COMP 4161
NICTA Advanced Course

Advanced Topics in Software Verification

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a = b = c = . . .

Slide 1

Last time ...

➜ fun, function
➜ Well founded recursion

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Content

➜ Intro & motivation, getting started [1]

➜ Foundations & Principles
- Lambda Calculus, natural deduction [1,2]
- Higher Order Logic [3[a]]
- Term rewriting [4]

➜ Proof & Specification Techniques
- Isar [5]
- Inductively defined sets, rule induction [6[b]]
- Datatypes, recursion, induction [7[c], 8]
- Calculational reasoning, code generation [9]
- Hoare logic, proofs about programs [10[d],11,12]

[a] a1 due; [b] a2 due; [c] session break; [d] a3 due

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CALCULATIONAL REASONING

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The Goal

$$
\begin{aligned}
x \cdot x^{-1} &= 1 \cdot (x \cdot x^{-1}) \\
\ldots &= 1 \cdot x \cdot x^{-1} \\
\ldots &= (x^{-1})^{-1} \cdot x^{-1} \cdot x \cdot x^{-1} \\
\ldots &= (x^{-1})^{-1} \cdot (x^{-1} \cdot x) \cdot x^{-1} \\
\ldots &= (x^{-1})^{-1} \cdot 1 \cdot x^{-1} \\
\ldots &= (x^{-1})^{-1} \cdot (1 \cdot x^{-1}) \\
\ldots &= (x^{-1})^{-1} \cdot x^{-1} \\
\ldots &= 1
\end{aligned}
$$

Can we do this in Isabelle?

- ➜ Simplifier: too eager
- ➜ Manual: difficult in apply style
- ➜ Isar: with the methods we know, too verbose

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Chains of equations

The Problem

$$
\begin{aligned}
a &= b \\
\ldots &= c \\
\ldots &= d
\end{aligned}
$$

shows $a = d$ by transitivity of $=$

Each step usually nontrivial (requires own subproof)

Solution in Isar:

- ➜ Keywords **also** and **finally** to delimit steps
- ➜ **...**: predefined schematic term variable,
  refers to right hand side of last expression
- ➜ Automatic use of transitivity rules to connect steps

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also/finally

	calculation register
have "$t_0 = t_1$" [proof]	
also	"$t_0 = t_1$"
have "$\ldots = t_2$" [proof]	
also	"$t_0 = t_2$"
$\vdots$	$\vdots$
also	"$t_0 = t_{n-1}$"
have "$\cdots = t_n$" [proof]	
finally	$t_0 = t_n$
show P	

— 'finally' pipes fact "$t_0 = t_n$" into the proof

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More about also

- ➜ Works for all combinations of $=$, $\leq$ and $<$.
- ➜ Uses all rules declared as `[trans]`.
- ➜ To view all combinations in Proof General:

  Isabelle/Isar $\to$ Show me $\to$ Transitivity rules

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Designing [trans] Rules

have = "$l_1 \odot r_1$" [proof]
also
have "$\ldots \odot r_2$" [proof]
also

Anatomy of a [trans] rule:

- Usual form: plain transitivity $[\![l_1 \odot r_1; r_1 \odot r_2]\!] \Longrightarrow l_1 \odot r_2$
- More general form: $[\![P\ l_1\ r_1; Q\ r_1\ r_2; A]\!] \Longrightarrow C\ l_1\ r_2$

Examples:

- pure transitivity: $[\![a = b; b = c]\!] \Longrightarrow a = c$
- mixed: $[\![a \le b; b < c]\!] \Longrightarrow a < c$
- substitution: $[\![P\ a; a = b]\!] \Longrightarrow P\ b$
- antisymmetry: $[\![a < b; b < a]\!] \Longrightarrow P$
- monotonicity: $[\![a = f\ b; b < c; \bigwedge x\ y.\ x < y \Longrightarrow f\ x < f\ y]\!] \Longrightarrow a < f\ c$

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DEMO

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HOL as programming language

We have

- numbers, arithmetic
- recursive datatypes
- constant definitions, recursive functions
- = a functional programming language
- can be used to get fully verified programs

Executed using the simplifier. But:

- slow, heavy-weight
- does not run stand-alone (without Isabelle)

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Generating code

Translate HOL functional programming concepts, i.e.

- datatypes
- function definitions
- inductive predicates

into a stand-alone code in:

- SML
- Ocaml
- Haskell
- Scala

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Syntax

export_code <definition_names> **in** SML
  module_name <module_name> **file** "<file path>"

export_code <definition_names> **in** Haskell
  module_name <module_name> **file** "<directory path>"

Takes a space-separated list of constants for which code shall be generated.

Anything else needed for those is added implicitly Generates ML stucture.

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DEMO

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Program Refinement

Aim: choosing appropriate code equations explicitly

Syntax:

lemma [code]:
  <list of equations on function_name>

Example: more efficient definition of fibonnacci function

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DEMO

Slide 16

Inductive Predicates

Inductive specifications turned into equational ones

Example:

```
append [] ys ys
append xs ys zs ⟹ append (x # xs ) ys (x # zs )
```

Syntax:

code_pred append .

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DEMO

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We have seen today ...

- ➜ Calculations: also/finally
- ➜ [trans]-rules
- ➜ Code generation

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