Graph Transformation-based Stochastic Simulation

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Network reconfiguration

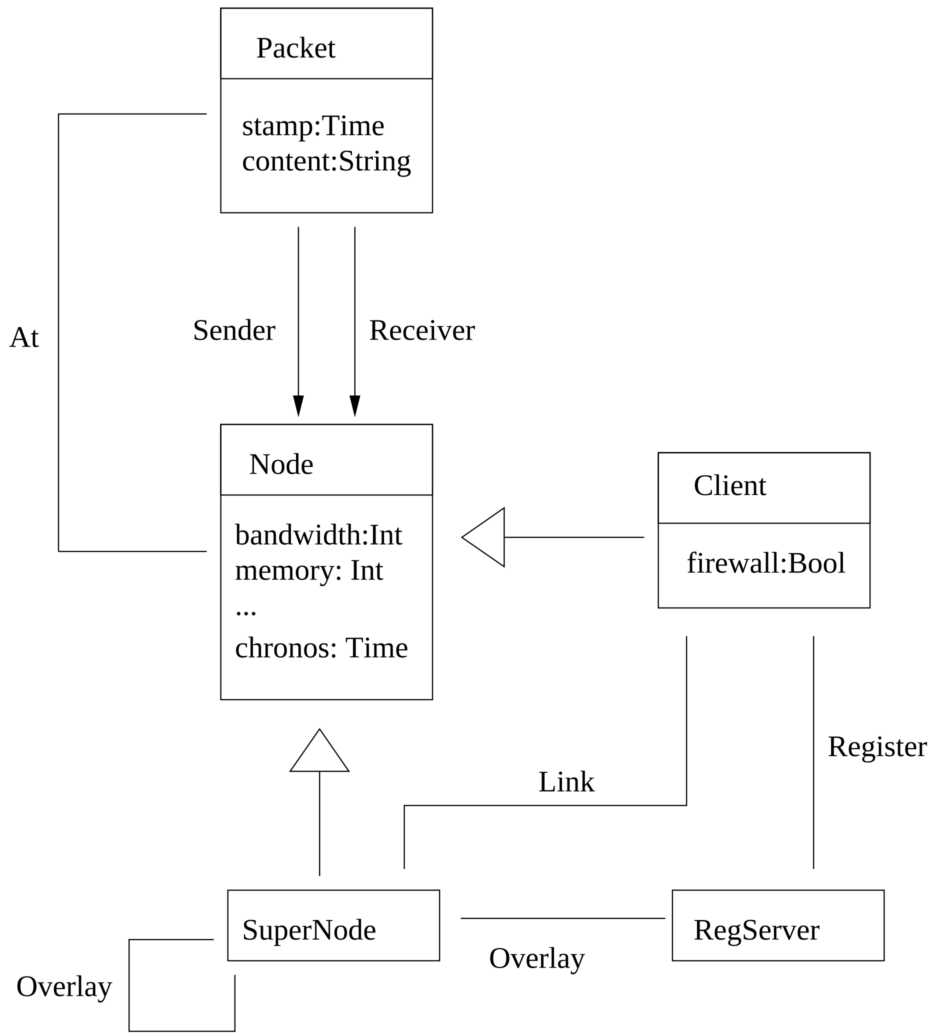
- Graph Transformation Systems as modelling technique
- Stochastic simulation as validation technique
- Application: simulation of system reconfiguration and behaviour
- Present focus: reconfiguration of P2P networks (previous work by Reiko), VoIP applications — esp. Skype (Ajab's PhD)
- Semantics: stochastic GTS interpreted as stochastic processes (previous work by Reiko *et al.*)
- Implementation: based on existing GTS tools (VIATRA)

Modelling networks

- Network as a typed graph (SPO):
  components as nodes
  connections as edges
- Transformations in our model:
  basic behaviour
  - sending packets
  - checking QoS parameters
  - connection/disconnection of clients

  reconfiguration
  - change of node status, client-supernode and overlay connections to improve QoS

Type graph



Packet
stamp:Time
content:String
At
Sender
Receiver
Node
bandwidth:Int
memory: Int
...
chronos: Time
Client
firewall:Bool
Link
Register
SuperNode
RegServer
Overlay
Overlay

Stochastic approach

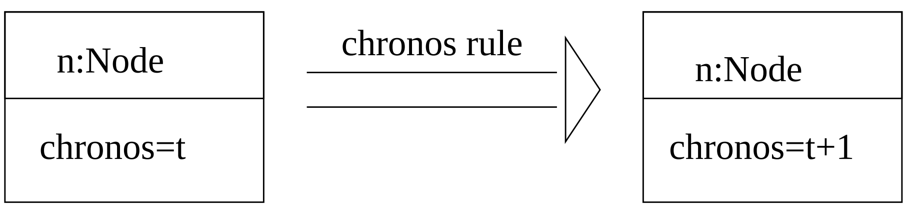
- Probabilistic rather than indeterministic actions
- Simulation based on sampling delay values according to given distributions
- Individual processes determined by Random Number Generator
- Rule application associated with an expected delay according to a probability distribution function

Probability distributions

- Expected delay (timer) — random variable associated to probability distribution function
- $F_T(x) = P\{T \leq x\}$
- Exponential distribution — determined by a rate, depends only on the present state
- Normal distribution — determined by mean and variance, finer modelling

Representing time

- Each component has a clock — *chronos* attribute
- *chronos* rule to advance time
- Normally distributed
  — exponential distribution would not do



GTS with probability

- Stochastic Graph Transformation Systems:
  rules associated with exponential probability distributions
- Generalised Stochastic Graph Transformation Systems:
  rule matches associated with general probability distributions
- Rule matches as equivalence classes to preserve inter-graph identity
  — restrictions on GSGTS to ensure they are a proper set (numbered graphs)
- Continuous time — timers are independent variables, so probability of two actions taking place at the same time is 0. So we skip parallelism

Stochastic processes

- Continuous-time stochastic process — time-indexed family of random variables over states
- Markov process: next state depends on current state only, interevent time is exponentially distributed
- Semi-Markov process: next state depends on time spent in current state, too
- Translation of GSGTS to Generalised Semi-Markov Processes

Stochastic structures

- Generalised Semi-Markov process:
  generated by a structure based on timers + race condition
- Timers as stochastic clock structure: Stochastic Timed Automata
- Timers set by RNG: Generalised Semi-Markov Scheme
- Timers do not need to be reset at each state change
  i.e. they do not need to be exponential — so neither interevent time do

GSGTS

- SPO — components may disconnect without warning
- $\mathcal{G} = \langle TG, P, \pi, G_0, F \rangle$
- Type graph, rule names, initial graph
- F maps rule matches to probability distribution functions (cumulative distributions:
  — max delay value mapped to probability)

GSMS

$$
\begin{aligned}
\mathcal{P} \quad = \langle \quad & States \\
& Events \\
& ActiveStates : State \rightarrow \wp Event \\
& Transition : State \times Event \rightarrow State \\
& \Delta : Event \rightarrow (\mathcal{R} \rightarrow [1, 0]) \\
& InitialState : State \qquad \rangle
\end{aligned}
$$

from GSGTS to GSMS

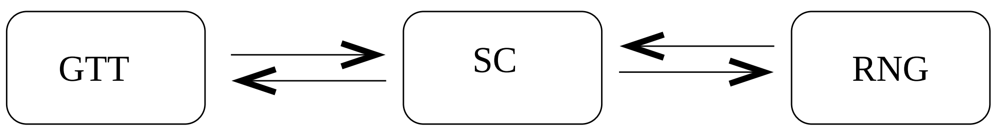
$$
\begin{aligned}
\mathcal{P} \quad = \langle \quad & ReachGraphs \\
& RuleMatches \qquad \text{(equivalence classes)} \\
& EnabledMatches : ReachGraph \to \wp RuleMatch \\
& GraphTrans : \\
& \qquad ReachGraph \times RuleMatch \to ReachGraph \\
& F : RuleMatch \to (\mathcal{R} \to [1, 0]) \\
& InitialGraph : ReachGraph \qquad \rangle
\end{aligned}
$$

GSMS-based simulation

- Simulation of GSMP based on Event Scheduling Scheme algorithm
- Refinement of ESS
  — for GSMP obtained from GSGTS
- Substantial problem: computation of active matches
  — we need to keep track of pre-existing matches
- Incremental pattern-matching
  — implemented in VIATRA (Eclipse plug-in)
- Planned Java implementation using SSJ libraries for RNG

Implementation architecture

- Graph transformation tool (GTT)
- Simulation control (SC)
- Random number generator (RNG)



Scheduling Scheme I

- Initial input:
  graph transformation system (for GTT)
  simulation time t (for SC)
  probability distribution functions (for RNG)
- Initialisation:
  active matches of the initial graph computed by GTT
  associated to scheduled delay d (from RNG)
  scheduled time = $t + d$
  collected in list ordered by scheduled time
- list ordering implements race condition

Simulation Control

1. First item $(\langle r, m \rangle, t')$ removed from list,
   simulation time updated to t'
2. Graph update (by GTT)
   — rule r applied to the current graph at m
   — new and surviving matches are computed
   (incremental approach should help)
3. New matches are associated to scheduling times
   — RNG calls
4. list ordering

Further work

- Containment relations and spatial aspect — to model domains, firewall restrictions, geographic locations
- *Chronos* rule application overkill: two possible strategies
  — temporal granularity with laziness
  — synchronous approach (global time)
- Comparison with existing simulation tools (such as NS2)
- A. Kahn, P. Torrini, R. Heckel — *Model-based Simulation of VoIP Network Reconfigurations using Graph Transformation Systems*
  Doctoral Symposium ICGT 2008 (post-proceedings, 2009)