Scalable Models Using Model Transformation

Thomas Huining Feng

Ph.D. Student, UC Berkeley

Edward A. Lee

Robert S. Pepper Distinguished Professor, UC Berkeley

1st International Workshop on Model Based Architecting and Construction of Embedded Systems (ACESMB 2008)

September 29, 2008

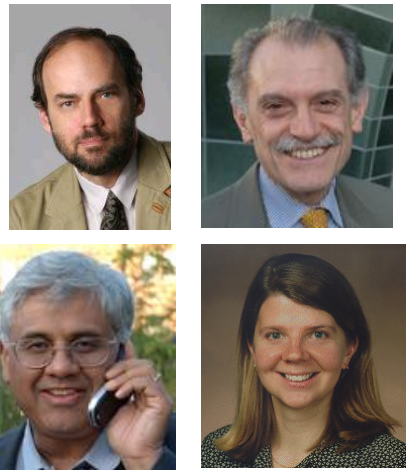
Toulouse, France

Context: Chess: Center for Hybrid and Embedded Software Systems

Principal Investigators
- Thomas Henzinger (EPFL)
- Edward A. Lee (Berkeley)
- Alberto Sangiovanni-Vincentelli (Berkeley)
- Shankar Sastry (Berkeley)
- Janos Sztipanovits (Vanderbilt)
- Claire Tomlin (Berkeley)

Executive Director
- Christopher Brooks

Associated Faculty
- David Auslander (Berkeley, ME)
- Ahmad Bahai (Berkeley)
- Ruzena Bajcsy (Berkeley)
- Gautam Biswas (Vanderbilt)
- Ras Bodik (Berkeley, CS)
- Bella Bollobas (Memphis)
- Karl Hedrick (Berkeley, ME)
- Gabor Karsai (Vanderbilt)
- Kurt Keutzer (Berkeley)
- George Necula (Berkeley, CS)
- Koushik Sen (Berkeley, CS)
- Sanjit Seshia (Berkeley)
- Jonathan Sprinkle (Arizona)
- Masayoshi Tomizuka (Berkeley, ME)
- Pravin Varaiya (Berkeley)

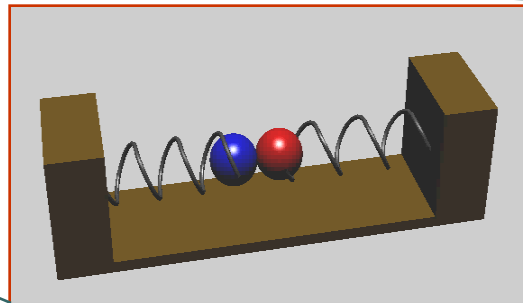


the Berkeley directors of Chess

This center, founded in 2002, blends systems theorists and application domain experts with software technologists and computer scientists.

Some Research Projects
- Precision-timed (PRET) machines
- Distributed real-time computing
- Systems of systems
- Theoretical foundations of CPS
- Hybrid systems
- Design technologies
- Verification
- Intelligent control
- Modeling and simulation

Applications
- Building systems
- Automotive
- Synthetic biology
- Medical systems
- Instrumentation
- Factory automation
- Avionics



Model Transformation

Model-based design has used static structure models such as UML class diagrams to provide meta models that guide model-based design processes.

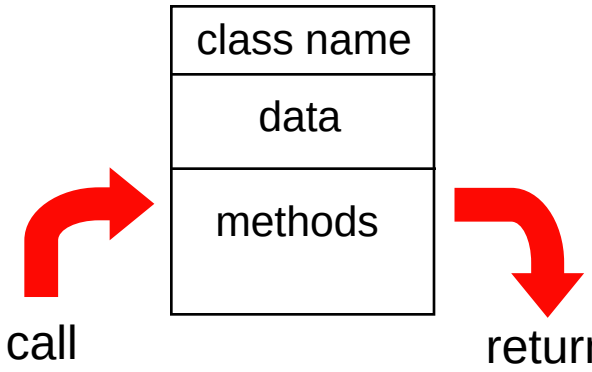
In this project, we are focusing more on actor models, which more directly express concurrency and system dynamics than what is possible with static structure models. Inspired by prior work on model-driven model transformation, we have prototyped a model-transformation mechanism that is actor-oriented.

Inspirations and Influences

- AGG [Taentzer, 1999]
- AToM3 [Lara, Vangheluwe, 2002]
- FUJABA [Nickel, Niere, Zündorf, 2000],
- GReAT [Agrawal, Karsai, Shi, 2003]
- OMG MOF QVT (Query/Views/Transformations)
- PROGRES [Schürr, Winter, Zündorf, 1995]
- VIATRA2 [Balogh, Varró, 2006]

Our Premise: Components are Actors rather than Objects

The established: Object-oriented:

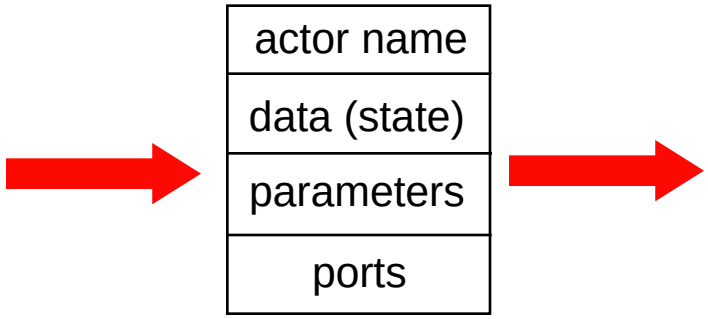


What flows through an object is sequential control

Things happen to objects

The alternative: Actor oriented:

Actors make things happen



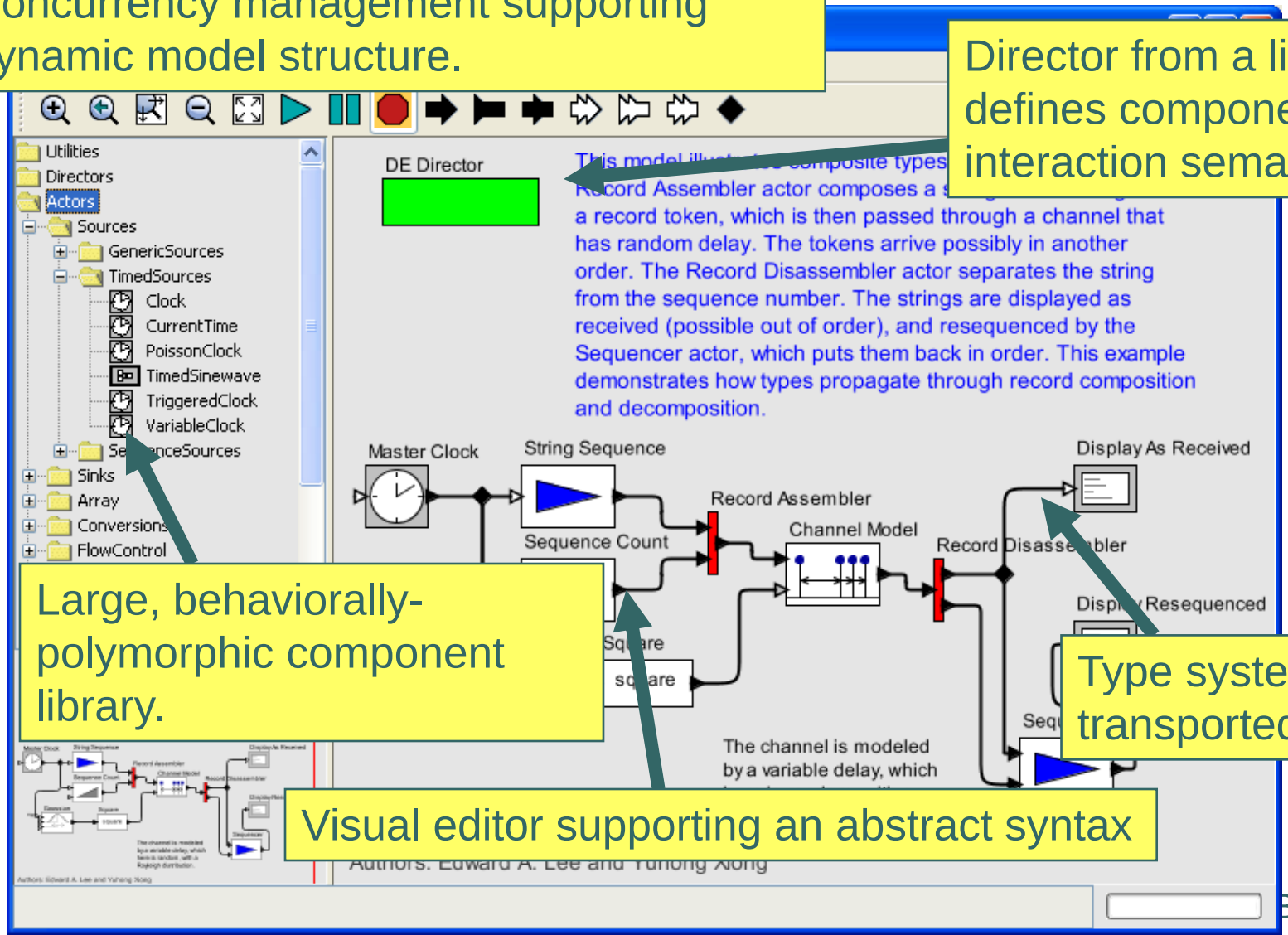
What flows through an object is evolving data

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

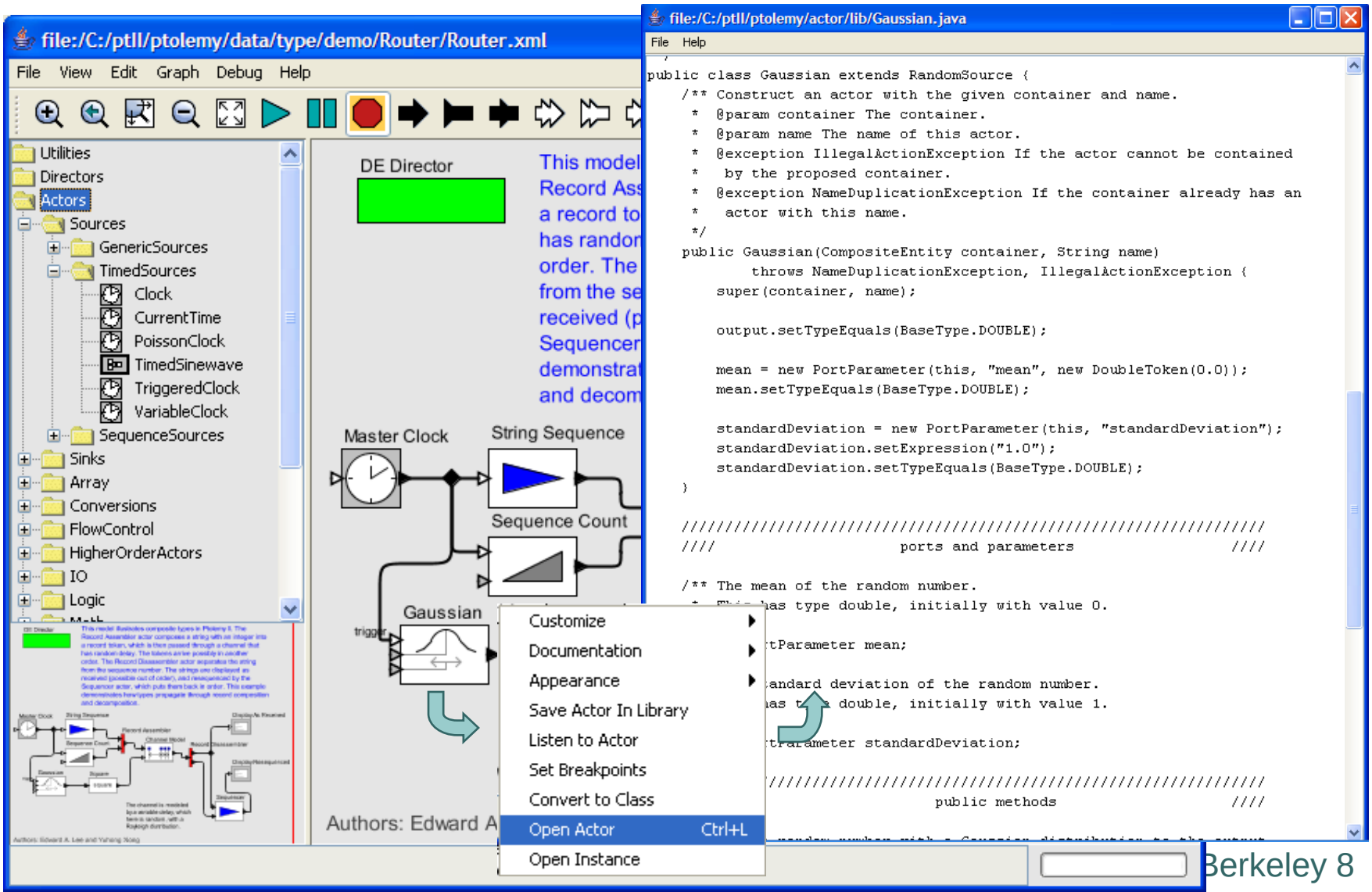


Large, behaviorally-polymorphic component library.

Type system for transported data

Visual editor supporting an abstract syntax

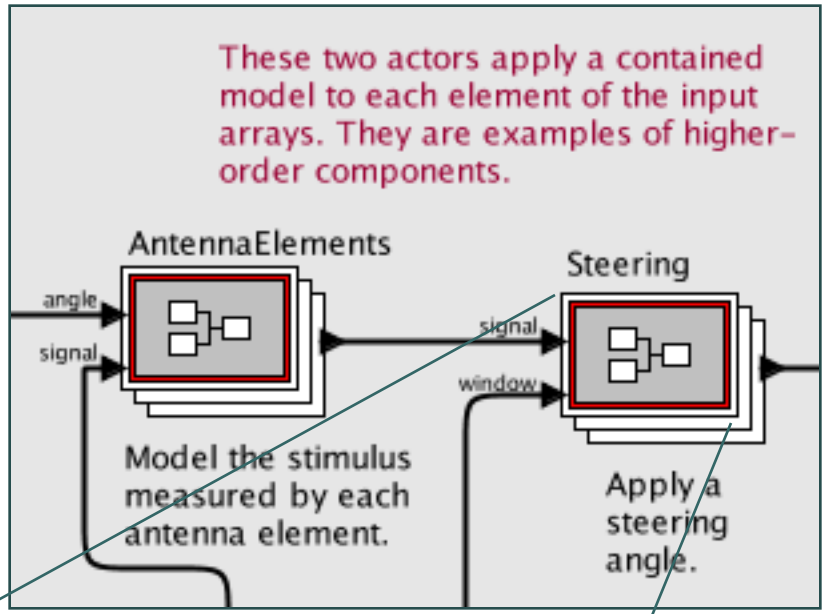
Approach: Concurrent Composition of Software Components, which are themselves designed with Conventional Languages (Java, C, C++ MATLAB, Python)

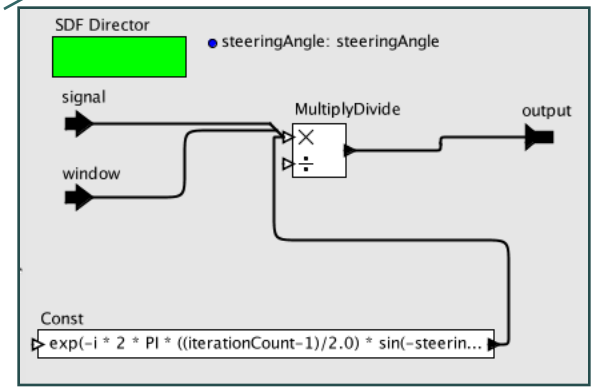


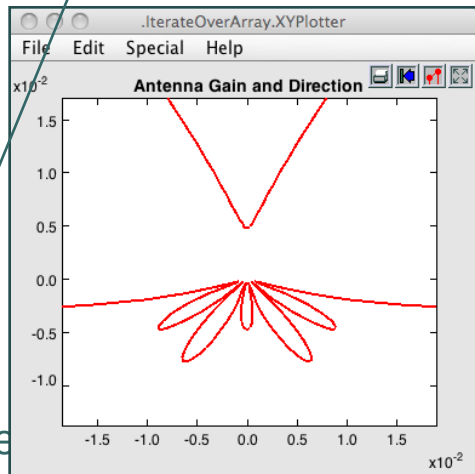
Key Prior Work from the Ptolemy Project: 1. Higher-Order Components

Examples of HoCs:

- Replicate a submodel over an array of inputs
- Structured dataflow components (case, iterate, recursion)
- Mobile models
- Parameterizing models with models
- Lifecycle models

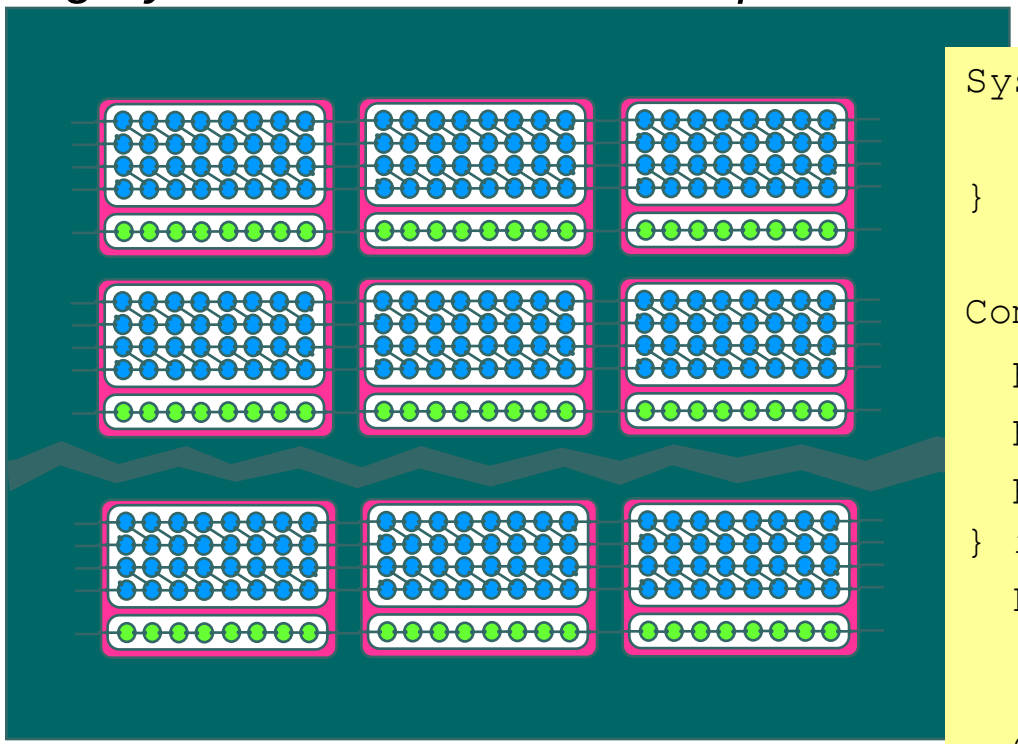






Key Prior Work from the Ptolemy Project: 2. Composition Languages

Big Systems with Small Descriptions

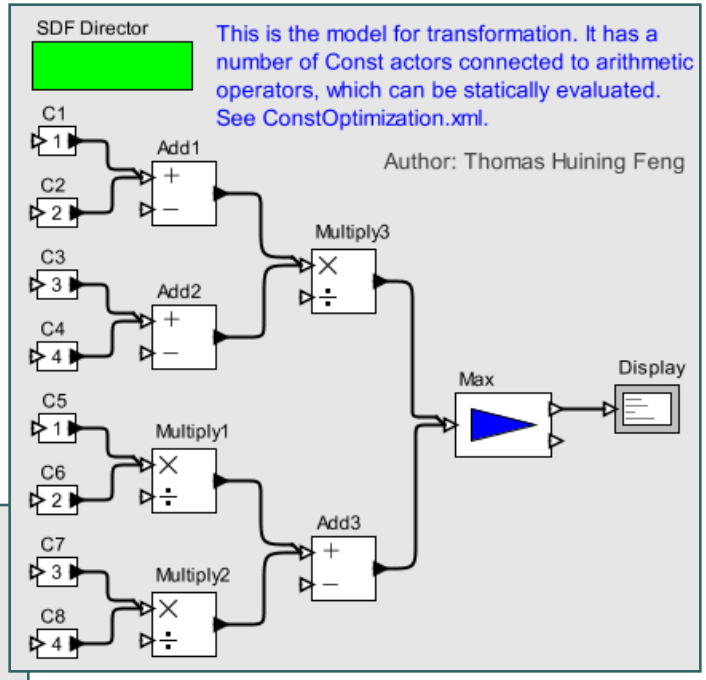


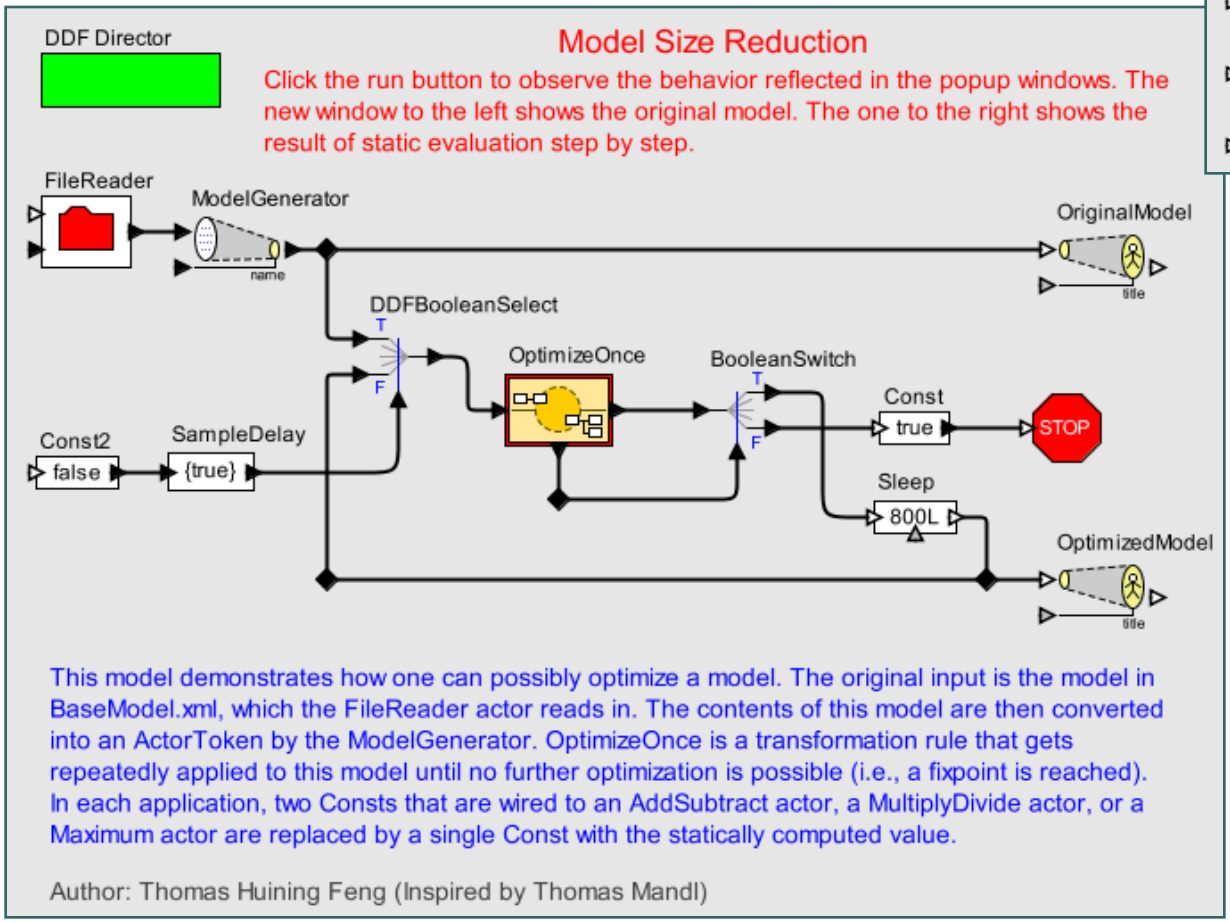
```
System is {
    Matrix(Component(2),20,3);
}

Component is {
  param n;
  port in[n*2+1];
  port out[n*2+2];
} in {
  Blue(n, in[1..n*2],
       out[1..n*2]);

  Green(n,  in[n*2+1],
        out[n*2+1]);
}
```

We have released a specification language that we call "Ptalon" for such systems, integrated into Ptolemy II [Cataldo 2006]

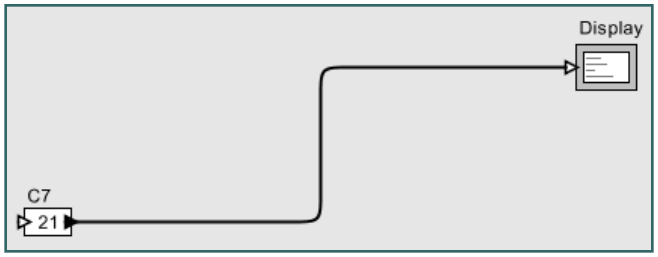
Demo: Pattern Matching and Graph Transformation

Model transformation workflow specifies iterative graph rewriting to transform the top-right model into the bottom-left model.





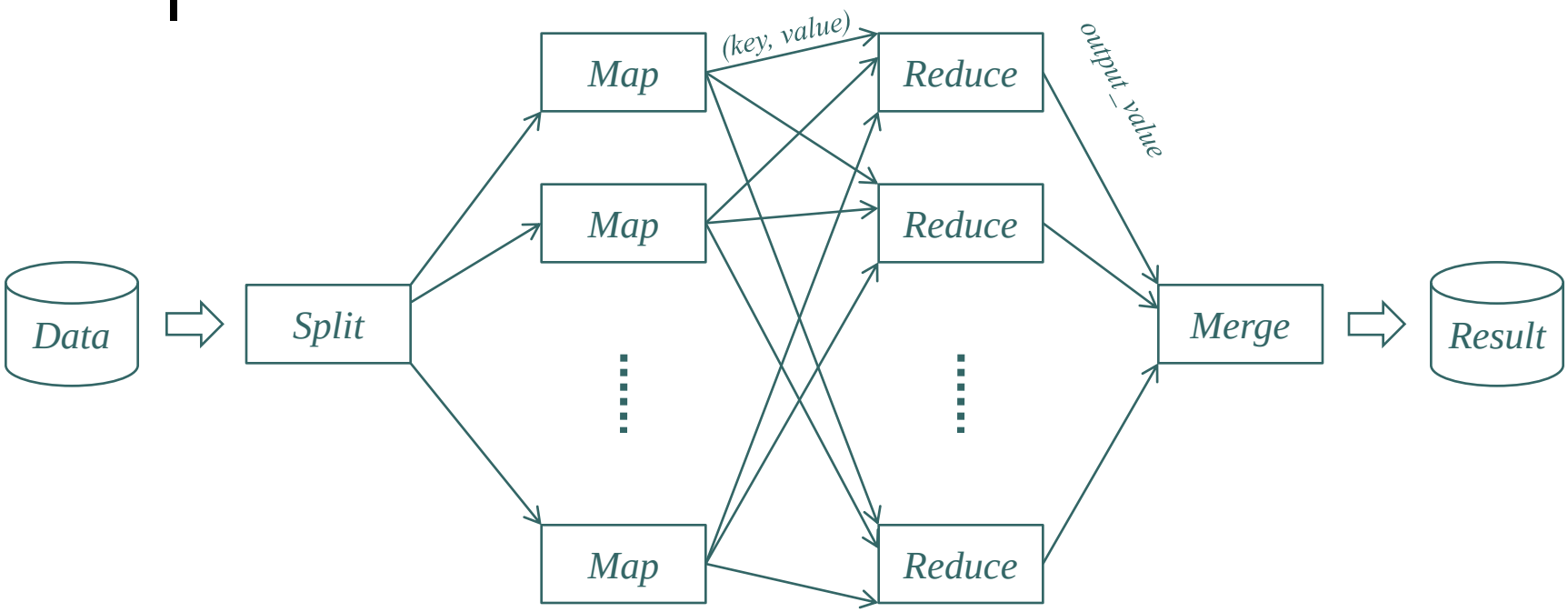
Executing the model at the left transforms the top model into the bottom model.



Applications

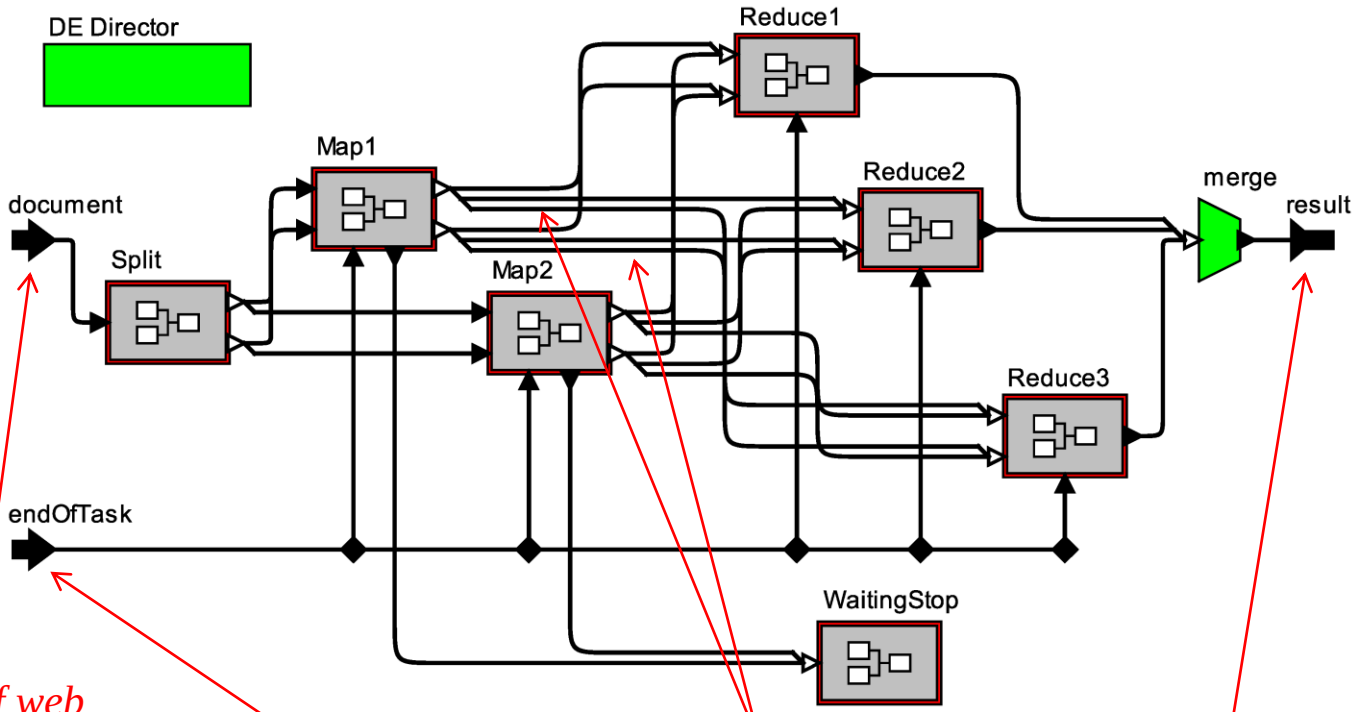
- *Model optimization* — *shown*
  - *Support programming idioms*
- *Scalable model construction* — *next*
  - *Adapt to problem size or parallelism*
- *Product families*
  - *A single model transforms to multiple products*
- *Design refactoring*
  - *Common model transformations*
- *Workflow automation*
  - *Configuration, composition, testing, versioning*

Scalable Model Construction: MapReduce Pattern [Dean, Ghemawat, 2004]



This pattern is intended to exploit parallel computing by distributing computations that fit the structure. The canonical example constructs an index of words found in a set of documents.

A MapReduce Model in Ptolemy II



Inputs of web documents

"contents of the first document"
"contents of the second document"
...
"contents of the last document"

End of all documents

false
false
...
true

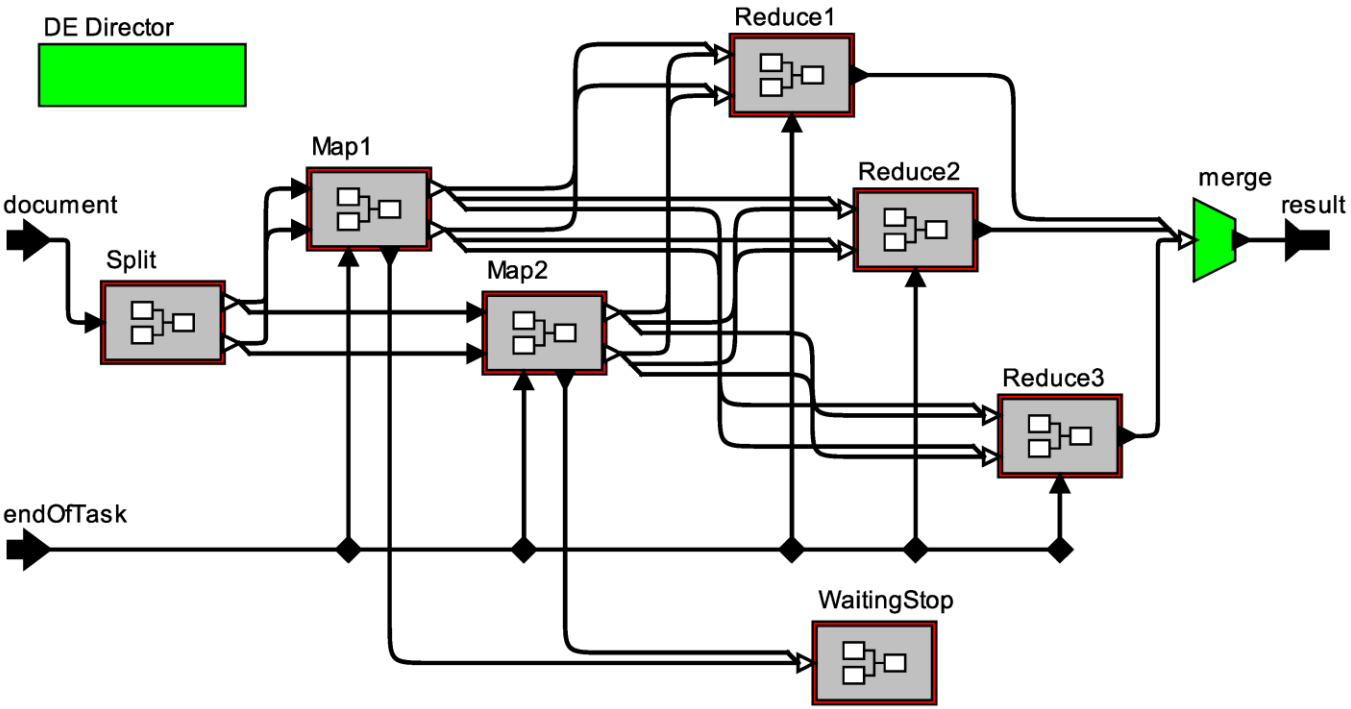
Word-value pairs

{"contents", 1}
{"of", 1}
...
{"document", 1}

Merged word-counting outputs

{"contents", 3}
{"first", 1}
...
{"document", 3}

Complexity of the Model Structure

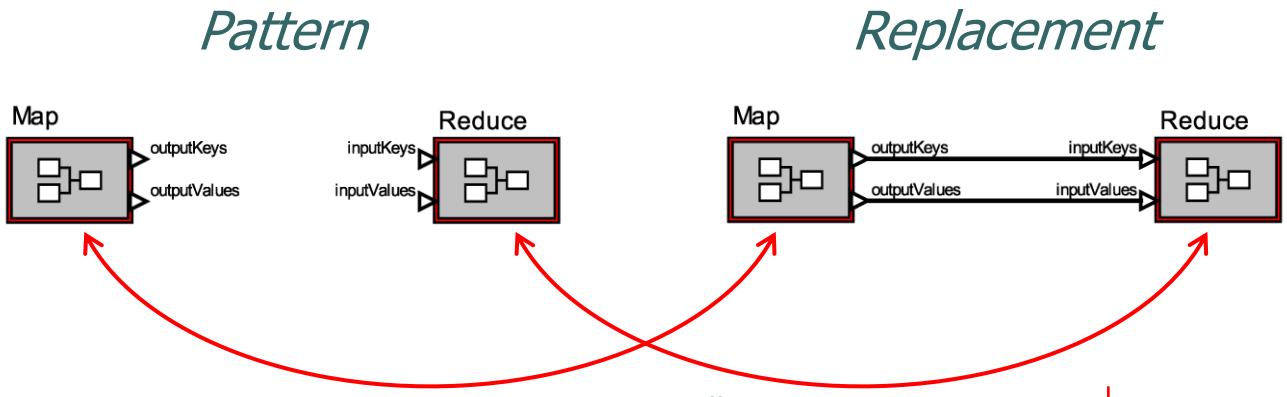


A configurable application with *m* Map actors and *n* Reduce actors has *O*(*m*×*n*) connections. Inside each actor, parameters need to be configured as well.

Observations

- The visual representation is only helpful for small models.
- The construction process by visual editing is tedious and error prone.
- Adapting the size of the model to varying numbers of compute resources by visual editing is unreasonable.
- Replacing the Map or Reduce actors with alternative functions by visual editing is also not reasonable.

Transformation Rule



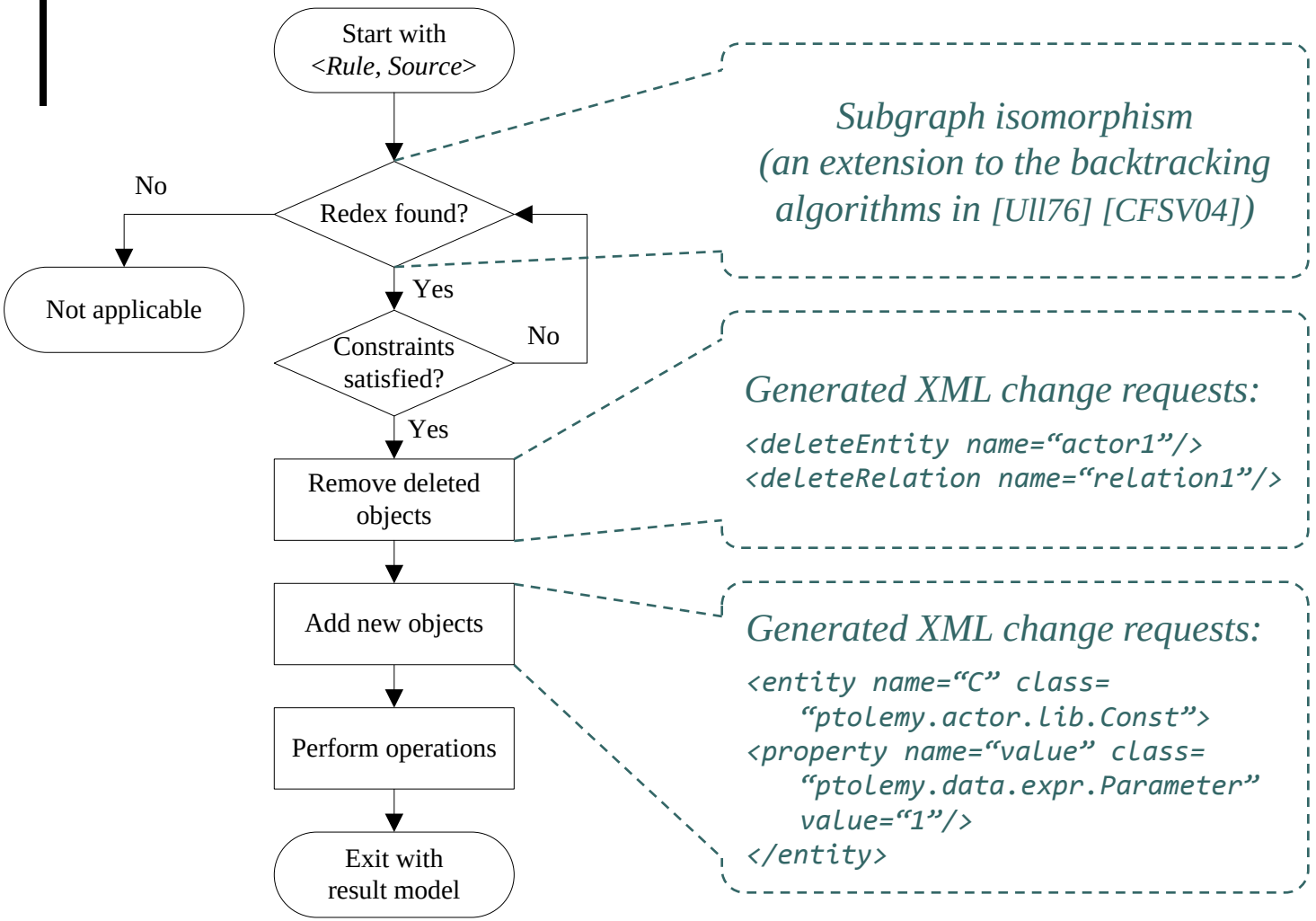
Constraint: *!Map.outputKeys.connectedPortList()*
.contains(Reduce.inputKeys)

Pattern	Replacement
Map	Map
Reduce	Reduce

A transformation rule to connect a Map actor to a Reduce actor

Map and Reduce are matchers to match arbitrary actors with the specified ports.

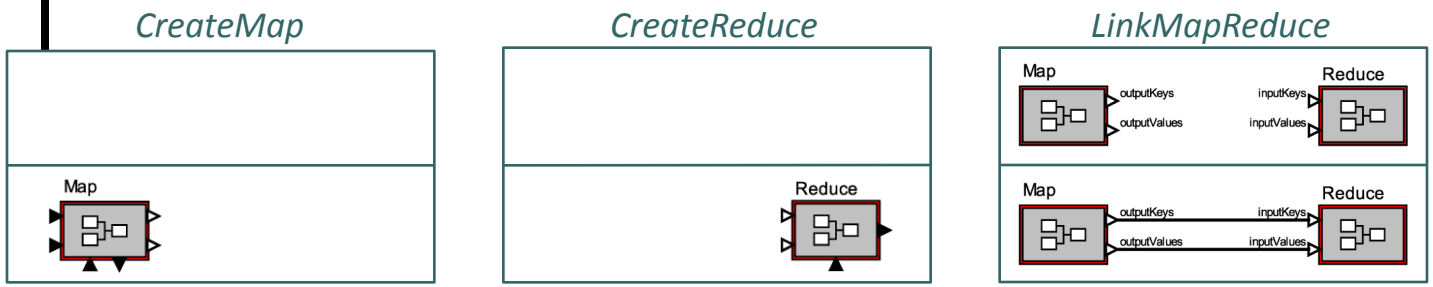
Rule Application

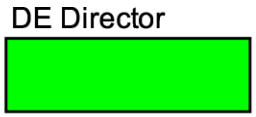


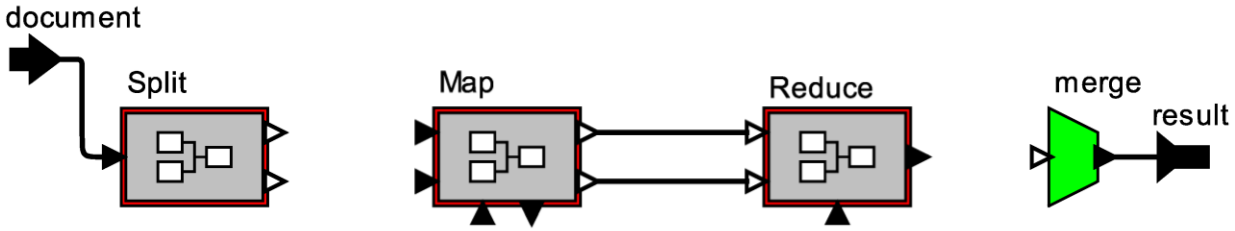
[Ull76] J. R. Ullmann. An algorithm for subgraph isomorphism. Journal of the ACM, 23(1), 1976.

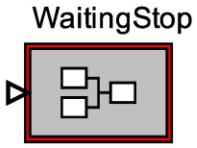
[CFSV04] L. P. Cordella, P. Foggia, C. Sansone, and M. Vento. A (sub)graph isomorphism algorithm for matching large graphs. IEEE Transactions on Pattern Analysis and Machine Intelligence, 26(10), 2004.

A Set of Transformation Rules

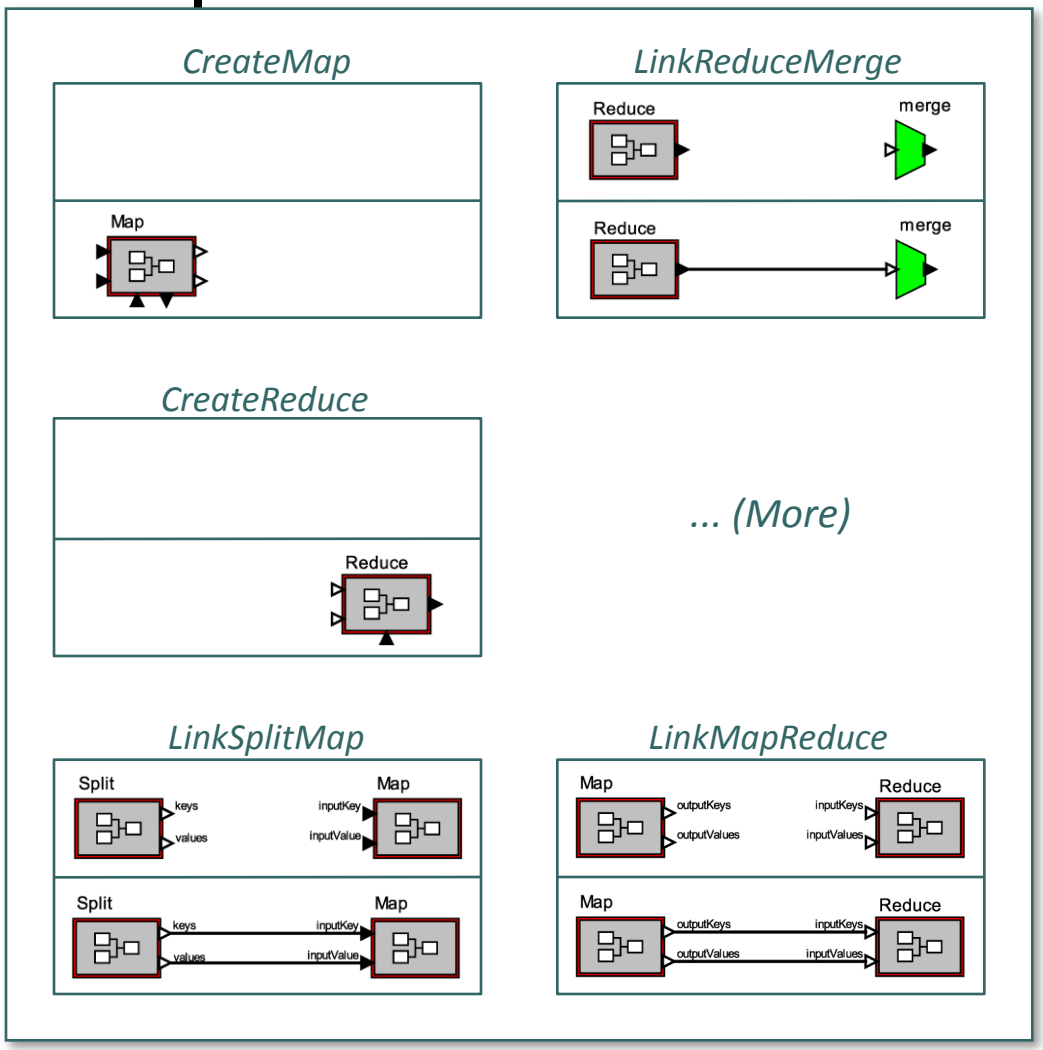








Model is built by repeatedly applying transformation rules drawn from a set



Workflow mechanisms:

- Priority (AGG, AToM3)
- Imperative programs (PROGRES)
- Story diagrams (FUJABA)
- Control flow and data flow (GReAT)
- Abstract State Machines (VIATRA2)

- Ptolemy II models (our approach)

The TransformationRule Actor

Encapsulates a transformation rule

Input:

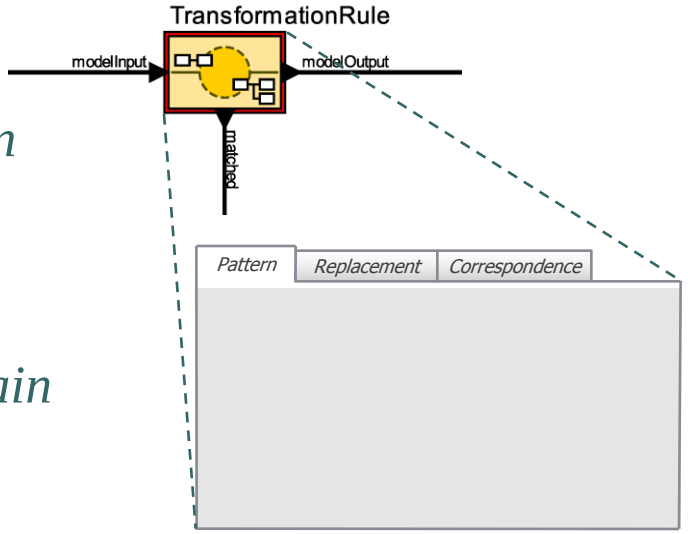
modelInput – actor tokens that contain model fragments

Output:

modelOutput – actor tokens that contain transformation results

matched – whether the last transformation was successful

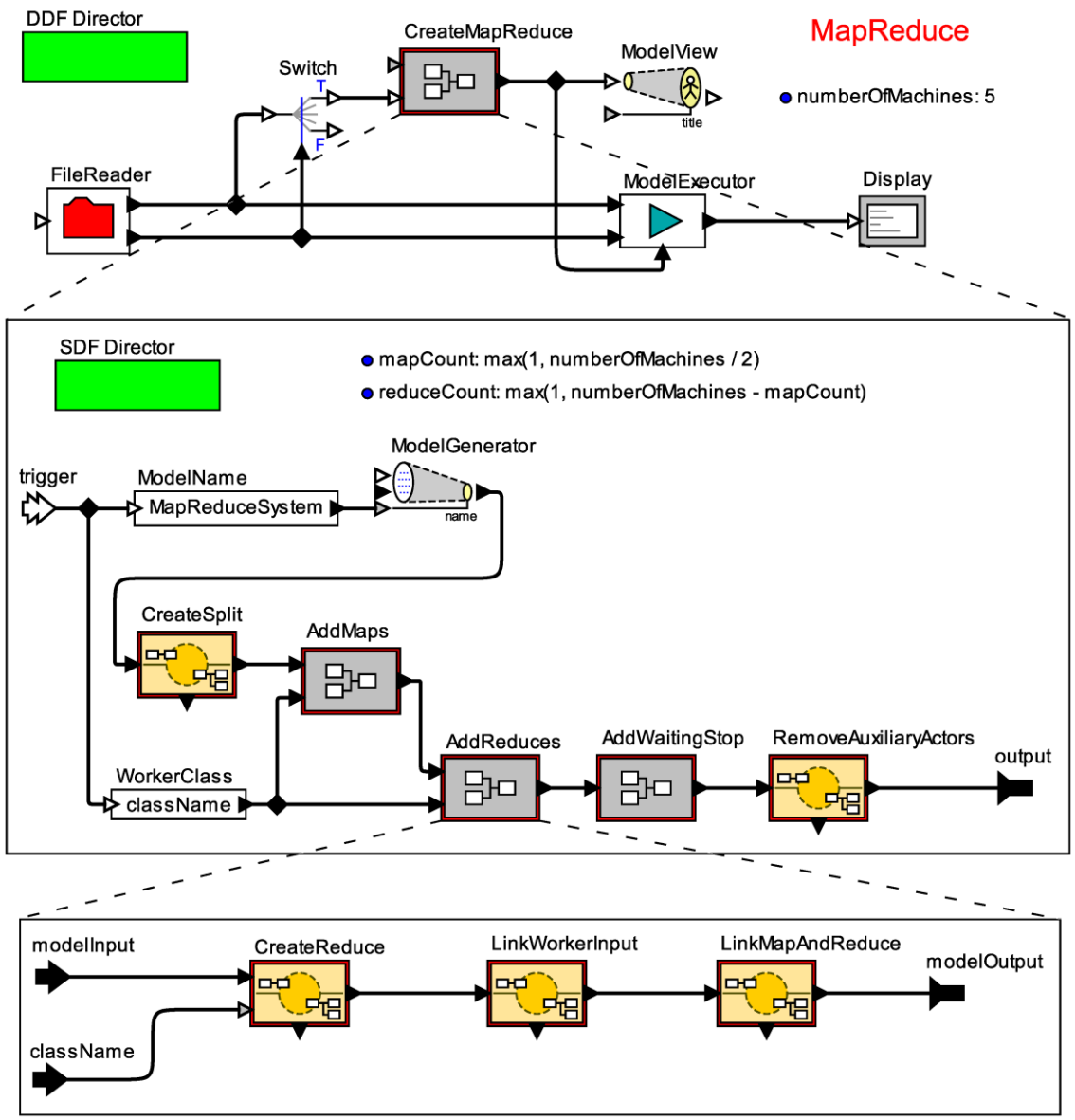
This actor may be used in nearly any Ptolemy model (dataflow, process networks, discrete-events, etc.)



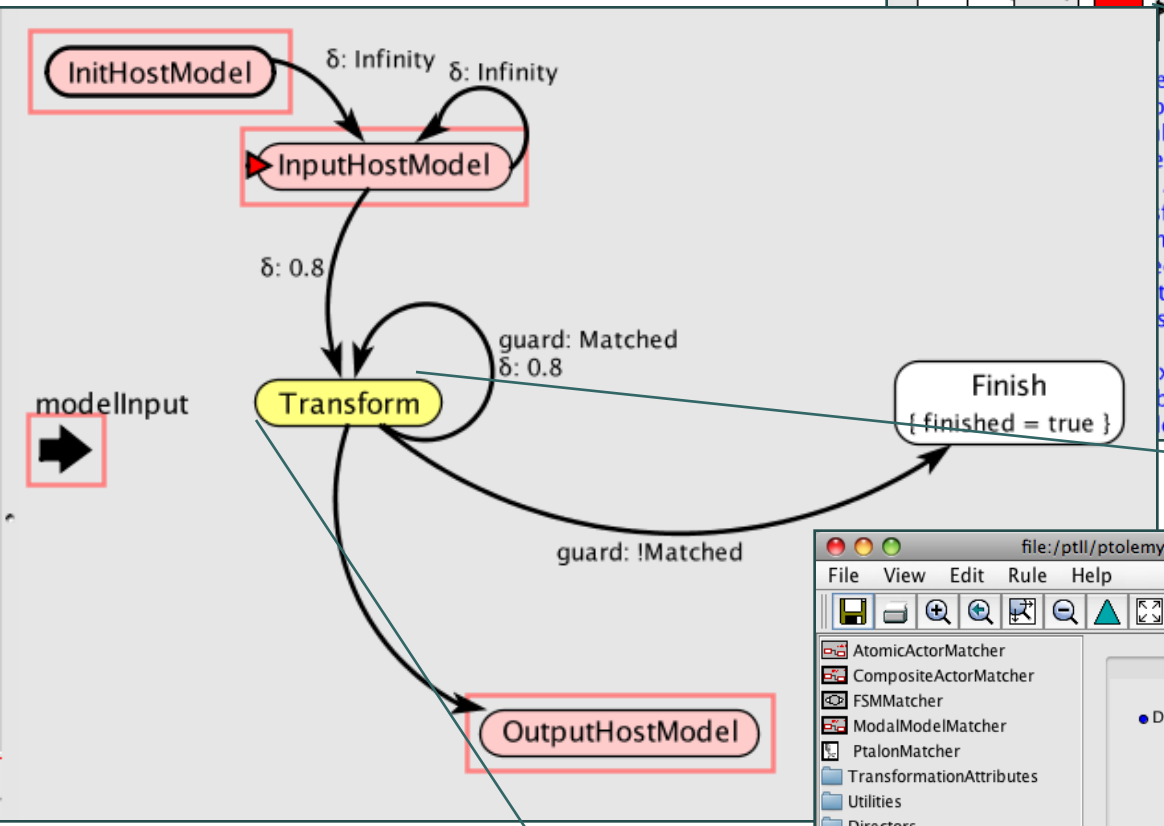
Actor provides a custom visual interface for specifying model transformations

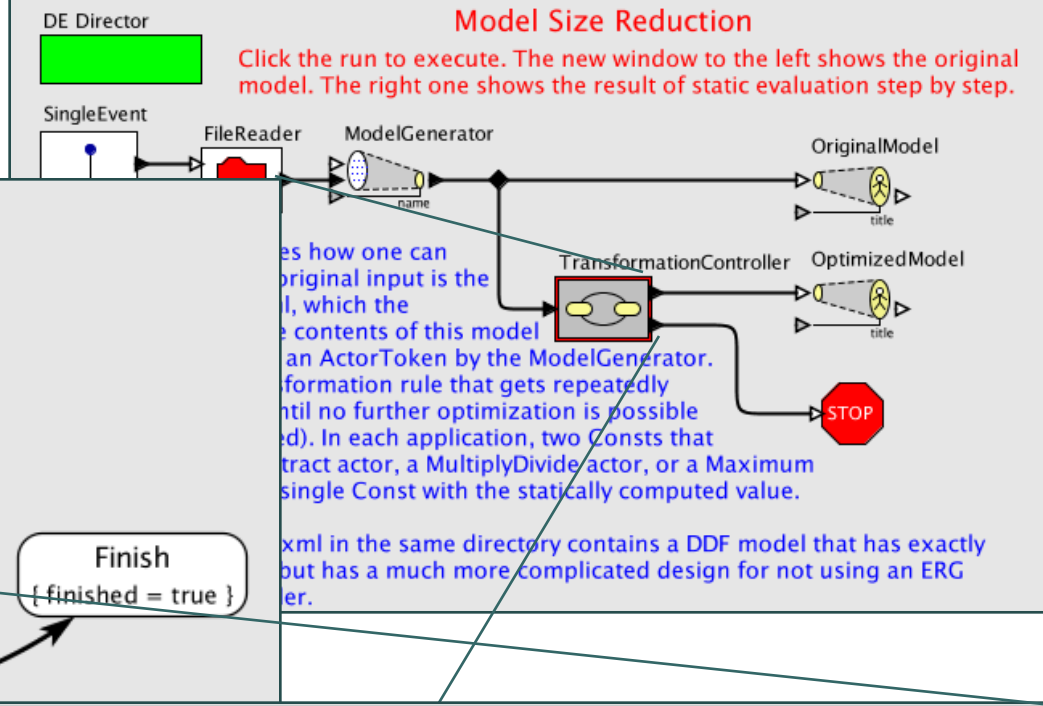
Ptolemy II Model Defines a Workflow

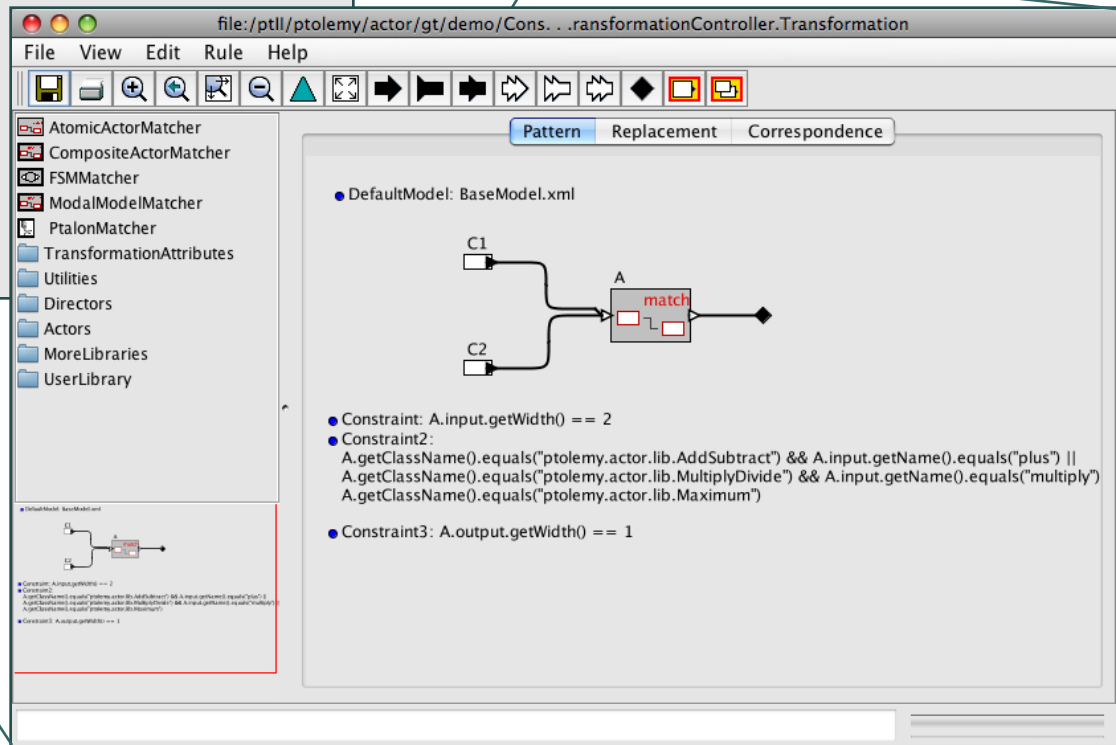
This Ptolemy II model creates and executes a MapReduce application for a parameterized number of machines.



Using Other MoCs







Here we have used Event-Relationship graphs [Schruben 83] to specify the transformation logic.

Summary

- Patterns, replacements, and workflows are all expressed using the same target modeling language(s) as the application.
- Mixing of modeling languages / models of computation (via the Ptolemy II framework) is supported in the application, patterns, replacements, and workflows.
- Visual syntaxes become more scalable and flexible.
- Applications
  - Model optimization
  - Scalable model construction
  - Product families
  - Design refactoring
  - Workflow automation
  - …