Model Checking for Performance Analysis of Klaim Systems

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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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From Klaim to StoKlaim

- 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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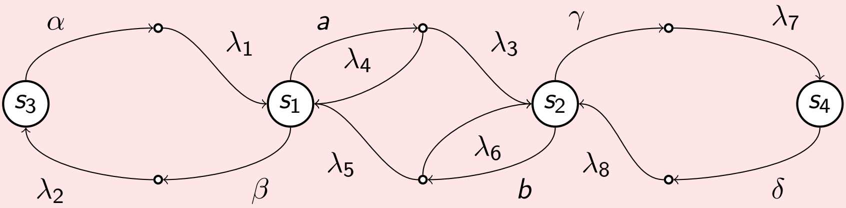

MoSL: General

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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Tuple Production:

Holds if the network satisfies Φ whenever tuple $\vec{f}$ is stored at site $\imath$.

MoSL: State formulae

$$\Phi ::= \mathsf{tt} \,|\, \aleph \,|\, \neg\Phi \,|\, \Phi \vee \Phi$$

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$$\Phi ::= \mathtt{tt} | \aleph \mid \neg\, \Phi \mid \Phi \ \vee \ \Phi \mid \mathcal{P}_{\bowtie p}(\varphi)$$

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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Satisfied by a state s iff the total probability mass for all paths starting in s that satisfy φ meets the bound $\bowtie p$;

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

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

- 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.
- Instantiations of variables in Ω act as binders Ψ.
- Simpler operator: $\Phi \ {}_{\Delta}\mathcal{U}^{<t} \ \Psi$.
- Time t can be omitted (assumed as ∞).

$$\mathsf{tt} \ {}_{\top}\mathcal{U}^{<t}_{\{init:\mathbf{O}(GO,A)\}} \ \mathsf{tt} \qquad \mathsf{tt} \ {}_{\top}\mathcal{U}^{<t}_{\top} \ \langle GO\rangle @A \qquad \mathsf{tt} \ {}_{\top}\mathcal{U}^{<\infty}_{\{i_1:\mathbf{N}(!z)\}} \ \mathbf{nil}@z$$

Model Checking MoSL

- 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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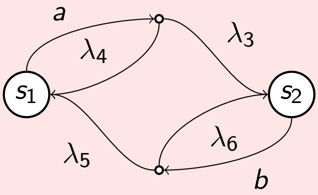
Translation:

- For each state s in $\mathcal{R}$, and for each transition pointing to s labelled by an action a, a distinct duplicate of s, labelled by a, is created in the target CTMC
- In order to consider the first transition delay correctly, one additional $\perp-$labelled duplicate is added for s.
- The outgoing transitions of these duplicate states have the same target and same rate as those of the original state.

An example...

From RTS...



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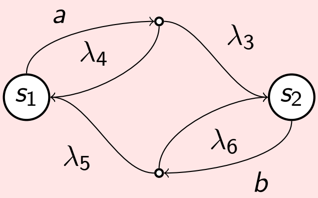

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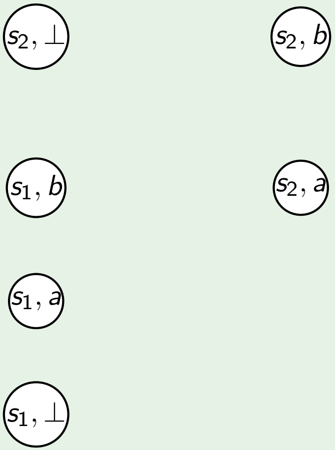

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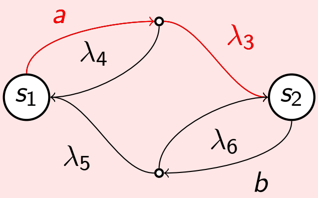

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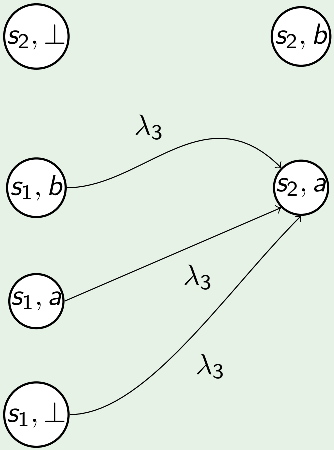

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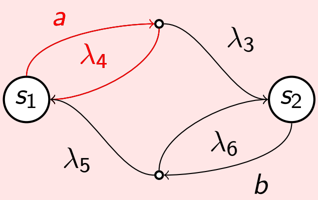

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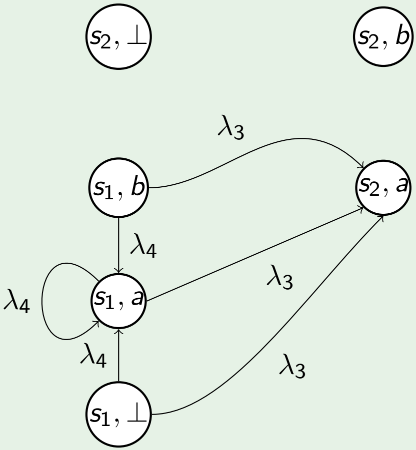

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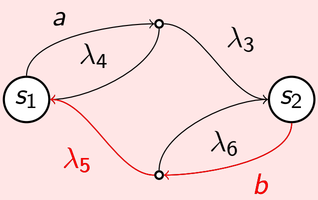

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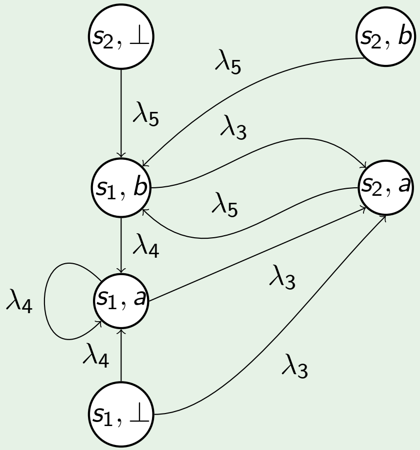

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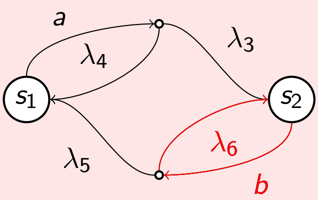

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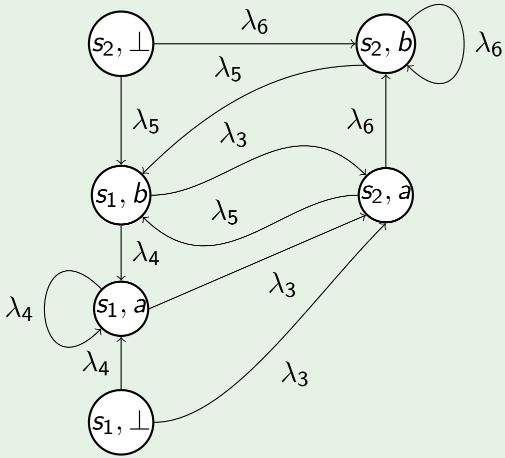

An example: Leader Election

Distributed leader election:

We consider an algorithm for *distributed leader election*:

- it is assumed that the nodes are always arranged in a ring
- in StoKlaim the system consists of N nodes each of which hosts the execution of a process.

All The Way...

In this algorithm every participants is univocally identified by an *id*. The leader will be the node with the minimum *id*. We assume that nodes identifiers are selected randomly.

An example: Leader Election

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1. When a process has determined its *id*, an ELECTION message is sent to the next node in the ring.
   - This message contain node's *id* and a counter (set to zero at the beginning).
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3. When a process receives back its ELECTION message, it knows the ring size.
4. The algorithm terminates when the number of messages received is equal to the ring size.

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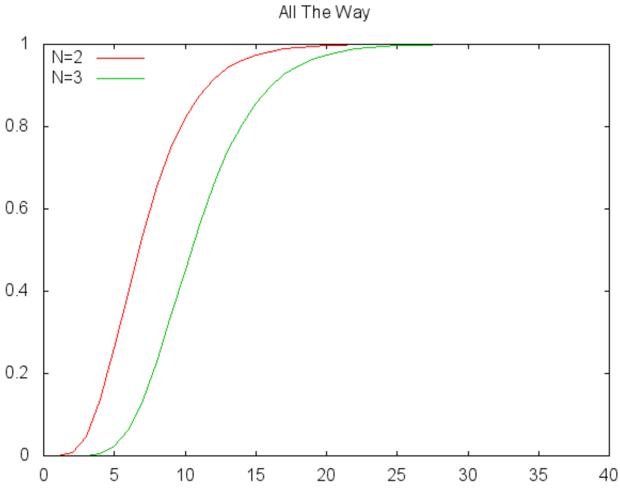

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All The Way:

Components	States	Transitions
2	116	180
3	6821	15129
4	952154	2770320

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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.

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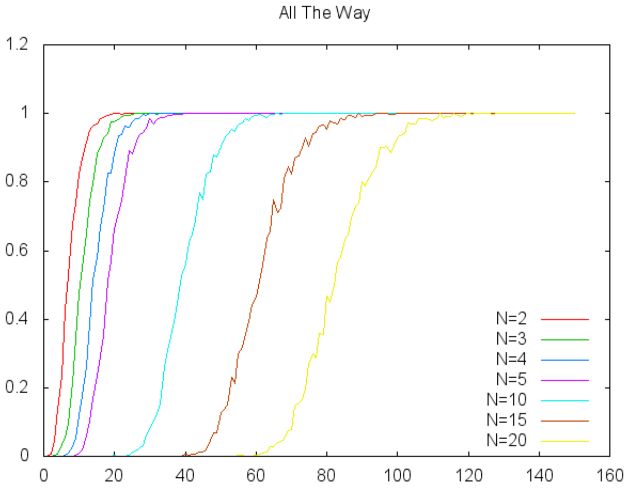
Statistical Analysis



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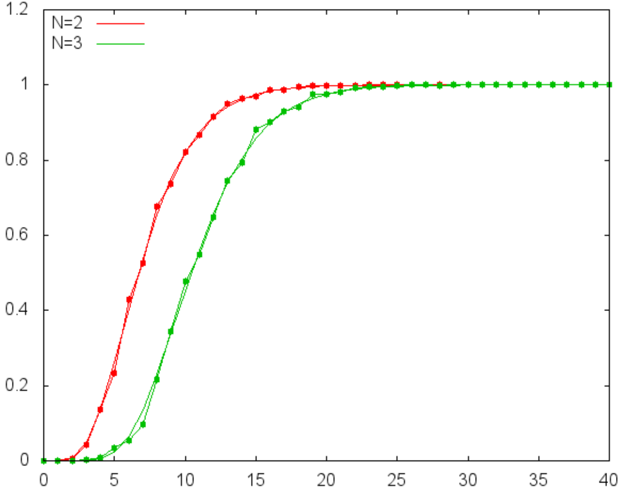
Statistical vs Numerical



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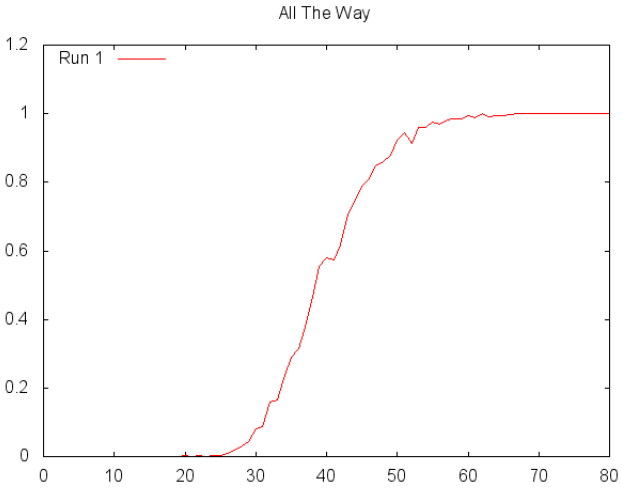

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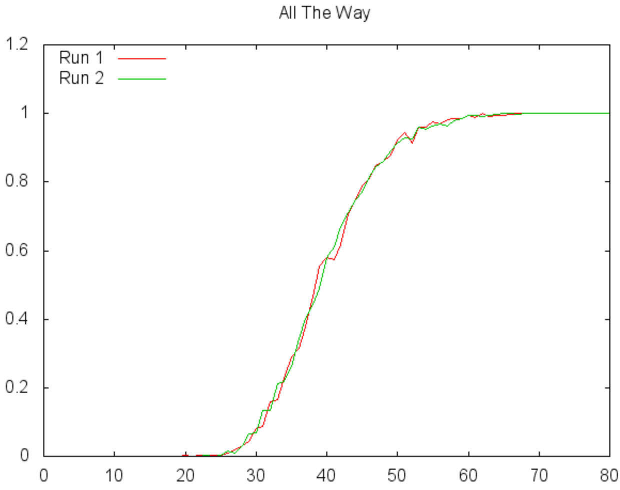

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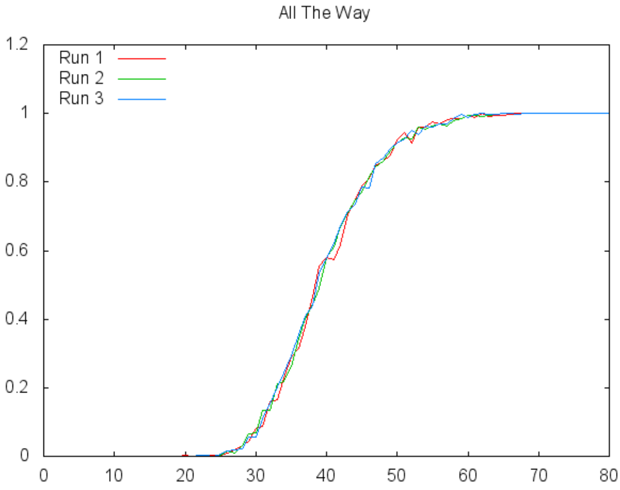

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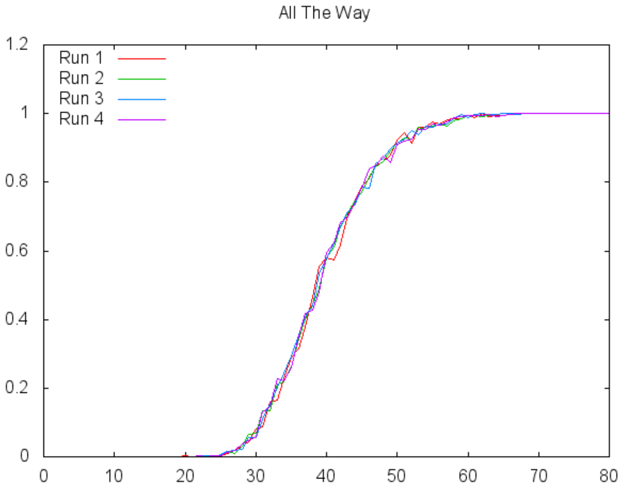

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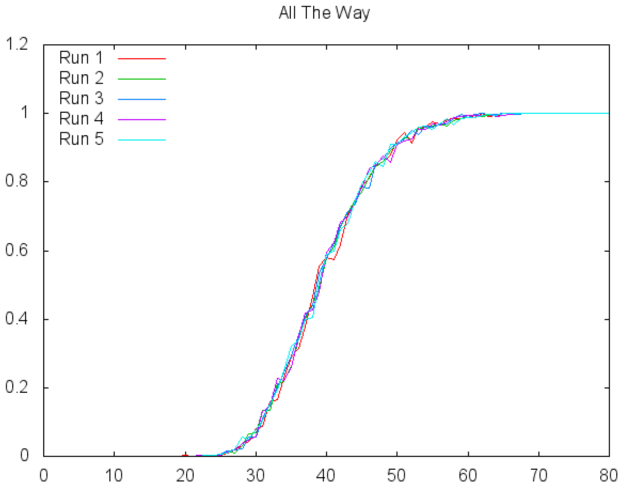

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    - statistical model-checking
  - simulating system behaviour.

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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

Only the braves...

SAM Home page:

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