CS 441: Rules of Inference

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[Motivation] Rules of Inference

The Case of the Missing Laptop

A brand-new, top-of-the-line laptop has gone missing from the university's computer science lab. There are three suspects: Alice, Bob, and Carol, all known to have been in the lab that day. Your job, as the Logic Detective Agency, is to use the provided clues to deduce who took the laptop.

The Suspects: Alice, Bob, and Carol

The Clues:

- If Alice took the laptop, then she was in the computer lab at 2 PM.
- Carol was in the lab at 2 PM.
- If Bob took the laptop, then he was not in the lab at 2 PM.
- Either Alice took the laptop or Carol took the laptop.
- If Carol was in the lab at 2 PM, then she did not take the laptop.

Who took the Laptop?

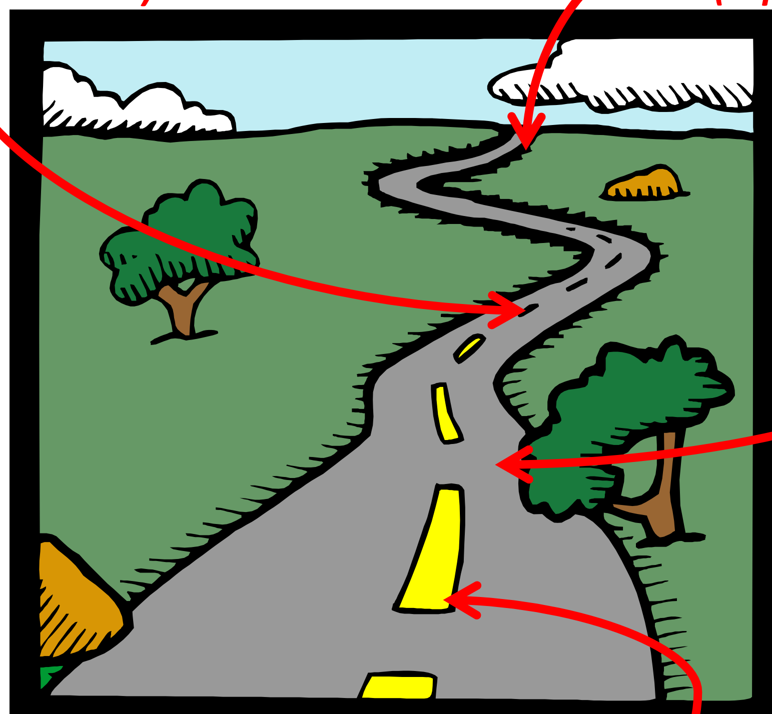
Today's topics

- Rules of inference
  - Logical equivalences allowed us to rewrite and simplify single logical statements.
  - How do we deduce new information by combining information from (perhaps multiple) known truths?

What have we learned? Where are we going?

Predicate logic (refined representation)

Propositional logic (representation)



Quantifiers (generalization)

Inference and proof (deriving new knowledge!)

Writing valid proofs is a subtle art

Step 1: Discover and formalize the property that you wish to prove

This is called "research"

Step 2: Formalize the ground truths (axioms) that you will use to prove this property

Mysterious, but not terribly difficult

Step 3: Show that the property in question follows from the truth of your axioms

This is the hard part…

What is science without jargon?

A conjecture is a statement that is thought to be true.

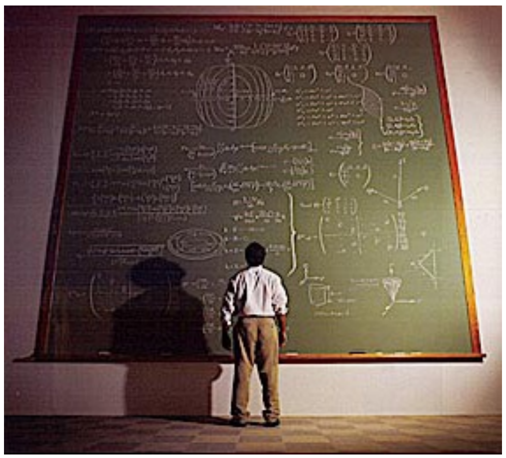
A proof is a valid argument that establishes the truth of a given statement (i.e., a conjecture)

After a proof has been found for a given conjecture, it becomes a theorem

A tale of two proof techniques

In a formal proof, each step of the proof clearly follows from the postulates and axioms assumed in the conjecture.

Statements that are assumed to be true



In an informal proof, one step in the proof may consist of multiple derivations, portions of the proof may be skipped or assumed correct, and axioms may not be explicitly stated.

How can we formalize an argument?

Consider the following argument:

"If you have an account, you can access the network"
"You have an account"
Therefore,
"You can access the network"

This argument *seems* valid, but how can we demonstrate this formally??

Let's analyze the *form* of our argument

p *q*

"If you have an account, then you can access the network"
"You have an account"
Therefore,
"You can access the network"

This is called a "rule of inference"

$p \rightarrow q$
p

$\therefore q$

Rules of inference are logically valid ways to draw conclusions when constructing a formal proof

The previous rule is called modus ponens

- Rule of inference: $$\begin{array}{l} p \rightarrow q \\ \underline{p \qquad\quad} \\ \therefore q \end{array}$$

- Informally: Given an implication $p \rightarrow q$, if we know that p is true, then q is also true

But why can we trust modus ponens?

- Tautology: $((p \rightarrow q) \land p) \rightarrow q$
- Truth table:

p	q	p→q
T	T	T
T	F	F
F	T	T
F	F	T

Any time that p→q and p are both true, q is also true!

There are lots of other rules of inference that we can use!

Addition

- *Tautology*: $p \rightarrow (p \vee q)$
- *Rule of inference*:

- *Example*: "It is raining now, therefore it is raining now or it is snowing now."

Simplification

- *Tautology*: $p \wedge q \rightarrow p$
- *Rule of inference*:

- *Example*: "It is cold outside and it is snowing. Therefore, it is cold outside."

There are lots of other rules of inference that we can use!

Modus tollens

- *Tautology*: $[\neg q \land (p \to q)] \to \neg p$
- *Rule of inference*:

.

- *Example*: "If I am hungry, then I will eat. I am not eating. Therefore, I am not hungry."

Hypothetical syllogism

- *Tautology*: $[(p \to q) \land (q \to r)] \to (p \to r)$
- *Rule of inference*:

.

- *Example*: "If I eat a big meal, then I feel full. If I feel full, then I am happy. Therefore, if I eat a big meal, then I am happy."

There are lots of other rules of inference that we can use!

Disjunctive syllogism

- *Tautology*: $[\neg p \land (p \lor q)] \rightarrow q$
- *Rule of inference*:

- *Example*: "Either the heat is broken, or I have a fever. The heat is not broken, therefore I have a fever."

Conjunction

- *Tautology*: $[(p) \land (q)] \rightarrow (p \land q)$
- *Rule of inference*:

- *Example*: "Jack is tall. Jack is skinny. Therefore, Jack is tall and skinny."

There are lots of other rules of inference that we can use!

Resolution

- *Tautology*: $[(p \lor q) \land (\neg p \lor r)] \rightarrow (q \lor r)$
- *Rule of inference*:

- *Example*: "If it is not raining, I will ride my bike. If it is raining, I will lift weights. Therefore, I will ride my bike or lift weights"

Special cases:

1. If r = q, we get

.

2. If r = F, we get

In-class Activities

Activity 1: Which rule of inference was used to make the following argument?

"Kangaroos live in Australia and are marsupials. Therefore, kangaroos are marsupials."

A. Disjunctive syllogism
B. Modus tollens
C. Simplification
D. Modus ponens

Steps:

1. Introduce to a classmate
2. Work in pairs on the exercise
3. Submit answers

In-class Activities

Activity 2: Which rule of inference was used to make the following argument?

"Adna is an excellent swimmer. If Adna is an excellent swimmer, then she can work as a lifeguard. Therefore, Adna can work as a lifeguard."

A. Disjunctive syllogism
B. Modus tollens
C. Simplification
D. Modus ponens

Steps:
1. Introduce to a classmate
2. Work in pairs on the exercise
3. Submit answers

In-class Activities

Activity 3: Put the proof steps in order. Introduce each premise immediately before using it.

Premises: Someone won the jackpot. Everyone who wins the jackpot is rich.

Prove: Someone is rich.

J(x) ≡ x won the jackpot
R(x) ≡ x is rich

A. R(s); modus ponens
B. ∃x R(x); existential generalization
C. J(s) → R(s); universal instantiation
D. ∃x J(x); premise
E. ∀x (J(x) → R(x)); premise
F. J(s); existential instantiation

Steps:
1. Introduce to a classmate
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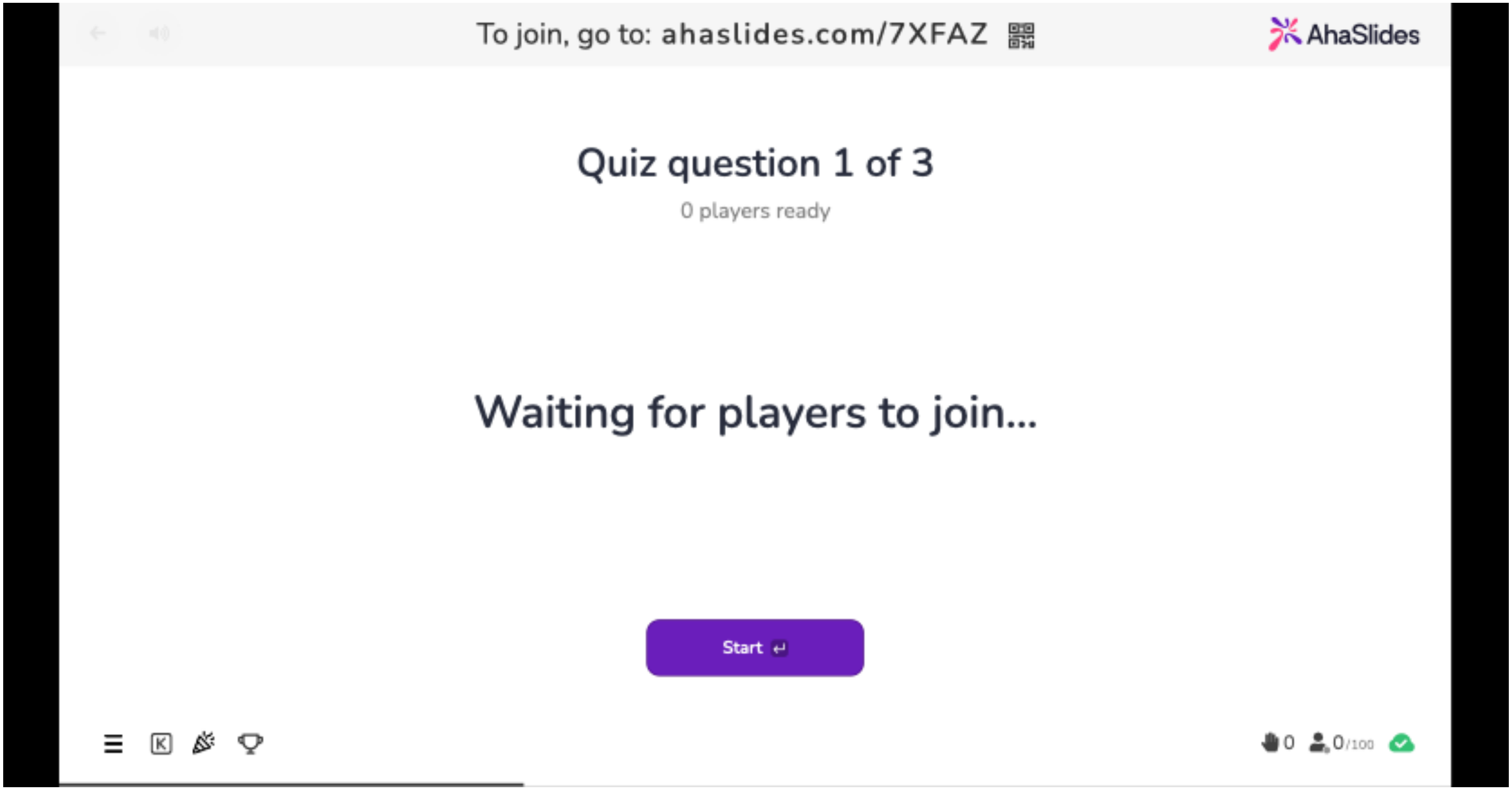

To join, go to: ahaslides.com/7XFAZ
AhaSlides
Quiz question 1 of 3
0 players ready
Waiting for players to join...
Start
0
0/100

We can use rules of inference to build valid arguments

If it is raining, I will stay inside. If I am inside, Lisa will stay home. If Lisa stays home and it is a Saturday, then we will play video games. Today is Saturday. It is raining.

***Let*:**

- r ≡ It is raining
- i ≡ I am inside
- l ≡ Lisa will stay home
- p ≡ we will play video games
- s ≡ it is Saturday

We can use rules of inference to build valid arguments

Let:

- r ≡ It is raining
- i ≡ I am inside
- l ≡ Lisa will stay home
- p ≡ we will play video games
- s ≡ it is Saturday

Hypotheses:

- $r \to i$
- $i \to l$
- $(l \land s) \to p$
- s
- r

Step:

y
es!

We also have rules of inference for statements with quantifiers

Universal Instantiation

- Intuition: If we know that P(x) is true for all x, then P(c) is true for a particular c
- Rule of inference:

Universal Generalization

- Intuition: If we can show that P(c) is true for an arbitrary c, then we can conclude that P(x) is true for any specific x
- Rule of inference:

P(c) is True for all elements c in its domain

Note that "arbitrary" does not mean "randomly chosen." It means that we cannot make any assumptions about c other than the fact that it comes from the appropriate domain.

We also have rules of inference for statements with quantifiers

Existential Instantiation

- Intuition: If we know that $\exists x\ P(x)$ is true, then we know that P(c) is true for some c
- Rule of inference:

Again, we cannot make assumptions about c other than the fact that it exists and is from the appropriate domain.

Existential Generalization

- Intuition: If we can show that P(c) is true for a particular c, then we can conclude that $\exists x\ P(x)$ is true
- Rule of inference:

Hungry dogs redux

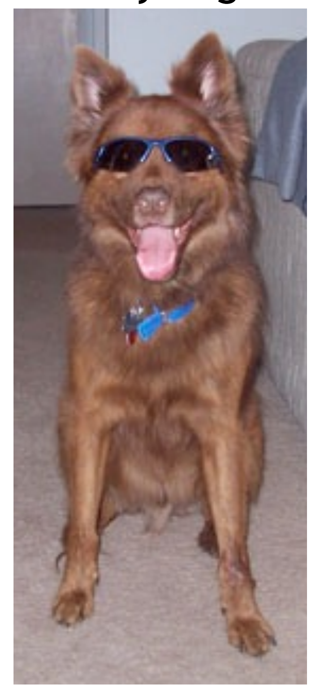
Given: All of my dogs like peanut butter

M(x) *P(x)*

1.
2.
3.
4.

Given: Kody is one of my dogs

M(Kody)



Reasoning about our class

Show that the premises “A student in this class has not read the book” and “everyone in this class turned in HW1” imply the conclusion “Someone who turned in HW1 has not read the book.”

***Let*:**

-
-
-

***Premises*:**

-
-

Reasoning about our class

Let:

- C(x) ≡ x is in this class
- B(x) ≡ x has read the book
- T(x) ≡ x turned in HW1

Premises:

- $\exists x\, [C(x) \land \neg B(x)]$
- $\forall x\, [C(x) \rightarrow T(x)]$

Steps:

1.
2.
3.
4.
5.
6.
7.
8.
9.

In-class Activities

Activity 4: Solve *The Case of the Missing Laptop* activity [miro]

Activity 5: Show that the premises "Everyone in this discrete math class has taken a course in computer science" and "Chike is a student in this discrete math class" lead to the conclusion "Chike has taken a course in computer science." [miro]

Steps:
1. Introduce to a classmate
2. Work in pairs on the exercise
3. Submit answers on miro
4. Volunteers to share answers

Final Thoughts

- Until today, we had look at representing different types of logical statements

- Rules of inference allow us to derive new results by reasoning about known truths

- Next time:
  - Proof techniques
  - Please read section 1.8