Interaction-based Paradigm

José Proença

Seminar Series, 11 April 2019

CISTER
Research Center in
Real-Time & Embedded
Computing Systems

2011
PhD @ CWI
Amsterdam (NL)

Coordination
Formal methods
Concurrency
Software Engineering

2005
Lic. @ UMinho
Braga

Mathematics &
Computer Science

2015
Postdoc @
KU Leuven (BE)

Programming languages
Variability

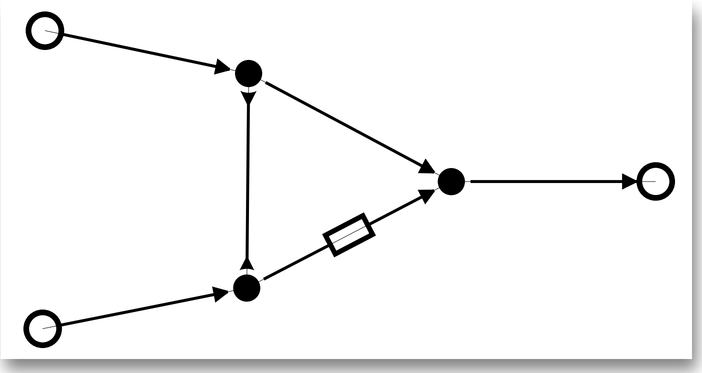
Wireless Sensor Netw.
Reactive programming

2019
Postdoc @ INESC TEC
Braga

Softw. Architectures
Design Calculi

Feb'19
Postdoc @ CISTER

Outline



What is **Coordination?**

Context & motivation

Reo coordination language

Recent research tracks

Analysis tools

Composing families of Timed Automata

Composing tasks in a RTOS

Software architecture for reactive systems

There is **no general-purpose**, **universally tailored**, approach to architectural design of **complex** and **reactive** systems

How to build and maintain a system built out of a **composition** of **reactive** entities

Models of Concurrency

Traditional models are **action-based**

- Petri nets
- Work flow / Data flow
- Process algebra / calculi
- Actor models / Agents
- ...

Interaction appears as an **implicit side-effect**;
Makes coordination of interaction more difficult to

- Specify
- Verify
- Manipulate
- Reuse

Interaction with process algebra

```
act
  g, r, b, d : String    % synchronisation points
  print, genG, genR;

proc
  B = b(t) . print(t) . d̅("done") . B
  G = g(k) . genG(t) . b̅(t) . d(j) . r̅(k) . G
  R = r(k) . genR(t) . b̅(t) . d(j) . g̅(k) . R

init
  G || R || B || g̅("token")
```

Model constructed by composing **actions** into more complex actions

Where is the INTERACTION?

Interaction with shared memory

```
private final bufferSemaphore = new Semaphore(1);
private final redSemaphore    = new Semaphore(0);
private final greenSemaphore  = new Semaphore(1);
private String buffer = Empty;
```

Shared

- Where is the green text computed?
- Where is the red text computed?
- where is the text printed?
- where is the protocol?
  - What determines who goes first?
  - What determines producers alternate?

Producer 1

```
while (true) {
  sleep(5000);
  greenText = ...;
  greenSemaphore.acquire();
  bufferSemaphore.acquire();
  buffer = greenText;
  bufferSemaphore.release();
  redSemaphore.release();
}
```

Producer 2

```
while (true) {
  sleep(5000);
  redText = ...;
  redSemaphore.acquire();
  bufferSemaphore.acquire();
  buffer = redText;
  bufferSemaphore.release();
  greenSemaphore.release();
}
```

Consumer

```
while (true) {
  sleep(4000);
  bufferSemaphore.acquire();
  if(buffer != EMPTY) {
    println(buffer);
    buffer = EMPTY;
  }
  bufferSemaphore.release();
}
```

Implicit **Interaction**

Interaction (protocol) is implicit in action-based models of concurrency

Interaction is a by-product of processes executing their actions

- Action *a* of process A **collides** with action *b* of process B
- **Interaction** is the specific (timed) sequence of such collisions in a run
- **Interaction protocol** is the (timed) sequence of the ***intended*** collisions in such a sequence.

How can the intended and the coincidental be differentiated?

How can the sequence of intended collisions (the interaction protocol) can be
- Manipulated?
- Verified?
- Debugged?
- Reused ?

Interaction with components

Shift from class inheritance to object composition

Avoid interference between inheritance and encapsulation and pave the way to a development methodology based on third-party assembly of components

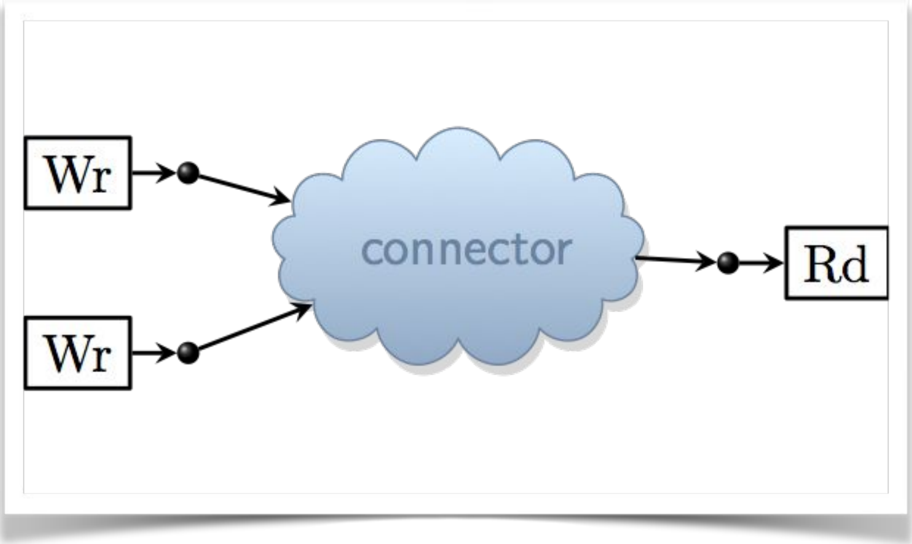
Move from an action-based to an interaction-based model of concurrency

Black box computation units

Canvas to drop them

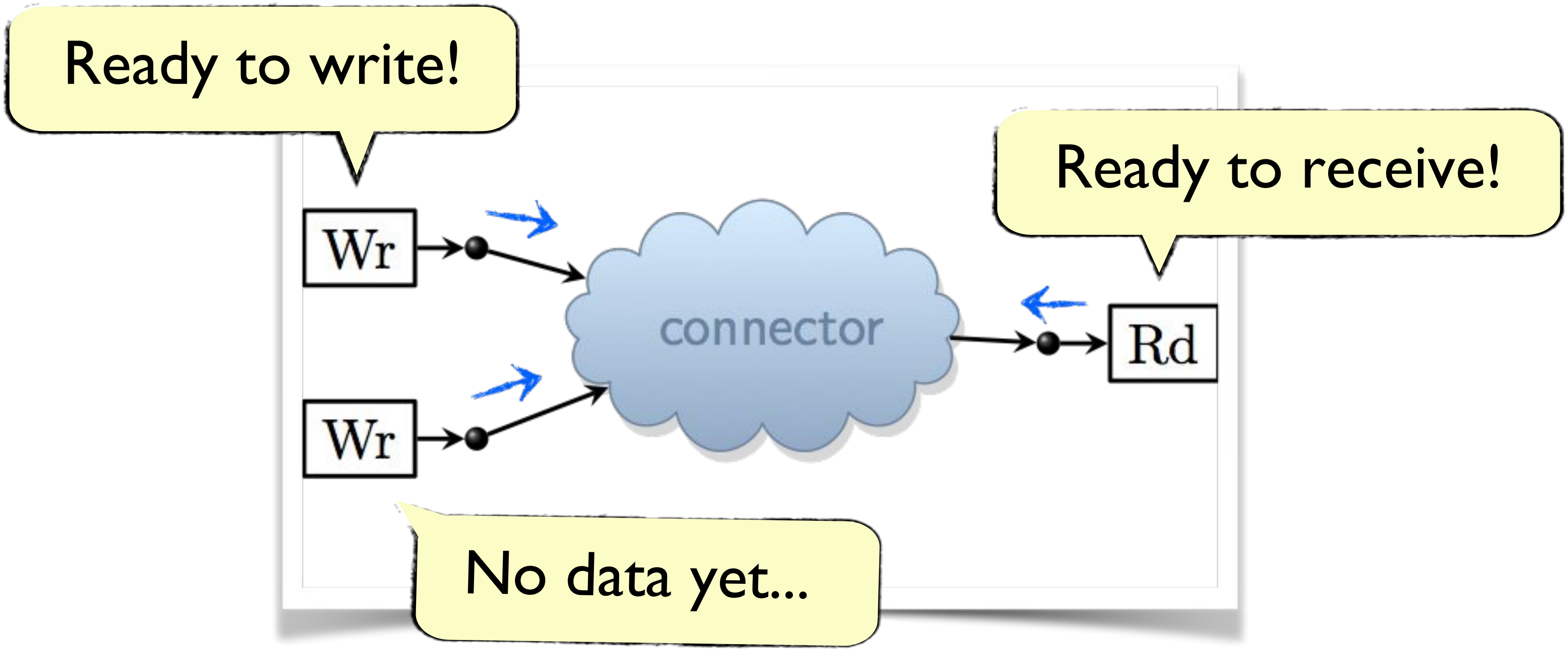
Connections via wires

Component coordination in Reo

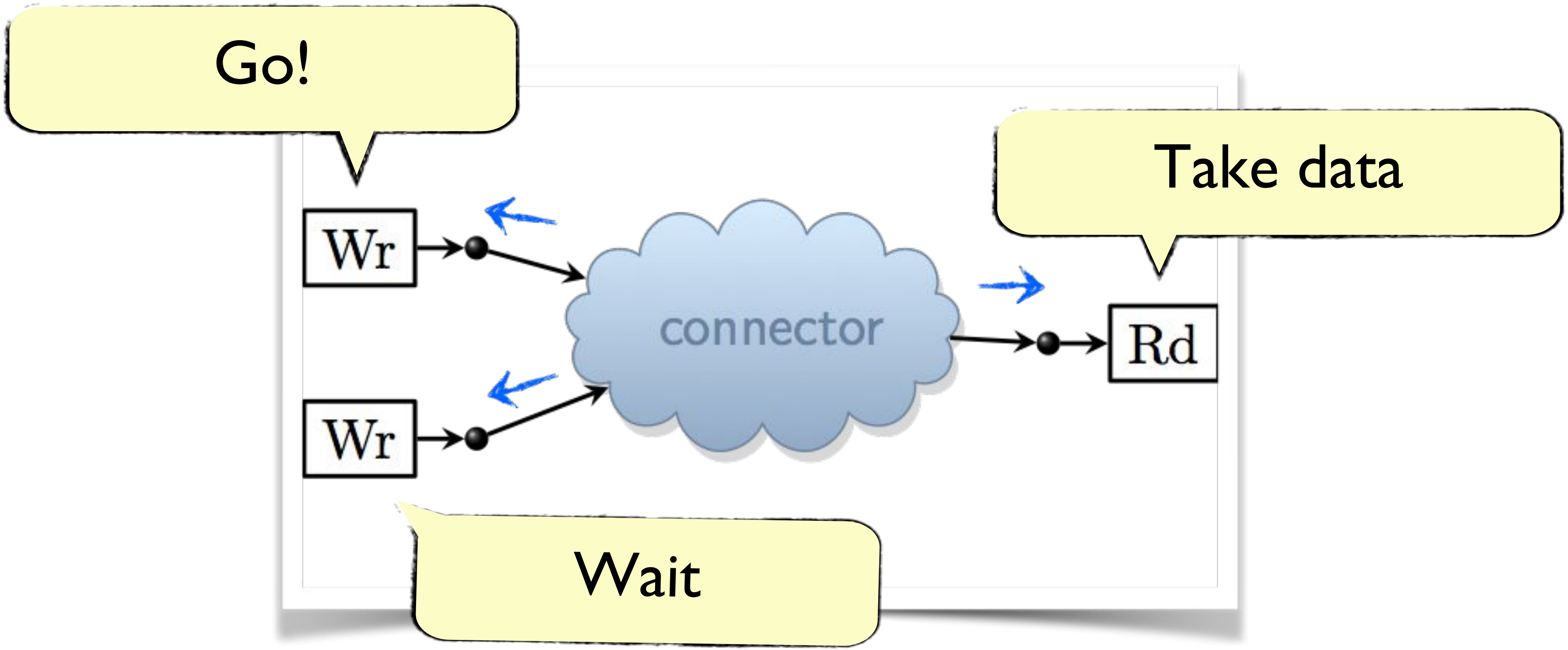


- Exogenous coordination
- Compositional (channel based)
- Synchronous (atomic)
- Coordination is constrained interaction

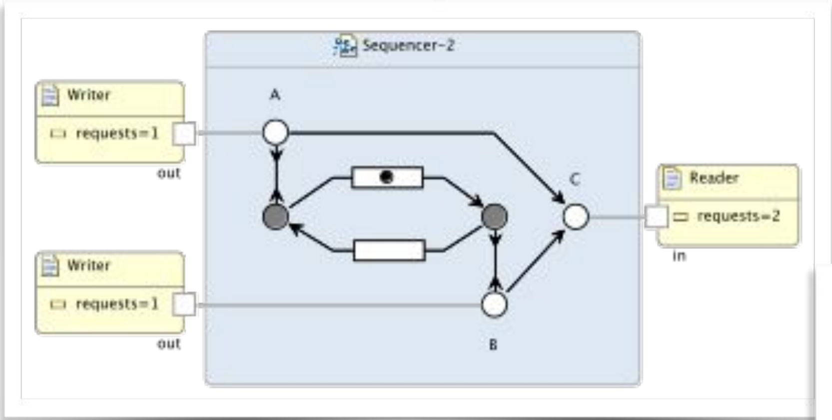
Discrete atomic steps

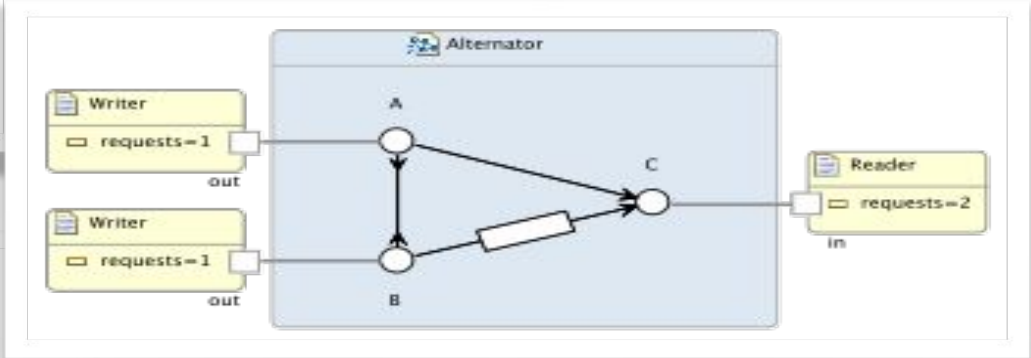


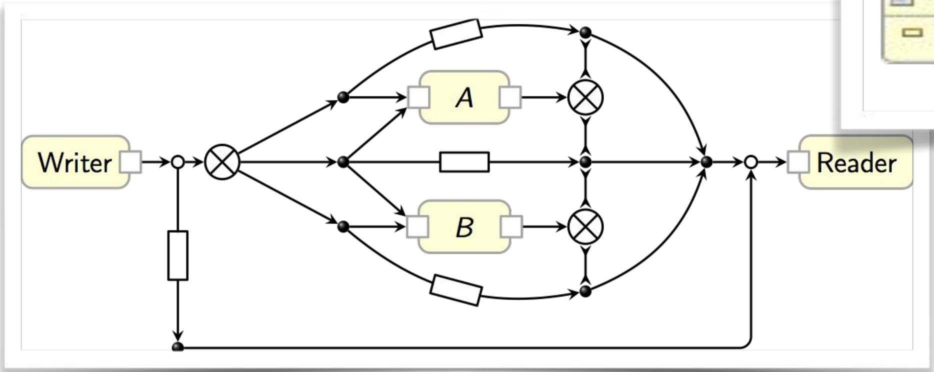
Discrete atomic steps



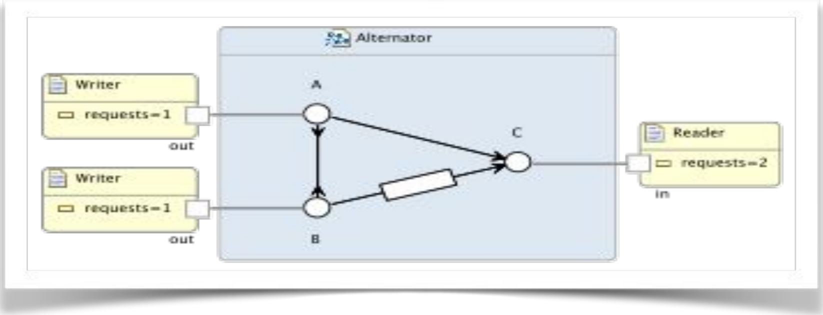
Reo: Channel composition







Reo

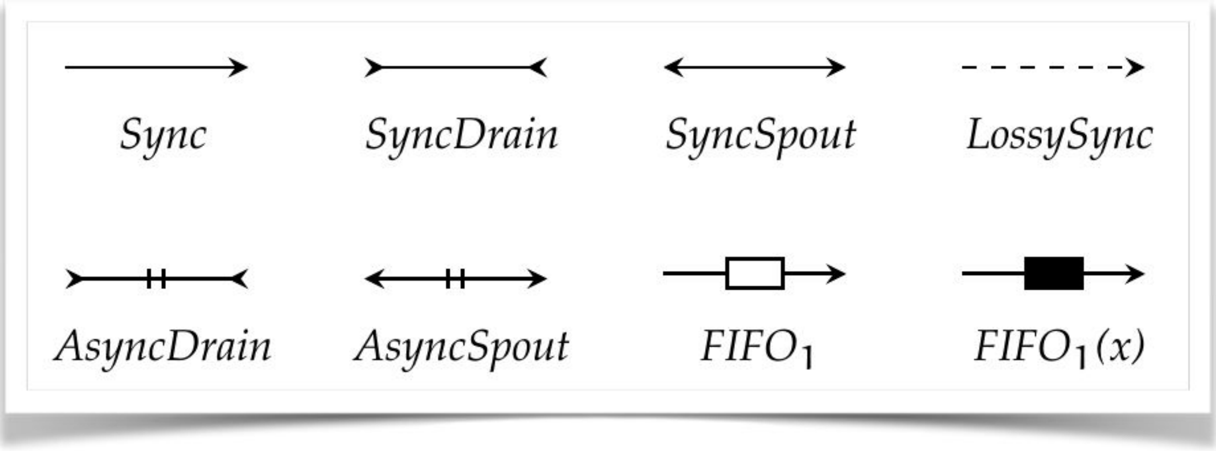


- Language for compositional construction of interaction protocols
- **Interaction** is the only first-class concept in Reo:
  - Explicit constructs representing interaction
  - Composition operators over interaction constructs
- Protocols manifest as a connectors
- In its graphical syntax, connectors are graphs
  - Data items flow through channels represented as edges
  - Boundary nodes permit (components to perform) I/O operations
- Formal semantics (various formalisms - shown later)
- Tool support: draw, animate, verify, compile

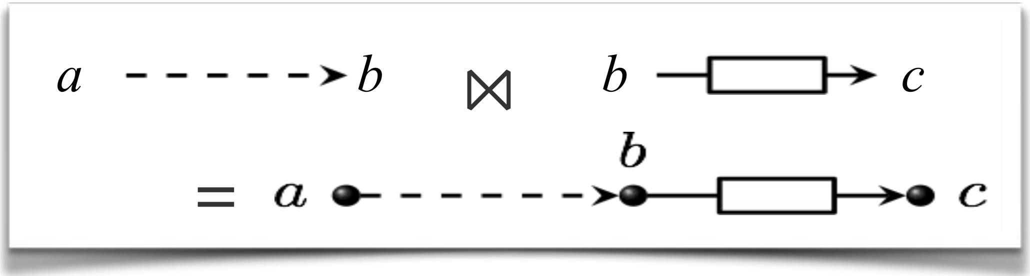
Reo connectors

- Source end: through which data enters the connector
- Sink end: through which data comes out of the connector

Examples:

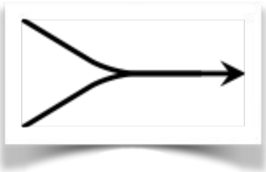


Composing Reo connectors

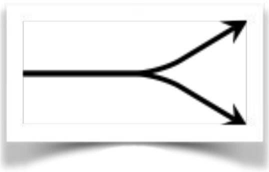


join
source ends
with
sink ends

one to one



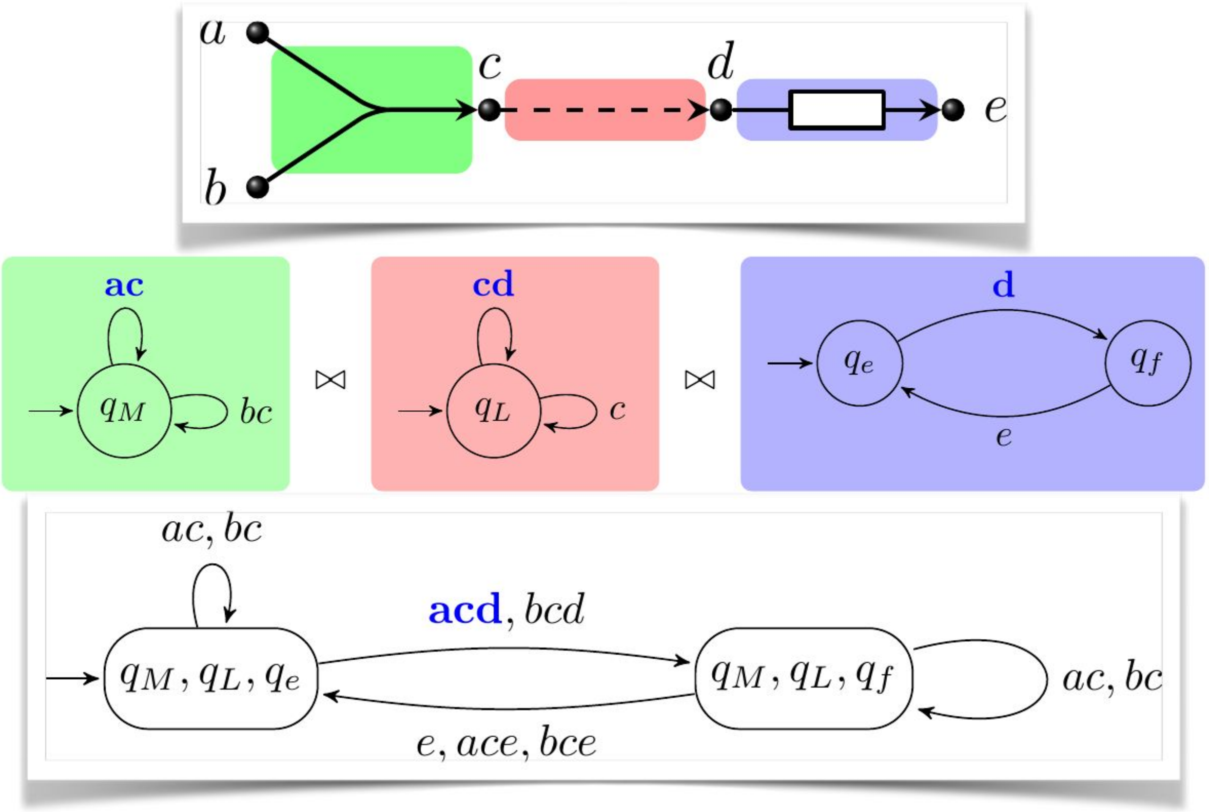
merger



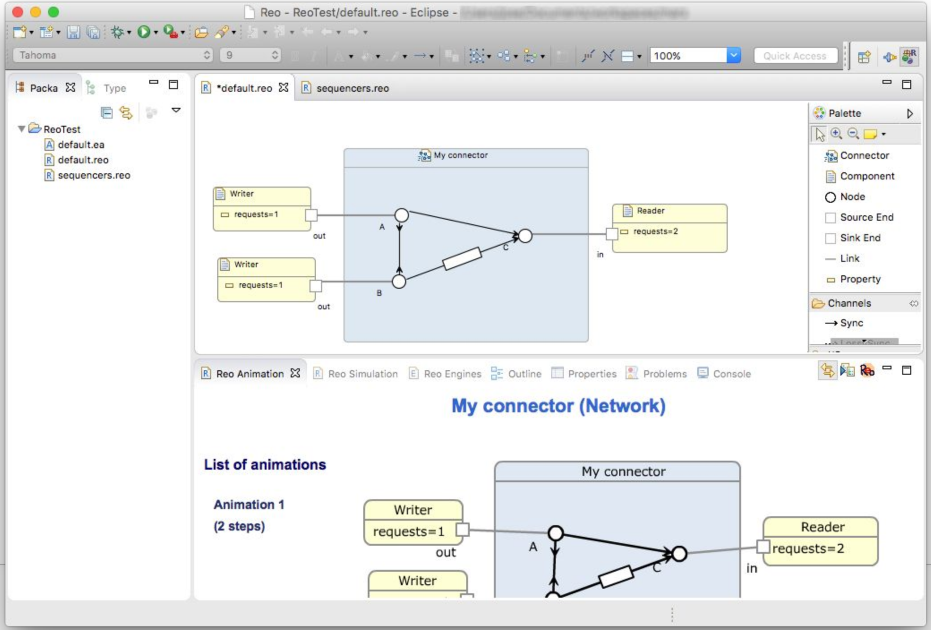
duplicator

Nodes act as
pumping-stations

Composing Reo connectors



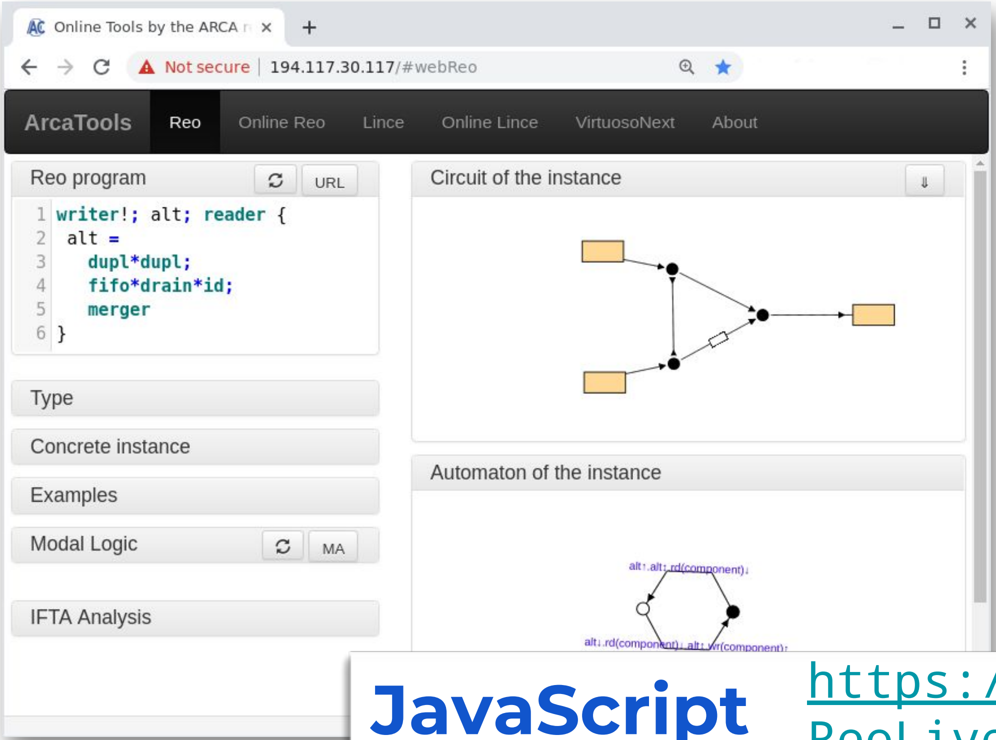
Reo eclipse toolset



Eclipse plug-in

http://reo.project.cwi.nl/update

Reo Live



JavaScript https://reolanguage.github.io/ReoLive/snapshot/

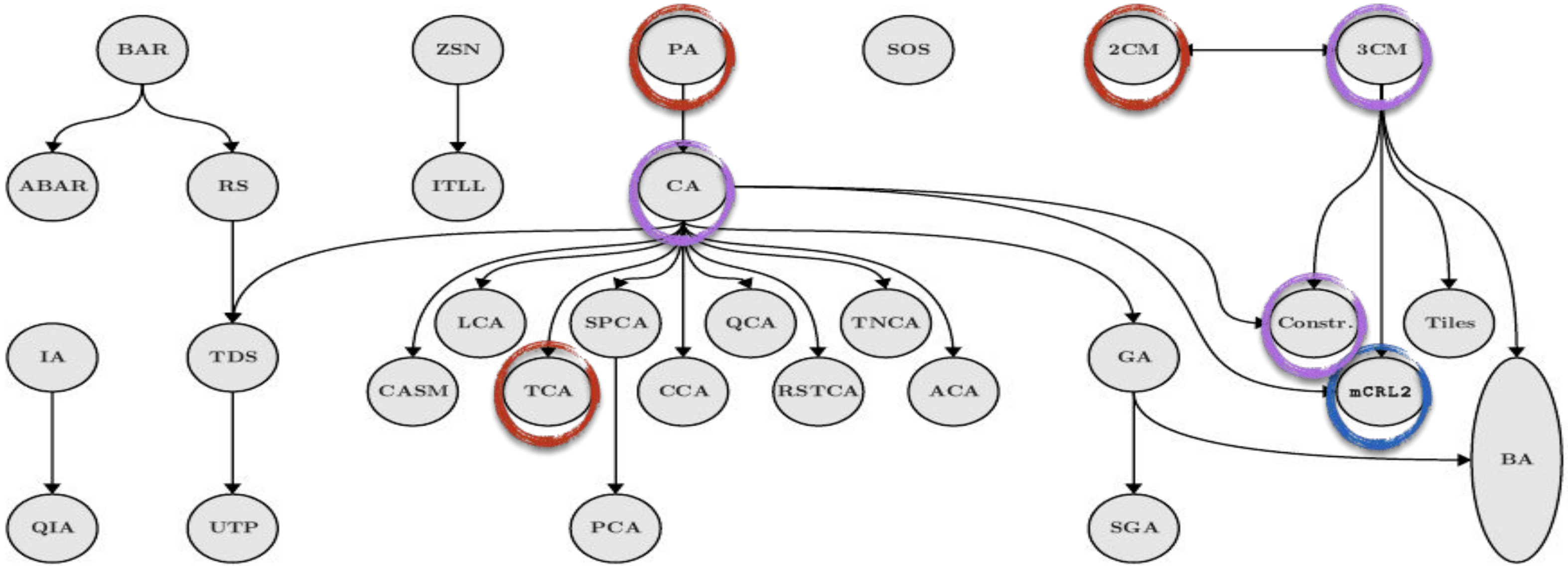
Reo semantics

Jongmans and Arbab 2012

Overview of Thirty Semantic Formalisms for Reo

Reo semantics

- *Coalgebraic models*
  - Timed data streams
  - Record streams
- *Coloring models*
  - **Two colors**
  - **Three colors**
  - Tile models
- *Other models*
  - **Process algebra**
  - **Constraints**
  - Petri nets & intuitionistic logic
  - Unifying theories of programming
  - Structural operational semantics
- *Operational models*
  - **Constraint automata**
  - Variants of constraint automata
    - **Port automata**
    - **Timed**
    - Probabilistic
    - Continuous-time
    - Quantitative
    - Resource-sensitive timed
    - Transactional
  - Context-sensitive automata
    - Büchi automata
    - Reo automata
    - Intentional automata
    - Action constraint automata
    - Behavioral automata
  - Structural operational semantics

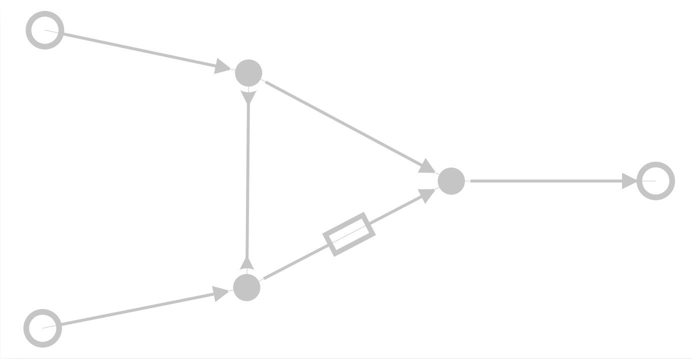


2CM : Coloring models with two colors [28, 29, 33]
3CM : Coloring models with three colors [28, 29, 33]
ABAR : Augmented BAR [39, 40]
ACA : Action CA [46]
BA : Behavioral automata [61]
BAR : Büchi automata of records [38, 40]
CA : Constraint automata [10, 17]
CASM : CA with state memory [60]
CCA : Continuous-time CA [18]
Constr. : Propositional constraints [30, 31, 32]
GA : Guarded automata [20, 21]
IA : Intentional automata [33]
ITLL : Intuitionistic temporal linear logic [27]
LCA : Labeled CA [44]
mCRL2 : Process algebra [47, 48, 49]

PA : Port automata [45]
PCA : Probabilistic CA [15]
QCA : Quantitative CA [12, 53]
QIA : Quantitative IA [13]
RS : Record streams [38, 40]
RSTCA : Resource-sensitive timed CA [51]
SGA : Stochastic GA [56, 57]
SOS : Structural operational semantics [58]
SPCA : Simple PCA [15]
TCA : Timed CA [8, 9]
TDS : Timed data streams [4, 5, 14, 62]
Tiles : Tile models [11]
TNCA : Transactional CA [54]
UTP : Unifying theories of programming [55, 52]
ZSN : Zero-safe nets [27]

A Hybrid Model of Connectors in CPS (2017)

Outline



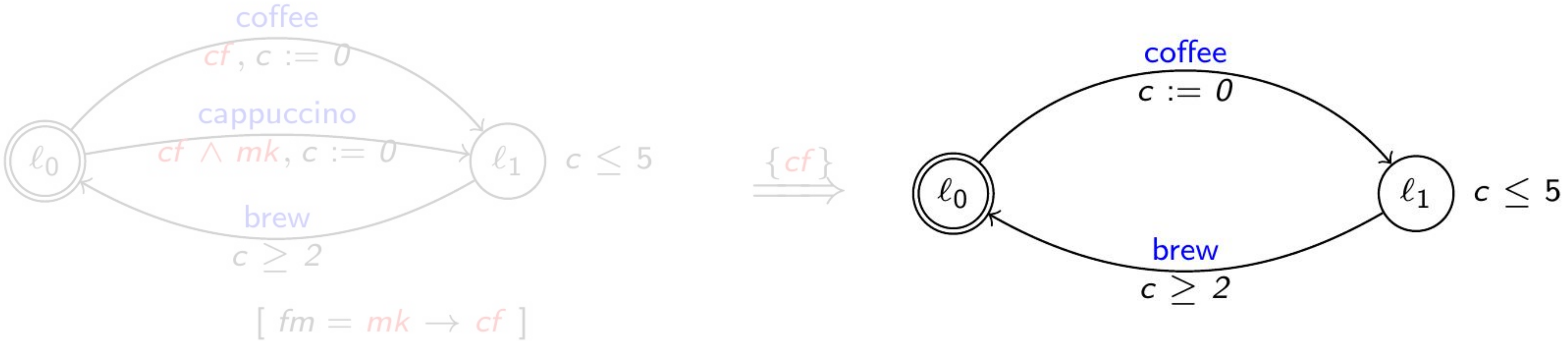
What is Coordination?

- Context & motivation
- Reo coordination language

Recent research tracks

- Analysis tools
- Composing families of Timed Automata
- Composing tasks in a RTOS

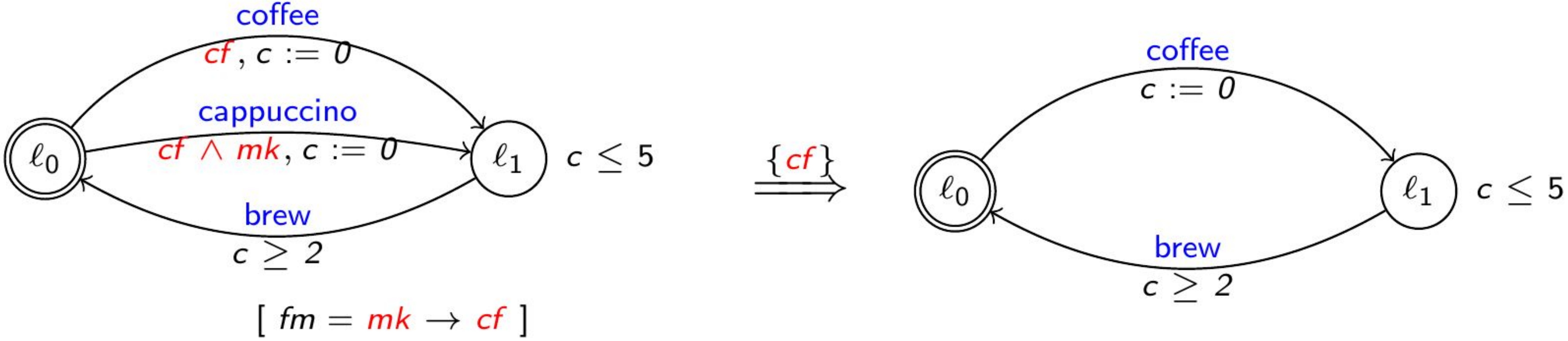
IFTA
interface **f**eature **t**imed **a**utomata



Timed Automata

IFTA

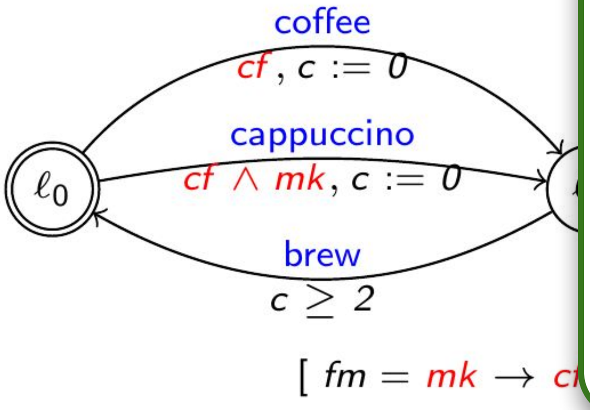
interface **f**eature **t**imed **a**utomata

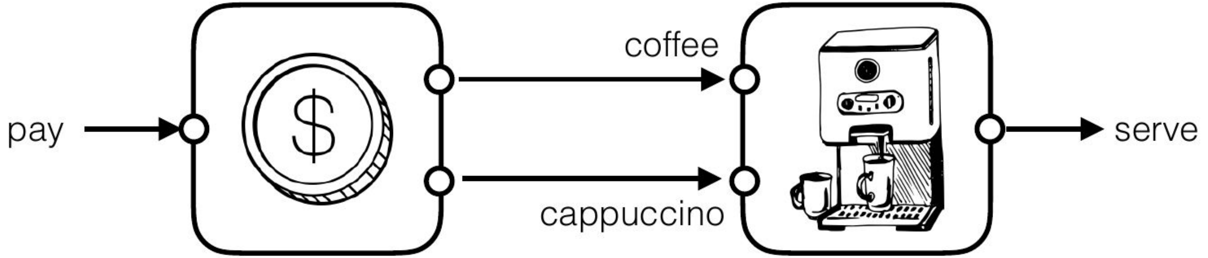


Features + Timed Automata

IFTA

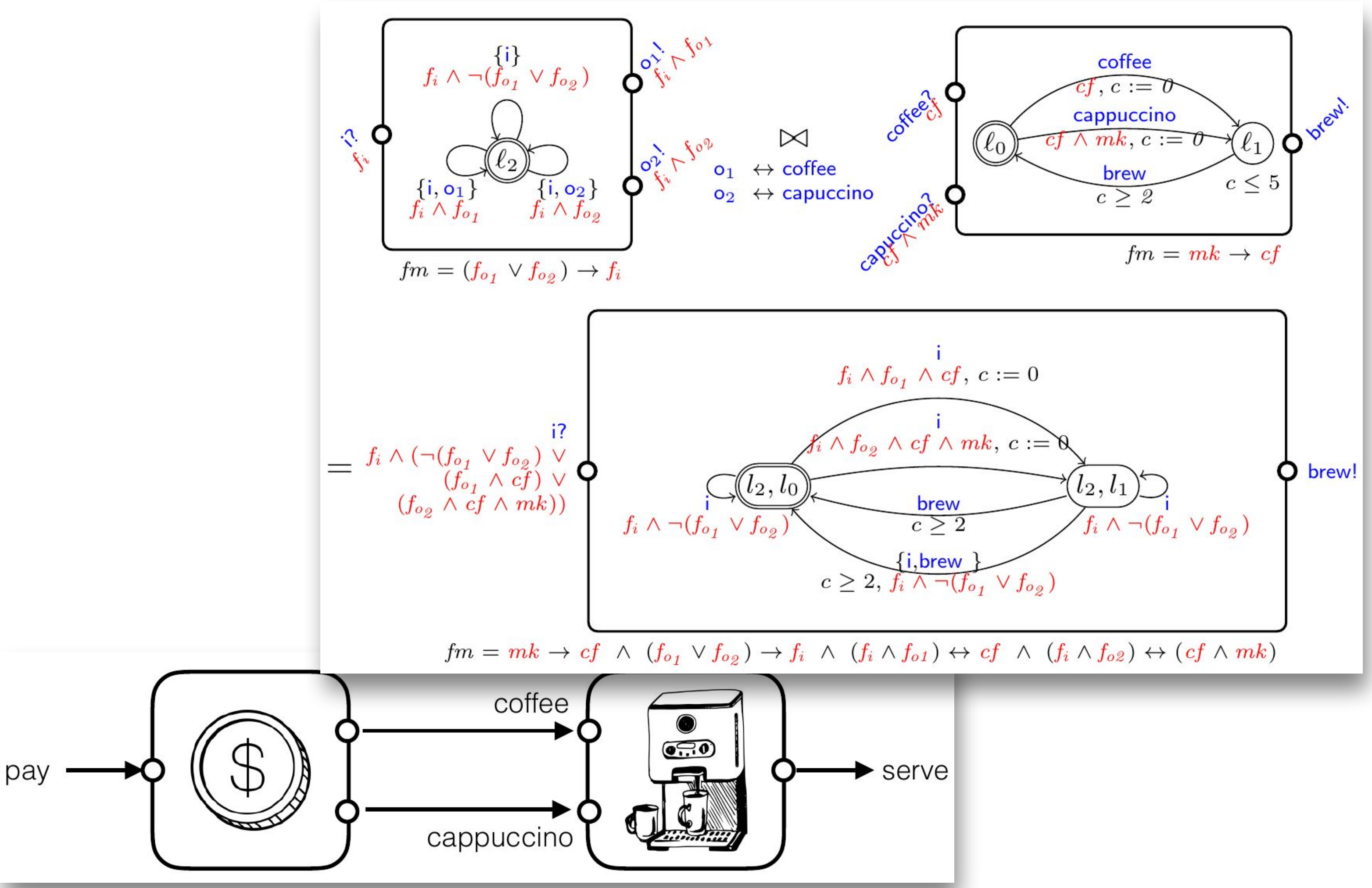
interface **f**eature **t**imed **a**utomata



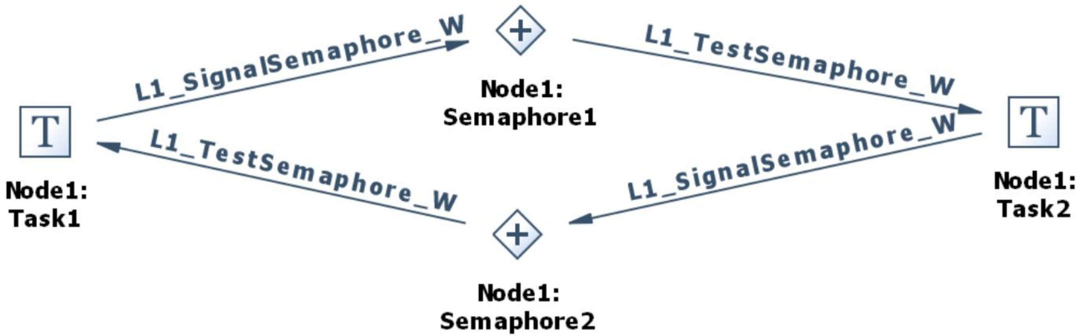


+ Interfaces (Composition)

Features + Timed Automata

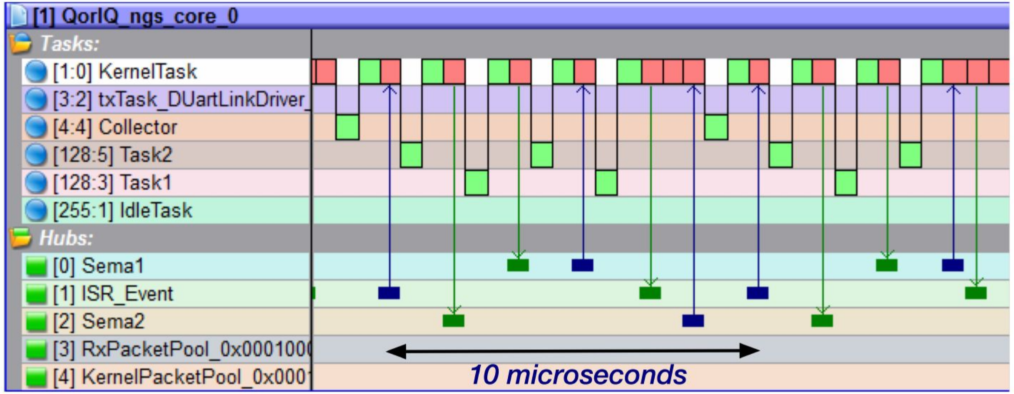

{i}
$f_i \wedge \neg(f_{o_1} \vee f_{o_2})$
i?
f_i
ℓ_2
{i, o1}
$f_i \wedge f_{o_1}$
{i, o2}
$f_i \wedge f_{o_2}$
o1!
$f_i \wedge f_{o_1}$
o2!
$f_i \wedge f_{o_2}$
$fm = (f_{o_1} \vee f_{o_2}) \rightarrow f_i$
$\bowtie$
o1 ↔ coffee
o2 ↔ capuccino
coffee?
cf
cappuccino?
$cf \wedge mk$
coffee
$cf,\ c := 0$
cappuccino
$cf \wedge mk,\ c := 0$
brew
$c \geq 2$
ℓ_0
ℓ_1
$c \leq 5$
brew!
$fm = mk \rightarrow cf$
$=$
i?
$f_i \wedge (\neg(f_{o_1} \vee f_{o_2}) \vee (f_{o_1} \wedge cf) \vee (f_{o_2} \wedge cf \wedge mk))$
i
$f_i \wedge f_{o_1} \wedge cf,\ c := 0$
i
$f_i \wedge f_{o_2} \wedge cf \wedge mk,\ c := 0$
l_2, l_0
l_2, l_1
i
$f_i \wedge \neg(f_{o_1} \vee f_{o_2})$
brew
$c \geq 2$
i
$f_i \wedge \neg(f_{o_1} \vee f_{o_2})$
{i,brew }
$c \geq 2,\ f_i \wedge \neg(f_{o_1} \vee f_{o_2})$
brew!
$fm = mk \rightarrow cf \ \wedge\ (f_{o_1} \vee f_{o_2}) \rightarrow f_i \ \wedge\ (f_i \wedge f_{o1}) \leftrightarrow cf \ \wedge\ (f_i \wedge f_{o2}) \leftrightarrow (cf \wedge mk)$
pay
coffee
cappuccino
serve

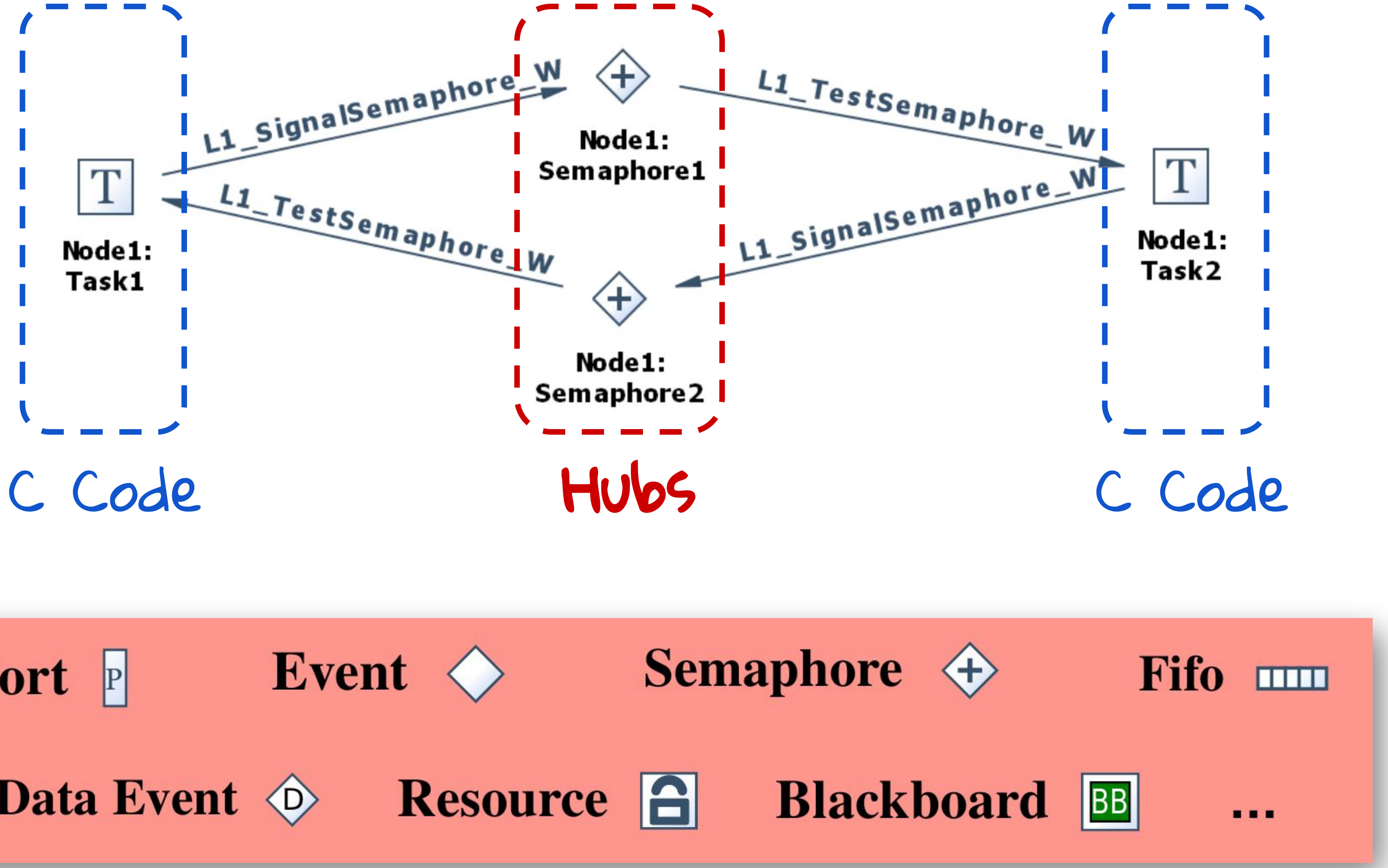
Programming real-time With **VirtuosoNext** @ Altreonic



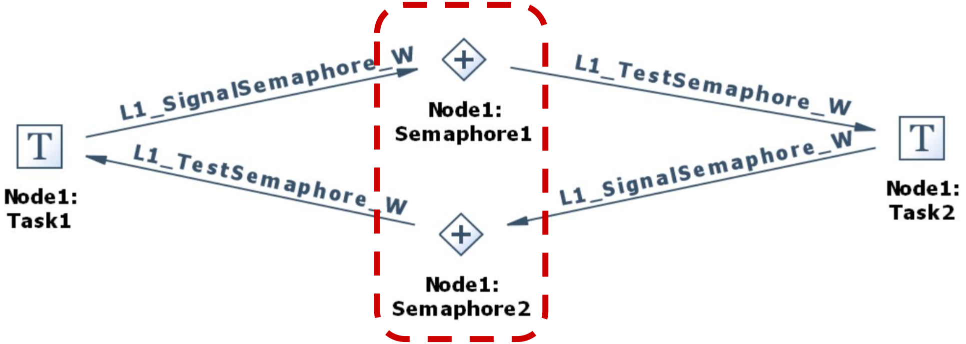
Visual IDE to compose tasks

Precise time traces on embedded SW



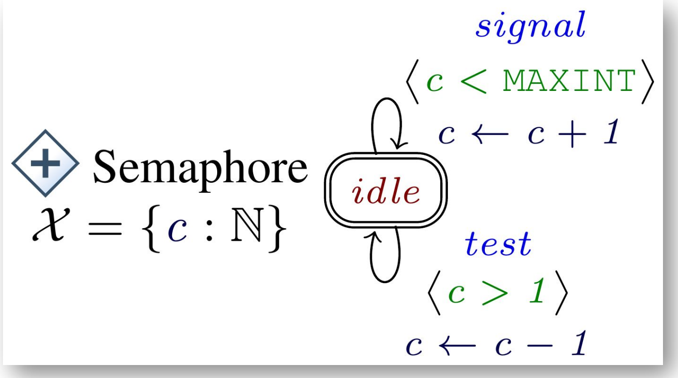

L1_SignalSemaphore_W
L1_TestSemaphore_W
L1_TestSemaphore_W
L1_SignalSemaphore_W
Node1: Task1
Node1: Semaphore1
Node1: Semaphore2
Node1: Task2
C Code
Hubs
C Code
Port
Event
Semaphore
Fifo
Data Event
Resource
Blackboard
...

Hubs ++

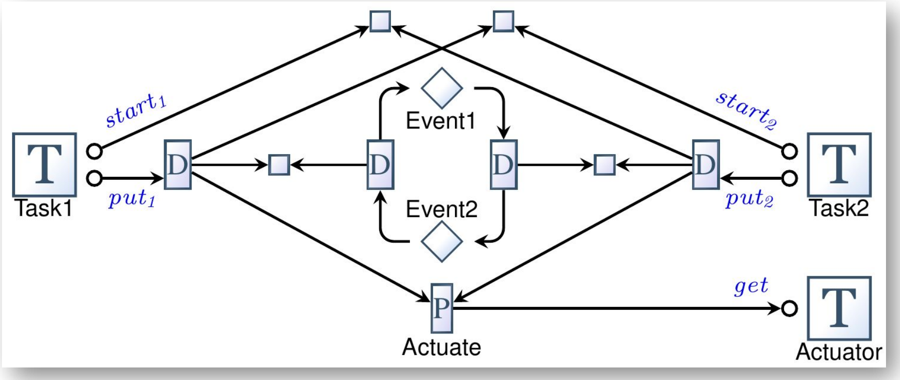


Hubs

Automata semantics

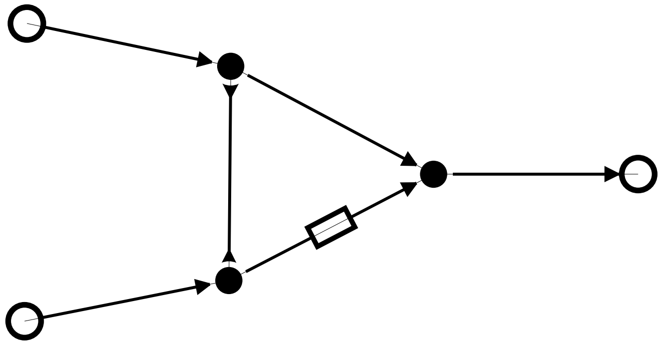


Complex hubs by composition



Communication between nodes?

Wrap up



What is **Coordination**?

Context & motivation

Reo coordination language

Recent research tracks

Analysis tools

Composing families of Timed Automata

Composing tasks in a RTOS

More:

Reactive Programming for IoT

Dynamic Logics

Hybrid Programs

(continuous + discrete behaviour)