Static Methods for Quantitative Program Analysis

Introduction
Winter Semester 2018/19; 10 October, 2018
Thomas Noll et al.
Software Modeling and Verification Group
RWTH Aachen University
https://moves.rwth-aachen.de/teaching/ws-1819/qpa/
Overview

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Overview

What Is It All About?

Static (Program) Analysis

Static analysis is a general method for reasoning on artefacts such as requirements, design models, and programs.

Here, “static” means: based on source code, not on (dynamic) execution (in contrast to testing, profiling, or run-time verification).
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(Main) Applications

Optimising compilers: exploit program properties to improve runtime or memory efficiency of generated code
  - dead code elimination, constant propagation,...
  - usually fully automated

Software validation: verify program correctness
  - bytecode verification, shape analysis, functional correctness, ...
  - varying degrees of automation
Overview

Dream of Program Analysis

Program

Analyzer

Result

Property specification

4 of 18 Static Methods for Quantitative Program Analysis
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Overview

Why “Quantitative”?  

Classical setting  

Addresses “yes/no problems”:

- Is control location $c$ reachable?  
- Is the value of variable $x$ always positive?  
- When we send a request to the server, will we eventually get an answer?
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Thomas A. Henzinger [Comp. Sc. – Research and Development 28(4), 2013]

“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 [...]”
### Overview

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**Interesting quantitative aspects**

- Execution time
- Resource consumption (energy, heap space, ...)
- Probabilistic properties (reliability, expected execution time, ...)
- Note: many “qualitative” properties pose “quantitative” questions  
  - e.g., balancedness of trees refers to height information
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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/rewriting
  - usually an “extended subset” of paper
    - “subset”: present core ideas and omit too specific details (e.g., extension of partial to total correctness)
    - “extended”: more extensive explanations, examples, ...
    - discuss with supervisor!
- Oral presentation of your results
  - can be “proper subset of report”
  - generally: less (detailed) definitions/proofs and more examples
Aims of this Seminar

Requirements on Report

Your report

- Independent writing of a report of 10–15 pages
- First milestone: detailed outline
  - but: 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
- Language: German or English
- We expect the correct usage of spelling and grammar
  - \( \geq 10 \) errors per page \( \implies \) abortion of correction
- \LaTeX\ template will be made available on seminar web page
## 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**
- **\LaTeX/beamer template** will be made available on seminar web page
Important Dates

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### Important Dates

#### Deadlines

- 5 November: Detailed outline of report due
- 3 December: Full report due
- 14 January: Presentation slides due
- 29 January (?): Seminar

Missing a deadline causes immediate exclusion from the seminar.
Important Dates

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Important Dates

Selecting Your Topic

Procedure

- You obtain(ed) a list of topics of this seminar.
- Indicate the preference of your topics (first, second, third).
- Return sheet here or by Sunday (14 October) via e-mail (noll@cs.rwth-aachen.de) or 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 web site next week.
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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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The Topics

Worst-Case Execution Time Analysis [Noll]

Goal

Analysis methods for establishing (safe and tight) timing constraints for (embedded) software, e.g. for ensuring schedulability

- challenge: execution times of instructions dependent on the execution history (caches, pipelines, speculative execution, ...)

Topics

1. Timing Analysis by Integer Linear Programs [B]
2. Timing Analysis by Abstract Segment Trees [B]
3. Power-Aware Worst Case Execution Time Analysis [B]
4. Timing Analysis by Abstract Interpretation
5. Semantics-Based Worst Case Execution Time Analysis
The Topics

Worst-Case Execution Time Analysis [Noll]

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Heap Resource Analysis [Matheja]

Goal

Logical methods for reasoning about memory resources (variables, heap)
The Topics

Heap Resource Analysis [Matheja]

Goal
Logical methods for reasoning about memory resources (variables, heap)

Topics

6. Introduction to Separation Logic [B]
7. Reasoning about Complexity of Data Structure Operations [B]
8. Permission Accounting for Concurrent Threads [B]
9. Graph-Based Reasoning about Relational Properties of Data Structures [B]
10. Variables as Resources [B]
11. Dataflow Analysis for Quantitative Properties of Tree Data Structures
The Topics

Static Analysis of Probabilistic Programs [Kaminski]

Goal

Reasoning about (expected) values of quantities such as reliability, termination and sizes of data structures in the presence of probabilistic behaviour (e.g., failures)
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### Topics

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<tr>
<th>No.</th>
<th>Topic</th>
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</thead>
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<tr>
<td>12.</td>
<td>Quantitative Separation Logic [B]</td>
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<td>13.</td>
<td>Abstract Interpretation of a Probabilistic $\lambda$-Calculus [B]</td>
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<td>15.</td>
<td>Static Quantitative Reliability Analysis [B]</td>
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<td>16.</td>
<td>Probabilistic Invariants and Almost-Sure Termination [B]</td>
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<td>17.</td>
<td>Abstract Interpretation of Imperative Probabilistic Programs I</td>
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<td>18.</td>
<td>Abstract Interpretation of Imperative Probabilistic Programs II</td>
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Final Hints

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