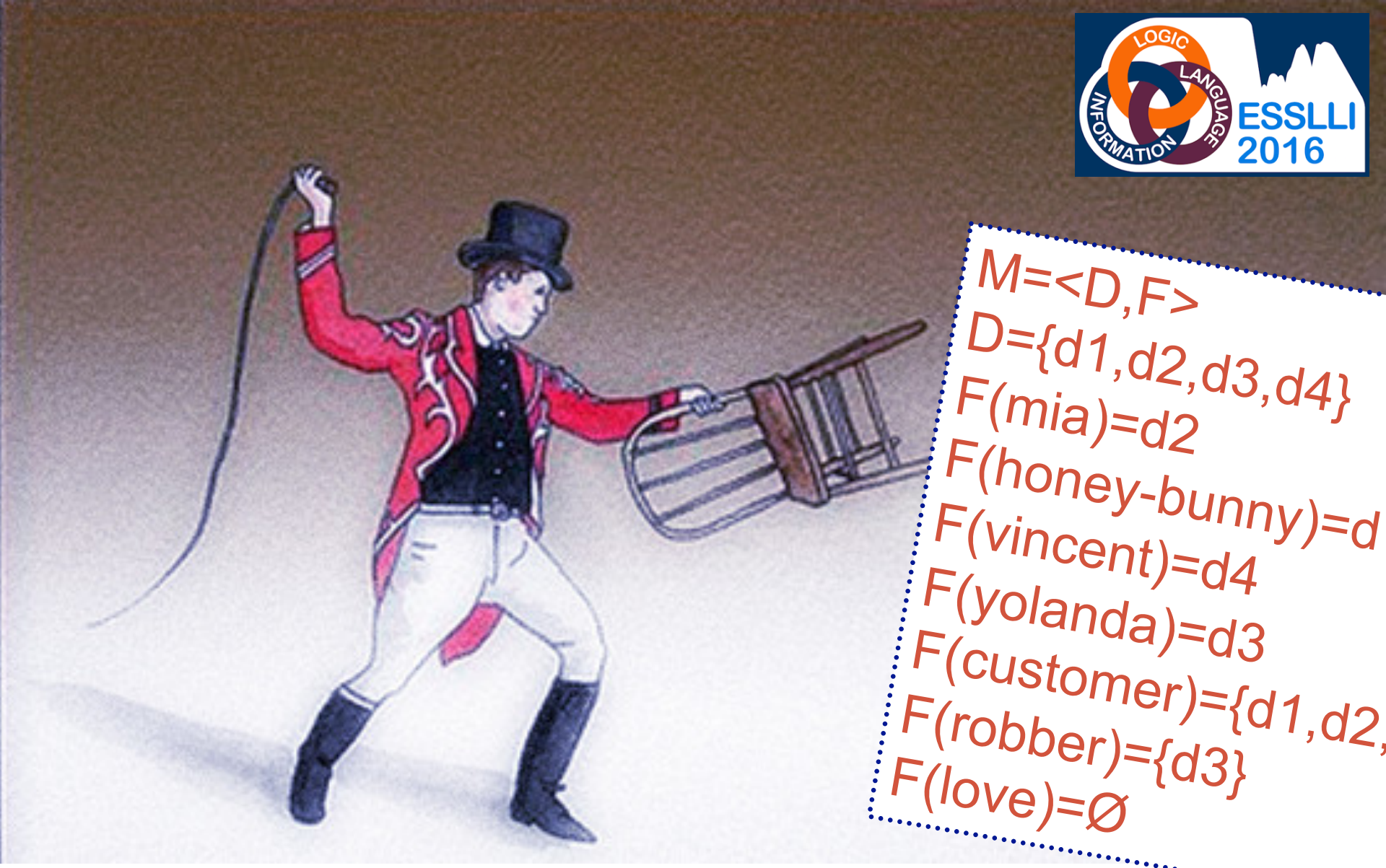
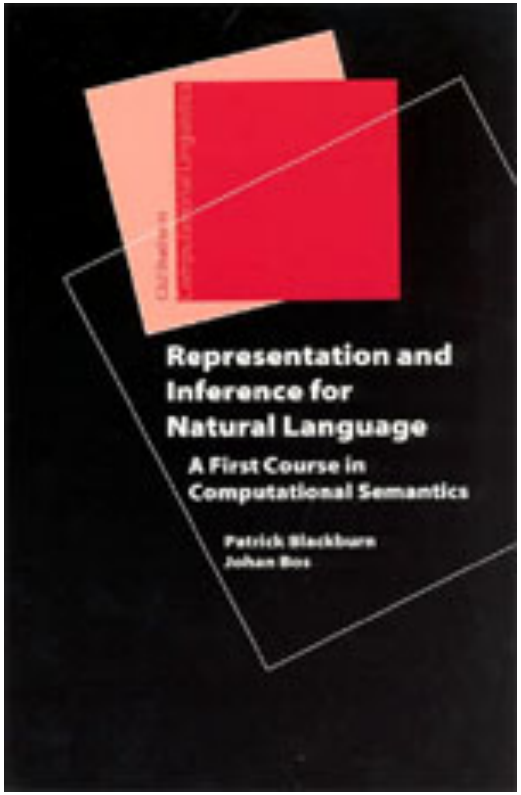


Day 1: Exploring Models

Johan Bos

Computational Semantics

- **Day 1: Exploring Models**
- Day 2: Meaning Representations
- Day 3: Computing Meanings
- Day 4: Drawing Inferences
- Day 5: Meaning Banking



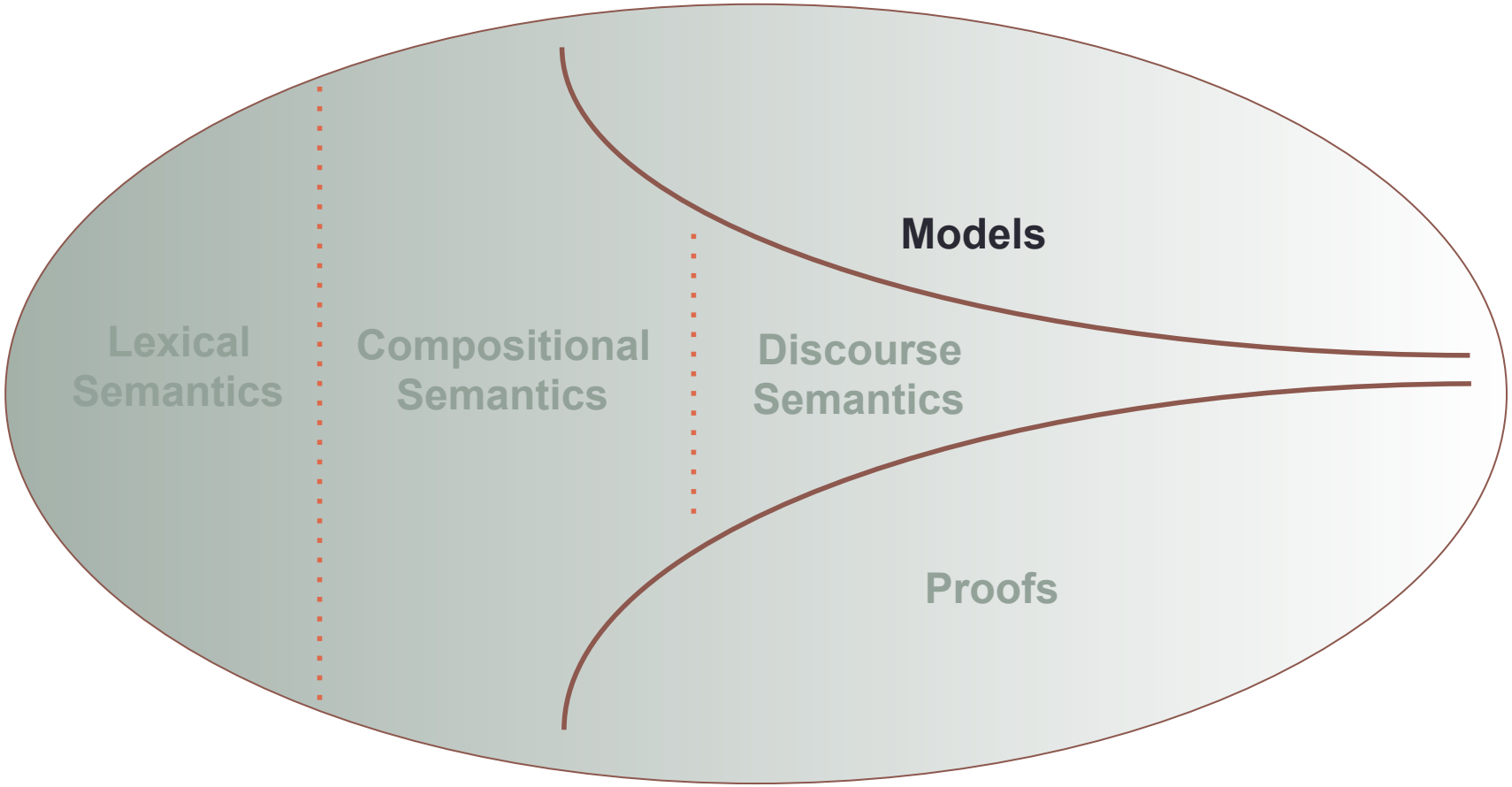
Truth Verification

Bolt is faster than everyone else. **YES**

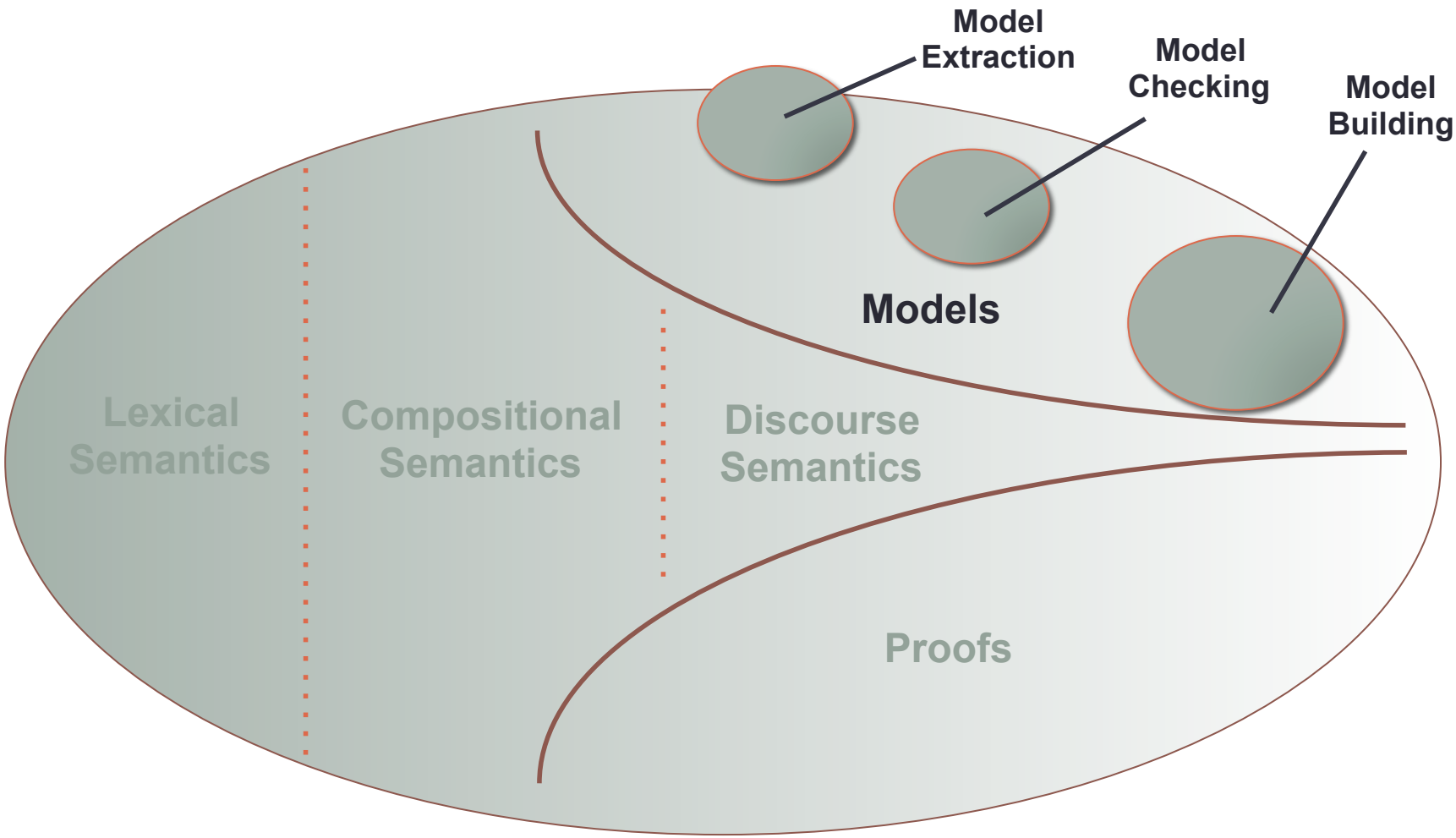
Bolt is in last position. **NO**

What is semantics about?

Model-Theoretic Semantics



Model-Theoretic Semantics



Models

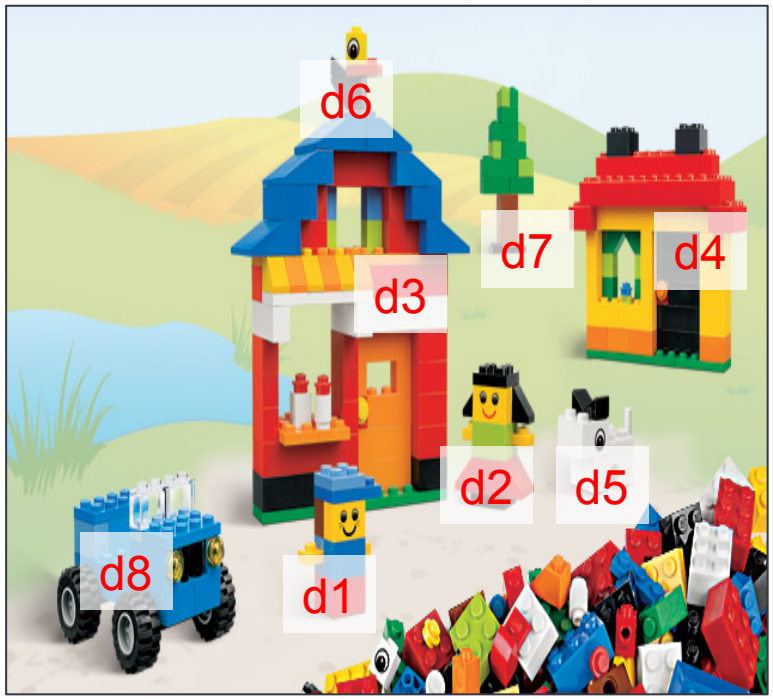
- Model-theoretic semantics
- Alfred Tarski

Models: simplifications of reality

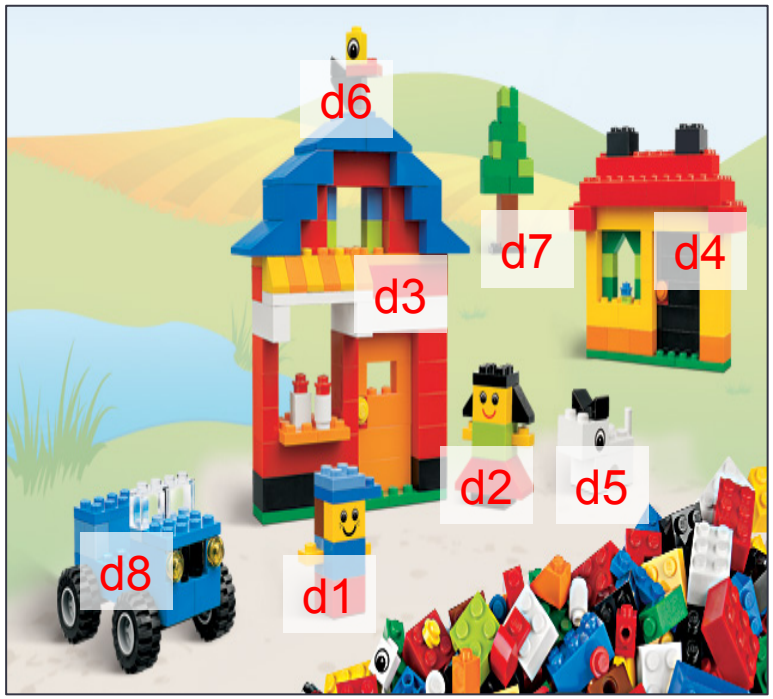
Models: approximations of reality

An example model

An example model

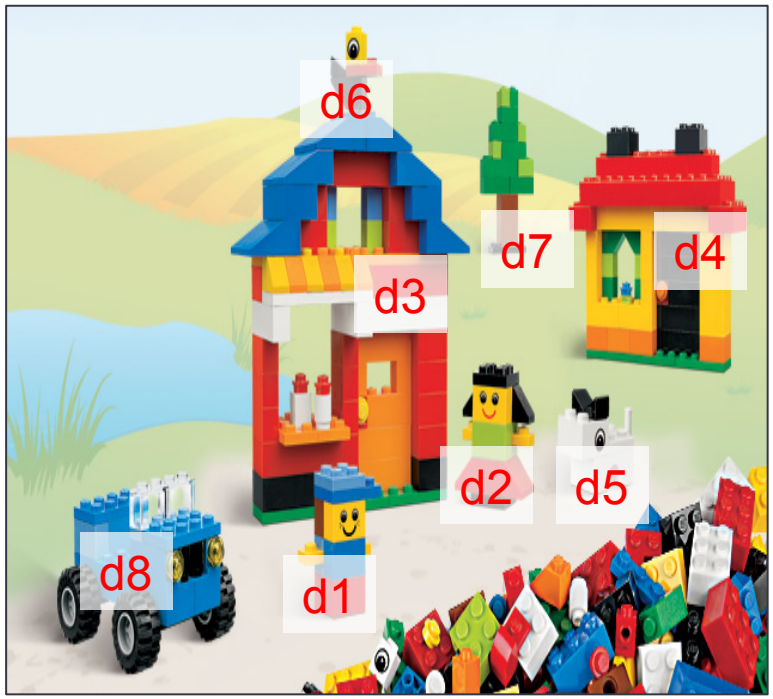


An example model



(non-logical) **symbols**:
man/1, woman/1, house/1, dog/1,
bird/1, car/1, tree/1, happy/1,
near/2, at/2

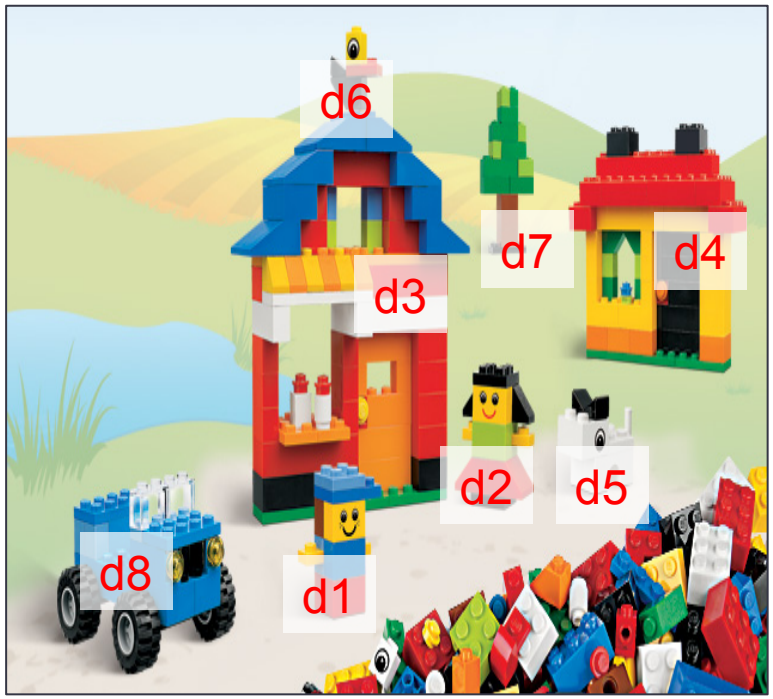
An example model



(non-logical) **symbols**:
man/1, woman/1, house/1, dog/1,
bird/1, car/1, tree/1, happy/1,
near/2, at/2

} ***VOCABULARY***

An example model



(non-logical) **symbols**:
man/1, woman/1, house/1, dog/1, bird/1, car/1, tree/1, happy/1, near/2, at/2

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)}

A first-order model

- A first-order model <D,F> has two parts:
  - D: a domain (the universe) of objects (entities)
  - F: an interpretation function

- The interpretation functions maps symbols from our vocabulary to members of the domain
  - Zero-place symbols (constants) are mapped to a single domain member
  - One-place symbols (predicates) are mapped to a set of domain members
  - Two-place symbols (relations) are mapped to a set of ordered pairs of domain members

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)=Ø

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}

Finite models

- In practice we can only work with finite models (obviously)
- But it is easy to find a description that is satisfiable but does not have a finite model

Herbrand models

M=<D,F>
D={d1,mia,d3,vincent}
F(customer)={d1,mia,vincent}
F(robber)={d3}
F(love)={(d1,mia),(vincent,vincent)}

first-order and second-order models

- a first-order domain consists of entities
- a second-order domain consists of entities *and* properties or relations:

$M=\langle D,F\rangle$
$D_e=\{d1,d2,d3\}$
$D_{e\rightarrow t}=\{man,woman\}$
$F(man)=\{d1,d2\}$
$F(woman)=\{d3\}$

Alternative names for models

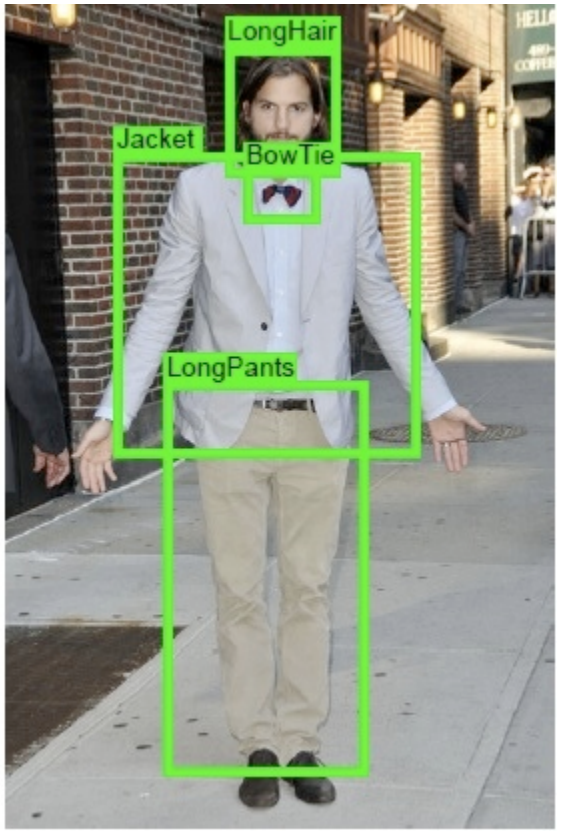
- Interpretation
- Structure

Model Extraction

- The task of mapping sensory input (an image, video, or audio) to a model

Input: **image**
Output: model

M=<D,F>
D={d1,d2,d3,d4,d5}
F(Jacket)={d2}
F(LongHair)={d3}
F(Has)={(d1,d3)}
....



source: Joo, Wang & Zhu (2013)

GRIM: Groningen Image Models

GRIM

- 200 pictures annotated with first-order models
- Common vocabulary and standard representation format (Blackburn & Bos)

Model extraction method

1. identify the entities
2. categorize the entities
3. add color terms
4. identify the relations
5. categorize the relations
6. check reflexive relations

Example

AMBIGUITY

Lexical Ambiguity

Most words in natural languages have multiple possible meanings

“pen” (noun)

- The dog is in the pen.
- The ink is in the pen.

“take” (verb)

- Take one pill every morning.
- Take the first right past the stoplight.

How many different senses for table are used in these five sentences?

① “See table 4.”
② “It was a sturdy table.”
③ "I reserved a table at my favorite restaurant.”
④ “She sets a fine table.”
⑤ “He entertained the whole table with his witty remarks.”

What is a “sense” of a word?

- **Homonyms**
  (same words, disconnected meanings)
- **Polysemes**
  (same words, connected meanings)
- **Metonyms**
  (systematically related meanings)

Homonyms: disconnected meanings

bank

- financial institute

bank

- sloping land next to river

Homonyms: disconnected meanings

fan

- device used to induce an airflow for the purpose of cooling or refreshing oneself

fan

- a person with a liking and enthusiasm for something

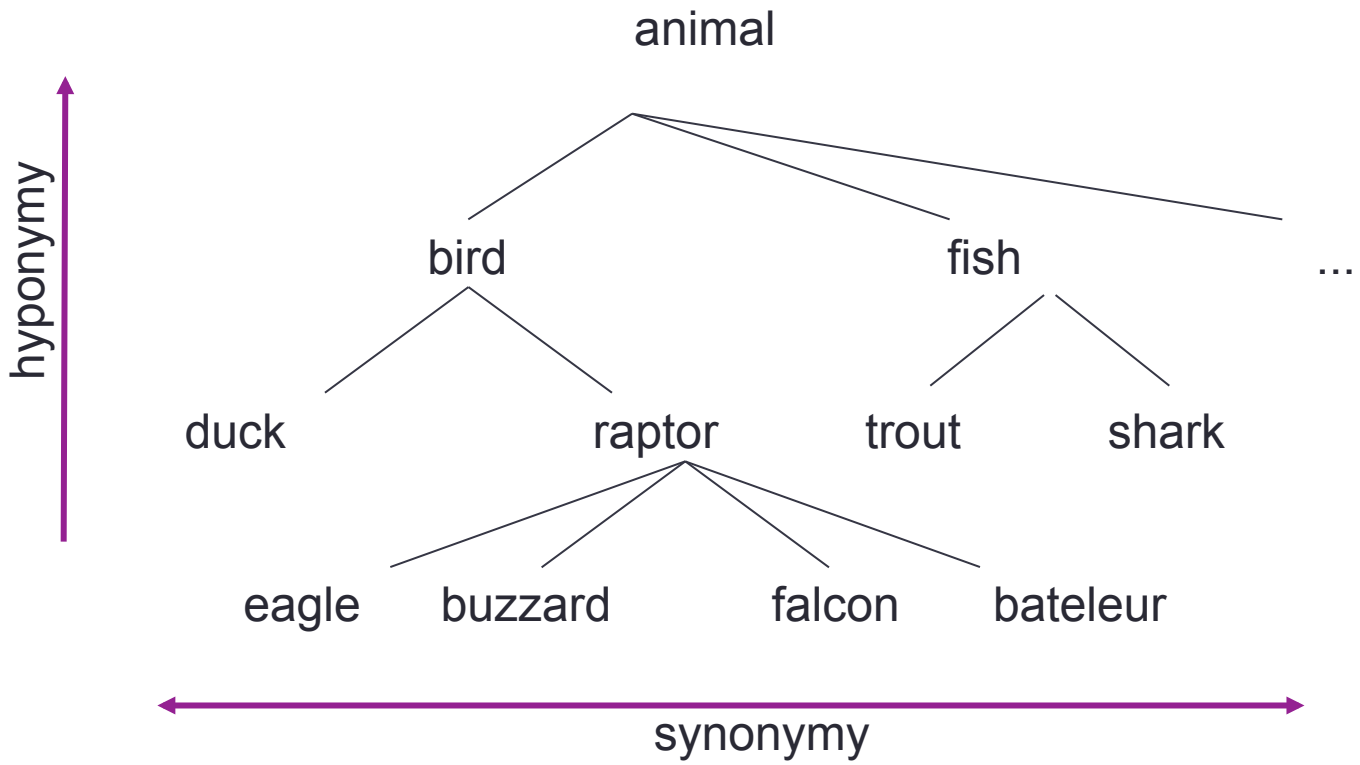
Hyponymy

- A sense is a hyponym of another sense if the first sense is more specific than the other
  (i.e., forms a subclass)

dog — pet
falcon — bird
house — building
company — organisation

- Note: similar to ISA links in a knowledge base

ISA-hierarchy



Hyperonymy

- A sense is a hyperonym of another sense if the first sense is more general than the other
  (i.e., forms a superclass)

dog — boxer
falcon — kestrel
house — villa
company — agency

- Note: inverse of hyponomy

WordNet

- A detailed database of semantic relationships between English words
- Developed by famous cognitive psychologist George Miller and team at Princeton University.
- Comprises about 155K English words.
- Nouns, adjectives, verbs, and adverbs grouped into about 117K synonym sets called *synsets*.

WordNet synsets

- How are word meanings represented in WordNet?
  - By **synsets** (synonym sets) as basic units
  - A concept (word meaning) is represented by listing the word forms that can be used to express it

Example of WordNet synset

Two senses of *board*

- Sense 1: a piece of lumber:
  {board, plank, ...}

- Sense 2: a group of people assembled
  for some purpose
  {board, committee, ...}

WordNet: global organisation

Division of the lexicon into four main categories:

- Nouns
- Verbs
- Adjectives
- Adverbs

WordNet: nouns

Noun

- hyponym
- hypernym
- holonym
- meronym

S: (n) **pony** (any of various breeds of small gentle horses usually less than five feet high at the shoulder)
- *direct hyponym* / *full hyponym*
- *direct hypernym* / ***inherited hypernym*** / *sister term*
  - S: (n) horse, Equus caballus (solid-hoofed herbivorous quadruped domesticated since prehistoric times)
    - S: (n) equine, equid (hoofed mammals having slender legs and a flat coat with a narrow mane along the back of the neck)
      - S: (n) odd-toed ungulate, perissodactyl, perissodactyl mammal (placental mammals having hooves with an odd number of toes on each foot)
        - S: (n) ungulate, hoofed mammal (any of a number of mammals with hooves that are superficially similar but not necessarily closely related taxonomically)
          - S: (n) placental, placental mammal, eutherian, eutherian mammal (mammals having a placenta; all mammals except monotremes and marsupials)
            - S: (n) mammal, mammalian (any warm-blooded vertebrate having the skin more or less covered with hair; young are born alive except for the small subclass of monotremes and nourished with milk)
              - S: (n) vertebrate, craniate (animals having a bony or cartilaginous skeleton with a segmented spinal column and a large brain enclosed in a skull or cranium)
                - S: (n) chordate (any animal of the phylum Chordata having a notochord or spinal column)
                  - S: (n) animal, animate being, beast, brute, creature, fauna (a living organism characterized by voluntary movement)
                    - S: (n) organism, being (a living thing that has (or can develop) the ability to act or function independently)
                      - S: (n) living thing, animate thing (a living (or once living) entity)
                        - S: (n) whole, unit (an assemblage of parts that is regarded as a single entity) *"how big is that part compared to the whole?"; "the team is a unit"*
                          - S: (n) object, physical object (a tangible and visible entity; an entity that can cast a shadow) *"it was full of rackets, balls and other objects"*
                            - S: (n) physical entity (an entity that has physical existence)
                              - S: (n) entity (that which is perceived or known or inferred to have its own distinct existence (living or nonliving))

deep

shallow

All nouns go up to the root synset: {entity}

Selecting senses from WordNet

F(n_car#1)={d1}

Noun

- S: (n) **car**, auto, automobile, machine, motorcar (a motor vehicle with four wheels; usually propelled by an internal combustion engine) *"he needs a car to get to work"*
- S: (n) **car**, railcar, railway car, railroad car (a wheeled vehicle adapted to the rails of railroad) *"three cars had jumped the rails"*
- S: (n) **car**, gondola (the compartment that is suspended from an airship and that carries personnel and the cargo and the power plant)
- S: (n) **car**, elevator car (where passengers ride up and down) *"the car was on the top floor"*
- S: (n) cable car, **car** (a conveyance for passengers or freight on a cable railway) *"they took a cable car to the top of the mountain"*

Selecting senses from WordNet

F(n_car#1)={d1}

F(n_cat#1)={d2}

Noun

- S: (n) **cat**, true cat (feline mammal usually having thick soft fur and no ability to roar: domestic cats; wildcats)
- S: (n) guy, **cat**, hombre, bozo, sod (an informal term for a youth or man) *"a nice guy"; "the guy's only doing it for some doll"; "the poor sod couldn't even buy a drink"*
- S: (n) **cat** (a spiteful woman gossip) *"what a cat she is!"*
- S: (n) kat, khat, qat, quat, **cat**, Arabian tea, African tea (the leaves of the shrub Catha edulis which are chewed like tobacco or used to make tea; has the effect of a euphoric stimulant) *"in Yemen kat is used daily by 85% of adults"*
- S: (n) cat-o'-nine-tails, **cat** (a whip with nine knotted cords) *"British sailors feared the cat"*
- S: (n) Caterpillar, **cat** (a large tracked vehicle that is propelled by two endless metal belts; frequently used for moving earth in construction and farm work)
- S: (n) big cat, **cat** (any of several large cats typically able to roar and living in the wild)
- S: (n) computerized tomography, computed tomography, CT, computerized axial tomography, computed axial tomography, **CAT** (a method of examining body organs by scanning them with X rays and using a computer to construct a series of cross-sectional scans along a single axis)

Selecting senses from WordNet

F(n_car#1)={d1}
F(n_cat#1)={d2}
F(a_green#1)={d1}

Adjective

- S: (adj) **green**, greenish, light-green, dark-green (of the color between blue and yellow in the color spectrum; similar to the color of fresh grass) *"a green tree"; "green fields"; "green paint"*
- S: (adj) **green** (concerned with or supporting or in conformity with the political principles of the Green Party)
- S: (adj) **green**, unripe, unripened, immature (not fully developed or mature; not ripe) *"unripe fruit"; "fried green tomatoes"; "green wood"*
- S: (adj) **green** (looking pale and unhealthy) *"you're looking green"; "green around the gills"*
- S: (adj) fleeceable, **green**, gullible (naive and easily deceived or tricked) *"at that early age she had been gullible and in love"*

First reminder for teacher:
show some GRIM models
(standard as well as grounded models)

Selecting senses from WordNet

F(n_car#1)={d1}
F(n_cat#1)={d2}
F(a_green#1)={d1}

Noun

- S: (n) hair's-breadth, hairsbreadth, hair, **whisker** (a very small distance or space) *"they escaped by a hair's-breadth"; "they lost the election by a whisker"*
- S: (n) **whisker**, vibrissa, sensory hair (a long stiff hair growing from the snout or brow of most mammals as e.g. a cat)

n_whisker#2

Models as Prolog terms

F(n_car#1)={d1}
F(n_cat#1)={d2}
F(a_green#1)={d1}

```
model([d1,d2],
      [f(1,n_car_1,[d1]),
       f(1,n_cat_1,[d2]),
       f(1,a_green_1,[d1]),
       f(2,supports,[(d1,d2)])])
```

lowercase letters because functors need to be atoms!

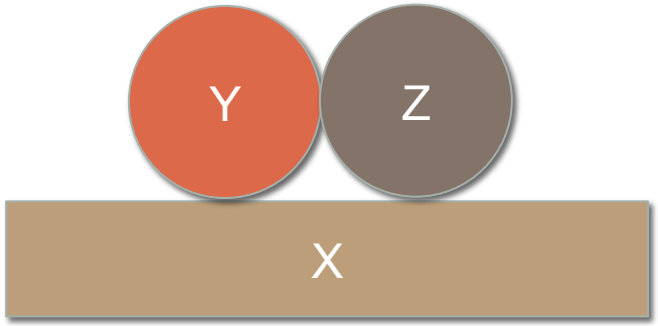
Spatial relations (in GRIM)

- part-of
- supports
- touches
- near
- occludes

Spatial relations

- X **touches** Y:
  X and Y have a point in common

- X **supports** Y:
  X and Y have a point in common, and the position of Y depends on the position of X



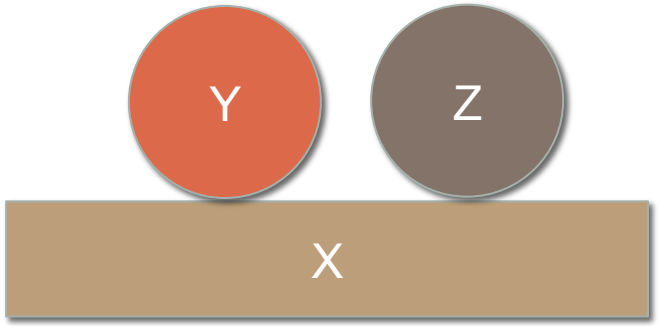
X supports Y
X supports Z
Y touches Z
Z touches Y

X touches Y
X touches Z
Y touches X
Z touches X

Inference rules:
X touches Y → Y touches X
X supports Y → ¬ Y supports X
X supports Y → X touches Y

Vague spatial relations

- X **is_near** Y:
  X and Y have no point in common, but their positions are relatively near to each other (in the real world?)



X supports Y
X supports Z
Y is_near Z
Z is_near Y

Inference rules:
X is_near Y → Y is_near X
X is_near Y → ¬ X touches Y
X is_near Y → ¬ X supports Y

Second reminder for teacher: show some GRIM models with spatial relations

Events

- So far we have only modelled static situations!
- But what about dynamic situations?

Modeling emotional states

M=<D,F>

D={d1,d2,d3,d4}

F(MIA)=d1

F(MONDAY)=d2

F(TUESDAY)=d3

F(WEDNESDAY)=d4

F(PERSON)={d1}

F(DAY)={d2,d3,d4}

F(PRECEDES)={(d2,d3),(d3,d4),(d2,d4)}

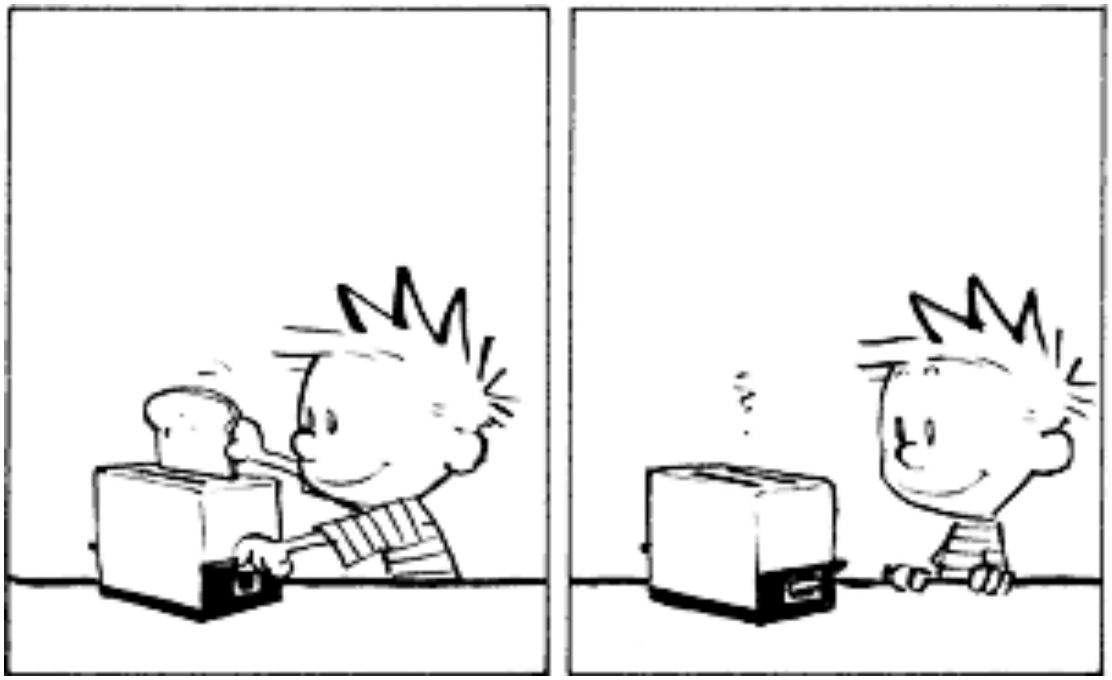
F(HAPPY)={(d1,d2),(d1,d4)}

monday

tuesday

wednesday

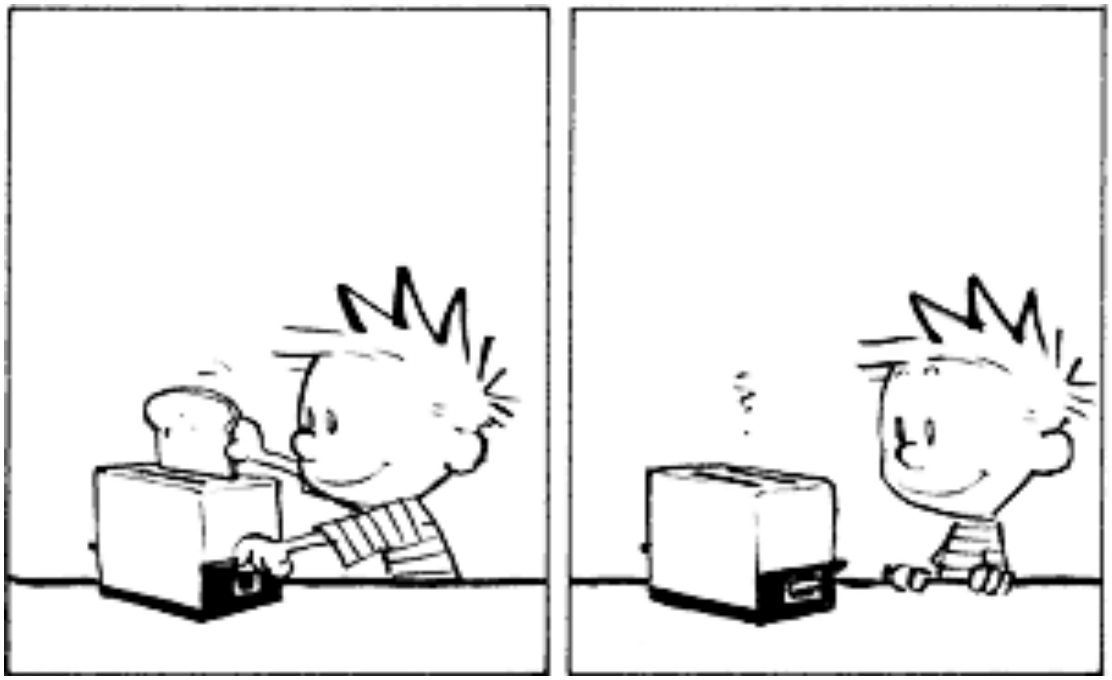
Calvin



M=<D,F>
D={d1,d2,d3}
F(calvin)=d1
F(toaster)={d2}
F(bread)={d3}
F(in)=Ø

M=<D,F>
D={d1,d2,d3}
F(calvin)=d1
F(toaster)={d2}
F(bread)={d3}
F(in)={(d3,d2)}

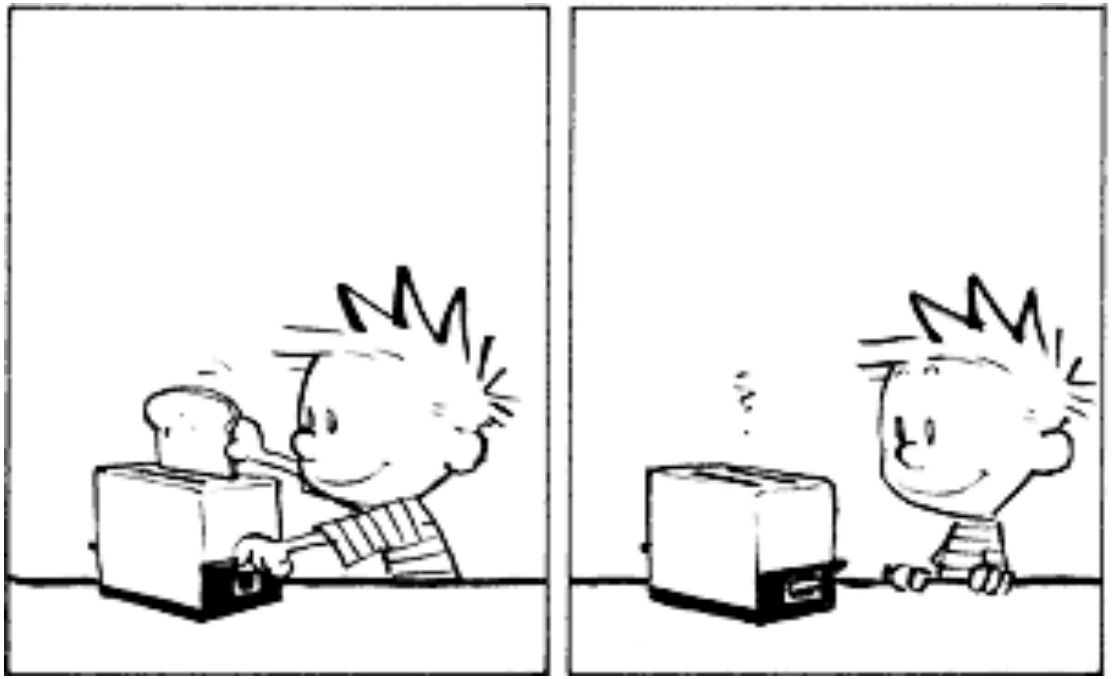
Calvin



M=<D,F>
D={d1,d2,d3}
F(calvin)=d1
F(toaster)={d2}
F(bread)={d3}
F(in)=Ø

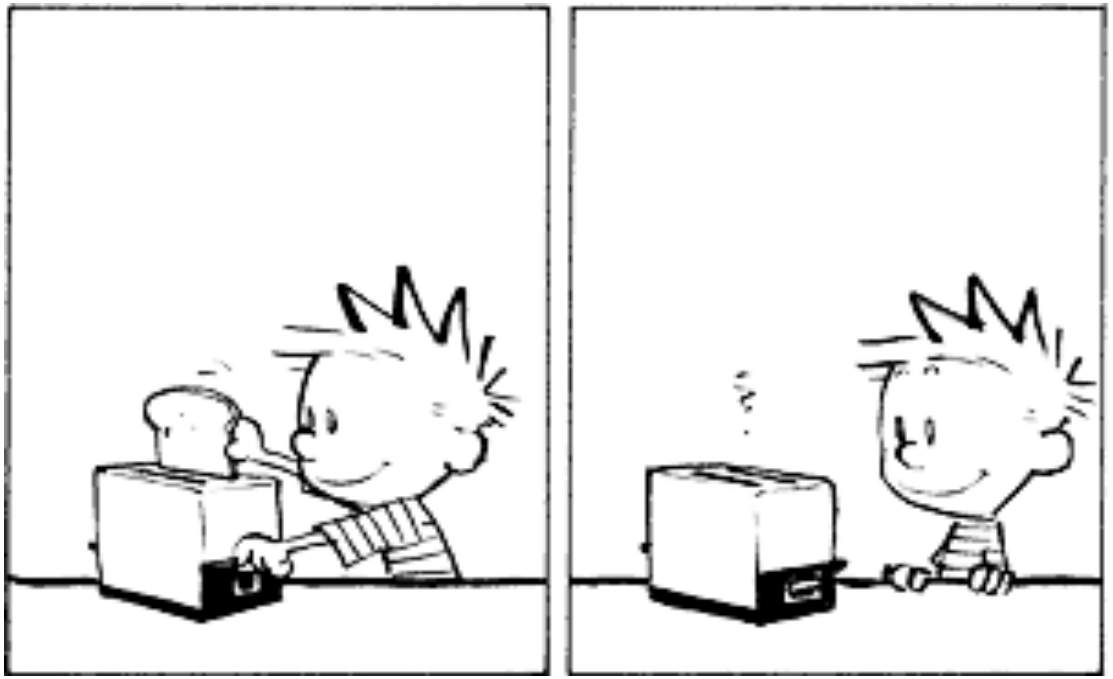
M=<D,F>
D={d5,d2,b6}
F(calvin)=d5
F(toaster)={d2}
F(bread)={b6}
F(in)={(b6,d2)}

Calvin



M=<D,F>
D={d1,d2,d3,t1,t2}
F(before)={(t1,t2)}
F(calvin)=d1
F(toaster)={d2}
F(bread)={d3}
F(in)={(t2,d3,d2)}
F(holding)={(t1,d1,d3)}

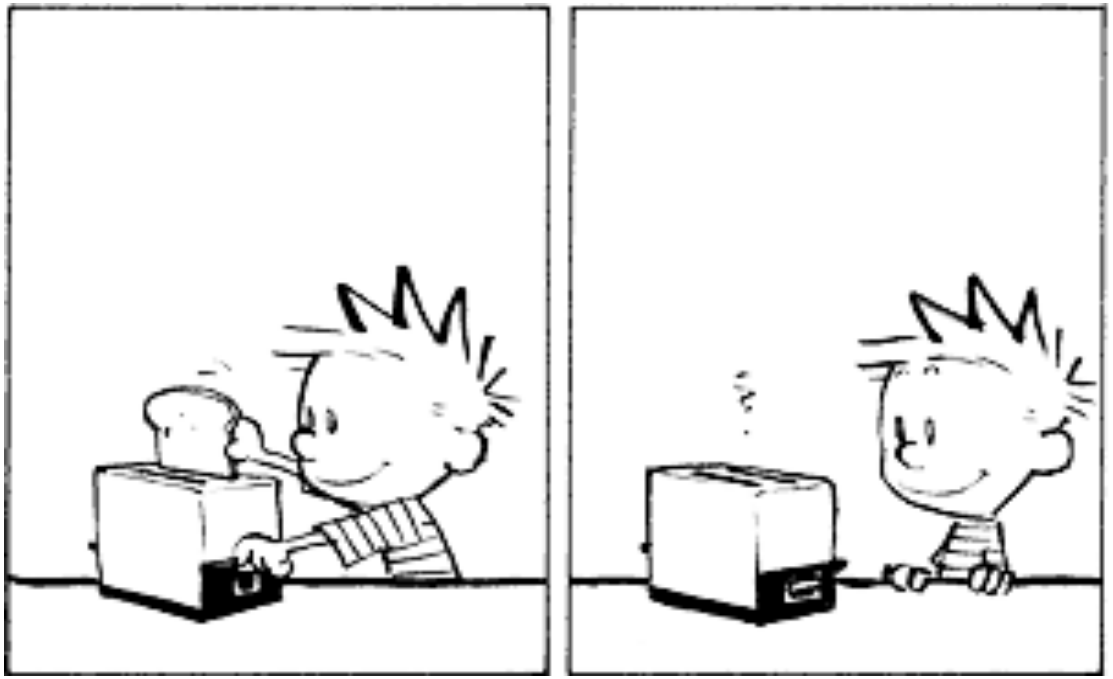
Calvin



STATIC PREDICATES

M=<D,F>
D={d1,d2,d3,t1,t2}
F(before)={(t1,t2)}
F(calvin)=d1
F(toaster)={d2}
F(bread)={d3}
F(in)={(t2,d3,d2)}
F(holding)={(t1,d1,d3)}

Calvin



M=<D,F>
D={d1,d2,d3,t1,t2}
F(before)={(t1,t2)}
F(calvin)=d1
F(toaster)={d2}
F(bread)={d3}
F(in)={(t2,d3,d2)}
F(holding)={(t1,d1,d3)}

DYNAMIC PREDICATES

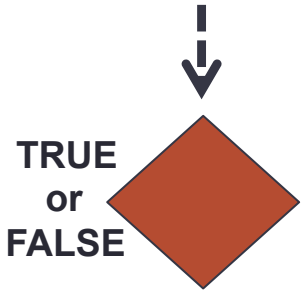
A person kicking something

On t_1: leg of person is *near* ball, but does not *touch* it
On t_2: leg of person *touches* ball
On t_3: ball is not *near* person

M=<D,F> D={d1,d2,d3,d4,t1,t2,t3}

F(woman)={d1}
F(ball)={d2}
F(leg)={d3,d4}
F(part-of)={(d3,d1),(d4,d1)}
F(before)={(t1,t2),(t2,t3),(t1,t3)}
F(abut)={(t1,t2),(t2,t3)}
F(near)={(t1,d1,d3),(t1,d1,d3)}
F(touches)={(t2,d1,d2),(t2,d3,d2),(t2,d2,d1),(t2,d2,d3)}

The Big Picture



real world

The Big Picture

Semantic Parsing

meaning

Model Checking

TRUE or FALSE

Model Extraction

model

The Big Picture

WEDNESDAY

Semantic Parsing

meaning

Model Checking

TUESDAY

TRUE or FALSE

Model Extraction

TODAY

model