Seminar *Theoretical Foundations of Programming Languages*

Introduction

Summer Semester 2016; 13 April, 2016

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https://moves.rwth-aachen.de/teaching/ss-16/tfopl/

Outline

Overview

Theoretical Foundations of Programming Languages

Theoretical Foundations of Programming Languages

- Seminar addresses several aspects of programming languages and software systems (in a broad sense)
- Emphasis: formal foundations and principles underpinning practical applications

Software Modeling and Verification Chair
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Theoretical Foundations of Programming Languages

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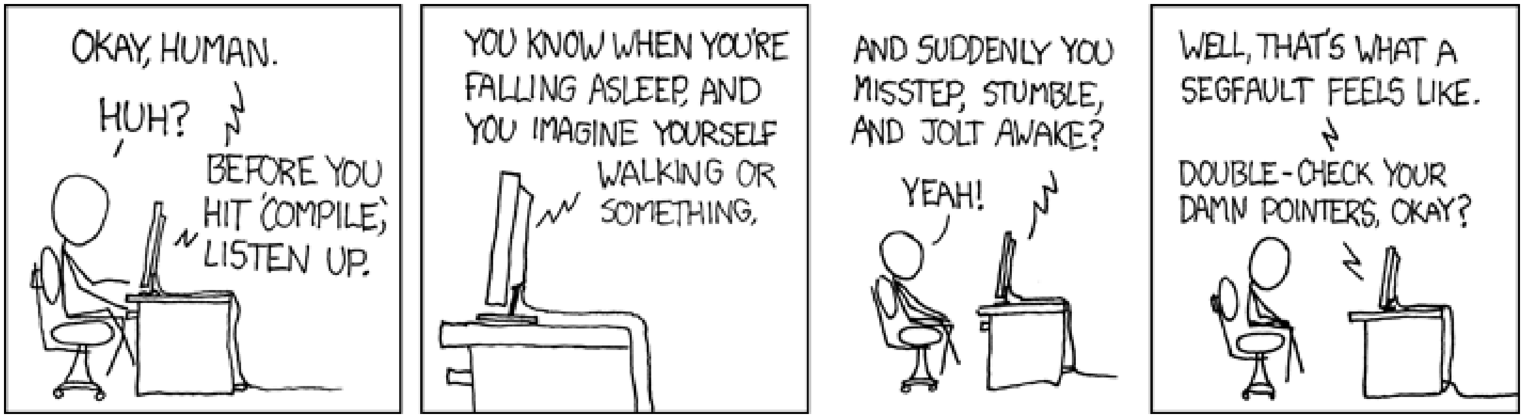
Aspects

- Analysis of Pointer Programs
  - *Static Program Analysis* (WS 2014/15)
  - *Semantics and Verification of Software* (SS 2015)
- Software Model Checking
  - *Introduction to Model Checking* (SS 2015, now)
  - *Advanced Model Checking* (SS 2014)
- Analysis of Probabilistic Systems
  - *Modelling and Verification of Probabilistic Systems* (SS 2014)

Overview

Analysis of Pointer Programs



https://xkcd.com/371

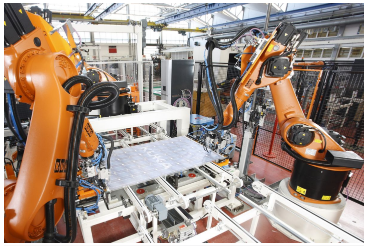
Pointer-related software errors

- Dereferencing null (or disposed) pointers
- Creation of memory leaks
- Accidental invalidation of data structures
- Deadlocks
- Data races, ...

Software Model Checking

Programmable Logic Controller (PLC) Code

- Tailored for automation processes
- Run ad infinitum
- Executed in a cyclic manner
- Terminate within predefined cycle time



Challenges

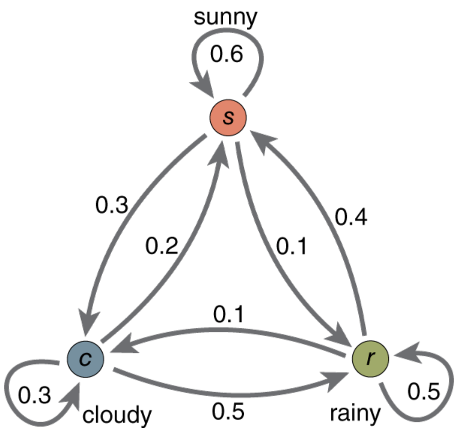
- Application domains have high safety requirements
- Violations entail high economical costs
- Currently checked by extensive testing

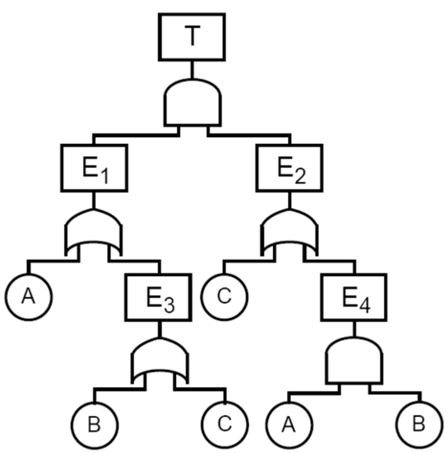
Example

Motor must move in safe range, otherwise worker gets injured.

Overview

Analysis of Probabilistic Systems





“Jungle” of models

- Discrete vs. continuous time
- Deterministic vs. non-deterministic
- ...

Interesting questions

- Reachability properties (of “bad” states)
- Transient probability distributions
- Model checking
- Analysis of failures (fault trees)
- ...

Outline

Aims of this Seminar

Goals

Aims of this seminar

- Independent understanding of a scientific topic
- Acquiring, reading and understanding scientific literature
- Writing of your own report on this topic
- Oral presentation of your results

Requirements on Report

Your report

- Independent writing of a report of $\approx$ 15 pages
- Complete set of references to all consulted literature
- Correct citation of important literature
- Plagiarism: taking text blocks (from literature or web) without source indication causes immediate exclusion from this seminar
- Font size 12pt with “standard” page layout
- Language: German or English
- We expect the correct usage of spelling and grammar
  - $\geq$ 10 errors per page $\Longrightarrow$ abortion of correction
- Report template will be made available on seminar web page

Requirements on Talk

Your talk

- Talk of about 45 (= 40 + 5) minutes
- Focus your talk on the audience
- Descriptive slides:
  - $\leq$ 15 lines of text
  - use (base) colors in a useful manner
- Language: German or English
- No spelling mistakes please!
- Finish in time. Overtime is bad
- Ask for questions

Final Preparations

Preparation of your talk

- Setup laptop and projector ahead of time
- Use a (laser) pointer
- Number your slides
- Multiple copies: laptop, USB, web
- Have backup slides ready for expected questions

Outline

Important Dates

Deadlines

- 09.05.2016: Detailed outline of report due
- 13.06.2016: Report due
- 04.07.2016: Slides due
- 18./19.07.2016 (???): Seminar

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Missing a deadline causes immediate exclusion from the seminar

Outline

Selecting Your Topic

Procedure

- You obtain(ed) a list of topics of this seminar.
- Classified according to BSc/MSc level (or both).
- Indicate the preference of your topics (first, second, third).
- Return sheet by Friday (15 April) via e-mail/to secretary.
- We do our best to find an adequate topic-student assignment.
  - disclaimer: no guarantee for an optimal solution
- Assignment will be published on website by 18 April.
- Please give language preference.
  - unsure $\Longrightarrow$ German

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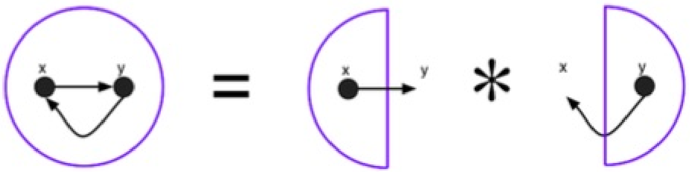
Withdrawal

- You have up to three weeks to refrain from participating in this seminar.
- Later cancellation (by you or by us) causes a not passed for this seminar and reduces your (three) possibilities by one.

Outline

1. B: Introduction to Separation Logic [Noll]



$$\frac{\{P\}\ C\ \{Q\}}{\{P * R\}\ C\ \{Q * R\}}\ \mathsf{mod}(C) \cap \mathsf{fv}(R) = \emptyset$$

Separation Logic (SL)

- Logic for reasoning about programs that manipulate pointer data structures
- Extension of Hoare logic (correctness properties and proof rules)
- SL formula represents set of heap states
- Symbolic execution of programs on SL formulae

2. M: Separation Logic with Permissions [Noll]

```
int a = 1;
int b = 2;
…
int thread1() {
  return a + b;
}
```

```
int thread2() {
  b = 42;
}
```

time

Idea

- Threads acquire/release read and write permissions
- Read permission for shared read access
- Write permissions for exclusive write access

Observations

- Permission not available $\Longrightarrow$ potential data race
- Permissions can always be acquired $\Longrightarrow$ data-race freedom

3. M: Concurrent Separation Logic [Noll]

$$\frac{\{P_1\}C_1\{Q_1\} \quad \{P_2\}C_2\{Q_2\}}{\{P_1 * P_1\}C_1 \parallel C_2\{Q_1 * Q_2\}}$$

Concurrent Separation Logic (CSL)

- Extension of SL that allows independent reasoning about threads that access separate storage
- Proving soundness of CSL is a difficult problem
- Earlier approaches are based on non-standard semantics or are purely syntactic
- Paper presents new soundness proof for CSL in terms of standard operational semantics

4. M: Compositional Shape Analysis by Means of Bi-Abduction [Matheja]

- Compositional analysis: each procedure is analyzed independently of its callers
- Shape analysis: static analysis to discover and verify properties of heap manipulating programs
- Abduction: identify part ? of a formula to make implication $\varphi * ? \rightarrow \psi$ valid
- Approach of this paper:
  - Heuristic to solve abduction problem of separation logic
  - Use abduction to obtain a compositional shape analysis generating pre/post-conditions for each procedure
  - Apply analysis to real-world programs: Linux Kernel, GIMP, Emacs, Sendmail. . .
- This paper provides the theoretical foundations of a static analyzer developed and used at Facebook called Infer

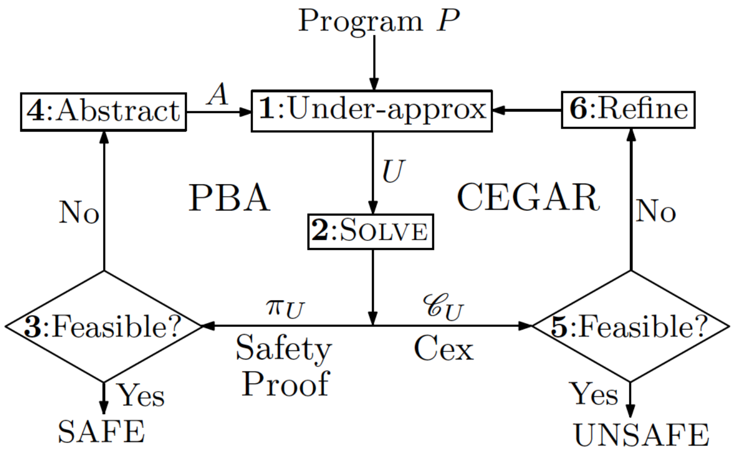
5. M: Verification of Pointer Programs with Data by Forest Automata [Matheja]

- Setting: C-like programs with dynamic data structures and integer data (e.g. binary search trees)
- Goal: Verify that a program successfully sorts a list, traverses a search tree. . .
- Forest automata: Extension of tree automata to accept graph-like structures
- Approach of this paper:
  - Extend forest automata to handle data structures with data
  - Develop a shape analysis based on forest automata
  - Apply analysis to several simple algorithms (e.g. binary search)

Outline

6. B: Abstraction in SMT-Based Unbounded Software Model Checking [Lange]

- Abstraction over data domains very successful
- Simple programs hard to verify
- Abstracted version of program easy to verify
- Combine abstraction of program and data



7. M: Configurable Software Verification [Lange]

Configurable SW Verification:

- Static Analysis (SA) and Verification reducible to each other
- SA knows generic algorithm for decades
- Won Goedel medal ”for their contributions to the development of efficient verification methods and algorithms”

Adjustable Block Encoding:

- CEGAR hampered by large programs, especially sequences
- Simplify program by folding sequences *[Beyer et al. 2009]*
- Folding until minimality sometimes not very efficient, follow spirit of CPA and make it adjustable

8. M: Inductive Invariant Generation via Abductive Inference [Lange]

- Invariants are at the heart of software verification
- Abduction: Inference of missing hypotheses
- Given known facts Γ and desired outcome ϕ, abductive inference finds "simple" explanatory hypothesis ψ such that

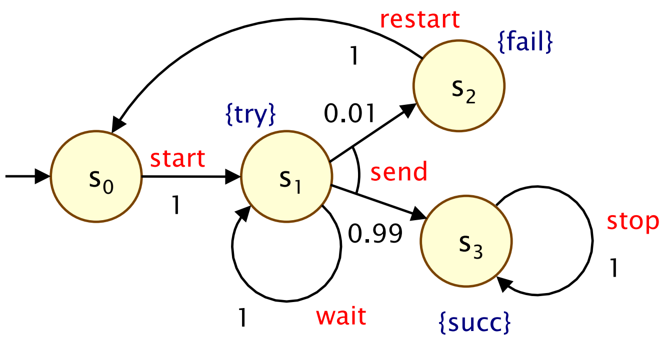
$$\Gamma \wedge \psi \models \phi \text{ and } \mathrm{SAT}(\Gamma \wedge \psi)$$

- i.e. given invalid formula $\Gamma \implies \phi$, find a "simple" formula ψ such that $\Gamma \wedge \psi \implies \phi$ is valid and ψ does not contradict Γ

Outline

9. B/M: Verification of MDPs Using Learning Algorithms [Dehnert]

observation: MDPs (probabilities + nondeterminism) used in various areas:



- randomized algorithms: leader election, mutual exclusion, . . .
- protocols: zeroconf, wlan, firewire, bluetooth, . . .
- (partially) unknown environments: planning (robots 'n stuff), power management

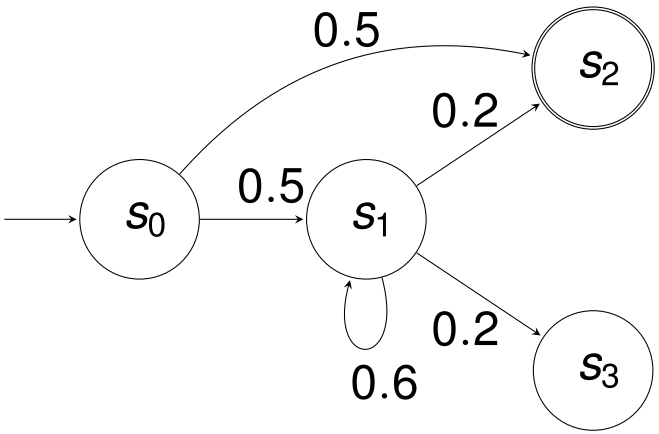
problem: state space explosion

idea: apply techniques from AI to compute reachability probabilities

approach: modify Q-learning to work with unbounded, undiscounted probs.

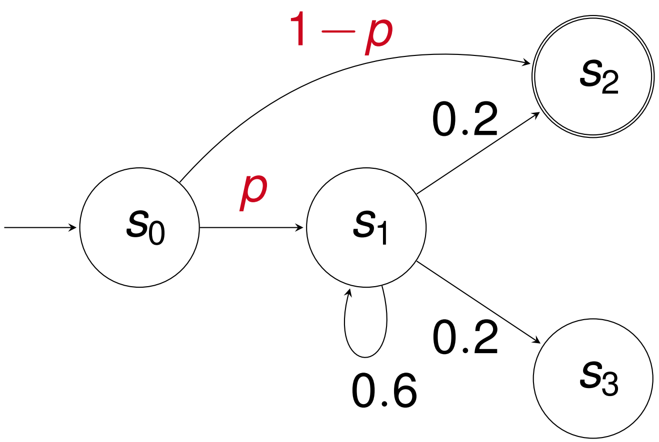
10. B: Parametric Probabilistic Reachability [Volk]

- Given: DTMC
- Goal: compute probability to reach target state



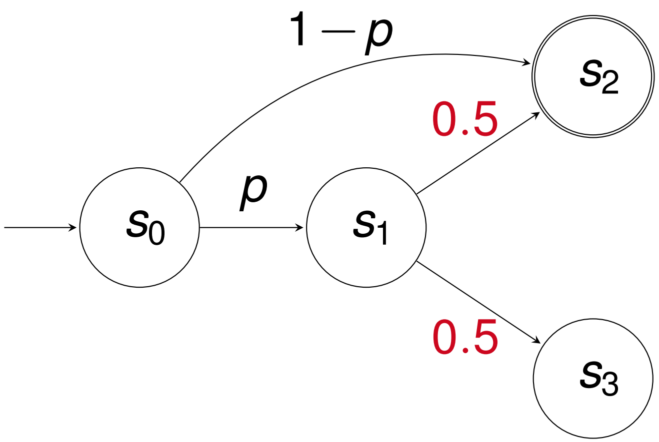
10. B: Parametric Probabilistic Reachability [Volk]

- Given: DTMC
- Goal: compute probability to reach target state
- Use parameters instead of concrete values



10. B: Parametric Probabilistic Reachability [Volk]

- Given: DTMC
- Goal: compute probability to reach target state
- Use parameters instead of concrete values
- Perform state elimination



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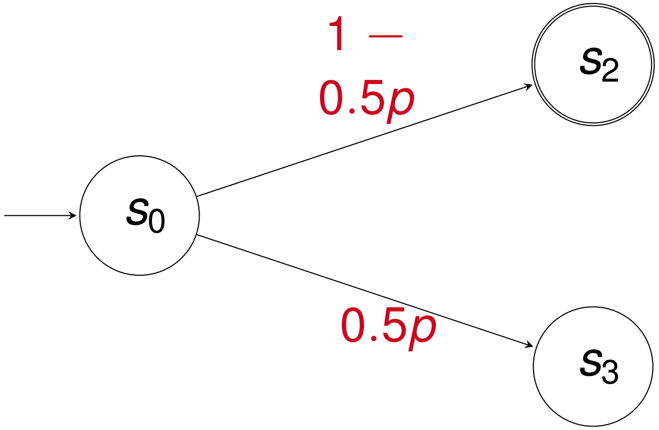
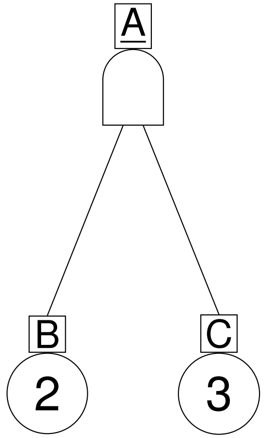


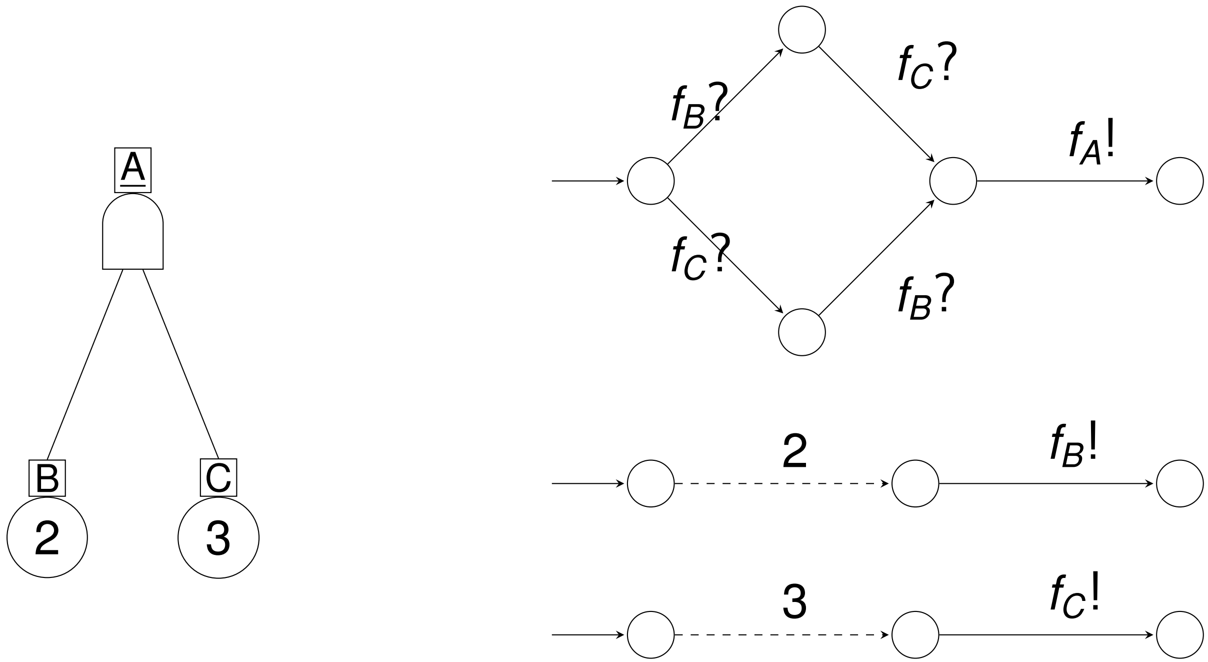
11. M: Fault Tree Analysis [Volk]

- Dynamic Fault Trees (DFT) model system failures



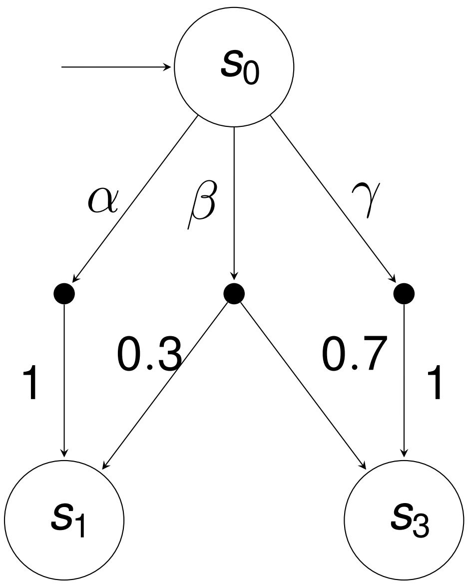
11. M: Fault Tree Analysis [Volk]

- Dynamic Fault Trees (DFT) model system failures
- Analyse DFTs by I/O-IMCs:
  - Convert each element into corresponding MC
  - Apply parallel composition



12. M: Multi-Objective Model Checking [Volk]

- Given: MDP
- Goal: compute strategy to fulfill each property φ_i with probability $\geq p_i$



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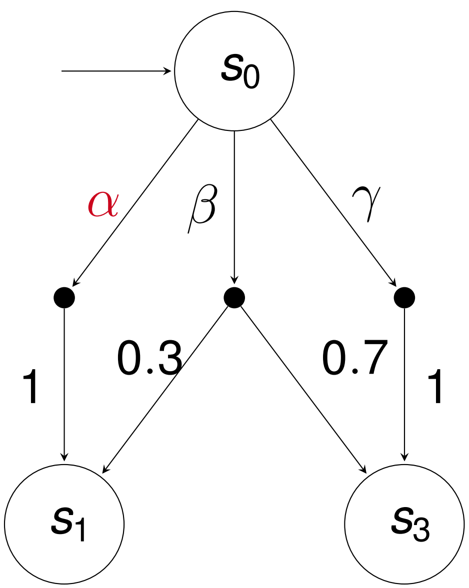

$$\mathbb{P}(\lozenge s_1) \geq 0.8$$

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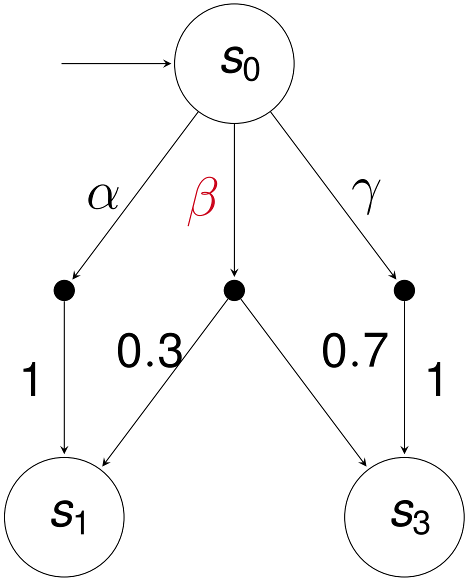

$$\mathbb{P}(\Diamond s_2) \geq 0.9$$

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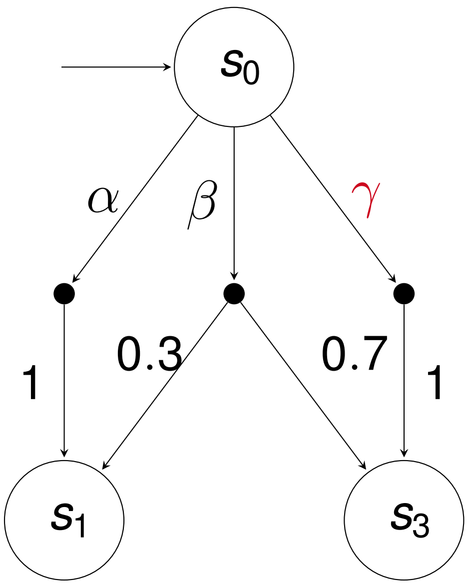
- Goal: compute strategy to fulfill each property φ_i with probability $\geq p_i$



$$\mathbb{P}(\Diamond s_1) \geq 0.3 \wedge \mathbb{P}(\Diamond s_2) \geq 0.3$$

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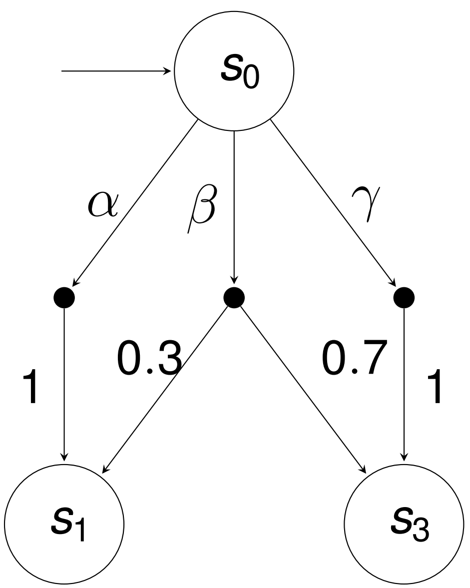
- Goal: compute strategy to fulfill each property φ_i with probability $\geq p_i$

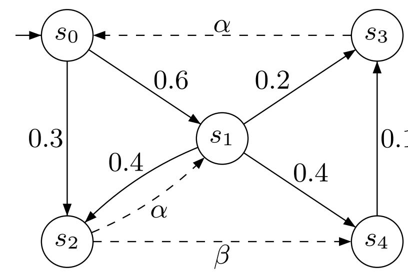


$$\mathbb{P}(\Diamond s_1) \geq 0.4 \land \mathbb{P}(\Diamond s_2) \geq 0.4$$

13. B/M: Interactive Markov Chains [Wu]

An *interactive Markov chain* is a tuple $I = (S, Act, \dashrightarrow, \longrightarrow, s_0)$, where

- S is a nonempty set of states with *initial state* $s_0 \in S$,
- *Act* is *a set of actions*,
- $\dashrightarrow \subseteq S \times Act \times S$ is a set of *interactive* transitions, and
- $\longrightarrow \subseteq S \times \mathbb{R}_{>0} \times S$ is a set of *Markovian* transitions.



The operators are defined on the IMCs such as:

- parallel composition $\mathcal{I}_1 \, \|_A \, \mathcal{I}_\in$ w.r.t to a synchronization set $A \in Act$,
- hiding $\mathcal{I} \backslash H$ w.r.t to a hiding set $H \in Act$.

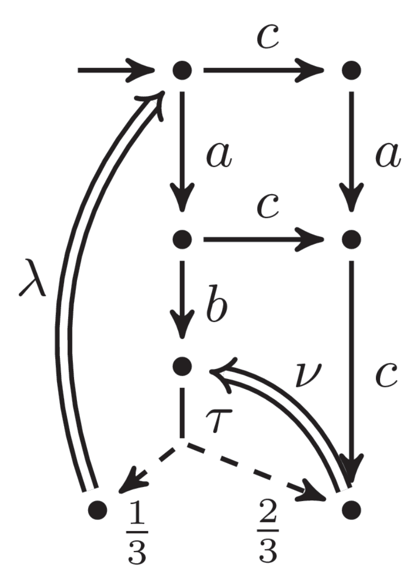
The interesting questions are:

- How to analysis the IMC?
- How make the IMC smaller?
- etc.

14. M: Analysis of Markov Automata [Wu]

A *Markov automaton (MA)* is a tuple $\mathcal{M} = (S, s_0, Act, \dashrightarrow, \Rightarrow)$, where

- S is a countable set of *states* with *initial state* $s_0 \in S$,
- Act is a countable set of *actions*,
- $\dashrightarrow \subseteq S \times Act \times Distr(S)$ is the *interactive probabilistic transition relation*,
- $\Rightarrow \subseteq S \times \mathbb{R}_{>0} \times S$ is the *Markovian transition relation*.



How we can compute the following properties on the MA?

- The expected time to reach a set of target states
- The long-run average time spend in a set of target states
- The time-bounded reachability to reach a set of target states within a given time interval

Outline

Some Final Hints

Hints

- Take your time to understand your literature.
- Be proactive! Look for additional literature and information.
- Discuss the content of your report with other students.
- Be proactive! Contact your supervisor on time.
- Prepare the meeting(s) with your supervisor.
- Forget the idea that you can prepare a talk in a day or two.

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We wish you success and look forward to an enjoyable and high-quality seminar!