

Model-Based Code Generation is not a Replacement for Programming

Edward A. Lee

*Robert S. Pepper Distinguished Professor
UC Berkeley*

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Invited Talk

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It *is* programming!

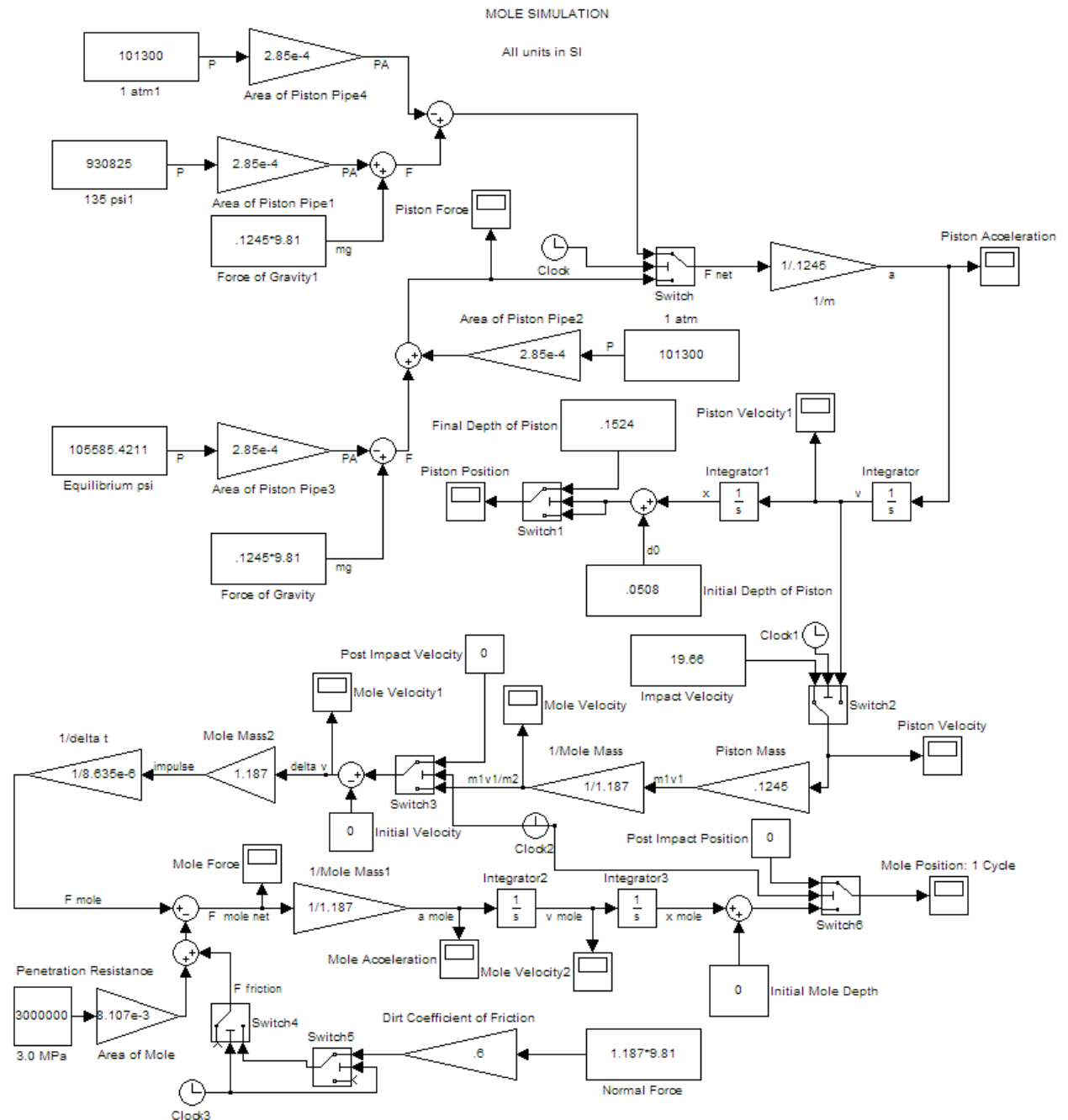
- The language is different.
- The language has features well suited to express some things.
- The language is not well suited to express some other things.
- Recognizing the difference appears to be difficult.



Raffaello Sanzio, The Athens School

The Problem

Students, professors, engineers, and even grownups will use whatever modeling tool they are familiar with for every task at hand, whether it is suitable or not.



Properties of Languages

- Modeling languages like Simulink
 - Concurrent
 - Timed
 - Express dynamics well
- Imperative languages like C
 - Sequential
 - Untimed
 - Express algorithms well
- Hybrid languages that mix imperative with threads like Java
 - Sequential unstructured nondeterminate concurrency
 - Untimed
 - Express few things well, unless you limit yourself to the sequential subset.

Maybe the features of the first two should be mixed in a different way

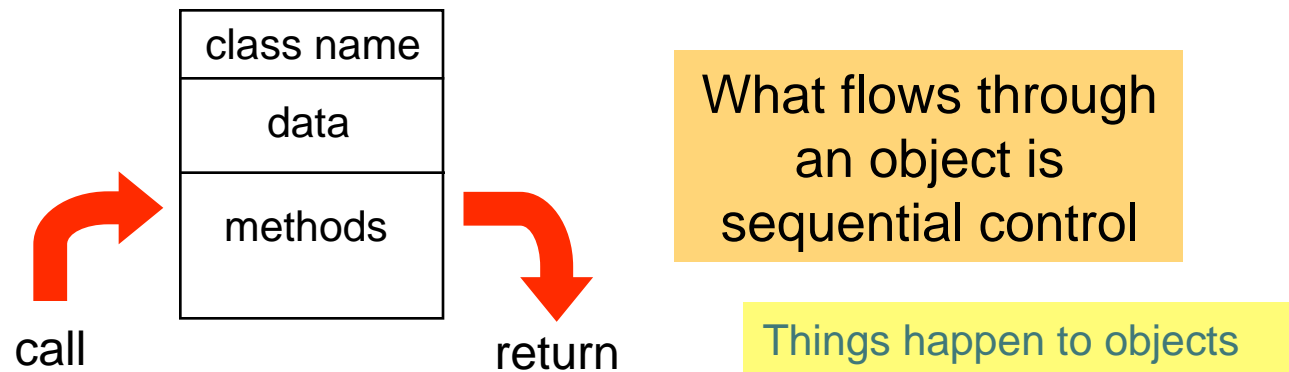
Respect for Imperative Reasoning!

- Imperative reasoning (algorithms, proofs, recipes, etc.) is unnatural to express in actor-oriented languages (as it is also in functional languages).
- Banning imperative reasoning does not seem like a good idea.
- Since people seem to insist on a homogeneous solution, the result is that only a tiny fraction of programmers use actor-oriented languages.

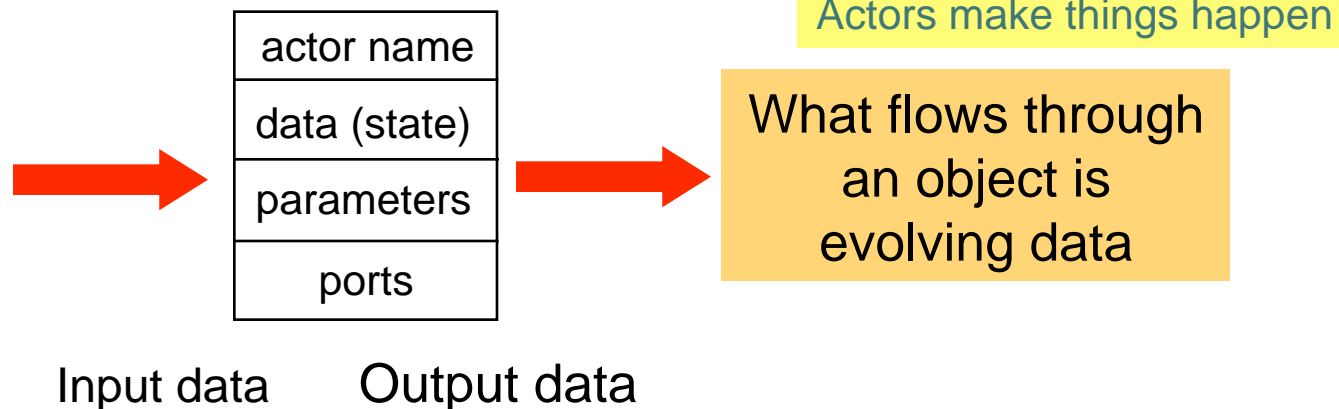
This can be fixed!

Our Proposal: Modeling Languages as Component Architectures rather than Languages

Established component architectures: Object-oriented:



Proposed component architectures: Actor oriented:



Ptolemy II: Our Open-Source Laboratory for Experiments with Actor-Oriented Design

<http://ptolemy.org>

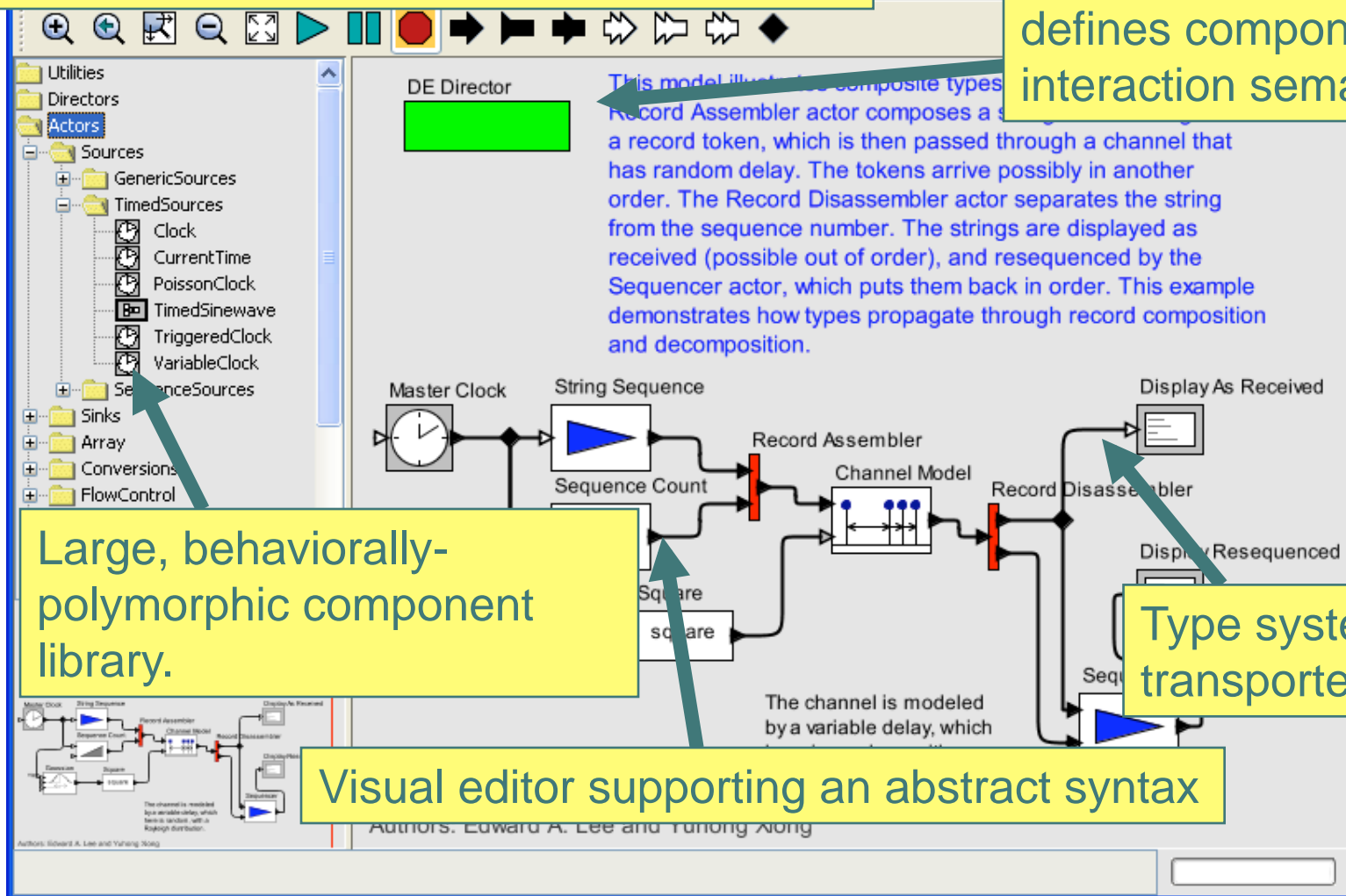
Concurrency management supporting dynamic model structure.

Director from a library defines component interaction semantics

Large, behaviorally-polymorphic component library.

Type system for transported data

Visual editor supporting an abstract syntax



The challenge is to synthesize good implementations from the blend!

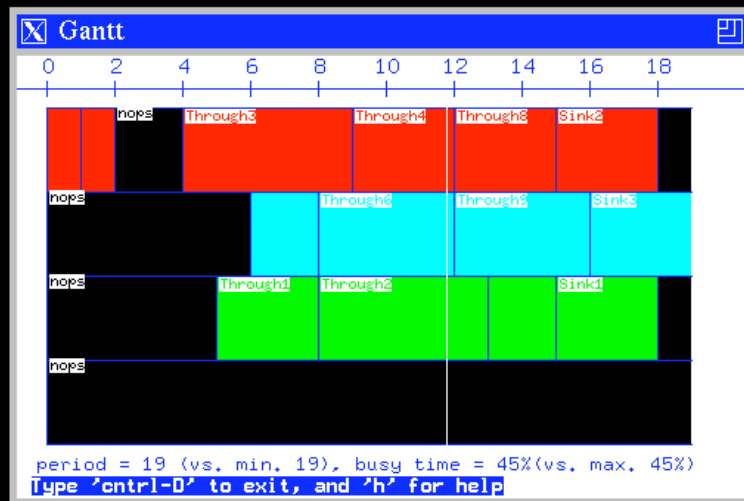
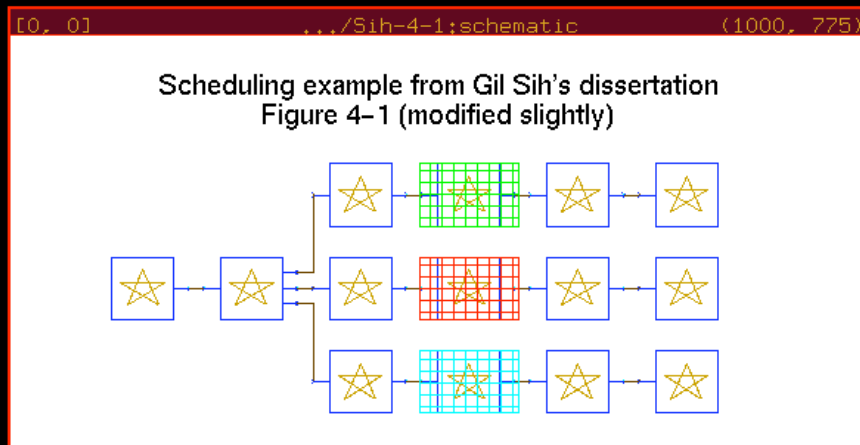
This would be a good problem for bored compiler people!

Our attempts:

- Ptolemy Classic (Buck, Pino, Ha, ... 1990-1997)
- Copernicus (Neuendorffer, 2002-2006)
- Ptolemy II codegen version 1 (2004-2008)
- Ptolemy II codegen version 2 (2009- ??)

Ptolemy Classic Leveraged SDF to Generate Parallel Code

SDF model, parallel schedule, and synthesized parallel code (1990)



```

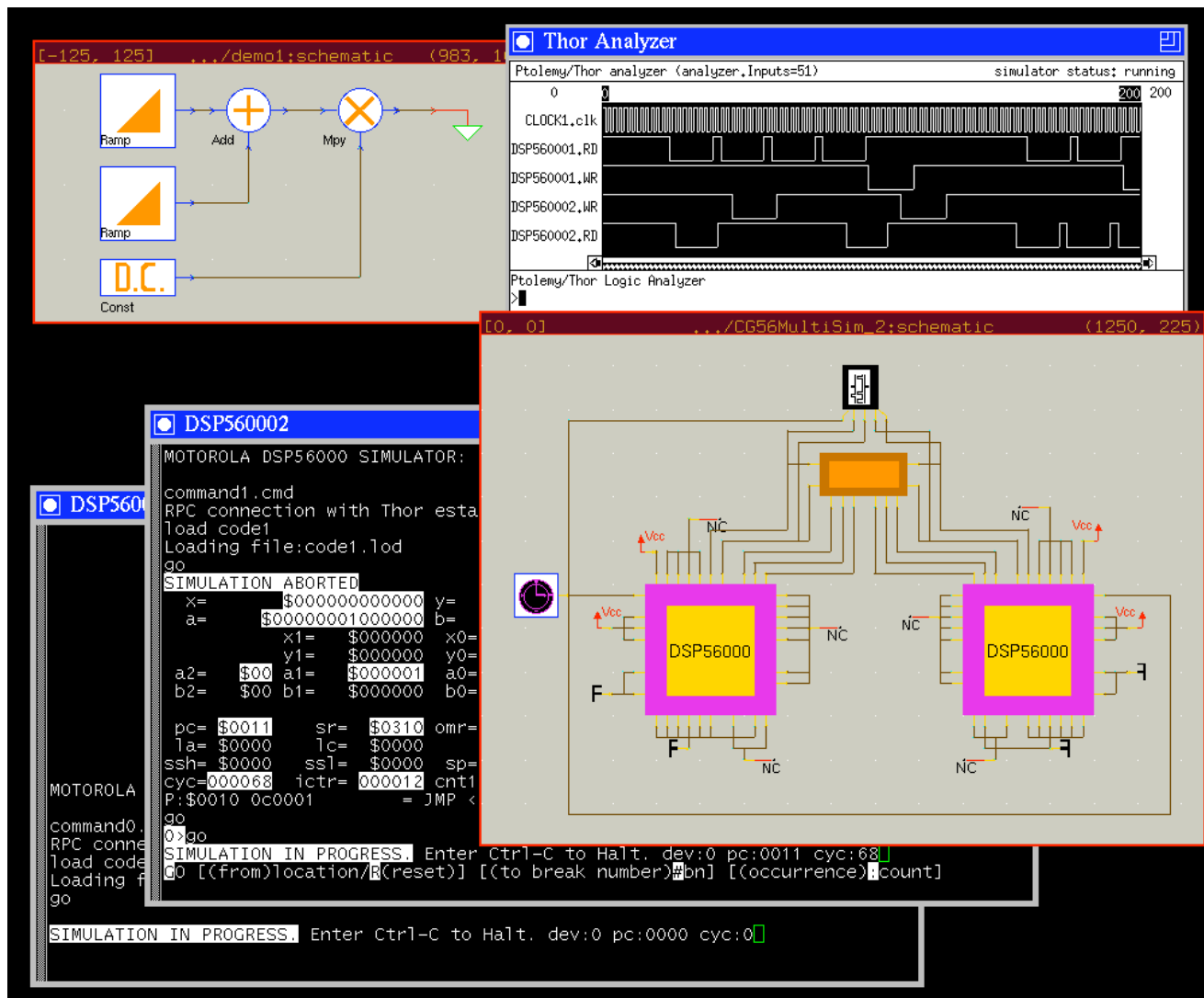
codeblock(std) {
    ; initialize address registers for coef and
    delayLineove    #saddr(coef)+$val(coefLen)-1,r3
; insert here
    move           $ref(delayLineStart),r5
; delayLine
    move           #sval(stepSize),x1
    move           $ref(error),x0
    mpyr          x0,x1,a
    move           a,x0
    move           x:(r3),b           y:(r5)+,y0
}

codeblock(loop) {
    do             #sval(loopVal), $label(endloop)
    macr          x0,y0,b
    move          b,x:(r3)-
    move          x:(r3),b           y:(r5)+,y0
$label(endloop)
}

codeblock(noloop) {
    macr          x0,y0,b
    move          b,x:(r3)-
    move          x:(r3),b           y:(r5)+,y0
}
    
```

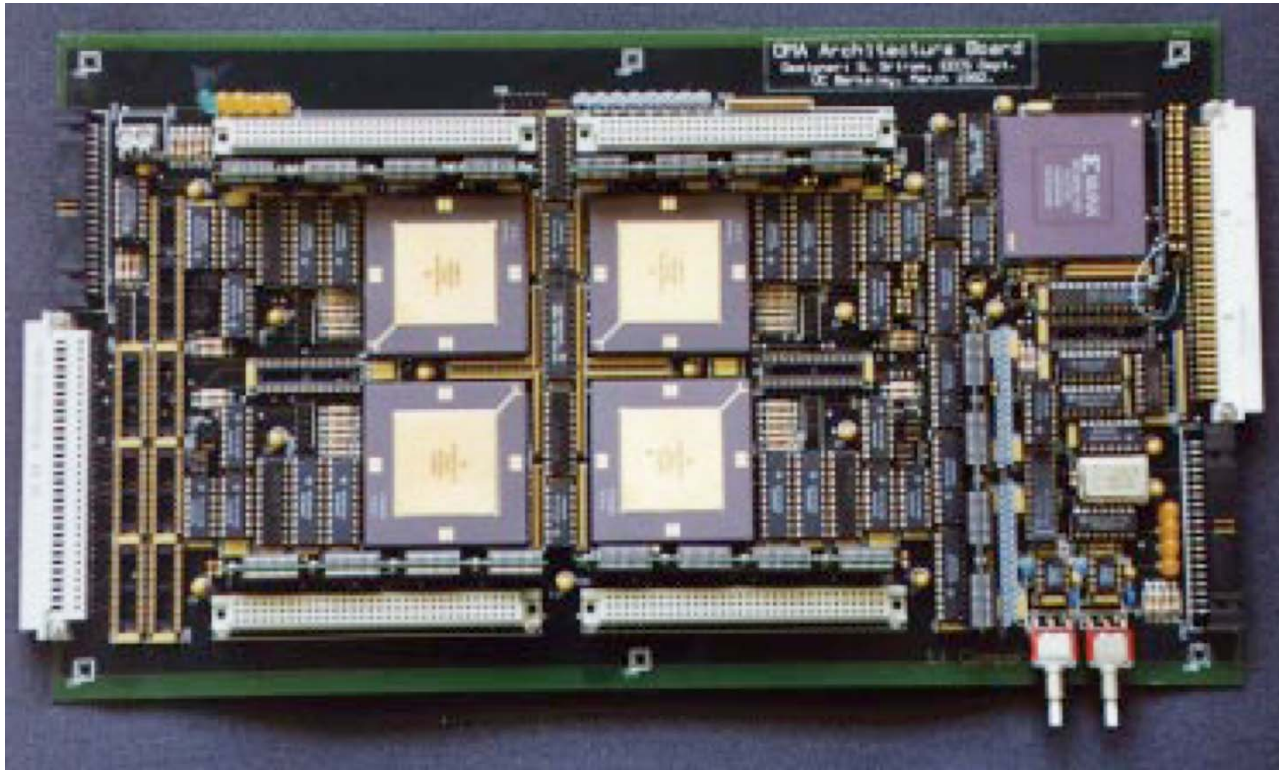
It is an interesting (and rich) research problem to minimize interlocks and communication overhead in complex multirate applications.

Ptolemy Classic Provided Cosimulation of Hardware and Generated Software



An SDF model, a “Thor” model of a 2-DSP architecture, a “logic analyzer” trace of the execution of the architecture, and two DSP code debugger windows, one for each processor (1990).

Multicore Architecture Targeted by Ptolemy Classic Code Generation (1993)

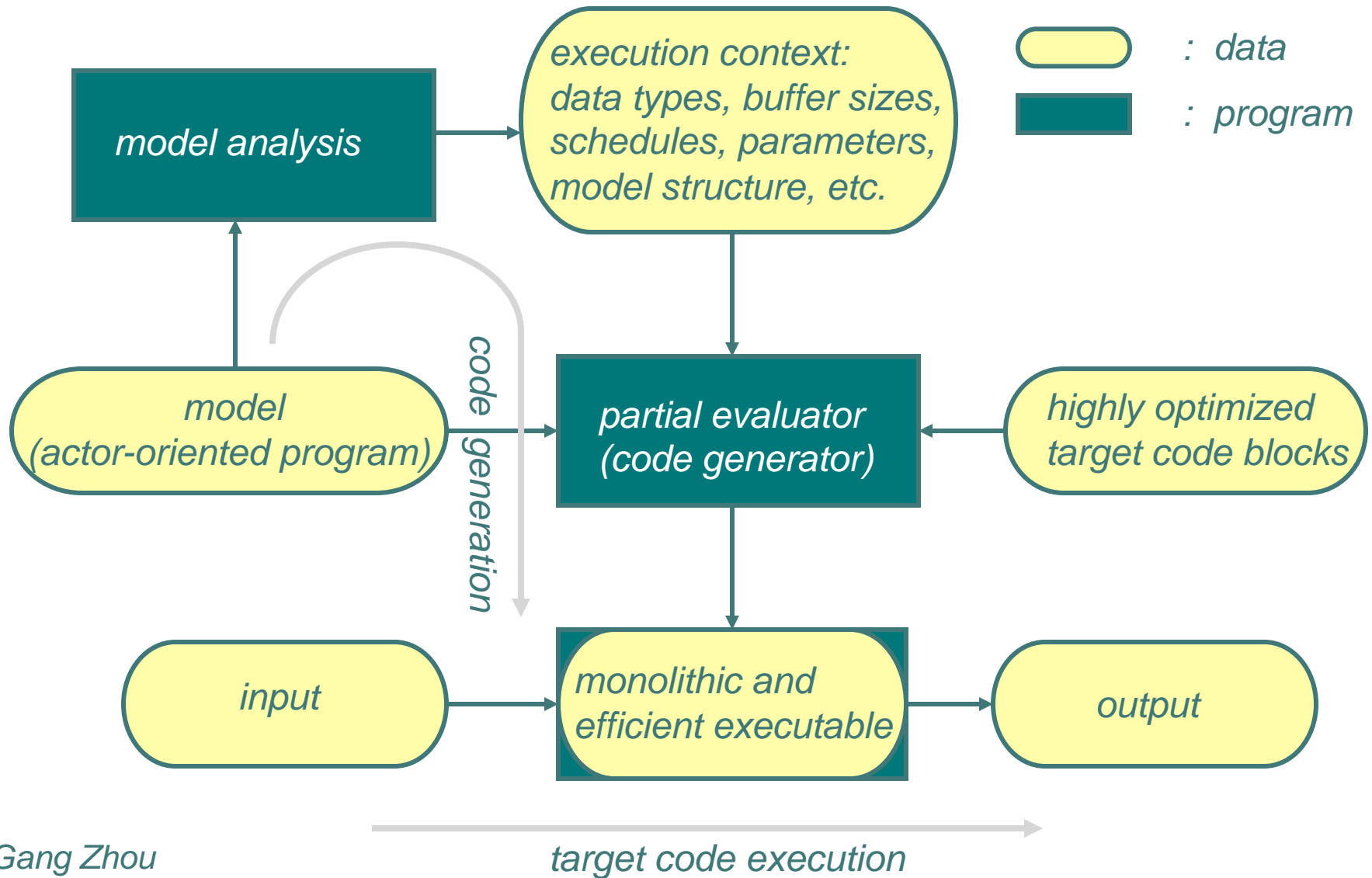


Four DSP 96000 floating point processors interconnected using the "ordered memory architecture," which greatly reduced shared memory synchronization costs [Sriram, 1993]

Second Attempt (Copernicus)

- Steve Neuendorffer created in Ptolemy II a code generator base on the idea of object specialization.
- Java objects would be translated at the byte code level to more specialized Java objects based on their usage in a particular context.
- A tour-de-force, but unmaintainable in our context...

Third attempt: resurrect Ptolemy Classic codegen, but with partial evaluation concepts

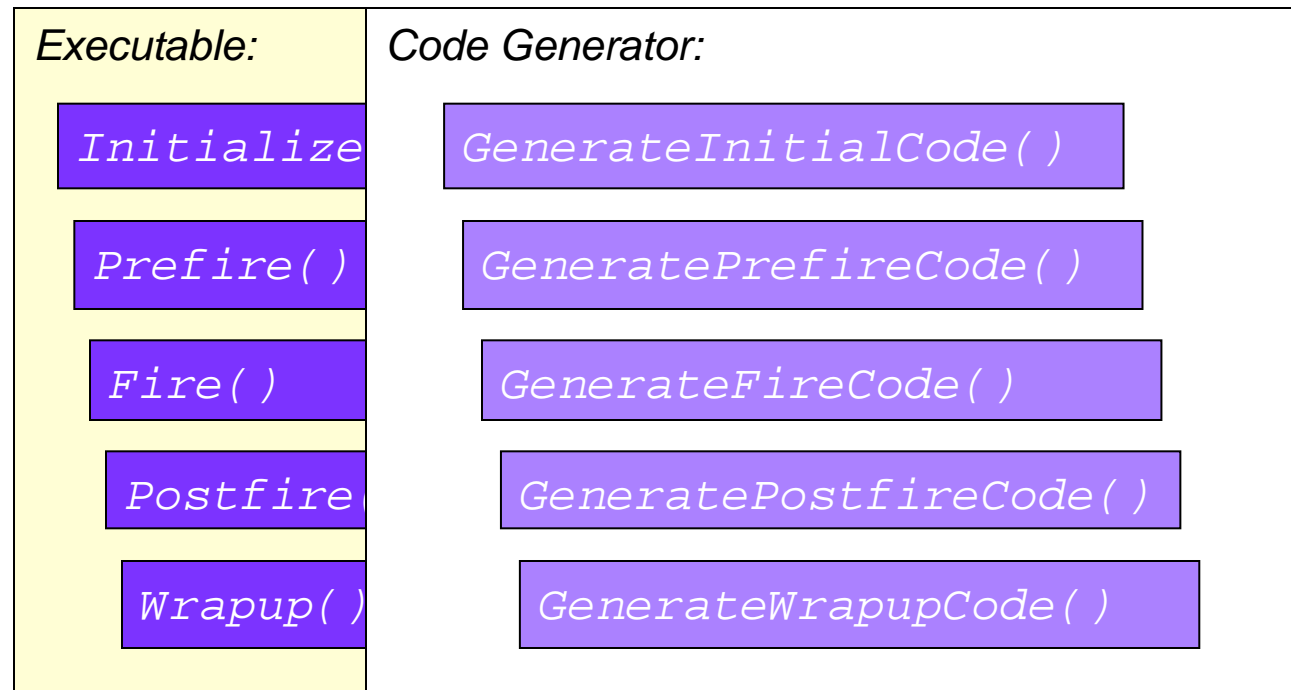


The Code Generation Process

- Definition

ITERATION := *prefire* . *fire** . *postfire*

EXECUTION := *initialize* . ITERATION* . *wrapup*



The Code Generation Process

CompositeActor:

```
fire() {  
    D.fire()  
}
```

Director:

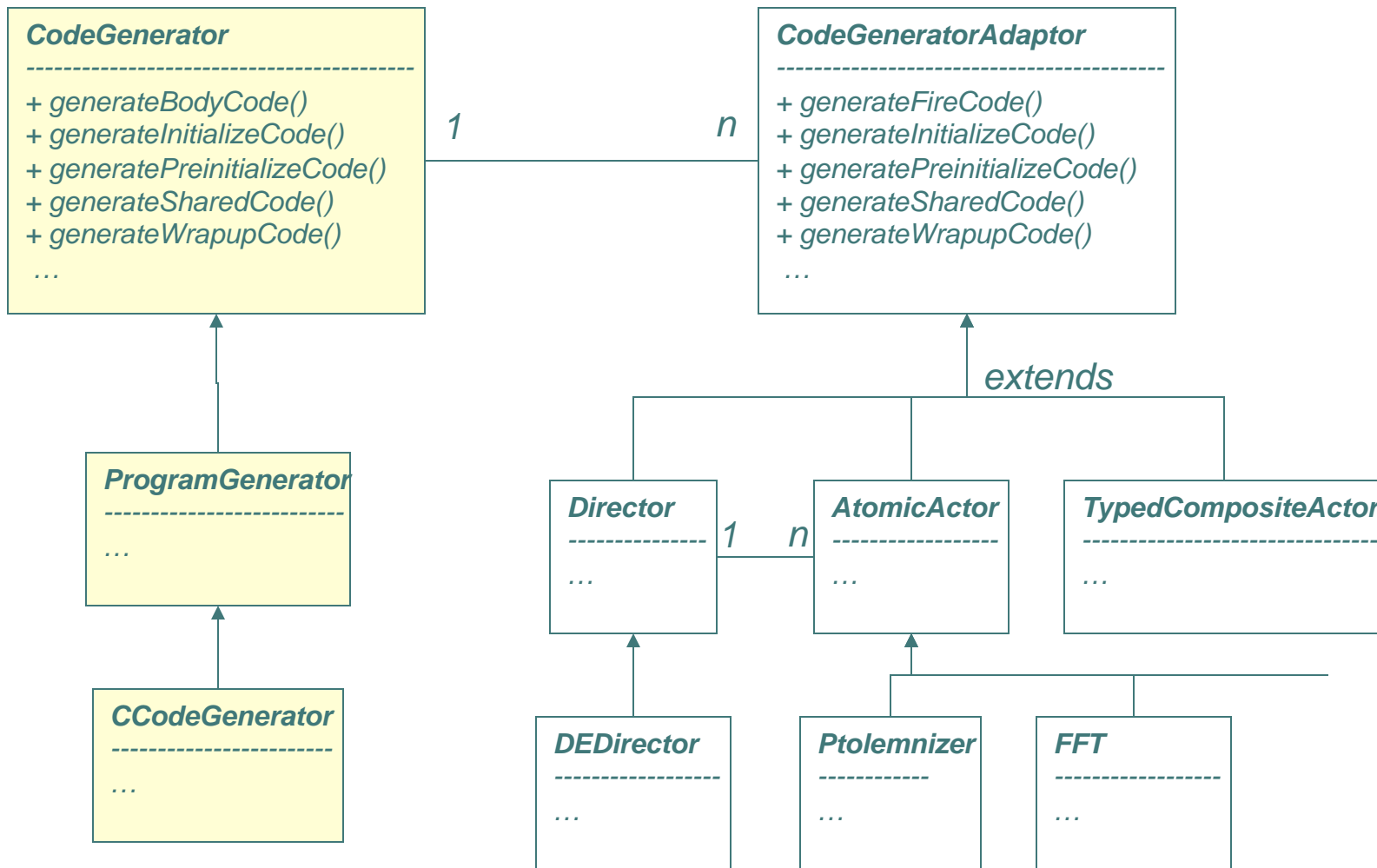
```
fire() {  
    order = getSchedule()  
    for each A ∈ order  
        A.fire()  
}
```

Generated code:

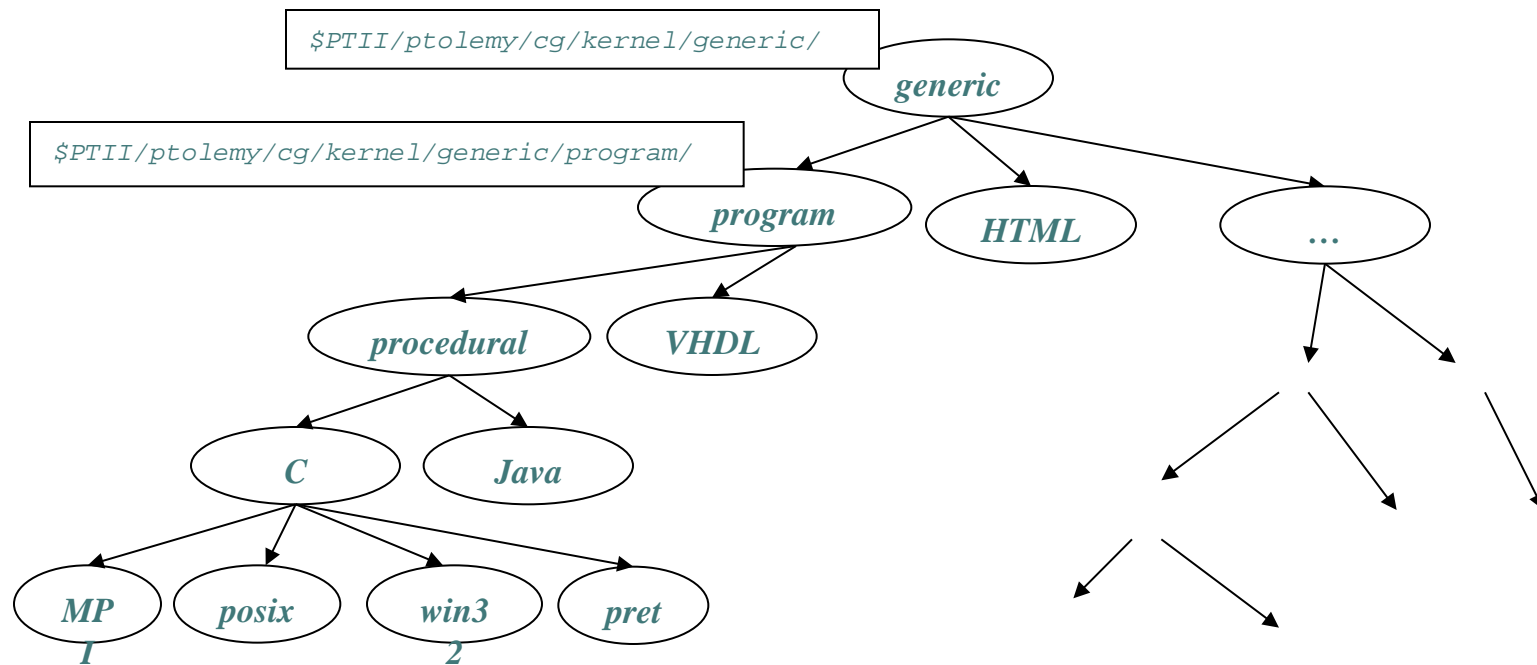
```
CompositeActor_fire() {  
    A1_fire();  
    A2_fire();  
    A3_fire();  
}
```

*The order is
pre-determined
at the time of
code
generation*

Fourth attempt: Build on this, but create a Software Architecture for Experimentation



Target Hierarchy

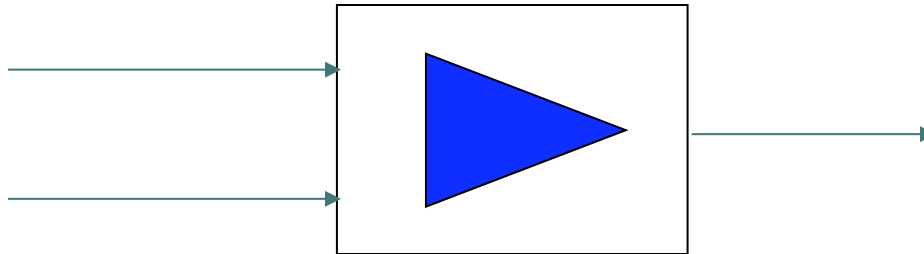


Sections of the Generated Content:



Non-trivial Components

*If we need to generate **complex** code for an atomic component (e.g. FFT) that is highly **parameterizable**...*



Meta Programming

Our (rather primitive) meta-programming mechanism uses templates:

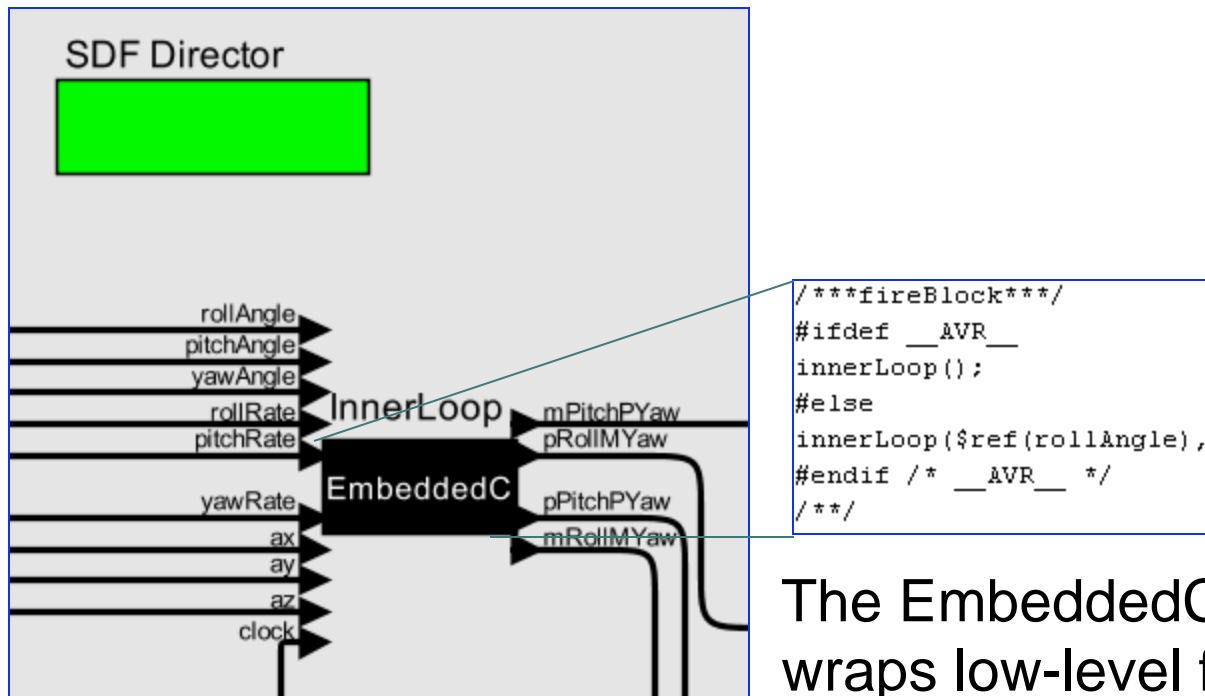
```
Var $v1;  
Var $v2;  
Var $v3;
```

```
Function $foo () {  
  loop i = 1 to $bound:  
    bar(i);  
  end loop  
}
```

Static Text

Holes
(parameterized text)

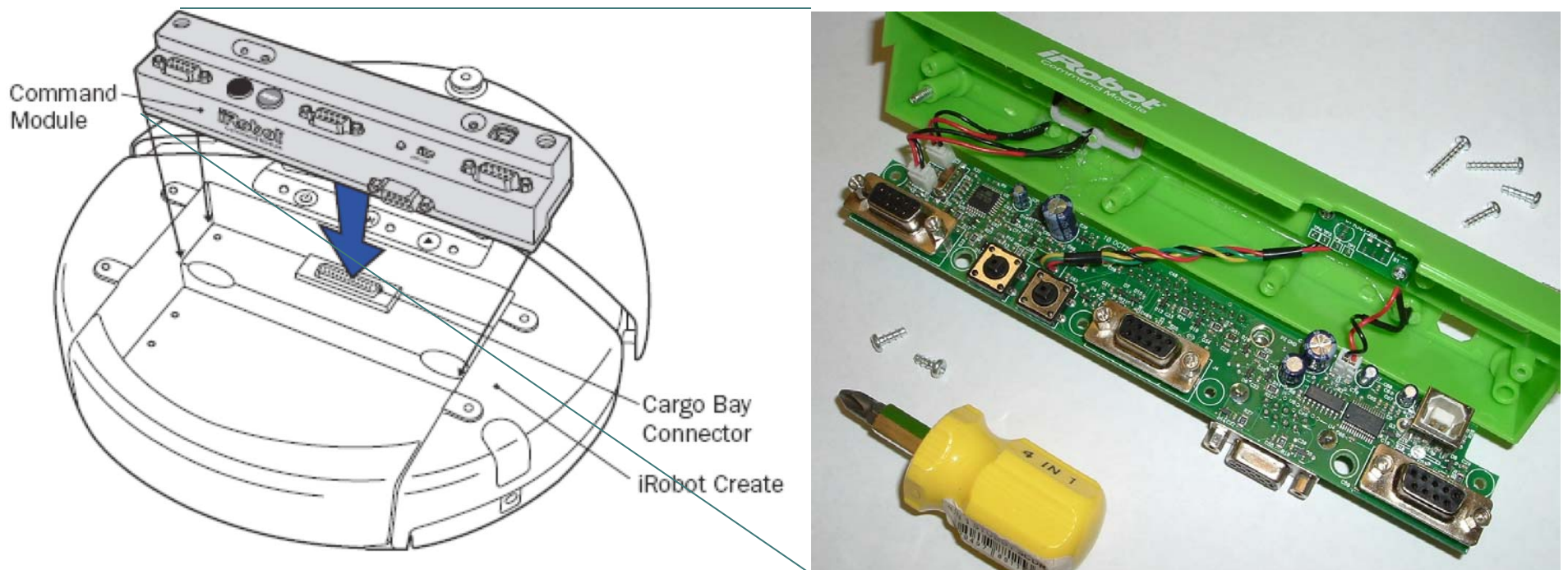
This mechanism enables integration of C code into actor-oriented models.



The EmbeddedCActor in Ptolemy II wraps low-level functionality (written in C) to define an actor. This approach makes it easy to build actor-oriented models and to generate efficient, platform-specific C implementations.

Example target showing that very low overhead code generation and integration of legacy C code is possible.

The iRobot Create (the platform for the Roomba vacuum cleaner) with a pluggable Command Module has an Atmel 8-bit microcontroller with a very small amount of memory.



This design of a hill-climbing control algorithm wraps code provided by iRobot as demo code into actors in Ptolemy II for accessing sensors and actuators.

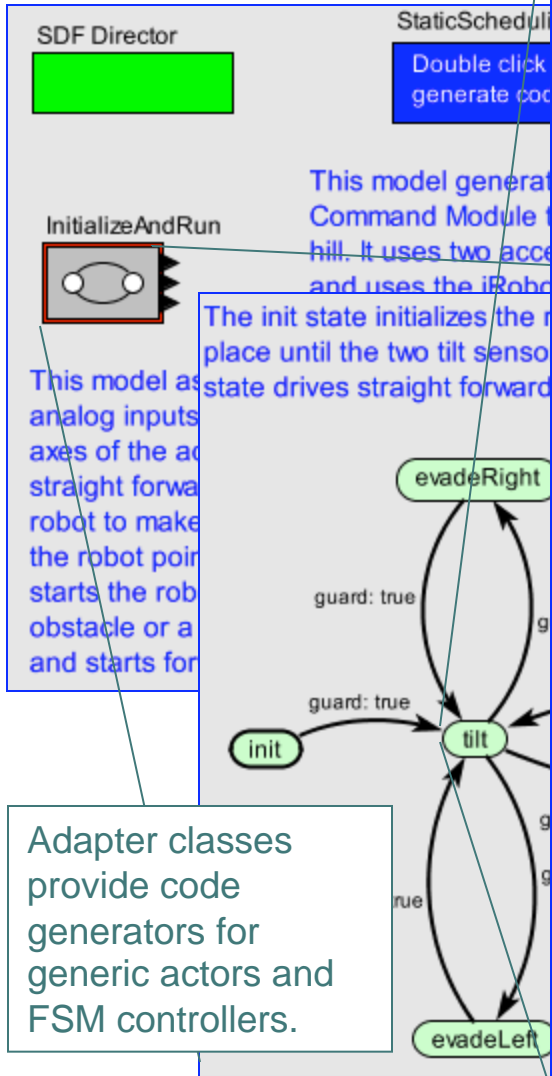
```

File Help

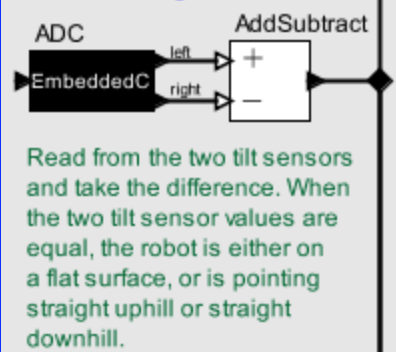
/**initBlock**/
// Set the sensor data to be all zero.
// This initializes the buffer that gets
// filled by the interrupt service routine that
// reads from the serial port.
for(int i = 0; i < Sen6Size; i++) {
    sensors[i] = 0x0;
}
/**/

/**fireBlock**/
if ($ref(trigger)) {
    // Request Sensors Packet 2
    byteTx(CmdSensors);
    // Request packet 0, which has 26 bytes of information.
    byteTx(0);

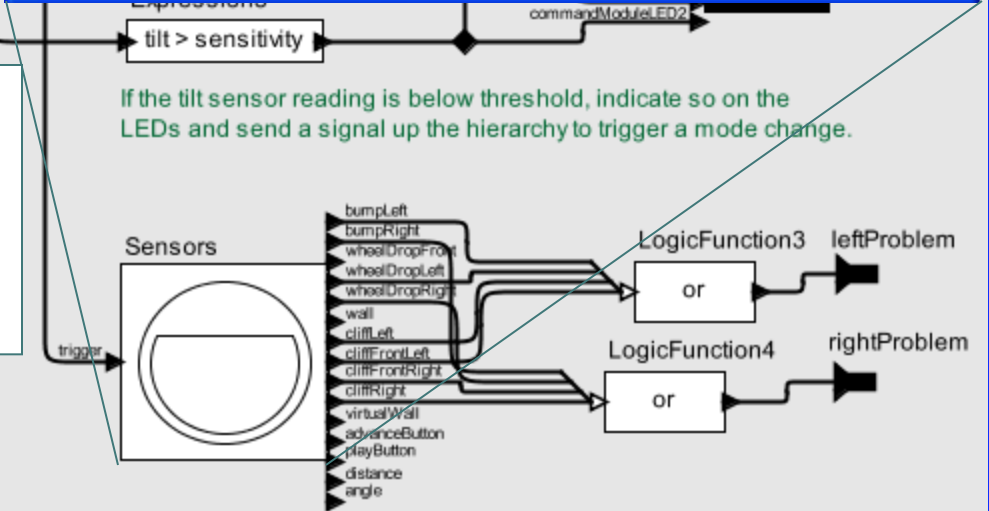
    for(int i = 0; i < Sen0Size; i++) {
        sensors[i] = byteRx();
    }
}
    
```



In this mode, the robot turns in place until the two tilt sensors give the same reading.



EmbeddedCActor provides code generator to interface the C templates with the rest of the system.



Adapter classes provide code generators for generic actors and FSM controllers.

Conclusion

- Heterogeneous models
 - Actor models
 - Imperative code
- Code generation
 - Synthesis of practical realization
- A component technology
 - Chunks of imperative logic encapsulated in a concurrent MoC