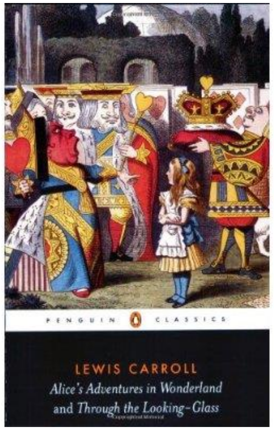

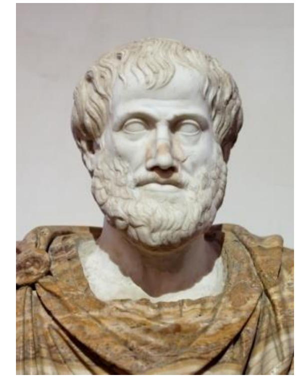

COMP 1002

Intro to Logic for Computer Scientists

Lecture 13

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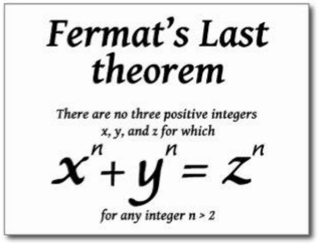


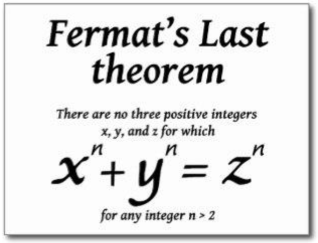
Puzzle 11

- Let $S = \{x \in \mathbb{N} \mid x \ is \ even\} \cap \{x \in \mathbb{N} | x \ is \ odd\}$

- Prove or disprove:

$$\forall x \in S, \qquad x \ does \ not \ divide \ x^2$$

Puzzle 11

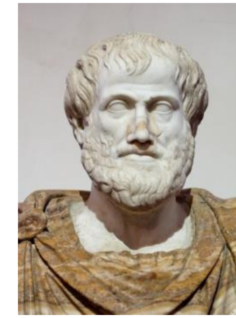


- Let $S = \{x \in \mathbb{N} \mid x\ is\ even\} \cap \{x \in \mathbb{N} | x\ is\ odd\}$
  - S = ∅
- Prove or disprove:

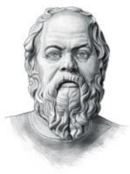
$$\forall x \in S, \qquad x\ does\ not\ divide\ x^2$$

  - Let P(x)= "$x\ does\ not\ divide\ x^2$"
  - To disprove, can give a counterexample
    - Find an element in S such that P(x) is true…
    - But there is no such element in S, because there are no elements in S at all!
  - To prove, enough to check that it holds for all elements of S.
    - There is none, so it does hold for every element in S.
  - Another way: Since S is defined as a subset of natural numbers, can read $\forall x \in S\ P(x)$ as $\forall x \in \mathbb{N}\ \left(x \in S \rightarrow P(x)\right)$.
    - Since "$x \in S$" is always false, $x \in S \rightarrow P(x)$ is true for every $x \in \mathbb{N}$
  - Call a statement $\forall x \in \emptyset\ P(x)$ **vacuously true.**

Universal Modus Ponens

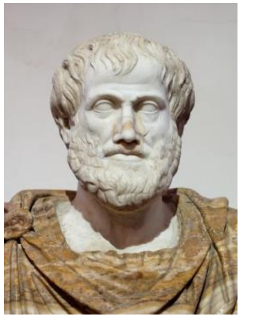


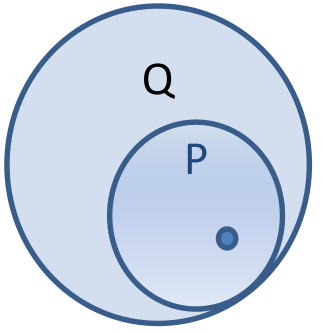
- All men are mortal
- Socrates is a man
- Therefore, Socrates is mortal



- All cats like fish
- Molly likes fish
- Therefore, Molly is a cat

Universal Modus Ponens



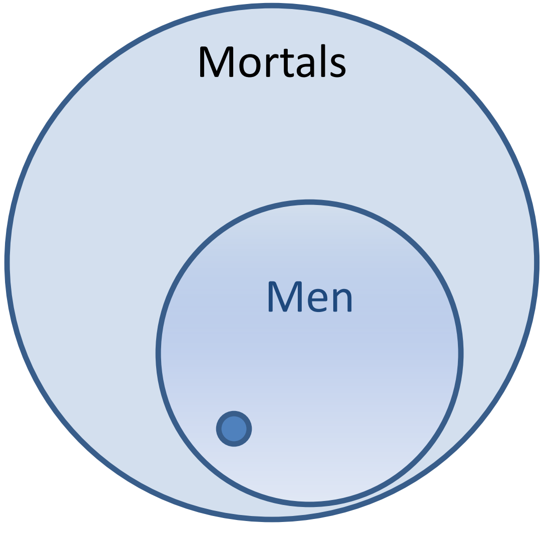


- $\forall x,\ P(x) \rightarrow Q(x)$
- $P(a)$
- -------------------------
- $Q(a)$

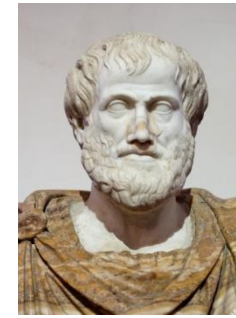
- All men are mortal ($\forall x,\ Man(x) \rightarrow Mortal(x)$)
- Socrates is a man ($Man(Socrates)$)
- Therefore, Socrates is mortal ($Mortal(Socrates)$)

- All numbers are either odd or even
- 2 is a number
- Therefore, 2 is either odd or even.

- All trees drop leaves
- Pine does not drop leaves
- Therefore, pine is not a tree



Universal Modus Ponens



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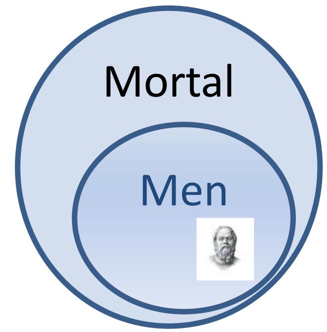
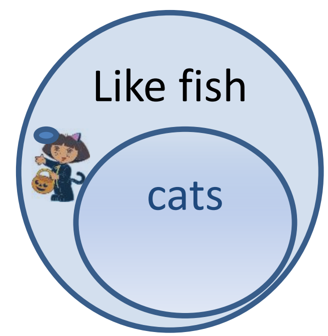


- All cats like fish
- Molly likes fish
- Therefore, Molly is a cat

- $(\forall x)\ Cat(x) \rightarrow like\_fish(x)$
- $like\_fish(Molly)$

____

∴ Cat(Molly) X



Instantiation/generalization

- Instantiation: taking a specific instance (value) of a variable
  - Can be just giving this variable a name
  - $Even(2),\ Even(k)$

- Generalization: replacing a specific value with a quantified variable
  - Have $Even(2)$
  - Get $\exists x\ Even(x)$
  - This is **existential generalization.**

Universal instantiation/generalization

- In general, if $\forall\, x \in S \;\; F(x)$ is true for some formula $F(x)$, if you take any specific element $a \in S$, then $F(a)$ must be true.
  - This is called the **universal instantiation** rule.
    - $\forall x \in \mathbb{N} \;\; (x > -1)$
    - $\therefore \;\; 5 > -1$

- If you prove $F(a)$ without any assumptions about a other than $a \in S$, then $\forall x \in S, F(x)$
  - This is called **universal generalization**.

Existential instantiation

- If $\exists\, x \in S \;\; F(x)$ is true, then you can give that element of S for which $F(x)$ is true a name, as long as that name has not been used elsewhere.
  - "Let n be an even number. Then n=2k for some k".
    - $\forall x \in \mathbb{N} \;\; Even(x) \rightarrow \;\; \exists\, y \in \mathbb{N} \;\; (x = 2 * y)$
  - Important to have a new name!
    - "Let n and m be two even numbers. Then n=2k and m=2k" is wrong!
    - $\forall x_1, x_2 \;\in \mathbb{N} \;\; Even(x_1) \wedge Even(x_2) \rightarrow$ $\exists\, y_{1,} y_2 \in \mathbb{N} \;\; (x_1 = 2 * y_1) \wedge (x_2 = 2 * y_2)$
    - "Let n and m be two even numbers. Then n=2k and m=2ℓ"

Other inference rules

- Combining universal instantiation with tautologies, get other types of arguments:

$p \rightarrow q$

$q \rightarrow r$

______

$\therefore p \rightarrow r$

- $\forall x\, P(x) \rightarrow Q(x)$
- $\forall x\, Q(x) \rightarrow R(x)$

____

$\therefore \forall x\, P(x) \rightarrow R(x)$

For any x, if $x > 3$, then $x > 2$

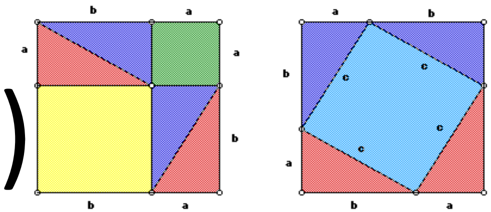
For any x, if $x > 2$, then $x \neq 1$

____

$\therefore$ For any x, if $x > 3$, then $x \neq 1$

- (This particular rule is called “transitivity”)

Types of proofs (1)



- Direct proof of $\forall x\ F(x)$
  - Show that $F(x)$ holds for arbitrary x, then use universal generalization.
    - Often, $F(x)$ is of the form $G(x) \rightarrow H(x)$
  - Example: A sum of two even numbers is even.

- Proof by cases
  - If can write $\forall x\ F(x)$ as $\forall x(G_1(x) \vee G_2(x) \vee \cdots \vee G_k(x)) \rightarrow H(x)$, prove $\big(G_1(x) \rightarrow H(x)\big) \wedge (G_2(x) \rightarrow H(x)) \wedge \cdots \wedge (G_k(x) \rightarrow H(x))$

Example: $x \in$ {days in August}

(∀x)(rain(x) V sunny(x) V foggy(x)) →hot(x)

you may prove

(∀x)

(rain(x)→hot(x))

∧ (sunny(x) →hot(x))

∧ (foggy(x)→hot(x)))

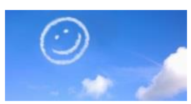
Type of Proof (2)

- Proof by contraposition
  - To prove $\forall x \; G(x) \rightarrow H(x)$, prove $\forall x \, \neg H(x) \rightarrow \neg G(x)$
  - Example: $(\forall x)(even(x) \rightarrow integer(x))$, *prove* $(\forall x)(\neg integer(x) \rightarrow \neg even(x))$
- Proof by contradiction
  - To prove $\forall x \, F(x)$, prove $\forall x \, \neg F(x) \rightarrow FALSE$
  - Example: $\sqrt{2}$ is not a rational number.
  - Example: There are infinitely many primes.

Puzzle: better than nothing

- Nothing is better than eternal bliss 
- A burger is better than nothing 

- Therefore, a burger is better than eternal bliss.

 $\leq$ $\leq$ 

Is there anything wrong with this argument?