Synchronous Statecharts

for executing Esterel with Ptolemy

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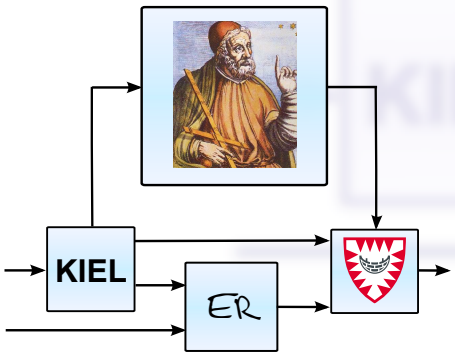
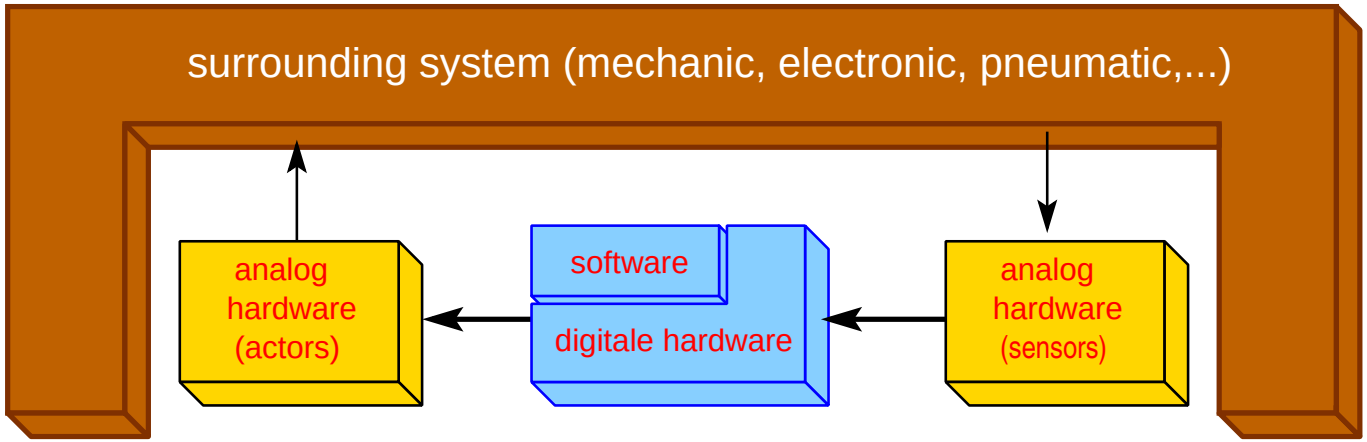


DREAMS Seminar,
03. OCT 2011

Embedded Systems

- Designed for dedicated applications inside a surrounding system
- „A computer that is not perceived as such“
- Often non-terminating SW, continuous interaction w/ HW
  $\Rightarrow$ Reactive Systems
- Often safety-critical systems

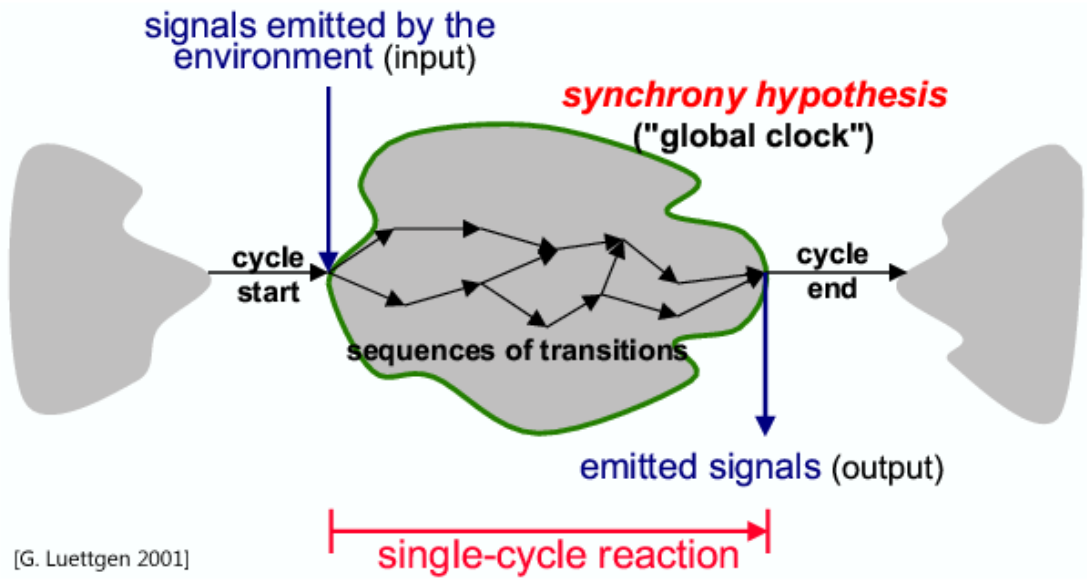
Reactive Systems



- Continuous, non-terminating interaction
- Pace is controlled by the environment
- Computation (output) of steps of the reactive system $\Rightarrow$ Reaction vs. interaction
- When to produce outputs? In real-time! $\rightarrow$ WCRT

Synchronous Languages

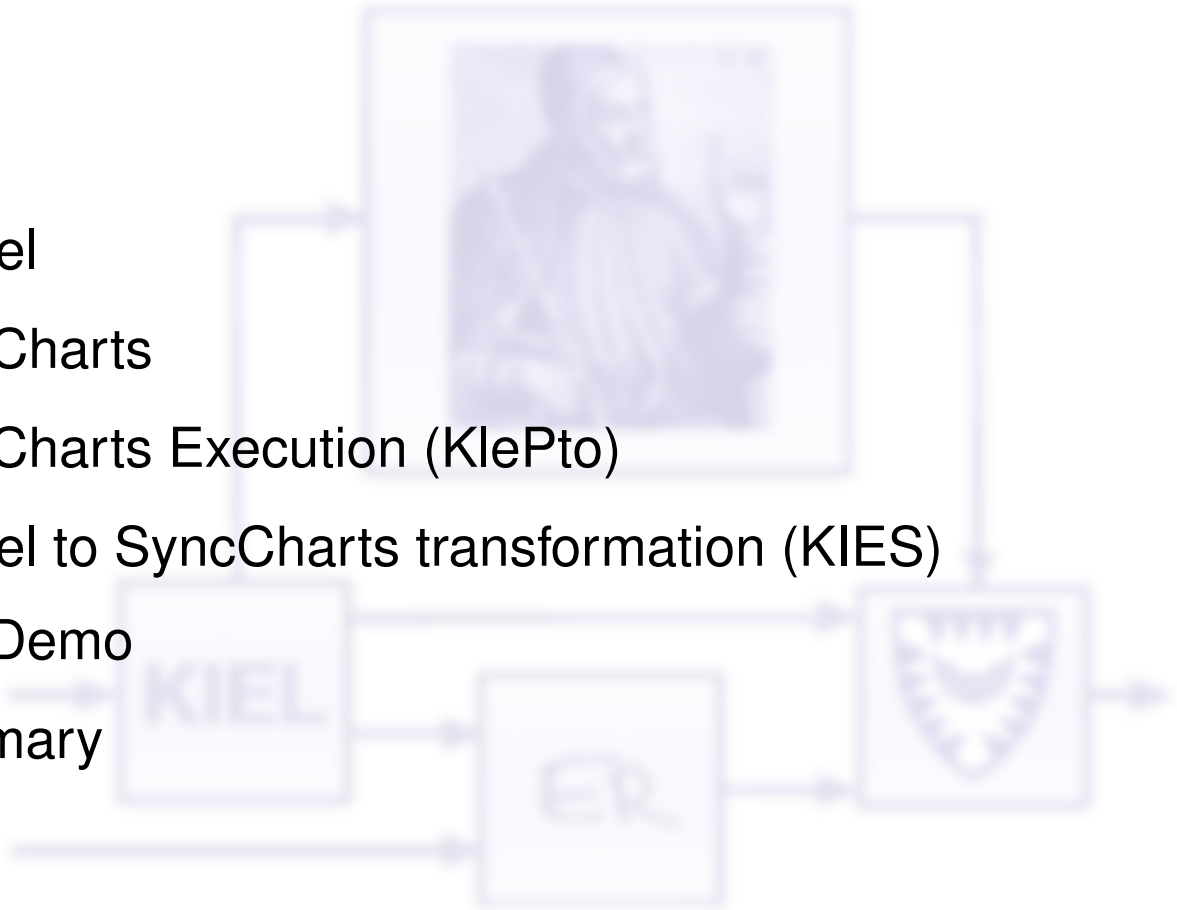
- Separate concerns
  1. Functionality
  2. Timing
- Specify functionality, logical timing only (order)
- Goal: Fully deterministic behavior
- Assume zero reaction time ⇒ perfect synchrony w/ interaction



Motivation

- Synchronous model of computation (MoC):
  - Esterel, SyncCharts, SC (control flow)
  - Lustre, Signal, SCADE (data flow)
  - Ptolemy (SR domain)
- SyncCharts a synchronous statechart dialect
  - $\rightarrow$ Primary example for KIELER framework
- KlePto: Executing SyncCharts w/ Ptolemy
- KIES: Esterel to SyncCharts transformation
- $\Rightarrow$ Execute Esterel w/ Ptolemy

Overview



- Esterel
- SyncCharts
- SyncCharts Execution (KlePto)
- Esterel to SyncCharts transformation (KIES)
  - Demo
- Summary

What is Esterel?

- Synchronous language
- Imperative
- Control flow oriented
- Deterministic programs
- History
  - Developed by J.-P. Marmorat and J.-P. Rigault (at Ecole des Mines de Paris)
  - G. Berry developed a formal semantics for Esterel in 1983
  - Esterel v5: Has been stable since late 1990s
  - Esterel v7: same principles as in v5, several extensions

Synchrony in Esterel

Definition[Perfect Synchrony]
A system works in perfect synchrony, if all reactions of the system are executed in zero time. Hence, outputs are generated at the same time, when the inputs are read.

- In practice, 'zero time' means before the next interaction
- Macro steps consist of only finitely many micro steps
  - $\Leftrightarrow$ No data dependent loops in a macro step
- WCET (high-level, low-level) to meet real-time constraints

Basic Concepts

- Imperative language
  - Statement (mostly instantanous)
  - Sequence of statements is a statement $\rightarrow s_1 ; s_2$
- Control flow oriented $\rightarrow$ `pause` statement
- Modules
  - Esterel programs are a list of modules
  - Module body is a statement
- Signals
  - Communication
  - Emission, Test $\rightarrow$ `emit S`, `present S`, `await S`
- Concurrency $\rightarrow$ `[` s_1 `||` s_2 `||` `...` `||` s_n `]`
- Preemption $\rightarrow$ `[weak] abort` s `when S`

Signals

Definition[Signal Coherence]
A signal is either present or absent within a macro tick but never both.

- Present iff emitted, absent otherwise
  - ”iff emitted” means iff an `emit` statement must be executed
- Constructiveness
  - Speculative executions are not allowed
  - E.g., `present S then emit S else emit S`

Example: ABRO

```
module ABRO:

input A, B, R;
output O;

loop
   abort
      [ await A  || await B ];
      emit O;
      halt
   when R
end loop

end module
```

„The system has boolean valued inputs A, B, R, and an output O. Output O shall be true as soon as both inputs A and B have been true. This behavior should be restarted if R is true.“

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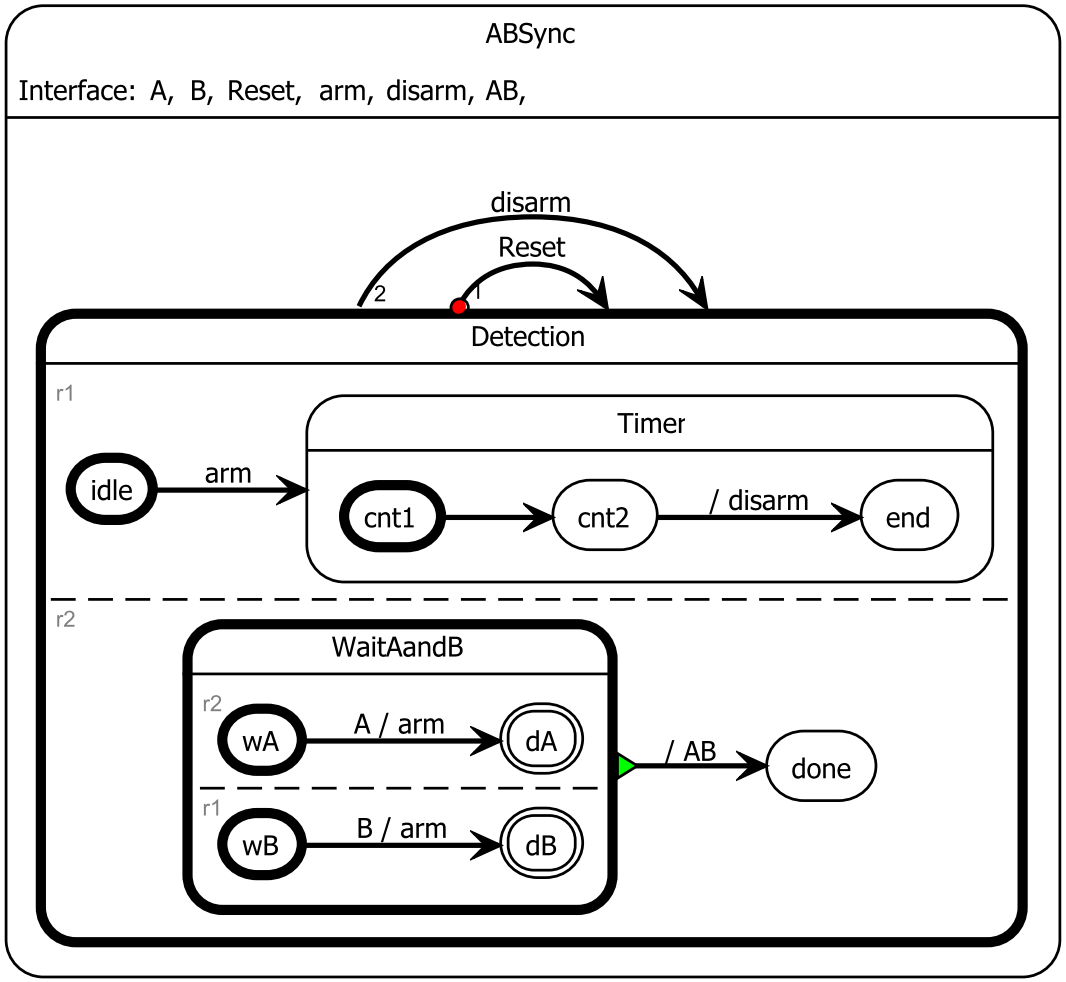
What are SyncCharts?

- Statechart dialect (Statecharts proposed by David Harel [1987])
- Built on Esterel semantics
- Invented by Charles André
- Safe State Machines
  - Was supported by the commercial tool Esterel Studio, which uses Esterel as intermediate step in code generation

SyncCharts



Charles André, Computing SyncCharts Reactions, 2003

- Statechart dialect
- Mealy machine with
  - Parallelism, hierarchy, compound events, broadcast
- Synchrony hypothesis
  - Discrete ticks
  - Computations take no time

Harel-Statecharts vs. SyncCharts—Similarities

SyncCharts are made up of elements common to most Statecharts dialects:

- States
- Initial/terminal states
- Transitions
- Signals/Events
- Hierarchy
- Modularity
- Parallelism

Harel-Statecharts vs. SyncCharts—Differences

SyncCharts differ from other implementations of Statecharts:

- Synchronous framework
- Determinism
- Compilation into backend language Esterel
- No interpretation for simulations
- No hidden behaviour
- Multiple events
- Negation of events
- No inter-level transitions

Example: ABRO

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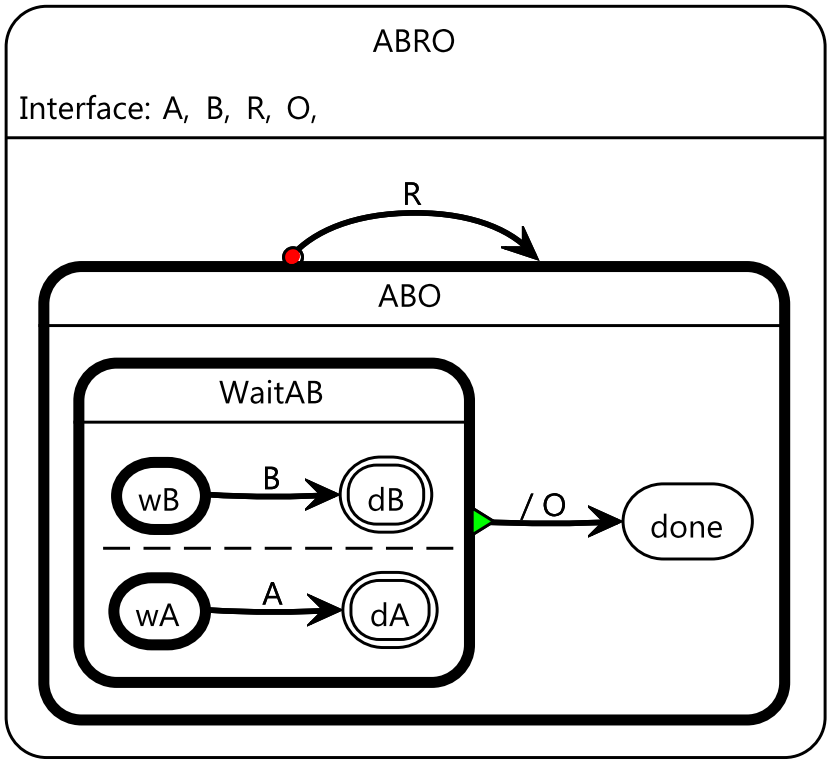

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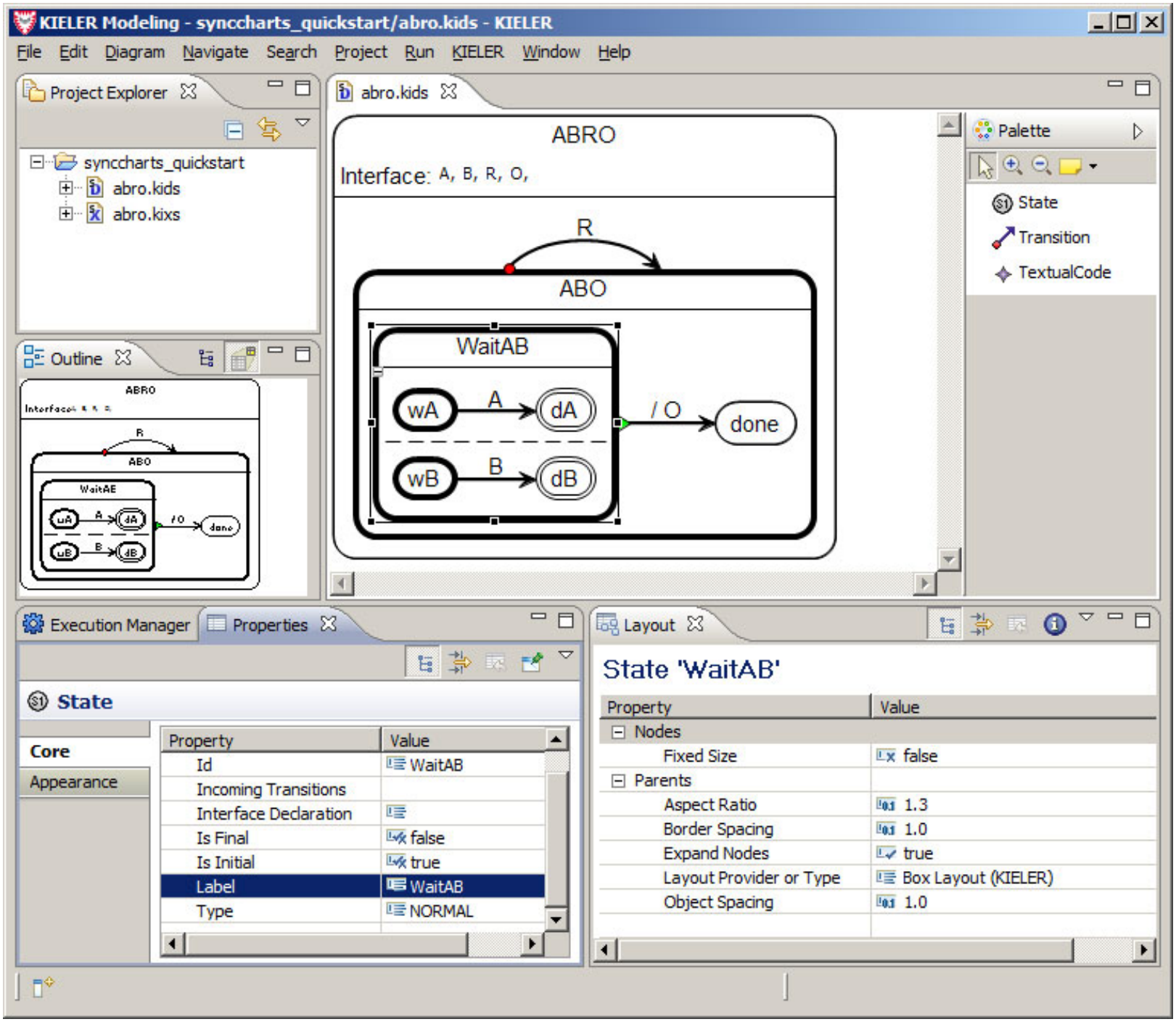
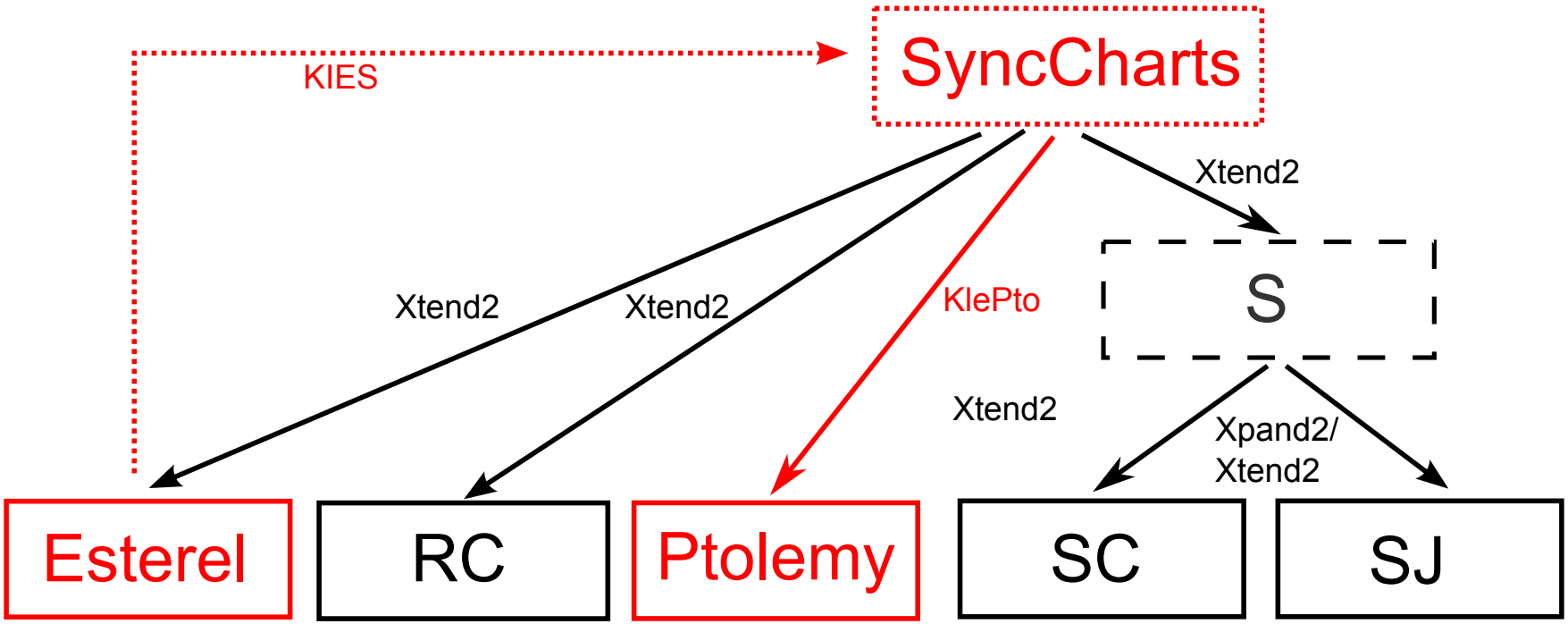
What is KIELER?

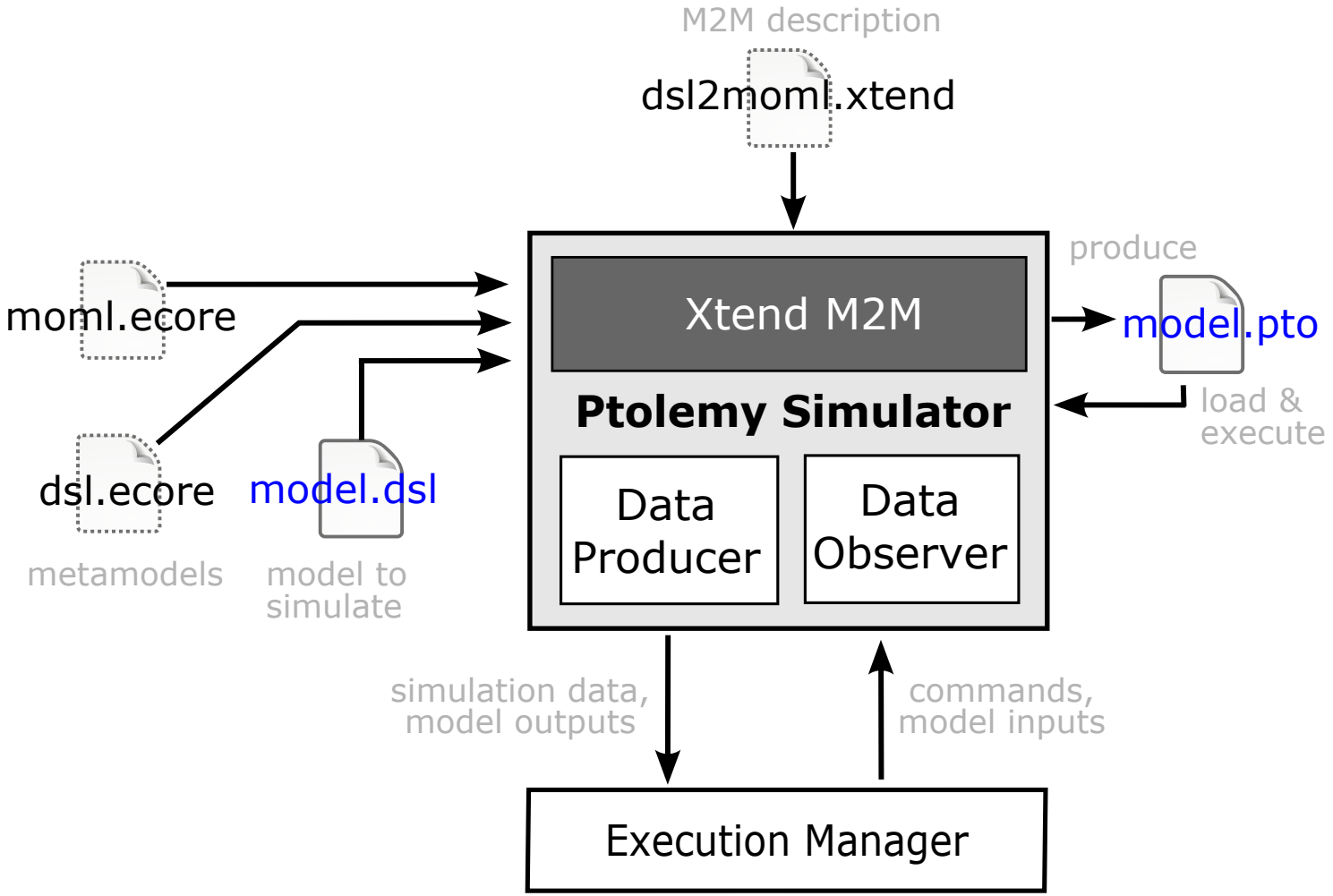
- Kiel Integrated Environment for Layout Eclipse Rich Client
- Modeling platform and test bed
  - Improve pragmatics
- Open source and Eclipse based (plug-ins)
- General concepts:
  - Generic approaches
  - Symbiosis w/ Eclipse technologies (e.g., EMF, GMF, TMF, Xpand, Xtend)
  - Interfaces to other tools (Ptolemy, Papyrus)


KIELER Modeling - synccharts_quickstart/abro.kids - KIELER
File Edit Diagram Navigate Search Project Run KIELER Window Help
Project Explorer
synccharts_quickstart
abro.kids
abro.kixs
Outline
abro.kids
ABRO
Interface: A, B, R, O,
R
ABO
WaitAB
wA
A
dA
/ O
done
wB
B
dB
Palette
State
Transition
TextualCode
Execution Manager
Properties
State
Core
Appearance
Property
Value
Id
WaitAB
Incoming Transitions
Interface Declaration
Is Final
false
Is Initial
true
Label
WaitAB
Type
NORMAL
Layout
State 'WaitAB'
Property
Value
Nodes
Fixed Size
false
Parents
Aspect Ratio
1.3
Border Spacing
1.0
Expand Nodes
true
Layout Provider or Type
Box Layout (KIELER)
Object Spacing
1.0

SyncCharts Execution in KIELER



KlePto Overview



[Semantics and Execution of Domain Specific Models, MEMWe 2010]

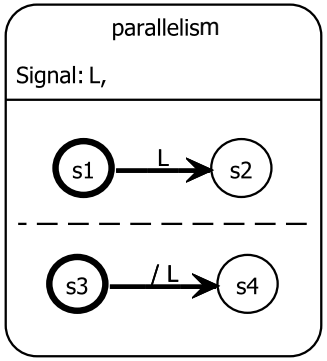
Ptolemy

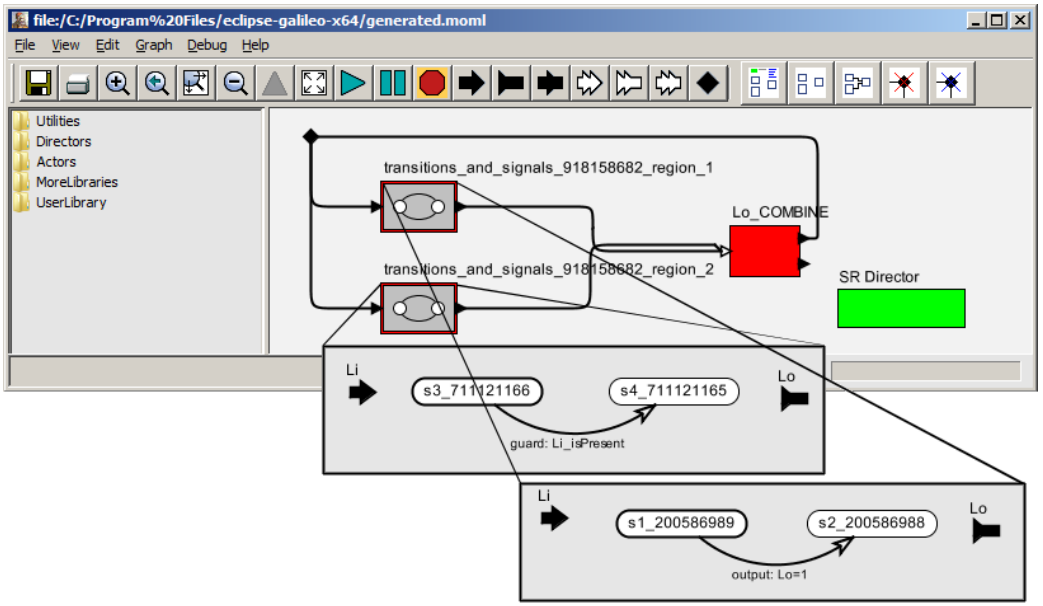
- „The Ptolemy project studies heterogeneous modeling, simulation, and design of concurrent systems.“

  Introduction to Ptolemy II, UC Berkeley

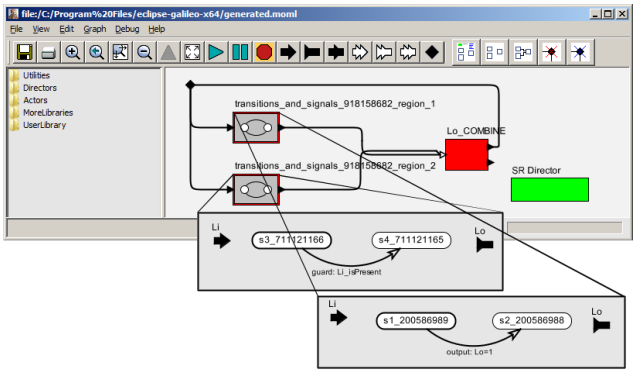
- Executable Models to describe behavior of reactive systems
- Ptolemy models are a set of interacting components $\rightarrow$ *Actor-Oriented Design*

SyncCharts in Ptolemy - Today





SyncCharts in Ptolemy - ModalModels and SR



- ModalModels do *cannot analysis* to expose signals that cannot be emitted
  - Signals can then be set to absent
- ModalModels can do this hierarchically
- Ptolemy models can be heterogeneous:
  - State refinement does not need to be a state machine (e.g., SR)
  - $\rightarrow$ Currently limits this approach
  - $\rightarrow$ Ptolemy Control Flow Domain (w/ Chris Shaver)

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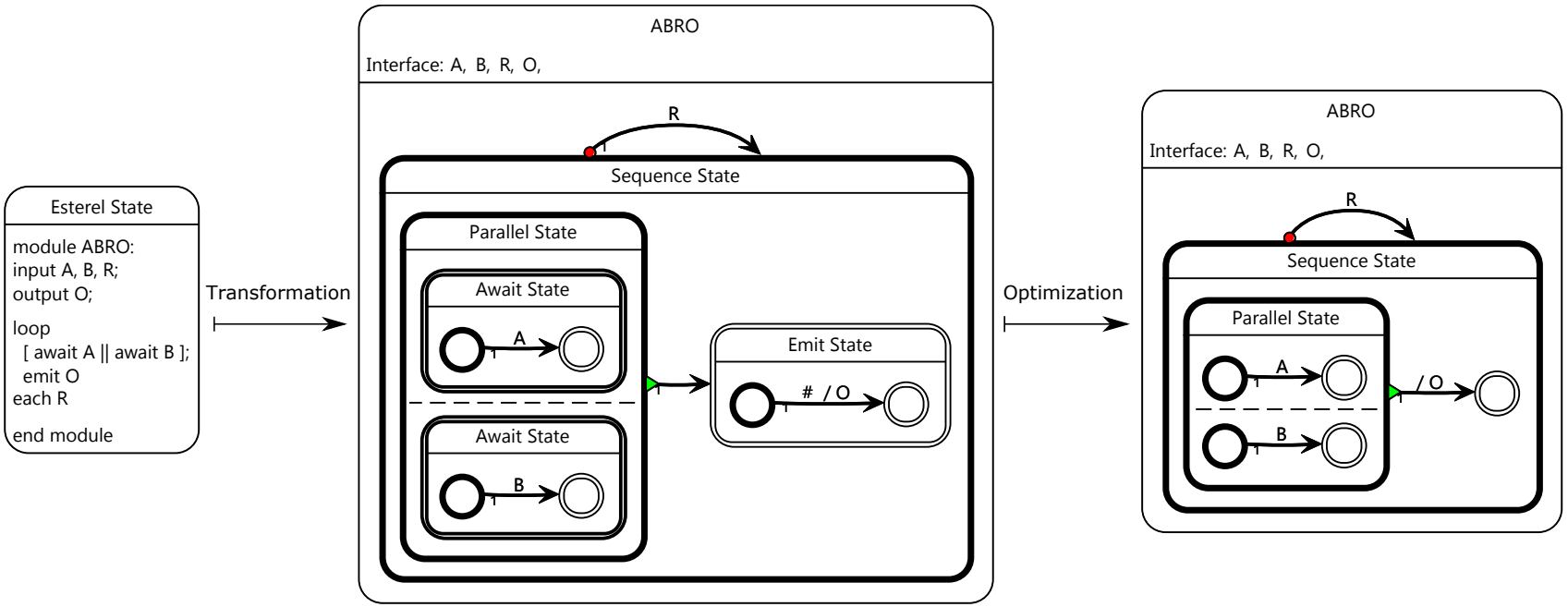
Model transformations

- Applications
  - Synthesize multiple (graphical/textual) views from one model
  - Edit a model (refactoring, optimization)
  - Code generation
  - Simulation desires
- Drawbacks
  - Large and inflexible
  - Hard to visualize
  - Hard to debug
  - Not interactive
- Goal of KIES: Address the above drawbacks
  $\rightarrow$ Use case: KIELER Esterel to SyncCharts transformation

Esterel to SyncCharts

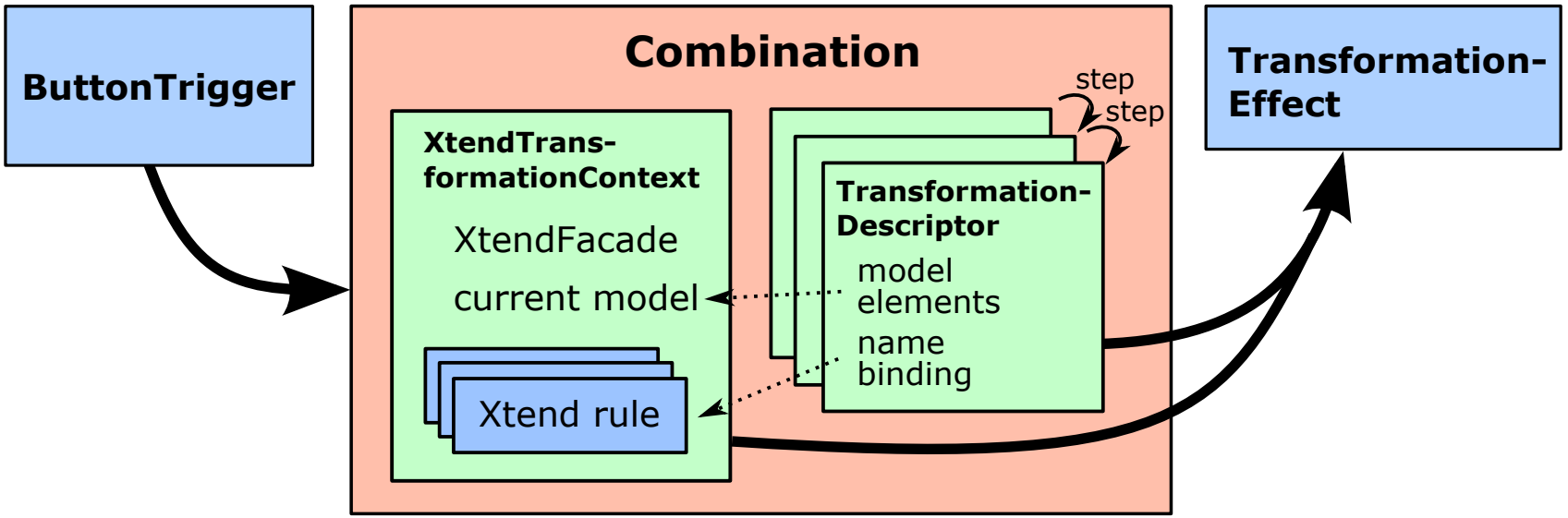


Transformation Rule

"A transformation rule is a description of how one or more constructs in the source language can be transformed into one or more constructs in the target language" (Mens and Gorp)

- Esterel to SyncCharts
  - One rule for each Esterel statement
- SyncCharts Optimization
  - One rule for a certain SyncCharts state
- Rules presented by Lars Kühl (also formal proofs for Esterel to SyncCharts)

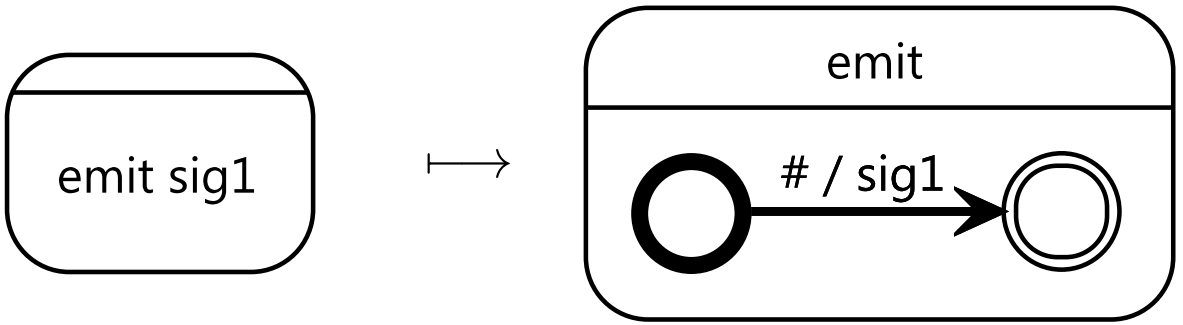
Implementation



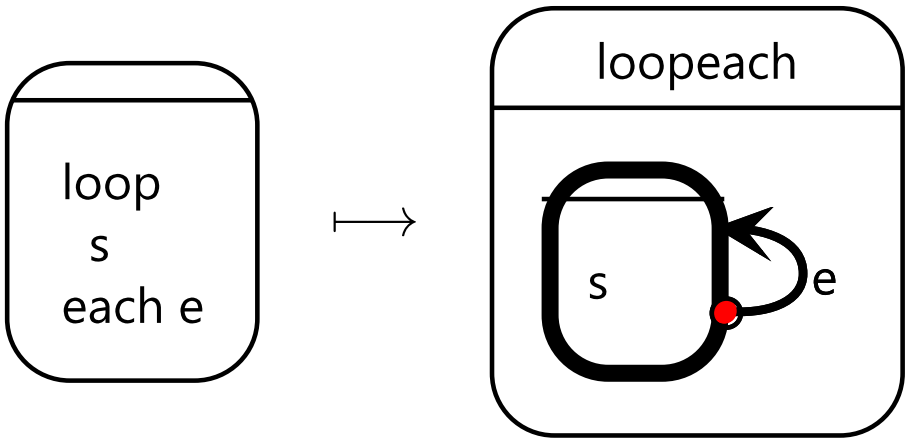
[Interactive Transformations for Visual Models, MEMWe 2011]

Esterel to SyncCharts

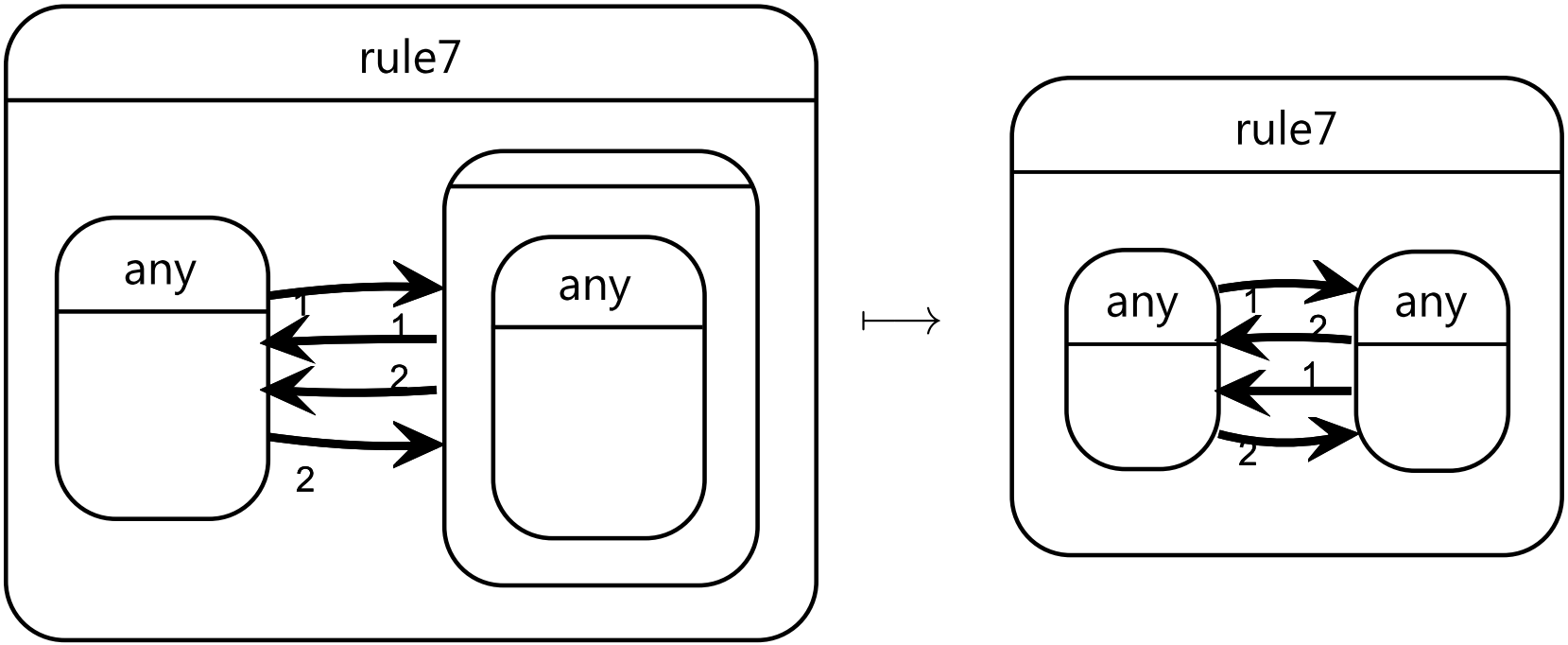
emit



loop-each



SyncCharts Optimization



KIELER Demo

LIVE DEMO

Summary

- Reasearch goals (long term)
  - Investigate on synchronous languages
  - Bringing together graphical and textual syntax
  - Integrate Esterel in KIELER
    - Improve pragmatics
    - Validation purposes (SC and ControlFlow Domain)
- Reasearch goals (near term)
  - Modular and interactive transformations
    - Understand
    - Debug
  - Teaching
- Acknowledgements: Reinhard v. Hanxleden, Ulf Rüegg

To Go Further

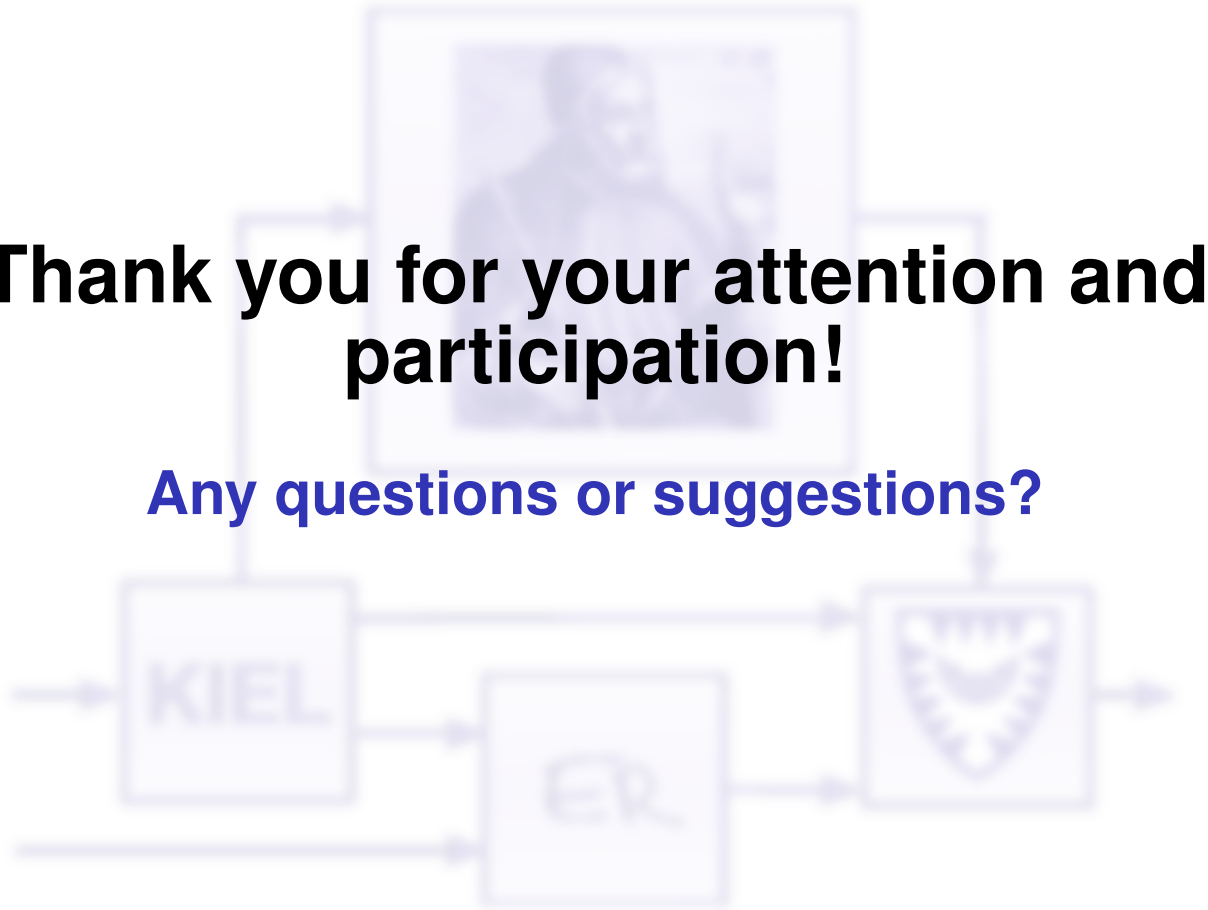

CHARLES ANDRÉ.
Semantics of SyncCharts, 2003.


GÉRARD BERRY.
The Esterel v5 Language Primer, 2000.


MOTIKA, C.
Semantics and execution of domain specific models—KlePto and an execution framework.


UC BERKELEY, EECS DEPT.
Ptolemy webpage.
http://ptolemy.eecs.berkeley.edu/.


UNI KIEL, REAL-TIME AND EMBEDDED SYSTEMS GROUP.
KIELER webpage.
http://www.informatik.uni-kiel.de/en/rtsys/kieler/.



Thank you for your attention and participation!

Any questions or suggestions?