



程序代写代做 CS 编程辅导



MP4161



UNSW
SYDNEY

Advanced Topics in Software Verification

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13/2022

Content

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→ Foundations & Principles

- Intro, Lambda calculus [1,2]
- Higher Order Logic (part 1) [2,3^a]
- Term rewriting [3,4]



→ Proof & Specification Techniques

- Inductively defined sets, rule induction [4,5]
- Datatype induction, primitive recursion [5,7]
- General recursive functions, termination proofs [7^b]
- Proof automation, Isar (part 2) [8]
- Hoare logic, proofs about programs, invariants [8,9]
- C verification [9,10]
- Practice, questions, exam prep [10^c]

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^aa1 due; ^ba2 due; ^ca3 due

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A Crash Course in Semantics

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see Concrete Semantics)

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IMP - a small Imperative Language

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Commands:
datatype com



P

gn vname aexp

hi com com

nd bexp com com

While bexp com

(_ := _)
(_; _)

(IF _ THEN _ ELSE _)
(WHILE _ DO _ OD)

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IMP - a small Imperative Language

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Commands:

datatype com



P

Assign vname aexp
Let com com
And bexp com com
While bexp com

(_ := _)
(_; _)
(IF _ THEN _ ELSE _)
(WHILE _ DO _ OD)

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type synonym vname = string

type synonym state = vname > nat

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IMP - a small Imperative Language

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type synonym vname = string

type synonym state = vname > nat

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type synonym aexp \equiv state \Rightarrow nat

type synonym bexp \equiv state \Rightarrow bool

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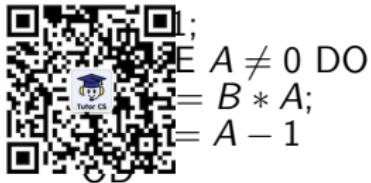
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Example Program

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Usual syntax:



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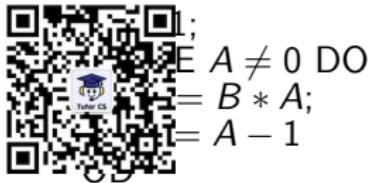
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Example Program

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Usual syntax:



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Expressions are functions from state to bool or nat:

B := (λσ. 1); Project Exam Help

WHILE (λσ. σ A ≠ 0) DO

B := (λσ. σ B * σ A)

A := (λσ. σ A - 1)

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What does it do?

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So far we have defined:



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What does it do?

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So far we have defined:

→ Syntax of commands
→ Session management



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What does it do?

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So far we have defined:

- Syntax of commands
- State of programs



(functions, sessions
from variables to values)

Now we need:

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What does it do?

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So far we have defined:

- Syntax of commands (semantics)
- State of programs (semantics from variables to values)



Now we need: the meaning (semantics) of programs

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What does it do?

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So far we have defined:

- Syntax of commands
- State of programs (from variables to values)



Now we need: the meaning (semantics) of programs

How to define execution of a program?

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What does it do?

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So far we have defined:

- Syntax of commands
- State of programs (from variables to values)



Now we need: the meaning (semantics) of programs

How to define execution of a program?

- A wide field of its own

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What does it do?

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So far we have defined:

- Syntax of commands (expressions)
- State of programs (from variables to values)



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)

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Structural Operational Semantics

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$P, \sigma \rangle \rightarrow \sigma$

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Structural Operational Semantics

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$P, \sigma \rangle \rightarrow \sigma$

$\langle \lambda : e, v \rangle \rightarrow$

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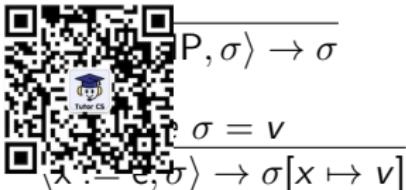
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Structural Operational Semantics

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Structural Operational Semantics

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$$\frac{\text{QR code}}{\text{P}, \sigma \rangle \rightarrow \sigma}$$
$$\frac{\text{QR code} \quad \sigma = v}{\langle x := v, \sigma \rangle \rightarrow \sigma[x \mapsto v]}$$

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Structural Operational Semantics

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$$\frac{\text{QR code}}{\langle P, \sigma \rangle \rightarrow \sigma}$$
$$\frac{\text{QR code} \quad \sigma = v}{\langle x := v, \sigma \rangle \rightarrow \sigma[x \mapsto v]}$$

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 $\langle c_1, \sigma \rangle \rightarrow \sigma' \quad \langle c_2, \sigma' \rangle \rightarrow \sigma''$

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Structural Operational Semantics

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$$\langle P, \sigma \rangle \rightarrow \sigma$$
$$\sigma = v$$
$$\langle x := v, \sigma \rangle \rightarrow \sigma[x \mapsto v]$$

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$$\langle c_1, \sigma \rangle \rightarrow \sigma' \quad \langle c_2, \sigma' \rangle \rightarrow \sigma''$$

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IF b THEN c_1 ELSE $c_2, \sigma \rangle \rightarrow \sigma'$
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Structural Operational Semantics

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$\langle P, \sigma \rangle \rightarrow \sigma$

$\sigma = v$

$\langle x := v, \sigma \rangle \rightarrow \sigma[x \mapsto v]$

WeChat: cstutorcs
 $\langle c_1, \sigma \rangle \rightarrow \sigma' \quad \langle c_2, \sigma' \rangle \rightarrow \sigma''$

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IF b THEN c_1 ELSE $c_2, \sigma \rangle \rightarrow \sigma'$
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Structural Operational Semantics

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$$\langle P, \sigma \rangle \rightarrow \sigma$$

$$\sigma = v$$

$$\langle x := v, \sigma \rangle \rightarrow \sigma[x \mapsto v]$$

$$\frac{\langle c_1, \sigma \rangle \rightarrow \sigma' \quad \langle c_2, \sigma' \rangle \rightarrow \sigma''}{\langle c_1 ; c_2, \sigma \rangle \rightarrow \sigma''}$$

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$$\frac{b \text{ True}}{\langle \text{IF } b \text{ THEN } c_1 \text{ ELSE } c_2, \sigma \rangle \rightarrow \sigma'}$$

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$b, \sigma = \text{False}$

$$\frac{\text{https://tutorcs.com}}{\langle \text{IF } b \text{ THEN } c_1 \text{ ELSE } c_2, \sigma \rangle \rightarrow \sigma'}$$

Structural Operational Semantics

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$$\langle P, \sigma \rangle \rightarrow \sigma$$

$$\sigma = v$$

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$$\frac{b \text{ True} \quad \langle c_1, \sigma \rangle \rightarrow \sigma'}{\langle \text{IF } b \text{ THEN } c_1 \text{ ELSE } c_2, \sigma \rangle \rightarrow \sigma'}$$

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$$\frac{b \sigma = \text{False} \quad \langle c_2, \sigma \rangle \rightarrow \sigma'}{\langle \text{IF } b \text{ THEN } c_1 \text{ ELSE } c_2, \sigma \rangle \rightarrow \sigma'}$$

Structural Operational Semantics

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$\langle \text{DO } c \text{ OD}, \sigma \rangle \rightarrow$

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Structural Operational Semantics

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$$\frac{\tau = \text{False}}{\langle \text{DO } c \text{ OD}, \sigma \rangle \rightarrow \sigma}$$

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Structural Operational Semantics

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$b \sigma = \text{True}$

$\frac{}{\langle \text{DO } c \text{ OD}, \sigma \rangle \rightarrow \sigma}$

$b \sigma = \text{True}$

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Structural Operational Semantics

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$b \sigma = \text{True}$

$\overline{\langle c, \sigma \rangle \rightarrow \sigma'}$

$\langle \text{WHILE } b \text{ DO } c \text{ OD}, \sigma \rangle \rightarrow \sigma$

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Structural Operational Semantics

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$$\frac{b \sigma = \text{True} \quad \langle c, \sigma \rangle \rightarrow \sigma' \quad \langle \text{WHILE } b \text{ DO } c \text{ OD}, \sigma' \rangle \rightarrow \sigma''}{\langle \text{WHILE } b \text{ DO } c \text{ OD}, \sigma \rangle \rightarrow \sigma''}$$

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Demo: The Definitions in Isabelle

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Proofs about Programs

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Now we know:

- What programs are
- On what they work
- How they work: Sel



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Proofs about Programs

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Now we know:

- What programs are
- On what they work
- How they work: Sel



So we can prove properties about programs

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Proofs about Programs

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Now we know:

- What programs are
- On what they work
- How they work: See



So we can prove properties about programs

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Example:

Show that example program from slide 6 implements H-factorial.

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lemma $\langle \text{factorial}, \sigma \rangle \rightarrow \sigma' \implies \sigma' B = \text{fac} (\sigma A)$
(where $\text{fac } 0 = 1$, $\text{fac} (\text{Suc } n) = (\text{Suc } n) * \text{fac } n$)
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Demo: Example Proof

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Too tedious

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Include [] needed for each loop

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Too tedious

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Include [] needed for each loop

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Is there something easier?

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Floyd/Hoare

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Idea: describe meaning of program by pre/post conditions

Examples:



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Floyd/Hoare

程序代写代做 CS编程辅导

Idea: describe meaning of program by pre/post conditions

Examples:

{True} $x := 2$ { $x = \boxed{2}$ }



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Floyd/Hoare

程序代写代做 CS编程辅导

Idea: describe meaning of program by pre/post conditions



Examples:

{True} $x := 2$ { $x = \boxed{2}$ }

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

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Floyd/Hoare

程序代写代做 CS编程辅导

Idea: describe meaning of program by pre/post conditions



Examples:

{True} $x := 2$ { $x = \boxed{2}$ }

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

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

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Floyd/Hoare

程序代写代做 CS编程辅导

Idea: describe meaning of program by pre/post conditions



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

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{ $A = n$ } factorial { $B = \text{fac } n$ }

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Floyd/Hoare

程序代写代做 CS编程辅导

Idea: describe meaning of program by pre/post conditions



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{ $A = n$ } factorial { $B = \text{fac } n$ }

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Proofs: have rules that directly work on such triples

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Meaning of a Hoare-Triple

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What are the asserti



{P}

Q?

c {Q}

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Meaning of a Hoare-Triple

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

What are the assertions?



$Q?$

- Here: again functions → type to bool
(shallow embedding of assertions)

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Meaning of a Hoare-Triple

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

What are the assertions?



$Q?$

- Here: again functions → type to bool
(shallow embedding of assertions)
- Other choice: syntax and semantics for assertions (deep embedding)

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What does $\{P\} \ c \ \{Q\}$ mean?

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Meaning of a Hoare-Triple

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

What are the assertions?



$Q?$

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- Other choice: syntax and semantics for assertions (deep embedding)

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What does $\{P\} \ c \ \{Q\}$ mean?

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Partial Correctness:

$$\models \{P\} \ c \ \{Q\} \equiv \forall \sigma \sigma'. P \sigma \wedge (c \sigma \rightarrow Q \sigma')$$

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Meaning of a Hoare-Triple

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

What are the assertions?



Q?

- Here: again functions → type to bool
(shallow embedding of assertions)
- Other choice: syntax and semantics for assertions (deep embedding)

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What does $\{P\} \ c \ \{Q\}$ mean?

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Partial Correctness:

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

Total Correctness:

$$\models \{P\} \ c \ \{Q\} \equiv (\forall \sigma \sigma'. P \sigma \wedge \langle c, \sigma \rangle \rightarrow \sigma' \rightarrow Q \sigma') \wedge \\ (\forall \sigma. P \sigma \rightarrow \exists \sigma'. \langle c, \sigma \rangle \rightarrow \sigma')$$

Meaning of a Hoare-Triple

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What are the assertions?

- Here: again functions → type to bool
(shallow embedding of assertions)
- Other choice: syntax and semantics for assertions (deep embedding)

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What does $\{P\} \ c \ \{Q\}$ mean?

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Partial Correctness:

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

Total Correctness:

$$\models \{P\} \ c \ \{Q\} \equiv (\forall \sigma \sigma'. P \sigma \wedge \langle c, \sigma \rangle \rightarrow \sigma' \rightarrow Q \sigma') \wedge \\ (\forall \sigma. P \sigma \rightarrow \exists \sigma'. \langle c, \sigma \rangle \rightarrow \sigma')$$

This lecture: partial correctness only (easier)

Hoare Rules

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Hoare Rules

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$$\overline{\{P\} \quad \text{SKIP}} \quad \overline{\{P[x \mapsto e]\} \quad x := e \quad \{P\}}$$



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Hoare Rules

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$$\frac{\overline{\{P\} \text{ SKIP}}} {\{P[x \mapsto e]\} \quad x := e \quad \{P\}}$$
$$\frac{\overline{\begin{array}{c} \{R\} \\ \text{QR} \end{array}} \quad \{R\} \ c_2 \ \{Q\}} {c_1; c_2 \quad \{Q\}}$$

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Hoare Rules

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$$\frac{\overline{\{P\} \text{ SKIP}}}{{\{P[x \mapsto e]\}} \quad x := e \quad \{P\}}$$

$$\frac{\overline{\{R\}} \quad \{R\} \ c_2 \ \{Q\}}{c_1; c_2 \quad \{Q\}}$$


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$$\frac{\overline{\{P\} \text{ IF } b \text{ THEN } c_1 \text{ ELSE } c_2}}{\{Q\}}$$

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Hoare Rules

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$$\frac{}{\{P\} \text{ SKIP } \{P\}} \quad \{P[x \mapsto e]\} \quad x := e \quad \{P\}$$

$$\frac{\begin{array}{c} \{R\} \\ \text{QR} \end{array} \quad \{R\} \quad \{R\} \quad \{Q\} \quad \{Q\}}{c_1; c_2 \quad \{Q\}}$$

$$\frac{\{P \wedge b\} \in \{Q\}}{\{P\} \text{ IF } b \text{ THEN } c_1 \text{ ELSE } c_2 \quad \{Q\}}$$

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Hoare Rules

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$$\frac{}{\{P\} \text{ SKIP } \{P\}} \quad \{P[x \mapsto e]\} \quad x := e \quad \{P\}$$

$$\frac{\begin{array}{c} \{R\} \\ \{R\} c_1 \{Q\} \\ \hline c_1; c_2 \end{array}}{c_1; c_2 \quad \{Q\}}$$

$$\frac{\{P \wedge b\} c_1 \{Q\} \quad \{P \wedge \neg b\} c_2 \{Q\}}{\{P\} \text{ IF } b \text{ THEN } c_1 \text{ ELSE } c_2 \quad \{Q\}}$$

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Hoare Rules

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$$\frac{}{\{P\} \text{ SKIP } \{P\}} \quad \{P[x \mapsto e]\} \quad x := e \quad \{P\}$$

$$\frac{\begin{array}{c} \{P\} \quad \{R\} \\ \text{WeChat: estutorcs} \\ \{R\} \quad \{R\} c_2 \{Q\} \end{array}}{c_1; c_2 \quad \{Q\}}$$

$$\frac{\{P \wedge b\} c_1 \{Q\} \quad \{P \wedge \neg b\} c_2 \{Q\}}{\{P\} \text{ IF } b \text{ THEN } c_1 \text{ ELSE } c_2 \quad \{Q\}}$$

$$\frac{\begin{array}{c} \text{Assignment Project Exam Help} \\ \{P \wedge b\} c \{P\} \quad P \wedge \neg b \implies Q \\ \{P\} \text{ WHILE } b \text{ DO } c \{Q\} \end{array}}{\{P\} \text{ WHILE } b \text{ DO } c \{Q\}}$$

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Hoare Rules

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$$\frac{}{\{P\} \text{ SKIP } \{P\}} \quad \{P[x \mapsto e]\} \quad x := e \quad \{P\}$$

$$\frac{\begin{array}{c} \{P\} \quad \{R\} \\ \text{QR} \end{array} \quad \{R\} \quad c_2 \quad \{Q\}}{c_1; c_2 \quad \{Q\}}$$

$$\frac{\begin{array}{c} \{P \wedge b\} \in \{Q\} \quad \{P \wedge \neg b\} \quad c_2 \quad \{Q\} \\ \text{WeChat: estutorcs} \end{array}}{\{P\} \quad \text{IF } b \text{ THEN } c_1 \text{ ELSE } c_2 \quad \{Q\}}$$

$$\frac{\begin{array}{c} \text{Assignment Project Exam Help} \\ \{P \wedge b\} \quad c \quad \{P\} \quad P \wedge \neg b \implies Q \\ \text{Email: tutors@163.com} \end{array}}{\{P\} \quad \text{WHILE } b \text{ DO } c \quad \{Q\}}$$

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$\frac{\{P'\} \in \{Q'\}}{\{P\} \quad c \quad \{Q\}}$

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Hoare Rules

程序代写代做 CS编程辅导

$$\frac{}{\{P\} \text{ SKIP } \{P\}} \quad \{P[x \mapsto e]\} \quad x := e \quad \{P\}$$

$$\frac{\begin{array}{c} \{P\} \\ \text{QR} \\ \{R\} \end{array} \quad \{R\} \ c_2 \ \{Q\}}{c_1; c_2 \quad \{Q\}}$$

$$\frac{\begin{array}{c} \{P \wedge b\} \ c \ \{Q\} \\ \text{WeChat: estutorcs} \end{array} \quad \{P \wedge \neg b\} \ c_2 \ \{Q\}}{\{P\} \text{ IF } b \text{ THEN } c_1 \text{ ELSE } c_2 \quad \{Q\}}$$

$$\frac{\begin{array}{c} \{P \wedge b\} \ c \ \{P\} \\ \text{Assignment Project Exam Help} \\ P \wedge \neg b \implies Q \end{array}}{\{P\} \text{ WHILE } b \text{ DO } c \text{ OD } \{Q\}}$$

$$\frac{P \Rightarrow Q \text{ QR: 749389476} \quad \{P'\} \ c \ \{Q'\} \quad Q' \implies Q}{\{P\} \ c \ \{Q\}}$$

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Hoare Rules

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$$\vdash \{P\} \text{ SKIP } \{P\} \quad \vdash \{P\} c \{Q\} \quad \vdash \{\lambda\sigma. P (\sigma(x := e \sigma))\} \quad x := e \quad \{P\}$$

$$\vdash \{P\} \quad \vdash \{R\} \quad \vdash \{R\} c_2 \{Q\}$$

$$c_1; c_2 \quad \{Q\}$$

$$\vdash \{\lambda\sigma. P \sigma \wedge b \sigma\} c_1 \{Q\} \quad \vdash \{\lambda\sigma. P \sigma \wedge \neg b \sigma\} c_2 \{Q\}$$

$$\vdash \{P\} \quad \text{IF } b \text{ THEN } c_1 \text{ ELSE } c_2 \quad \{Q\}$$

$$\vdash \{\lambda\sigma. P \sigma \wedge b \sigma\} c \{P\} \quad \wedge \sigma. P \sigma \wedge \neg b \sigma \Rightarrow Q \sigma$$

$$\vdash \{P\} \text{ WHILE } b \text{ DO } c \{Q\}$$

$$\wedge \sigma. P \sigma \Rightarrow P' \sigma \quad \vdash \{P'\} c \{Q'\} \quad \wedge \sigma. Q' \sigma \Rightarrow Q \sigma$$

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

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Are the Rules Correct?

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Soundness: $\vdash \{P\} \leftarrow \square \rightarrow \square \{Q\}$



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Are the Rules Correct?

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Soundness: $\vdash \{P\} c \rightarrow \{Q\}$



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

Proof: by rule induction



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

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Are the Rules Correct?

程序代写代做 CS编程辅导

Soundness: $\vdash \{P\} c \rightarrow \{Q\}$



Proof: by rule induction $\vdash \{P\} c \{Q\}$



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Demo: Hoare Logic in Isabelle

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