COMP4161: Advanced Topics in Software Verification

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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
  - Inductively defined sets, rule induction [5]
  - Datatypes, recursion, induction [6, 7]
  - Hoare logic, proofs about programs, C verification [8[b],9]
  - (mid-semester break)
  - Writing Automated Proof Methods [10]
  - Isar, codegen, typeclasses, locales [11[c],12]

[a] a1 due; [b] a2 due; [c] a3 due

A Crash Course in Semantics

(For more, see the book Concrete Semantics by Tobias Nipkow and Gerwin Klein)

IMP - a small Imperative Language

Commands:

datatype com = SKIP
| Assign vname aexp (_ := _)
| Semi com com (_; _)
| Cond bexp com com (IF _ THEN _ ELSE _)
| While bexp com (WHILE _ DO _ OD)

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type_synonym vname = string
type_synonym state = vname $\Rightarrow$ nat

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type_synonym vname	=	string
type_synonym state	=	vname ⇒ nat

type_synonym aexp	=	state ⇒ nat
type_synonym bexp	=	state ⇒ bool

Example Program

Usual syntax:

$$
\begin{array}{l}
B := 1; \\
\text{WHILE } A \neq 0 \text{ DO} \\
\quad B := B * A; \\
\quad A := A - 1 \\
\text{OD}
\end{array}
$$

Example Program

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Expressions are functions from state to bool or nat:

$$\begin{array}{l} B := (\lambda\sigma.\ 1); \\ \text{WHILE } (\lambda\sigma.\ \sigma\ A \neq 0) \text{ DO} \\ \quad B := (\lambda\sigma.\ \sigma\ B * \sigma\ A); \\ \quad A := (\lambda\sigma.\ \sigma\ A - 1) \\ \text{OD} \end{array}$$

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Now we need: the meaning (semantics) of programs

How to define execution of a program?

- ➜ A wide field of its own
- ➜ Some choices:
  - Operational (inductive relations, big step, small step)
  - Denotational (programs as functions on states, state transformers)
  - Axiomatic (pre-/post conditions, Hoare logic)

Structural Operational Semantics

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$$\frac{}{\langle \mathsf{SKIP}, \sigma \rangle \to \sigma}$$

$$\frac{e\ \sigma = v}{\langle \mathsf{x := e}, \sigma \rangle \to \sigma[x \mapsto v]}$$

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Demo: The Definitions in Isabelle

Proofs about Programs

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- ➜ On what they work: State
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Example:

Show that example program from slide 6 implements the factorial.

$$\textbf{lemma}\ \langle \text{factorial}, \sigma\rangle \rightarrow \sigma' \Longrightarrow \sigma' B = \text{fac}\ (\sigma A)$$
$$(\text{where}\quad \text{fac}\ 0 = 1, \quad \text{fac}\ (\text{Suc}\ n) = (\text{Suc}\ n) * \text{fac}\ n)$$

Demo: Example Proof

Too tedious

Induction needed for each loop

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Is there something easier?

Floyd/Hoare

Idea: describe meaning of program by pre/post conditions

Examples:

Floyd/Hoare

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$\{\text{True}\} \quad x := 2 \quad \{x = 2\}$

Floyd/Hoare

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Examples:

$\{\text{True}\} \quad x := 2 \quad \{x = 2\}$

$\{y = 2\} \quad x := 21 * y \quad \{x = 42\}$

Floyd/Hoare

Idea: describe meaning of program by pre/post conditions

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$\{x = n\} \quad \text{IF } y < 0 \text{ THEN } x := x + y \text{ ELSE } x := x - y \quad \{x = n - |y|\}$

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Proofs: have rules that directly work on such triples

Meaning of a Hoare-Triple

$$\{P\} \quad c \quad \{Q\}$$

What are the assertions P and Q?

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$$\models \{P\}\ c\ \{Q\} \quad \equiv \quad \forall \sigma\ \sigma'.\ P\ \sigma \wedge \langle c, \sigma \rangle \rightarrow \sigma' \longrightarrow Q\ \sigma'$$

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$$(\forall \sigma.\ P\ \sigma \longrightarrow \exists \sigma'.\ \langle c, \sigma \rangle \rightarrow \sigma')$$

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This lecture: partial correctness only (easier)

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Demo: Hoare Logic in Isabelle

