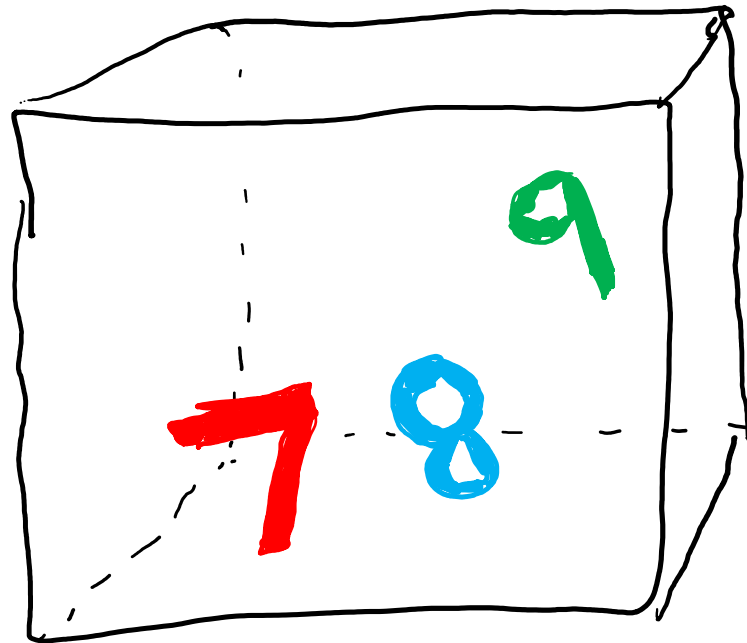
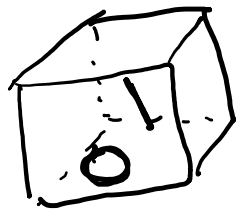
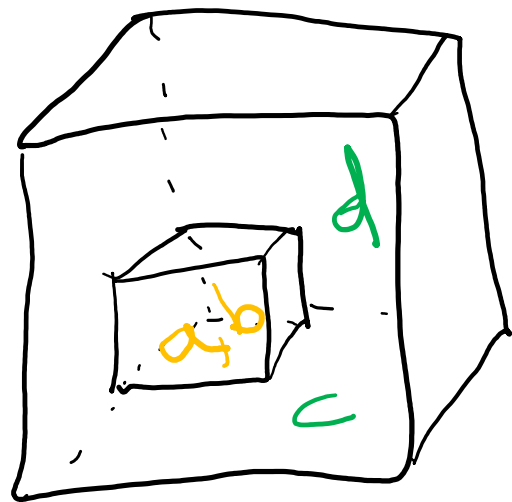


No warm-up
today



Sets

No activity
today either

poller.com/cse311

- What should we
- keep doing
 - start doing
 - stop doing

Anonymous
please be honest!

Cse 311 Autumn 20
Lecture 10

Announcements

Midterm logistical information is posted.

Don't worry it's not for a while! Just posting the information now so you can prepare.

1. It'll be from 11:59 PM Thursday Nov. 12 to 11:59 PM Sunday Nov. ~~16~~¹⁵.
2. You can work with up to 3 others, otherwise collaboration rules are like a homework assignment.
3. If you expect DRS accommodations to apply (and I haven't already talked to you) please send me an email as soon as possible.

Today

Is a laundry list day – everything you ever wanted to know about sets.

By the end, we'll get to do two proofs.

No activity today– polleverywhere will be open all day

Asking you what we should keep/

Start/stop in lectures.

It's anonymous (so you can give honest feedback).

Fill out the poll everywhere for
Activity Credit!

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

Or text cse311 to 22333

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.

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

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

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

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

$$\{a, 1\}$$

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 $\{1\} \notin A$
 \uparrow
 $1 \in A$

\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 $\underline{A} \subseteq A$? Yes!

Is $\underline{B} \subseteq A$? Yes

Is $\underline{A} \subseteq B$? No

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

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

Some old friends (and some new ones)

\mathbb{N}

\mathbb{N} is the set of Natural Numbers; $\mathbb{N} = \{0, 1, 2, \dots\}$

\mathbb{Z} is the set of Integers; $\mathbb{Z} = \{\dots, -2, -1, 0, 1, 2, \dots\}$

\mathbb{Q} is the set of Rational Numbers; e.g. $\frac{1}{2}$, -17 , $\frac{32}{48}$

\mathbb{R} is the set of Real Numbers; e.g. 1 , -17 , $\frac{32}{48}$, π , $\sqrt{2}$

$[n]$ is the set $\{1, 2, \dots, n\}$ when n is a ~~natural number~~ *positive integer*

$\{\} = \emptyset$ is the **empty set**; the *only* set with no elements

$\{\} = \emptyset$

Definitions

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

$A = \{1, 2, 3, \dots\}$
 $A \subseteq A$

$$A \subseteq B \equiv \forall x(x \in A \rightarrow x \in B)$$

$\emptyset \subseteq A$, $\emptyset \subseteq \emptyset$

$A = B$ (" A equals B ") iff A and B have identical elements.

$$A = B \equiv \forall x(x \in A \leftrightarrow x \in B) \equiv A \subseteq B \wedge B \subseteq A$$

Set Builder Notation

Sometimes we want to give a property and say "everything with that property is in the set (and nothing else is in the set)."

"the set of all even integers"

$$A = \{x : \text{Even}(x)\}$$

"The set of all x such that x is even."

In general $\{\underbrace{\text{variable}} : \underbrace{\text{Condition}(\text{variable})}\}$

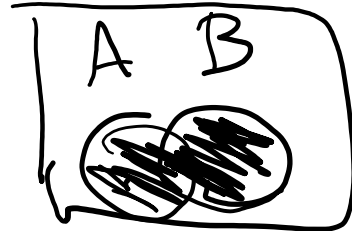
Sometimes the colon is replaced with |

What do we do with sets?

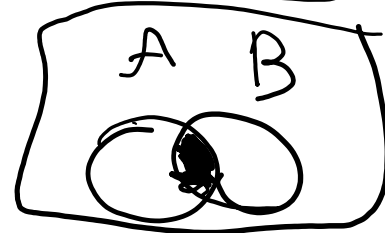
We combined propositions with \vee, \wedge, \neg .

We combine sets with \cap [intersection], \cup [union], $\bar{}$ [complement]

$$\underline{A \cup B} = \{x: \underline{x \in A \vee x \in B}\}$$



$$\underline{A \cap B} = \{x: x \in A \wedge x \in B\}$$



$$\bar{A} = \{x: x \notin A\}$$



That's a lot of elements...if we take the complement, we'll have some "universe" U , and $\bar{A} = \{x: x \in U \wedge x \notin A\}$
It's a lot like the domain of discourse.

A proof!

$$\neg p \wedge \neg q \equiv \neg(p \vee q)$$

$$\forall x (x \in \bar{A} \cap \bar{B} \rightarrow x \in \overline{A \cup B})$$

What's the analogue of DeMorgan's Laws...

$$\bar{A} \cap \bar{B} = \overline{A \cup B}$$

$$A = B \equiv \forall x (x \in A \leftrightarrow x \in B) \equiv A \subseteq B \wedge B \subseteq A$$

$$\bar{A} \cap \bar{B} \subseteq \overline{A \cup B}$$

$$x \in \overline{A \cup B}$$

$$\overline{A \cup B} \subseteq \bar{A} \cap \bar{B} \rightarrow \neg(x \in A \vee x \in B)$$

Let x be arb.
 $\rightarrow x \in \bar{A} \cap \bar{B}$ (assumption)
 $\rightarrow x \notin A \wedge x \notin B$
DeMorgan's
 $\rightarrow \neg(x \in A \vee x \in B)$
 $\rightarrow x \in \overline{A \cup B}$

A proof!

What's the analogue of DeMorgan's Laws...

$$\bar{A} \cap \bar{B} = \overline{A \cup B}$$

$$A = B \equiv \forall x(x \in A \leftrightarrow x \in B) \equiv A \subseteq B \wedge B \subseteq A$$

$$\bar{A} \cap \bar{B} \subseteq \overline{A \cup B}$$

- Let x be an arbitrary element of $\bar{A} \cap \bar{B}$.
- By definition of \cap and complement, $x \notin A \wedge x \notin B$.
- Applying DeMorgan's Law, we get that it is not the case that $x \in A \vee x \in B$.
- That is, x is in the complement of $A \cup B$, as required.

$$\overline{A \cup B} \subseteq \bar{A} \cap \bar{B}$$

- Let x be an arbitrary element of $\overline{A \cup B}$.
- By definition, x is not an element of $A \cup B$. That is, $\neg(x \in A \vee x \in B)$
- Applying DeMorgan's Law, we get: $x \notin A \wedge x \notin B$
- By definition of \cap and complement, we get $x \in \bar{A} \cap \bar{B}$

Proof-writing advice


When you're writing a set equality proof, often the two directions are nearly identical, just reversed.

It's very tempting to use that $x \in A \leftrightarrow x \in B$ definition.

Be VERY VERY careful. It's easy to mess that up, at every step you need to be saying "if and only if."

More connectors!

$A \setminus B$ "A minus B"



$$A \setminus B = \{x: \underbrace{x \in A} \wedge \underbrace{x \notin B}\}$$

$A \oplus B$ "XOR" (also called "symmetric difference")

$$A \oplus B = \{x: \underbrace{x \in A} \oplus \underbrace{x \in B}\}$$

Two claims, two proof techniques

Suppose I claim that for all sets $A, B, C: A \cap B \subseteq C$

That...doesn't look right.

How do you prove me wrong?

Want to show: $\exists A, B, C: A \cap B \not\subseteq C$

Proof. Consider $A = \{1, 2, 3\}$, $B = \{1, 2\}$, $C = \{2, 3\}$, then $A \cap B = \{1, 2\}$, which is not a subset of C .

Proof By [Counter]Example

To prove an existential statement (or disprove a universal statement), provide an example, and demonstrate that it is the needed example.

You don't have to explain where it came from! (In fact, you **shouldn't**)

Computer scientists and mathematicians like to keep an air of mystery around our proofs.

(or more charitably, we want to focus on just enough to believe the claim)

Proof by Cases

U, domain: positive integers

Let $A = \{x : \text{Prime}(x)\}$, $B = \{x : \text{Odd}(x) \vee \text{PowerOfTwo}(x)\}$

Where $\text{PowerOfTwo}(x) := \exists c(\text{Integer}(c) \wedge x = \underline{2^c})$

Prove $A \subseteq B$

We need two different arguments – one for 2 and one for all the other primes...

Proof By Cases

Let x be an arbitrary element of A .

We divide into two cases.

Case 1: x is even

{ If x is even and an element of A (i.e. both even and prime) it must be 2.
So it equals 2^c for $c = 1$, and thus is in B by definition of B .

Case 2: x is odd

{ Then $x \in B$ by satisfying the first requirement in the definition of B .

In either case, $x \in B$. Since an arbitrary element of A is also in B , we have $A \subseteq B$.

Proof By Cases

Make it clear how you decide which case your in.

It should be obvious your cases are "exhaustive"

Reach the same conclusion in each of the cases, and you can say you've got that conclusion no matter what (outside the cases).

{ Advanced version: sometimes you end up arguing a certain case "can't happen"

Two More Set Operations

Given a set, let's talk about its powerset.

$$\mathcal{P}(A) = \{X: X \text{ is a subset of } A\}$$

The powerset of A is the **set** of all subsets of A .

$$\mathcal{P}(\{1,2\}) = \{\emptyset, \{1\}, \{2\}, \{1,2\}\}$$

$$\mathcal{P}(\{a,b,c\}) = \left\{ \begin{array}{l} \emptyset \\ \{a\}, \{b\}, \{c\} \\ \{a,b\}, \{a,c\}, \{b,c\} \\ \{a,b,c\} \end{array} \right\}$$

$$\emptyset \in \mathcal{P}(\{1,2\})$$
$$\{1,2\} \in \mathcal{P}(\{1,2\})$$

$$\emptyset \subseteq \mathcal{P}(\{1,2\})$$
$$\{1,2\} \not\subseteq \mathcal{P}(\{1,2\})$$

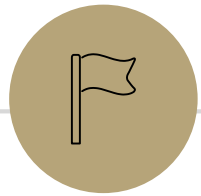
Two More Set Operations

$$A \times B = \{(a, b) : a \in A \wedge b \in B\}$$

Called “the Cartesian product” of A and B .

$\mathbb{R} \times \mathbb{R}$ is the “real plane” ordered pairs of real numbers.

$$\{1,2\} \times \{1,2,3\} = \{(1,1), (1,2), (1,3), (2,1), (2,2), (2,3)\}$$



Number Theory



Divides

$$2|4, \quad \cancel{4|2}$$

For integers x, y we say $x|y$ (" x divides y ") iff there is an integer z such that $zx = y$.

$$x|y$$

" x is a divisor of y " or " x is a factor of y " means the same thing as x divides y .

"The small number goes first"