Formal Foundations of Software Engineering

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Goals of the course

• Show methods and tools for specification and modeling of
  - Requirements
  - Architecture
  - System behavior

• Show methods, languages and tools for
  - More formal design, specification and prototyping of software systems
Structure

- Lectures
  - Basic concepts ("theory")
  - Languages (syntax, usage)
  - Tool demo & examples

- Labs
  - Small practical tasks
  - Playing with tools
Why you should attend

• Get some knowledge about formal methods
  - Commonly used languages
  - Benefits & limitations

• Usage of formal methods can actually help you in software development practice
Contents

- General introduction to formal methods
- Algebraic specification techniques (CASL)
- Rewriting systems (Maude, OBJ3)
- Model-oriented languages (Z, VDM, Alloy)
- UML (modeling) & OCL (specification)
- Petri nets (modeling concurrent systems)
- Temporal & dynamic logics (TLA+)
- Domain-specific languages (DSLs)
Grading

- **Homeworks**
  - Topics: Maude, Alloy, UML/OCL, Petri nets
  - Each awarded with 0-20 points
  - You need to submit at least 2 for “zápočet”

- **Final exam**
  - Basic principles, theory, comparing approaches
  - Awarded with 0-30 points

- **Scale**
  - 71-110: excellent
  - 55-70: very good
  - 41-54: good (pass)
  - 40 and less: failure
Contact

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Related courses

- System Behavior Models and Verification (NSWI101)
  - [http://d3s.mff.cuni.cz/teaching/nswi101](http://d3s.mff.cuni.cz/teaching/nswi101)

- Program Analysis and Code Verification (NSWI132)
  - [http://d3s.mff.cuni.cz/teaching/nswi132](http://d3s.mff.cuni.cz/teaching/nswi132)
General introduction to formal methods
What are formal methods?

- Mathematical techniques
- Supported by tools

- Languages
  - Specification notation
    - Formal syntax & semantics
  - Reasoning mechanism

- Enable rigorous software development
Formal description of software systems

- **Interface perspective**
  - Specifying requirements and desired properties
- **Implementation perspective**
  - Modeling internal behavior

- **Characteristics**
  - Expression in some formal language
  - Typically at certain level of abstraction
  - Precise, consistent, and unambiguous
What are formal methods good for

- Precisely capturing user’s requirements
- Modeling behavior of critical subsystems
- Validation (testing, analysis, verification)
- Generating code from specification/models
  - Iterative refinement (transformations)
  - Model-driven engineering (MDE)
Usage pattern

1. Manually write a formal specification (model)

2. Semi-automatically validate & fix all problems

3. Iteratively transform (refine) into real code
   - Allow provably correct refinement steps
   - Implementation correct-by-construction
Benefits

- General: improved quality of software systems
- Enable system validation at very early stage
- Detecting many issues (but some remain!!)
  - ambiguity, inconsistency, plain bugs, missing pieces
- Better resilience against non-standard states
- Required for mission/safety-critical systems
Limitations

- Insufficient scalability to realistic systems
- High overall costs (man-power, time)
Practice: critical systems

- Application domains
  - transportation, military, healthcare, tele-com

- Small or middle-sized
  - 10-1000 KLOC

- Very high cost of errors
Case study: subway line in Paris

• Development process
  1. Abstract models and specifications in B
  2. Iterative refinement to concrete models
  3. Transformation to source code in ADA

• Quantitative metrics
  • Formal specification: 100 KLOC in B
  • Source code: 87 KLOC in ADA
  • Validation: proved 28K claims and found many bugs
    • No error found after the deployment !!
MDE & formal methods

- MDE: model-driven engineering
  - Automated code generation

- Model-based testing

- Domains: embedded systems
  - automotive, industry manufacturing robots
Disclaimer

- Formal methods do not guarantee correctness
  - "a formally verified program is only as good as its specification"

- It is very easy to create a bad specification
  - Problems: incompleteness, inconsistency, typos

- Remedy: search for bugs & validate everything
Ten Commandments of Formal Methods

1. Choose an appropriate notation
2. Formalize, but do not over formalize
3. Estimate costs
4. Have a formal methods guru on call
5. Not abandon traditional development methods
6. Document sufficiently
7. Not compromise quality standards
8. Not be dogmatic
9. Test, test, and test again
10. Reuse
Design by Contract

- Granularity: procedures, objects
- Preconditions
- Postconditions
- Invariants

- Methodology
  - Define contracts by hand
  - Use tool for verification