

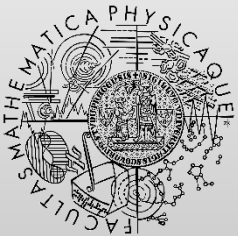
Program Analysis and Code Verification

<http://d3s.mff.cuni.cz>

Department of
Distributed and
Dependable
Systems



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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
- CHES (<https://www.microsoft.com/en-us/research/project/chess-find-and-reproduce-heisenbugs-in-concurrent-programs/>)
 - 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++
- Code Contracts (<https://www.microsoft.com/en-us/research/project/code-contracts/>)
 - behavior specification language for C# + abstract interpretation
- Dafny (<https://dafny.org/>, <https://github.com/dafny-lang/dafny>)
 - programming language with built-in support for verification (based on Spec#)
- Soot, WALA and LLVM (<https://sable.github.io/soot/>, <https://wala.github.io/>, <http://llvm.org/>)
 - 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

Program

- 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 !!

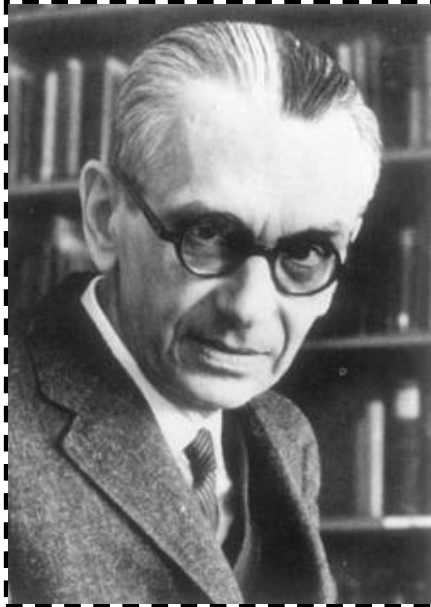


Kurt Gödel
(1906-1978)



Alan Turing
(1912-1954)

Know your enemy !!



Completeness theorem

$$T \models f \Rightarrow T \vdash f$$

Incompleteness theorem

For “interesting” theories T

$$\exists f: (T \not\vdash f) \wedge (T \not\vdash \neg f)$$



*“Halting problem is **undecidable**”*

What do they really say ?



Completeness theorem (CT)

$$T \models f \Rightarrow T \vdash f$$

Incompleteness theorem (IT)

For “interesting” theories T

$$\exists f: (T \not\models f) \wedge (T \not\models \neg f)$$

Claim:

The completeness and incompleteness theorems contradict.

- 1) Let's take f from IT
- 2) Any f either holds or not:
 $(T \models f) \vee (T \models \neg f)$
- 3) From CT follows:
 $(T \vdash f) \vee (T \vdash \neg f)$

4) Contradiction

What do they really say ?

Completeness theorem (CT)

$$T \models f \Rightarrow T \vdash f$$

Incompleteness theorem (IT)

For “interesting” theories T

$$\exists f: (T \not\models f) \wedge (T \not\models \neg f)$$

$$T \models f$$

in **all** models of T , f **holds**

$$T \models \neg f$$

in **all** models of T , f **doesn't hold**

$$T \not\models f \wedge T \not\models \neg f$$

there is a model of T

where f **holds** and a model

where f **doesn't hold**

1) Let's take f from **IT**

2) Any f either holds or not:

$$(T \models f) \vee (T \models \neg f)$$

3) From **CT** follows:

$$(T \vdash f) \vee (T \vdash \neg f)$$

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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.*



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:

```
void main() {  
    printf("Going to halt right away!\n");  
}
```

What do they really say ?

*“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.*



What do they really say ?

“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:

```
void main(program A, data D) {  
    ... simulate A(D) ...  
    printf("YES");  
}
```

What do they really say ?

*“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 → excellent
 - 72-84 → very good
 - 60-71 → 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
 - Contracts languages (Dafny, ...)
 - Write specification for given program and then verify it
 - Static analysis
 - Finding real bugs
 - Presentation of research publication
 - Group homework (2-3 people)