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Lessons of Teaching Formal Methods with Isabelle

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Introduction

- Experiences teaching two courses
- Isabelle/Pure and Isabelle/HOL
- Why is it hard to learn Isabelle?
- Tools interfacing with Isabelle

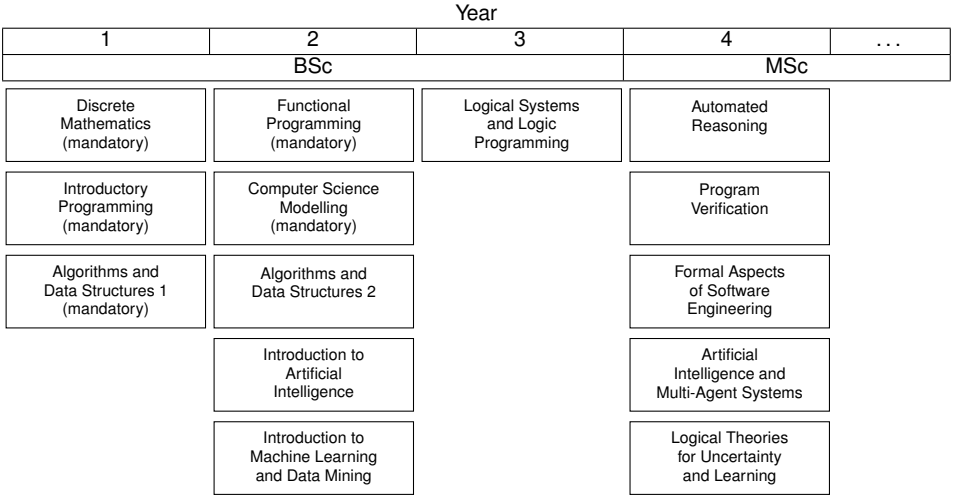
Our undergraduate course

- Logical systems and logic programming
- Run for many years
- Recently introduced more and more Isabelle
- Topics: propositional and first-order logic, Hilbert systems, tableaux, sequent calculus, resolution
- . . . and programming in Prolog
- 80+ students

Our graduate course

- Automated reasoning
- Has run only a few times
- Topics: Isabelle, higher-order logic, type theory, practical formal proofs, verification of functional programs, automated theorem provers
- 40+ students

The surrounding curriculum



Natural Deduction Assistant

- Graphical interface for natural deduction proofs
- Classical first-order logic with functions
- Metatheory formalized in Isabelle
- Impossible to make syntax mistakes, and suggests applicable proof rules automatically (i.e. impossible to apply a rule wrong)
- Easy to use, but annoyingly slow after a while

Sequent Calculus Verifier

- Textual interface for sequent calculus proofs
- Same logic and metatheory as NaDeA
- Possible to make syntax mistakes, does not suggest proof rules, user must write out result of applying rule manually
- No special characters or order of precedence (all parentheses required)
- Still gives good warnings/errors if proof rules are applied wrong
- Slightly harder to use, but quite fast
- Looks quite a lot like “manual” proofs in Isabelle

Intuitionistic propositional logic

- Formalization in Isabelle/Pure (heavily inspired by Makarius' examples)
- Why? No clutter, just the rules
- No automation
- Students are forced to write structured proofs and think about which rules to use

Intuitionistic higher-order logic

- Introduce higher-order logic
- More involved examples
- Learning how to work with quantifiers

Classical higher-order logic

- Essentially just Isabelle/HOL, but with no automation
- Learning how to approach proofs by contradiction through various possible rules
- Quite involved examples
- Builds a good understanding of what automation does under the hood

The basics of Isabelle

- In parallel with learning logic, we teach formal verification of functional programs
- Getting used to the syntax of Isabelle and the use of Isabelle/jEdit (or Isabelle/VSCode)
- Getting back up to speed on functional programming
- Students generally have a hard time for the first several weeks
- The documentation they get by searching online (i.e. the Isar reference manual) is difficult for them to understand

Automation

- We introduce basic automation (i.e. auto) quite quickly, but do not explain what it does immediately
- When students have worked through the Isabelle/Pure section of the course, they can understand what the automation does
- We exhibit some basic automated theorem provers (for SeCaV) to give students an idea of how proof search can be implemented

The exercises

- Widely varying difficulty
- Some are too hard for any students to finish without substantial help

Summary

- Isabelle is very complex, so it is difficult for beginners to jump in
- We start outside of Isabelle and slowly build up to the “full experience”
- It seems like we need more relatively easy exercises
- Students need to get their hands dirty to succeed

Ideas and future work

- Beginner version of the reference manual
- More easy exercises in the tutorial
- “Project”-based exercises that guide students along
- Better integration between our tools and Isabelle
- We’re working on it!