Einführung in die formale Spezifikation von Software

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UNIVERSITÄT KOBLENZ-LANDAU

Winter 2008/2009

This Course / Web Page

Web page

All information relevant to this lecture can be found on the web page

`www.uni-koblenz.de/~beckert/Lehre/Formale-Spezifikation/`

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Make this a lively course

- **Ask questions!**

Contents

- **Introduction: Formal Methods and Formal Specification**

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- Design by Contract
- Invariants, Pre- and Post-Conditions

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- **Object Constraint Language (OCL)**
- **Java Modelling Language (JML)**

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What are Formal Methods?

Software Development Methods

- Analysis
- Modelling (Specification)
- Implementation
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- 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

- **Run the system at chosen inputs and observe its behaviour**
  - **Randomly chosen**
  - **Intelligently chosen (by hand: expensive!)**
  - **Automatically chosen (need formalized spec)**

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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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- communication, protocols
- real-time requirements
- memory use
- security
- robustness
- etc.

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Different Formal Methods

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

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- model checking
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  (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

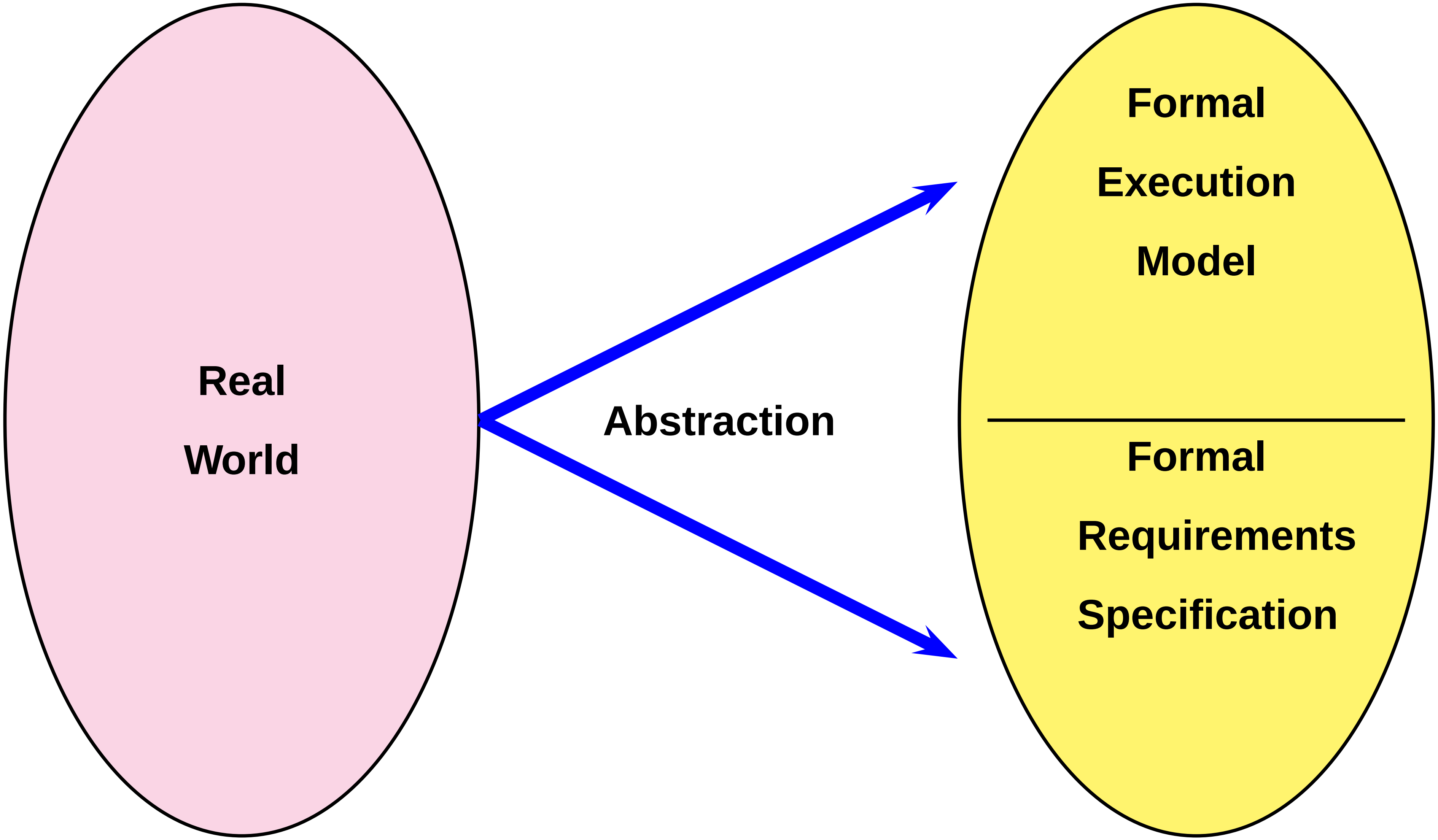
But

- **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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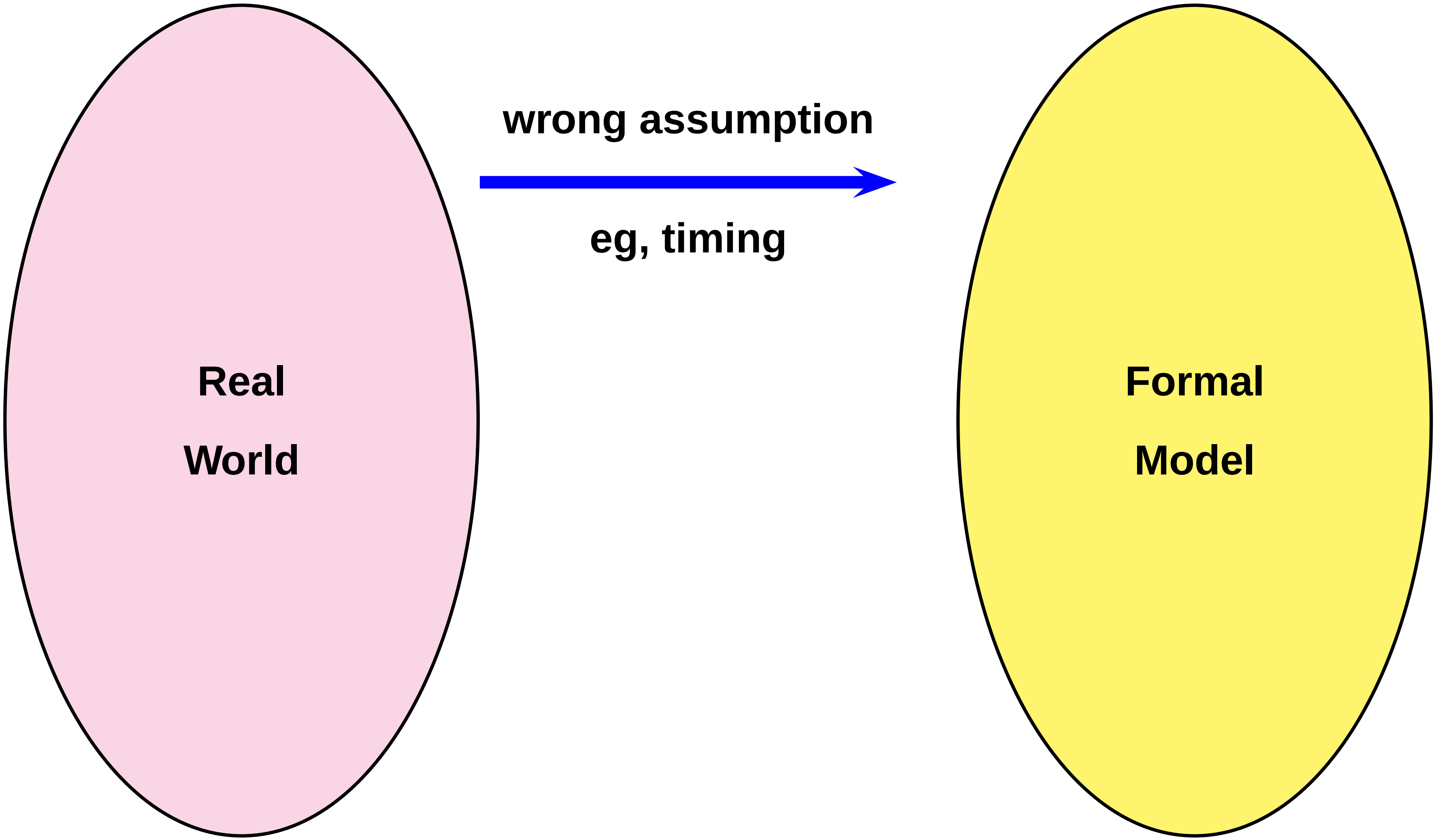

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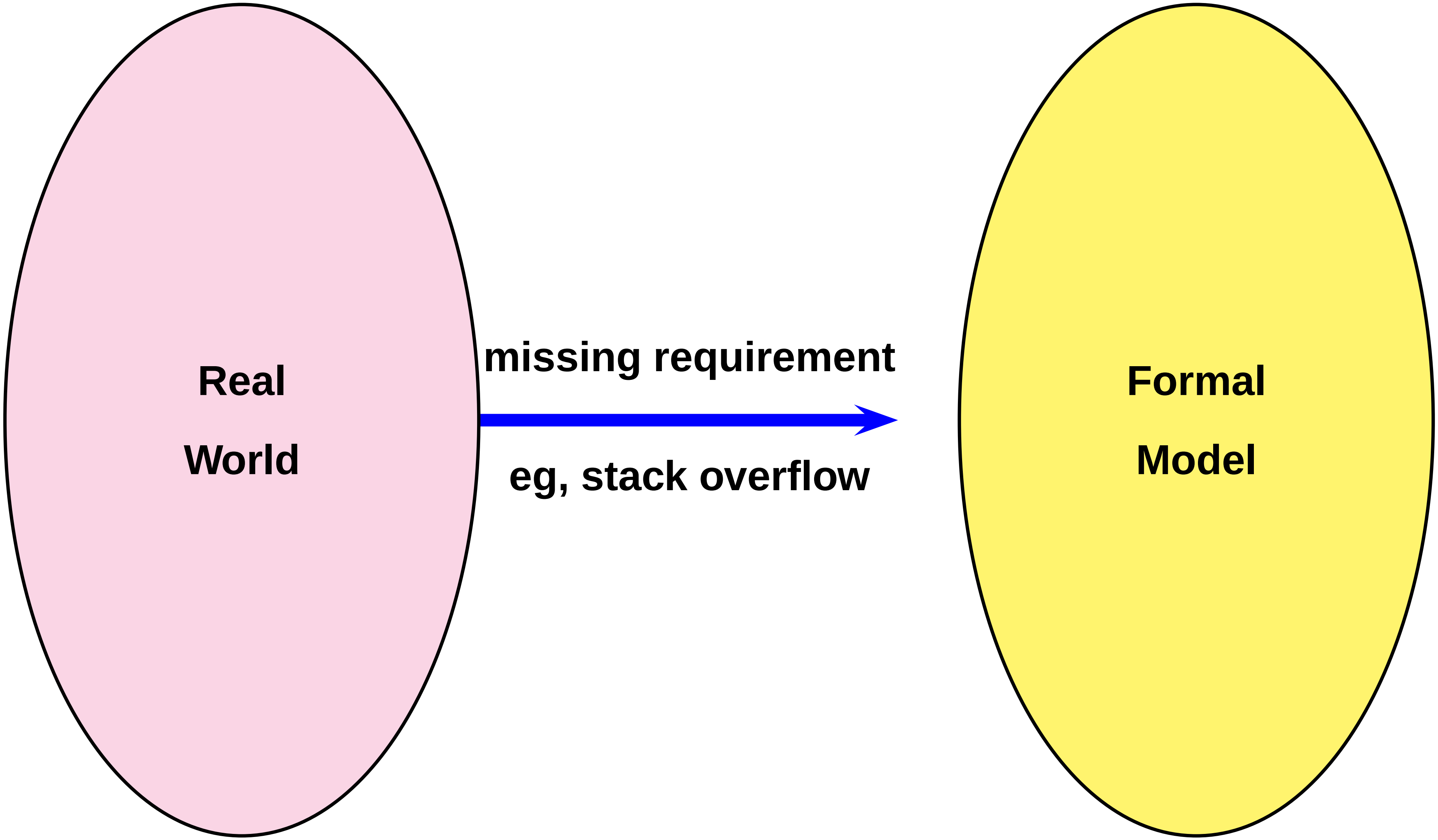

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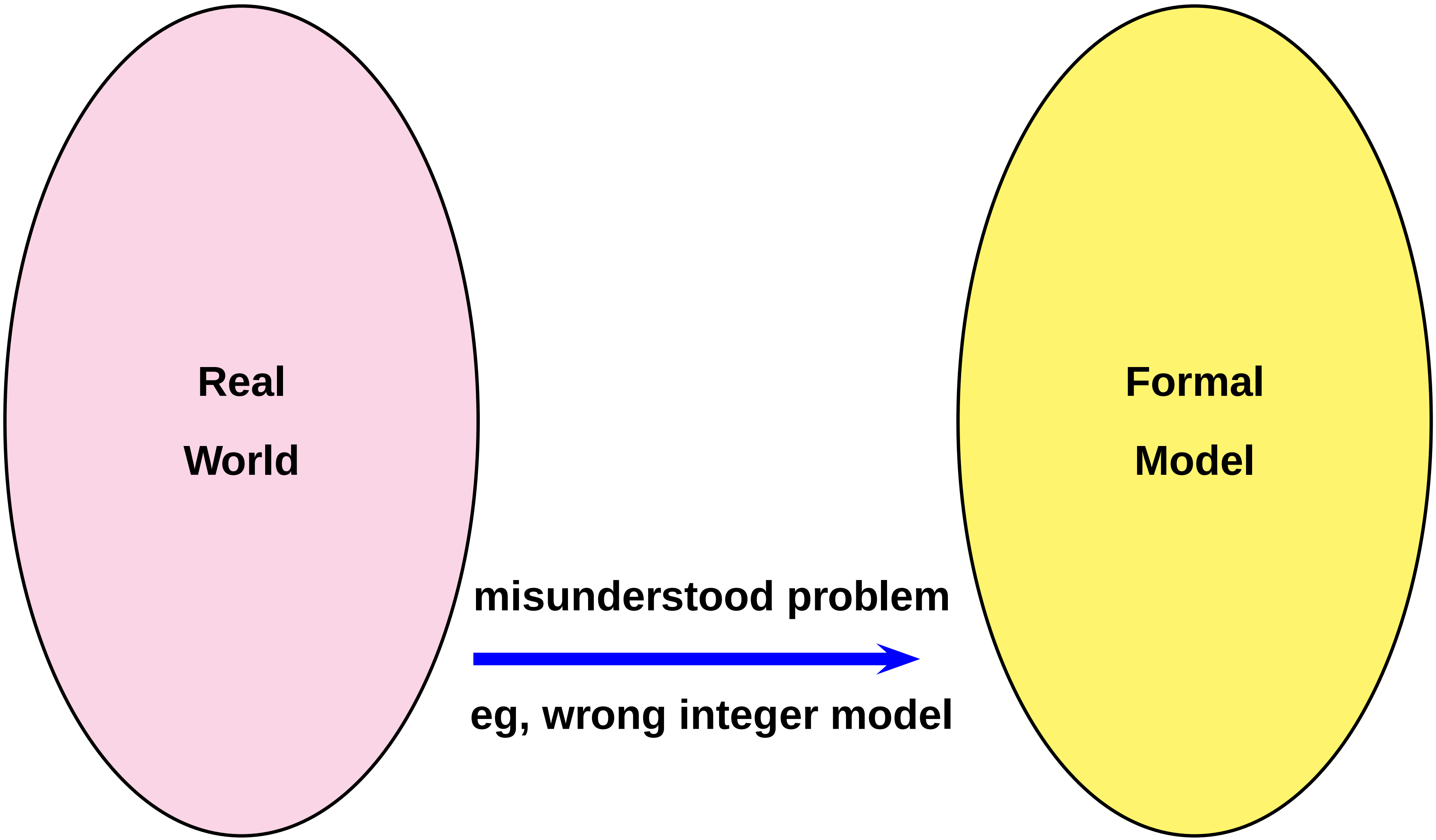
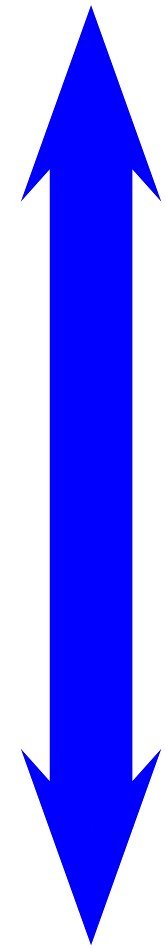


Another Fundamental Fact

Proving properties of systems can be hard

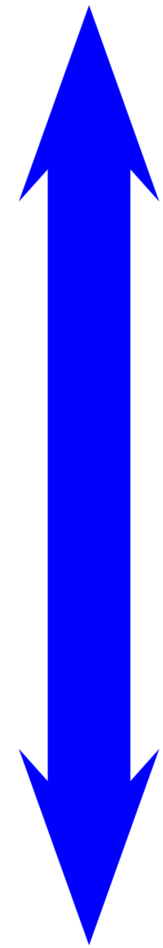
System Abstraction Level

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

Model Checking

Main Approaches

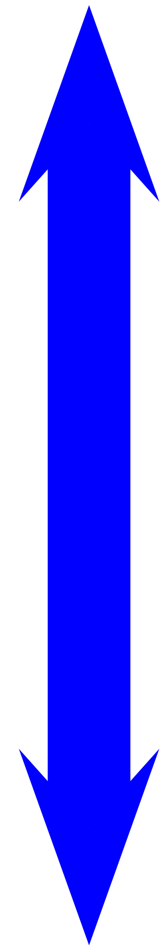
KeY System

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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- Are (more and more) used in practice
- 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