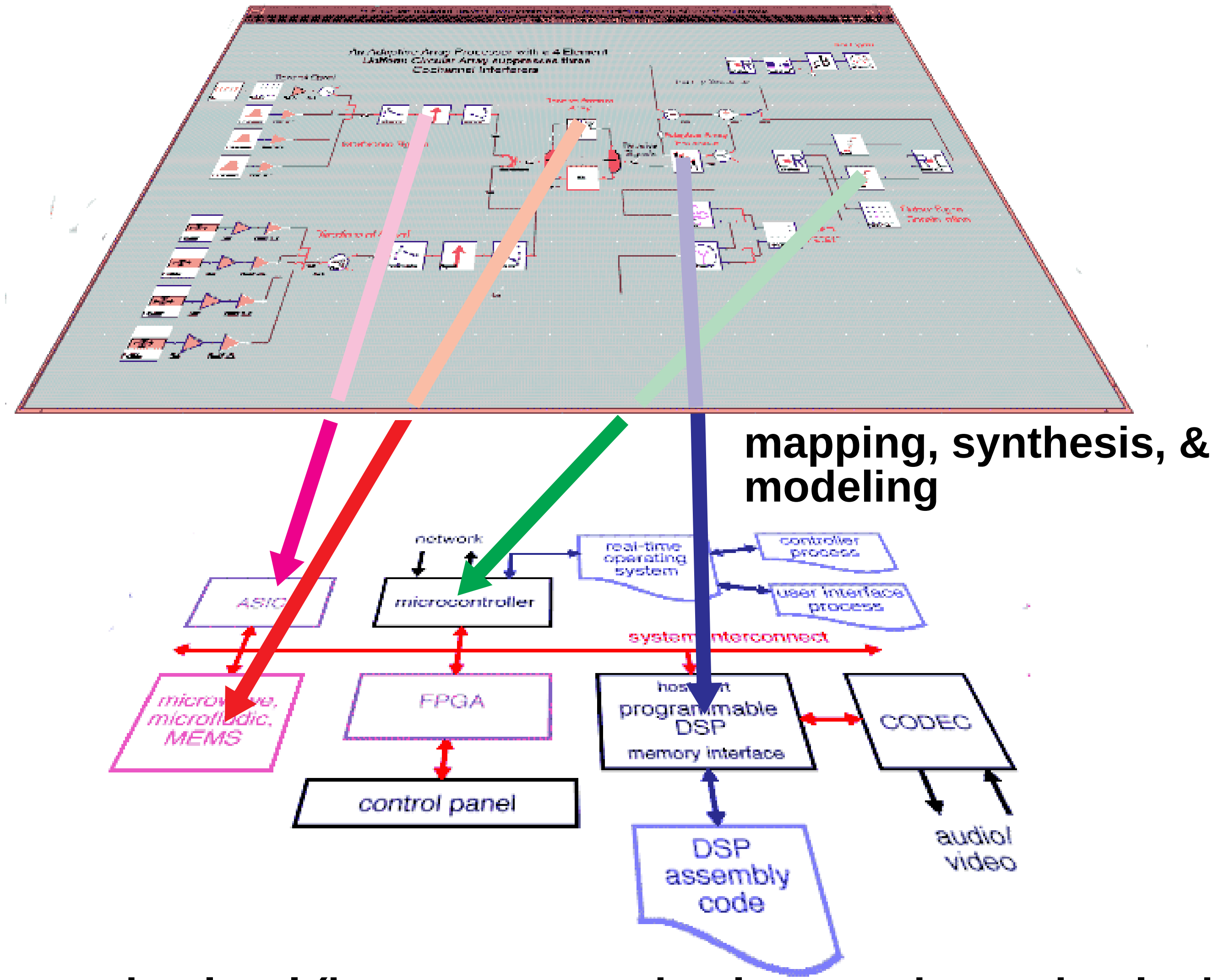
- **The grand-unified approach**
  - **Find a common representation language for all components**
  - **Develop techniques to synthesize diverse implementations from this**
- **The heterogeneous approach**
  - **Find domain-specific *models of computation* (MoC)**
  - **Hierarchically mix and match MoCs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

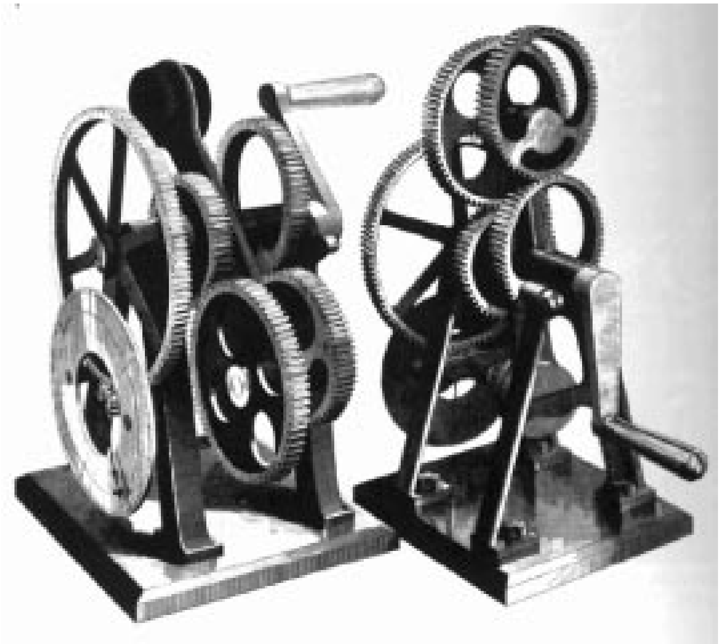
Heterogeneous System-Level Specification & Modeling

problem level (heterogeneous models of computation)



implementation level (heterogeneous implementation technologies)

Some Problem-Level Models of Computation



- Gears
- Differential equations
- Difference equations
- Discrete-events
- Petri nets
- Dataflow
- Process networks
- Actors
- Threads
- Synchronous/reactive languages
- Communicating sequential processes
- Hierarchical communicating finite state machines

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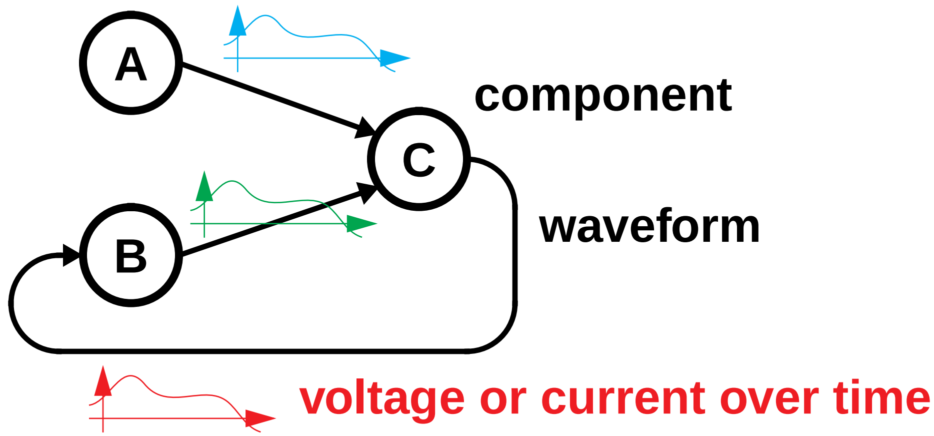
Example — Analog Circuit Modeling



Strengths:

- Accurate model for many physical systems
- Declarative
- Determinate

Weaknesses:

- Tightly bound to an implementation
- Expensive to simulate
- Difficult to implement in software

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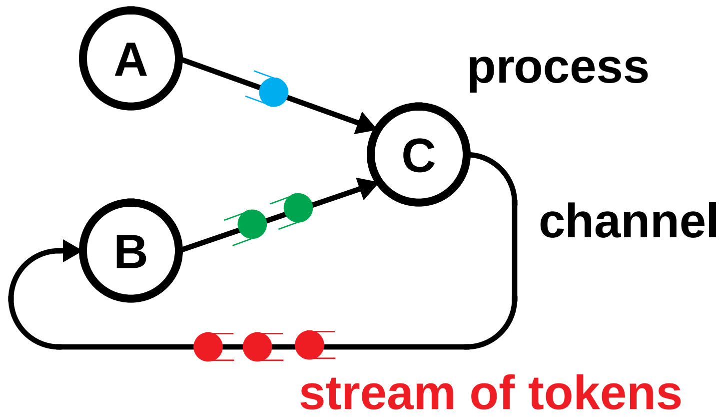
Example — Process Networks

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

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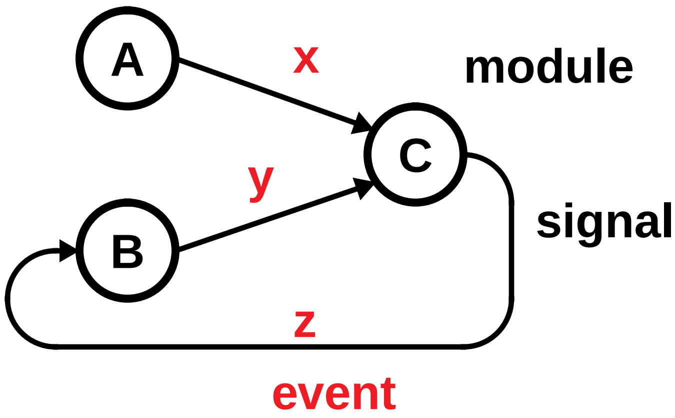
Example — Synchronous/Reactive Models



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

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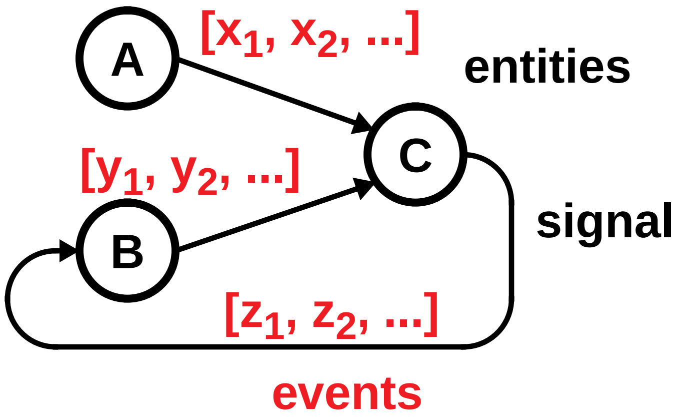
Example — Discrete-Event Models



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

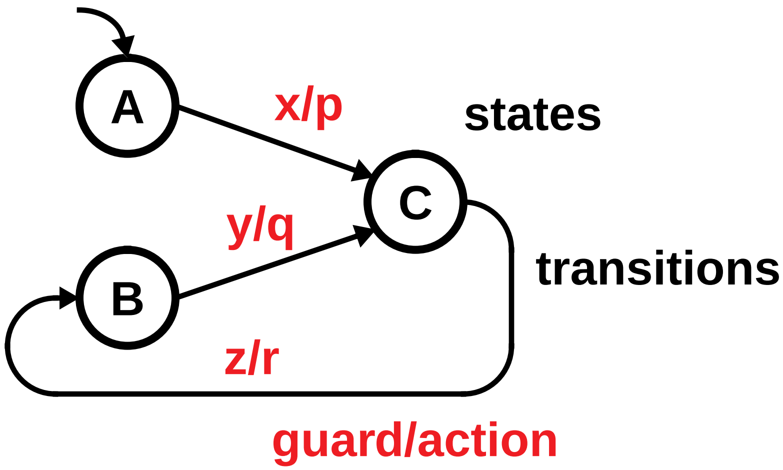
Strengths:

- Natural description of digital 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

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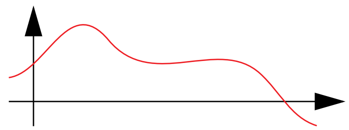
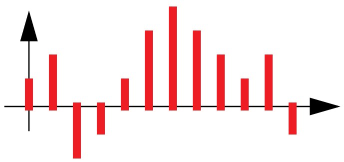
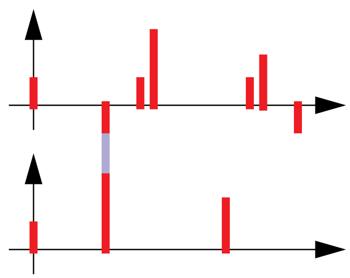
Essential Differences — Models of Time



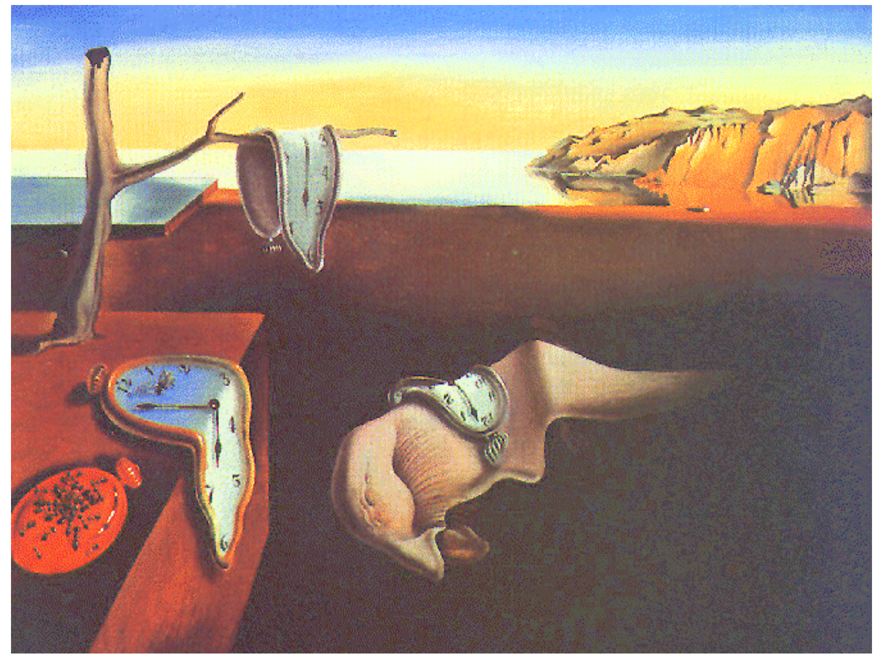
continuous time



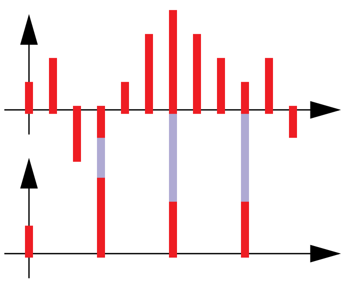
discrete time



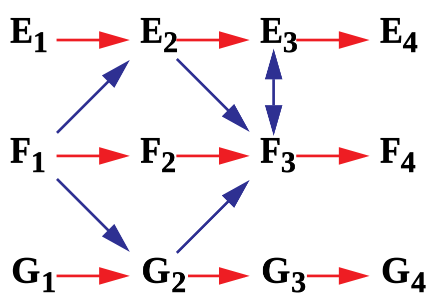
totally-ordered discrete events



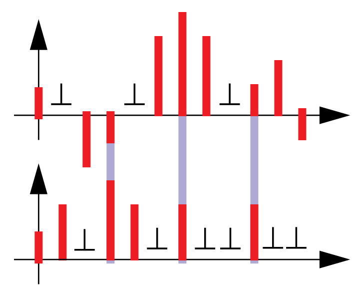
Salvador Dali, ***The Persistence of Memory***, 1931



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.**
- **Composing multiple models of computation.**

History of the Ptolemy Project

- **1990 — started with seed support from DARPA VLSI program. Focus on embedded DSP software and communication networks.**
- **1993 — joined DARPA RASSP program. Focus on high-throughput embedded real-time signal processing systems.**
- **1995 — The Alta Group at Cadence announces software using Ptolemy dataflow and mixed dataflow/discrete-event technology (SPW).**
- **1997 — joined DARPA Composite CAD program. Focus on distributed adaptive reactive systems with mixed implementation technologies and modeling techniques.**
- **1997 — Hewlett-Packard (EEsof) announces "HP Ptolemy," an integration of Ptolemy dataflow technology with analog RF and microwave design and modeling tools.**

Our Contributions to Dataflow Modeling

— the most mature parts of Ptolemy —

- **Compile-time scheduling of *synchronous dataflow* graphs with optimized partitioning and memory utilization.**
- **Specification of the *Boolean dataflow (BDF) model*, which is Turing complete.**
- **Proof that the existence of a finite complete cycle and a bounded memory implementation for BDF is *undecidable*.**
- ***Heuristics* for constructing finite complete cycles and bounded memory schedules most of the time.**
- ***Multidimensional* generalization to dataflow models.**
- ***Process network* model generalization to dataflow.**
- ***Visual programming* formulation and use of *higher-order functions*.**

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Composite CAD Project

Phase 1 (11/96 — 5/98)

- **Modular deployable design tools**
- **Domain-specific tools emphasizing control and signal proc.**
- **Models for dynamically configured systems**

Phase 2 (6/98 — 11/99)

- **Process-level types for managing heterogeneity**
- **Formal analysis and computer-aided debugging**
- **System-level visualization with heterogeneous syntaxes**

Option (4/97 — 12/97)

- **Array formalism for multidimensional signal processing**

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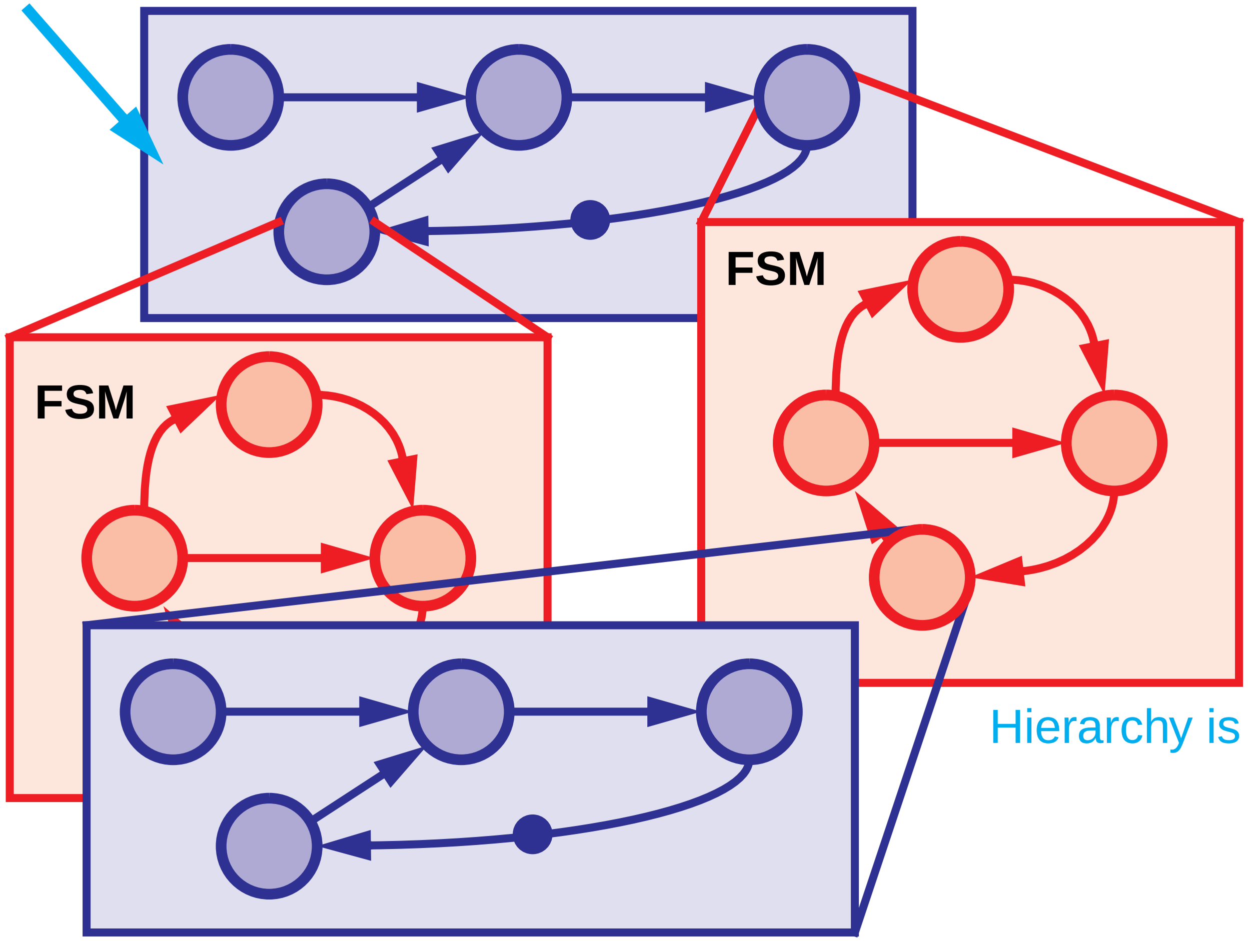
Progress: Generalized Hybrid Systems — *Charts

Choice of domain here determines concurrent semantics



Hierarchy is free

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Near Term Software Strategy

— Java plus Itcl —

- Object-oriented.
- Systems programming plus scripting.
- Network-aware design tools.
- Deployable tool packages.
- Sophisticated heterogeneous visualization.

Ptolemy Software as a Tool and as a Laboratory

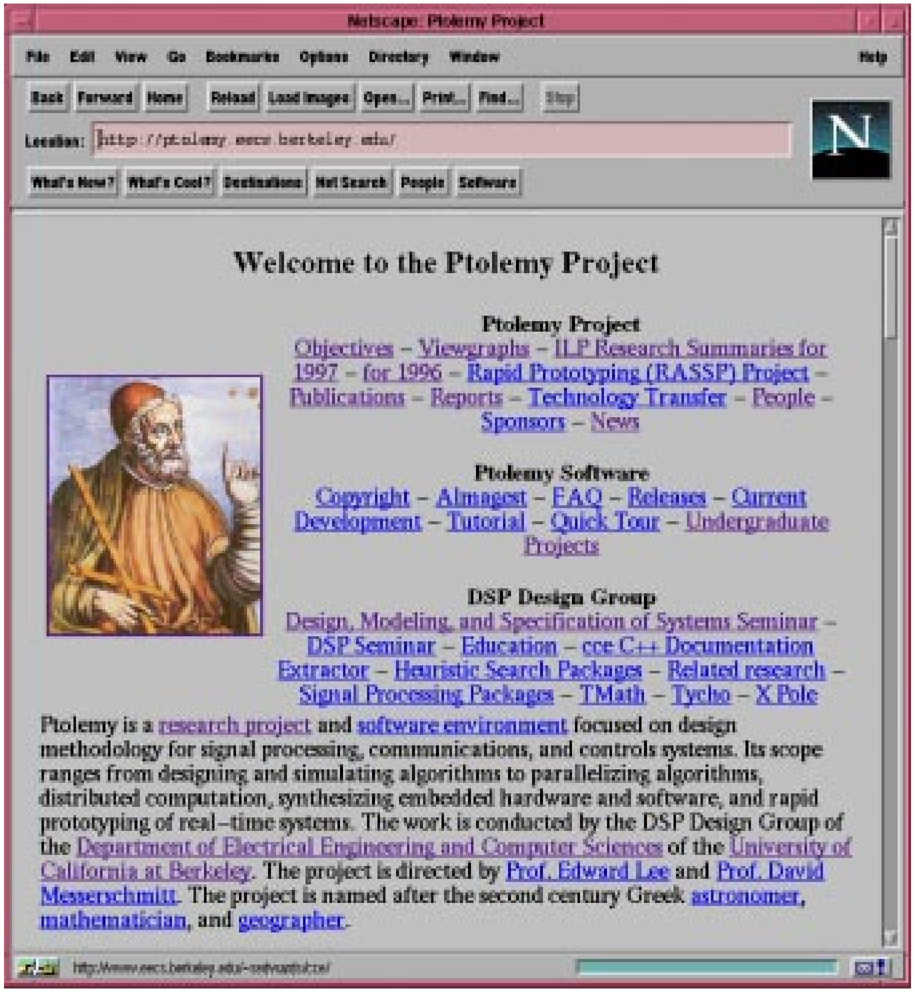
Ptolemy software is

- 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)

Further Information



- Software distributions
- Small demonstration versions
- Project overview
- *The Almagest* (software 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