# Advanced Tool Architectures

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Chess Review
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VANDERBILT UNIVERSITY
INSTITUTE FOR SOFTWARE INTEGRATED SYSTEMS

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## Tool Projects

- Concurrent model-based design
  - Giotto (Henzinger)
  - E machine & S machine (Henzinger)
  - NP-Click (Keutzer)
  - Streambit (Bodik)
  - Metropolis (Sangiovanni-Vincentelli)
  - Ptolemy II (Lee)
- Meta modeling
  - GME (Sztipanovits, *Vanderbilt*)
  - GREAT=Language,Engine,C/G,Debugger (Karsai, *Vanderbilt*)
  - MOF-based Metamodeling (Sztipanovits, *Vanderbilt*)
- Verification
  - Blast (Henzinger)
  - CCured (Necula)
  - Chic (Henzinger)
  - SMoLES (Karsai, *Vanderbilt*)

investigator in charge

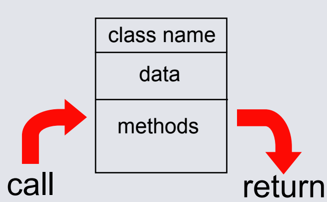
## Emphasis of Each Tool

| | Tool | Emphasis |
|---|---|---|
| Concurrent model-based design | Giotto | A particular concurrent, timed model of computation (MoC) |
| | E/S machines | O/S neutral run-time virtual machine |
| | NP-Click | Programming model for network processors |
| | Streambit | Domain-specific language for bit stream processing |
| | Metropolis | Design refinement and mapping. |
| | Ptolemy II | MoCs and visualization of design. |
| Meta modeling | UML-OCL/GME | Modeling the modeling languages using UML class diagrams and OCL |
| | GReAT/GME, GRE,C/G | Modeling Model transformations using the GReAT Language, Transformation engine, Code Generator, Debugger |
| | MOF/GME | Metamodeling using the Meta-Object Facility |
| Verification | Blast | Model checking C programs. |
| | CCured | Making C programs more reliable. |
| | SMOLES | Simple Modeling Language for Embedded Systems with Timing Analysis (using Timed Automata) |
| | Chic | Checking interface compatibility in component compositions. |



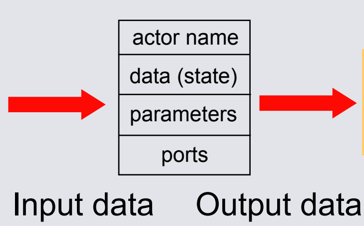
## A Common Approach in Many of These: *Actor-Oriented Design*

Object orientation:




What flows through an object is sequential control

Actor orientation:



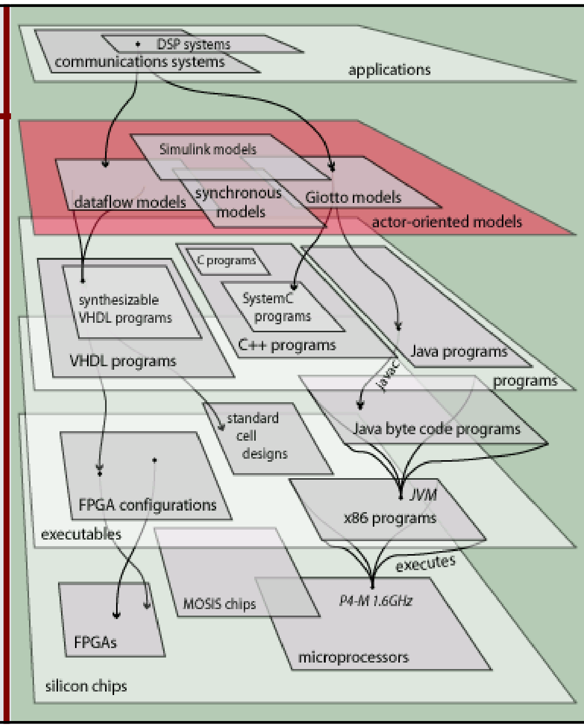

What flows through an object is streams of data

A key theme is to identify the fundamentals of actor-oriented design and to show how to leverage a solid actor-oriented foundation to create domain-specific modeling languages (DSMLs)

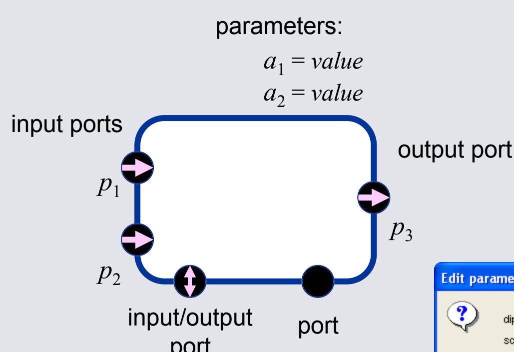
# Actor-Oriented Platforms

*Actor oriented* models compose concurrent components according to a model of computation.

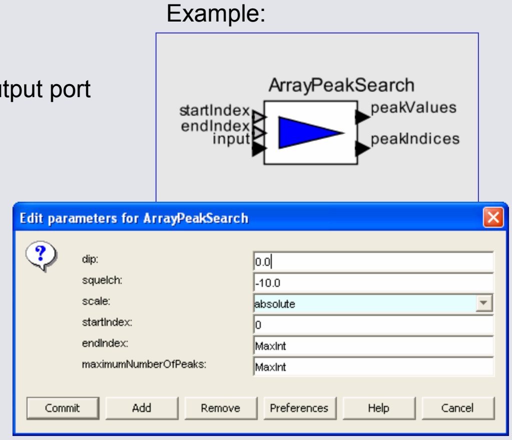
Time and concurrency become key parts of the programming model.




# Actor Interfaces: Ports and Parameters




Example:



## Our Actor-Oriented Domain-Specific Modeling Languages: DSMLs

- Giotto
  - time-triggered
  - hard-real-time periodic tasks
  - deterministic mode switching
- NP-Click
  - push/pull semantics
  - combines application modeling language with target architecture abstraction
  - targeted towards network processors
- HyVisual
  - continuous-time semantics with mode changes
  - intended for hybrid systems modeling
- GME-generated languages (Vanderbilt)
  - meta modeling
  - synthesis of domain-specific visual languages

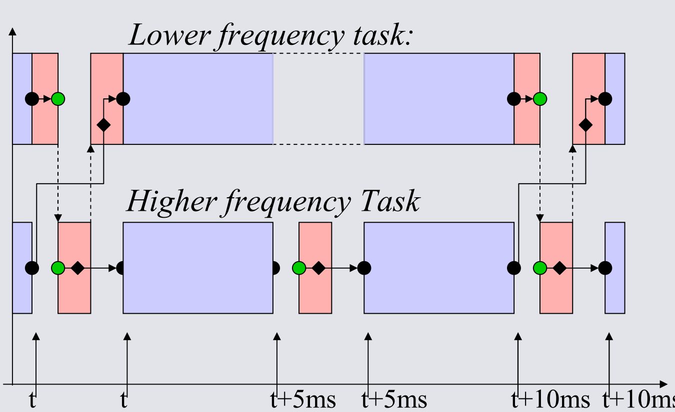


## Giotto and xGiotto: Time-Driven Languages

Giotto – Periodic hard-real-time tasks with precise mode changes.

xGiotto – Extended to support event triggering

*Deterministic task interaction.*



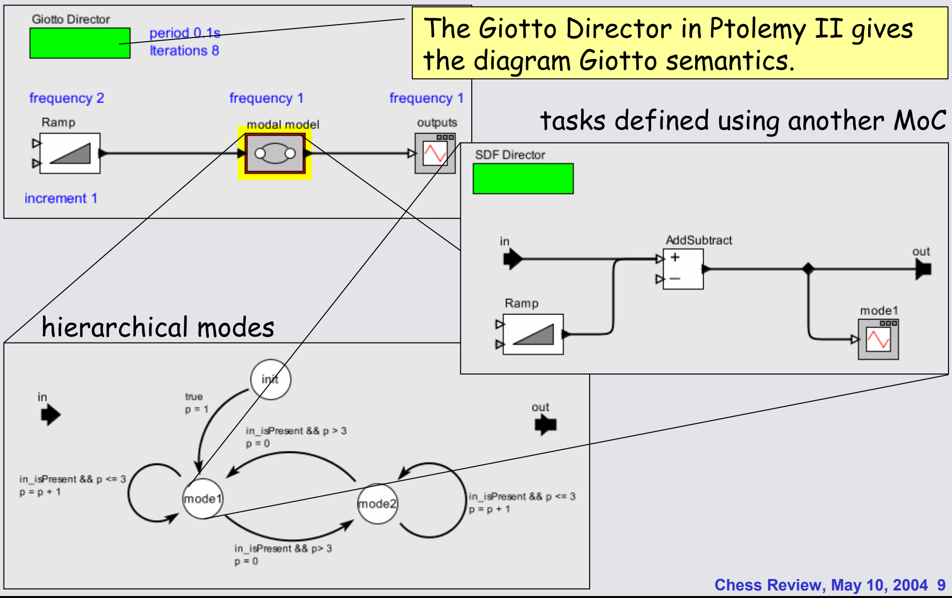

- Giotto compiler targets the E Machine/S Machine
- Giotto model of computation also implemented in Ptolemy II

## Giotto with a Visual Syntax

The Giotto Director in Ptolemy II gives the diagram Giotto semantics.

tasks defined using another MoC

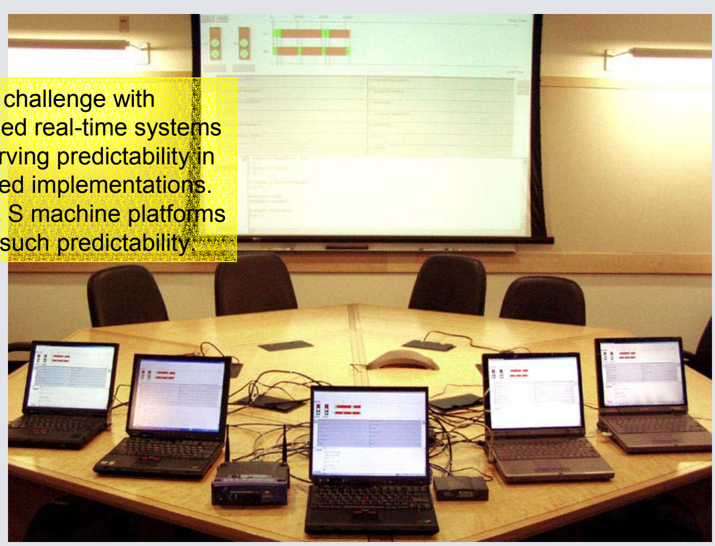
hierarchical modes





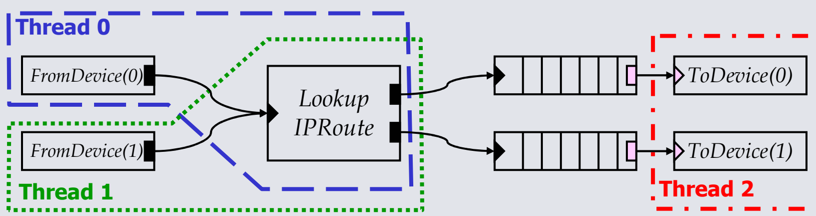

## Distributed E and S Machines

A major challenge with embedded real-time systems is preserving predictability in distributed implementations. The E & S machine platforms provide such predictability.



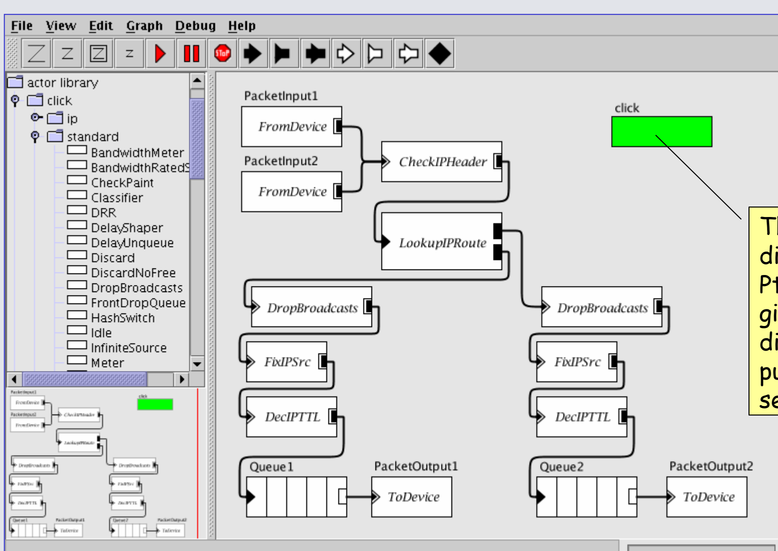
# NP-Click: A Programming Model for Network Processors

- Concurrent composition of elements for packet processing
- Elements communicate via ports that pass packets
  - push: initiated by source element
  - pull: initiated by sink element
- Salient features of target architecture
  - threads
  - data layout
  - arbitration of shared resources






# Click Router Application




The Click director in Ptolemy II gives the diagram push/pull semantics.

## StreamBit: Sketching bitstream programs

- What is StreamBit?
  - language for developing bit-stream programs (e.g., crypto)
  - but mainly, a case study in *programming by sketching*
- What is programming by sketching?
  - separate Specification and Implementation
  - Specification (correctness): an SDF-based DSL
  - Implementation (performance): implementation strategy is only sketched; the compiler will derive the missing details
- What does this mean for the programmer?
  - First, program without concern for performance
  - Next, experiment with implementations w/out introducing bugs
- Sketching used to implement DES:
  - a brief sketch achieved 600% performance increase over naïve implementation (within ¾ of a hand-tuned library)



## Frameworks

- Metropolis
  - Unified model of computation (MoC)
  - Formal semantics given w.r.t. this MoC
  - Emphasis on joint modeling of hardware architecture and application
  - Modeling of design constraints and assertions
- Ptolemy II
  - Framework for experimentation with MoCs
  - Many MoCs have been implemented
    - discrete-event, continuous-time, dataflow, push/pull, process networks, CSP, FSMs, …
  - Emphasis on heterogeneous mixing of domain-specific MoCs.

# Metropolis Framework

Function Specification

Design Constraints and Assertions

Architecture (Platform) Specification

## Metropolis Infrastructure

- Design methodology
- Meta model of computation
- Base tools
  - Design imports
  - Meta-model compiler
  - Simulation

Joint modeling of function, constraints, and implementation platform.

## Synthesis/Refinement

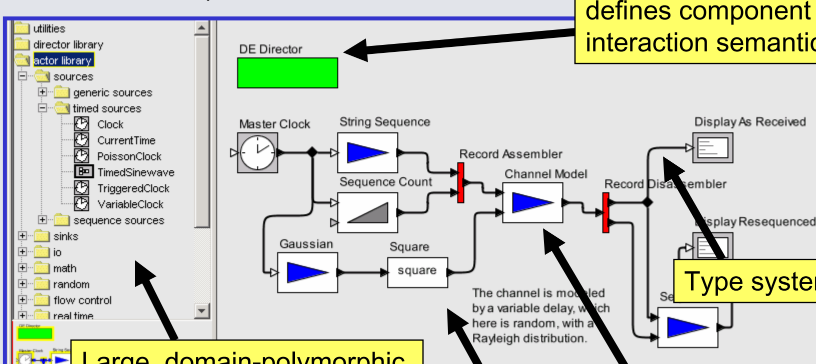
- Compile-time scheduling of concurrency
- Communication-driven hardware synthesis
- Protocol interface generation

## Analysis/Verification

- Static timing analysis of reactive systems
- Invariant analysis of sequential programs
- Refinement verification
- Formal verification of embedded software

# Ptolemy II Framework

Basic Ptolemy II infrastructure:




Director from a library defines component interaction semantics

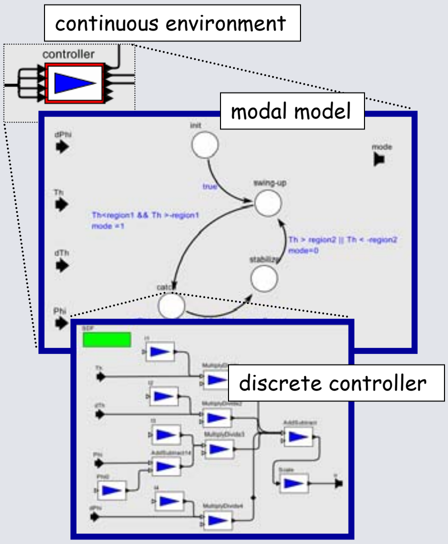
Type system

Large, domain-polymorphic component library.

Hierarchical components

Visual editor

## Hierarchical Heterogeneity



example Ptolemy II model: hybrid control system

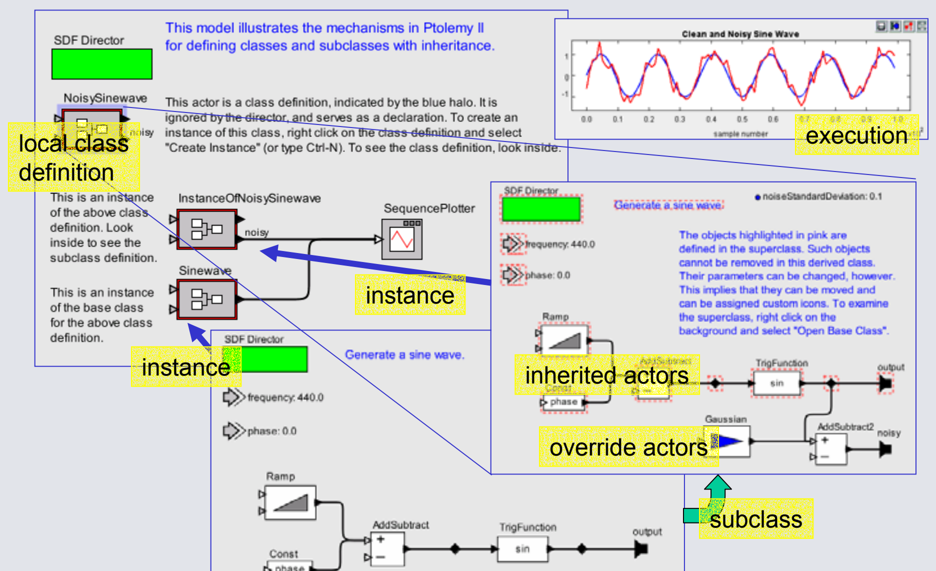
Hierarchy allows distinct models of computation at distinct levels of the hierarchy. An "abstract semantics" defines the interaction across levels of hierarchy where the semantics differ.



## Actor-Oriented Classes

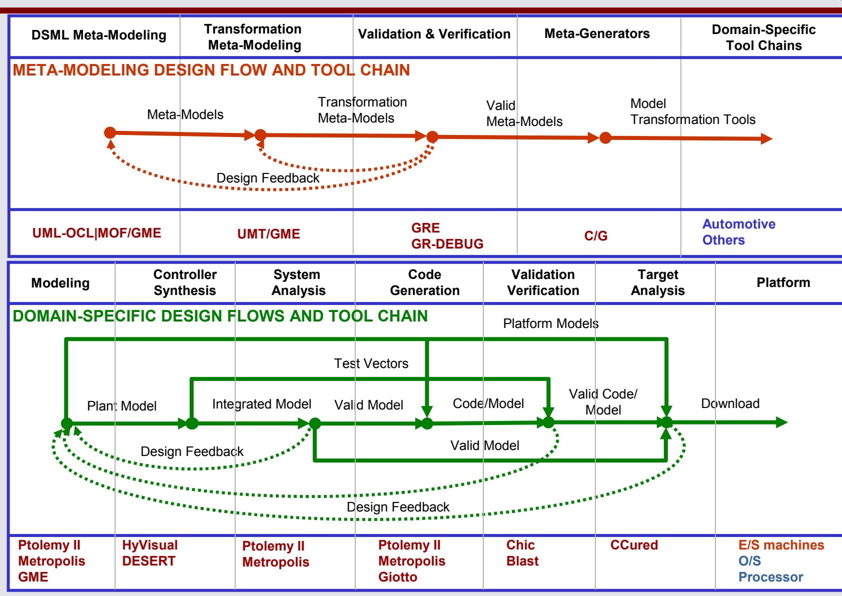
- Objective is to bring modern modularity mechanisms to actor-oriented design:
  - classes
  - subclasses
  - inheritance
  - interfaces
  - subtypes
  - aspects
- Early, highly experimental prototype in Ptolemy II includes:
  - classes, inheritance, inner classes
  - interactive editing of class relationships

# Example Using Actor-Oriented Classes

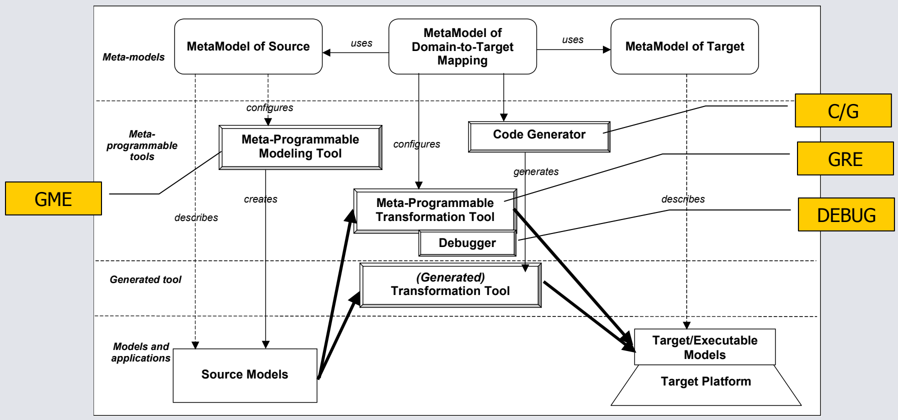





# Meta Modeling
# Specifying and Integrating Tool Chains



## GReAT: Model Transformation Tool Chain




Tools: UMT Language, GRE (engine), C/G, GR-DEBUG

http://www.isis.vanderbilt.edu



## Verification

- Blast
  - Scalable verification through lazy refinement of the state space.
- CCured
  - Static analysis of C programs for type safety.
  - Where static analysis fails, run-time checks are added automatically.
- Chic
  - Expresses assumptions made by module about environment, and guarantees made by module if assumptions are satisfied.
  - Checks compatibility of interfaces of composed components.

Both based on **CIL** (C Intemediate Language), a representation of C code along with a set of tools that permit easy analysis and source-to-source transformation.

## Many In-Depth Talks have a Tools Element

10:10-11:10 a.m.

Event-driven Real-Time Programming
(Arkadeb Ghosal and Tom Henzinger)

A Comparison of Network Processor Programming Environments
(William Plishker and Kurt Keutzer)

Classes and Inheritance in Actor-Oriented Models
(Stephen Neuendorffer and Edward A. Lee)

2:00-3:00 p.m.

Metropolis, an Environment for System-level Design
(Abhijit Davare and Alberto Sangiovanni-Vincentelli)

StreamBit: Sketching Implementations for Bitstream Programs
(Armando Solar-Lezama and Ras Bodik)

Verifying Data Structure Invariants in Device Drivers
(Scott McPeak and George Necula)



## Many Posters have a Tools Element

Wireless Sensor Network Design Methodology

galsC: A Language for Event-Driven Embedded Systems

Metamodeling Infrastructure for Model-Integrated Computing

Distributed Diagnosis Algorithm

Multiple Aspect Modeling Front-End for SIGNAL

Online supervisory control

Platform-based Design for Mixed Analog-Digital Designs

Distributing Giotto

Hierarchical Reconfiguration of Dataflow Models

Fault Tolerant Design of Distributed Automotive Systems

Modeling of Sensor Nets in Ptolemy II