Model Checking Mobile Stochastic Logics

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Outline

1. A brief introduction to StoKlaim
2. MoSL: Mobile Stochastic Logic
3. Model Checking MoSL
4. Concluding Remarks

Kernel Language for Agent Interaction and Mobility

Process Calculus Flavored

- Small set of basic combinator;
- Clean operational semantics.

Linda based communication model

- Asynchronous communication;
- Shared tuple spaces;
- Pattern Matching

Explicit Distribution

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

From Linda and Process Algebras to KLAIM

Explicit Localities to model distribution

- *Physical Locality* (sites)
- *Logical Locality* (names for sites)
- A distinct name *self* (or *here*) indicates the site a process is on.

Allocation environment to associate sites to logical localities

- This avoids the programmers to know the exact physical structure.

Process Algebras Operators to compose programs

- Sequentialization
- Parallel composition
- Creation of new names

KLAIM Nodes and KLAIM Nets

KLAIM Nodes

consist of:

- a site
- a tuple space
- a set of parallel processes
- an allocation environment

KLAIM Nets

are:

- a set of KLAIM nodes linked via the allocation environment

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- Klaim Action Prefix: $A.P$
- StoKlaim Action Prefix: $(A, r).P$

StoKlaim Actions

- $(\mathbf{out}(T)@l2, r1)$
  - *uploads* tuple T to $l2$,
  - *the time it takes* is e.d. with rate $r1$
- $(\mathbf{eval}(P)@l1, r2)$
  - *spawns* process P to $l1$,
  - *the time it takes* is e.d. with rate $r2$
- $(\mathbf{newloc}(!u), r3)$
  - *creates* a new site (with locality) u,
  - *the time it takes* is e.d. with rate $r3$
- $(\mathbf{in}(F)@l1, r4)$
  - *downloads*, if available, a tuple matching F from $l1$,
  - *it takes a time* which is e.d. with rate $r4$,
- $(\mathbf{read}(F)@l1, r4)$
  - *reads*, if available, a tuple matching F from $l1$, without consuming it
  - *it takes a time* which is e.d. with rate $r4$,

StoKlaim Syntax

Nets: $N ::= \mathbf{0} \mid i ::_\rho E \mid N \parallel N$

Node Elements: $E ::= P \mid \langle \vec{f} \rangle$

Processes: $P ::= \mathbf{nil} \mid (A, r).P \mid P + P \mid P \mid P \mid X(\vec{P}, \vec{\ell}, \vec{e})$

Actions: $A ::= \mathbf{out}(\vec{f})@\ell \mid \mathbf{in}(\vec{F})@\ell \mid \mathbf{read}(\vec{F})@\ell \mid \mathbf{eval}(P)@\ell \mid \mathbf{newloc}(!u)$

Tuple Fields: $f ::= P \mid \ell \mid e$

Template Fields: $F ::= f \mid !X \mid !u \mid !x$

Operational Semantics for StoKlaim

Stochastic semantics of StoKlaim is defined by means of a transition relation $\longrightarrow$ that associates to a process P and a transition label α a function ($\mathscr{P}$, $\mathscr{Q}$,...) that maps each process into a non-negative real number.

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$P \xrightarrow{\alpha} \mathscr{P}$ means that:

- if $\mathscr{P}(Q) = x$ ($\neq 0$) then Q is reachable from P via the execution of α with rate or weight x
- if $\mathscr{P}(Q) = 0$ then Q is not reachable from P via α

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We have that if $P \xrightarrow{\alpha} \mathscr{P}$ then

- $\oplus\mathscr{P} = \sum_Q \mathscr{P}(Q)$ represents the total rate/weight of α in P.

Rate transition systems...

Definition (Rate Transition Systems)

A rate transition system is a triple $(S, A, \longrightarrow)$ where:

- S is a set of states;
- A is a set of transition labels;
- $\rightarrow \subseteq S \times A \times [S \rightarrow \mathbb{R}_{\geq 0}]$

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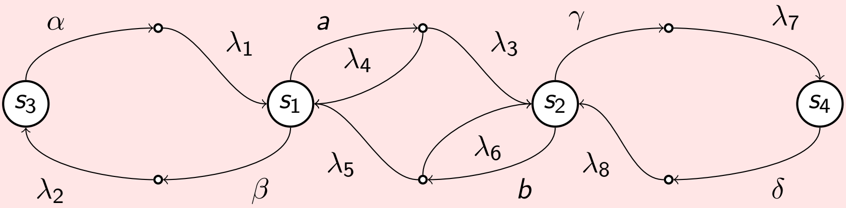

Rate transition systems. . .

Notations:

- RTS will be denoted by $\mathcal{R}$,$\mathcal{R}_1$,$\mathcal{R}'$,. . . ,
- Elements of $[S \rightarrow \mathbb{R}_{\geq 0}]$ are denoted by $\mathscr{P}, \mathscr{Q}, \mathscr{R}, \ldots$
- $\emptyset$ denotes the constant function 0
- $[s_1 \mapsto v_1, \ldots, s_n \mapsto v_n]$ identifies a function associating v_i to s_i and 0 to all the other states.
- χ_s stands for $[s \mapsto 1]$.
- $\mathscr{P} + \mathscr{Q}$ denotes the function $\mathscr{R}$ such that: $\mathscr{R}(s) = \mathscr{P}(s) + \mathscr{Q}(s)$.
- $\mathscr{P} \cdot \frac{x}{y}$ denotes function $\mathscr{R}$ such that: $\mathscr{R}(s) = \mathscr{P}(s) \cdot \frac{x}{y}$ if $y \neq 0$, and $\emptyset$ if $y = 0$.

MoSL: General

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

MoSL: Atomic propositions

$$\aleph ::= Q(\vec{Q}', \vec{\ell}, \vec{e})@\imath \rightarrow \Phi \mid \langle \vec{F} \rangle @\imath \rightarrow \Phi \mid Q(\vec{Q}', \vec{\ell}, \vec{e})@\imath \leftarrow \Phi \mid \langle \vec{f} \rangle @\imath \leftarrow \Phi$$

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Process Consumption:

Holds for a network whenever in the network there exists a process Q running at site $\imath$, and the "remaining" network satisfies Φ.

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Tuple Consumption:

Holds whenever a tuple $\vec{f}$ matching $\vec{F}$ is stored in a node of site $\imath$ and the "remaining" network satisfies Φ.

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Process Production:

Holds if the network satisfies Φ whenever process $Q(\vec{Q}', \vec{\ell}, \vec{e})$ is executed at site $\imath$.

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with $\bowtie \in \{<, >, \leq, \geq\}$ and $p \in [0, 1]$

CSL path-operator: $\mathcal{P}_{\bowtie p}(\varphi)$
Satisfied by a state s iff the total probability mass for all paths starting in s that satisfy φ meets the bound $\bowtie p$;

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CSL Steady-state operator: $\mathcal{S}_{\bowtie p}(\Phi)$
Satisfied by a state s iff the probability of reaching from s, in the long run, a state which satisfies Φ is $\bowtie$ p.

MoSL: Path formulae

$$\Phi \;\, {}_{\Delta}\mathcal{U}_{\Omega}^{<t} \;\Psi$$

- Satisfied by those paths where eventually a Ψ-state is reached, by time t, via a Φ-path, *and*, in addition, while evolving between Φ states, actions are performed satisfying Δ and the Ψ-state is entered via an action satisfying Ω.

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- Model-checking of RTSs is performed by using a CSL model checker.
- The proposed model-checking algorithm manipulates the input RTS obtained from a StoKlaim specification
  - the RTS to be model-checked is translated into an *equivalent* state-labelled CTMC
  - obtained CTMC is then analysed by making use of existing (state-based) CSL model checkers.

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- $\mathcal{R} \oplus (i, E)$ denotes the RTS obtained from $\mathcal{R}$ by adding (i, E)
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- A finite RTS $\mathcal{R}$ is translete into a finite, state-labelled, CTMC ($\mathcal{K}(\mathcal{R})$)
- The states of such CTMC will contain information which will be used by the model-checking algorithm; consequently

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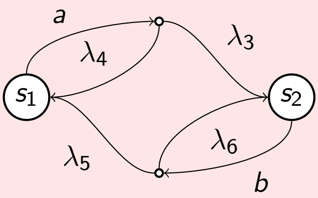
- The outgoing transitions of these duplicate states have the same target and same rate as those of the original state.
  - All copies of state s in the target CTMC are strong Markovian bisimilar and therefore enjoy the same transient and steady state properties.

An example...

...to CTMC

From RTS...



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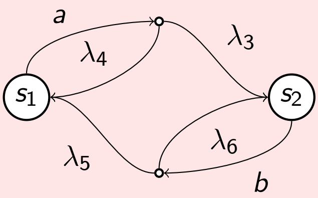

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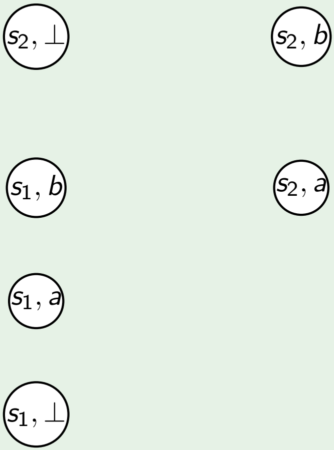

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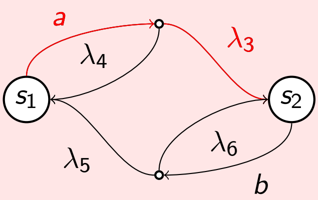

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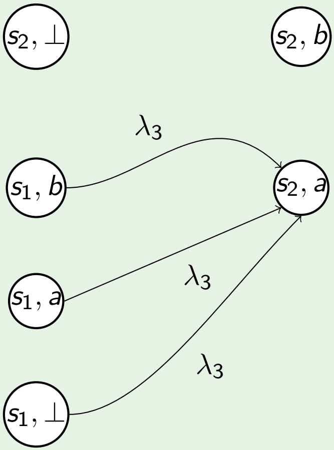

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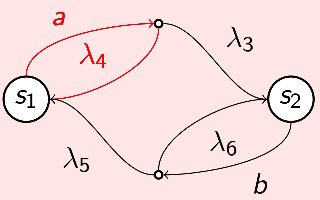

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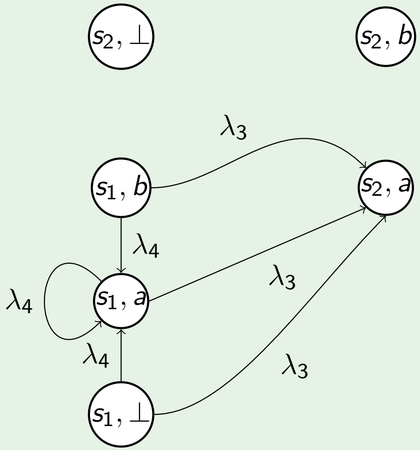

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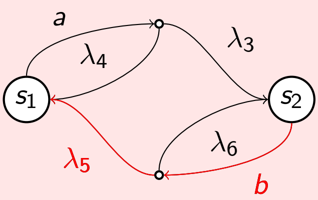

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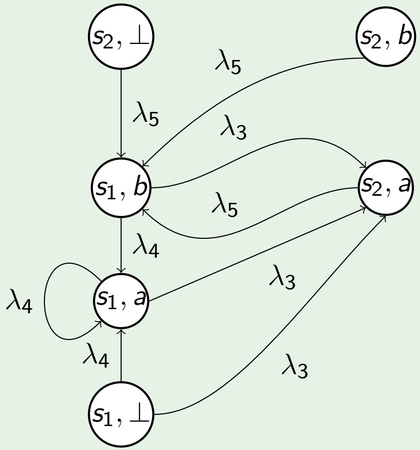

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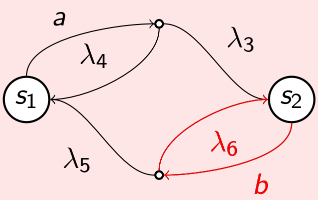

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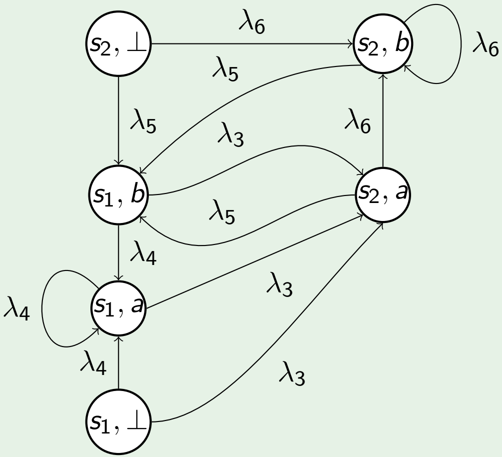

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For each RTS $\mathcal{R}$ and for each MoSL formula Φ, $Sat(\Phi, \mathcal{R})$ returns the set of all states of $\mathcal{R}$ which satisfy Φ, and is defined recursively on the structure of Φ as follows:

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- $Sat(\mathrm{tt}, \mathcal{R}) \stackrel{\text{def}}{=} S$
- $Sat(\neg\, \Phi, \mathcal{R}) \stackrel{\text{def}}{=} S \setminus Sat(\Phi, \mathcal{R})$
- $Sat(\Phi \,\vee\, \Psi, \mathcal{R}) \stackrel{\text{def}}{=} Sat(\Phi, \mathcal{R}) \cup Sat(\Psi, \mathcal{R})$
- ...

Model Checking Algorithm

Definition

- ...
- $Sat(\mathcal{P}_{\bowtie p}(\Phi \ {}_{\Delta}\mathcal{U}_{\Omega}^{<t} \ \Psi), \mathcal{R}) \stackrel{\text{def}}{=}$

$$\begin{array}{l}\text{let } S_1 = Sat(\Phi, \mathcal{R}) \times (\Delta \cup \{\bot\}) \text{ in} \\ \text{let } S_2 = Sat(\Psi, \mathcal{R}) \times \Omega \text{ in}\end{array}$$

$$\{s \in S \mid (s, \bot) \in until(\bowtie, p, t, S_1, S_2, \mathcal{K}(\mathcal{R}))\}$$

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Computation of function *until* relies on an existing Stochastic Model Checker like, for instance, MRMC.

Model Checking Algorithm

Definition

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- $Sat(\langle\vec{f}\rangle@i \rightarrow \Psi, \mathcal{R}) = \{s \mid s \ominus (i, \vec{f}) \in Sat(\Psi, \mathcal{R} \ominus (i, \vec{f}))\}$
- $Sat(\langle\vec{f}\rangle@i \leftarrow \Psi, \mathcal{R}) = \{s \mid s \oplus (i, \vec{f}) \in Sat(\Psi, \mathcal{R} \oplus (i, \vec{f}))\}$

Distributed Mobile Service Example

- A service is built on two sites, A and B;
- Client software and service dispatcher run on A;
- two types of services are available, S1 and S2:
  - each S1-service request is satisfied using local resources only (i.e. in A)
  - each S2-service request requires
    - *first*, some computation at A
    - *followed by*, a computation at B

    $\Rightarrow$ *thus* the *agent* taking care of the request is *launched* in A and then *migrates* to B.

MoSL: DMS Example

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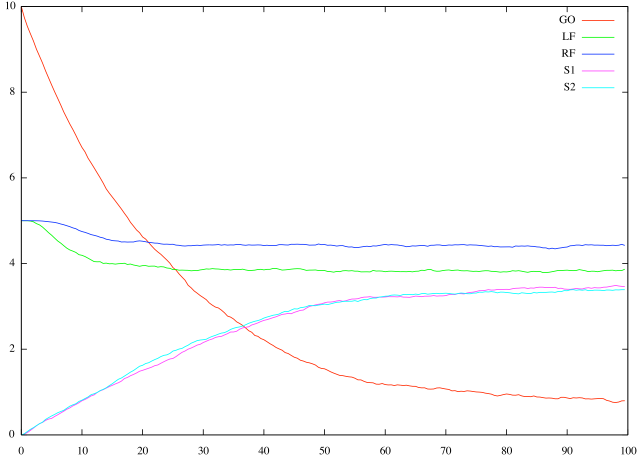
Simulating STOKLAIM Networks

Simulating StoKlaim Networks: DMS



Simulating StoKlaim Networks. . .

- In StoKlaim the number of tuples matching a given template does not alter the rate of executing action
- Sometimes one is interested in increasing the rate of an input/read action when more instances of a same tuple are available (biological applications)

Simulating StoKlaim Networks…

Example

Let $A = (\mathbf{in}(X)@,\lambda).A$:

$$l :: A || l :: \langle X \rangle || \cdots || l :: \langle X \rangle$$

Simulating StoKlaim Networks...

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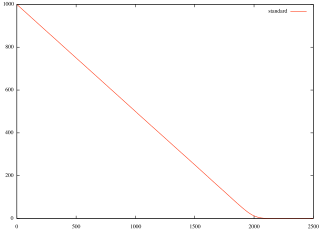

Simulating StoKlaim Networks...

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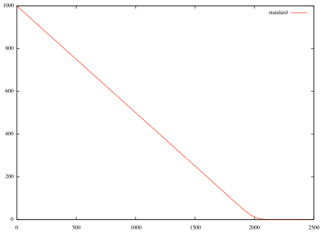
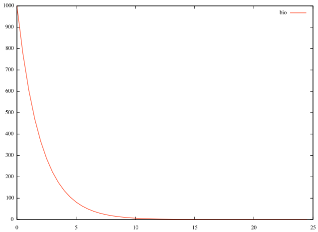
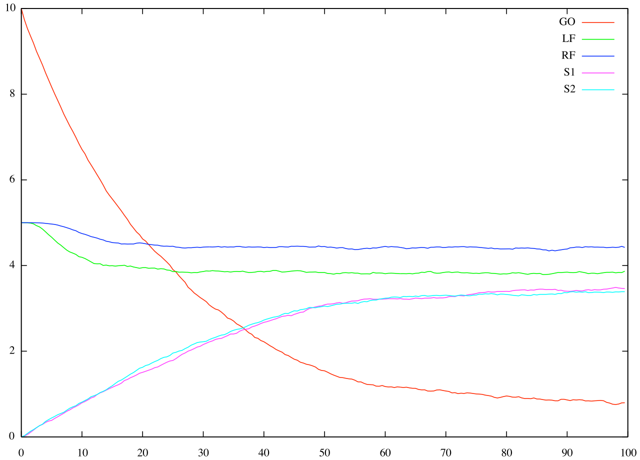
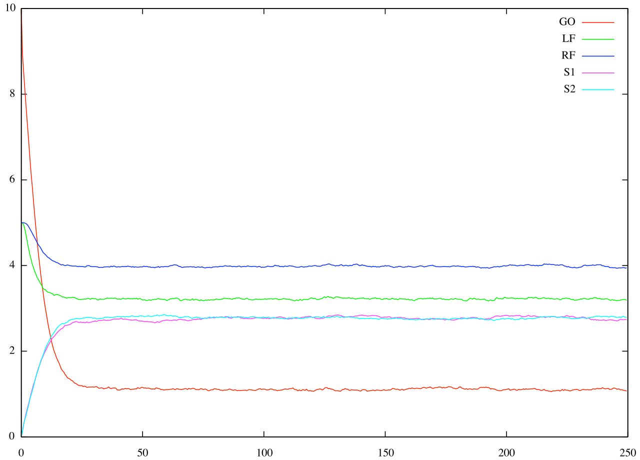




Simulating STOKLAIM Networks: DMS



Simulating StoKlaim Networks: DMS (bio)



Concluding Remarks

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- StoKlaim and MoSL can ben used for specifying and verifying properties of mobile and distributed systems.
- The proposed tool (SAM) permits:
  - verifying whether a given system satisfies or not a given property (by relying on MRMC)
  - simulate system behaviour.

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- StoKlaim and MoSL can ben used for specifying and verifying properties of mobile and distributed systems.
- The proposed tool (SAM) permits:
  - verifying whether a given system satisfies or not a given property (by relying on MRMC)
  - simulate system behaviour.

On going work:

- Investigating direct (on-the-fly) model-checking algorithms for the logic and StoKlaim
  - An on-the-fly model-checker for PCTL is under construction
- Define an ODE semantics of StoKlaim to predict behaviour of StoKlaim systems
  - Simulation and model checking will be used to validate the obtained results

THANK YOU FOR YOUR ATTENTION