LANGUAGE AND INFERENCE

Day 1: Types of Inference
Day 2: Designing Meaning Representations
Day 3: Building Meaning Representations
Day 4: Projection and Presupposition
Day 5: Inference in the Real World

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Language

Natural Language

Spoken by humans

- English, Dutch, ...
- Italian,German, ...

Artificial/Formal Language

“Spoken” by machines

- Logical languages (calculi)
- Programming languages

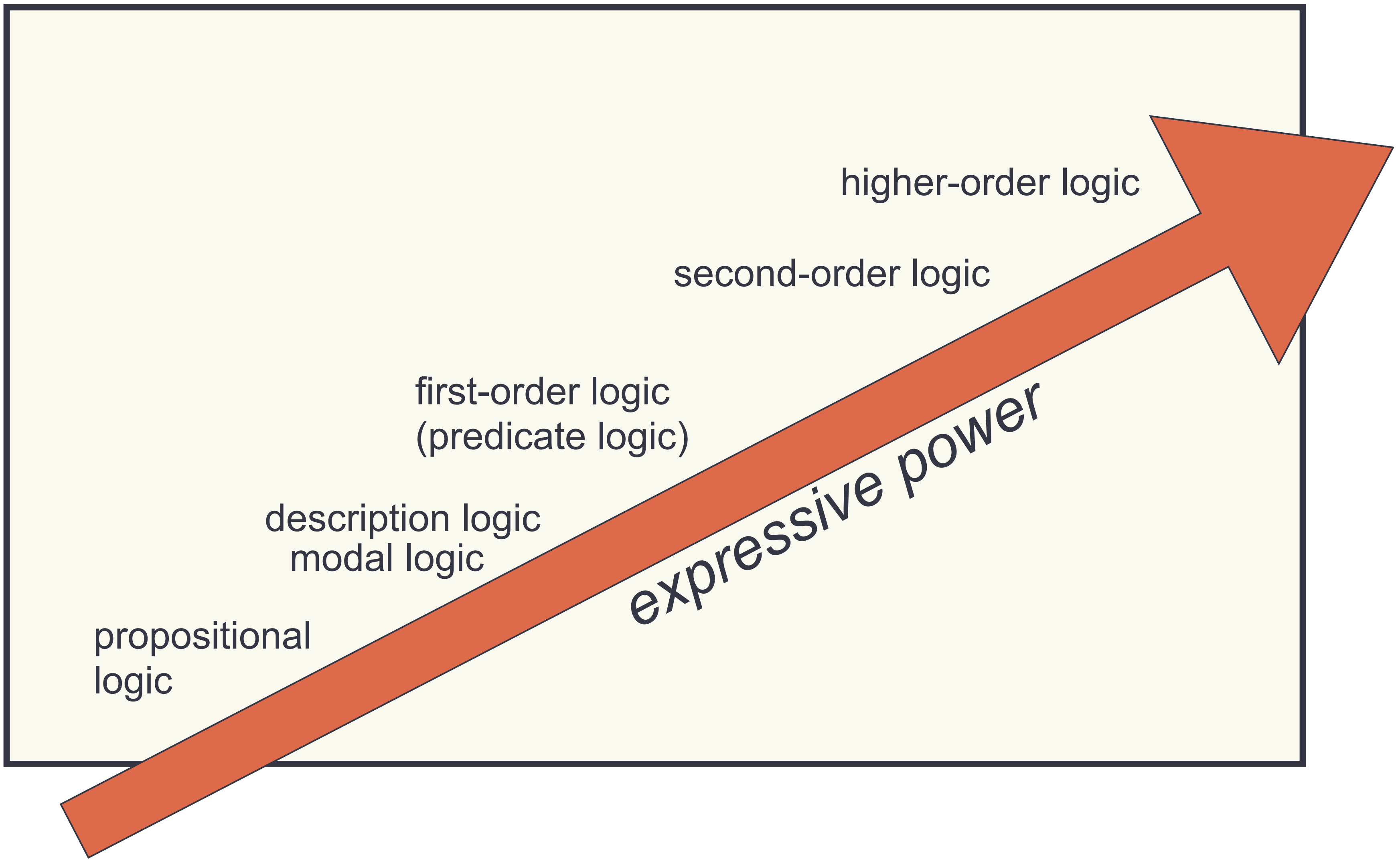
Basic idea of formal semantics

- Provide a mapping from ordinary language to logic
- Aim: predict inferences (study of meaning)

Human Language (ambiguous)	→	**Logical Language** (unambiguous)

But what are logical languages or calculi ?

Logical languages



Inference

- “Making explicit what is implicit”
- “Drawing conclusions from premises”
- “Gaining knowledge through reasoning”

Types of inference

- Abductive reasoning
- Inductive reasoning
- Deductive reasoning

Inference games

Can we derive the conclusion from the premises?:

Every boy smiled.
Mia is a woman. *premises*

Mia smiled. *conclusion*

Note:

- Can be read as: "if" premise "and" premise "then" conclusion
- References (e.g. names) and contexts are considered constant

Abductive reasoning (Abduction)

Guessing for an explanation...

The dog is wet.

? It’s raining outside.

? It jumped in the pool.

Inductive reasoning (Induction)

Making generalizations...

This dog has four legs.

That dog has four legs.

And that one. And this one.

And that one too.

All dogs have four legs.

Inductive reasoning (Induction)

Making generalizations...

This dog has four legs.

That dog has four legs.

And that one. And this one.

And that one too.

All dogs have four legs.

Deductive reasoning (Deduction)

Drawing conclusions from a set of premises

Every dog jumped in the pool.

Fido is a dog.

Fido jumped in the pool.

The Inference Tasks

- Concentrate on **deductive** reasoning
- With the help of (first-order) **logic**
- Two inference tasks:

① **informativeness/entailment** checking

② **consistency/contradiction** checking

Single sentence games

For each example sentence: judge whether it is:

- consistent (true in at least one situation) or
- inconsistent (false in every situation)

- informative (false in at least one situation) or
- uninformative (true in every situation)

Example 1: Bush

“... when there's more trade, there's more commerce."

informative?
consistent?

George W. Bush, at the Summit of the Americas in Quebec City, April 21, 2001 (source: Language Log 24/10/2004)

Example 2: Snowden

“Information chiefs in many countries sound alarm over revelations by Edward Snowden”

The Guardian11/06/2013

informative?
consistent?

Example 3: Venice

Turn (simultaneously) left and right to go to San Marco.

informative?
consistent?

Multi-sentence games

For each example: judge whether a new contribution is:

- consistent (possible to be true in a situation) or
- inconsistent (impossible to be true in a situation) wrt previous text

- informative (possibly true and false) or
- uninformative (true in any situation) wrt previous text

Example 1 (a):

The king had cornflakes for breakfast this morning.

The king had cornflakes for breakfast.

informative?
consistent?

Example 1 (b):

The king had cornflakes for breakfast this morning.

The queen had cornflakes for breakfast.

informative?
consistent?

Example 2 (a):

informative?
consistent?

Bob and Sue are married.

Bob and Sue are married to each other.

Example 2 (b):

Bob is married to Sue.

Sue is married to Bob.

informative?
consistent?

Example 3 (a):

Jules eats a kahuna burger every day.

Jules eats a kahuna burger every Tuesday.

informative?
consistent?

Example 3 (b):

Jules eats a kahuna burger every Tuesday.

Jules eats a kahuna burger every day.

informative?
consistent?

Example 3 (c):

Jules eats a kahuna burger every day.

Jules eats a big kahuna burger every day.

informative?
consistent?

Example 3 (d):

Jules eats a big kahuna burger every day.

Jules eats a kahuna burger every day.

informative?
consistent?

Determiners summed up

- **every**(↓,↑)
  every boy runs -> every small boy runs
  every boy runs quickly -> every boy runs

- **a**(↑,↑)
  a small boy runs -> a boy runs
  a small boy runs quickly -> a small boy runs

- **no**(↓,↓)
  no boy runs -> no small boy runs
  no boy runs -> no boy runs quickly

Example 4 (a):

Jerry is a large mouse.
Every mouse is an animal.

Jerry is an animal.

informative?
consistent?

Example 4 (b):

Jerry is a large mouse.
Every mouse is an animal.

Jerry is a large animal.

informative?
consistent?

Example 4 (c):

Jerry is a brown mouse.
Every mouse is an animal.

Jerry is a brown animal.

informative?
consistent?

Example 5 (a):

Marsellus is a clever person.

Marsellus is clever.

informative?
consistent?

Example 5 (b):

Marsellus is a clever criminal.

Marsellus is clever.

informative?
consistent?

Example 6

Bolt is faster than Powel.

Powel is faster than Bolt.

informative?
consistent?

informative?
consistent?

Example 7

No pets are allowed in this area.

All pets must be on the leash in this area.

informative?

consistent?

Example 8

Steve visited only Bologna.

Steve visited Bologna and Pisa.

informative?
consistent?

Example 9 (a):

We bought fresh milk last week.

Today we drink what we bought last week.

Today we drink fresh milk.

informative?
consistent?

Example 9 (b):

We bought fresh milk last week.

So did the neighbours.

The neighbours bought fresh milk last week.

informative?

consistent?

Example 10

Bill ordered a beer.

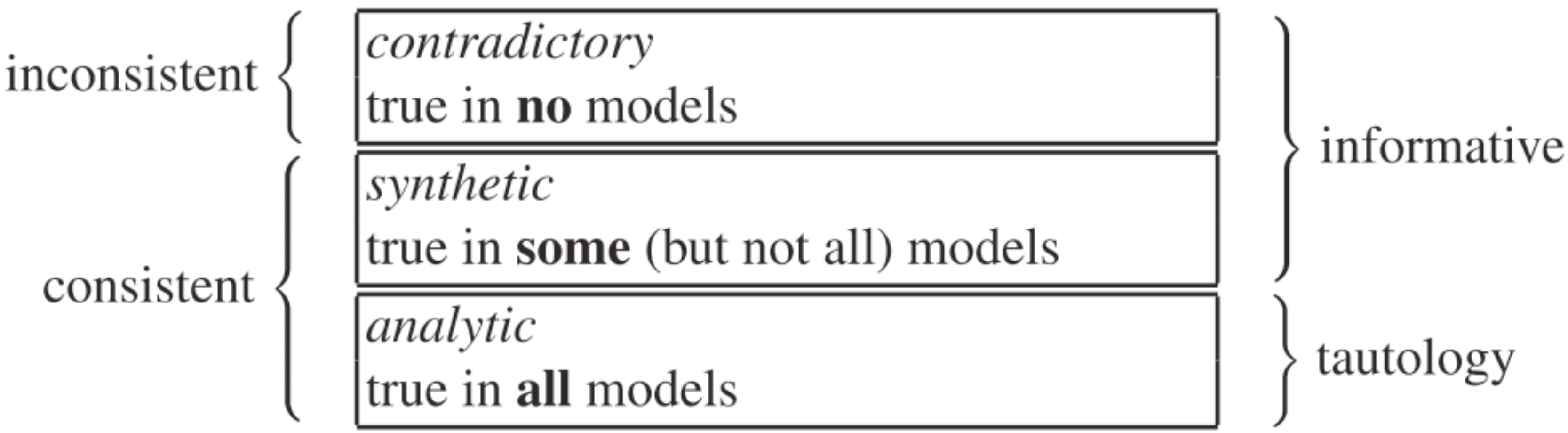
John ordered one too.

John ordered a beer.

informative?
consistent?

Terminology

(Matthews 1997, Bos 2011)



Grice's Maxims

- Maxim of quality
  - do not say what you belief to be false
  - do not say that for which you lack evidence

- Maxim of quantity
  - Make your contribution as informative as is needed
  - Do not make your contribution more informative than needed

Paul Grice

Entailments & Paraphrases

- Observation 1:
  Text T entails sentence S iff S is not informative wrt T (i.e. contains no new information)

- Observation 2:
  Two sentences are paraphrases of each other iff they entail each other

Semantic relations

Relation between sentences	**Relation between words**
entailment	...
paraphrase	...
contradiction	...

Semantic relations

Relation between sentences	Relation between words
entailment	hyponymy
paraphrase	synonymy
contradiction	antonymy

Terminology

(Matthews 1997, Bos 2011)

inconsistent	*contradictory* true in **no** models	informative
consistent	*synthetic* true in **some** (but not all) models	
	analytic true in **all** models	tautology

Models

- Model-theoretical semantics
- Alfred Tarski

Models: approximations of reality

Models: approximations of reality

Interpretation

- A model *satisfies* a sentence
- A sentence S is true in a model M
  (M satisfies S, M is an interpretation of S)

M:

M satisfies "The dog is outside"
M does not satisfy: "A bird sits on a car"

An example model

M=<D,F>
D={d1,d2,d3,d4,d5,d6,d7,d8}
F(man)={d1}
F(woman)={d2}
F(house)={d3,d4}
F(dog)={d5}
F(bird)={d6}
F(tree)={d7}
F(car)={d8}
F(happy)={d1,d2}
F(near)={(d5,d2),(d2,d5)}
F(at)={(d6,d3)}

Vocabularies (Signatures)

- Ensuring that descriptions and situations belong together
- Example vocabulary:

  { love:2, hate:2, man:1, woman:1, mia:0, vincent:0) }

  This tells us: (a) the topic of conversation
  (b) the language of the conversation

An example model

M=<D,F>
D={d1,d2,d3,d4}
F(mia)=d1
F(honey-bunny)=d2
F(vincent)=d3
F(yolanda)=d4
F(customer)={d1,d3}
F(robber)={d2,d4}
F(love)={(d4,d2),(d3,d1)}

An example model

M=<D,F>
D={d1,d2,d3,d4}
F(mia)=d2
F(honey-bunny)=d1
F(vincent)=d4
F(yolanda)=d3
F(customer)={d1,d2,d4}
F(robber)={d3}
F(love)={}

A very small model

M=<D,F>
D={d5}

A very large model

M=<D,F>

D={d1,d2,d3,d4,d5,d6,d7,d8,d9,d10

F(man)={d1,d4,d12}

F(woman)={d2,d3}

F(car)={d14,d13}

F(love)={(d2,d1), (d4,d4)}

F(hate)={(d5,d1), (d1,d4),(d2,d2)}

F(chopper)={d10}

Ingredients of a first-order language

1. All **symbols** in the vocabulary – the non-logical symbols of the languages
2. Enough **variables** (a countably infinite collection): x, y, z, etc.
3. The boolean **connectives** ¬ (negation), ∧ (conjunction), ∨ (disjunction), and → (implication)
4. The **quantifiers** ∀ (the universal quantifier) and ∃ (the existential quantifier)
5. Some **punctuation** symbols: round brackets and the comma.

George Boole

pioneer of modern
mathematical logic

First-order terms

- Any constant or any variable is a first-order term
- Terms are the noun phrases of first-order languages
  - constants are first-order analogs of proper names
  - variables are first-order analogs of pronouns

Atomic formulas

- If R is a relation symbol of arity n, and $t_1,...,t_n$ are terms, then $R(t_1,....,t_n)$ is an atomic formula
- If t_1 and t_2 are terms, then $t_1 = t_2$ is an atomic formula

Well formed formulas (wffs)

1. All atomic formulas are wffs
2. If φ and ψ are wffs,
   then so are $\neg\varphi$, $(\varphi \wedge \psi)$, $(\varphi \vee \psi)$, $(\varphi \rightarrow \psi)$
3. If φ is a wff, and x is a variable,
   then both $\exists x\varphi$ and $\forall x\varphi$ are wffs
4. Nothing else is a wff

Free and Bound Variables

- A variable is free in a formula ψ if it is not bound in ψ
- A variable x is bound in a formula ψ if it appears in the scope of a quantifier $\exists x$ or $\forall x$ in ψ

Closed formulas

- Formulas that have no free variables are called *closed*
- Usually we're only interested in closed formulas
- Translating a natural language sentence to first-order logic should produce a closed formula
- Free variables can be thought of as "pronouns"

Logicians are only human

- Logicians (and mathematicians) are usually very precise in their formulations
- However, they sometimes drop punctuation symbols if no confusion arises
- Often outermost brackets are dropped; also other brackets as long as no confusion arises
- Examples:

$p \wedge q$	instead of	$(p \wedge q)$
$p \vee (q \wedge r)$	instead of	$(p \vee (q \wedge r))$
$(p \vee q \vee r)$	instead of	$(p \vee (q \vee r))$

A note on notation…

- Negation: $\neg$ or $\sim$
- Conjunction: $\wedge$ or &
- Implication: $\rightarrow$ or $\supset$
- Equivalence: $\leftrightarrow$ or $\equiv$
- Brackets: (…) or […]

The satisfaction definition

$$
\begin{array}{lll}
M, g \models R(\tau_1, \cdots, \tau_n) & \textit{iff} & (I_F^g(\tau_1), \cdots, I_F^g(\tau_n)) \in F(R), \\
M, g \models \tau_1 = \tau_2 & \textit{iff} & I_F^g(\tau_1) = I_F^g(\tau_2), \\
M, g \models \neg\phi & \textit{iff} & \text{not } M, g \models \phi, \\
M, g \models (\phi \wedge \psi) & \textit{iff} & M, g \models \phi \text{ and } M, g \models \psi, \\
M, g \models (\phi \vee \psi) & \textit{iff} & M, g \models \phi \text{ or } M, g \models \psi, \\
M, g \models (\phi \rightarrow \psi) & \textit{iff} & \text{not } M, g \models \phi \text{ or } M, g \models \psi, \\
M, g \models \exists \text{x}\phi & \textit{iff} & M, g' \models \phi, \text{ for some x-variant } g' \text{ of } g, \\
M, g \models \forall \text{x}\phi & \textit{iff} & M, g' \models \phi, \text{ for all x-variants } g' \text{ of } g.
\end{array}
$$

$I_F^g(\tau)$ is $F(\text{c})$ if the term τ is a constant c, and $g(\text{x})$ if τ is a variable x.

Terminology

(Matthews 1997, Bos 2011)

<table>
<tr><td>inconsistent</td><td>contradictory
true in no models</td><td rowspan="2">informative</td></tr>
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Do we really need all this stuff?

- implication
- disjunction
- quantifiers

What's wrong with these translations?

English	First-order logic
A dog barks.	$\exists x(dog(x) \rightarrow bark(x))$
Vincent likes every dog.	$\forall x(dog(x) \wedge like(v,x))$
No dog barks.	$\exists x(dog(x) \wedge \neg bark(x))$
Every dog chases a cat.	$\forall x(dog(x) \rightarrow \exists y(cat(y) \wedge chase(y,x))$