Program Analysis and Code Verification

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Language

• Lectures: English
• Labs: English

• Homework: Czech/English
• Final exam: Czech/English

• Questions: Czech/English
Software bugs and errors

- Race condition
- Deadlock
- Null pointer dereference
- Array index out of bounds
  ...
- Firefox crashes
- Blue screen of death
  ...
- Train accident
Why bugs matter?

- Mission- and safety-critical systems
  - Industry: robots, assembly lines
  - Transportation: cars, trains, airplanes

- Embedded systems
  - Mobile phones, tablets, household appliances, consumer electronics
Detecting bugs

• Software testing is not enough
  ▪ Pros: scalable, precise, well-established (industry)
  ▪ Cons: very expensive (people, money), selected executions, bugs depend on thread interleaving

• Program verification
  ▪ Pros: coverage, multi-threaded programs
  ▪ Cons: precision, scalability, performance
Tools

- Java Pathfinder (https://github.com/javapathfinder/jpf-core/wiki/)
  - exhaustive state space traversal of Java

  - systematic testing of multi-threaded programs in C#

- SLAM/SDV (https://www.microsoft.com/en-us/research/project/slam/)
  - software model checking for Windows device drivers

- KLEE (http://klee.github.io/)
  - symbolic execution for low-level C programs (e.g., Linux binutils)

- CBMC (http://www.cprover.org/cbmc/)
  - bounded model checking for system programs in C and C++

- Spec# (https://www.microsoft.com/en-us/research/project/spec/)
  - behavior specification language for C# + deductive methods

- Code Contracts (https://www.microsoft.com/en-us/research/project/code-contracts/)
  - behavior specification language for C# + abstract interpretation

  - static analysis frameworks/libraries for Java and C/C++

- Infer (http://fbinfer.com/)
  - static analysis and bug-finding tool for Java, C/C++ and Objective-C
Goals of the course

- Show algorithms and tools for program analysis, verification, and bug detection
- Practical experience with selected tools
Why you should attend

- Basic knowledge of the main program analysis and verification techniques
  - Key aspects: scalability, coverage, automation, ...

- Current state of the art
  - How good or bad the tools are
• Model checking of programs
• Detecting concurrency errors
• Symbolic execution
• Dynamic analysis
• Deductive methods (SAT solvers, SMT solvers)
• Bounded model checking
• Predicate abstraction and CEGAR
• Selected applications of deductive methods in software verification
  ▪ Verification of program code against contracts
• Static analysis and its usage in program verification
• Abstract interpretation
• Combination of verification techniques
• Program termination
• Program synthesis and repair
Theoretical limitations
Know your enemy!!
Know your enemy!!

Kurt Gödel
(1906-1978)

Alan Turing
(1912-1954)
Know your enemy !!

Completeness theorem
\[ T \models f \Rightarrow T \vdash f \]

Incompleteness theorem
For “interesting” theories \( T \)
\[ \exists f: ( T \nvdash f ) \land ( T \nvdash \neg f ) \]

“Halting problem is **undecidable**”
What do they really say?

Completeness theorem (CT)

\[ T \models f \implies T \vdash f \]

Incompleteness theorem (IT)

For “interesting” theories \( T \)

\[ \exists f: ( T \nvdash f ) \land ( T \nvdash \neg f ) \]

Claim:

The completeness and incompleteness theorems contradict.

1) Let’s take \( f \) from IT

2) Any \( f \) either holds or not:

\[ ( T \models f ) \lor ( T \models \neg f ) \]

3) From CT follows:

\[ ( T \vdash f ) \lor ( T \vdash \neg f ) \]

4) Contradiction
Completeness theorem (CT)

\[ T \models f \Rightarrow T \vdash f \]

Incompleteness theorem (IT)

For “interesting” theories \( T \)

\[ \exists f : ( T \not\models f ) \land ( T \not\models \neg f ) \]

1) Let’s take \( f \) from IT

2) Any \( f \) either holds or not:

\[ ( T \models f ) \lor ( T \models \neg f ) \]

3) From CT follows:

\[ ( T \vdash f ) \lor ( T \vdash \neg f ) \]

4) Contradiction
What do they really say?

Completeness theorem
\[ T \vDash f \implies T \vdash f \]

Incompleteness theorem
For "interesting" theories \( T \)
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Claim:
The completeness and incompleteness theorems contradict.
“Halting problem is undecidable”

Claim:
Given a program $A$ and input data $D$, you can never decide whether $A(D)$ terminates or not.
What do they really say?

“Halting problem is *undecidable*”

Claim: Given a program $A$ and input data $D$, you can never decide whether $A(D)$ terminates or not.

Sometimes you can. Consider:

```c
void main() {
    printf(“Going to halt right away!\n”);
}
```
“Halting problem is **undecidable**”

**Claim:**
*You can *never* construct a general algorithm that would *for any* program \( A \) and *any* input data \( D \) *always* answer YES if \( A(D) \) terminates.*
“Halting problem is **undecidable**”

Claim:
You can *never* construct a general algorithm that would for any program $A$ and any input data $D$ always answer YES if $A(D)$ terminates.

Yes, you can (but it may not terminate). Consider:

```c
void main(program A, data D) {
    ... simulate A(D) ...
    printf(“YES”);
}
```
“Halting problem is undecidable”

Claim:
There is no general algorithm that would always terminate and solve the halting problem for all programs and all inputs.
Consequences

- Program verification (analysis) is **undecidable**
  - Example: assertion checking for multi-threaded programs with procedures

- But, in practice, ...
  - Many interesting properties can be successfully verified for many interesting programs
Consequences

- It may take very long
  - Out of reach of current hardware and user patience
  - More than the expected age of the known universe
  - Definitely past the hard deadline of your project

- But there is still hope
  - Full verification is not always necessary
  - Search for errors (detect some bugs)
Grading

- Five homeworks
  - Each will be awarded with 0-20 points
  - No. 5: presenting research publication
- Final exam (voluntary)
  - Awarded with 0-25 points
  - Basic principles (algorithms, theory)
  - Comparing different techniques

Result
- 85-125 $\rightarrow$ excellent
- 72-84 $\rightarrow$ very good
- 60-71 $\rightarrow$ good
Homework assignments

- Deadlines are **strict**
  - We will deduct 10% of your points total for every calendar day your assignment is late
- You have to do homework no. 5 (presentation) and two other to get “zápočet”

- **Topics**
  - Java Pathfinder
    - Implement custom modules and verify given program
  - Code Contracts
    - Write specification for given program and then verify it
  - Static analysis
  - Finding real bugs
  - Presentation of research publication
    - Group homework (2-3 people)
Be active during lectures and labs!!

- Participate
- Answer questions
- Think deeply
Contact

- Web: http://d3s.mff.cuni.cz/teaching/nswi132
- Email: parizek@d3s.mff.cuni.cz
- Room 309
We are hiring

- Master thesis
- PhD studies

- Theory + Implementation

- Program verification, analysis, synthesis
- Debugging, tool support for developers
- Programming languages, concurrency
- Java, C/C++, C#, PHP, JavaScript, Scala