



# Seminar *Probabilistic Programming*

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Summer Semester 2023

# Overview

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## Outline

### Overview

### Aims of this Seminar

### Important Dates

### The Topics

### Final Hints

## Probabilistic Programming

### Probabilistic programs

Probabilistic programs = classical programs + probabilistic choice + conditioning

- choice: “execute program  $P$  with probability  $\frac{2}{3}$  and  $Q$  with  $\frac{1}{3}$ ”
- conditioning: “observe that value of variable  $x$  is positive”
- describe posterior probability distributions over variable output values

### Applications

- Randomised algorithms (e.g., randomised Quicksort)
- Computer vision (e.g., image generation)
- Security
- Biology, coding theory, cryptographic protocols, machine learning, quantum computing, reliability analysis, ...

## An Example

### Virus infection

```
bool alicelInfectious = true
bool bobInfected = false
while alicelInfectious {
  prob 0.1 {
    bobInfected = true
  }
  prob 0.6 {
    alicelInfectious = false
  }
}
```

- What is the probability of Bob becoming infected?
- How long is Alice likely to be infectious?

# Overview

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## Areas Covered in this Seminar

### Topic areas

- Semantics
  - mathematical approaches to formally define precise meaning of programs
- Verification
  - providing (in)correctness proofs for programs (termination, program equivalence...)
- Programming Languages & State Machines
  - new probabilistic and probabilistic extensions of classical programming languages
- Static analysis
  - slicing, resource consumption, ... based on source code
- Bayesian networks
  - probabilistic graphical models used in AI

# Aims of this Seminar

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# Aims of this Seminar

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## 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 than just a translation/rewording
  - usually an **“extended subset”** of original literature
    - “subset”: present core ideas and omit too specific details (e.g., related work or optimisations)
    - “extended”: more extensive explanations, examples, ...
  - discuss contents with supervisor!

# Aims of this Seminar

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## 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
  - **L<sup>A</sup>T<sub>E</sub>X 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  $\implies$  abortion of correction



# Aims of this Seminar

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## 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**
- Have **backup slides** ready for expected questions
- **L<sup>A</sup>T<sub>E</sub>X/beamer template** will be made available on seminar web page

# Important Dates

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# Important Dates

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## Important Dates

### Deadlines

- April 11: Topic preferences due
- May 9: Detailed outline due
- June 7: Full report due
- June 27: Presentation slides due
- July 10 + 11: Seminar talks

### Important

Missing a deadline causes **immediate exclusion** from the seminar

# Important Dates

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## Selecting Your Topic

### Procedure

- You obtain a list of topics of this seminar.
- Classified according to BSc/MSc level.
  - MSc students please choose at least one “M-only” topic
- Indicate at least three topics of interest at  

<https://terminplaner4.dfn.de/j8Eh6YBXPS1prkKW>
- Can indicate preference in the comments field
- We do our best to find an adequate topic-student assignment.
  - disclaimer: no guarantee for an optimal solution
- Assignment will be published on web page **TBA**.
- Then also your **supervisor** will be indicated.
- Please give language preference (unsure  $\implies$  German).

# Important Dates

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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.

# The Topics

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## Semantics

1. Paradoxes of probabilistic programming: and how to condition on events of measure zero with infinitesimal probabilities (B/M)
  - How to deal with conditioning on events that occur with probability 0?
2. Probabilistic Strategy Logic (B/M)
  - Express (properties of) strategic behaviors of probabilistic multi-agent systems
3. Beyond Strong-Cyclic: Doing Your Best in Stochastic Environments (M)
  - What is the relation between behaving optimal and behaving in a “best effort” manner?
4. Quantitative Safety and Liveness (B/M)
  - Generalize elementary concepts of computation and verification to the quantitative/probabilistic setting

# The Topics

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## Verification

5. An Assertion-Based Program Logic for Probabilistic Programs (B/M)
6. A Specification Logic for Programs in the Probabilistic Guarded Command Language (B/M)
  - How to express and verify properties of probabilistic programs?
7. Outcome Logic: A Unifying Foundation for Correctness and Incorrectness Reasoning (B/M)
  - How to reason about *both* correctness *and* incorrectness?
8. On incorrectness logic for Quantum programs (M)
  - Reasoning about incorrectness of Quantum programs
9. Solving Invariant Generation for Unsolvable Loops (M)
  - Computing loop invariants for probabilistic loops



# The Topics

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## Programming Languages & State Machines

10. A simple differentiable programming language (B/M)
  - Differentiating probabilistic programs
11. Second order uncertainty in state machines (B/M)
  - Modeling uncertainty about uncertainty

## Program analysis

12. Symbolic Execution for Randomized Programs (B/M)
  - Automatic analysis of probabilistic programs
13. A Theory of Slicing for Imperative Probabilistic Programs (B/M)
  - Which parts of a program can be removed without changing its semantics?
14. Slicing of probabilistic programs based on specifications (B/M)
  - Which parts of a program can be removed while preserving a given property?
15. Automated quantized inference for probabilistic programs with AQUA (M)
  - Efficient sampling-based inference on probabilistic programs with continuous distributions

# The Topics

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## Program analysis

16. Parsing randomness (M)
  - Generating and checking data structures satisfying user-specified preconditions
17. Guaranteed bounds for posterior inference in universal probabilistic programming (M)
  - Approximate inference on probabilistic programs with hard guarantees
18. Scaling exact inference for discrete probabilistic programs (B/M)
  - A domain specific programming language, exploits factorization and weighted model counting
19. This is the moment for probabilistic loops (B/M)
  - Automatically derive higher moments for program variables

## Bayesian Networks

20. Moment-based analysis of Bayesian network properties (B/M)
  - Analyze Bayesian networks by means of algebraic reasoning
21. Graphical models for imprecise probabilities (B/M)
  - What to do if we are given, e.g., probability intervals rather than precise probabilities?
22. Balanced sensitivity functions for tuning multi-dimensional Bayesian network classifiers (M)
  - Studies and propose new techniques for parameterizing Bayesian networks

# Final Hints

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## 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!