- "activity pdf" on the calendar has the slide you'll want in the breakouts.
- New slides were posted ~1:20.

English Proofs and Sets

CSE 311 Winter 22
Lecture 9

Announcements

- We corrected typos in HW3 Problem 7 (the find the bug problem).
  - There were two bugs other than the typos, so please go back and find the intended bugs ☺

- President Cauce's office sent an email today confirming the intended return to in-person next week.
  - We'll have official announcements soon.
  - We'll have a survey for preferred ***office hours*** mode coming soon.

What’s Next

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.

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

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.

3:2:1,5

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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

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 ∃/∀ so we end up with fewer "dummy variables"

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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 $x = p/q$.

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

Let's do another!

"The product of two rational numbers is rational."

What is this statement in predicate logic? DoD: all real #s.

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

Remember unquantified variables in English are implicitly universally quantified.

Doing a Proof

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

"The product of two rational numbers is rational."

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!

"The product of two rational numbers is rational."

Let x, y be arbitrary rational numbers.

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!

set is "closed" under
an operation

"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.

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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 $x = 2z$.

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Help me adjust my explanation!

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.

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

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

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

Sets

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.

$|A| = 2$. "The size of A is 2." or "A has cardinality 2."

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

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

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

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 $A \subseteq A$? Yes!

Is $B \subseteq A$? Yes

Is $A \subseteq B$? No

Is $\{1\} \in A$? No

Is $1 \in A$? Yes