Probabilistic Models of Concurrency

Introduction

Summer Semester 2020; April 2020

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https://moves.rwth-aachen.de/teaching/ss-20/pmc/

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Outline

Concurrency

Importance

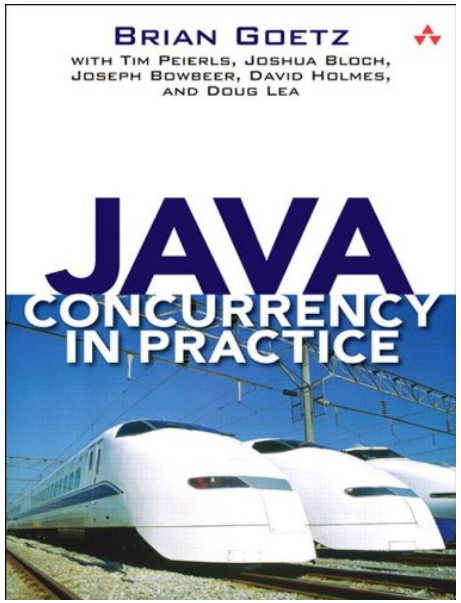
- Increasingly important for programming
  - further performance improvements only achievable by parallelism (multi-cores, GPGPUs, FPGAs, ...)
- Inherent property of distributed/embedded/reactive/... systems

Concurrency models

- Goals:
  - avoid concurrency faults (deadlocks, data races, ...)
  - ensure correctness of control systems
- Requires solid formal basis
- Therefore: concurrency models
  - automata, process algebras (CSP, CCS, π-calculus, ...), Petri nets, ...

Analysis and verification techniques

- Identification of deadlocks/data races
- Model checking based on temporal logics, ...



Quantitative Extensions

Basic setting: “qualitative” modelling

- Considers causal order of actions but ignores explicit timing
- Considers uncertainty (non-deterministic branching) but ignores likelihood of branches

Here: quantifiable uncertainty (aka probability)

- Take likelihood of certain behaviours into account
- Allows to quantify “degree of correctness” of systems:

  “the Boolean partition of software into correct and incorrect programs falls short of the practical need to assess the behavior of software in a more nuanced fashion”

  [Tom Henzinger, 2013]
- Considers non-functional aspects of system behaviour
  - reliability
  - performance
  - survivability
  - ...

Areas Covered in this Seminar

Topic areas

- Probabilistic automata models and their analysis
  - essentially: probabilistic extensions of automata and Petri nets
  - state-space reduction techniques (partial-order reduction, bisimulation, ...)
- Probabilistic process algebras
  - probabilistic extensions of “classical” approaches (CSP, CCS, π-calculus, ...)
  - algebraic modelling of Markov automata
- Probabilistic extensions of temporal logics
  - Probabilistic Computation Tree Logic (PCTL)

Outline

Goals

Aims of this seminar

- Independent understanding of a scientific topic
- Acquiring, reading and understanding scientific literature
  - given references sufficient in most cases
- Writing of your own report on this topic
  - far more that just a translation/rewording
  - usually an “extended subset” of paper
    - “subset”: present core ideas and omit too specific details (e.g., related work)
    - “extended”: more extensive explanations, examples, ...
    - discuss contents with supervisor!
- Oral presentation of your results
  - can be “proper subset” of report
  - generally: less (detailed) definitions/proofs and more examples

Requirements on Report

Your report

- Independent writing of a report of 12–15 pages
- First milestone: detailed outline
  - not: “1. Introduction/2. Main part/3. Conclusions”
  - rather: overview of structure (section headers, main definitions/theorems) and initial part of main section (one page)
- 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
  - LaTeX template will be made available on seminar web page
- Language: German or English
- We expect the correct usage of spelling and grammar
  - $\geq$ 10 errors per page $\Longrightarrow$ abortion of correction

Requirements on Talk

Your talk

- Talk of 30 minutes
- Available: projector, presenter, [laptop]
- Focus your talk on the audience
- Descriptive slides:
  - $\leq$ 15 lines of text
  - use (base) colors in a useful manner
  - number your slides
- Language: German or English
- No spelling mistakes please!
- Finish in time. Overtime is bad
- Ask for questions
- LaTeX/beamer template will be made available on seminar web page

Outline

Important Dates

Deadlines

- 17.04.2020: Topic preferences due
- 04.05.2020: Detailed outline due
- 02.06.2020: Full report due
- 29.06.2020: Presentation slides due
- 13./14.07.2020 (?): Seminar talks

Missing a deadline causes immediate exclusion from the seminar

Selecting Your Topic

Procedure

- Check out Foodle poll at `https://terminplaner.dfn.de/zBXuOBPuQVxkcBvU`
- Please give at least three “Yes” votes ✓
- Preferably additional “Maybe” votes (✓)
- Topics classified according to BSc/MSc level
  - MSc students please choose at least one “M-only” topic
- Give as comment:
  - Preference of topics (if desired)
  - Language of report and talk (English/German)
- **Fill form by Friday, April 17**
- We do our best to find an adequate topic-student assignment
  - disclaimer: no guarantee for an optimal solution
- Assignment of topics and supervisors will be published on web site in week 17

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

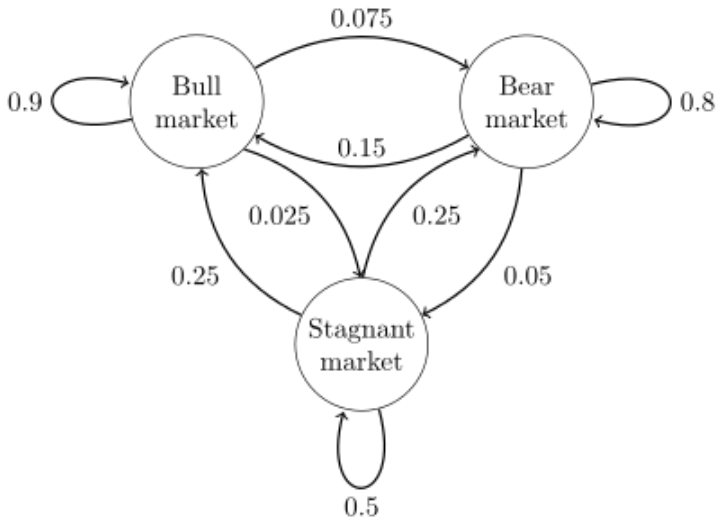
Automata Models

Goal

Probabilistic extensions of classical models to deal with stochastic behaviour

Topics

1. Probabilistic Automata (B)
2. Markov Automata (B)
3. Probabilistic Timed Automata (B)
4. Generalised Stochastic Petri Nets (B/M)
5. Probabilistic Petri Nets (B/M)



Process Algebras

Goal

Probabilistic extensions of algebraic specification formalisms for concurrent systems

Topics

6. Stochastic Process Algebras (B/M)
7. Probabilistic CCS (B/M)
8. Probabilistic CSP (B/M)
9. Probabilistic pi-calculus (B/M)
10. Markov Automata Process Algebra (B/M)

$$
\begin{aligned}
&\textbf{constant } \mathit{queueSize} = 10, \mathit{nrOfJobTypes} = 3\\
&\textbf{type } \mathit{Stations} = \{1,2\},\ \ \mathit{Jobs} = \{1,\ldots,\mathit{nrOfJobTypes}\}\\
&\mathit{Station}(i:\mathit{Stations}, q:\mathrm{Queue}, \mathit{size}:\{0..\mathit{queueSize}\})\\
&\quad = \mathit{size} < \mathit{queueSize} \Rightarrow (2i+1)\cdot \textstyle\sum_{j:\mathit{Jobs}} \mathit{arrive}(j)\cdot \mathit{Station}(i,\mathrm{enqueue}(q,j),\mathit{size}+1)\\
&\quad + \mathit{size} > 0 \Rightarrow \mathit{deliver}(i,\mathrm{head}(q)) \sum_{k\in\{1,9\}} \tfrac{k}{10} : k = 1 \Rightarrow \mathit{Station}(i,q,\mathit{size})\\
&\qquad\qquad + k = 9 \Rightarrow \mathit{Station}(i,\mathrm{tail}(q),\mathit{size}-1)\\
&\mathit{Server} = \textstyle\sum_{n:\mathit{Stations}} \sum_{j:\mathit{Jobs}} \mathit{poll}(n,j)\cdot(2*j)\cdot\mathit{finish}(j)\cdot\mathit{Server}\\
&\gamma(\mathit{poll},\mathit{deliver}) = \mathit{copy}\\
&\mathit{System} = \tau_{\{\mathit{copy},\mathit{arrive},\mathit{finish}\}}(\partial_{\{\mathit{poll},\mathit{deliver}\}}(\mathit{Station}(1,\mathrm{empty},0) \,||\, \mathit{Station}(2,\mathrm{empty},0) \,||\, \mathit{Server}))
\end{aligned}
$$

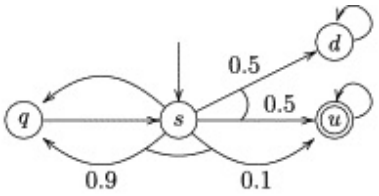
Scheduling

Goal

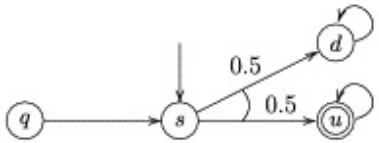
Development and analysis of scheduling algorithms for resolving non-determinism

Topics

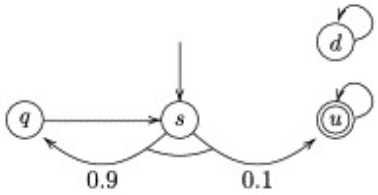
11. Sampling of MDP Schedulers (M)
12. Distributed Schedulers (M)



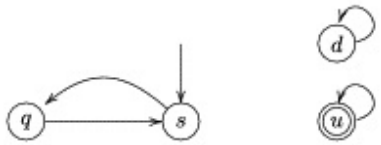
(a) A Markov decision process



(b) A scheduler that reaches the target with probability 1/2



(c) Reaching the target with probability 1



(d) Reaching the target with probability 0

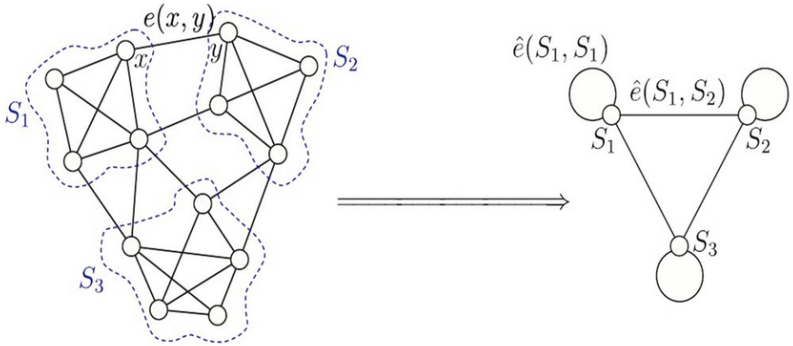
Abstraction Techniques

Goal

Application of state-space reduction techniques to increase efficiency of modelling and analysis

Topics

13. Game-Based Abstraction (M)
14. Probabilistic Partial-Order Reduction (M)
15. Confluence Reduction (M)
16. Probabilistic Bisimulation (M)
17. Lumping of Markov Chains (M)



Probabilistic Temporal Logics

Goal

Extensions of temporal logics to incorporate stochastic behaviour

Topics

18. Probabilistic Computation Tree Logic (B/M)

$$P_{>0.8}\,\Diamond(\mathit{state} = \mathit{success})$$

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.

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