Methods in AI Research

Knowledge-based reasoning

Lecture 12

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Rosalie Iemhoff is a logician specializing in mathematical logic. Her research interests range from mathematical to philosophical topics, with a special interest in proof theory, its questions and its methods. Rosalie studied mathematics at the University of Amsterdam, and obtained a PhD in mathematical logic at the same university in 2001. After spending several years as a postdoc, at the University of California, San Diego and the Technical University Vienna, she joined the

Four lectures on logic and reasoning in AI:

Lecture 1. Knowledge-based reasoning

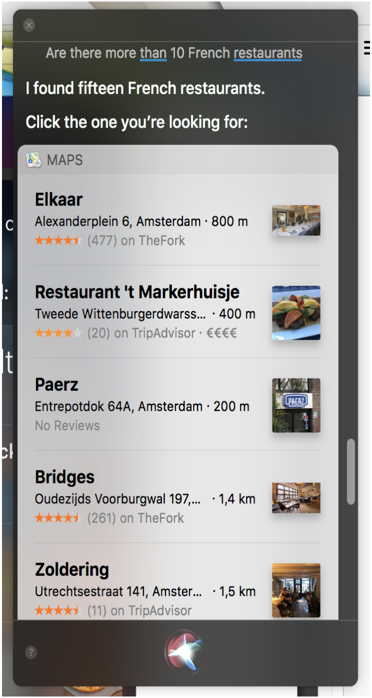
Lecture 2. Fragments and Subsymbolic vs symbolic AI

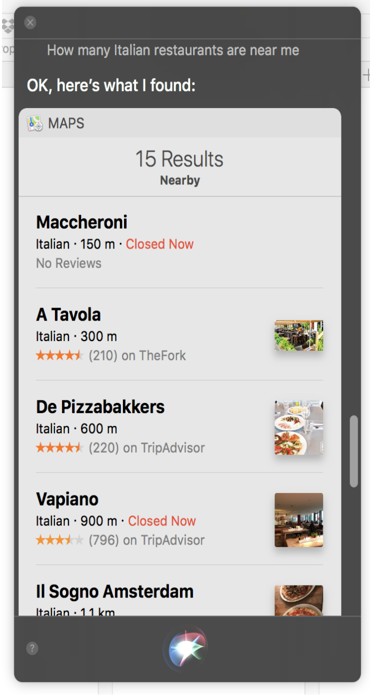
Lecture 3. Nonmonotonic reasoning

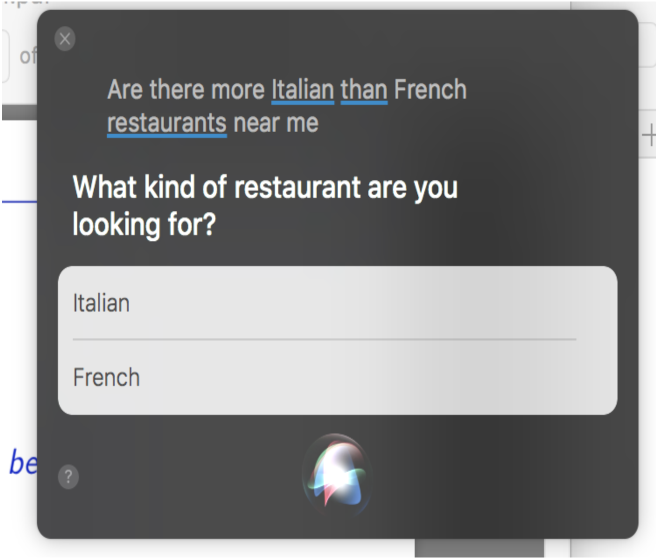
Lecture 4. Common sense reasoning

1. *Introduction*
2. *History and Examples*
3. *Logic*

1. Introduction


Are there more than 10 French restaurants
I found fifteen French restaurants.
Click the one you're looking for:
MAPS
Elkaar
Alexanderplein 6, Amsterdam · 800 m
(477) on TheFork
Restaurant 't Markerhuisje
Tweede Wittenburgerdwarss... · 400 m
(20) on TripAdvisor · €€€€
Paerz
Entrepotdok 64A, Amsterdam · 200 m
No Reviews
Bridges
Oudezijds Voorburgwal 197,... · 1,4 km
(261) on TheFork
Zoldering
Utrechtsestraat 141, Amster... · 1,5 km
(11) on TripAdvisor


How many Italian restaurants are near me
OK, here's what I found:
MAPS
15 Results
Nearby
Maccheroni
Italian · 150 m · Closed Now
No Reviews
A Tavola
Italian · 300 m
(210) on TheFork
De Pizzabakkers
Italian · 600 m
(220) on TripAdvisor
Vapiano
Italian · 900 m · Closed Now
(796) on TripAdvisor
Il Sogno Amsterdam
Italian · 1,1 km


Are there more Italian than French restaurants near me
What kind of restaurant are you looking for?
Italian
French

Does your dialogue system show intelligent behavior?

Is your dialogue system intelligent?

What is intelligent behavior?

What does it mean to be intelligent?

Key qualities of an Artificial Intelligence:

Knowledge, reasoning, learning, natural language processing.

Lectures 12-15: knowledge and reasoning.

(Other aspects are treated in the other lectures)

Ex. Possible application:
Medical database and software that support diagnostics
(clinical decision support system CDSS).

Knowledge Representation Hypothesis (Brian Cantwell Smith)

Any mechanically embodied intelligent process will be comprised of structural ingredients that a) we as external observers naturally take to represent a propositional account of the knowledge that the overall process exhibits, and b) independent of such external semantic attribution, play a formal but causal and essential role in engendering the behaviour that manifests that knowledge.

Dfn. Such systems are knowledge-based systems (KBS) and the symbolic representations involved their knowledge bases (KBs).

How to represent knowledge?

How to reason on the basis of this knowledge?

Size matters:
the aim is an efficient knowledge-based reasoning system.

One of the challenges: the open-endedness of the tasks.

2. History and Examples

(Some of these were discussed by Dong in Lecture 2)

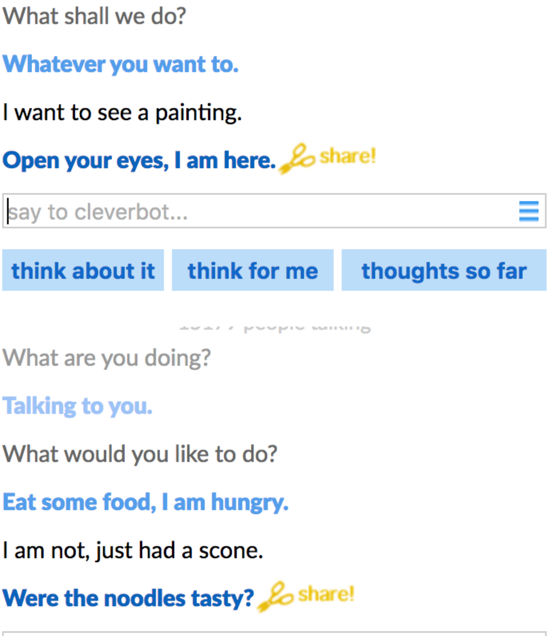
1960s *Eliza – Joseph Weizenbaum (computer science)*
Eliza "simulates" a psychiatrist

1970s *Parry – Kenneth Colby (psychiatry)*
Parry "simulates" a patient with schizophrenia

1970s *MYCIN – Edward Shortliffe (biomedical informatics)*
Reason about bacterial infections. No background knowlegde

1990s *Alice – Richard Wallace (computer science)*
More sophisticated responses than Eliza

1980s, 2000s *Jabberwacky/Cleverbot – Rollo Carpenter*
Dynamically growing the database.


What shall we do?
Whatever you want to.
I want to see a painting.
Open your eyes, I am here.
share!
say to cleverbot...
think about it
think for me
thoughts so far
What are you doing?
Talking to you.
What would you like to do?
Eat some food, I am hungry.
I am not, just had a scone.
Were the noodles tasty?
share!

21th century: learning becomes a feature of chatbots.

IBM Watson wins Jeopardy in 2011 from two of the greatest (human) Jeopardy champions.
(He had to work too hard at keeping his cool and was so noisy, it was thought he was too disruptive to take the podium in person.)

Healthcare Watson assists oncologists. It has the ability to go online (dynamic KB).

Chatbots in finance.

Virtual Personal Assistents.

3. Logic

How to represent knowledge?

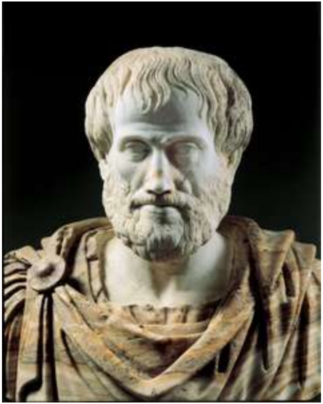
How to reason on the basis of this knowledge? How to draw conclusions?

Answer: *By using (a) logic.*

The KB is expressed in terms of (the language of) the logic and the reasoning is carried out with/in the logic.

Advantages: logical theories in AI are independent of implementations, generality, flexibility (applicable in many many contexts), understanding ...

One of the oldest occurrences of logic in written text is Aristotle's syllogisms.



All students are wise. You are a student. So you are wise.

Dfn. *A syllogism (Aristotle) consists of 2 premisses and 1 conclusion, all of the form*

all x are y	*A*	*Affirmo*
some x are y	*I*	*affIrmo*
no x is y	*E*	*nEgo*
some x are not y	*O*	*negO.*

Ex.

$$\frac{Axy \quad Ayz}{Axz}\ \checkmark \qquad \frac{Ixy \quad Ayz}{Ixz}\ \checkmark \qquad \frac{Axy \quad Oyz}{Oxz}\ \times$$

Dfn. *A syllogism is true if whenever its two premisses are true, so is its conclusion.*

Rather than putting the answers to the 256 possible syllogisms in KB, want to reason about quantifiers to obtain syllogistic answers.

The language of First-Order Logic (next slide).

Dfn. The syntax/language of first-order logic FOL consists of

- *brackets (and) and equality* $=$
- *variables* $x, y, z, x_i, y_i, \ldots$
- *function symbols* $f(x_1, \ldots, x_n), \ldots$ *for every arity* n
- *predicate symbols* $P(x_1, \ldots, x_n), \ldots$ *for every arity* n
- *connectives* $\wedge$ *(and),* $\vee$ *(or),* $\neg$ *(negation)*
- *quantifiers* $\forall$ *(universal) and* $\exists$ *(existential).*

Terms is the least set that contains all variables and satisfies: If $t_1, \ldots, t_n$ *are terms and* $f(x_1, \ldots, x_n)$ *is an n-ary function, then* $f(t_1, \ldots, t_n)$ *is a term.*

Formulas is the least set that satisfies these conditions:

- *If* $t_1, \ldots, t_n$ *are terms and* $P(x_1, \ldots, x_n)$ *is an n-ary predicate, then* $P(t_1, \ldots, t_n)$ *is a formula.*
- *If* t_1, t_2 *are terms, then* $t_1 = t_2$ *is a formula;*
- *If* φ, ψ *are formulas and* x *is a variable, then* $\neg\varphi, \varphi \wedge \varphi, \varphi \vee \varphi, \exists x\varphi, \forall x\varphi$ *are formulas.*

Ex. $\forall x \forall y (P_1(x,y) \wedge P_2(y,y)) \vee \neg \forall x \exists z P_1(x,z)$ *is a formula.*

Ex. *(earlier Siri example)*
$F(x)$ $(I(x))$ *x is a French (Italian) restaurant near me.*

Are there more than 10 French restaurants near me? I found 15:

$$\exists x_1 \ldots x_{11} (\bigwedge_{i=1}^{11} F(x_i) \wedge \bigwedge_{1 \le i \ne j \le 11} x_i \ne x_j)?$$

$$\exists x_1 \ldots x_{15} (\bigwedge_{i=1}^{15} F(x_i) \wedge \bigwedge_{1 \le i \ne j \le 15} x_i \ne x_j).$$

$\forall x_1 \ldots x_n$ *abbreviates* $\forall x_1 \forall x_2 \ldots \forall x_n$, *likewise for* $\exists$.
$t \ne s$ *abbreviates* $\neg(t = s)$.

FOL is very expressive:

Ex. *(earlier Siri example)*
$F(x)$ ($I(x)$) *x is a French (Italian) restaurant near me.*
$\varphi \rightarrow \psi$ *is short for* $\neg\varphi \vee \psi$.

Are there more Italian than French restaurants near me?

$$\forall x(F(x) \rightarrow \exists y\big(I(y) \wedge R(x,y)\big)\wedge$$

$$\forall x_1 x_2 y_1 y_2 \big(R(x_1,y_1) \wedge R(x_2,y_2) \wedge x_1 \neq x_2 \rightarrow y_1 \neq y_2\big)\wedge$$

$$\exists y(I(y) \wedge \neg\exists x R(x,y))?$$

The semantics of First-Order Logic (next two slides).

Dfn. *A model/interpretation/structure $M = (D, I)$ consists of a set D (the domain) and a function I (the interpretation) that interprets the language in D:*

$$\text{for } n\text{-ary predicate } P(x_1, \ldots, x_n),\ I(P) \text{ is a subset of } D^n$$
$$\text{for } n\text{-ary function } f(x_1, \ldots, x_n),\ I(f) \text{ is a function from } D^n \text{ to } D.$$

A valuation/variable assignment μ assigns elements of D to the variables.

A denotation $|t|_{I,\mu}$ (often written as $|t|$) of a term t is inductively defined as follows:

- *If t is a variable x, then $|x|_{I,\mu} = \mu(x)$.*
- *If $t = f(t_1, \ldots, t_n)$, then $|t|_{I,\mu} = I(f)(|t_1|_{I,\mu}, \ldots, |t_n|_{I,\mu})$.*

Ex. *Let $D = \{0, 1, 2\}$ and $I(f) : D \to D$ the function such that $f(0) = 1$ and $f(1) = f(2) = 0$. Let $\mu(x) = 1$ and $\mu(y) = 2$.*

$$|f(f(y))|_{I,\mu} = |x|_{I,\mu} = 1.$$

A formula φ is valid/satisfied in M under valuation v ($M, v \models \varphi$) if

- $\varphi = P(t_1, \ldots, t_n)$ *and* $(|t_1|_{I,\mu}, \ldots, |t_n|_{I,\mu})$ *belongs to* $I(P)$
- $\varphi = \neg\psi$ *and* $M, \mu \not\models \psi$
- $\varphi = \varphi_1 \wedge \varphi_2$, *and* $M, \mu \models \varphi_1$ *and* $M, \mu \models \varphi_2$
- $\varphi = \varphi_1 \vee \varphi_2$, *and* $M, \mu \models \varphi_1$ *or* $M, \mu \models \varphi_2$
- $\varphi = \exists x \psi(x)$ *if* $M, \mu' \models \psi(x)$ *for some valuation* μ' *that differs from* μ *at most at* x
- $\varphi = \forall x \psi(x)$ *if* $M, \mu' \models \psi(x)$ *for all valuations* μ' *that differ from* μ *at most at* x.

Ex. Let M be the model (D, I), where $D = \{0, 1, 2\}$ and $I(f) : D \to D$ such that $f(0) = 1$ and $f(1) = f(2) = 0$. P is a 1-ary predicate and $I(P) = \{0, 2\}$ Let $\mu(x) = 1$ and $\mu(y) = 2$.

$$M, \mu \models P(y) \wedge \neg P(x) \wedge \forall z (P(f(z)) \wedge P(z) \to z = y).$$

Homework:
Exercises 1 & 2 in Section 2.7 of Chapter 2.

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