A Stochastic Logic for Mobility and Global Computing

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Formal Methods && Tools Lab

MLQA
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Tribute

Many concepts and ideas presented here are based on results on formal modeling and analysis of stochastic aspects of system behaviour achieved in the last few years by many colleagues and friends, a.o.:

- C. Baier et al. (Tec. Univ. of Dresden, D);
- M. Bravetti et al. (Univ. Bologna, IT);
- R. Gorrieri et al. (Univ. of Bologna, IT);
- B. Haverkort et al. (Univ. of Twente, NL);
- H. Hermanns (Univ. of Saarbruecken, D);
- J. Hillston et al. (Univ. of Edinburg, UK);
- J.P. Katoen et al. (Univ. of Aachen, D);
- M. Kwiatkowska et al. (Univ. of Birmingham, UK);
- K. Larsen et al. (Aalborg Univ.);
- C. Priami et al. (Univ. of Trento);
- S. Smolka et al. (SUNY)
- . . . and many others!

The focus on GC and SOC is the subject of cooperative work in the context of the EU Projects

AGILE and SENSORIA

with:

- R. De Nicola (Univ. Firenze)
- J. P. Katoen (Univ. Aachen)
- M. Loreti (Univ. Firenze)
- M. Massink (CNR/ISTI, Pisa)

Outline

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1. StoKlaim in one slide;

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2. MoSL: General;

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3. MoSL: Operators

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1. StoKlaim in one slide;
2. MoSL: General;
3. MoSL: Operators (informal!);
4. Example properties (Airbag);
5. Developments

Klaim in one slide

KLAIM in one slide

- *System:*

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  Collection of Sites (i.e. physical addresses) with

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  - using logical addresses (locally mapped to physical ones)

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StoKlaim in one (more) slide

- *Actions*

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

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- *Processes*

  $$P ::= \mathbf{nil} \,\Big|\, (A, r).P \,\Big|\, P + P \,\Big|\, P \mid P \,\Big|\, X$$

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$$N ::= \mathbf{0} \;\Big|\; i ::_{\rho} P \;\Big|\; i ::_{\rho} \langle \vec{f} \rangle \;\Big|\; N \parallel N$$

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- *Stored Tuples*

  $$\langle f_1, \ldots, f_n \rangle \text{ with } f_j ::= v \Bigg| P$$

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

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  $\langle f_1, \ldots, f_n \rangle$ with $f_j ::= v \;\Big|\; P$

- *Patterns*

  $F_1, \ldots, F_n$ as usual ...

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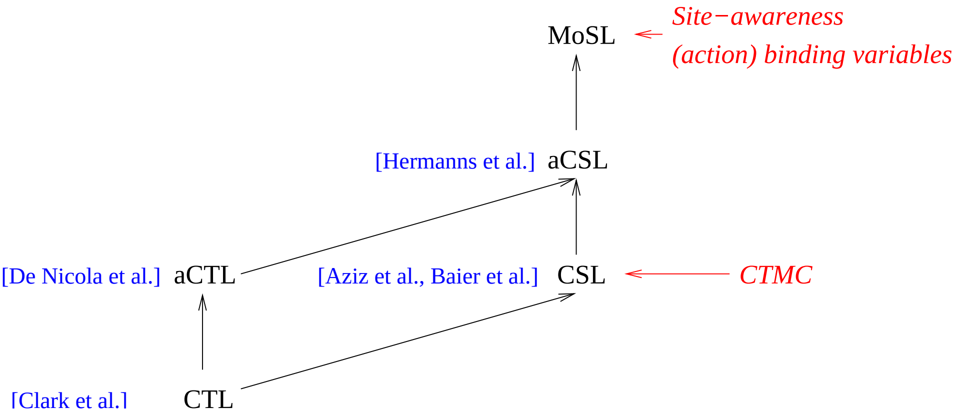
6. a *resource-oriented logic* (GC open-endedness)

MoSL:General (cont'd)



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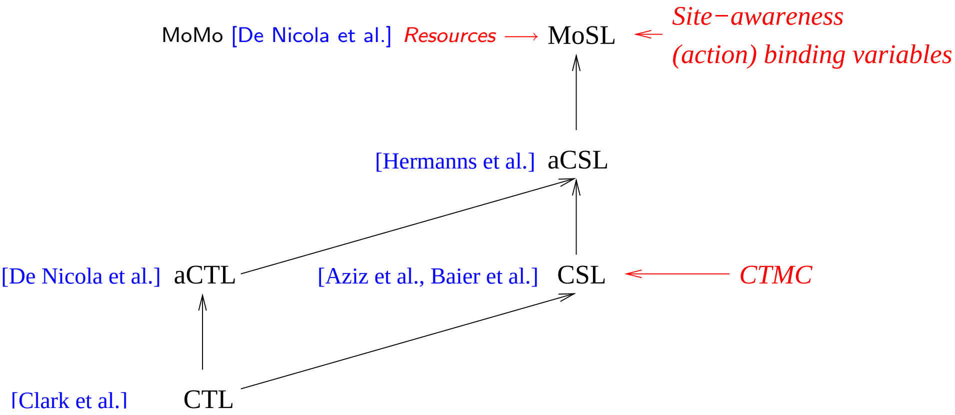

MoSL: Atomic propositions

$\aleph$

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$$\aleph \quad ::=$$

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Boot@A (satisfied if process *Boot* is ready to start at A)

MoSL: Atomic propositions

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$Boot@A$ (satisfied if process $Boot$ is ready to start at A)

$\langle GO \rangle @A$ (satisfied if value GO is stored at A)

MoSL: Action specifiers and action sets

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In CTL

$$\Phi \;\; \mathcal{U} \, \Psi$$

MoSL: Action specifiers and action sets

In aCTL

$$\Phi \ {}_{\Delta}\mathcal{U}_{\Omega} \ \Psi$$

Δ, Ω: Sets of actions (uninterpreted, atomic)

MoSL: Action specifiers and action sets

In MoSL

$$\Phi \; {}_{\Delta}\mathcal{U}_{\Omega} \; \Psi$$

Δ, Ω: Sets of *action specifiers*, to be matched against KLAIM actions

$$init : \mathrm{o}(GO, A)$$

Satisfied by any action executed at site *init*, by means of which a process uploads value *GO* to site *A*;

MoSL: Action specifiers and action sets (cont'd)

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Satisfied by any action, executed at some site (z_1), by means of which a process uploads value *GO* to some site (z_2);

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$\Delta = \{\xi_1, \ldots \xi_n\}$ satisfied by any action satisfying any of ξ_j;

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$\top$: satisfied by *any* action.

MoSL: Action specifiers and action sets (cont'd)

ACTION SPECIFIER	IS SATISFIED BY
$g_1 : \mathbf{O}(\vec{F}, g_2)$	any **out** action, executed at a site i_1 matching g_1, uploading a tuple $\vec{f}$ matching $\vec{F}$ to a site i_2 matching g_2
$g_1 : \mathbf{I}(\vec{F}, g_2)$	any **in** action, executed at a site i_1 matching g_1, downloading a tuple $\vec{f}$ matching $\vec{F}$ from a site i_2 matching g_2
$g_1 : \mathbf{R}(\vec{F}, g_2)$	any **read** action, executed at a site i_1 matching g_1, reading a tuple $\vec{f}$ matching $\vec{F}$ from a site i_2 matching g_2
$g_1 : \mathbf{E}(F, g_2)$	any **eval** action, executed at a site i_1 matching g_1, spawning a process P matching F to a site i_2 matching g_2
$g_1 : \mathbf{N}(g_2)$	any **newloc** action executed at a site i_1 matching g_1, creating a node with physical address i_2 matching g_2

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

- 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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MoSL: State formulae

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$$\langle\vec{F}\rangle @\imath \rightarrow \Phi \; \textit{consumption}$$

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MoSL: State formulae

$$
\begin{aligned}
\Phi \quad ::= \quad & \mathtt{tt} \mid \langle \vec{F} \rangle @\imath \mid Q @\imath \mid \\
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\end{aligned}
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& \mathcal{P}_{\bowtie p}(\varphi)
\end{aligned}
$$

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

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$$\mathcal{S}_{\bowtie p}(\Phi)$$

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State Formulae Satisfaction relation

$$
\begin{array}{lllll}
s & \models & \langle\vec{F}\rangle @\imath \rightarrow \Phi & \text{iff} & s \equiv \imath ::_\rho \langle\vec{f}\rangle \parallel s', match(\vec{F},\vec{f}) = \theta, \text{ and } s' \models \Phi \\
s & \models & \langle\vec{f}\rangle @\imath \leftarrow \Phi & \text{iff} & s \equiv \imath ::_\rho \mathbf{nil} \parallel s' \text{ and } \imath ::_\rho \langle\vec{f}\rangle \parallel s \models \Phi \\
s & \models & \mathcal{P}_{\bowtie p}(\varphi) & \text{iff} & \mathbf{IP}\{\pi \in \text{Paths(s)} \mid \pi \models \varphi\} \bowtie p \\
s & \models & \mathcal{S}_{\bowtie p}(\Phi) & \text{iff} & lim_{t\rightarrow\infty}\mathbf{IP}\{\pi \in \text{Paths(s)} \mid \pi[t] \models \Phi\} \bowtie p
\end{array}
$$

Path Formulae Satisfaction relation

$\pi \models \Phi \; {}_{\Delta}\mathcal{U}_{\Omega}^{<t} \; \Psi$ if and only if there exists $k, 0 < k \leq \mathsf{len}(\pi)$ s.t.:

1. $\sum_{j=0}^{k-1} \mathsf{time}(\pi, j) < t$
2. there exists Θ_{k-1} s.t.:
   1. $\mathsf{state}(\pi, k-1) \models \Phi$,
   2. $\mathsf{act}(\pi, k-1), \Theta_{k-1} \models \Omega$,
   3. $\mathsf{state}(\pi, k) \models \Psi\Theta_{k-1}$
3. if $k > 1$ there exist $\Theta_0, \ldots, \Theta_{k-2}$ s.t. for all $j, 0 \leq j \leq k-2$:
   1. $\mathsf{state}(\pi, j) \models \Phi$,
   2. $\mathsf{act}(\pi, j), \Theta_j \models \Delta$

$\gamma, \Theta \models \top$

$\gamma, \Theta \models \{\xi_1, \ldots, \xi_n\}$ iff there exists $0 < j \leq n$ s.t. $\gamma, \Theta \models \xi_j$

$\gamma, \Theta \models \xi$ iff $\mathsf{match}(\xi, \gamma) = \Theta$

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- In equilibrium, the probability is at least 0.87 that in at least 75% of the cases a *S1*-type request is placed at site A within 500 time units:

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- In equilibrium, the probability is at least 0.87 that in at least 75% of the cases a *S1*-type request is placed at site A within 500 time units:

$$\mathcal{S}_{\geq 0.87}(\mathcal{P}_{\geq 0.75}(\mathrm{tt} \;{}_{\top}\mathcal{U}^{<500}_{\{!z:\mathbf{O}(S1,A)\}} \; \mathrm{tt}))$$

The Airbag scenario - Sensoria D8.0

When an accident occurs to a car registered with the Accident Assistance Service and the airbag of the car deploys, the following happens. First, an automated message is sent to the Accident Assistance Server which contains the vehicle's GPS data, the vehicle identification number and a collection of sensor data. Then, the Accident Assistance Server places a call to the driver's mobile phone. If, due to his injuries, the driver is unable to answer the call, and the severity of the accident is confirmed also by the sensor data, the emergency services are alerted and the vehicle location is communicated to them. Incoming car are alerted as well.

The Airbag scenario - Sensoria D8.0

Simplifications

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Simplifications

- Airabag deployment is not considered.
- If the driver does not answer the phone call, the emergency services are alerted *anyway*.
- Alerting cars which are approaching the accident area *not considered*.

Modelling assumptions

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- Each entity of interest is (assumed modeled as a StoKlaim site and is) provided with its physical address.
  - Accident Assistance Server address: *AccAssSrv*,
  - Phone Server address: *PhSrv*,
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- The Accident Assistance Server alerts the Emergency Server by uploading the GPS data to site *EmSrv*.

Performance (Response time)

Guaranteeing acceptable timing for the detection of an accident which seriously injured the driver and for rescue alerting.

Performance (Response time)

Suppose it has been detected that an accident involving car *car_id* has taken place and that the driver is seriously injured

Ideal Requirement:

$\boxed{\text{Emergency Service alerted within maximal time } t\_alert}$

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■-property:

$$\mathcal{P}_{\geq 0.997}\left({}_{\top}\Diamond^{<t\_alert}_{\{AccAssSrv:\mathbf{o}((car\_id,gps),EmSrv)\}}\ \mathrm{tt}\right)$$

Performance (Response time, cont'd)

Focus on those states reached after a phone call has been placed to the driver mobile phone, and nobody has answered for a given period of time, t_answ.

Ideal Requirement:

> It should never happen that the phone is ringing for t_answ time units without a ■-state being reached.

Performance (Response time, cont'd)

Focus on those states reached after a phone call has been placed to the driver mobile phone, and nobody has answered for a given period of time, *t_answ*.

Realistic Requirement:

In at most 0.2% of the cases the phone is ringing for *t_answ* time units without a ■-state being reached.

Performance (Response time, cont'd)

Focus on those states reached after a phone call has been placed to the driver mobile phone, and nobody has answered for a given period of time, *t_answ*.

Realistic Requirement:

In at most 0.2% of the cases the phone is ringing for *t_answ* time units without a ■-state being reached.

■-property:

$$\mathcal{P}_{<0.002}(\langle PhNr(car\_id)\rangle @ PhSrv\ {}_{\top}\mathcal{U}^{[t\_answ, t\_answ]}\ \neg ■)$$

Performance (Response time, cont'd)

Consider now the situation in which an accident has been just notified.

Ideal Requirement:

> A phone call is placed to the driver mobile phone with a delay of at most *t_call* time units, bringing to a ■-state.

Performance (Response time, cont'd)

Consider now the situation in which an accident has been just notified.

Realistic Requirement:

> In at least 99.8% of the cases, a phone call is placed to the driver mobile phone with a delay of at most *t_call* time units, bringing to a $\blacksquare$-state.

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Performance (Response time, cont'd)

REQUIREMENT:

Ideal Requirement:

$\boxed{\text{The system does not behave } \textit{unacceptably}\text{, after an accident has been notified.}}$

Performance (Response time, cont'd)

REQUIREMENT:

Realistic Requirement:

> The probability that the system behaves *unacceptably*, after an accident has been notified, is less than 0.004.

Performance (Response time, cont'd)

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FINAL property:

$$\mathcal{P}_{<0.004}\left(\top \Diamond_{\{!car\_addr:\mathbf{o}((!car\_id,!gps,!sdata),AccAssSrv)\}} \neg \blacksquare\right)$$

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there are no paths without accident notifications reported

Performance (Response time, cont'd)

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$$\mathcal{P}_{\leq 0}({}_{\top}\Box\ \neg(\langle(!car\_id,!gps,!sdata)\rangle @AccAssSrv))$$

Performance (Response time, cont'd)

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Periodic testing the system with *fake* accident notifications

Performance (Response time, cont'd)

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Availability

Assume furthermore that the presence of token *FAULT* at address *AccAssSrv* signals that the Accident Assistance Server is down.

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$$\mathcal{S}_{>0.99}(\neg(\langle \mathit{FAULT} \rangle @ \mathit{AccAssSrv}))$$

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$$\mathcal{P}_{\bowtie p}(\neg(\langle ERR003\rangle @AccAssSrv)\ {}_{\top}\mathcal{U}^{[t,t]}\ \langle ERR003\rangle @AccAssSrv).$$

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- $\mathcal{U}^{[t,t']}$ generalises $\mathcal{U}^{<t}$
- model-checking $\mathcal{P}_{\bowtie p}(\varphi)$ automatically returns also $\mathbb{P}(\{\pi \mid \pi \models \varphi \text{ and } \pi \text{ from } s\})$ for all states s.

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2. More advanced Model-checking techniques
   - On the fly path model-checking (DT - bounded/unbounded until);
   - StoKLAIM uIMC semantics plus CTMDP model-checking.

SAM Model Checker

- StoKlaim simulation and reachability graph generation.
- StoKLAIM $\models$ MoSL verification
- implemented in OCaML
  - OCaML provides mechanisms for interoperability with the C language
  - these primitives are used for interacting with MRMC (computing *steady* and *path* probabilities)
- The tool is still at a prototype level
  - systems with about 10^6 states can be handled

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