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Simulating Midlet's Security Claims with Automata Modulo Theory

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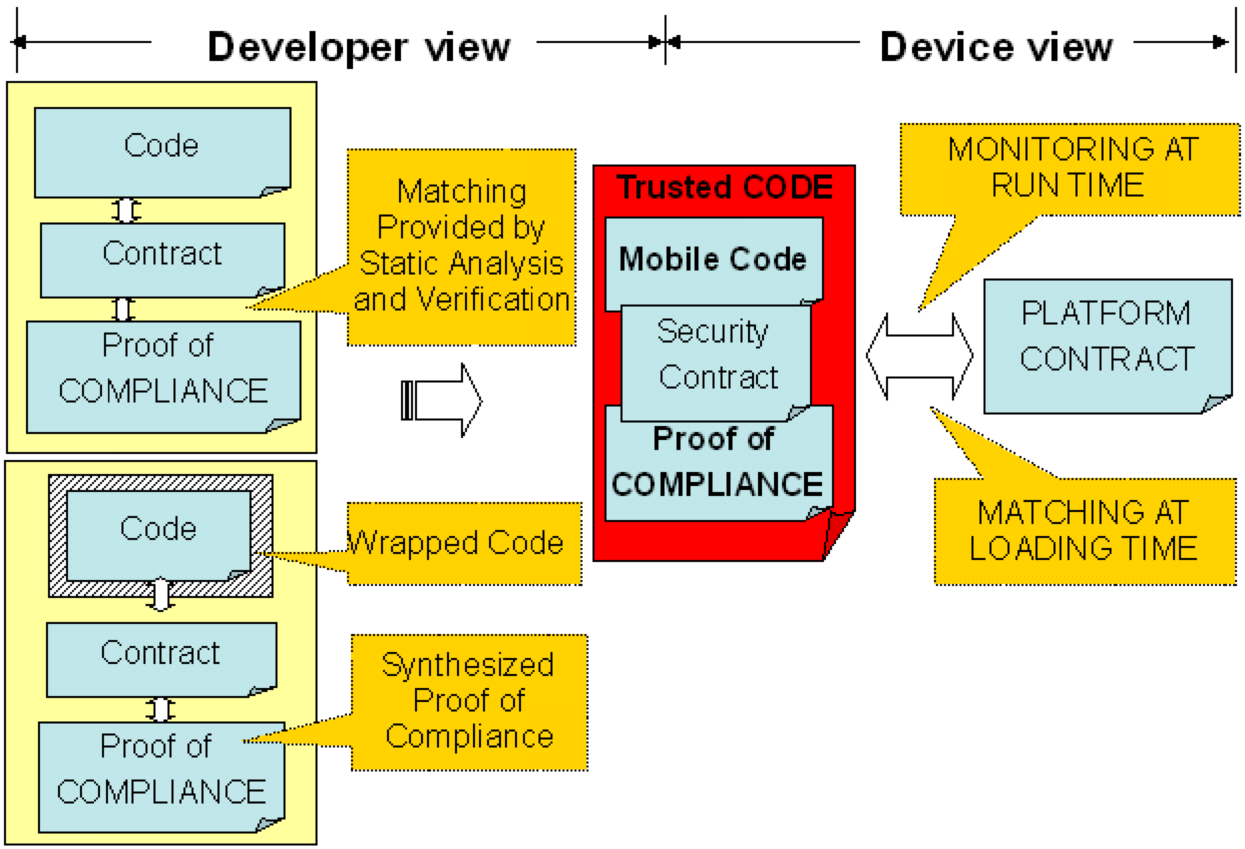
Outline

- Motivation
- Security x Contract
  - Concepts
  - Workflow
- Automata Modulo Theory (AMT)
  - AMT Theory
  - Contract/Policy Matching
- Conclusions
  - Issues yet to be addressed

Motivations

- A validation infrastructure exists
  - – A signature is checked on the device
  - – No semantics is attached to it
- Some technologies exist
  - – Static analysis to prove program properties
  (Leroy et al., Morriset et al., Fournet et al.)
  - – Monitor generation for complex properties
  (Havelund & Rosu, Erlingsson et al., Hamlen et al., Ligatti et al.)
- Security-by-Contract (SxC) puts them together
  - – Use contracts as semantics for the signatures
  - – Use static analysis and monitors as basis

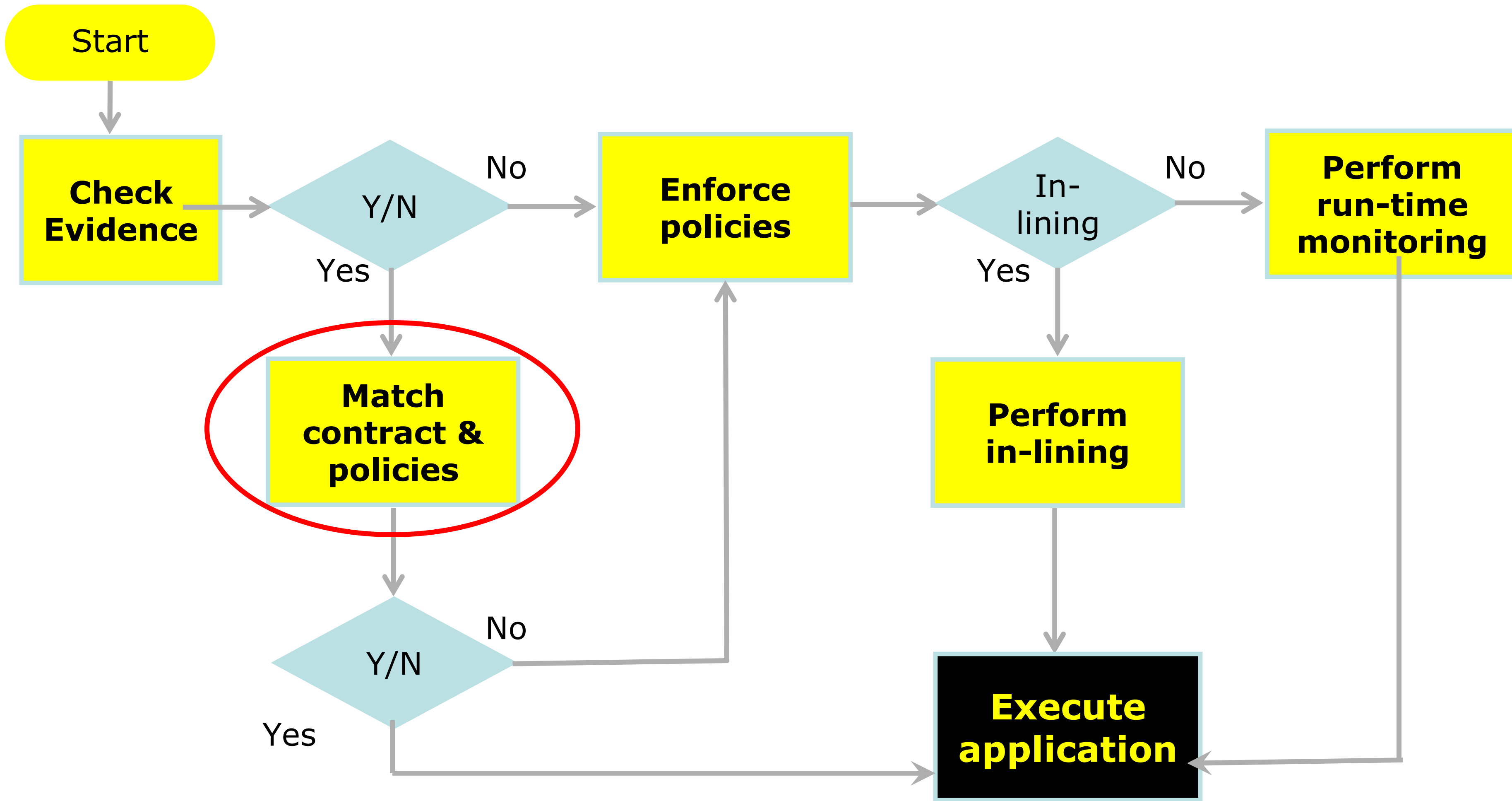
Mobile Code Components



Key Concepts

- Contract carried by application;
  - Claimed Security behavior of application
  - (Security) interactions with its host platform
  - Maybe with Proof that code satisfies contract
- Policy specified by a platform.
  - Desired Security behavior of application
  - Fine-grained resource control
- But I trust nobody, I just need policy monitor
  - Monitoring ONLY part of the story…

SxC Workflow – User's View



Contract vs Policy

Contract = What you Claim

Rules

- Used Methods
- Bounds on Methods Args
- Bounds on ret Values
- Allowed Sequences
- *Achievable Obligations*

Policy = What you should at most do

Rules

- Possible Methods
- Constraints on Methods Args
- Constraints on ret Values
- History-based access control
- *Desired Obligations*

Language Containment = Simulation of Finite Automata?

[NORDSEC'07] [PLAS'08]

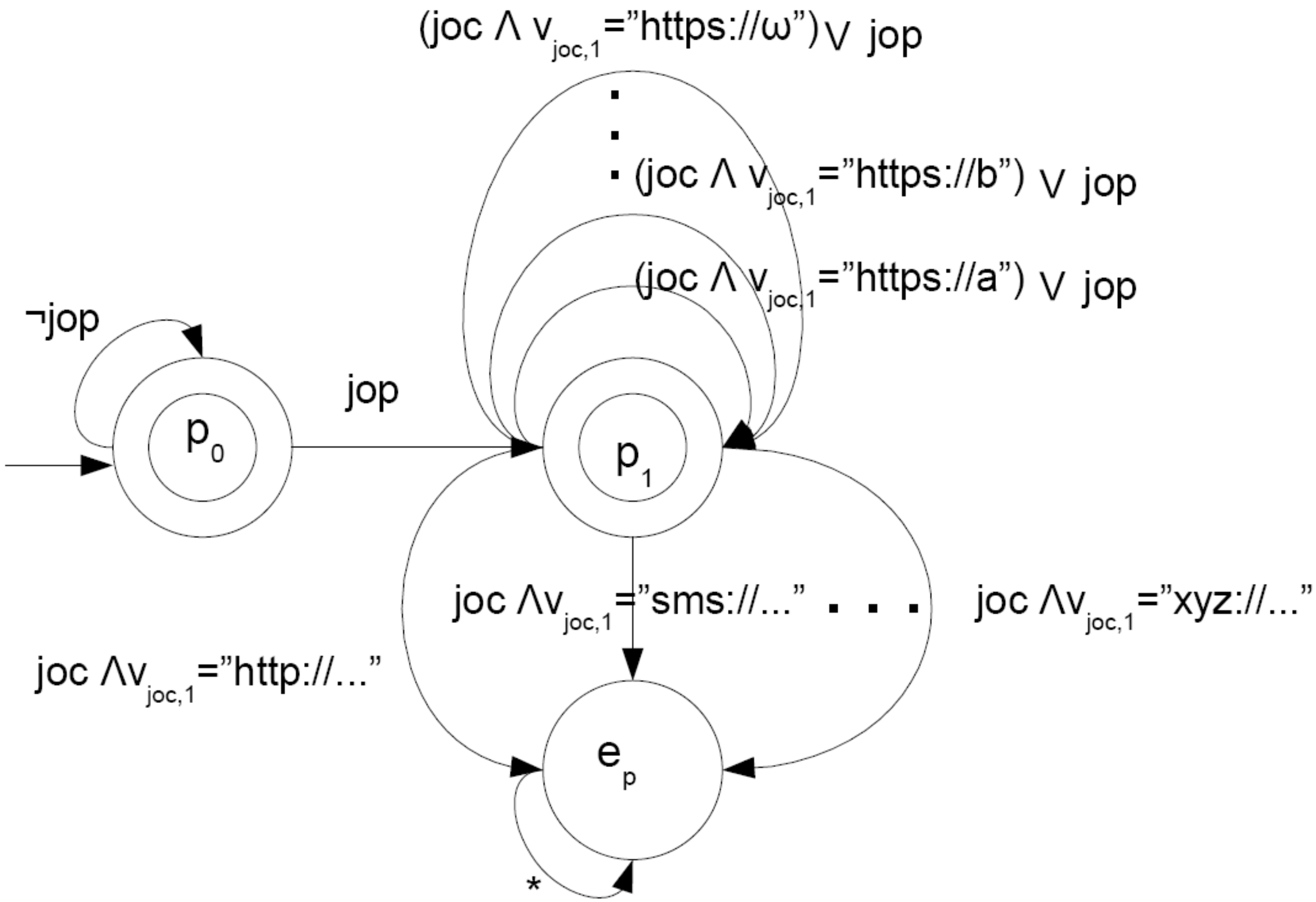
(Sekar et al. 2003)

Contract vs Policy: Practice

Contract = What you Claim	**Policy = What you should at most do**
Rules	**Rules**
• No connections After PIM was opened	• After PIM was accessed only secure connections can be opened
• Exec Connector.open() only if PIM.openPIMList() never called before.	• Exec Connector.open(url) only if url starts with “https://”

Language Simula Nondeterministic complementation????

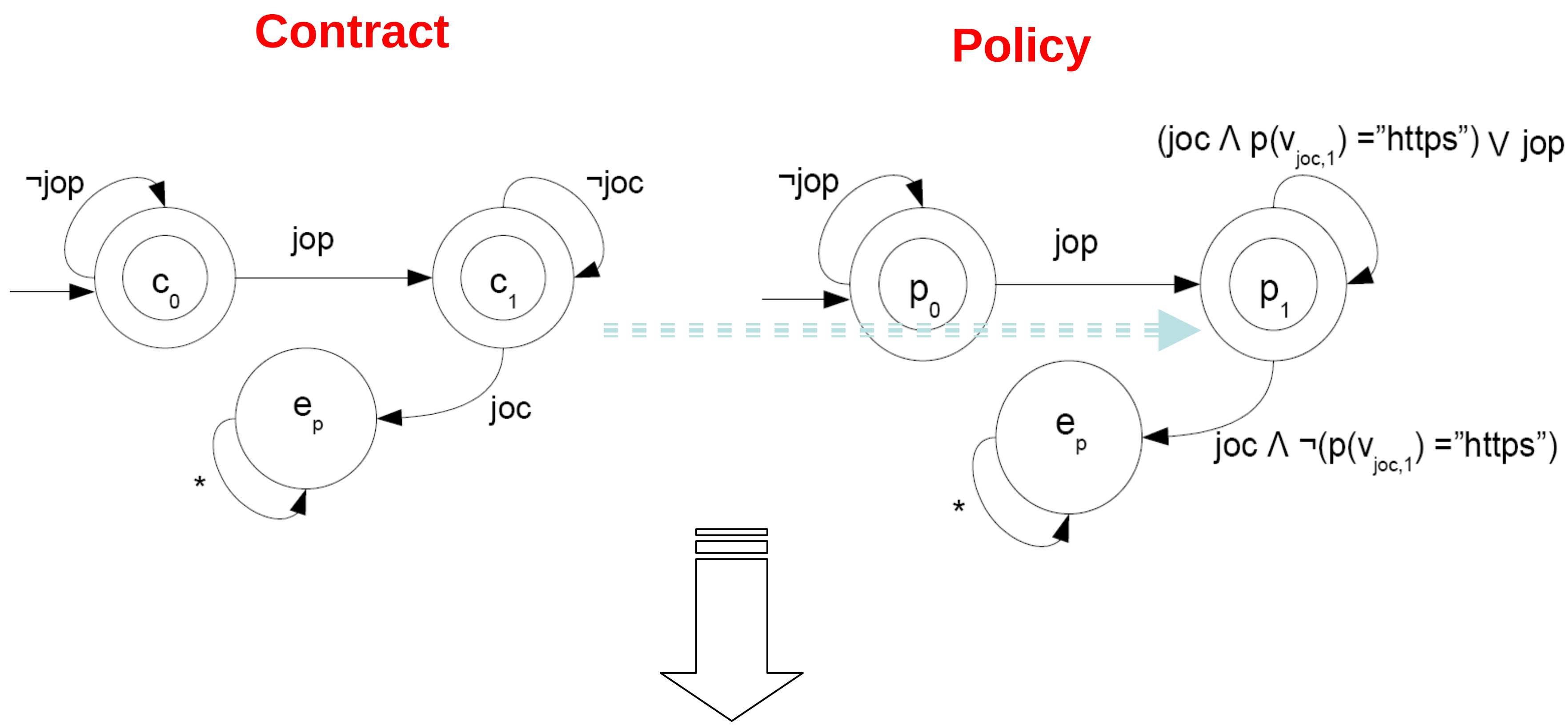
A Practical “Infinite” Policy



What's Automata Modulo Theory ($\mathcal{AMT}$)?

- *Finite state* Automata
  - They represent the security behavior (claimed or desired)
- But *Infinite edges*
  - Url starting with "https://" are not that few…
  - Battery Levels less than 30%
- Yet Finitely represented with Expressions
  - m=Java.IO.Connector &&
  - protocol(x)==https && protocol(x)==http
  - applicationType(x)!=jpg || appType(x)=appType(y)
- Needed Decidable theory for expressions

Contract vs Policy in $\mathcal{AMT}$



Simulation of Automata Modulo Theory

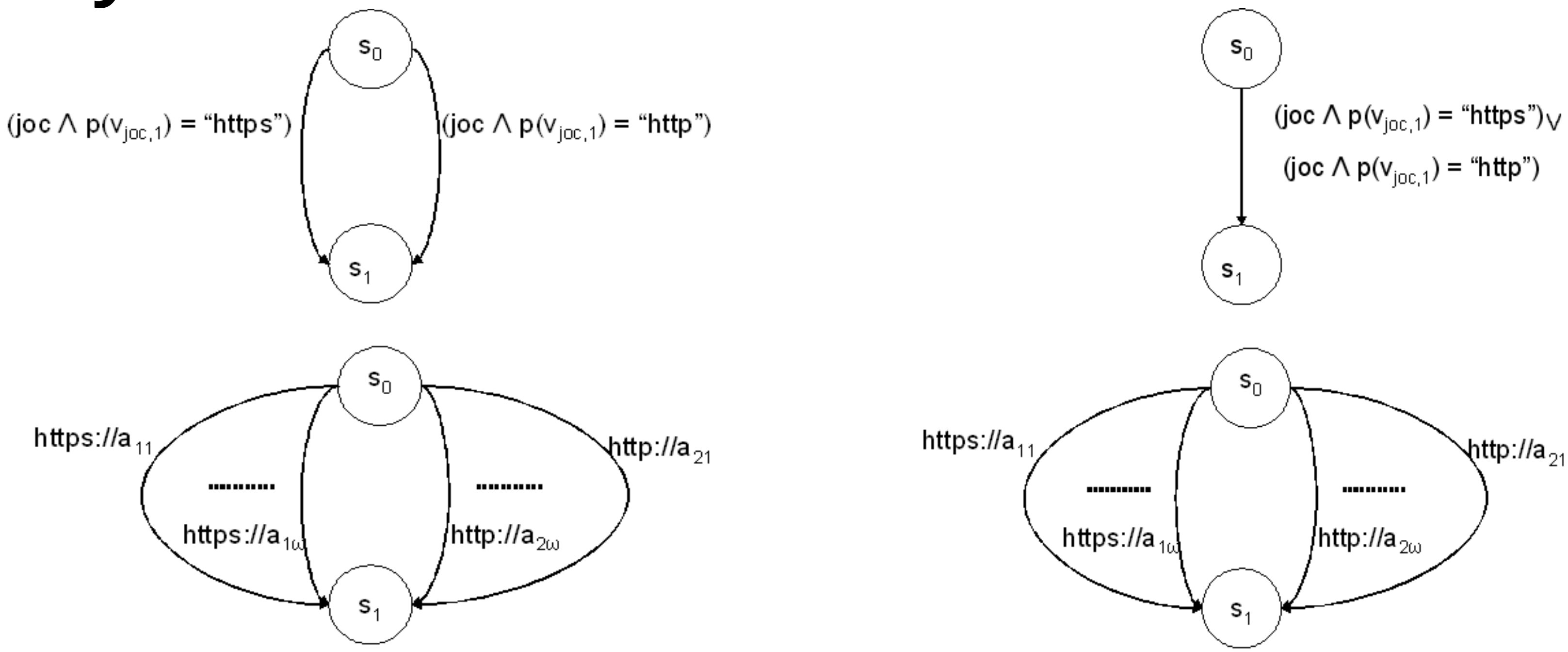
Matching as Simulation

- Matching = Simulation
  - Every APIs invoked by Contract can also be invoked by Policy.
    - Every behavior of Contract is also behavior of Policy.
  - Usually stronger than language inclusion
    - Policy allows midlet's Contract actions ”step-by-step”
- Compliance Game
  - Contract tries to make a concrete move and Policy follows accordingly to show that the Contract move is allowed.
  - IF expression of Contract implies expression of Policy is VALID (modulo theory)
  - THEN exists a move

Simulation as Game

- Winner of the game:
  - Contract cannot move: Policy wins.
  - Policy cannot move: Contract wins.
  - Otherwise, two infinite concrete runs *s* and *t* resp. of Contract and Policy:
    - *s* is an accepting concrete run and *t* is not an accepting concrete run: Contract wins.
    - Other cases: Policy wins.
- Failure of Matching
  - Policy cannot move => Contract is not compliant

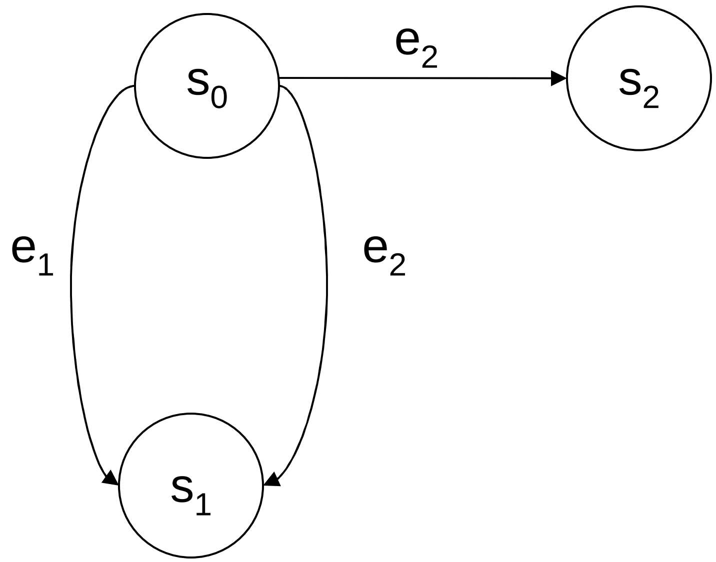
Symbolic vs Concrete Automaton

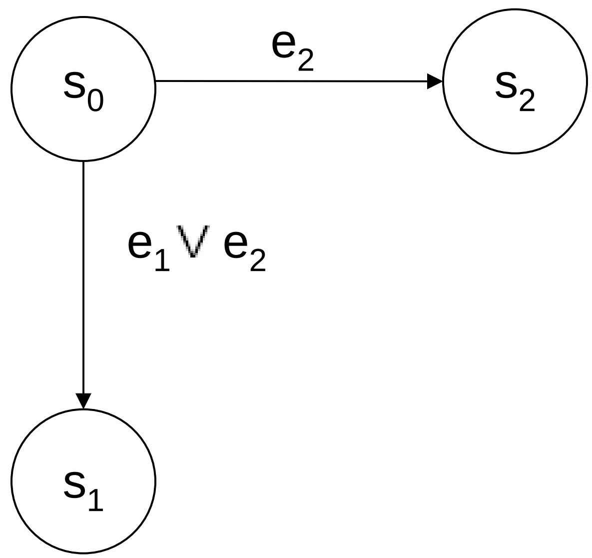


- If Ac ≤ Ap is an AMT fair simulation relation then Ac ⊑ Ap is a concrete fair simulation relation.
  - The converse does not hold in general.
  - Contrast to the simulation notions of (Hennessy and Lin 1995)
- AMT fair simulation is stronger than AMT language inclusion.

Normalized AMT

- For every q,q1 in set of states S there is at most one expression e1 in set of expressions E such that q1 in transition (q, e1).
  - Example from previous figure: Left is NOT normalized, Right is normalized
- Normalization is NOT always applicable:
  - disjunction of all expressions going to the same state as may change nondeterministic automata into deterministic automata (see figure below).
- IF automata are in normalized form
- THEN AMT fair simulation coincides with concrete fair simulation.





Simulation Policy-Contract Algorithm

- Finding counterexamples faster:
  - adapts Jurdzinski's algorithm on parity games (Jurdzinski 2000)
  - combine decision procedure for SMT (Cimatti et al.)
- Algorithm
  - Create compliance game graph G
  - $\mu(v) := 0$ for all v □ V
  - while $\mu(v) \neq \mu_{new}(\mu, v)$ for some v □ V do
    - $\mu := \mu new(\mu, v)$
  - IF $\mu < \infty$ THEN
    - Simulation exists

A bit Complexity for $\mathcal{AMT}$

- $\mathcal{AMT}$ runs
  - Concrete:
    - a sequence of states alternating with assignments (instantiation method args)
  - Symbolic:
    - a sequence of states alternating with expressions
- Criticality of fair simulation for matching
  - Jurdzinski's algorithm on parity games (Jurdzinski 2000)
- IF theory $\mathcal{T}$ decidable with oracle for SMT problem in complexity class $\mathcal{C}$ then:
  - Fair simulation of $\mathcal{AMT}_\mathcal{T}$ in *POL-TIME*$^{\mathcal{C}}$
  - Fair simulation of $\mathcal{AMT}_\mathcal{T}$ is $O(|S^c|.|S^p|.|\Delta^c+\Delta^p|)^{\mathcal{C}}$

Issues yet to be addressed

- Encoding of history dependent policies
  - allow certain strings we saw in the past
    - Eg connect only to url in the JAR manifest
    - Combine AMT with History Dependent Automata (Montanari & Pistore 1998)
    - Combine AMT with Extended Finite State Automata (Sekar et al. 2002)
- Infinite expressions
  - allow concrete run of infinite domains
    - Eg natural number not limited to some maximum length
    - Combine AMT with Finite Memory Automata (Kaminski & Francez 1994)

Conclusions

- Idea of Security-by-Contract
  - Always consider complete lifecycle monitoring is the end
  - Matching: be able to check that claimed security behavior of what you want to run is good for your security policy
- Concept of Automata Modulo Theory
  - we invented it for security policies of mobile code but…
  - usable for any security policy with a finite control structure but potentially infinite data
    - (secure workflows, protocol analysis, control-flow analysis etc.)
  - IF polynomial theory for deciding edges THEN Practical
  - Language Containment ≠ Simulation for AMT