



程序代写代做 CS 编程辅导



MP4161



UNSW
SYDNEY

Advanced Topics in Software Verification

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HOL

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13/2022

Last time...

程序代写代做 CS编程辅导

- natural deduction rules /, \rightarrow , \neg , iff...
- proof by assumption rule, elim rule
- safe and unsafe rules
- indent your proofs! (one space per subgoal)
- prefer implicit backtracking (chaining) or `rule_tac`, instead of `backtrack`
- *prefer* and *defer*
- *oops* and *sorry*



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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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Quantifiers
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Scope

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- Scope of parameters: $\lambda x. \dots$ or subgoal
- Scope of \forall, \exists, \dots : $\forall x. \dots$; or \Rightarrow



Example:

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Scope

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- Scope of parameter: $\lambda x. P \rightarrow Q$; or $\lambda x. Q$
- Scope of \forall, \exists, \dots : $\forall x. P \rightarrow Q$; or $\exists x. P \rightarrow Q$



Example:

$\lambda x. y. [\forall y. P y \rightarrow Q z y; Q x y] \Rightarrow \exists x. Q x y$

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means

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Scope

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- Scope of parameter: $\lambda x. P \rightarrow Q$; or $\lambda x. Q$ subgoal
- Scope of \forall, \exists, \dots : $\forall x. P \rightarrow Q$; or $\exists x. P \rightarrow Q$



Example:

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$$\lambda x. y. [\forall y. P y \rightarrow Q z y; Q x y] \Rightarrow \exists x. Q x y$$

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means

$$\lambda x. y. [(\forall y_1. P y_1 \rightarrow Q z y_1); Q x y] \Rightarrow (\exists x_1. Q x_1 y)$$

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Natural deduction for quantifiers

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$$\frac{}{\forall x. P x} \quad \frac{P x}{\exists x. P x} exI \quad \frac{R}{\forall x. P x} allE$$


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$$\frac{\exists x. P x}{\exists x. P x} exE$$

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Natural deduction for quantifiers

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$$\frac{}{\forall x. P x}$$



$$\frac{P x}{R}$$

allE

$$\frac{}{\exists x. P x}$$

$$\frac{}{\exists x. P x}$$

exE

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Natural deduction for quantifiers

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$$\frac{}{\forall x. P x}$$



$$\frac{P x \quad P ?x \implies R}{R} \text{ allE}$$

$$\frac{}{\exists x. P x} \text{ exI}$$

$$\frac{}{\exists x. P x} \text{ exE}$$

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Natural deduction for quantifiers

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$$\frac{}{\forall x. P x}$$



$$\frac{P x \quad P ?x \implies R}{R} \text{ allE}$$

$$\frac{P ?x}{\exists x. P x} \text{ exI}$$

$$\frac{\exists x. P x}{P ?x} \text{ exE}$$

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Natural deduction for quantifiers

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$$\frac{}{\forall x. P x}$$



$$\frac{P x \quad P ?x \implies R}{R} \text{ allE}$$

$$\frac{P ?x}{\exists x. P x} \text{ exI}$$

$$\frac{\exists x. P x \quad \forall x. P x \implies R}{R} \text{ exE}$$

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Natural deduction for quantifiers

程序代写代做 CS编程辅导

$$\frac{\Lambda x. P x}{\forall x. P x}$$



$$\frac{P x \quad P ?x \Rightarrow R}{R} \text{ allE}$$

$$\frac{P ?x}{\exists x. P x} \text{ exI}$$

$$\frac{\exists x. P x \quad \Lambda x. P x \Rightarrow R}{R} \text{ exE}$$

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- **allI** and **exE** introduce new parameters (Λx).
- **allE** and **exI** introduce new unknowns ($?x$).

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Instantiating Rules

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Like **rule**, but $?x$ in $rule$ is instantiated by $term$ before application.

Similar: **erule_tac**

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! x is in rule, not in goal !

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Two Successful Proofs

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 . $\exists y. \ x = y$



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Two Successful Proofs

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 . $\exists y. x = y$

 y (rule all)

 . $\exists y. x = y$

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Two Successful Proofs

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. $\exists y. x = y$



y (rule all)



. $\exists y. x = y$

best practice

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apply (rule_tac x = "x" in exl)

1. $\wedge x. x = x$ Assignment Project Exam Help

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Two Successful Proofs

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. $\exists y. x = y$



y (rule all)



. $\exists y. x = y$

best practice

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apply (rule_tac x = "x" in exl)

1. $\wedge x. x = x$ Assignment Project Exam Help

apply (rule refl)
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Two Successful Proofs

程序代写代做 CS编程辅导

 . $\exists y. x = y$

 y (rule all)

 . $\exists y. x = y$

best practice

WeChat: cstutorcs apply (rule_tac $x = "x"$ in exl) exploration

1. $\wedge x. x = x$ Assignment Project Exam Help apply (rule exl)

apply (rule refl) Email: tutorcs@163.com

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Two Successful Proofs

程序代写代做 CS编程辅导

 . $\exists y. x = y$

 $\exists y. x = y$ (rule all)

 . $\exists y. x = y$

best practice

WeChat: cstutorcs apply (rule_tac $x = "x"$ in exl) apply (rule exl)

1. $\wedge x. x = x$ Assignment Project Exam Help

apply (rule refl) Email: tutorcs@163.com apply (rule refl)

? $y \mapsto \lambda u.u$

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Two Successful Proofs

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 . $\exists y. x = y$

 $\exists y. x = y$ (rule all)

 . $\exists y. x = y$

best practice

apply (rule_tac $x = "x"$ in exl)

1. $\wedge x. x = x$

apply (rule refl)

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simpler & clearer

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exploration

apply (rule exl)

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apply (rule refl)

? $y \mapsto \lambda u.u$

shorter & trickier

Two Unsuccessful Proofs

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1. $\exists y. \forall x. x = y$



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Two Unsuccessful Proofs

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1. $\exists y. \forall x. x = y$

apply (rule_tac x = ?



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Two Unsuccessful Proofs

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1. $\exists y. \forall x. x = y$



apply (rule_tac x = ?

apply (rule exl)

1. $\forall x. x = ?y$

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Two Unsuccessful Proofs

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1. $\exists y. \forall x. x = y$



apply (rule_tac x = ?

apply (rule exl)

1. $\forall x. x = ?y$

apply (rule all)

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Two Unsuccessful Proofs

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1. $\exists y. \forall x. x = y$



apply (rule_tac x = ?y)

apply (rule exl)

1. $\forall x. x = ?y$

apply (rule alll)

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apply (rule refl)

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 $?y \rightarrow x$ yields $\forall x. x' = x$

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Two Unsuccessful Proofs

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1. $\exists y. \forall x. x = y$



apply (rule_tac x = ?y)

apply (rule exl)

1. $\forall x. x = ?y$

apply (rule alll)

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apply (rule refl)

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 $?y \rightarrow x$ yields $\forall x. x' = x$

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Principle:

?f x₁ ... x_n can only be replaced by term t

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if params(t) ⊆ x₁, ..., x_n

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Safe and Unsafe Rules

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Safe and Unsafe Rules

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Safe allI, exE



Unsafe allE, exI

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Safe and Unsafe Rules

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Safe all!, exE



Unsafe all!, exI

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Create parameters first, unknowns later

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Demo: Quantifier Proofs

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Parameter names

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Paramet



are chosen by Isabelle

$$1. \forall x. \exists y. x = y$$

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Parameter names

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Paramet



are chosen by Isabelle

$$1. \forall x. \exists y. x = y$$

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apply (rule all)

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Parameter names

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Paramet



are chosen by Isabelle

$$1. \forall x. \exists y. x = y$$

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apply (rule all)

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apply (rule_tac x = " " in exI)
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Renaming parameters

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1.  = y

a  |||)

1.  x = y

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Renaming parameters

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1.  = y

apply (rename tac N)

1.  x = y

apply (rename tac N)

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1. $\bigwedge N. \exists y. N = y$

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Renaming parameters

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1.  = y

apply (rule_tac x = y in exl)

1.  = y

apply (rename_tac N)

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1. $\bigwedge N. \exists y. N = y$

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apply (rule_tac x = "N" in exl)

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In general:

(`rename_tac` $x_1 \dots x_n$) renames the rightmost (inner) n parameters
to $x_1 \dots x_n$

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Forward Proof: frule and drule

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 rule <rule>

Rule:  $[A_1; \dots; A_m] \implies A$

Subgoal:  $[B_1; \dots; B_n] \implies C$

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Forward Proof: frule and drule

程序代写代做 CS编程辅导

 rule <rule>

Rule:  $[A_1; \dots; A_m] \implies A$

Subgoal:  $[B_1; \dots; B_n] \implies C$

Substitution: $\sigma(B_i) \equiv \sigma(A_1)$
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Forward Proof: frule and drule

程序代写代做 CS编程辅导

Rule:  rule <rule>

Rule:  $[A_1; \dots; A_m] \implies A$

Subgoal:  $[B_1; \dots; B_n] \implies C$

Substitution: $\sigma(B_i) \equiv \sigma(A_1)$

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New subgoals: 1. $\sigma([B_1; \dots; B_n] \implies A_2)$

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m-1. $\sigma([B_1; \dots; B_n] \implies A_m)$

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$([B_1; \dots; B_n; A] \implies C)$

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Forward Proof: frule and drule

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apply (frule <rule>)

Rule:  $[B_1; \dots; A_m] \implies A$

Subgoal:  $[B_1; \dots; B_n] \implies C$

Substitution: $\sigma(B_i) \equiv \sigma(A_i)$

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New subgoals: 1. $\sigma([B_1; \dots; B_n] \implies A_2)$

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Like **frule** but also deletes B_i : apply (drule <rule>)

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Examples for Forward Rules

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$$\frac{P \wedge G}{P}$$

$$\frac{P \wedge Q}{Q} \text{ conjunct2}$$

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 $\frac{P}{Q} \text{ map}$

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Email: $\frac{\forall x. P(x)}{P ?_x \text{ spec}}$

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Forward Proof: OF

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Prove assumption 1 with theorem r with theorem r₁, and assumption 2 with theorem r₂, ...

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Forward Proof: OF

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Prove assumption 1 with theorem r with theorem r₁, and assumption 2 with theorem r₂ ...

Rule r WeChat: cstutors

Rule r₁ [B₁; ...; B_i] \Rightarrow B
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Forward Proof: OF

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 F $r_1 \dots r_n]$

Prove assumption 1 with theorem r with theorem r_1 , and assumption 2 with theorem r_2 ...

Rule r WeChat: cstutors $[A_1; \dots; A_m] \rightarrow A$

Rule r_1 Assignment Project Exam Help

Substitution $\sigma(B) \equiv \sigma(A_1)$
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Forward Proof: OF

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Prove assumption 1 with theorem r with theorem r₁, and assumption 2 with theorem r₂, ...

Rule r WeChat: cstutors

Rule r₁ Assignment Project Exam Help

Substitution $\sigma(B) \equiv \sigma(A_1)$

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Forward Proof: OF

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Prove assumption 1 with theorem r with theorem r₁, and assumption 2 with theorem r₂, ...

Rule r WeChat: cstutors

$\llbracket A_1; \dots; A_m \rrbracket \rightarrow A$

Rule r₁ Assignment Project Exam Help

$\llbracket B_1; \dots; B_n \rrbracket \implies B$

Substitution $\sigma(B) \equiv \sigma(A_1)$

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r [OF r₁] $\sigma(\llbracket B_1; \dots; B_n; A_2; \dots; A_m \rrbracket \implies A)$

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Example:

dvd_add : $\llbracket ?a \text{ dvd } ?b; ?a \text{ dvd } ?c \rrbracket \implies ?a \text{ dvd } ?b + ?c$

dvd_refl : ?a dvd ?a

dvd_add[OF dvd_refl] : $\llbracket ?a \text{ dvd } ?c \rrbracket \implies ?a \text{ dvd } ?a + ?c$

Forward proofs: THEN

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r_1 [] means r_2 [OF r_1]

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Demo: Forward Proofs

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Hilbert's Epsilon Operator

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(David Hilbert, 1862-1943)

$\varepsilon x. Px$ is a value that satisfies P (if such a value exists)

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Hilbert's Epsilon Operator

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(David Hilbert, 1862-1943)

$\varepsilon x. P x$ is a value that satisfies P (if such a value exists)

ε also known as **description operator**.

In Isabelle the ε -operator is written **SOME** $x. P x$

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Hilbert's Epsilon Operator

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(David Hilbert, 1862–1943)

$\varepsilon x. P x$ is a value that satisfies P (if such a value exists)

ε also known as **description operator**.

In Isabelle the ε -operator is written `SOME x. P x`

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$$\frac{P ?x}{P (\text{SOME } x. P x)}$$
 somel

More Epsilon

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Axiom of Choice:

$$\forall x. \exists f. \forall x. Q x (f x)$$

Existential and universal quantification can be defined with ε .

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More Epsilon

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$\forall x. \exists f. \forall x. Q x (f x)$

Existential and universal quantification can be defined with ε .

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Isabelle also knows the definite description operator **THE** (aka ι):

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(THE x. x = a) = a the_eq_trivial

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Some Automation

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More Proof Methods:

apply (*intro* <*intro-rule*>)



repeatedly applies intro rules

apply (*elim* <*elim-rule*>)

repeatedly applies elim rules

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Some Automation

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More Proof Methods:

apply (*intro* <*intro-rule*>)



repeatedly applies intro rules

apply (*elim* <*elim-rule*>)



repeatedly applies elim rules

apply *clarify*

applies all safe rules

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that do not split the goal

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Some Automation

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More Proof Methods:

apply (intro <intro-rule>)



repeatedly applies intro rules

apply (elim <elim-rule>)



repeatedly applies elim rules

apply clarify



applies all safe rules

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apply safe

applies all safe rules
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Some Automation

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More Proof Methods:

apply (intro <intro-rule>)



repeatedly applies intro rules

apply (elim <elim-rule>)



repeatedly applies elim rules

apply clarify

applies all safe rules

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apply safe

applies all safe rules

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apply blast

an automatic tableau prover

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(works well on predicate logic)

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Some Automation

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More Proof Methods:

apply (intro <intro-rule>)



repeatedly applies intro rules

apply (elim <elim-rule>)



repeatedly applies elim rules

apply clarify

applies all safe rules

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apply safe

applies all safe rules

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apply blast

an automatic tableau prover

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(works well on predicate logic)

apply fast

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another automatic search tactic

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Epsilon and Automation Demo

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We have learned so far...

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→ Proof rules for pred



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We have learned so far...

程序代写代做 CS编程辅导

- Proof rules for predicates
- Safe and unsafe rules



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We have learned so far...

程序代写代做 CS编程辅导

- Proof rules for predicates
- Safe and unsafe rules
- Forward Proof



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We have learned so far...

程序代写代做 CS编程辅导

- Proof rules for predicates
- Safe and unsafe rules
- Forward Proof
- The Epsilon Operator



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We have learned so far...

程序代写代做 CS编程辅导

- Proof rules for predicates
- Safe and unsafe rules
- Forward Proof
- The Epsilon Operator
- Some automation



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Isar (Part 1)

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A Language for Structured Proofs

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Motivation

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Is thi



$\rightarrow B) = (B \vee \neg A)$?

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Motivation

程序代写代做 CS编程辅导

Is the  $\rightarrow B) = (B \vee \neg A)$?

YES!

```
(rule iffI)
apply (cases A)
apply (rule disjI1)
apply (erule impE)
apply assumption
apply assumption
apply (rule disjE)
apply assumption
apply assumption
apply (rule impI)
apply (rule disjE)
apply assumption
apply assumption
apply (rule notE)
apply assumption
done
```

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Motivation

程序代写代做 CS编程辅导

Is this $\square \rightarrow B) = (B \vee \neg A)$?



YES!

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(rule iffI)
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apply (rule impE)
apply assumption
apply assumption
```

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apply (rule notE)
apply assumption
done

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Motivation

程序代写代做 CS编程辅导

Is this  $\rightarrow B) = (B \vee \neg A)$?

YES!

```
(rule iffI)
apply (cases A)
apply (rule disjI1)
apply (rule impE)
apply assumption
```

```
apply assumption
apply (rule disjE)
apply assumption
```

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<https://tutorcs.com> OK it's true. But WHY?

Motivation

程序代写代做 CS编程辅导

WHY is  $(A \rightarrow B) = (B \vee \neg A)$?

Demo

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程序代写代做 CS编程辅导

apply



→ unreadab



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程序代写代做 CS编程辅导

apply



- unreadable
- hard to maintain

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程序代写代做 CS编程辅导

apply



- unreadable
- hard to maintain
- do not scale

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- unreadable
- hard to maintain
- do not scale

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What about..

- unreadable
- hard to maintain
- do not scale

Elegance?

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What about..

- unreadable
- hard to maintain
- do not scale

Elegance?

Explaining deeper insights?

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What about..

- unreadable → Elegance?
- hard to maintain → Explaining deeper insights?
- do not scale → Large developments?

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What about..

- unreadable → Elegance?
- hard to maintain → Explaining deeper insights?
- do not scale → Large developments?

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A typical Isar proof

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$formula_0$
 $formula_1 \quad \text{by simp}$

have $formula_n \quad \text{by blast}$
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show $formula_{n+1} \quad \text{by } \dots$

qed
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A typical Isar proof

程序代写代做 CS编程辅导



$formula_0$
 $formula_1 \quad \text{by simp}$

have $formula_n$ by blast
show $formula_{n+1}$ by ...

qed

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proves $formula_0 = a formula_{n+1}$

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A typical Isar proof

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$formula_0$
 $formula_1 \quad \text{by simp}$

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have $formula_n$ by blast
show $formula_{n+1}$ by ...

qed
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proves $formula_0 = a formula_{n+1}$

(analogous to assumes/shows in lemma statements)
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Isar core syntax

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proof = **proof** [method] statement* **qed**
| **by** method



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Isar core syntax

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proof = **proof** [method] statement* **qed**
| **by** method



method = (simp ...) | (rule ...) | ...

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Isar core syntax

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proof = **proof** [method] statement* **qed**
| **by** method



method = (simp ...) | (rule ...) | ...

statement = **fix** variables
| **assume** proposition
| **[from** name⁺] (**have** | **show**) proposition proof
| **next** Assignment Project Exam Help

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Isar core syntax

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proof = **proof** [method] statement* **qed**
| **by** method

method = (simp ...) | (rule ...) | ...

statement = **fix** variables | **assume** proposition
| **[from** name⁺] (**have** | **show**) proposition proof
| **next** Assignment Project Exam Help

proposition = [name:] formula
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proof and qed

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proof [method] statement* qed

lemma " $[A; B] \implies A$



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proof and qed

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proof [method] statement* **qed**

lemma "〔A; B〕 \implies A
proof (rule conjl)



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proof and qed

程序代写代做 CS编程辅导

proof [**method**] **statement*** **qed**

lemma "〔*A; B*〕 $\implies A$

proof (**rule conjl**)

assume *A*: "*A*"

from *A* **show** "*A*" **by** **assumption**



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proof and qed

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proof [method] statement* qed

lemma "〔A; B〕 \implies A

proof (rule conjI)

assume A: "A"

from A **show** "A" **by** assumption

next



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proof and qed

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proof [**method**] **statement*** **qed**



lemma " $[A; B] \implies A$ "

proof (**rule conjI**)

assume $A: "A"$

from A **show** " A " **by** **assumption**

next

assume $B: "B"$

from B **show** " B " **by** **assumption** Assignment Project Exam Help

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proof and qed

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proof [**method**] **statement*** **qed**



lemma " $[A; B] \implies A$ "

proof (**rule conjl**)

assume $A: "A"$

from A **show** " A " **by** assumption

next

assume $B: "B"$

from B **show** " B " **by** assumption

qed

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proof and qed

程序代写代做 CS编程辅导

proof [**method**] **statement*** **qed**



lemma " $[A; B] \implies A$ "

proof (**rule conjl**)

assume $A: "A"$

from A **show** " A " **by** assumption

next

assume $B: "B"$

from B **show** " B " **by** assumption

qed

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→ **proof** (<**method**>) applies method to the stated goal

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proof and qed

程序代写代做 CS编程辅导

proof [**method**] **statement*** **qed**



lemma " $[A; B] \implies A$ "

proof (**rule conjl**)

assume $A: "A"$

from A **show** " A " **by** assumption

next

assume $B: "B"$

from B **show** " B " **by** assumption

qed

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→ **proof** (<**method**>) applies method to the stated goal

→ **proof** applies a single rule that fits

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proof and qed

程序代写代做 CS编程辅导

proof [**method**] **statement*** **qed**



lemma " $[A; B] \implies A$ "

proof (**rule conjl**)

assume $A: "A"$

from A **show** " A " **by** assumption

next

assume $B: "B"$

from B **show** " B " **by** assumption

qed

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→ **proof** (<**method**>) applies method to the stated goal

→ **proof** applies a single rule that fits

→ **proof** - does nothing to the goal

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How do I know what to Assume and Show?

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lemma " $\llbracket A; B \rrbracket \implies A$ "
proof (rule conjl)



the proof state!

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How do I know what to Assume and Show?

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the proof state!

lemma " $\llbracket A; B \rrbracket \implies A$ "

proof (rule conjl)

→ **proof** (rule conjl) changes proof state to

1. $\llbracket A; B \rrbracket \implies A$
2. $\llbracket A; B \rrbracket \implies B$

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How do I know what to Assume and Show?

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the proof state!

lemma " $\llbracket A; B \rrbracket \implies A$ "

proof (rule conjl)

→ **proof** (rule conjl) changes proof state to

1. $\llbracket A; B \rrbracket \implies A$ WeChat: cstutorcs

2. $\llbracket A; B \rrbracket \implies B$

→ so we need 2 shows: show "A" and show "B"

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How do I know what to Assume and Show?

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the proof state!

lemma " $[A; B] \implies A$ "

proof (rule conjl)

→ **proof** (rule conjl) changes proof state to

1. $[A; B] \implies A$ WeChat: cstutorcs
2. $[A; B] \implies B$

→ so we need 2 shows: show "A" and show "B"

→ We are allowed to **assume** A ,
because A is in the assumptions of the proof state.

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The Three Modes of Isar

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→ [prove]:

goal has been state  goals to follow.



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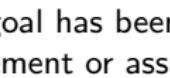
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程序代写代做 CS编程辅导

→ [prove]:

goal has been stated.  steps to follow.

→ [state]:

proof block has opened.  goal has been proved,
new from statements  comment or assumptions can follow.

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The Three Modes of Isar

程序代写代做 CS编程辅导

→ [prove]:

goal has been stated.  goals to follow.

→ [state]:

proof block has opened.  goal has been proved,
new *from* statement or assumptions can follow.

→ [chain]:

from statement has been made, goal statement needs to follow.

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The Three Modes of Isar

程序代写代做 CS编程辅导

→ [prove]:

goal has been stated.  goals to follow.

→ [state]:

proof block has opened.  goal has been proved,
new from statements or assumptions can follow.

→ [chain]:

from statement has been made, goal statement needs to follow.

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lemma "【A; B】 \implies A  B"

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The Three Modes of Isar

程序代写代做 CS编程辅导

→ [prove]:

goal has been stated.  goals to follow.

→ [state]:

proof block has opened.  goal has been proved,
new from statements or assumptions can follow.

→ [chain]:

from statement has been made, goal statement needs to follow.

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lemma "【A; B】 \implies A" Assignment Project Exam Help

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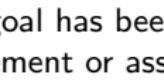
The Three Modes of Isar

程序代写代做 CS编程辅导

→ [prove]:

goal has been state ds to follow.

→ [state]:

proof block has opened  goal has been proved,
new from statement  statement or assumptions can follow.

→ [chain]:

from statement has been made, goal statement needs to follow.

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lemma "〔A; B〕 \implies A" Assignment Project Exam Help

proof (rule conjl) [state]

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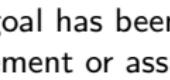
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程序代写代做 CS编程辅导

→ [prove]:

goal has been state eds to follow.

→ [state]:

proof block has opened  goal has been proved,
new *from* statement  statement or assumptions can follow.

→ [chain]:

from statement has been made, goal statement needs to follow.

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lemma "〔*A; B*〕 \implies *A*  *B*"  Project Exam Help

proof (rule conjl)  [state]

assume *A*: "*A*"  Email: tutorcs@163.com

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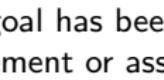
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→ [prove]:

goal has been state eds to follow.

→ [state]:

proof block has opened  goal has been proved,
new *from* statement  statement or assumptions can follow.

→ [chain]:

from statement has been made, goal statement needs to follow.

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lemma "〔*A; B*〕 \implies *A*  *B*"  Project Exam Help

proof (rule conjl) [state]

assume *A*: "*A*"  Email: tutorcs@163.com

from *A* [chain]

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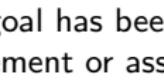
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程序代写代做 CS编程辅导

→ [prove]:

goal has been state  ds to follow.

→ [state]:

proof block has opened  goal has been proved,
new from statement  statement or assumptions can follow.

→ [chain]:

from statement has been made, goal statement needs to follow.

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lemma "【A; B】 \implies A"  Assignment Project Exam Help

proof (rule conjl) [state]

assume A: "A"  Email: tutorcs@163.com

from A [chain] show "A"  [prove] by assumption [state]

next [state] ...

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Have

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Can be made intermediate steps.

Example:



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Have

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Can be made intermediate steps.

Example:



lemma " $(x + y) + z = x + (y + z)$ "

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Have

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Can be made intermediate steps.

Example:



lemma " $(x + 1) + 1 = 1 + x$ "

proof -

have A: " $x + 1 = \text{Suc } x$ " **by** simp

have B: " $1 + x = \text{Suc } x$ " **by** simp

show " $x + 1 = 1 + x$ " **by** (simp only: A B)

qed

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Demo

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Backward and Forward

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Backward reasoning: ... have " $A \wedge B$ " proof



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Backward and Forward

程序代写代做 CS编程辅导

Backward reasoning: ... have " $A \wedge B$ " proof

→ proof picks an intr



mathematically

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Backward and Forward

程序代写代做 CS编程辅导

Backward reasoning: ... have " $A \wedge B$ " proof

- proof picks an intr
- conclusion of rule n



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Backward and Forward

程序代写代做 CS编程辅导

Backward reasoning: ... have " $A \wedge B$ " proof

- proof picks an intr... logically
- conclusion of rule n... with $A \wedge B$



Forward reasoning: .

assume AB: " $A \wedge B$ "
from AB have "..." proof

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Backward and Forward

程序代写代做 CS编程辅导

Backward reasoning: ... have " $A \wedge B$ " proof

- proof picks an intro rule automatically
- conclusion of rule must be consistent with $A \wedge B$



Forward reasoning: .

assume AB: " $A \wedge B$ "

from AB have " " proof

- now proof picks an elim rule automatically

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Backward and Forward

程序代写代做 CS编程辅导

Backward reasoning: ... have " $A \wedge B$ " proof

- proof picks an intro rule automatically
- conclusion of rule must be consistent with $A \wedge B$



Forward reasoning: .

assume AB: " $A \wedge B$ "

from AB have " " proof

- now proof picks an elim rule automatically
- triggered by from Assignment Project Exam Help

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Backward and Forward

程序代写代做 CS编程辅导

Backward reasoning: ... have " $A \wedge B$ " proof

- proof picks an intro rule automatically
- conclusion of rule must unify with $A \wedge B$

Forward reasoning: .



assume AB: " $A \wedge B$ "

from AB have " " proof

- now proof picks an elim rule automatically
- triggered by from Assignment Project Exam Help
- first assumption of rule must unify with AB

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Backward and Forward

程序代写代做 CS编程辅导

Backward reasoning: ... have " $A \wedge B$ " proof

- proof picks an intro rule automatically
- conclusion of rule must unify with $A \wedge B$



Forward reasoning: .

assume AB: " $A \wedge B$ "

from AB have " " proof

- now proof picks an elim rule automatically
- triggered by from Assignment Project Exam Help
- first assumption of rule must unify with AB

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General case: from $A_1 \dots A_n$ have R proof

- first n assumptions of rule must unify with $A_1 \dots A_n$
- conclusion of rule must unify with R

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Fix and Obtain

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$v_1 \dots v_n$

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Fix and Obtain

程序代写代做 CS编程辅导



$v_1 \dots v_n$

Introdu

arbitrary but fixed variables
(\sim parameters, \wedge)

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Fix and Obtain

程序代写代做 CS编程辅导



$v_1 \dots v_n$

Introduces arbitrary but fixed variables
(\sim parameters, \wedge)

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Fix and Obtain

程序代写代做 CS编程辅导



$v_1 \dots v_n$

Introduces arbitrary but fixed variables
(\sim parameters, \wedge)

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Introduces new variables together with property
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Fancy Abbreviations

程序代写代做 CS编程辅导

this



previous fact proved or assumed

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Fancy Abbreviations

程序代写代做 CS编程辅导

this



previous fact proved or assumed

then



on this

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Fancy Abbreviations

程序代写代做 CS编程辅导

this



previous fact proved or assumed

then



on this

thus



then show

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Fancy Abbreviations

程序代写代做 CS编程辅导

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previous fact proved or assumed

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on this

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then show

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then have

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Fancy Abbreviations

程序代写代做 CS编程辅导

this



previous fact proved or assumed

then



on this

thus



then show

hence



then have

with $A_1 \dots A_n$



from $A_1 \dots A_n$ this

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Fancy Abbreviations

程序代写代做 CS编程辅导

this



previous fact proved or assumed

then



on this

thus



then show

hence



then have

with $A_1 \dots A_n$



from $A_1 \dots A_n$ this

?thesis



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the last enclosing goal statement

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程序代写代做 CS编程辅导



Demo

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Moreover and Ultimately

程序代写代做 CS编程辅导

have $X_1: P_1$
have $X_2: P_2$
⋮
have $X_n: P_n$



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from $X_1 \dots X_n$ **show** ...

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Moreover and Ultimately

程序代写代做 CS编程辅导

have $X_1: P_1$
have $X_2: P_2$
⋮
have $X_n: P_n$



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from $X_1 \dots X_n$ **show** ...

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wastes lots of brain power
on names $X_1 \dots X_n$
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Moreover and Ultimately

程序代写代做 CS编程辅导

have $X_1: P_1$
have $X_2: P_2$
⋮
have $X_n: P_n$



have $P_1 \dots$
moreover have $P_2 \dots$
⋮
moreover have $P_n \dots$

from $X_1 \dots X_n$ **show** ...

ultimately show ...

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wastes lots of brain power
on names $X_1 \dots X_n$

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General Case Distinctions

程序代写代做 CS编程辅导

show formula

proof -



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General Case Distinctions

程序代写代做 CS编程辅导

show *formula*

proof -

have $P_1 \vee P_2$  **proof**>

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General Case Distinctions

程序代写代做 CS编程辅导

show *formula*



proof -

have $P_1 \vee P_2$

proof >

moreover

$P_1 \dots$ **have** ?thesis <proof> }

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General Case Distinctions

程序代写代做 CS编程辅导

show formula



<proof>

proof -

have $P_1 \vee P_2$



<proof>

moreover

{ have ?thesis <proof> }

moreover

{ assume $P_2 \dots$ have ?thesis <proof> }

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General Case Distinctions

程序代写代做 CS编程辅导

show formula



<proof>

proof -

have $P_1 \vee P_2$



<proof>

moreover

{ have $P_1 \dots$ have ?thesis <proof> }

moreover

{ assume $P_2 \dots$ have ?thesis <proof> }

moreover

{ assume $P_3 \dots$ have ?thesis <proof> }

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General Case Distinctions

程序代写代做 CS编程辅导

show formula



<proof>

proof -

have $P_1 \vee P_2$

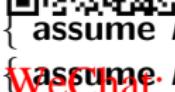


<proof>

moreover

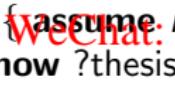
{ have $P_1 \dots$ have ?thesis <proof> }

moreover



{ assume $P_2 \dots$ have ?thesis <proof> }

moreover



{ assume $P_3 \dots$ have ?thesis <proof> }

ultimately show ?thesis **by** blast

qed

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General Case Distinctions

程序代写代做 CS编程辅导

show formula



<proof>

proof -

have $P_1 \vee P_2$

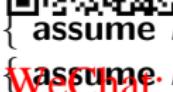


<proof>

moreover

{ have $P_1 \dots$ have ?thesis <proof> }

moreover



{ assume $P_2 \dots$ have ?thesis <proof> }

moreover



{ assume $P_3 \dots$ have ?thesis <proof> }

ultimately show ?thesis by blast

qed

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{ ... } is a proof block similar to **proof** ... **qed**

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General Case Distinctions

程序代写代做 CS编程辅导

show formula



<proof>

proof -

have $P_1 \vee P_2$



<proof>

moreover

{ have $P_1 \dots$ have ?thesis <proof> }

moreover



{ assume $P_2 \dots$ have ?thesis <proof> }

moreover



{ assume $P_3 \dots$ have ?thesis <proof> }

ultimately show ?thesis **by** blast

qed

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{ ... } is a proof block similar to **proof** ... **qed**

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{ assume $P_1 \dots$ have P <proof> }

QQ stands for $P_1 \Rightarrow P$

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Mixing proof styles

程序代写代做 CS编程辅导

from ...



have ...

apply -



incoming facts assumptions

apply (

⋮

apply (...)

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done

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We have learned so far...

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→ Isar style proofs



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We have learned so far...

程序代写代做 CS编程辅导

- Isar style proofs
- proof, qed



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We have learned so far...

程序代写代做 CS编程辅导

- Isar style proofs
- proof, qed
- assumes, shows



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We have learned so far...

程序代写代做 CS编程辅导

- Isar style proofs
- proof, qed
- assumes, shows
- fix, obtain



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We have learned so far...

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- Isar style proofs
- proof, qed
- assumes, shows
- fix, obtain
- moreover, ultimately



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We have learned so far...

程序代写代做 CS编程辅导

- Isar style proofs
- proof, qed
- assumes, shows
- fix, obtain
- moreover, ultimately
- forward, backward



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We have learned so far...

程序代写代做 CS编程辅导

- Isar style proofs
- proof, qed
- assumes, shows
- fix, obtain
- moreover, ultimately
- forward, backward
- mixing proof styles



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