Model Transformation with Hierarchical Discrete-Event Control

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Outline

• **Motivation and Contribution**
• Transformation Rules: Syntax and Semantics
• Ptera (Ptolemy Event Relationship Actor)
• Model-Based Transformation
• Conclusion and Future Directions
Motivation

- Models can get large
  - A simplified 4-way Intersection (230 actors, 2000 attributes)
  - How about Street?
  - How about City?
  - Other types? ($n$-way, irregular, European)

- Need automatic model construction and maintenance
• An SDF (synchronous dataflow) model to generate a sine wave with:

$$\sin\left(\frac{2\pi Fn}{Fs}\right)$$

• Static partial evaluation improves run-time performance (similar to program optimization in compilers)
Contribution

• A model transformation tool
  ○ Convenient – an intuitive visual syntax
  ○ Flexible – compositional workflow
  ○ Efficient – by using an appropriate model of computation

• The Ptera model of computation
  ○ Syntax and semantics based on event graphs
  ○ Hierarchical composition
  ○ Composition with DE, FSM and more

• Applications
  ○ Transformation for actor models
  ○ Simulation of discrete-event processes
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• Pattern matching (locate a part of the model)
Intuition of Model Transformation

- Pattern matching (locate a part of the model)
- Replace the part with a more compact design
Intuition of Model Transformation

- Pattern matching (locate a part of the model)
- Replace the part with a more compact design
- Repeat transformations until fixpoint
Control

• A control mechanism is needed
  ○ Transform until fixpoint
  ○ Try multiple alternative transformation rules
  ○ Pause and ask user a question
  ○ Branch with user input or current state
  ○ Perform IO before/after transformation
  ○ ...

• Examples of existing approaches
  ○ Priority (AToM³, AGG)
  ○ Control flow + Statecharts (FUJABA)
  ○ Abstract state machines (VIATRA2)
  ○ Dataflow + Implicit shared variables (GReAT)
  ○ Imperative programs (PROGRES)

• The Ptolemy II approach
  ○ Hierarchical heterogeneous models of computation
  ○ Ptera (Ptolemy event relationship actor)
A Ptera Transformation Workflow

- SimplifyMultiply
- SimplifyDivide
- RemoveMultiply

Constraints:
- M.multiply.getWidth() == 1 && M.divide.getWidth() == 0 && M.output.getWidth() == 1
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Syntax

- Based on event graphs [Schruben 1983]
- Visual representation
  - Nodes are events
  - Edges are scheduling relations
- Compare to FSM
  - Actions on events
  - Can schedule multiple events
  - Timed

CarWash: single queue multiple servers
Execution

- During execution, the event queue stores *instances* of events
- Start by scheduling an instance of each initial event at time 0
- Remove and process the first instance in each *firing*
- Terminate when the event queue becomes empty
Simultaneous Events

Events with instances that

1. coexist in the event queue, and
2. are scheduled to occur at the same time

E.g., Enter and Leave.
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E.g., Enter and Leave.
FIFO and LIFO Policies

• With FIFO (First In First Out) policy

![Diagram of FIFO policy]

• With LIFO (Last In First Out) policy

![Diagram of LIFO policy]
1. With **FIFO**, when $x \cdot t_1 = y \cdot t_2 \land t_1 > t_2$
   ReadOpen → WriteOpen → Read → Write → ReadClose → WriteClose

2. With **LIFO**, always
   (ReadOpen → Read → ReadClose), (WriteOpen → Write → WriteClose)
Execution Algorithm

1. Initialize $E$ to contain all initial events
2. While $E$ is not empty
   a. Remove the top instance $t$ from $E$
   b. Execute $t$’s actions
   c. Terminate if $t$ is a final event
   d. Schedule events in $E$ in the order of
      1. Time stamp
      2. FIFO or LIFO policy
      3. Event name
      4. Scheduling relation name
Model Hierarchy: Previous Attempts

- Submodel associated with scheduling relation [Schruben 1995]

- Submodel associated with event [Schruben 1995]

- LEGOos (Listener Event Graph Objects) [Buss & Sánchez 2002]
Model Hierarchy: The Ptera Approach

- A submodel is itself a model
  - No difference in syntax
  - Conceptually equipped with an isolated event queue
  - A global notion of model time

- Implication: events (or tasks) are no longer instantaneous
  - Start of an event causes start of its submodel
  - End of the submodel causes end of the event
Hierarchical CarWash

- Hierarchical workflow:
  - Global time, separate event queues
  - A composite task (CT) is composed of smaller tasks
  - Execution of CTs interleave
  - The whole workflow is a top-level CT

Hierarchical workflow diagram with tasks and time stamps.
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# Transformation Workflow

## Table of Parameters and Usage

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>Temporarily store the model to be transformed</td>
</tr>
<tr>
<td>Event</td>
<td>Action</td>
</tr>
<tr>
<td>Configure</td>
<td>Pop up a dialog for the user to input values of some variables</td>
</tr>
<tr>
<td>Execute</td>
<td>Execute the model in the Model variable to completion</td>
</tr>
<tr>
<td>InitModel</td>
<td>Set the Model variable to contain an empty model</td>
</tr>
<tr>
<td>InitModelWithContainer</td>
<td>Set the Model variable to contain the container of this workflow</td>
</tr>
<tr>
<td>ListDirectory</td>
<td>List the names of all files in a directory</td>
</tr>
<tr>
<td>Match</td>
<td>Match a pattern with the model in the Model variable</td>
</tr>
<tr>
<td>ReadModel</td>
<td>Read the model stored in a file into the Model variable</td>
</tr>
<tr>
<td>Report</td>
<td>Report a message or an error to the user</td>
</tr>
<tr>
<td>Sleep</td>
<td>Wait for a certain amount of real time (in seconds)</td>
</tr>
<tr>
<td>Stop</td>
<td>Clear the event queue</td>
</tr>
<tr>
<td>Test</td>
<td>Perform pure testing (on the outgoing edges) with no side effect</td>
</tr>
<tr>
<td>Transform</td>
<td>Transform the model in the Model variable with a basic transformation</td>
</tr>
<tr>
<td>View</td>
<td>Show the model in the Model variable in a separate window</td>
</tr>
<tr>
<td>WriteModel</td>
<td>Output the model in the Model variable into a file</td>
</tr>
</tbody>
</table>

## Diagram

A simple workflow for repeated transformation
Hierarchical Workflow

- A hierarchical workflow to break down complexity
- Schedule multiple events (compare to FSM and control flow)
- Model time is useful for
  - animation
  - specifying time or cost
  - simulation
  - ...

InitModel → ReadModel → ViewOriginalModel → Transform → ViewOptimizedModel

Start
{ again = false }

SimplifyMultiply
SimplifyDivide
RemoveMultiply

NeedRepeat
{ again = true }

guard: again
δ: 1.0

Model

Feng, Dissertation Talk, 05/06/2009
Comparison

- Priority: not expressive enough
- Control flow, state machine: bounded state, not hierarchical, not timed
- Imperative program: lack of abstraction
- Dataflow: overhead of message passing

Shared variables are introduced in GReAT to improve performance, but they cause new problems.
Applications

- **Model optimization**
  E.g., partial evaluation, removal of nonfunctional parts

- **Model construction**
  E.g., generating a family of products

- **Model refactoring**
  E.g., flattening hierarchy, introducing hierarchy

- **Simulation**
  E.g., Conway’s game of life
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**Conclusion:**
- Transformation rule in the same modeling language
- Model-based transformation is essentially a model
- Ptera
  - Convenient and expressive
  - Compositional
  - Timed
  - Avoids message passing

**Future Directions:**
- Analyze properties of transformations
- Compose Ptera with other MoCs (DE and FSM studied)
- Model checking (bound of event queue, simultaneous events, termination condition, ...)
- Behavior-preserving concurrent and distributed execution
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