Formal Verification of Software

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UNIVERSITÄT KOBLENZ-LANDAU

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Make this a lively course

- Ask questions!

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- **Ask questions!**
- **Don't fall asleep**

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- **Keep cool**

Contents

- **Why verification?**
  Advantages and disadvantage. Costs and gains.

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- **Basics of deductive program verification:**
  Hoare Logic and Dynamic Logic
- **Deductive verification of object-oriented programming languages (using Java as an example)**

What are Formal Methodsn?

Software Development Methods

- Analysis
- Modelling (Specification)
- Implementation
- Validation (Verification, Testing)

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- Languages and notations with (mathematical) precise semantics
- Logic-based techniques

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Note

formal $\neq$ theoretical

Why Formal Methods?

Quality: Important for . . .

- **Safety-critical applications** (railway switches)
- **Security-critical applications** (access control, electronic banking)
- **Financial reasons** (phone cards)
- **Legal reasons** (electronic signature, EAL6/7 in Common Criteria)

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Productivity: Important for . . .

Obvious reasons

Why Formal Methods?

Quality through . . .

- Better and more precise understanding of model and implementation
- Better written software (modularisation, information hiding, . . .)
- Error detection with runtime checks
- Test case generation
- Static analysis
- Deductive verification

Why Formal Methods?

Productivity through

- Error detection in early stages of development
- Re-use of components (requires specification and validation)
- Better documentation, maintenance
- Test case generation
- Knowledge about formal methods leads to better software development

Testing

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  - **Randomly chosen**
  - **Intelligently chosen (by hand: expensive!)**
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Challenges can be addressed by/require formal methods

Favourable Development

Design and specification

- **Unified Modeling Language – UML**

  Graphical language for object-oriented modelling
  Standard of Object Management Group (OMG)

- **Object Constraint Language – OCL**

  Formal textual assertion language
  UML Substandard

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  Patterns, idioms, architectures, frameworks, etc.

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Industrial implementation languages

- **Java, C#**

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- real-time requirements
- memory use
- security
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Different Formal Methods

- deductive verification
- model checking
- static analysis
- run-time checks
  (of formel specification)

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Different Formal Methods

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- model checking
- static analysis
- run-time checks
  (of formel specification)

Limitations of Formal Methods

Possible reasons for errors

- **Program is not correct (does not satisfy the specification)**
  Formal verification proves absence of this kind of error
- **Program is not adequate (error in specification)**
  Formal specification/verification avoid/find this kind of error
- **Error in operating system, compiler, hardware**
  Not avoided (unless compiler etc. specified/verified)

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No full specification/verification

In general, it is neither useful nor feasable to fully specify and verify large software systems. Then, formal methods are restricted to:

- **Important parts/modules**
- **Important properties/requirements**

The Main Point of Formal Methods is Not

- To show "correctness" of entire systems
  (What IS correctness? Always go for specific properties!)
- To replace testing entirely
- To replace good design practices

There is no silver bullet that lets you get away without writing crystal clear requirements and good design, in particular, Formal Methods aren't one

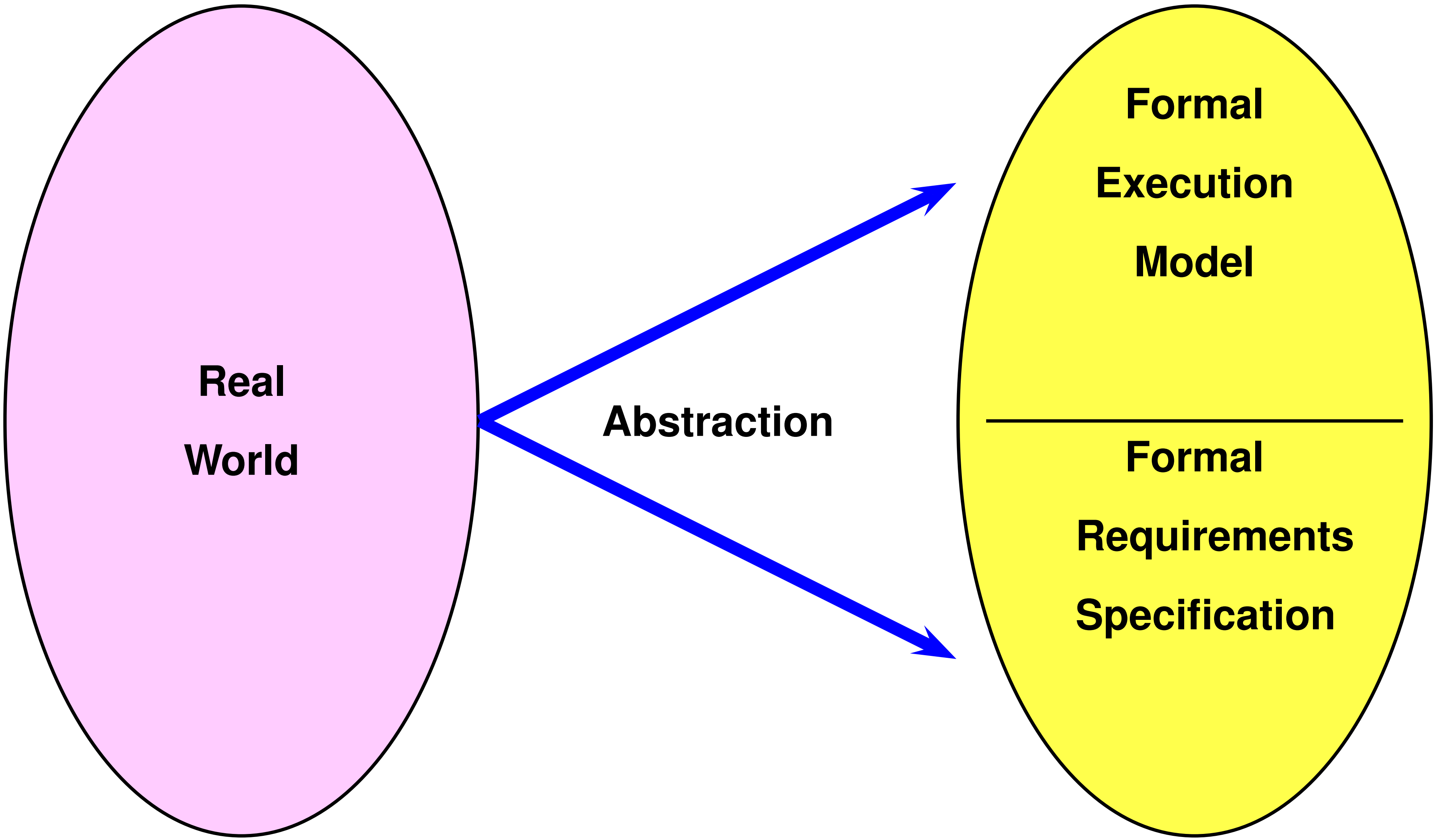
But

- Formal proof can replace many test cases
- Formal methods can be used in automatic test case generation
- Formal methods improve the quality of specifications

A Fundamental Fact

Formalisation of system requirements is hard

Difficulties in Creating Formal Models



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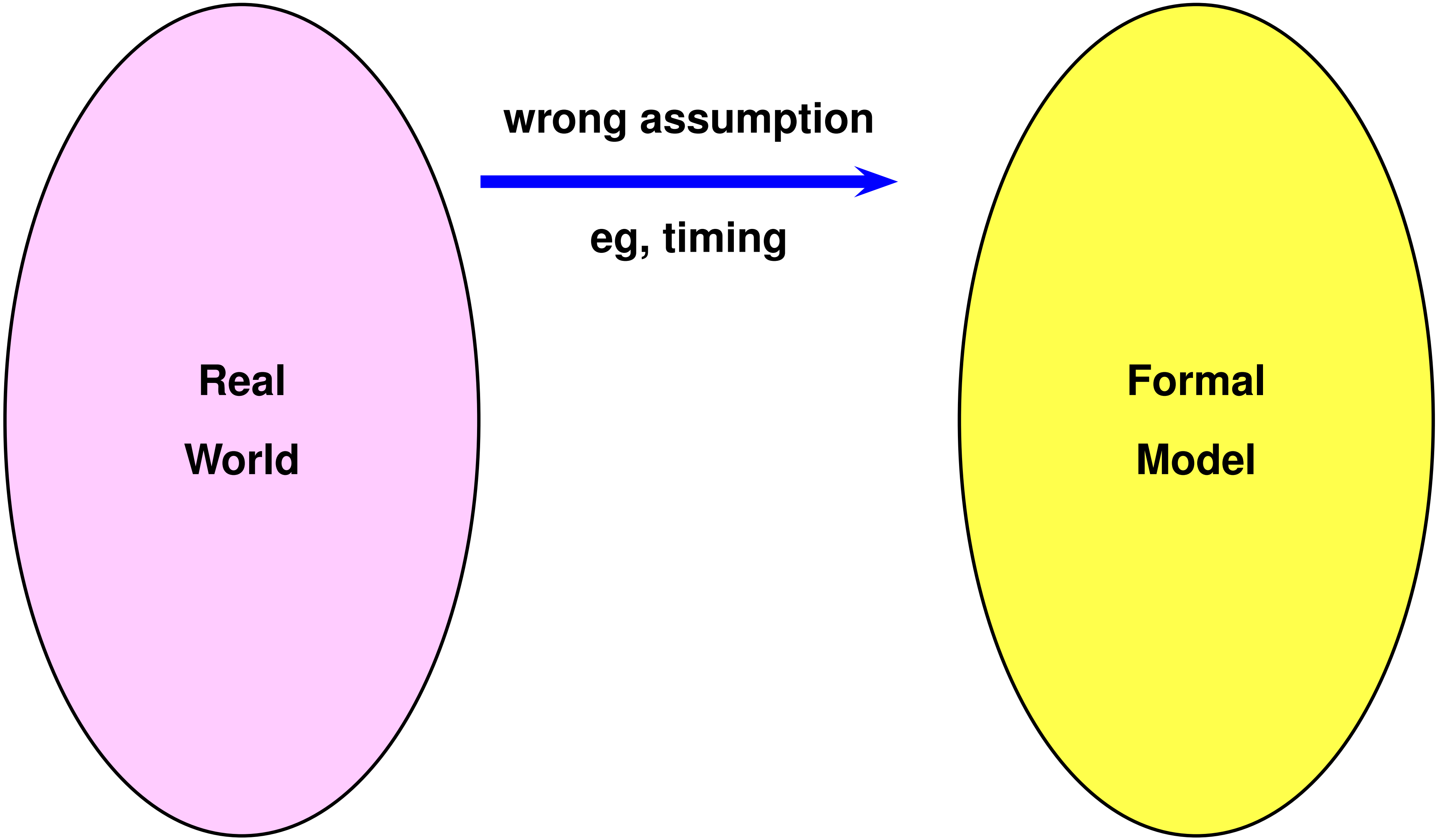

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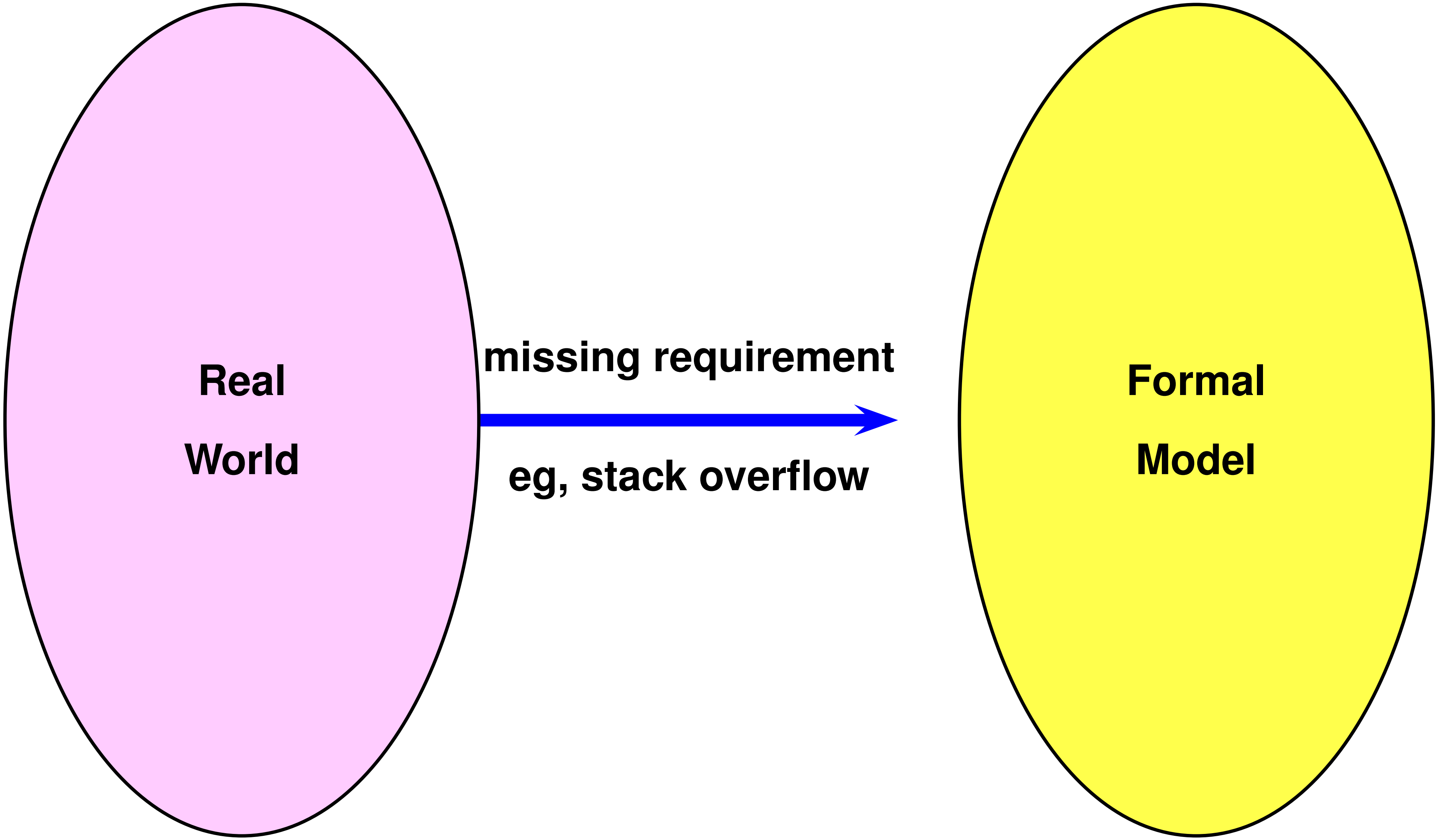

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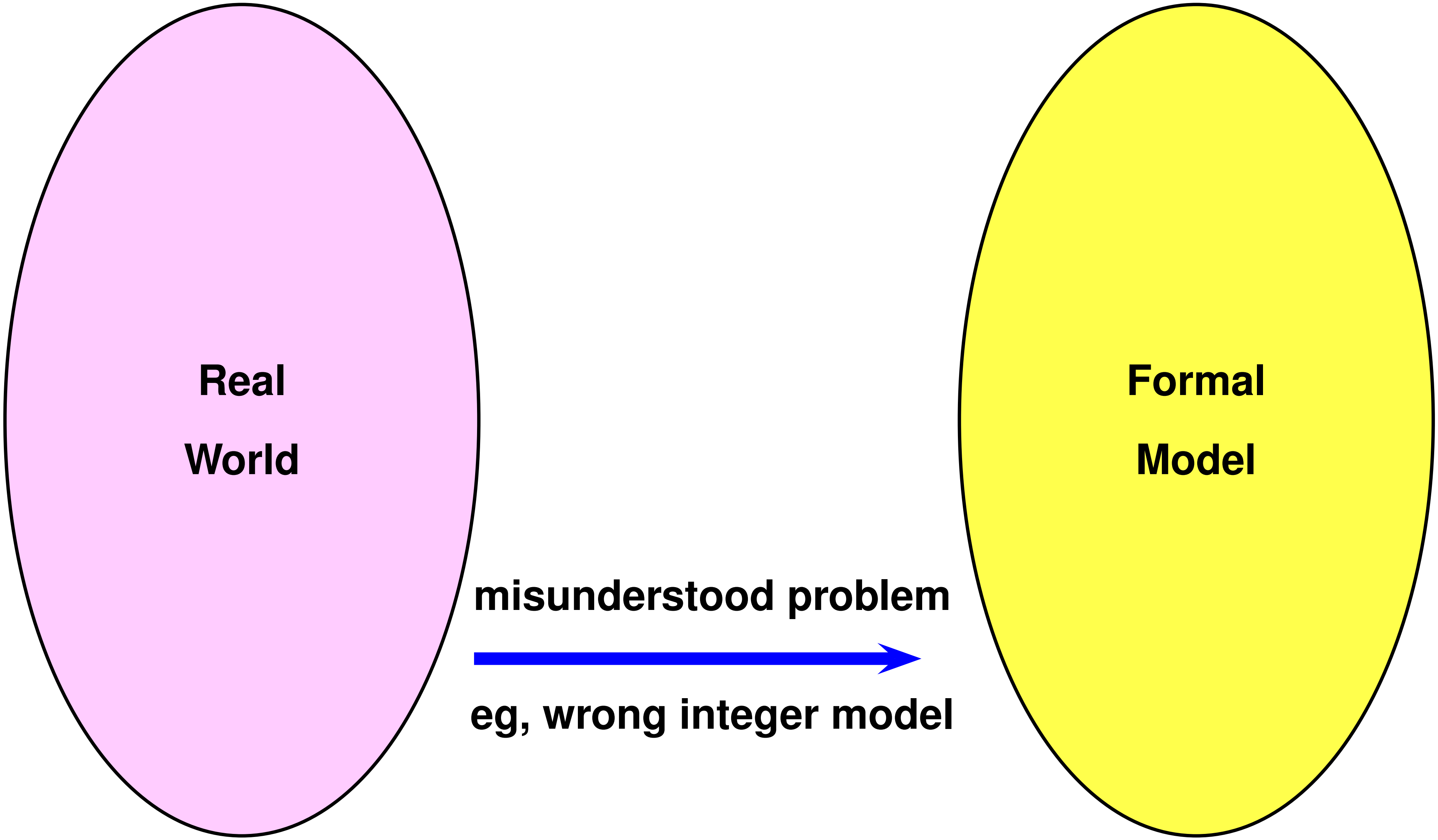
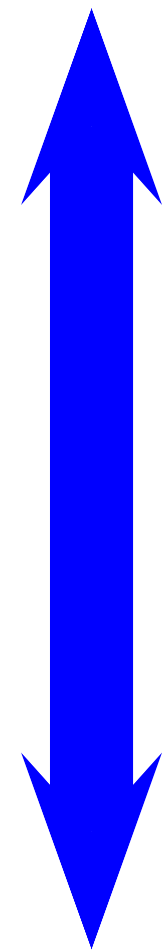


Another Fundamental Fact

Proving properties of systems can be hard

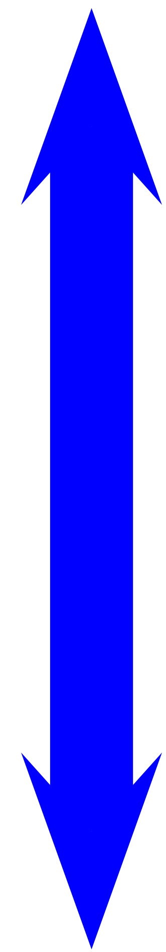
System Abstraction Level

- Low level of abstraction
  - Finitely many states
  - Tedious to program, worse to maintain
  - Automatic proofs are (in principle) possible
- High level of abstraction
  - Complex datatypes and control structures
  - Easier to program
  - Automatic proofs (in general) impossible!



Specification Abstraction Level

- **Low level of abstraction**
  - **Finitely many cases**
  - **Approximation, low precision**
  - **Automatic proofs are (in principle) possible**
- **High level of abstraction**
  - **General properties**
  - **High precision, tight modeling**
  - **Automatic proofs (in general) impossible!**



Main Approaches

High-level programs, Complex properties	High-level programs, Simple properties
Low-level programs, Complex properties	Low-level programs, Simple properties

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Model Checking

Main Approaches

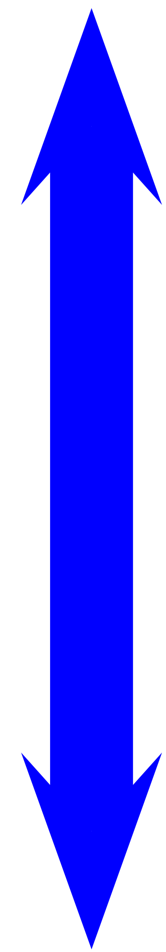
KeY System

High-level programs, Complex properties	High-level programs, Simple properties
Low-level programs, Complex properties	Low-level programs, Simple properties

Model Checking

Proof Automation

- “Automatic” Proof
  - No interaction
  - Sometimes help is required anyway
  - Formal specification still “by hand”
- “Semi-Automatic” Proof
  - Interaction may be required
  - Very often proof tool suggests proof rules
  - Proof is checked by tool



SPIN at Bell Labs

Feature interaction for telephone call processing software

- Tool works directly on C source code
- Web interface to track properties
- Work farmed out to large numbers of computers
- Finds shortest possible error trace
- 18 months, 300 versions, 75 bugs found
- Main burden: Defining meaningful properties

SLAM at Microsoft

- Device drivers running in “kernel mode” should respect API
- Third-party device drivers that do not respect APIs responsible for 90% of Windows crashes
- SLAM inspects C code, builds a finite state machine, checks requirements
- Being turned into a commercial tool right now

Future Trends

- **Design for formal verification**
- **Combining automatic methods with theorem provers**
- **Combining static analysis of programs with automatic methods and with theorem provers**
- **Combining test and formal verification**
- **Integration of formal methods into SW development process**
- **Integration of formal method tools into CASE tools**

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- Can shorten development time
- Can push the limits of feasible complexity
- Can increase product quality

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Those responsible for software management should consider formal methods, in particular, where safety-critical, security-critical, and cost-intensive software is concerned