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REPRESENTING KNOWLEDGE

IN FIRST-ORDER LOGIC (FOL)

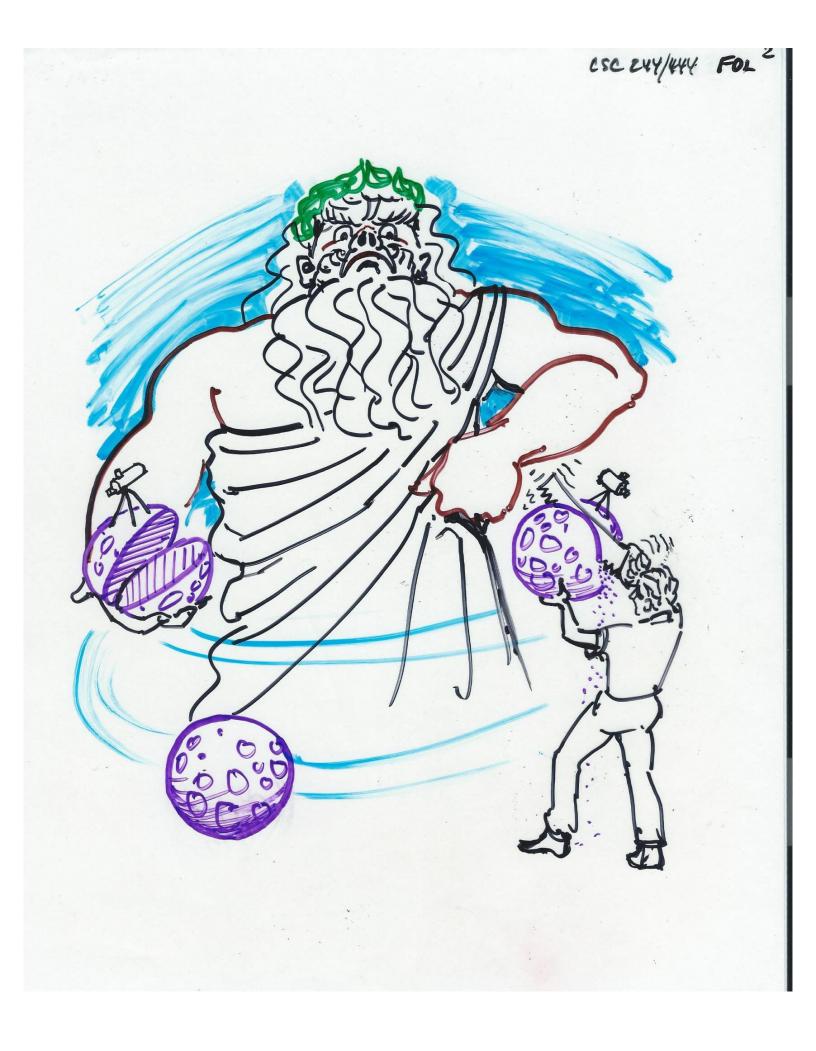
Much of the knowledge that we can informally express in ordinary language can be formally represented in FOL

But if our goal is to capture such "verbalizable" facts, why not use ordinary language (English, Mandarin, Sanskrit,...)?? Consider truth, reasoning

"I SAW THE MOONS OF JUPITER WITH A TELESCOPE LAST NIGHT"

- · AMBIGUOUS
- · INDEXICAL

Open question: How can LLMs help us get from NL to FOL, while abstracting away irrelevancies? E.g., suppose we want to infer that the sky was not clouded over...



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"winograd schema challenge]

FOL avoids ambiguity, indexicality" by • using brackets o using unambiguous symbols · using formalized versions of and, or, not, implies o using 3, V, and Variables to talk about existing, unspecified individuals, or about all individuals * In its most general sense, "indexicality" refers to all the contextual factors that influence meaning, including background knowledge.

- Consider: -In the storm, <u>a tree</u> fell on <u>our roof</u>. [cf: Levesques I hired a crew to repair <u>it</u>. "wimograd remove <u>it</u>. "wimograd scheme a chelleneo"
- -Dialogue:

"I'm studying computer science. What about you?" "I mostly wetch action movies.

We need at least the expressiveness of FOL if we wish to · refer to individuals : Nadia, CSC244, Rome, X,... · express properties : Nadia is single, Odie has rabies,... · express relationships : The Morning Star is Venus, Romeo loved Juliet, M. Curie discovered radium the population of the world exceeds 7 billion ... · express alternatives : (V) you got to school on foot, on a bicycle, by bus, or by car. · express negative facts: (~) There is no life on Mars o express general facts : (V) All poodles are dogs, All (living) parents are older than their children

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- see inductive definition

SYNTAX OF FOL

Predication and equality Dog(Fido) Loves (Romeo, Juliet) Morning-Star = Planet-Venus
Logical connectives ~ Likes (Cheney, Nader) Loves (Romeo, Juliet) ~ Loves (Juliet, Romeo) At-home (Mary) ~ At-work (Mary) Poodle (Fifi) => Dog(Fifi) (A>B) <> (B<A)

Avoiding ambiguity
 (P(A) ∨ ¬Q(A, B)) ∧ R(B, A)

(officially, conjunctions, disjunctions, quantified sentences, & equalities are always bracketed) CSC 244/444

Functions (prefixed & infixed)*
 Hot (surface of (Planet-Venus))
 Larger-than (surface of (Earth), surface of (Venus))
 sum (weight (John), weight (Mary)) = 300
 weight (John) + weight (Mary) = 300
 weight (John) > weight (Mary) = infixed

Quantification

 $\begin{array}{l} (\forall x \; \text{Entity}(x)) \\ (\forall x \; (\text{Poodle}(x) \Rightarrow \text{Dog}(x))) \\ (\exists x \; \text{Robot}(x)) \\ (\exists x \; \text{Robot}(x)) \\ (\forall x \; (\text{Robot}(x) \Rightarrow (\exists y \; \text{Built}(y, x)))) \\ (\forall x \; (\text{Robot}(x) \Rightarrow \neg \text{Intelligent}(x))) \\ (\exists x \; (\text{Robot}(x) \land \text{Intelligent}(x))) \\ (\exists x \; (\text{Robot}(x) \land \text{Intelligent}(x))) \\ \text{Robot} \; (\text{Dancel}) \land (\forall x \; (\text{Robot}(x) \Rightarrow x = \text{Dancel})) \end{array}$

* Functions are single-valued relations and can be partial or total 6

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Syntax of FOL, more formally

REASONING

A robot's (Robbie's) KB:

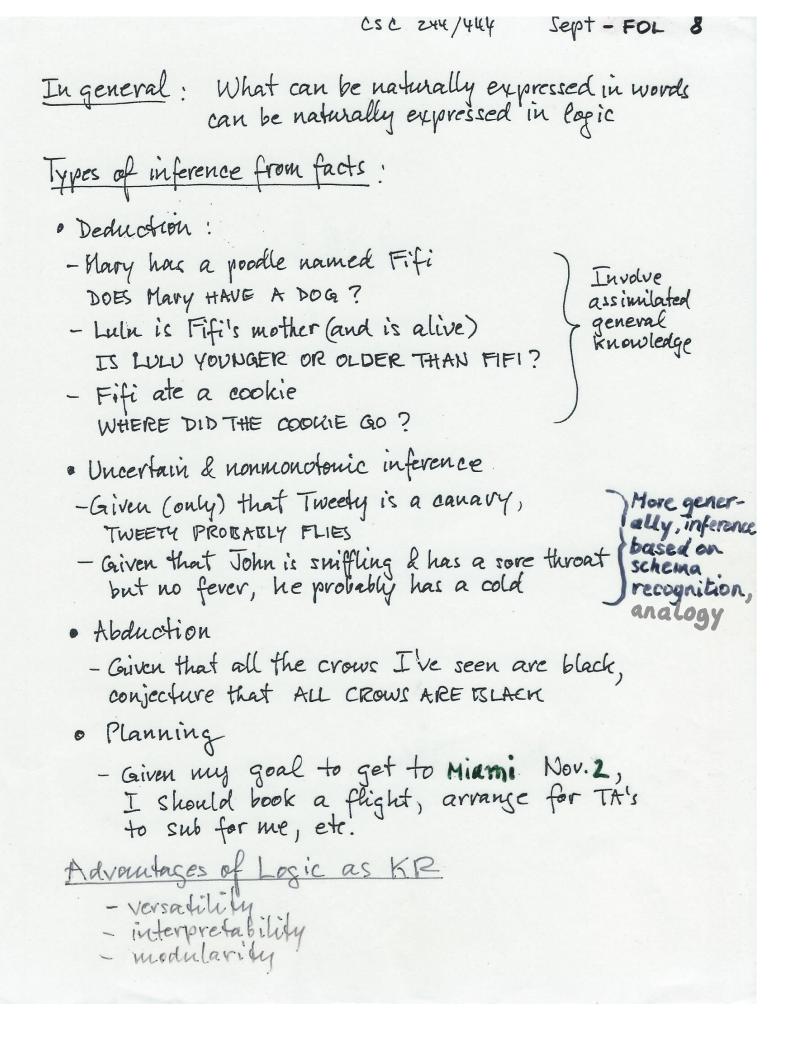
[Robot(Robbie), Located-in (Robbie, Rochester, Curr-Time*), Dog(Snoopy), Person(Jack), $(\forall x)$ Person(x) $\Rightarrow \neg Robot(x)$, clause form $\neg Rerson(x) \lor \neg Robot(x)$, $\neg Rerson(x) \lor \neg Robot(x)$ $(\forall x)$ $Dog(x) \Rightarrow \neg Person(x)$ $(\forall x)$ $Dog(x) \Rightarrow \neg Robot(x)$

7.5

Question 1 : Are you a person? Person (Robbie)?

Reasoning: - Person(x) V-Robot(x), Robot(Robbie) - Person(Robbie), i.e., "No"

Question 2: Where everyou? (IX) Located-in (Robbic, X, Curr-Time*)? Reasoning: Instantiate X to Rochester, i.e., "in Rochester" Question 3: Is there a drg? (IX) Dog(X)? Reasoning: Instantiate X to Snoopy; i.e., "Yes, Snoopy"



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What about "how to" knowledge?

- Many <u>skills</u> are hard to <u>express</u> in words, & seem too low-level to be expressed declaratively (it seems better to use mechanisms/procedures to implement or model them);
 - how the tune for "Twinkle, twinkle" goes
 - how to ride a bike, catch a ball, use chopsticks, tie shoelaces,...
 - how to interpret retinal images
 - how to speak grammatically;...
 - how to learn
- Procedural knowledge can be just as transparent and "logical" as factual knowedge
 - recipes, assembly instructions, emergency procedures, etc.
 - dynamic logic
 - procedures written at a high level, with all symbols meaningful in the domain (no "extrancous" symbols)