Quantitative Analysis of KLAIM Nets

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joint work with

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Linda communication model...

Basic ingredients:

- Asynchronous communication;
- Shared tuple space;
- Pattern matching

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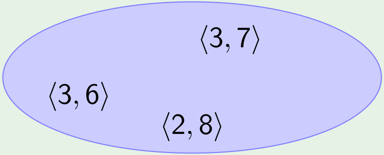

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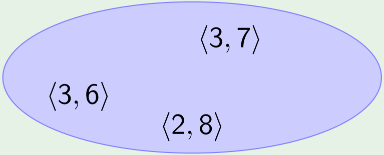

$\mathbf{out}(3, 4)$

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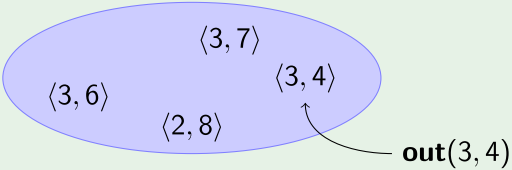

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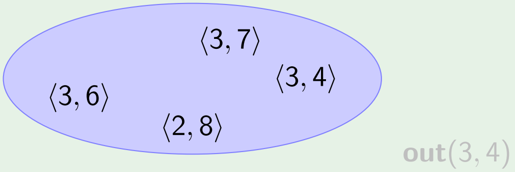

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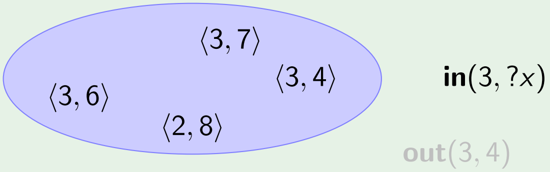

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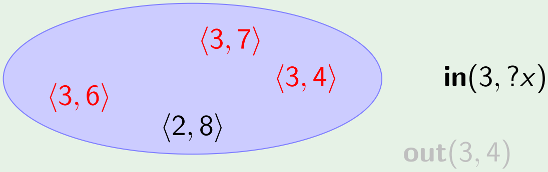

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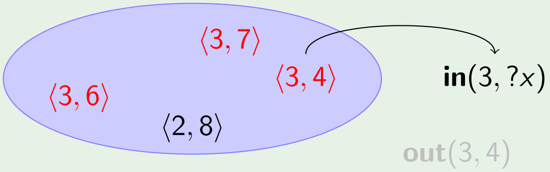

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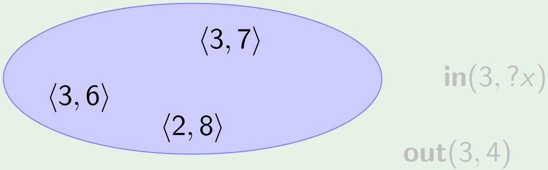

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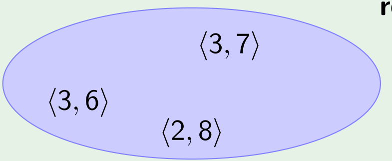

$\mathbf{read}(?x, ?y)$

$\mathbf{in}(3, ?x)$

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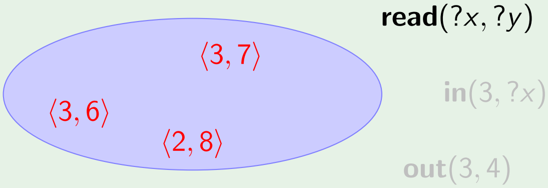

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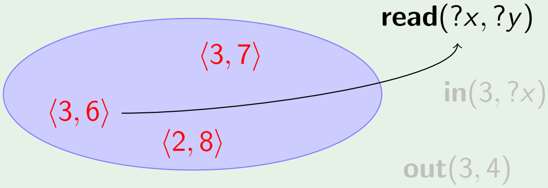

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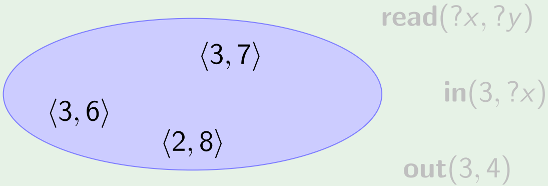


KLAIM...

Kernel Language for Agent Interaction and Mobility

Explicit Distribution

- Multiple distributed tuple spaces;
- Code and Process mobility.

KLAIM Nodes

consist of:

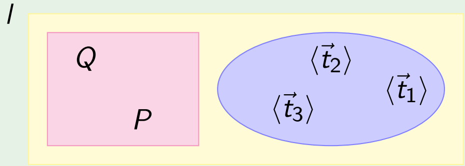
- a site
- a tuple space
- a set of parallel processes

KLAIM Nets...

...consist of a set of KLAIM nodes running in parallel

Klaim...

Kernel Language for Agent Interaction and Mobility



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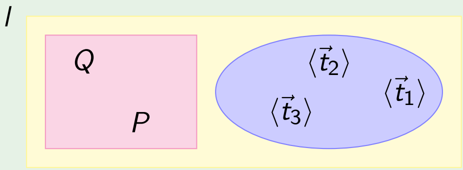


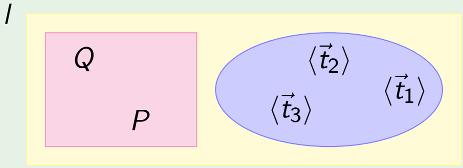
read$(\vec{t})@l$

in$(\vec{t})@l$

out$(\vec{d})@l$

Klaim. . .

Kernel Language for Agent Interaction and Mobility



eval$(R)@l$

read$(\vec{t})@l$

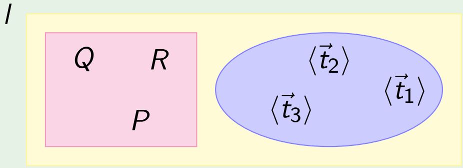
in$(\vec{t})@l$

out$(\vec{d})@l$

Klaim...

Kernel Language for Agent Interaction and Mobility

$\mathbf{eval}(R)@l$



$\mathbf{read}(\vec{t})@l$

$\mathbf{in}(\vec{t})@l$

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StoKlaim: Stochastic Klaim

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StoKlaim is the stochastic extension of Klaim where:

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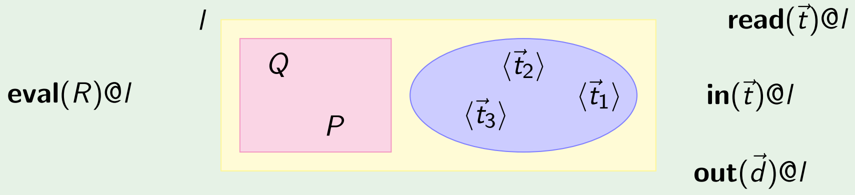

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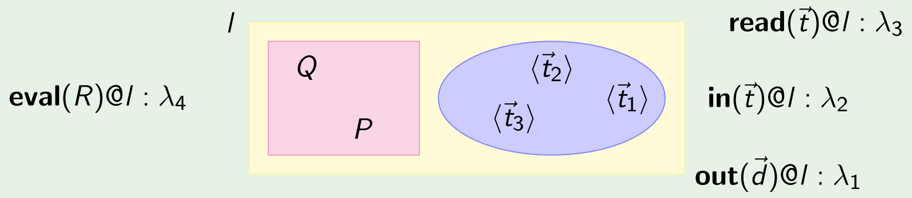

A simple example. . .

DMS: Distributed Mobile Service

A DMS is a network service that exploits capabilities of different network resources

- The service relies on two sites, say l and r.
  - Client software is assumed to run only on l.
- A service dispatcher, running at l, receives service requests from local users and dispatches them to the appropriate sites.
  - There are two types of services, S1 and S2.
  - S1-type service is a simple service that requires only local resources.
  - S2-type service requires first resources in l and then resources in r.

DMS in StoKlaim

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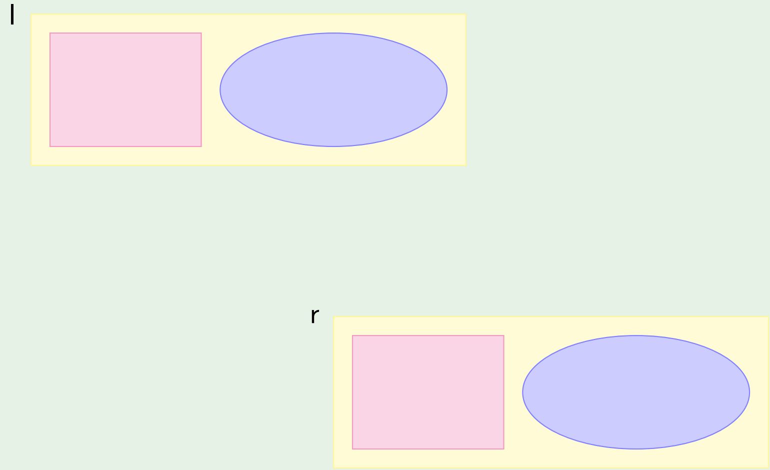

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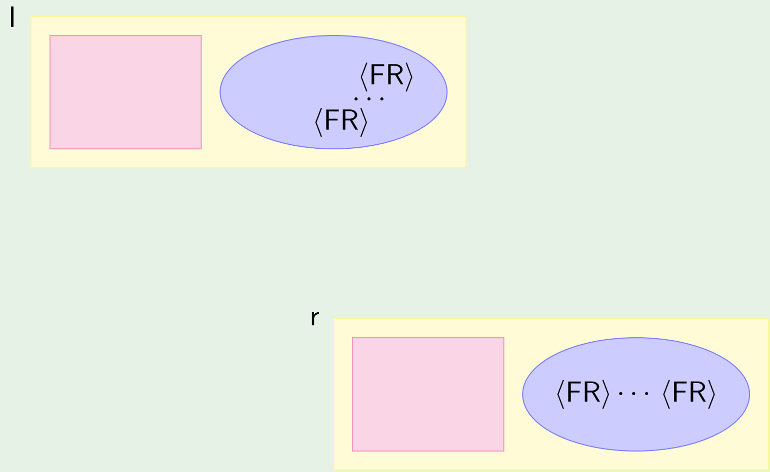

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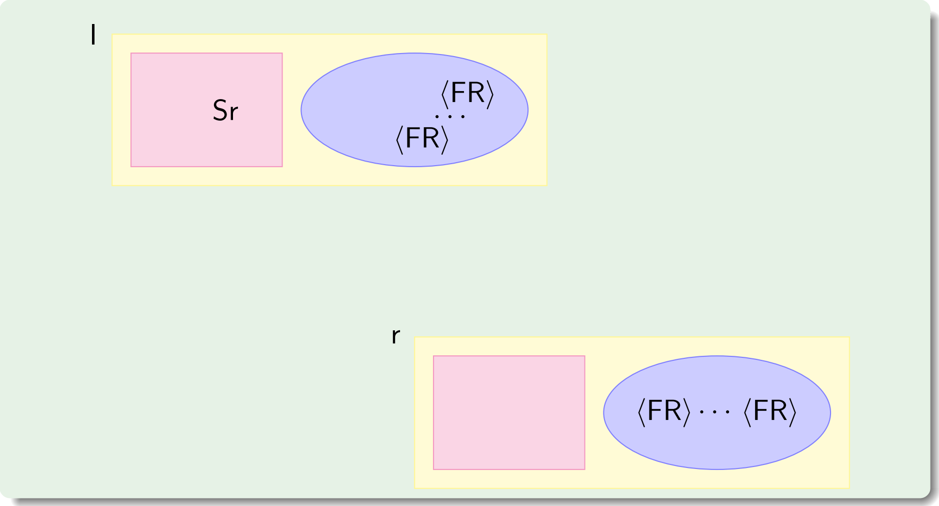

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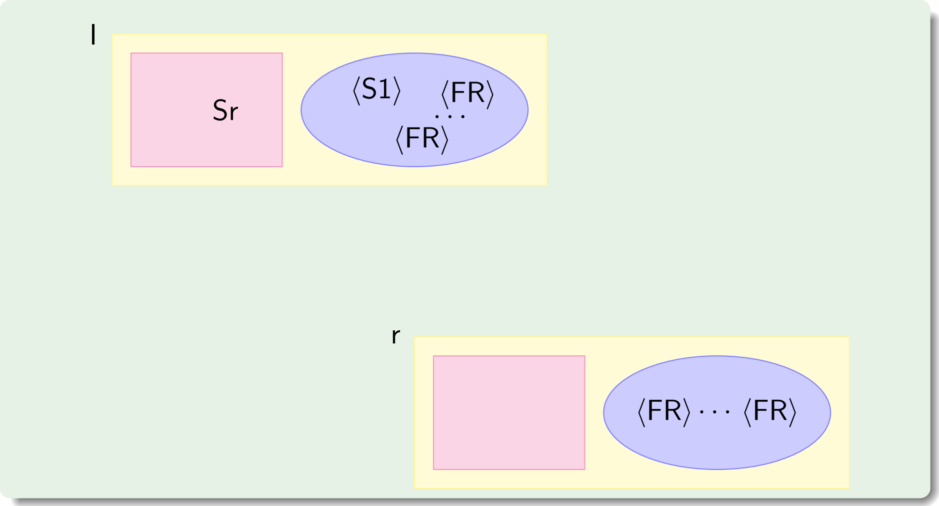

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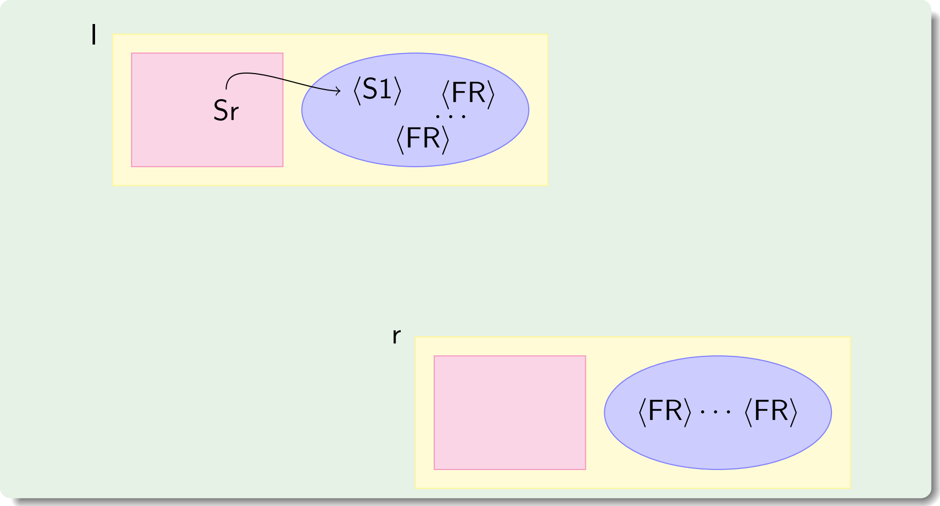

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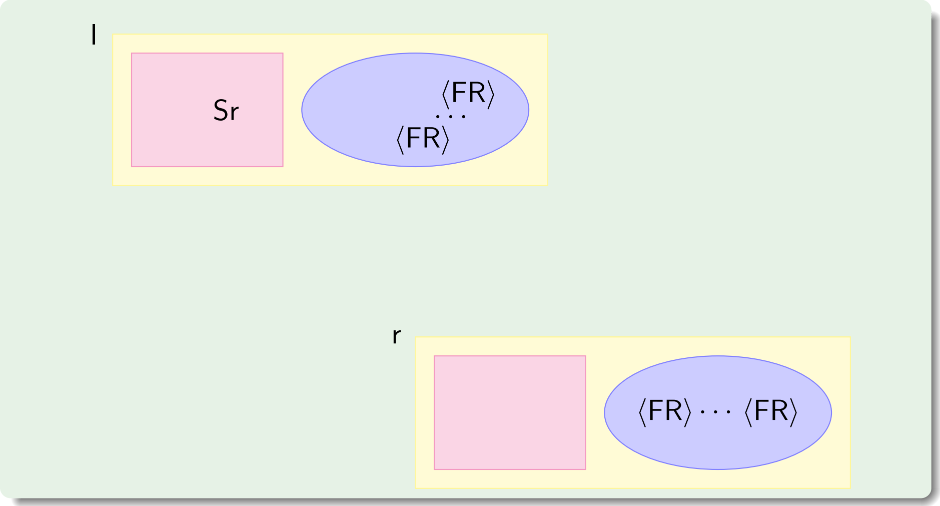

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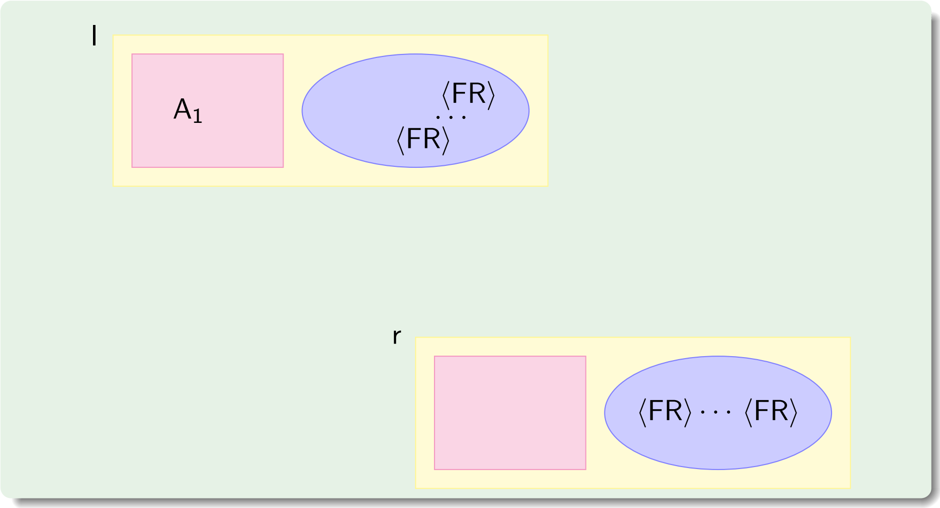

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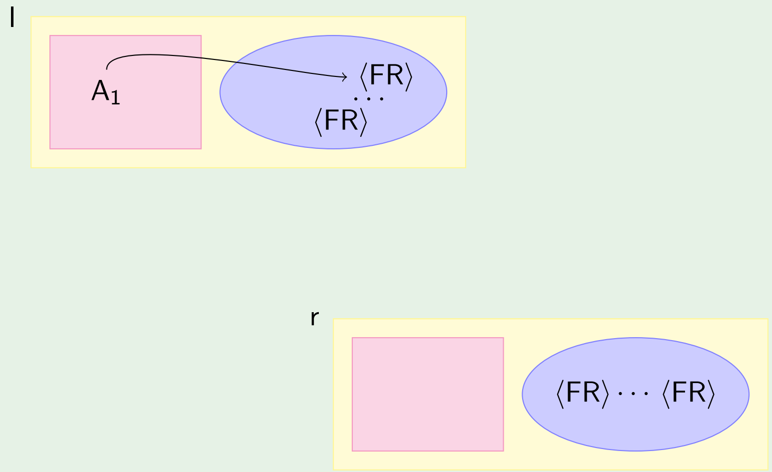

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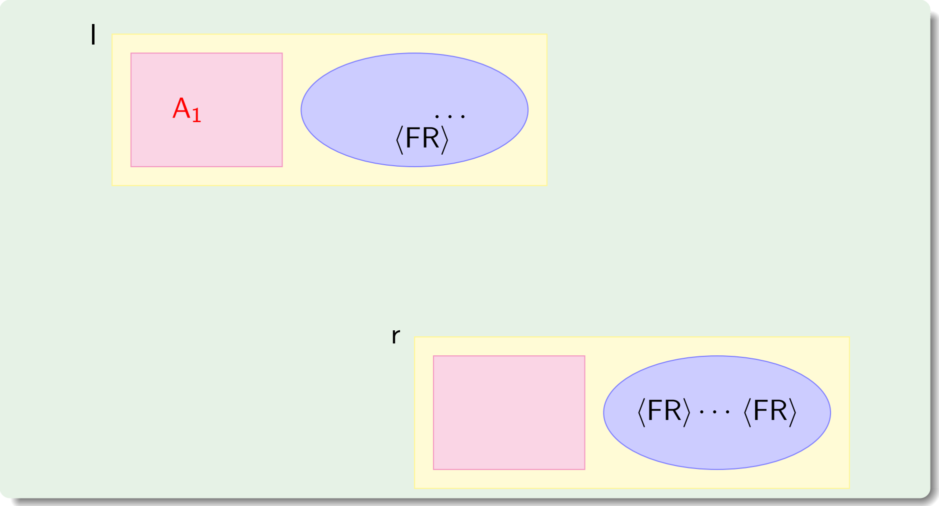

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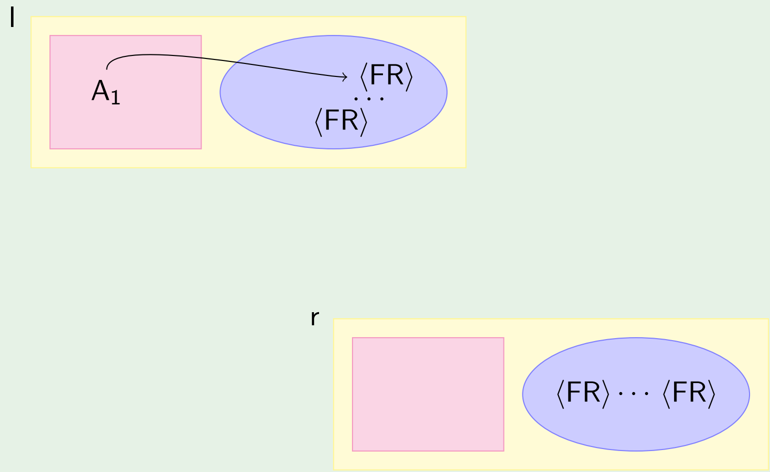
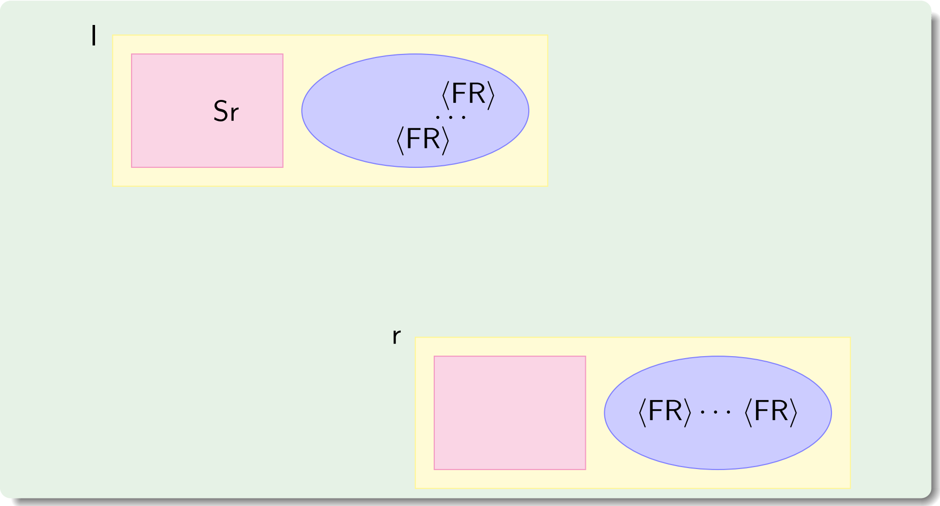


DMS in STOKLAIM



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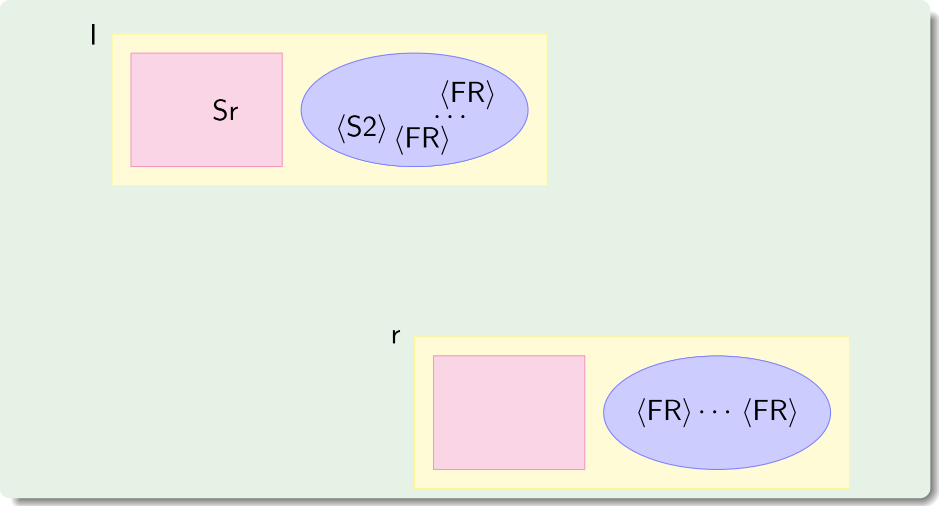

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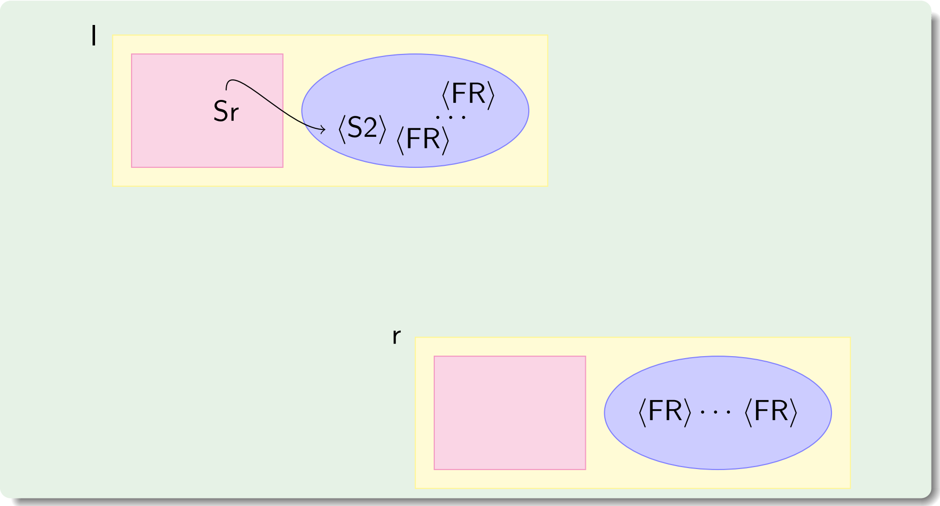

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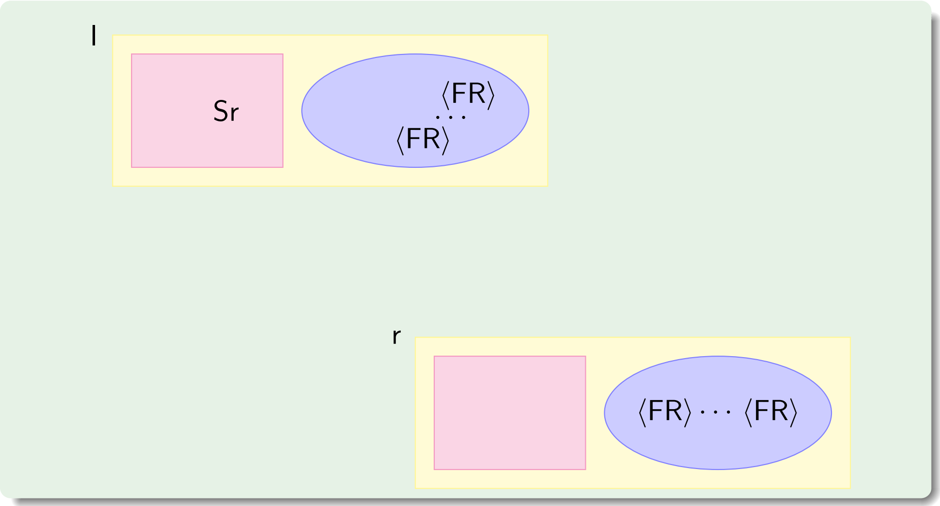

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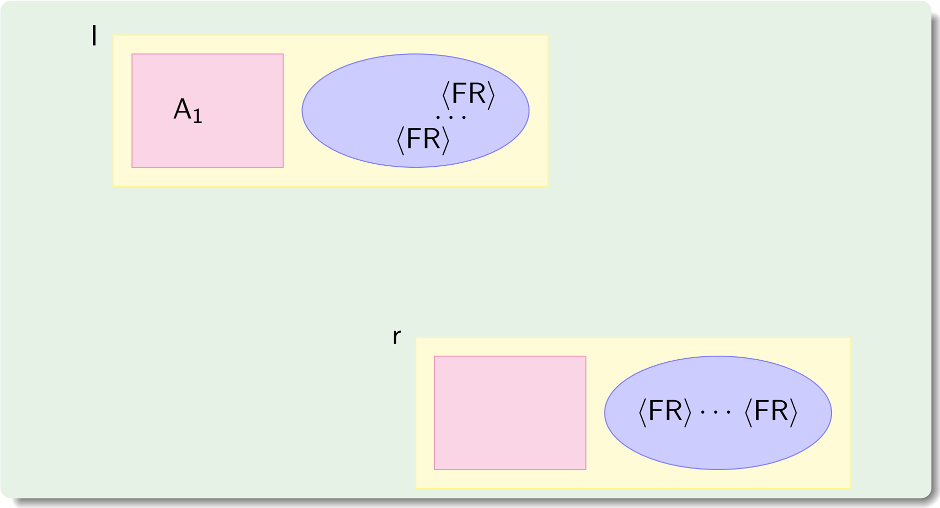

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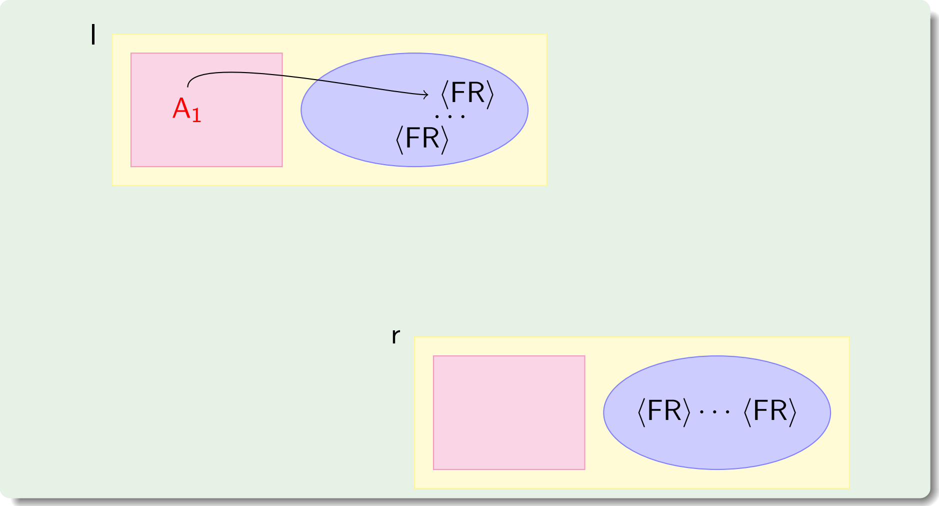

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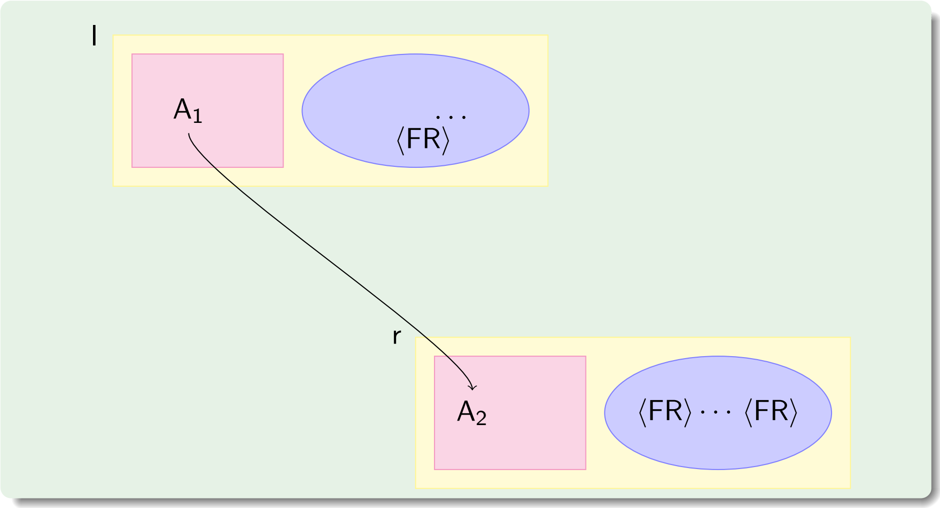

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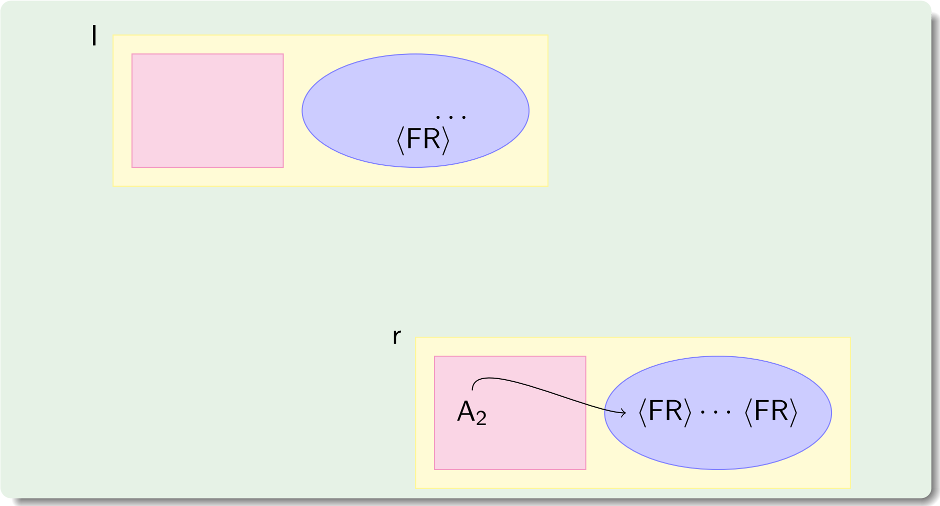

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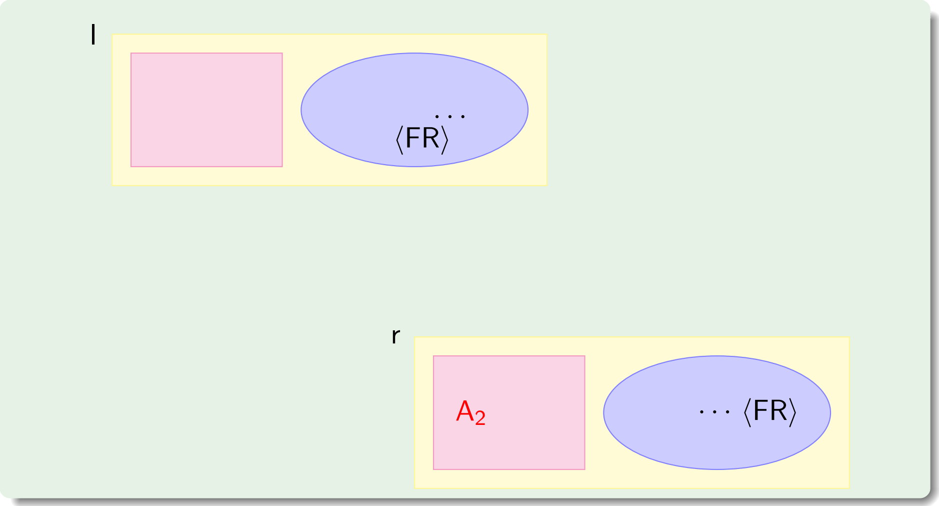

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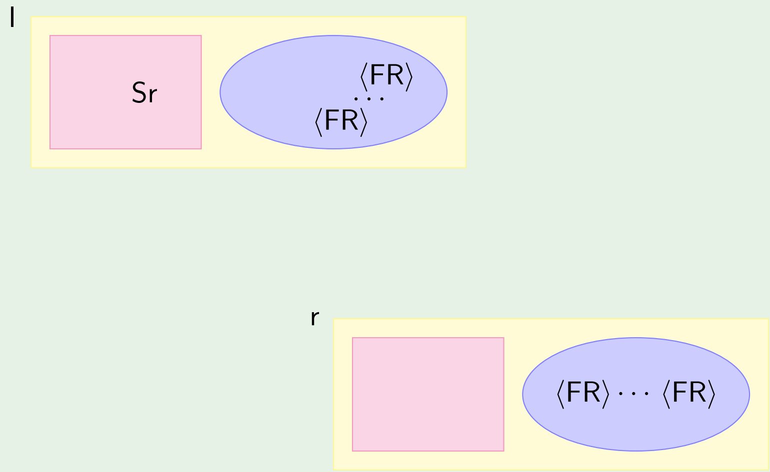

MoSL: Mobile Stochastic Logic

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Features:

- a temporal logic (dynamic evolution);
- both action- and state-based;
- a real-time logic (real-time bounds);
- a probabilistic logic (performance and dependability aspects);
- a spatial logic (spatial structure of the network).

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MoSL extends aCSL with specific operators (*production* and *consumption*) to reason about distribution of resources (*processes* and *tuples*) over the net and to specify the ability to react to *external* stimuli:

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- Which is the probability that within t time units both local and remote resources are unavailable?

$$\mathcal{P}_{=?}(\mathsf{true}\ \mathcal{U}^{\leq t}\ \neg(\langle \mathsf{FR} \rangle @\mathsf{l} \rightarrow \mathsf{true} \vee \langle \mathsf{FR} \rangle @\mathsf{r} \rightarrow \mathsf{true})$$

Model-checking MoSL

- Model-checking of MoSL formulae is performed by relying on a CSL model checker.
- The proposed model-checking algorithm manipulates the Rate Transition System (RTS) obtained from a StoKlaim specification:
  - the RTS to be model-checked is translated into an equivalent state-labelled CTMC
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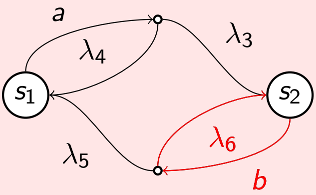
Warning:

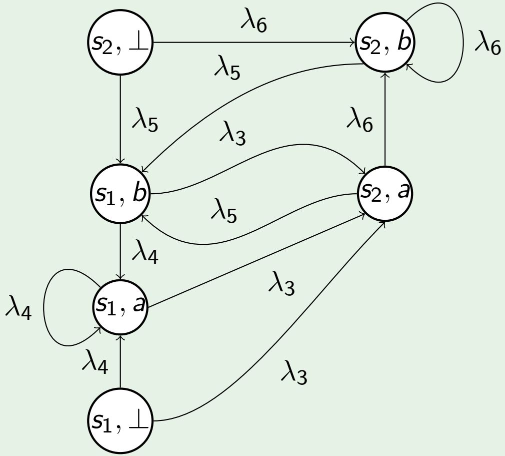
State-space explotion problem!

Translation. . .

From RTS. . .



. . . to CTMC



DMS: State space

Clients	States	Transitions
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15	264860	1402480
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Statistical model checking

To overcome the state explosion problem, a statistical model-checker can be used.

- this approach has been successfully applied to existing model checkers (YMER, sCOWS,. . .)

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In a numerical model-checker, the exact probability to satisfy a path-formula is computed up to a precision ε.

A statistical model-checker is parametrised with respect to a given tollerance ε and error probability δ. The algorithm guarantees that the difference between the computed values and the exact ones are greater than ε with a probability that is less than δ.

DMS Analysis (50 clients, 3 resources)

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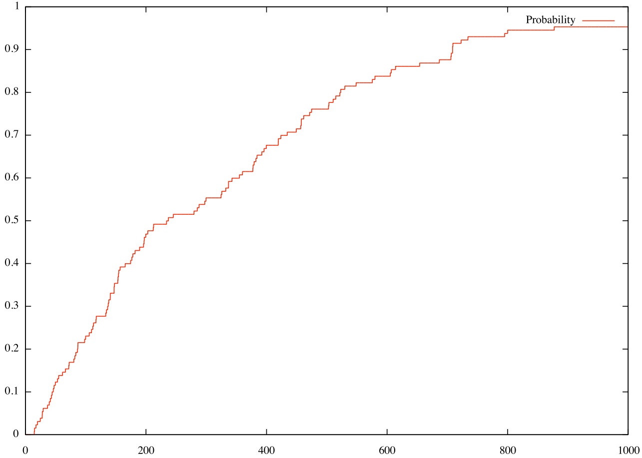

Figure: $\delta = 0.1$, $\varepsilon = 0.2$ (Execution time=13.6 sec)

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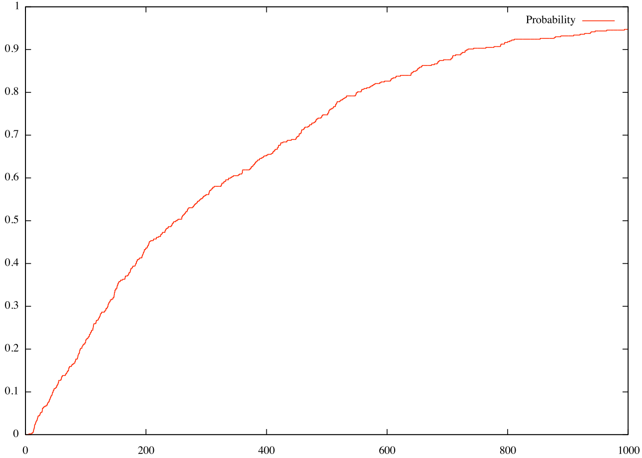

Figure: $\delta = 0.1$, $\varepsilon = 0.1$ (Execution time=56.2 sec)

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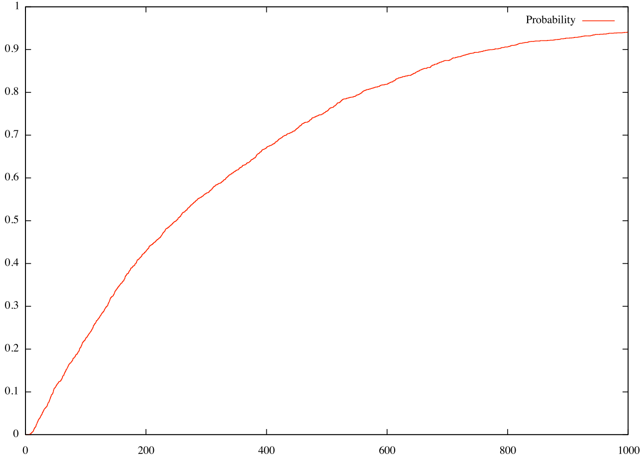

Figure: $\delta = 0.1$, $\varepsilon = 0.05$ (Execution time=233.2 sec)

Continuous Semantics of StoKlaim nets

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We consider a family of continuous random variables of the form:

$\mathcal{F}^{k}_{P@l}(t)=$ probability to have k instances of process P running at locality l at time t

$\mathcal{F}^{k}_{T@l}(t)=$ probability to have k instances of tuple T at locality l at time t

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- ODE systems can be resolved by relying on standard iterative ODE resolution methods
- Obtained values can be used to model check a large class of formulae (e.g. reachability properties)

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$X = \mathbf{out}(T)@l : \lambda.Y$

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ODE Functions (Kolmogorov-Chapman): $(k > 0)$

$$\frac{d\mathcal{F}^{k}_{X@l}}{dt} = \lambda \cdot (k+1) \cdot \mathcal{F}^{k+1}_{X@l}(t) - \lambda \cdot k \cdot \mathcal{F}^{k}_{X@l}(t)$$

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$$\frac{d\mathcal{F}^{k}_{X@l}}{dt} = \lambda \cdot (k+1) \cdot \mathcal{F}^{k+1}_{X@l}(t) - \lambda \cdot k \cdot \mathcal{F}^{k}_{X@l}(t)$$

There are $k+1$ instances of X at l one of which performs action $\mathbf{out}(T)@l$, the probability to have k instances of X at l increases.

Continuous Semantics of StoKlaim nets

$X = \mathbf{out}(T)@l : \lambda.Y$

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$$\frac{d\mathcal{F}^{k}_{T@l}}{dt} = \lambda \cdot \mathcal{F}^{k-1}_{T@l}(t) \cdot \sum_{i} i \cdot \mathcal{F}^{i}_{T@l}(t) - \lambda \cdot k \cdot \mathcal{F}^{k1}_{T@l}(t) \cdot \sum_{i} i \cdot \mathcal{F}^{i}_{T@l}(t)$$

Producer-consumer

Example

We consider a simple system composed of two processes:

- A set of *producers* that continuously emit a tuple T
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Warning!

This simple specification generates an infinite state space!

Producer-consumer: ODE vs Simulation

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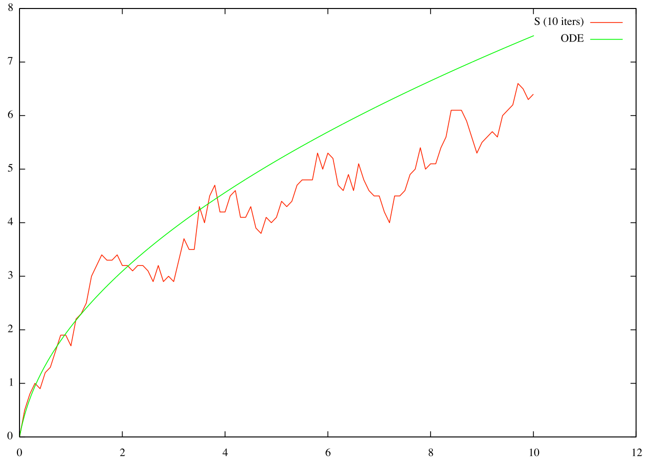

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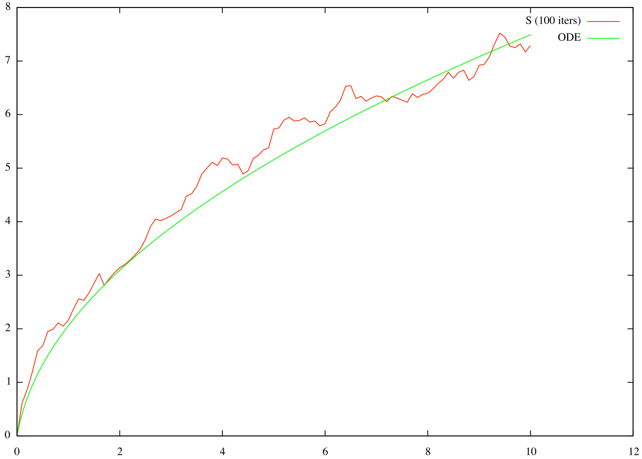

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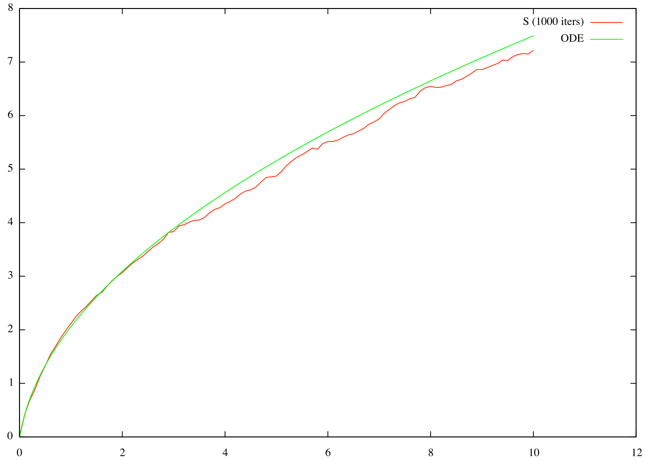

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A tool has been developed for supporting analysis of StoKlaim systems:

- http://rap.dsi.unifi.it/SAM/

On going work

- Complete the integration of ODE semantics of StoKlaim in SAM
- Equip StoKlaim with a language for specifying *rewards* and extends MoSL accordingly
- Use StoKlaim and its tools to specify and verify a larger class of case studies
  - networks (gossip protocols, crowds,. . .)
  - economics
  - evolutionary systems
  - biological systems
  - . . .

Thank you for your attention!