An Introduction to Formal Methods for Specification and Analysis in Software Engineering

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Contents

1 Software Engineering and Formal Methods?

1. SE Methodology is based on a reccomended development process:
    (a) Analysis
    (b) Specification
    (c) Design
    (d) Coding
    (e) Unit Testing
    (f) Integration and System Testing
    (g) Maintenance
2. Formal Methods can be:
    - Be a foundation for describing complex systems.
    - Be a foundation for reasoning about systems.
    - Provide support for program development.
3. In essence, formal methods have a complementary approach to SE Methodology,

2 Testing: Static vs Dynamic Analysis

2.1 Static Analysis of code

- Does not require exection of code.
- Lexical analysis of program syntax and investigates and checks the structure and usage of individual statements; often automated.

2.2 Dynamic Analysis of code

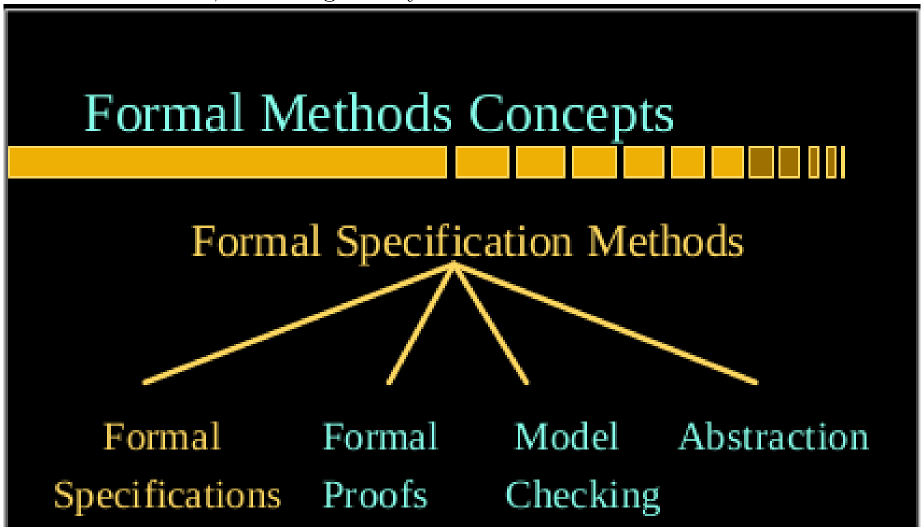
- Program run formally under controlled condition with specific results expected.
- Path and Branch Testing.

3 What are Formal Methods Actually?

Techniques and tools based on Mathematics and formal logic Allow us to assume various forms and levels of rigor.

4 Why Consider a Formal Method?

Most of today's systems are complex. Thus, we use formal methods to systems. Though keep in mind, the more compelx a system, the harder is it to model. But as we will see, Modeling is only **one of 4 formal methods**.



5 Formal Methods Concepts

- Formal Specifications
- Formal Proofs
- Model Checking
- Abstraction

6 Formal Specifications

- **Defintion:** Translation of prose (diagrams, tables, english text) into formal specification language.
- A formal spec provides a concise definition of high-level behavior and properties of a system.
- Well-defined language sematincs suppourt formal deduction about specification.
- **Informal Spec**
  - Free form, natural language

- Ambiguity and lack of organization can lead to incompleteness, inconsistency and misunderstandings.

- **Formatted Spec**
  - Standarized syntax
  - Basic consistency and completeness checks
  - Impercisce sematincs implies other sources of error may be still present n̄ot complete or sound.

- **Formal Spec**
  - Syntax and Semantics rigorously defined.
  - Percise form, perhaps mathematical.
  - Eliminate impercision and ambiguity.
  - Provide basis for mathematically verifying equivalence between specification and implementation.
  - May be hard to read without training.

7 Formal Specs

- Goal: Describe external behavior without describing or constraining implemetation.
- This formal method has 2 parts:
  - Logic Theory:
    * Means by which one reasons about Specifications, properties and programs
    * First Order Predicate Calculus (quantification over calculus)
    * Second Order Predicate Calculus (quantification over relations)
    * Temporal Logic
  - Strcturing Theory:
    * Defines elements being reasoned about.

8 Types of Formal Specifications

8.1 Property Oriented

- State desired properties in a purely declarative way.
- Involves 2 Key Concepts:
  - Algebraic: Data type viewed as an Algebra, Axioms state properties of data type's operations.

  - Axiomatic: Uses first order predicate logic, pre and post conditons Operation Specification: Describe desired behaviour by providing model of system.

8.2 Model Oriented

- Provide direct way of describing system behaviour(sets, squences, tuples, maps)
- Involves 2 Key Concepts:
  - Abstract Model (in terms of previously defined mathematical objects, eg: sets, sequences, functions and mappings)
  - State Machines.

9 Property Oriented

9.1 Uses

- Input-Output Assertions
- Sets of operations
- Axioms specifying behaviour of operations.

9.2 Two Parts of Specification

- Syntax
- Axioms.

10 Model Oriented: Abstract Model Specifications

- Build an abstract model of required software behaviour using mathematicially defined types (sets, relations)
- Define operations by showing effects of that operation on the model.
- Specification includes:
  - Model Types
  - Invariant properties of Model
  - For each operation Name, Parameters and return values.
  - Pre and post condtions

11 Formal Proofs

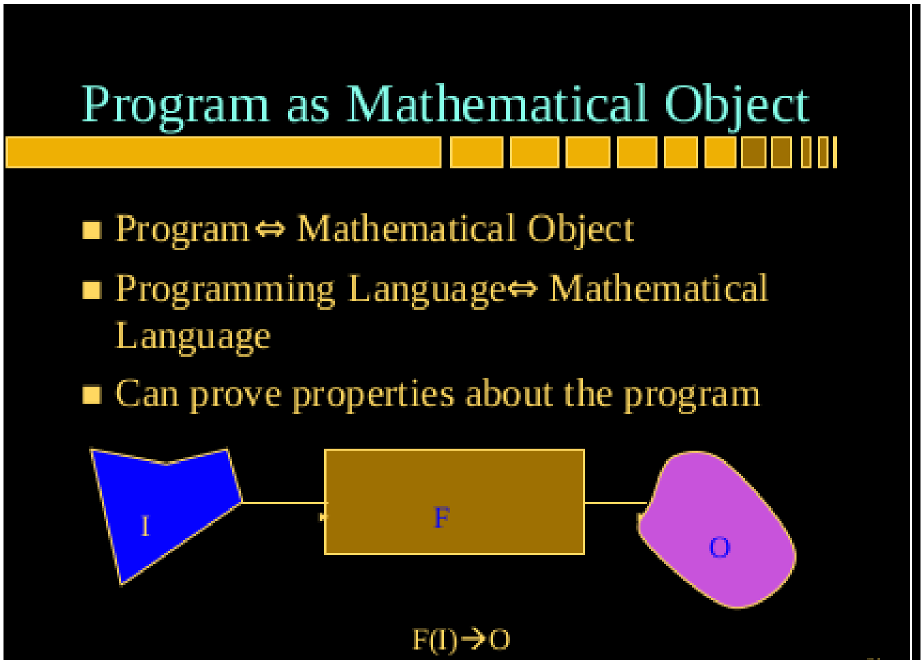
- Complete and convincing argument for validity of some property of some the system description.
- Constructed as a series of steps, each of which is justified from a small set of rules.
- Eliminates ambiguity and subjectivity inherent when drawing informal conclusions.
- May be manual but usually constructed with automated assistance.

12 Model Checking

- Operational rather than analytic.
- State machine model of a system is expressed in a suitable language.
- Model checker determines if the given finite state machine model satisfies requirements expressed as formulas in a given logic.
- Basic method is to explore all reachable paths in a computational tree derived from the state machine model.

13 Abstraction

- Simplify and ignore irrelevant details
- Focus on and generalize important central properties and characteristics.
- Avoid premature commitment to design and implementation choices.



14 Logical Errors in Formal Specification

14.1 Logical Inconsistency

Easiest logical errors to detect.

14.2 Accuracy

does this specification mean what it intended? System invariants can help in detection.

14.3 Completeness

does the specification identify all contigencies and specify appropiate behavior for all cases? (Peer review can aid detection)

15 Techniques for Detection of Errors in Formal Specifications

Listed in increasing order of rigor and cost of application:

- Inspection of formal speicification (manual)
- Parsing for syntactic correctness (automated)
- Type-checking for semantic consistency (automated)
- Simulation/animation based on the specification (automated).
- Theorm proving, proof checking, model checking for logic anomalies.

16 Formal Specification as a System Description

- Clarify requirements and high-level design.
- Articulate implicit assumptions.
- Identify undocumented or unexpected assumptions.
- Expose flaws.
- Identify exceptions.
- Evaluate test coverage.

17 Benefits of Formal Specifications

- Higher level of rigor enable a better understanding of the problem.
- Defects are uncovered that would likely go unnoticed with traditional specification methods.
- Identify defects earlier in life cycle.
- Can guarantee the absence of certain defects.
- Formal specification language sematics allow checks for self-constency of a problem sepcification.
- Formal specification enable formal proofs which can establish fundamental system properties and invariants.
- Repeatable analysis means reasoning and conclusions can be checked by colleagues.
- Encourages an abstract view of system– focusing on what a proposed system should accomplish as opposed to how to accomplish it.

- Abstract formal view helps seperate specification from design.0
- Enhances exsisting review processes by adding a degree of rigor.

18 Limitation to Formal Methods

- Used as an adjunct to, not a replacement for, standard quality assurance methods.
- Formal methods are not a panacea (solution), but can increase confidence in a product's reliability if applied with care and skill.
- Very useful for consistency checks, but can not assure completeness of a specification.

19 Conclusion

- FM are no panacea(solution).
- FM can detect defects earlier in life cycle.
- FM can be applied at various levels of resource investment.
- FM can be integrated within exsisting project process models.
- FM can improve quality assurance when applied judiciously(with good judgement or sense) to appropiate projects.

20 Reference text

https://web.mit.edu/16.35/www/lecturenotes/FormalMethods.pdf