

# Applied Logic in Engineering

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**Abstract.** Logic not only helps to solve complicated and safety-critical problems, but also disciplines the mind and helps to develop abstract thinking, which is very important for any area of Engineering. In this technical report, we present an overview of common challenges in teaching of formal methods and discuss our experiences from the course *Applied Logic in Engineering*. This course was taught at TU Munich, Germany, in Winter Semester 2012/2013.

## 1 Introduction

David Parnas, a pioneer of Software Engineering, stated that a solid understanding of logic should be essential for a software engineer, cf. [13]: “*Professional engineers can often be distinguished from other designers by the engineers ability to use mathematical models to describe and analyze their products.*”. This statement is also true for any kind of engineering, from Software to Mechanical Engineering. However, (i) this subject is in most cases avoided by students as “too boring” and “too complicated” as well as (ii) the formal methods are often treated by engineers as “something that is theoretically important but practically too hard to understand and to use”, where the second is in many aspects a consequence of the first.

Unfortunately, dealing with formal methods often assumes that only two factors must be satisfied: the method must be sound and give such a representation, which is concise and beautiful just from the mathematical point of view, without taking into account any question of readability, usability, or tool support. This leads to the fact that the term “formal” is for many people just some kind of synonym for “unreadable”, however, even small syntactical changes of a formal method can make it more understandable and usable for an average engineer. In our work on *Human Factors of Formal Methods* [20,21] we aim to apply the engineering psychology achievements to the design of formal methods, focusing on the specification phase of a system development process.

Dealing with Formal Methods require a mathematical background and abstract thinking skills, which brings us to another problem: many students have negative perceptions and even fear of courses that require dealing with complex mathematical notations. This is strongly related to the phenomenon of *mathematical anxiety*, cf. [23,18]. The term *mathematical anxiety* was introduced in 1972 by Richardson and Suinn as “*feelings of tension and anxiety that interfere with the manipulation of numbers and the solving of mathematical problems in*

*a wide variety of ordinary life and academic situations,*” cf. [14]. As stressed by Wang et al., mathematical anxiety has attracted recent attention because of its damaging psychological effects and potential associations with mathematical problem solving and achievement.

Thus, the usability improvement is only a partial solution to the problem. To overcome the preconceived notions about formal methods we should start a bit earlier as on the development stage, by trainings and teaching of logic not only by presenting its theoretical aspects but also focusing on its real applications, industrial and non-industrial ones, referring to the programming languages where the formal side is almost covered, or to famous fiction books and movies, e.g., to the famous crime stories by A.C. Doyle.

A novel way to attract students while teaching Formal Methods was presented in [4]. Within the engagement project *cs4fn*, Computer Science for Fun, the authors taught logic and computing concepts using magic tricks, which inspired students to work with logical tasks. Our approach was less revolutionary: we based the course on both practical examples and entertainment examples, such as formal modelling of Sherlock Holmes deductions.

## 2 Applied logic in Engineering

The course *Applied logic in Engineering* (ACE) was introduced at TU Munich, Germany, in Winter Semester 2012/2013 as a face-to-face course.<sup>1</sup>

In contrary to the many courses on Formal Methods, we did not expect any previous knowledge on logics and abstract thinking. We introduced this lecture course as a “logic for everybody”, to engage pupils studying an engineering subject and is interested in getting the knowledge about logic and its application areas. However, this course would be especially beneficial for Computer Science students, as well as for the IT students who aim to work as Requirements Engineers and Testers.


The course has the following *learning outcomes*: On completion of this course students (1) will be able to state the basic principles of logic applied in Engineering and (2) will experience practical applications of these principles.

To explain the core ideas of basic logics, we provided illustrative examples. Some of the examples will come from industrial problems, where some of the examples will have more entertainment nature (to show to the students that logic is not necessary “a very dry subject”) be presented by puzzles and analysis of situations from famous fiction books and movies.

The course was partially based on the book of Schönig [16], which introduces the notions and methods of formal logic from a computer science standpoint, as well as on the book of Russell and Norvig [15]. We also recommended our students to read the book of Harrison, which focuses on practical application of logic and automated reasoning [8], as well as a number of other books on logic and (semi-)automated theorem proving, cf. [10,7,3].

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<sup>1</sup> <http://www4.in.tum.de/lehre/vorlesungen/Logic/WS1213/index.shtml>

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## Einstein' Logic Puzzle


- The Briton lives in the red house.
- The Swede keeps dogs as pets.
- The Dane drinks tea.
- Looking from in front, the green house is just to the left of the white house.
- The green house's owner drinks coffee.
- The person who smokes Pall Malls raises birds.
- The owner of the yellow house smokes Dunhill.
- The man living in the center house drinks milk.
- The Norwegian lives in the leftmost house.
- The man who smokes Blends lives next to the one who keeps cats.
- The man who keeps a horse lives next to the man who smokes Dunhill.
- The owner who smokes Bluemasters also drinks beer.
- The German smokes Prince.
- The Norwegian lives next to the blue house.
- The man who smokes Blends has a neighbor who drinks water.

Who owns fish?

<b>Norwegian</b> Cats Water Dunhill	<b>Dane</b> Horse Tea Blends	<b>Briton</b> Birds Milk Pall Malls	<b>German</b> Flech Coffee Prince	<b>Swede</b> Dogs Beer Bluemasters
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**Fig. 1.** Solving the Einstein puzzle: A task for formal methods

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## Example

from [Schöning1989]

Formalize the following puzzle in FOL and solve it:

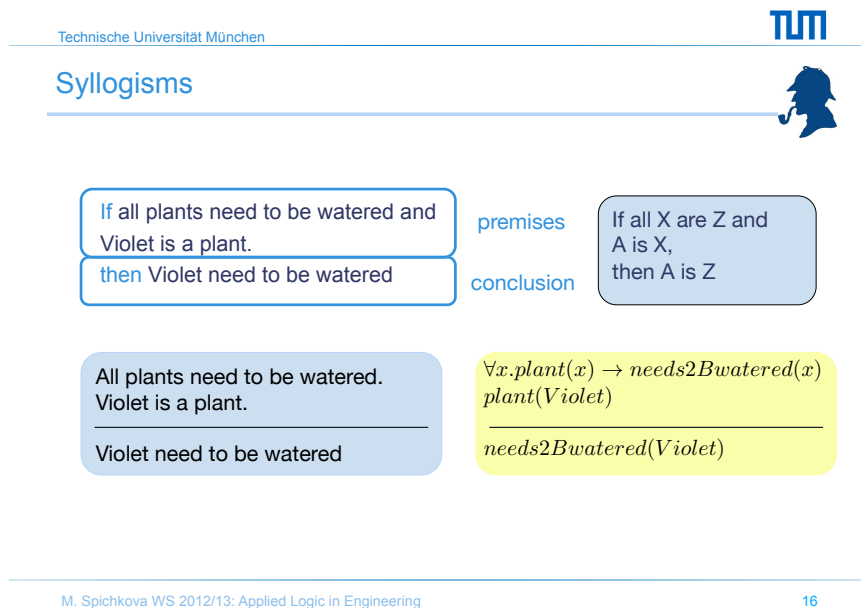
Tom, Mike, and John are members of the alpine club.  
 Each member of the alpine club is either skier or climber or both.  
 No climber likes the rain and all skiers like the snow.  
 Mike likes everything that Tom dislikes, and vice versa.  
 Mike and John like the snow.  
 Is there a member of the alpine club who is climber but no skier, and who is this?

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**Fig. 2.** Solving a puzzle in First-Order Logic (FOL)

The general structure of the course is presented below:

- Part 1. *What is Logic?*
  - History and application areas
  - “Dry formal methods” vs. “Sherlock Holmes deduction methods”
  - Abstract representation and abstract thinking
  - ProLog
    - \* Another way of thinking (in comparison with C, Java, etc.)
    - \* Current projects (e.g., at Siemens AG)
  - Overview of logics: propositional, first order/predicate, fuzzy, Higher-Order Logic
  
- Part 2. *Propositional logic*
  - Syntax and semantics
  - Normal form transformation
  - Calculi
    - \* Natural deduction
    - \* Resolution
  - Binary decision diagrams
  - ProLog representation
  
- Part 3. *First Order/ Predicate logic*
  - Syntax and semantics
  - Normal form transformation
  - Substitution
  - Calculi
    - \* Natural deduction
    - \* Resolution
  - ProLog representation
  
- Part 4. *Special Cases*
  - Datalogic and databases
  - Description Logic and Entity-Relation Diagram
  - Closed world assumption
  
- Part 5. *Applications*
  - Formal specification and verification
    - \* Algebraic specification
    - \* Specification in Attempto Controlled English
    - \* HOL specification (Microsoft: Hypervisor Verification in VerisoftXT)
  - Reasoning, problem of planning
    - \* Event calculi
    - \* FLUX language (ProLog + current projects)



**Fig. 3.** Visual explanation of formal notation: Introduction to the Syllogisms

Thus, the course gives an introduction not only to the basic principles of logic, but also to some of its applications, such as

- Reasoning and Planning problems;
- Formal Specifications/ models for precise description of systems and requirements and analysis of systems;
- Verification: Proving that a system fulfils its requirements, and that a new version of a system is a refinement of the previous version;
- Theorem proving/Model checking allowing (semi-)automated proofs;
- Design/optimization of digital circuits: Claude Shannon has shown that propositional logic can be used to describe and optimize electromechanical circuits, [17];
- Formalisation of queries in databases.

We also discussed application of formal methods in a number of recent research projects, cf. [22,2,19,12,11,6,9,5].

**Example.** Let us discuss an example of a task for tutorial:

*Formalize the following sentences as formulas and then show that they are equivalent:*

- (1) *The following property holds not for all time intervals: If the system gets a signal from its sensors that there is no communication at a time interval  $t$  or that the battery power gets low at a time interval  $t$ , and exists an information package that have to be send, then at a time interval  $t$  there is an information package in the temporal buffer.*
- (2) *At some time interval  $t$  the following holds for all information packages: there is an information package that have to be send, but there is no information package in the temporal buffer, and the system gets a signal from its sensors that there is no communication or that the battery power gets low.*

One possible solution:

Formalisation of the sentences would be

(1)  $\neg\forall t. ((C(t) \vee B(t)) \wedge S(t) \rightarrow T(t))$  and

(2)  $\exists t. (S(t) \wedge \neg T(t) \wedge (C(t) \vee B(t)))$ .

Proof that both formulas are equal:

$$\begin{aligned} & \neg\forall t. ((C(t) \vee B(t)) \wedge S(t) \rightarrow T(t)) \\ & \equiv \exists t. \neg((C(t) \vee B(t)) \wedge S(t) \rightarrow T(t)) \\ & \equiv \exists t. \neg(\neg((C(t) \vee B(t)) \wedge S(t)) \vee T(t)) \\ & \equiv \exists t. (((C(t) \vee B(t)) \wedge S(t)) \wedge \neg T(t)) \\ & \equiv \exists t. (S(t) \wedge \neg T(t) \wedge (C(t) \vee B(t))) \end{aligned}$$

Another possible solution:

Formalization of (1):  $\neg\forall t. \exists p. ((C(t) \vee B(t)) \wedge S(p, t) \rightarrow T(p, t))$

Formalization of (2):  $\exists t. \forall p. (S(p, t) \wedge \neg T(p, t) \wedge (C(t) \vee B(t)))$

Proof that both formulas are equal:

$$\begin{aligned} & \exists t. \forall p. (S(p, t) \wedge \neg T(p, t) \wedge (C(t) \vee B(t))) \\ & \equiv \neg\forall t. \neg(\forall p. (S(p, t) \wedge \neg T(p, t) \wedge (C(t) \vee B(t)))) \\ & \equiv \neg\forall t. (\exists p. \neg(S(p, t) \wedge \neg T(p, t) \wedge (C(t) \vee B(t)))) \\ & \equiv \neg\forall t. (\exists p. (\neg S(p, t) \vee T(p, t) \vee \neg(C(t) \vee B(t)))) \\ & \equiv \neg\forall t. (\exists p. (\neg S(p, t) \vee \neg(C(t) \vee B(t)) \vee T(p, t))) \\ & \equiv \neg\forall t. (\exists p. (\neg(S(p, t) \wedge (C(t) \vee B(t))) \vee T(p, t))) \\ & \equiv \neg\forall t. (\exists p. ((S(p, t) \wedge (C(t) \vee B(t))) \rightarrow T(p, t))) \end{aligned}$$

□

ACE was introduced as an elective course and attracted 20 students. The exam for this course was organised as an *open book* exam, as our goal was to examine whether the students understand and are able to apply the core principles of logic methods, rather than check they memory.

### 3 Evaluation and Conclusions

As per evaluation report [1], the majority of the students agreed that the provided examples were very helpful, and the learning amount and the amount of the material provided within the course were “exactly right” (German, “genau richtig”). We got the following comments from our students:

“Structured logically and builds up stuff part by part; nice additions as Sherlock video”;

“The topic presented are interesting and indeed “applied”, unlike other logical courses that are more theoretic”;

“I liked the small size of the course and I got a deeper understanding of logic”.

To the question what did you most liked in the course, the students replied

“Sherlock, Examples during lecture” .

This technical report presents an overview of common challenges in teaching of formal methods and suggested solutions to them. We discussed our experiences from the course *Applied Logic in Engineering* taught at TU Munich, Germany.

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