

# Semantic Theory

Week 0: Introduction

# Information about this course

- Course website: <http://njvenhuizen.github.io/teaching/ST22/index.html>
- Email: [noortjev@coli.uni-saarland.de](mailto:noortjev@coli.uni-saarland.de) / [brouwer@coli.uni-saarland.de](mailto:brouwer@coli.uni-saarland.de)
- Main communication platform: Microsoft Teams (slides, exercises, chat)
- Prerequisites: Familiarity with first-order predicate logic.
  - See: Logic in Action, Chapter 4 (Sec. 4.1 & 4.2): <http://logicinaction.org/docs/ch4.pdf>

# Information about this course

## Lectures, Exercises, Exam

- Lectures will take in person (starting 19.04.: room -1.05, C7.2; basement)
  - Standard university hygiene regulations apply: distancing & face masks
  - Tuesday and Wednesday will be flexibly used as lectures/exercise sessions
- Final exam date: 20.07.2022
  - Your grade for the final exam will be your grade for the course
- There will be 8 exercises throughout the semester; to be admitted to the exam, you may skip or fail at most one weekly exercise

# Course Materials

## Optional reading material

- The slides provide the main course material.
- For additional background reading, we use several online resources:
  - Logic in Action, J. van Benthem, H. van Ditmarsch, J. van Eijck and J. Jaspars, 2016. <http://logicinaction.org/>
  - Elements of Formal Semantics (Ch. 1-3), Yoad Winter, Edinburgh University Press, 2016.  
<https://www.phil.uu.nl/~yoad/efs/main.html>
  - Stanford Encyclopedia of Philosophy, Edward N. Zalta (principal editor).  
<https://plato.stanford.edu/>

# Semantic Theory

Semantic Theory is the study of (linguistic) meaning

The image displays two overlapping windows. The background window is a dictionary page for the word "cat". It shows the word "cat" with its phonetic transcription [kæt] and the definition: "a small domesticated mammal with retractable claws. It has various breeds and has been domesticated for thousands of years." The dictionary also lists various phrases and related terms like "cat-and-mouse", "cat and mouse", "cat-bear", etc.

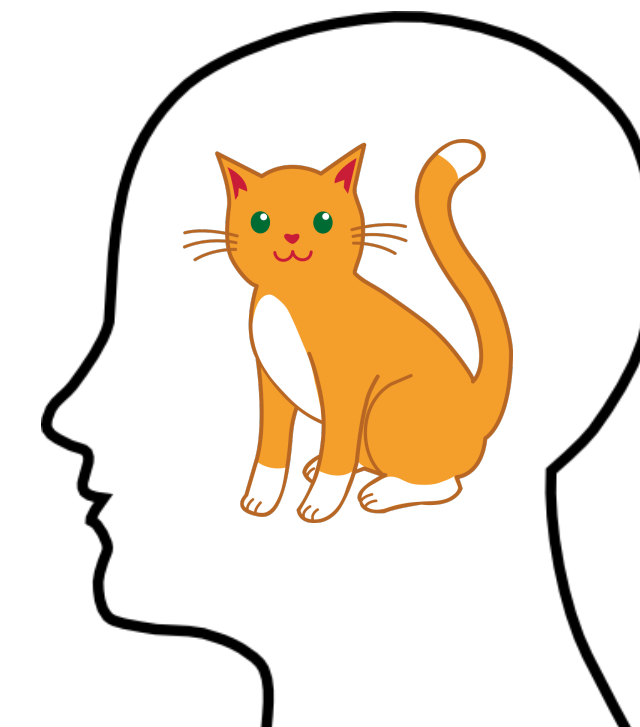
The foreground window is a Google search results page for the word "cat". The search bar contains the word "cat". The results are categorized into "Cute", "And Kittens", "Clipart", "Drawing", and "Cute Baby". Each category shows a grid of images: "Cute" shows a tabby cat lying down; "And Kittens" shows a ginger kitten sitting; "Clipart" shows various cartoon-style cat illustrations; "Drawing" shows line art drawings of cats; "Cute Baby" shows a small kitten sitting in grass. Below these categories, there are several more images of cats in various poses and breeds, including a ginger cat, a grey cat, a tabby cat, and the famous grumpy-looking cat Grumpy Cat.

# A philosophical question

What is 'meaning'?

"cat"

"a small domesticated carnivorous mammal with soft fur, a short snout, and retractile claws"



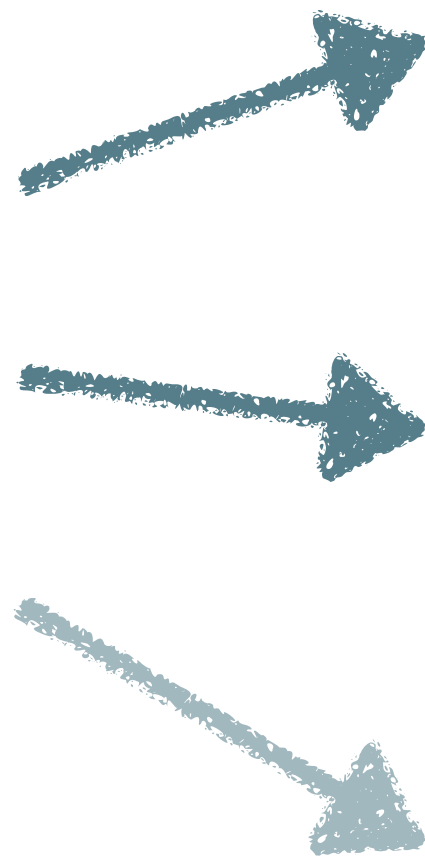
# Formal semantics

## Goal of Formal Semantics:

- To explain how meaning derives from linguistic **form**;
- Using **formal** mathematical principles.

Handwritten mathematical derivations for the maximum likelihood estimation of a normal distribution parameter. The equations shown include:

$$\ln(L(\mu)) = \ln\left(\frac{1}{\sigma\sqrt{2\pi}}\right)^n \cdot \exp\left(-\frac{1}{2\sigma^2} \sum_{i=1}^n (x_i - \mu)^2\right)$$
$$\frac{\partial}{\partial \mu} \ln(L(\mu)) = \frac{1}{\sigma^2} \sum_{i=1}^n (x_i - \mu) = 0$$
$$\sum_{i=1}^n (x_i - \mu) = 0 \Rightarrow \sum_{i=1}^n x_i - n\mu = 0 \Rightarrow \mu = \frac{\sum_{i=1}^n x_i}{n}$$
$$\hat{\mu}_{ML} = \bar{x}$$

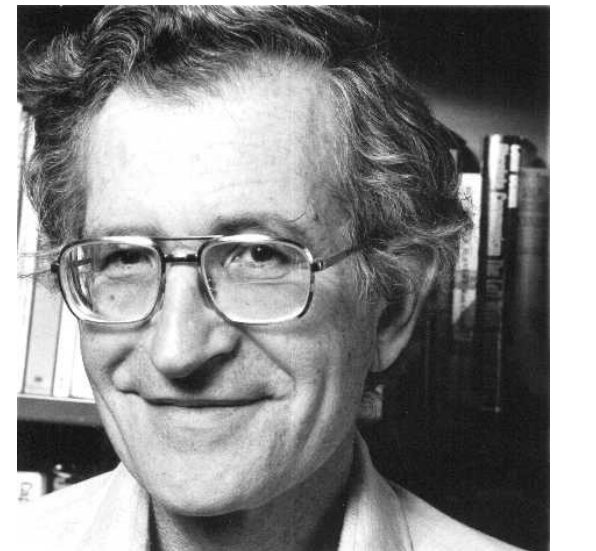


# The development of formal semantics

1933 — Bloomfield: “The statement of meanings is [...] the weak point in language-study, and will remain so until human knowledge advances very far beyond its present state.”



1957 — Chomsky: “there is little evidence that ‘intuition about meaning’ is at all useful in the actual investigation of linguistic form”



1970 — Montague: “There is in my opinion no important theoretical difference between natural languages and the artificial languages of logicians”

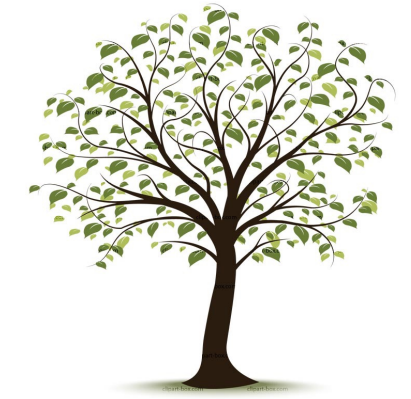




# Course Overview

## Semantic Theory 2022

- **Part I:** Sentence semantics (Montague semantics)
- **Part II:** Lexical semantics
- **Part III:** Discourse semantics
- **Part IV:** Current issues in Semantic Theory



# Part I: Sentence semantics



# Truth-conditional semantics

## A basic semantic principle

**"For two sentences A and B, if in some possible situation A is true and B is false, A and B must have different meanings."**

(M. Cresswell, 1975)

Applied to logical representations:

- For a logical formula  $\alpha$  and a sentence A: If in some possible situation corresponding to a model structure M, sentence A is true, and  $\alpha$  is not, or vice versa, then  $\alpha$  is not an appropriate meaning representation for A.

# Truth-conditional semantics

## Sentence meaning

- To know the meaning of a (declarative) sentence is to know what the world would have to be like for the sentence to be true
- Sentence meaning = truth-conditions
- Indirect interpretation:
  1. Translate sentences into logical formulas:  
Every student works  $\mapsto \forall x(\text{student}'(x) \rightarrow \text{work}'(x))$
  2. Interpret these formulas in a logical model:  
 $\llbracket \forall x(\text{student}'(x) \rightarrow \text{work}'(x)) \rrbracket_{M,g} = 1$  iff  $VM(\text{student}') \subseteq VM(\text{work}')$

# Step 1: from sentence to formula

## Logical Languages

**Propositional logic:** Propositions as basic atoms

- Syntax: propositions ( $p, q, \dots$ ), logical connectives ( $\neg, \wedge, \vee, \rightarrow, \leftrightarrow$ )
- Semantics: truth tables, truth conditions

$p$	$q$	$p \& q$	$p \vee q$	$p \rightarrow q$	$p \leftrightarrow q$
T	T	T	T	T	T
T	F	F	T	F	F
F	T	F	T	T	F
F	F	F	F	T	T

**Predicate logic:** Predicates and arguments

- Syntax: predicates & terms ( $\text{love}'(j', m')$ ,  $\text{mortal}'(x)$ ,  $\dots$ ), quantifiers ( $\forall x \phi, \exists x \phi$ ), logical connectives ( $\wedge, \vee, \neg, \rightarrow, \leftrightarrow$ )
- Semantics: model structures and variable assignments

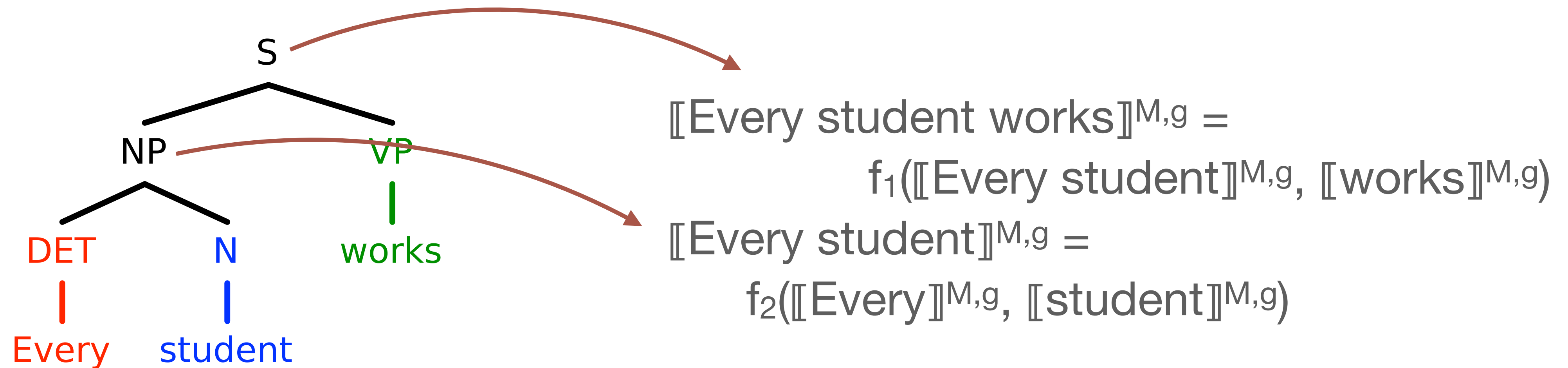
**Type theory:** Higher-order predicate logic with type-theoretic denotations

# Step 1': from words to sentence meaning

## The principle of compositionality

“The meaning of a complex expression is a function of the meanings of its parts and of the syntactic rules by which they are combined”

(Barbara Partee, 1993)

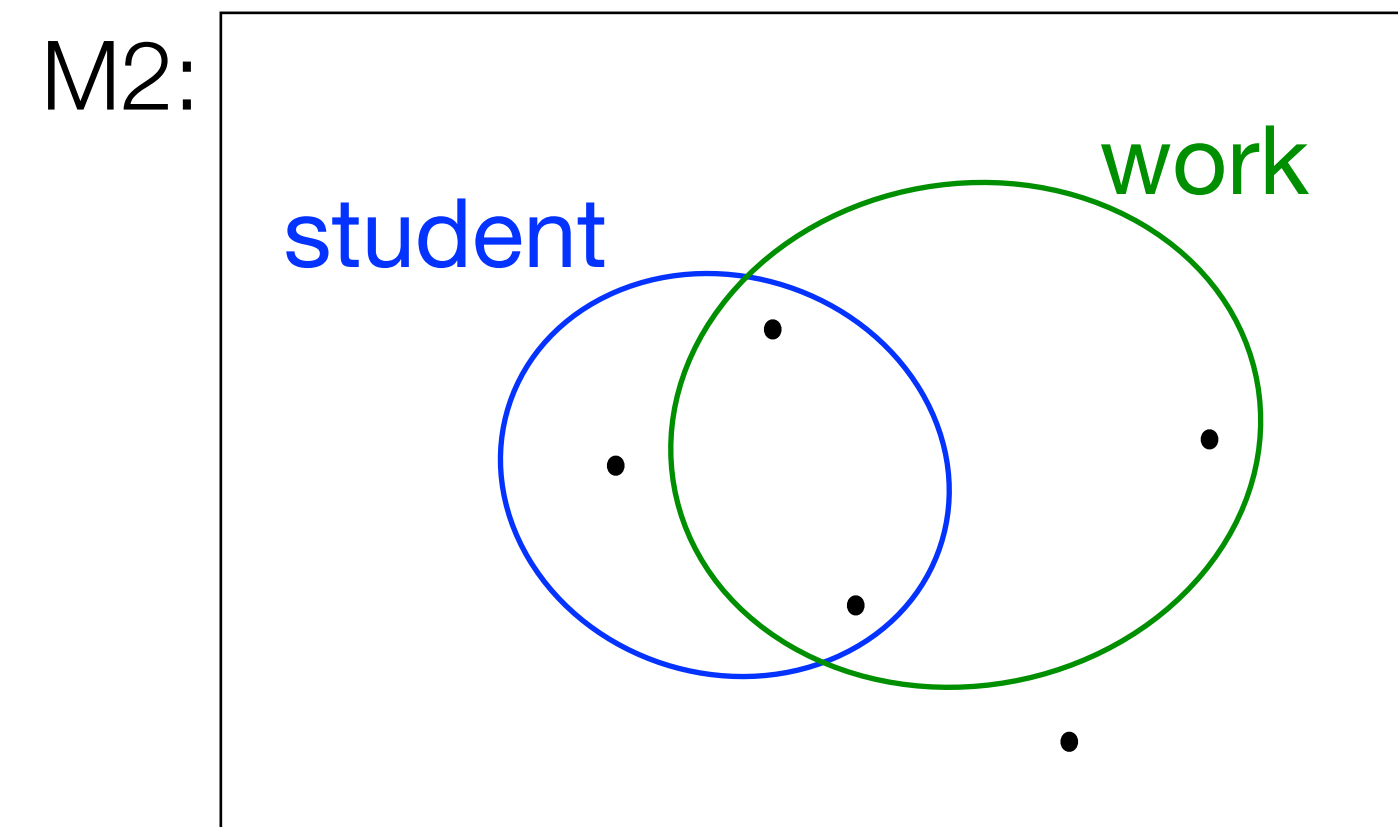
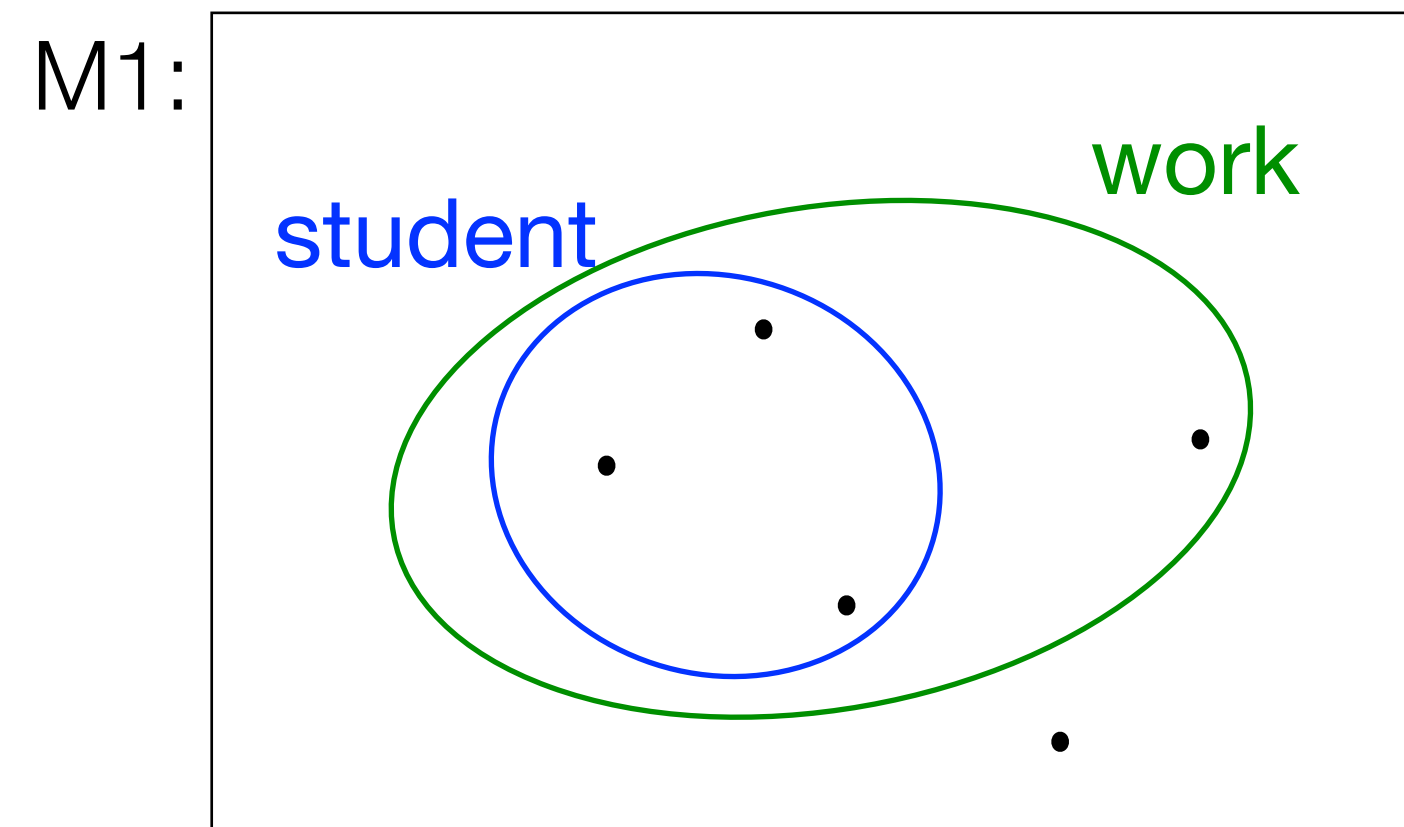


# Step 2: from formula to model

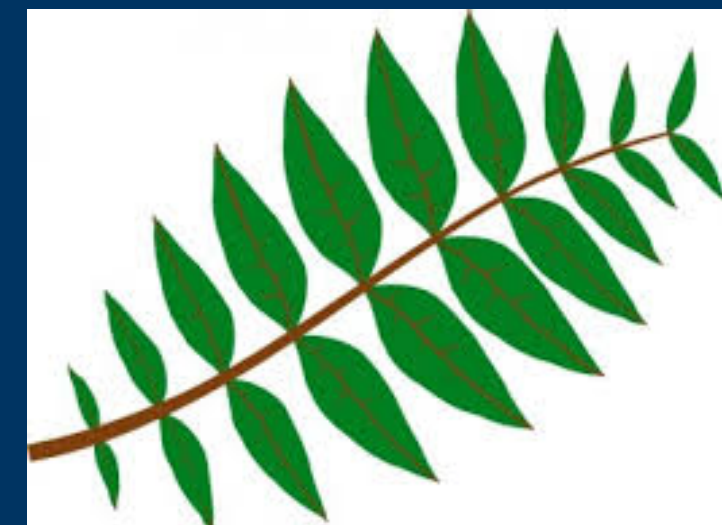
## Model-theoretic interpretation of first-order predicate logic

Every student works

$\llbracket \forall x(\text{student}'(x) \rightarrow \text{work}'(x)) \rrbracket^{M,g} = 1$  iff  $V_M(\text{student}') \subseteq V_M(\text{work}')$



# Part II: Lexical semantics





# Zooming in: the meaning of words

## Lexical semantics revisited

- student  $\mapsto$  **student'** ... what does the ' stand for?



Structured approaches to the lexicon: Lexical meaning defined as relations between concepts in a model

- a “student” is someone who studies
- a “bachelor” is a man who is not married

# Topics in lexical semantics

## Event-denoting expressions

1. a. Bill saw an elephant.  
b. Bill saw an accident.  
c. Bill saw the children play.

## Verb alternatives and semantic roles

2. a. The window broke.  
b. A rock broke the window.  
c. John broke the window with a rock.

## Monotonicity and generalised quantifiers

3. All children came home late  $\rightarrow$  All children came home
4. No children came home late  $\nrightarrow$  No children came home

# Part III: Discourse semantics



# Beyond the sentence boundary

## Limitations of sentence-level semantics

- **Anaphora**

1. John hit Bill. He hit him back.
2. If a farmer owns a donkey, he feeds it.

- **Presuppositions**

3. a. Bill regrets that his cat has died.  
b. Bill doesn't regret that his cat has died

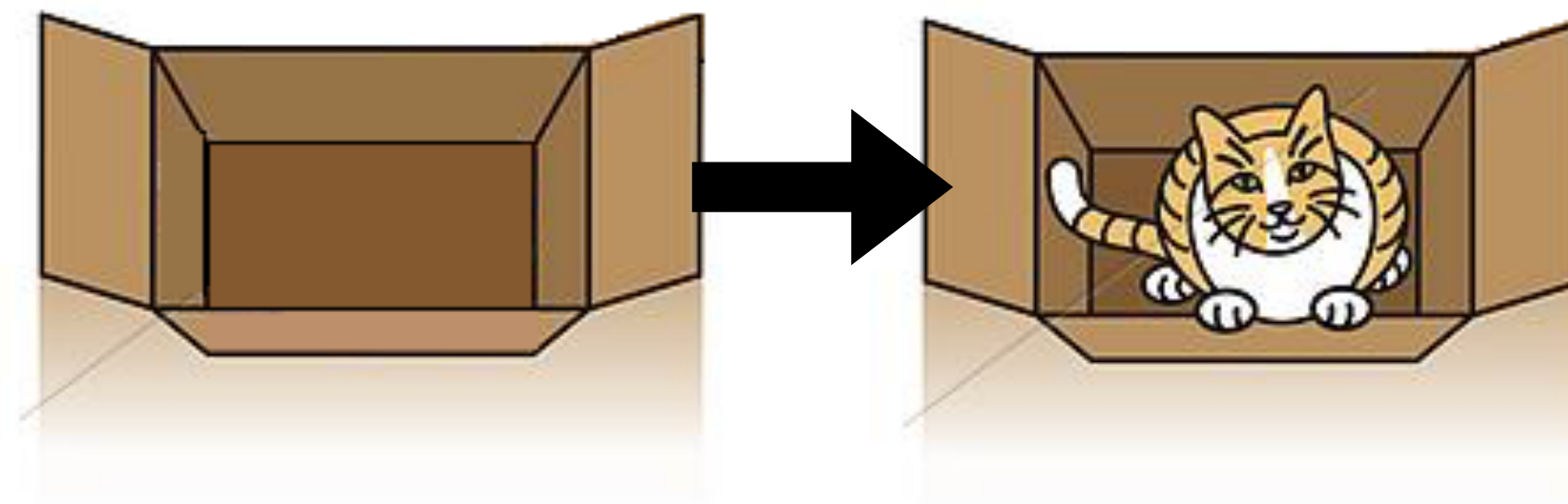
- **Discourse relations**

4. John fell. Mary helped him up.
5. John fell. Mary pushed him.

# Dynamic Semantics

## Revisiting the idea of meaning as truth-conditions

- There is more to meaning than truth-conditions
- Meaning is context-dependent
- Meaning is dynamic: it keeps changing
- Solution: Meaning = context-change potential

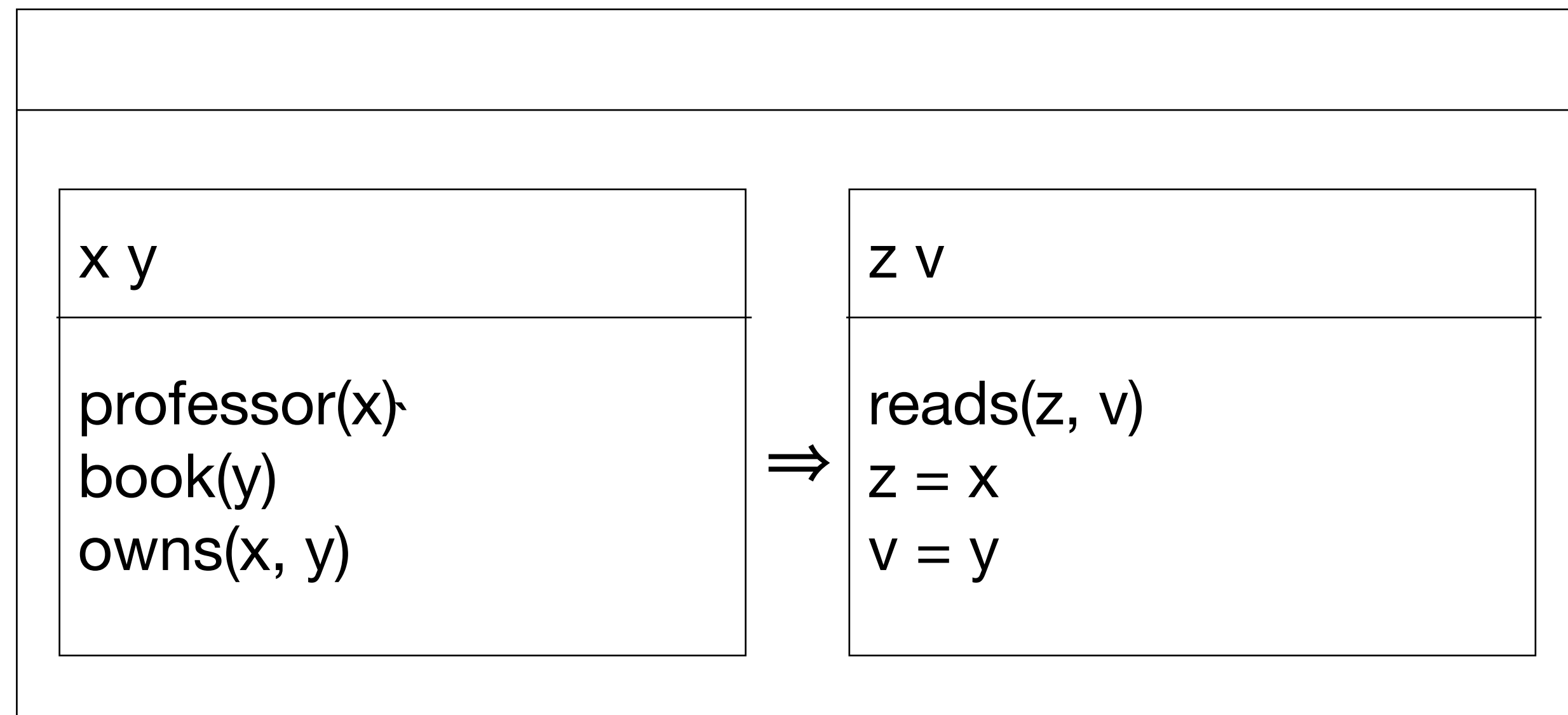


# Discourse Representation Theory

## Representational, mentalist approach to semantics

If a professor owns a book, he reads it.

- $\forall x \forall y [\text{professor}(x) \wedge \text{book}(y) \wedge \text{own}(x, y) \rightarrow \text{read}(x, y)]$



# Discourse Representation Theory

## Applications

The image displays a web browser window showing the PDRT Sandbox application. The browser address bar shows `gmb.let.rug.nl`. The page title is "Document 88/0480 - GMB Explorer". The application header includes the Groningen University logo and navigation links: [explore](#), [challenges](#), [semantic lexicon](#), [search](#), [news feed](#), [statistics](#), [warnings](#), [users](#). A user greeting says "Welcome, noortje (Master Annotator)" with links for [logout](#) and [change password](#).

The main content area shows document information: "Document 481 of 10102, ID: 88 / 0480" with a "Go!" button. Navigation links include [< first](#), [<< previous](#), [next >>](#), and [last >](#), along with a [random](#) button. The status is "accepted" with a [history](#) link. A "Change to:" dropdown is set to "accepted" and a "Comment:" field is present with a "Submit" button.

Below the document info, there are tabs for [metadata](#), [raw](#), [tokens](#), [sentences](#), [discourse](#), [8 bits of wisdom](#), and [0 warnings](#). The "discourse" tab is active, showing three discourse segments (k1, k2, k3) with their respective entities and relations. For example, k1 includes `people(x1)`, `touch(e1)`, `Experiencer(e1, x1)`, `now(t1)`, `x2 = t1`, `t2 ⊃ x2`, `e1 ⊃ t2`, `lx3l = 31`, `x4 c x3`, `x5 c x3`, `city(x4)`, `town(x5)`, `named(x6, america, geo)`, `across(x3, x6)`, and `in(e1, x3)`.

Overlaid on the main interface is a smaller window titled "PDRT - ghc - 114x39". This window shows a DRS (Discourse Representation Structure) visualization. The top part shows a DRS: `Prelude Data.DRS> DRS [DRSRef "x"] [Rel (DRSRel "Luke") [DRSRef "x"]]`. Below this, there are boxes representing the DRS content, including `x`, `Luke(x)`, `father(y)`, `of(x,y)`, and `like(x,y)`. The bottom part of the window shows a DRS operation: `Prelude Data.DRS> printMerge luke doesntlikehisfather`, resulting in a visual equation: `Luke(x) + father(y) of(x,y) = Luke(x) father(y) of(x,y)`. The right side of this window contains filter controls: "Filter by part:", "Filter by status: accepted", "Filter by subcorpus:", and "Effective BOWs:" with a search button.

**PDRT**  
**SANDBOX**

# Part IV: Current Issues in Semantic Theory





# The Next Big Thing in Semantic Theory...

## Formal semantics for deep learning?

**Distributional Semantics**     *“You shall know a word by the company it keeps”* (J. R. Firth, 1957)

- lexical meaning: high dimensional vectors derived from corpora (*big data!*)
- semantic similarity ~ vector similarity
- ... but what about formal semantic principles such as compositionality?

## Distributional Formal Semantics

- Meaning vectors defined over propositions in a world
- Expressive, compositional, probabilistic, inferential and neurally plausible
- ... but how does it relate to formal semantic models?



# Current issues in Semantic Theory

## Open questions

- Where is the border between semantics and pragmatics?
- What do (or: can) formal semantic theories say about the way meaning is stored and created in the human brain?
- How can we use formal semantics for practical purposes (for example to improve machine translation)?

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- Main communication platform: Microsoft Teams (slides, exercises, chat)
- Prerequisites: Familiarity with first-order predicate logic.
- See: Logic in Action, Chapter 4 (Sec. 4.1 & 4.2): <http://logicinaction.org/docs/ch4.pdf>

**See you on Tuesday (in person!) 😊**