Concurrent Models of Computation for Embedded Software

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Lecture 5: Extending Ptolemy II

Background for Ptolemy II

Gabriel (1986-1991)
- Written in Lisp
- Aimed at signal processing
- Synchronous dataflow (SDF) block diagrams
- Parallel schedulers
- Code generators for DSPs
- Hardware/software co-simulators

Ptolemy Classic (1990-1997)
- Written in C++
- Multiple models of computation
- Hierarchical heterogeneity
- Dataflow variants: BDF, DDF, PN
- C/VHDL/DSP code generators
- Optimizing SDF schedulers
- Higher-order components

Ptolemy II (1996-2022)
- Written in Java
- Domain polymorphism
- Multithreaded
- Network integrated
- Modal models
- Sophisticated type system
- CT, HDF, CI, GR, etc.

Each of these served us, first-and-foremost, as a laboratory for investigating design.

PtPlot (1997-??)
- Java plotting package

Tycho (1996-1998)
- Itcl/Tk GUI framework

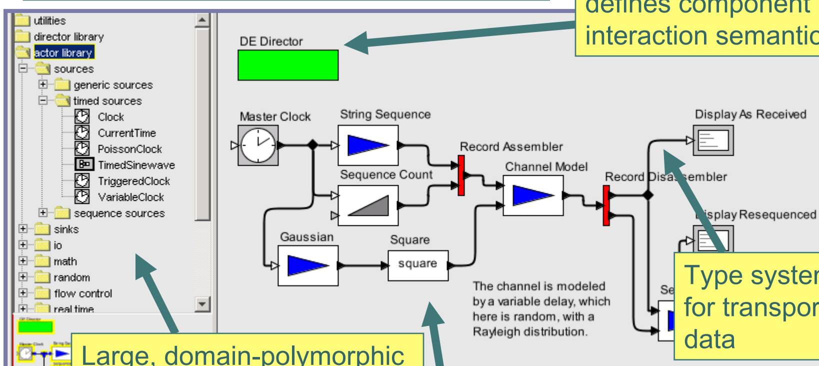
Diva (1998-2000)
- Java GUI framework

All open source.
All truly free software (cf. FSF).

Framework Infrastructure that Supports Diverse Experiments with Models of Computation

Concurrency management supporting dynamic model structure.

Director from a library defines component interaction semantics

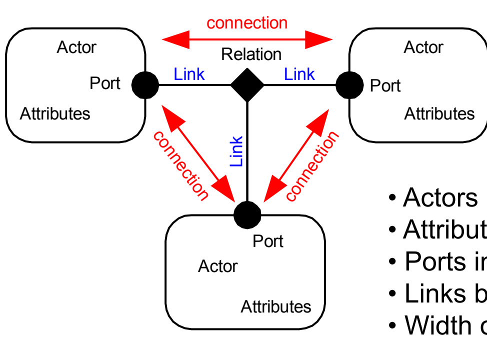


Type system for transported data

Large, domain-polymorphic component library.

Visual editor supporting an abstract syntax

The Basic Abstract Syntax



- Actors
- Attributes on actors (parameters)
- Ports in actors
- Links between ports
- Width on links (channels)
- Hierarchy

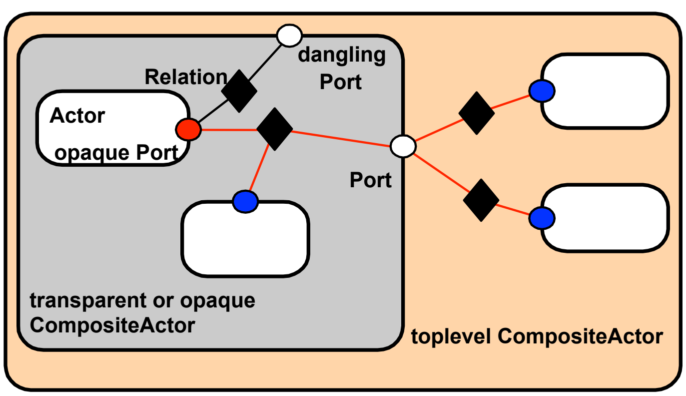
Concrete syntaxes:
- XML
- Visual pictures
- Actor languages (Cal, StreamIT, …)

MoML
XML Schema for this Abstract Syntax

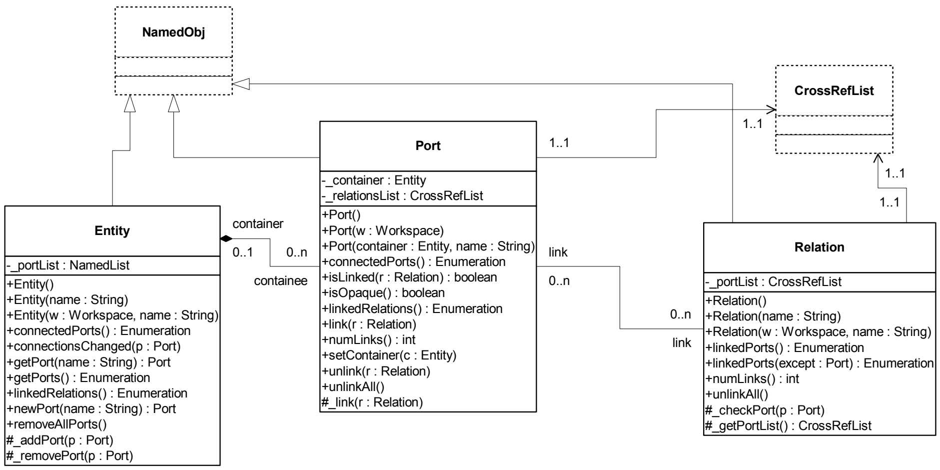
Ptolemy II designs are represented in XML:

```
...
<entity name="FFT" class="ptolemy.domains.sdf.lib.FFT">
    <property name="order" class="ptolemy.data.expr.Parameter" value="order">
    </property>
    <port name="input" class="ptolemy.domains.sdf.kernel.SDFIOPort">
       ...
    </port>
    ...
</entity>
...
<link port="FFT.input" relation="relation"/>
<link port="AbsoluteValue2.output" relation="relation"/>
...
```


Hierarchy - Composite Components



Kernel Classes
Support the Abstract Syntax



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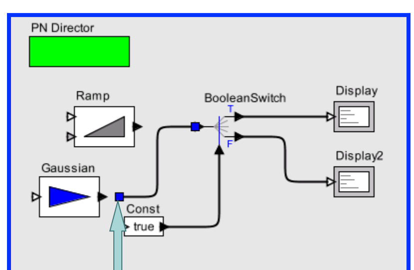
Concurrency Management Supporting Dynamic Model Structure

Changes to a model while the model is executing:

- Change parameter values
- Change model structure

How can this be made safe?

- Workspace class
- ChangeRequest class
- stopFire() method



Can dynamically modify the model while it executes… safely.

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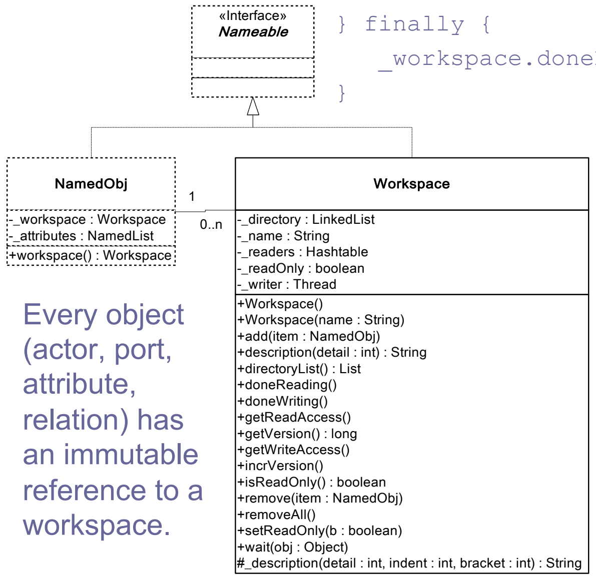
Workspace

```
try {
   _workspace.getReadAccess();
   … actions depending on model structure
} finally {
   _workspace.doneReading();
}
```



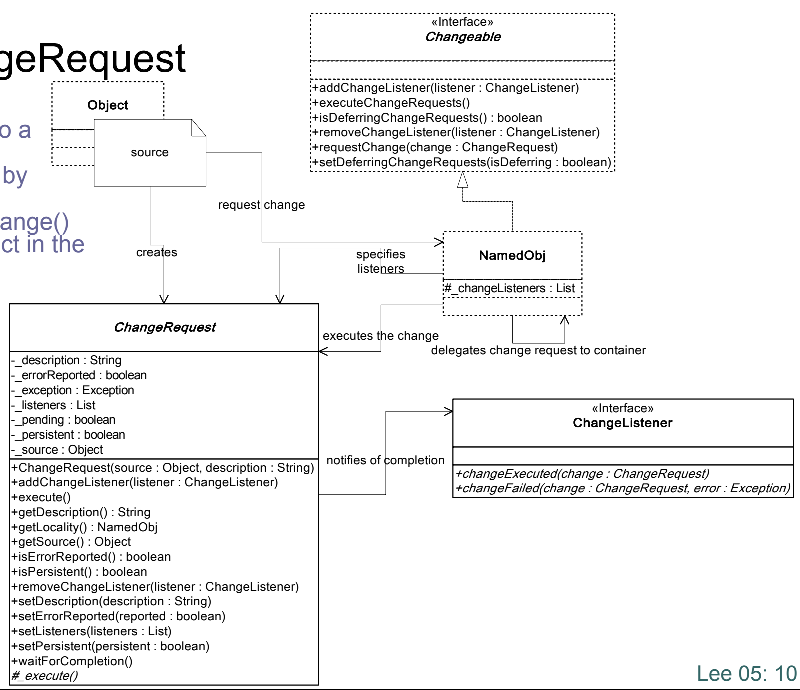
Every object (actor, port, attribute, relation) has an immutable reference to a workspace.

Many threads can have read access at the same time. Only one thread can have write access, and only if no other thread has read access.

Specialized wait(Object) method releases the locks during the wait().

ChangeRequest

Changes to a model are requested by calling requestChange() on an object in the model.



When to Execute Change Requests

In many models of computation, there is a natural time: between iterations.

In PN, this is not a trivial question…

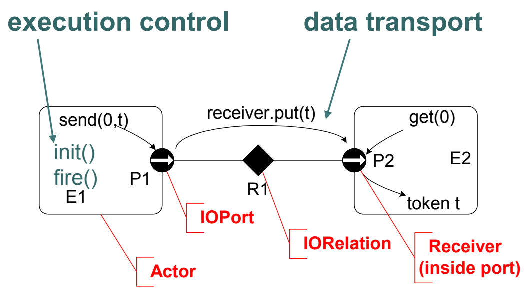
- All threads must be stopped (blocked)
  - On reads
  - On writes to full buffers
  - Or block themselves with a wait()
- What happens when the model structure changes during a call to get()?

ProcessThread with Pauses for Mutations

```
while(iterate) {
    if (_director.isStopFireRequested()) {
        synchronized (_director) {
            _director._actorHasStopped();
                while (_director.isStopFireRequested()) {
                    try {
                        workspace.wait(_director);
                    } catch (InterruptedException ex) {
                        break;
                    }
                }
                _director._actorHasRestarted();
            }
        }
    }
    boolean iterate = true;
    while (iterate) {
        if (_actor.prefire()) {
            _actor.fire();
            iterate = _actor.postfire();
        }
    }
```

Specialized wait() method releases workspace locks while the thread is suspended.

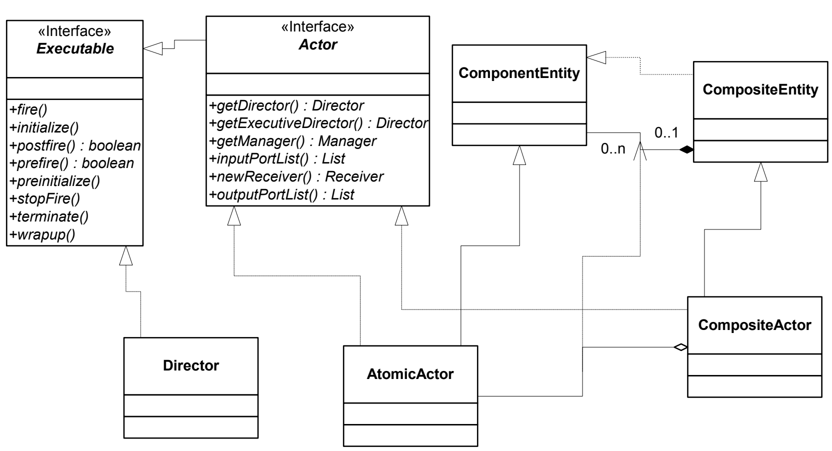
Abstract Semantics
of *Actor-Oriented* Models of Computation



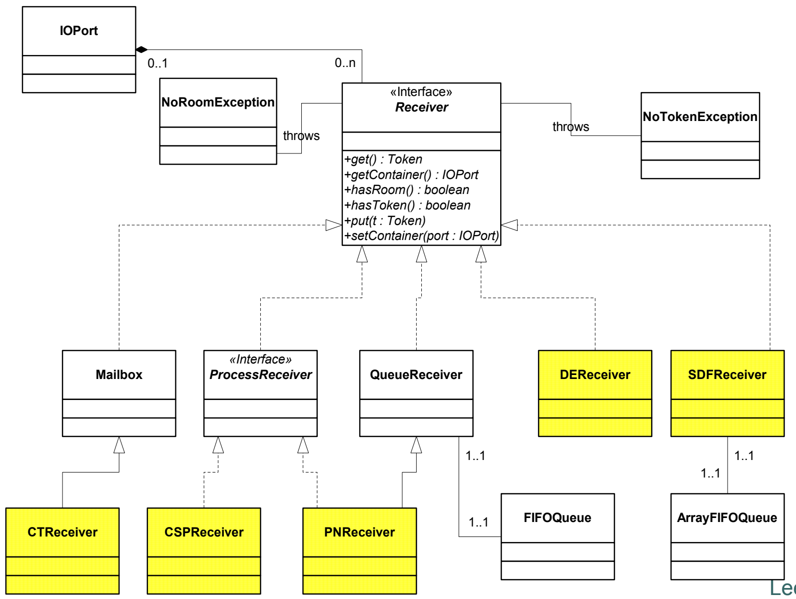
Actor-Oriented Models of Computation that we have implemented:

- dataflow (several variants)
- process networks
- distributed process networks
- Click (push/pull)
- continuous-time
- CSP (rendezvous)
- discrete events
- distributed discrete events
- synchronous/reactive
- time-driven (several variants)
- …

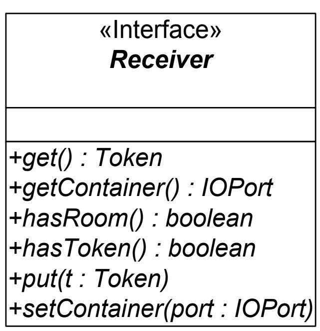
Object Model for Executable Components



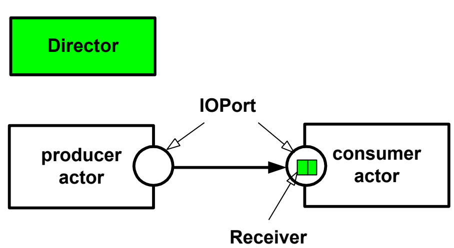
Object Model (Simplified) for Communication Infrastructure



Object-Oriented Approach to Achieving Behavioral Polymorphism



These polymorphic methods implement the communication semantics of a domain in Ptolemy II. The receiver instance used in communication is supplied by the director, not by the component.



Recall: Behavioral polymorphism is the idea that components can be defined to operate with multiple models of computation and multiple middleware frameworks.

Extension Exercise

Build a director that subclasses PNDirector to allow ports to alter the "blocking read" behavior. In particular, if a port has a parameter named "tellTheTruth" then the receivers that your director creates should "tell the truth" when hasToken() is called. That is, instead of always returning true, they should return true only if there is a token in the receiver.

Parameterizing the behavior of a receiver is a simple form of communication refinement, a key principle in, for example, Metropolis.

Implementation of the New Model of Computation

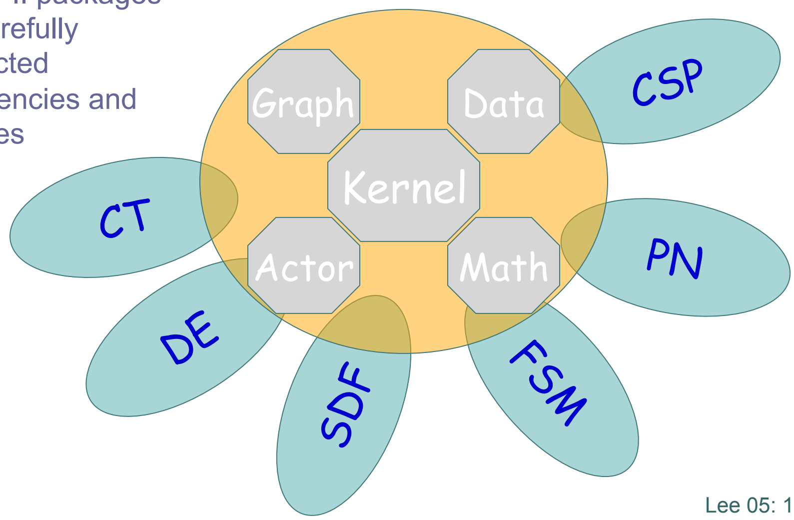
```
package experiment;

import …

public class NondogmaticPNDirector extends PNDirector {
    public NondogmaticPNDirector(CompositeEntity container, String name)
           throws IllegalActionException, NameDuplicationException {
       super(container, name);
    }
    public Receiver newReceiver() {
        return new FlexibleReceiver();
    }
    public class FlexibleReceiver extends PNQueueReceiver {
        public boolean hasToken() {
            IOPort port = getContainer();
            Attribute attribute = port.getAttribute("tellTheTruth");
            if (attribute == null) {
                 return super.hasToken();
            }
            // Tell the truth...
            return _queue.size() > 0;
        }
    }
}
```

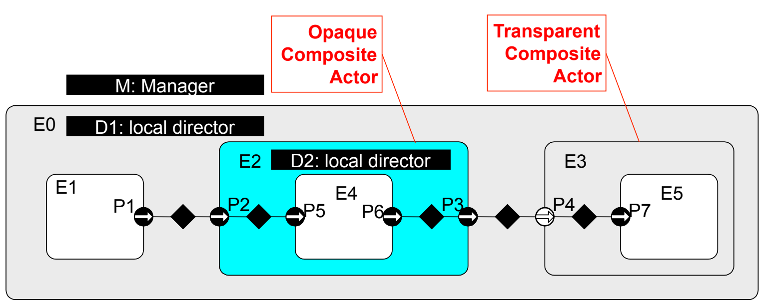
Ptolemy II Software Architecture Built for Extensibility

Ptolemy II packages have carefully constructed dependencies and interfaces

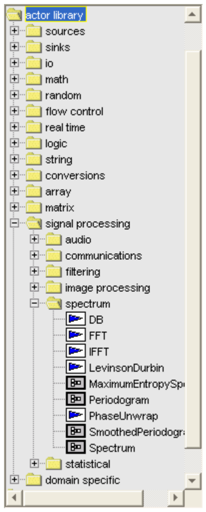


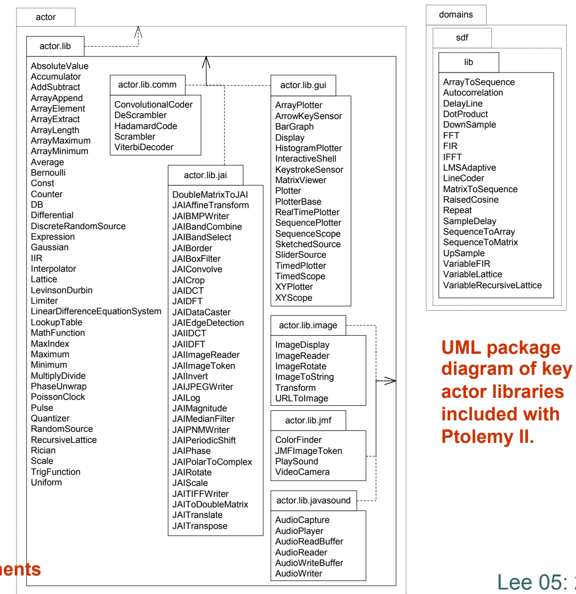
Hierarchical Heterogeneity

Directors are domain-specific. A composite actor with a director becomes opaque. The Manager is domain-independent.



Ptolemy II Component Library

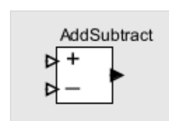




UML package diagram of key actor libraries included with Ptolemy II.

- **Data polymorphic components**
- **Behaviorally polymorphic components**

Polymorphic Components - Component Library Works Across Data Types and Domains

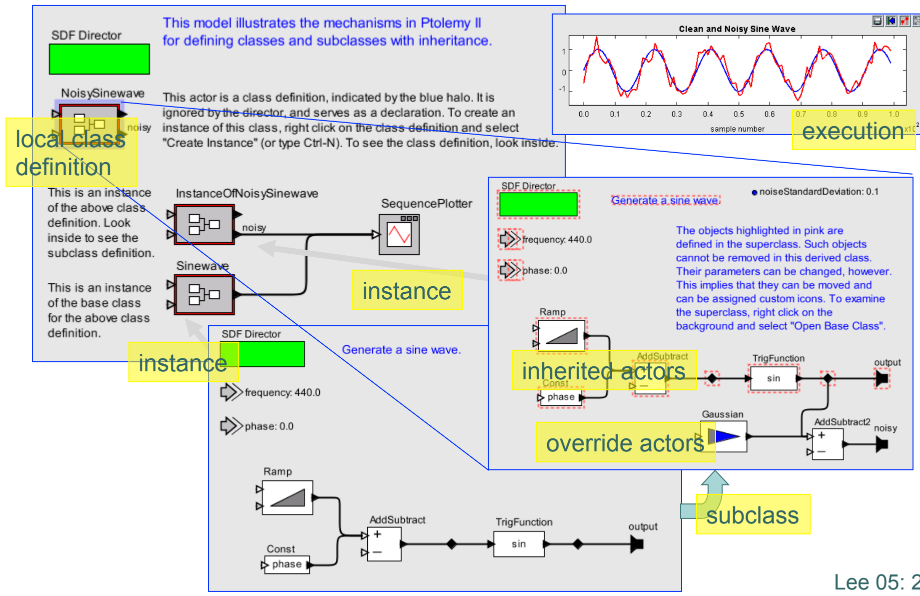


Data polymorphism:
- Add numbers (int, float, double, Complex)
- Add strings (concatenation)
- Add composite types (arrays, records, matrices)
- Add user-defined types

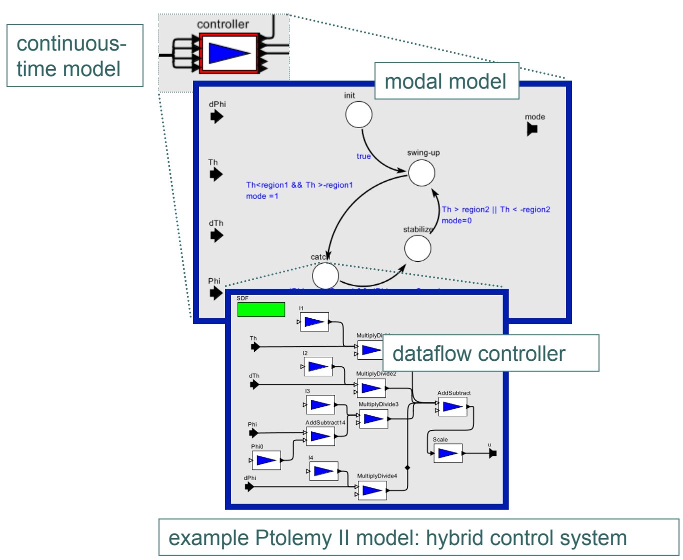
Behavioral polymorphism:
- In dataflow, add when all connected inputs have data
- In a time-triggered model, add when the clock ticks
- In discrete-event, add when any connected input has data, and add in zero time
- In process networks, execute an infinite loop in a thread that blocks when reading empty inputs
- In CSP, execute an infinite loop that performs rendezvous on input or output
- In push/pull, ports are push or pull (declared or inferred) and behave accordingly
- In real-time CORBA, priorities are associated with ports and a dispatcher determines when to add

By not choosing among these when defining the component, we get a huge increment in component re-usability. But how do we ensure that the component will work in all these circumstances?

Shared Infrastructure Modularity Mechanisms



More Shared Infrastructure: Hierarchical Heterogeneity and Modal Models



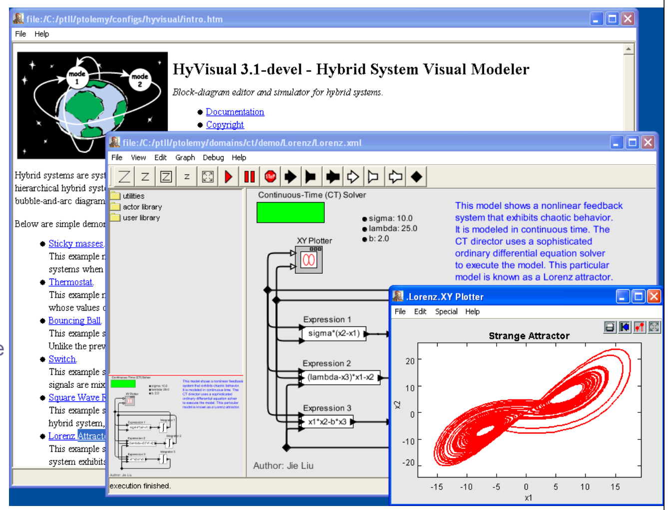
Branding

Ptolemy II *configurations* are Ptolemy II models that specify

- welcome window
- help menu contents
- library contents
- File->New menu contents
- default model structure
- etc.

A configuration can identify its own “brand” independent of the “Ptolemy II” name and can have more targeted objectives.

An example is HyVisual, a tool for hybrid system modeling. VisualSense is another tool for wireless sensor network modeling.

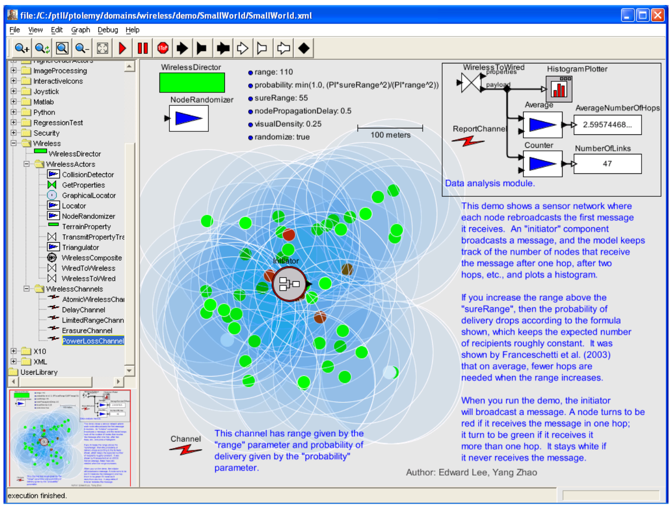


Ptolemy II Extension Points

- Define actors
- Interface to foreign tools (e.g. Python, MATLAB)
- Interface to verification tools (e.g. Chic)
- Define actor definition languages
- Define directors (and models of computation)
- Define visual editors
- Define textual syntaxes and editors
- Packaged, branded configurations

All of our “domains” are extensions built on a core infrastructure.

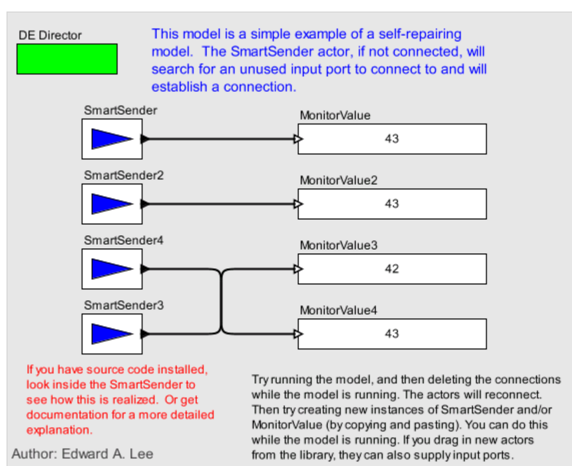
Example Extension: VisualSense



- Branded
- Customized visualization
- Customized model of computation (an extension of DE)
- Customized actor library
- Motivated some extensions to the core (e.g. classes, icon editor).

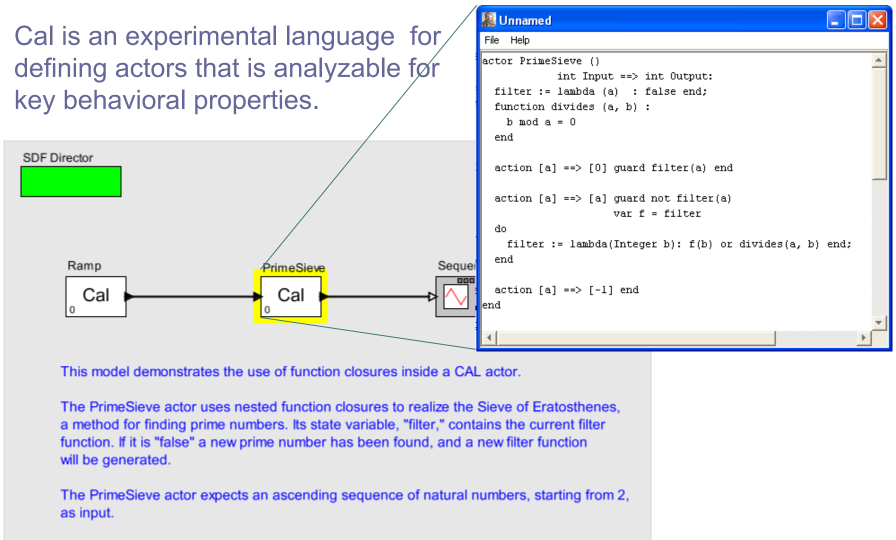
Example Extensions: Self-Repairing Models

Concept demonstration built together with Boeing to show how to write actors that adaptively reconstruct connections when the model structure changes.

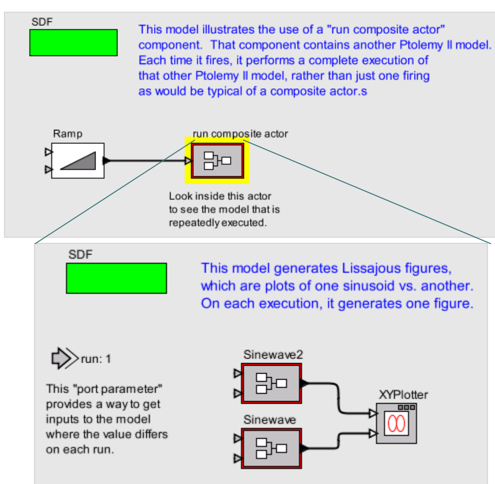


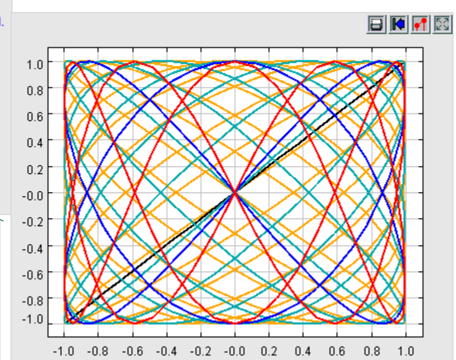
Example Extensions
Python Actors and Cal Actors

Cal is an experimental language for defining actors that is analyzable for key behavioral properties.



Example Extensions
Using Models to Control Models

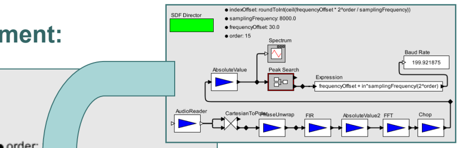


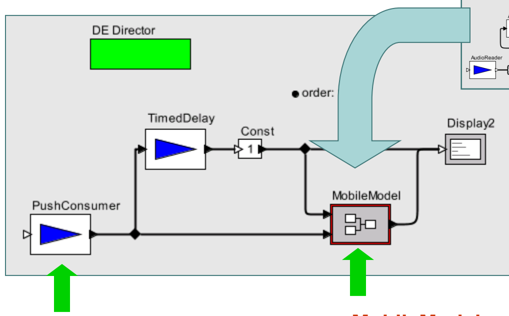


This is an example of a "higher-order component," or an actor that references one or more other actors.

Examples of Extensions
Mobile Models

Model-based distributed task management:





Authors:
Yang Zhao
Steve Neuendorffer
Xiaojun Liu

PushConsumer actor receives pushed data provided via CORBA, where the data is an XML model of a signal analysis algorithm.

MobileModel actor accepts a StringToken containing an XML description of a model. It then executes that model on a stream of input data.

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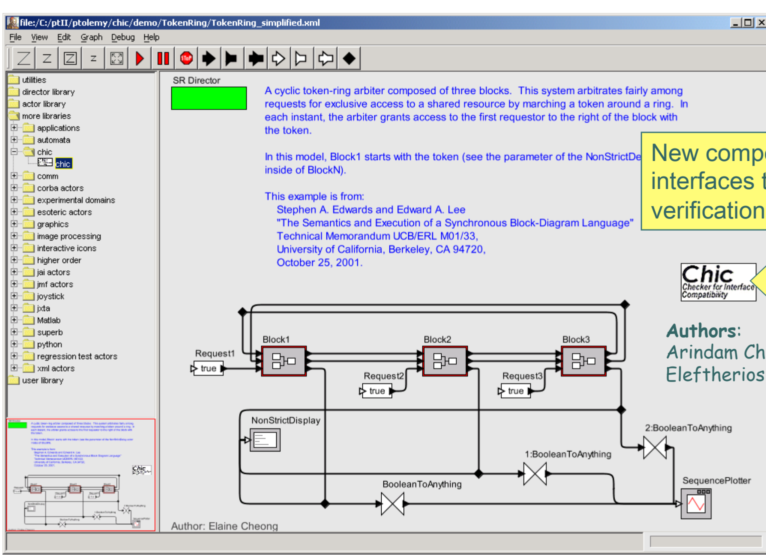
Examples of Extensions
Hooks to Verification Tools



New component interfaces to Chic verification tool

Authors:
Arindam Chakrabarti
Eleftherios Matsikoudis

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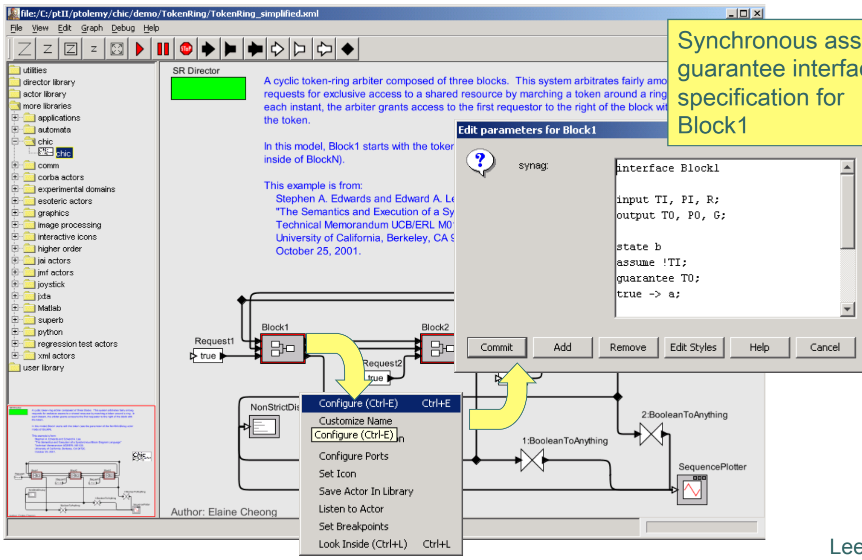
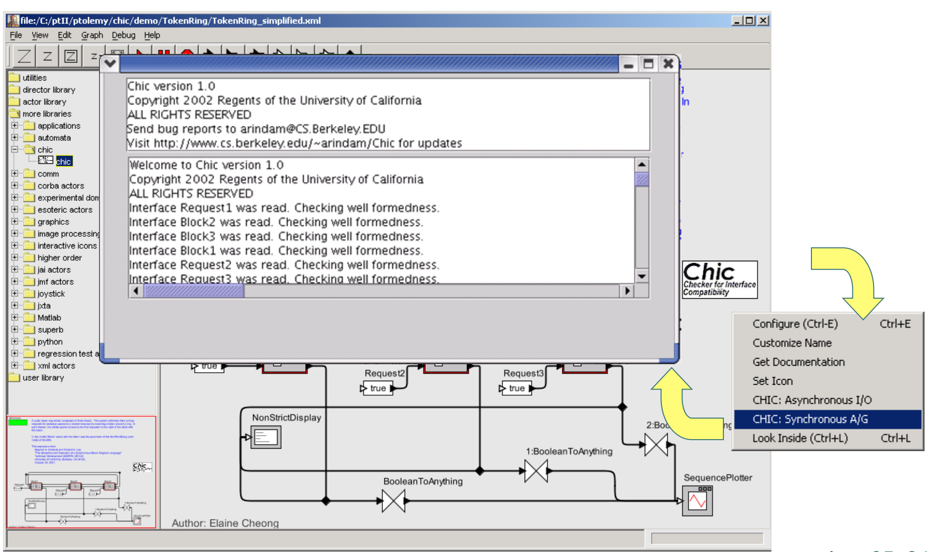
Examples of Extensions
Hooks to Verification Tools

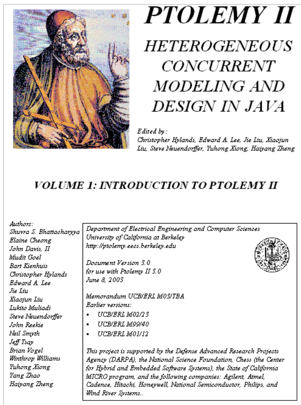


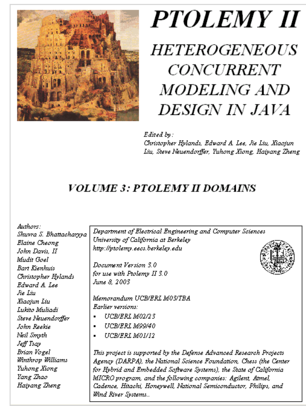
Synchronous assume/ guarantee interface specification for Block1

Examples of Extensions
Hooks to Verification Tools



Getting More Information: Design Document





Volume 1:
User-Oriented

Volume 2:
Developer-Oriented

Volume 3:
Researcher-Oriented

Summary

Ptolemy II provides considerable infrastructure for experimenting with models of computation.