Warm-up

Even

An integer x is even if (and only if) there exists an integer z, such that $x = 2z$.

Let your domain of discourse be integers.

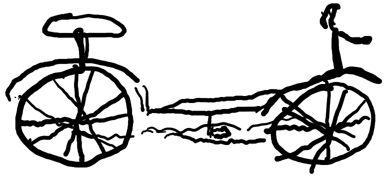
Let $\texttt{Even}(x) :=\ \exists y(x = 2y)$.

Prove "if x is even then x^2 is even."

Write a symbolic proof (with the extra rules "Definition of $\texttt{Even}$" and "Algebra").

Then we'll write it in English.

What's the claim in symbolic logic? $\forall x(\texttt{Even}(x) \rightarrow \texttt{Even}(x^2))$



Find The Bug

Let your domain of discourse be integers.
We claim that given $\forall x \exists y\ \texttt{Greater}(y, x)$, we can conclude $\exists y \forall x\ \texttt{Greater}(y, x)$
Where $\texttt{Greater}(y, x)$ means $y > x$

1.	$\forall x \exists y\ \texttt{Greater}(y, x)$	Given
2.	Let a be an arbitrary integer	--
3.	$\exists y\ \texttt{Greater}(y, a)$	Elim $\forall$ (1)
4.	$\texttt{Greater}(b, a)$	Elim $\exists$ (2)
5.	$\forall x\ \texttt{Greater}(b, x)$	Intro $\forall$ (4)
6.	$\exists y \forall x\ \texttt{Greater}(y, x)$	Intro $\exists$ (5)

$a+1$

$\mathrm{Prop}(a, a)$

$\exists x.\ \mathrm{Prop}(x, a)$

"b depends on a)"

$\mathrm{Greater}(a, a)$

$\forall x \quad \mathrm{Greater}(x, x)$

Bug Found

There's one other "hidden" requirement to introduce $\forall$.

"No other variable in the statement can depend on the variable to be generalized"

Think of it like this -- b was probably $a + 1$ in that example.

You wouldn't have generalized from `Greater`$(a + 1, a)$

To $\forall x$ `Greater`$(a + 1, x)$. There's still an a, you'd have replaced all the a's.

x depends on y if y is in a statement when x is introduced.

This issue is much clearer in English proofs, which we'll start next time.

English Proofs

CSE 311 Fall 2020
Lecture 9

Announcements

Please download a new copy of HW3.

We fixed two typos over the weekend.

Two optional readings going up today (maybe tomorrow…).

Another explanation of domain restriction.

An explanation of why mathematicians and computer scientists agreed that vacuous truth was the “right” definition.

We’ll link both on this week’s section in the calendar.

Today

We’re taking off the training wheels!

Our goal with writing symbolic proofs was to prepare us to write proofs in English.

Let’s get started.

The next 3 weeks:

- Practice communicating clear arguments to others.
- Learn new proof techniques.
- Learn fundamental objects (sets, number theory) that will let us talk more easily about computation at the end of the quarter.

Warm-up

Let your domain of discourse be integers.

Let $\texttt{Even}(x) :=\ \exists y(x = 2y)$.

Prove "if x is even then x^2 is even."

Write a symbolic proof (with the extra rules "Definition of $\texttt{Even}$" and "Algebra").

Then we'll write it in English.

What's the claim in symbolic logic? $\forall x(\texttt{Even}(x) \rightarrow \texttt{Even}(x^2))$

Even

An integer x is even if (and only if) there exists an integer z, such that $x = 2z$.

If x is even, then x^2 is even.

$\forall x\,(\mathrm{Even}(x) \to \mathrm{Even}(x^2))$

$\mathrm{Even}(x) := (\exists y\ 2y = x)$

1. Let a be arbitrary

2.1 $\mathtt{Even}(a)$	Assumption
2.2 $\exists y\,(2y = a)$	Definition of Even (2.1)
2.3 $2z = a$	Elim $\exists$(2.2)
2.4 $a^2 = 4z^2$	Algebra (2.3)
2.5 $a^2 = 2 \cdot 2z^2$	Alegbra (2.4)
2.6 $\exists w(2w = a^2)$	Intro $\exists$ (2.5)
2.7 $\mathtt{Even}(a^2)$	Definition of Even
3. $\mathtt{Even}(a) \to \mathtt{Even}(a^2)$	Direct Proof Rule (2.1-2.7)
4. $\forall x(\mathtt{Even}(x) \to \mathtt{Even}(x^2))$	Intro $\forall$ (3)

If x is even, then x^2 is even.

Dfn of even(x)

$\exists y\,(2y = x)$

Domain: integers

1.	Let a be arbitrary	
2.1	$\texttt{Even}(a)$	Assumption
2.2	$\exists y\,(2y = a)$	Definition of Even (2.1)
2.3	$2z = a$	Elim $\exists$(2.2)
2.4	$a^2 = 4z^2$	Algebra (2.3)
2.5	$a^2 = 2 \cdot 2z^2$	Alegbra (2.4)
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2.7	$\texttt{Even}(a^2)$	Definition of Even
3.	$\texttt{Even}(a) \rightarrow \texttt{Even}(a^2)$	Direct Proof Rule (2.1-2.7)
4.	$\forall x(\texttt{Even}(x) \rightarrow \texttt{Even}(x^2))$	Intro $\forall$ (3)

Let x be an arbitrary even integer.
By definition, there is an integer y such that $2y = x$.

Squaring both sides, we see that $x^2 = 4y^2 = 2 \cdot 2y^2$.

Because y is an integer, $2y^2$ is also an integer, and x^2 is two times an integer. Thus x^2 is even by the definition of even.
Since x was an arbitrary even integer, we can conclude that for every even x, x^2 is also even.

Converting to English

1. Let x be an arbitrary integer
2. Suppose Even(x)

Start by introducing your assumptions.

Introduce variables with "let." Introduce assumptions with "suppose."

Always state what type your variable is. English proofs don't have an established domain of discourse.

Don't just use "algebra" explain what's going on.

We don't explicitly intro/elim $\exists/\forall$ so we end up with fewer "dummy variables"

Let x be an arbitrary even integer.
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Let’s do another!

First a definition

Rational

A real number x is rational if (and only if) there exist integers p and q, with $q \neq 0$ such that $x = p/q$.

$$\boxed{\texttt{Rational}(x) \coloneqq \exists p \exists q(\texttt{Integer}(p) \land \texttt{Integer}(q) \land (x = p/q) \land q \neq 0)}$$

Let's do another!

"The product of any two rational numbers is rational."

What is this statement in predicate logic?

Rational(x) is a predicate.

$\forall x \forall y([\mathtt{rational}(x) \wedge \mathtt{rational}(y)] \rightarrow \mathtt{rational}(xy))$

Remember unquantified variables in English are implicitly universally quantified.

Doing a Proof

$\forall x \forall y([\texttt{rational}(x) \wedge \texttt{rational}(y)] \rightarrow \texttt{rational}(xy))$

"The product of two rational numbers is rational."

is $\exists$ integers p, q $p/q = x$, $q \neq 0$.

DON'T just jump right in!

Look at the statement, make sure you know:

1. What every word in the statement means.
2. What the statement as a whole means.
3. Where to start.
4. What your target is.

Let's do another!

Claim: "The product of two rational numbers is rational."

Let x, y be arbitrary rational numbers.

By defn of rational, $x = \frac{a}{b}$, $y = \frac{c}{d}$ where a, b, c, d are all integers, $b \neq 0$, $d \neq 0$.

Multiplying, we get: $xy = \frac{ac}{bd}$.

Therefore, xy is rational.

Since x and y were arbitrary, we can conclude the product of two rational numbers is rational.

Let's do another!

"The product of two rational numbers is rational."

Let x, y be arbitrary rational numbers.

By the definition of rational, $x = a/b$, $y = c/d$ for integers a, b, c, d where $b \neq 0$ and $d \neq 0$.

Multiplying, $xy = \frac{a}{b} \cdot \frac{c}{d} = \frac{ac}{bd}$.

Since integers are closed under multiplication, ac and bd are integers.

Moreover, $bd \neq 0$ because neither b nor d is 0. Thus xy is rational.

Since x and y were arbitrary, we can conclude the product of two rational numbers is rational.

Now You Try

The sum of two even numbers is even.

1. Write the statement in predicate logic.
2. Write an English proof.
3. If you have lots of extra time, try writing the symbolic proof instead.

Now You Try

The sum of two even numbers is even.

Make sure you know:

1. What every word in the statement means.
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Even

An integer x is even if (and only if) there exists an integer z, such that $x = 2z$.

Fill out the poll everywhere for Activity Credit!

Go to pollev.com/cse311 and login with your UW identity
Or text cse311 to 22333

1. Write the statement in predicate logic.
2. Write an English proof.
3. If you have lots of extra time, try writing the symbolic proof instead.

Here's What I got.

$\forall x \forall y([\mathtt{Even}(x) \land \mathtt{Even}(y)] \rightarrow \mathtt{Even}(x+y))$

Let x, y be arbitrary integers, and suppose x and y are even.

$x=2a$, $y=2a$

By the definition of even, $x = 2a, y = 2b$ for some integers a and b.

Summing the equations, $x + y = 2a + 2b = 2(a + b)$.

Since a and b are integers, $a + b$ is an integer, so $x + y$ is even by the definition of even.

Since x, y were arbitrary, we can conclude the sum of two even integers is even.

Why English Proofs?

Those symbolic proofs seemed pretty nice. Computers understand them, and can check them.

So what's up with these English proofs?

They're far easier for **people** to understand.

But instead of a computer checking them, now a human is checking them.

Sets

Set

A set is an **unordered** group of **distinct** elements.

We'll always write a set as a list of its elements inside {curly, brackets}.

Variable names are capital letters, with lower-case letters for elements.

$A = \{\text{curly, brackets}\}$

$B = \{0,5,8,10\} = \{5,0,8,10\} = \{0,0,5,8,10\}$

$C = \{0,1,2,3,4, \dots\}$

Sets

Some more symbols:

$a \in A$ (a is in A or a is an element of A) means a is one of the members of the set.

For $B = \{0,5,8,10\}, \;\; 0 \in B$.

$A \subseteq B$ (A is a subset of B) means every element of A is also in B.

For $A = \{1,2\}$, $B = \{1,2,3\}$ $A \subseteq B$

Sets

Be careful about these two operations:

If $A = \{1,2,3,4,5\}$

$\{1\} \subseteq A$, but $\{1\} \notin A$

$\in$ asks: is this item in that box?

$\subseteq$ asks: is everything in this box also in that box?

Try it!

Let $A = \{1,2,3,4,5\}$

$B = \{1,2,5\}$

Is $A \subseteq A$?

Is $B \subseteq A$?

Is $A \subseteq B$?

Is $\{1\} \in A$?

Is $1 \in A$?