NATURAL LANGUAGE INTERPRETATION

DIT411/TIN175, Artificial Intelligence

Peter Ljunglöf

26 January, 2018

TABLE OF CONTENTS

WHAT IS NATURAL LANGUAGE?

Natural language

- Any language that develops naturally in humans through use and repetition
    - e.g.: English, Swedish, Runyankole, Kangiryuarmiutun
- Imprecisely defined: is “*I totally lol’ed*” correct?
- Interpretation can be ambiguous

Formal language

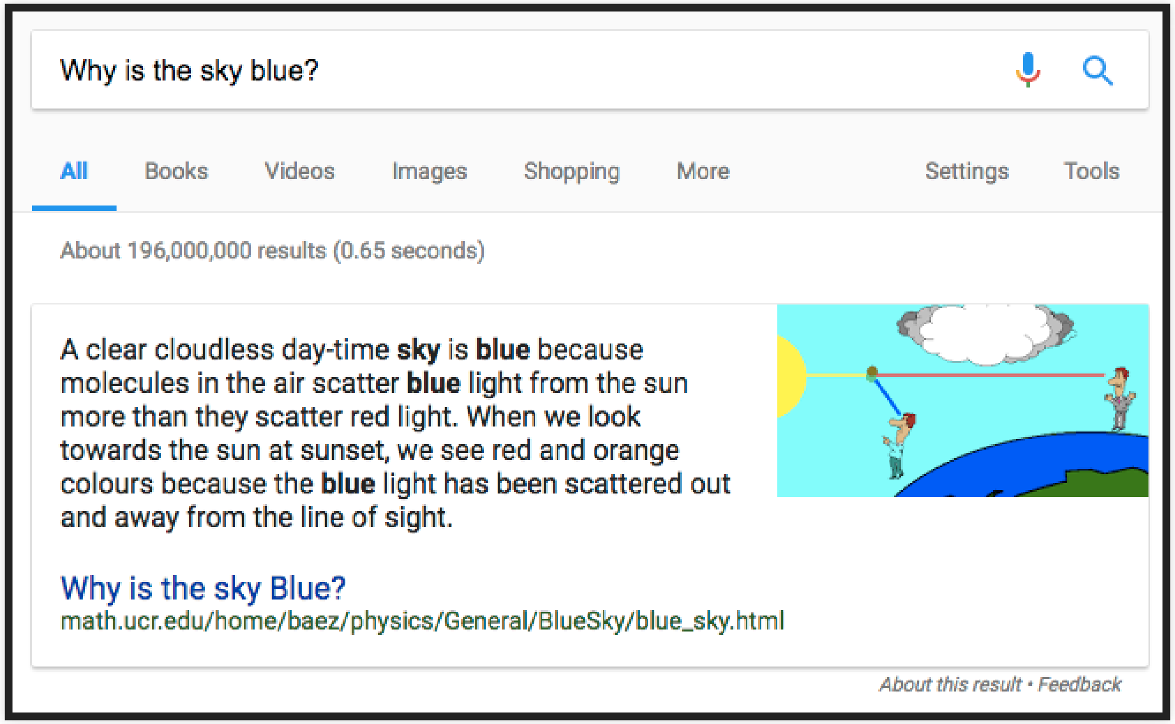
- Specifically constructed for some purpose, e.g.: Javascript, propositional logic
- Precisely defined
    - print(1 + 2) ✅
    - print(+ 1 2. ❌
- Unambiguous, precise semantics

NATURAL LANGUAGE PROCESSING (NLP)

Some examples of NLP tasks:

- Information retrieval, e.g., web search
- Machine translation, e.g. Google translate
- Classification, e.g. sentiment analysis
- Information extraction, e.g. Named entity recognition

INFORMATION RETRIEVAL



Why is the sky blue?

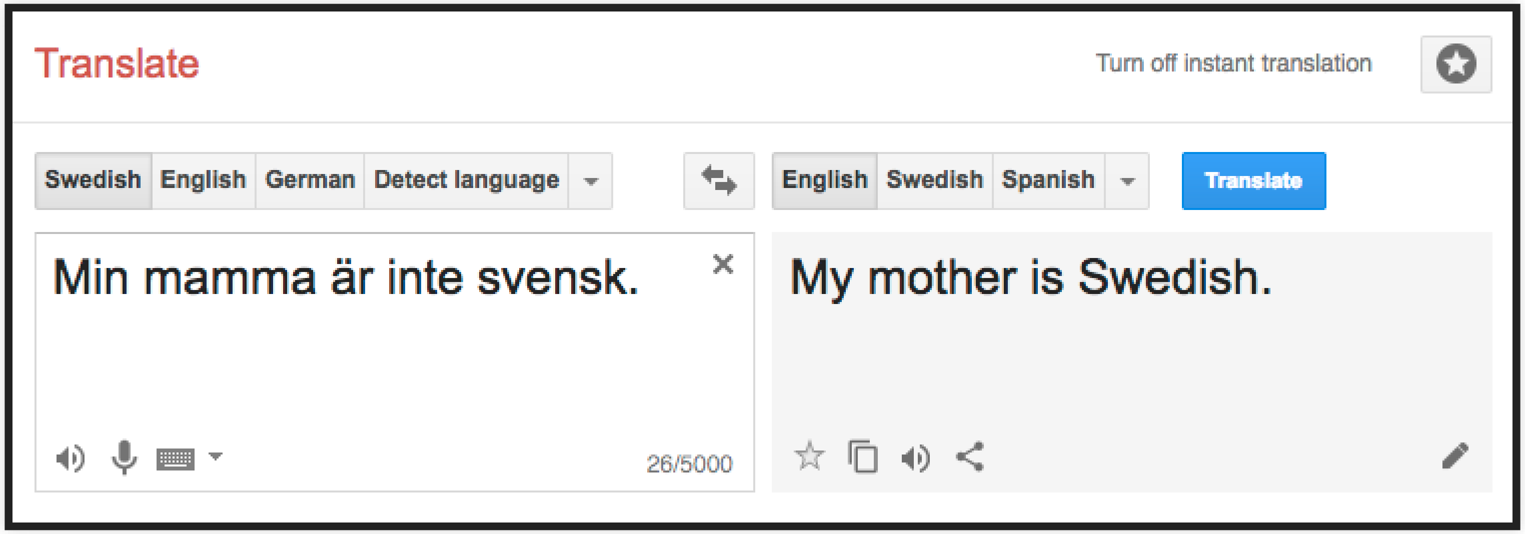
About 196,000,000 results (0.65 seconds)

A clear cloudless day-time **sky** is **blue** because molecules in the air scatter **blue** light from the sun more than they scatter red light. When we look towards the sun at sunset, we see red and orange colours because the **blue** light has been scattered out and away from the line of sight.

Why is the sky Blue?
math.ucr.edu/home/baez/physics/General/BlueSky/blue_sky.html

About this result • Feedback

MACHINE TRANSLATION

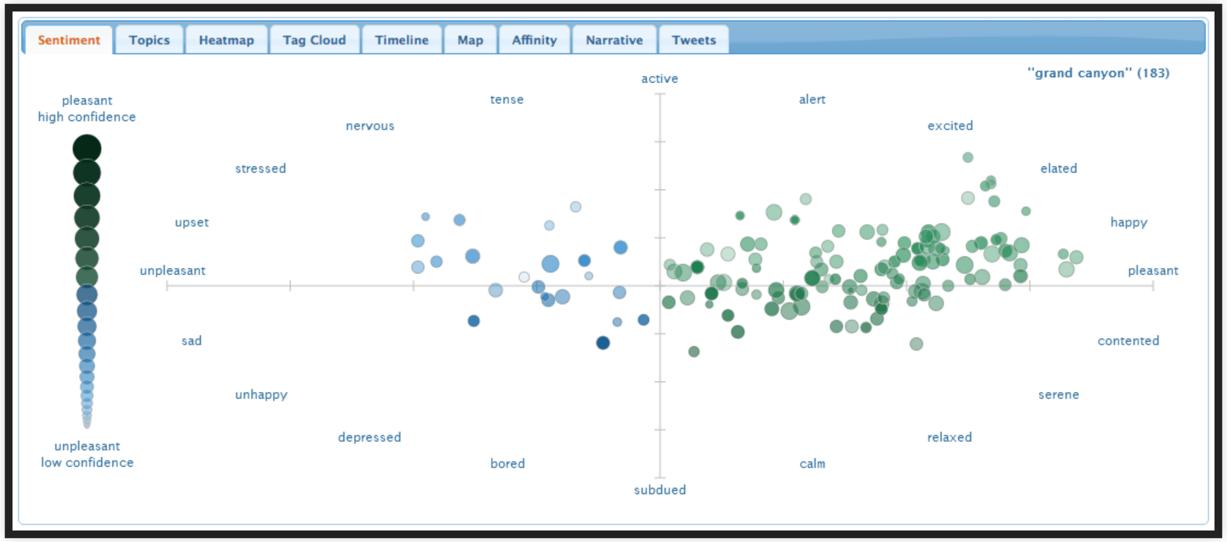


Min mamma är inte svensk.

My mother is Swedish.

CLASSIFICATION

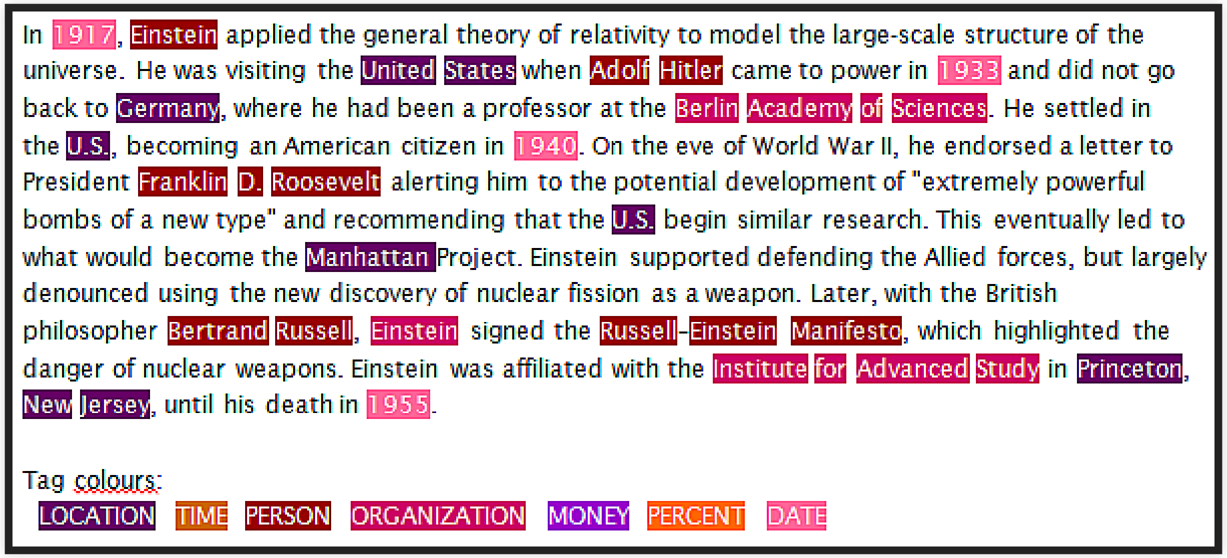
Sentiment analysis



https://www.csc.ncsu.edu/faculty/healey/tweet_viz

INFORMATION EXTRACTION

Named entity recognition


In 1917, Einstein applied the general theory of relativity to model the large-scale structure of the universe. He was visiting the United States when Adolf Hitler came to power in 1933 and did not go back to Germany, where he had been a professor at the Berlin Academy of Sciences. He settled in the U.S., becoming an American citizen in 1940. On the eve of World War II, he endorsed a letter to President Franklin D. Roosevelt alerting him to the potential development of "extremely powerful bombs of a new type" and recommending that the U.S. begin similar research. This eventually led to what would become the Manhattan Project. Einstein supported defending the Allied forces, but largely denounced using the new discovery of nuclear fission as a weapon. Later, with the British philosopher Bertrand Russell, Einstein signed the Russell–Einstein Manifesto, which highlighted the danger of nuclear weapons. Einstein was affiliated with the Institute for Advanced Study in Princeton, New Jersey, until his death in 1955.

Tag colours:
LOCATION TIME PERSON ORGANIZATION MONEY PERCENT DATE

http://www.europeana-newspapers.eu/named-entity-recognition-for-digitised-newspapers

APPROACHES

Rules vs Statistics

- Today many NLP tasks are powered by machine learning
- We have lots of data (corpora), fast processors, cheap storage
- Until the 1990s, most NLP systems were based on complex sets of hand-written rules

Does anyone use rule-based systems today?

- Many NLP systems still use hand-written rules
- E.g., domain-specific dialogue systems
    - Siri, Alexa, Cortana, …, use both hand-written rules and statistical NLP
    - …and not to forget Shrdlite!

PHRASE-STRUCTURE GRAMMARS

Words have different lexical categories:

- noun, verb, adjective, prepositions, adverbs, …

We can combine them into phrasal categories:

- “*the*” (determiner) + “*ball*” (noun) = “*the ball*” (noun phrase)
- “*in*” (preposition) + “*a box*” (noun phrase) = “*in a box*” (prep. phrase)
- “*put*” (verb) + “*the ball*” (noun phrase) + “*in a box*” (prep. phrase) = “*put the ball in a box*” (imperative sentence)

A grammar is a set of rules that describe which combinations are possible

- “*put a ball in a box on the floor*” ✅
- “*put a ball in a box on the*” ❌

CONTEXT-FREE GRAMMARS (CFG)

A Context-Free Grammar is a 4-tuple $G = (V, \Sigma, R, S)$ where:

- V is a finite set of non-terminals (called “syntactic categories”)
- Σ is a finite set of terminals (disjoint from V)
- R is the set of production rules $X \rightarrow \beta$,
  where $X \in V$ and $\beta \in (V \cup \Sigma)^*$
- $S \in V$ is the start symbol

Common syntactic sugar:

- $X \rightarrow \alpha \mid \beta \mid \gamma$ is the same as $X \rightarrow \alpha,\ X \rightarrow \beta,\ X \rightarrow \gamma$
- $X \rightarrow \alpha?\ \beta\ \gamma?$ is the same as $X \rightarrow \alpha\beta\gamma \mid \beta\gamma \mid \alpha\beta \mid \beta$

CONTEXT-FREE GRAMMAR, EXAMPLE

A first attempt at a context-free grammar for Shrdlite:

```
Command    →  take Entity | drop it Location | move Entity Location
Entity     →  Quantifier Object | the floor
Object     →  Size? Color? Form | Object (that is)? Location
Location   →  Relation Entity
Quantifier →  every | a | the | all
Size       →  large | small
Color      →  red | blue | white | black | …
Form       →  box | ball | pyramid | … | boxes | balls | pyramids | …
Relation   →  in | beside | under | …
```

This example grammar overgenerates:

- "put *every bricks* on the floor"
- "put *all brick* on the floor"

HANDLING AGREEMENT IN CFG

CFG solution to overgeneration: add more rules

$$
\begin{array}{lll}
\text{Entity} & \rightarrow & \text{QuantifierSG ObjectSG} \mid \text{QuantifierPL ObjectPL} \mid \ldots \\
\text{ObjectSG} & \rightarrow & \text{Size? Color? FormSG} \mid \text{ObjectSG } (\textit{that is})\text{? Location} \\
\text{ObjectPL} & \rightarrow & \text{Size? Color? FormPL} \mid \text{ObjectPL } (\textit{that are})\text{? Location} \\
\text{QuantifierSG} & \rightarrow & \textit{every} \mid \textit{a} \mid \textit{the} \\
\text{QuantifierPL} & \rightarrow & \textit{all} \\
\text{FormSG} & \rightarrow & \textit{box} \mid \textit{ball} \mid \textit{pyramid} \mid \ldots \\
\text{FormPL} & \rightarrow & \textit{boxes} \mid \textit{balls} \mid \textit{pyramids} \mid \ldots
\end{array}
$$

This is how we do it in Shrdlite.

AGREEMENT AND DEFINITE CLAUSE GRAMMAR

The CFG solution is not feasible for, e.g., German:

$$\begin{array}{l}
\text{Entity} \rightarrow \text{QuantFemNomSg ObjFemNomSg} \mid \text{QuantMascAckSg ObjMascAckSg} \mid \ldots \\
\text{QuantFemNomSg} \rightarrow \textit{die} \\
\text{QuantMascAckSg} \rightarrow \textit{den} \\
\text{ColorFemNomSg} \rightarrow \textit{rote} \mid \textit{blaue} \mid \ldots \\
\text{ColorMascAccSg} \rightarrow \textit{roten} \mid \textit{blauen} \mid \ldots
\end{array}$$

German has 2 × 3 × 4 = 24 combinations of Number, Gender and Case.

Definite-Clause Grammars use attributes and unification:

$$\begin{array}{l}
\text{Entity} \rightarrow \text{Quantifier}[g, c, n] \ \ \text{Object}[g, c, n] \qquad \Longleftarrow \textit{Note! Only one rule} \\
\text{Quantifier[fem,nom,sg]} \rightarrow \textit{die} \\
\text{Quantifier[masc,acc,sg]} \rightarrow \textit{den} \\
\text{Color[fem,nom,sg]} \rightarrow \textit{rote} \mid \textit{blaue} \mid \ldots \\
\text{Color[masc,acc,sg]} \rightarrow \textit{roten} \mid \textit{blauen} \mid
\end{array}$$

SYNTACTIC ANALYSIS (PARSING)

Problem: Given a grammar, find a derivation from S for an input string

Function from string to a list of parse results:
$\mathrm{parse}(g : \mathrm{Grammar}, s : \mathrm{String}) : \mathrm{Result}[]$

- 0 results: input is invalid
- 1 result: input is valid and unambiguous
- 2+ results: input is valid and ambiguous

Algorithms:

- Parsing can be formulated as a search problem
- CKY algorithm, chart parsing, probabilistic parsing, …

SHRDLITE PARSE RESULTS

The Nearley CFG formalism lets you specify how the parse results should look like:

Command	→	*take* Entity	{ (d) => new TakeCommand(d[1]) }
Command	→	*drop it* Location	{ (d) => new DropCommand(d[2]) }
Command	→	*move* Entity Location	{ (d) => new MoveCommand(d[1], d[2]) }

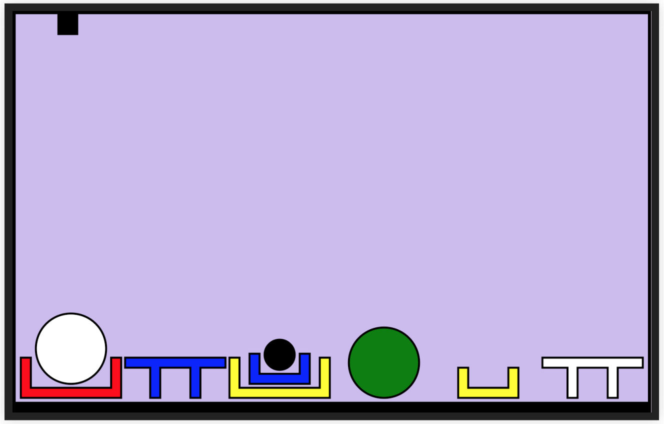
"*put a green ball beside every large box*"

$\Longrightarrow$ MoveCommand(

    Entity("any", SimpleObject("ball", null, "green")),
    Location("beside",
        Entity("all", SimpleObject("box", "large", null))))

SYNTACTIC AMBIGUITY

“*put a ball right of a box in a box beside a table*”



How many syntactic analyses?

“*put (a ball) right of ((a box in a box) beside a table)*”
“*put (a ball) right of (a box in (a box beside a table))*”
“*put (a ball right of a box) in (a box beside a table)*”
“*put ((a ball right of a box) in a box) beside (a table)*”
“*put (a ball right of (a box in a box)) beside (a table)*”

LEVELS OF AMBIGUITY

Most of the sentences we hear seem unambiguous. But almost every utterance contains some kinds of ambiguity. We are just very good at disambiguating!

Different levels of ambiguity:

- Lexical: a word can belong to multiple categories
  - “*Buffalo buffalo buffalo buffalo*”
  - “*Bison [from] Buffalo [often] confuse [other] bison*”
- Syntactic: Phrases can attach at different points in the tree
  - “*I ordered a pizza with rucola*”
  - “*I ordered a pizza with my phone*”
- Semantic: Multiple interprations
  - “*Everyone loves someone*”
  - $\forall x \exists y.\, Love(x, y)$ or $\exists y \forall x.\, Love(x, y)$?

WHY SYNTAX, ANYWAY?

So far, I’ve talked about grammars and parse results

- but what do we do with them?
- the parse results themselves are never our final goal

The next step is semantics (= interpretation)

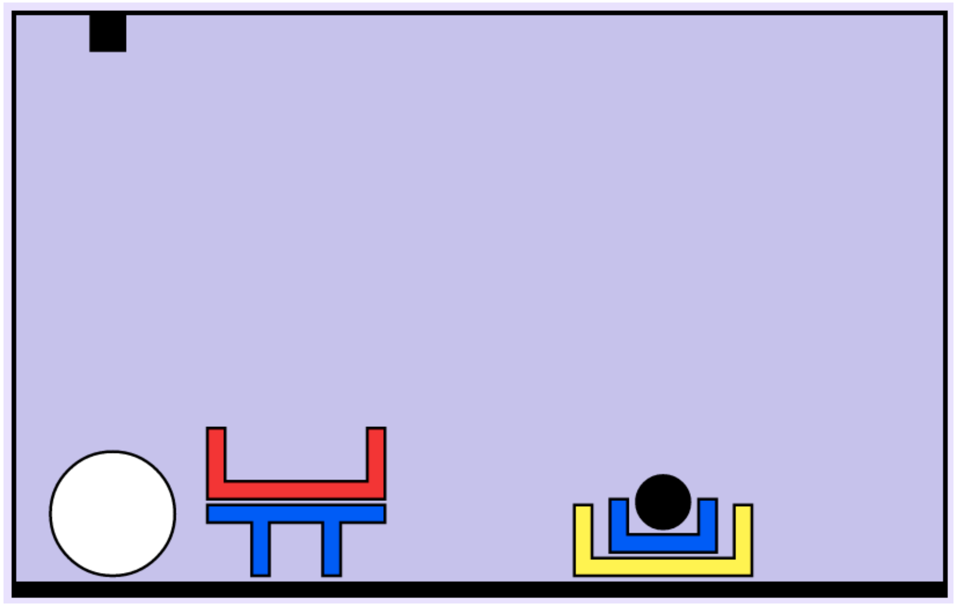
- statistical approaces:
    - e.g., named entitiy recognition, sentiment analysis, relation extraction
- logical approaches:
    - e.g., predicate logic, lambda calculus

SEMANTIC REPRESENTATION, THE SHRDLITE WAY

Shrdlite semantics is propositional logic:

- a logical description of how we want the final state to look like
    - one term for every object in the world:
        - $WhiteBall, BlackBall, \ldots$
    - one predicate for every relation:
        - $holding(x), inside(x,y), leftof(x,y), \ldots$
    - logical disjunction and conjunction instead of quantifiers:
        - $P \lor (Q \land R)$
- This works because the world is finite!

INTERPRETATION, AMBIGUITIES



Is this ambiguous? “*put the white ball in the red box*”

How about this? “*put the ball in the red box*”

SHRDLITE PIPELINE

This is how Shrdlite goes from text input to a final plan:

1. *Parsing*: text input → (many) parse results
2. *Interpretation*: parse result + world → (many) goals
3. (*Ambiguity resolution*: many goals → one goal)
4. *Planning*: goal → plan
5. (*Ambiguity resolution*: many plans → one plan)

PARSING: TEXT INPUT $\rightarrow$ PARSE RESULTS

```
function parse(input : string) : ShrdliteResult[]
        (this function is already implemented)

interface ShrdliteResult {
        input : string
        parse : Command
        interpretation : DNFFormula
        plan : string[] }
```

This is already implemented using the Nearley grammar and parser

- after parsing, every ShrdliteResult contains the input string and a parse result
- the interpretation and plan are dummy values

INTERPRETATION: PARSE RESULT + WORLD → GOALS

```
function interpret(parses : ShrdliteResult[], world : WorldState) : ShrdliteResult[]
        (this function is already implemented, but calls interpretCommand)

class Interpreter {
        interpretCommand(cmd : Command) : CommandSemantics
        interpretEntity(ent : Entity) : EntitySemantics
        interpretLocation(loc : Location) : LocationSemantics
        interpretObject(obj : Object) : ObjectSemantics }
```

This is what you have to implement in lab 2!

- the Interpreter methods should call each other
- what should the respective semantics be?

SEMANTICS OF COMMANDS: DISJUNCTIVE NORMAL FORM

DNF = Disjunctive Normal Form = a disjunction of conjunctions of literals
(normal form = all logical formulae can be converted into this form)

```
type CommandSemantics = DNFFormula
class DNFFormula {
        conjuncts : Conjunction[] }
class Conjunction {
        literals : Literal[] }
class Literal {
        relation : string
        args : string[] = []
        polarity : boolean = true }
```

Example: the formula $(p(x) \wedge q) \vee (\neg r(y,z))$ is created by:

```
new DNFFormula([
        new Conjunction([new Literal("p", ["x"]), new Literal("q")]),
        new Conjunction([new Literal("r", ["y","z"], false)]) ])
```

SEMANTICS OF OBJECTS, ENTITIES AND LOCATIONS

The semantics of an object description is a collection of the objects that match the description:

```
type ObjectSemantics = string[]
```

- Example: the semantics of “*large box*” is ["RedBox", "YellowBox"]

The semantics of an Entity or a Location is just a wrapper around the semantics of its children:

```
type EntitySemantics = {quantifier : string; object : ObjectSemantics}
type LocationSemantics = {relation : string; entity : EntitySemantics}
```

- Example: the semantics of “*in every large box*” is
  {relation: "inside", {quantifier: "all", object: ["RedBox", "YellowBox"]}}

SEMANTIC AMBIGUITY

DNF inherently captures ambiguity

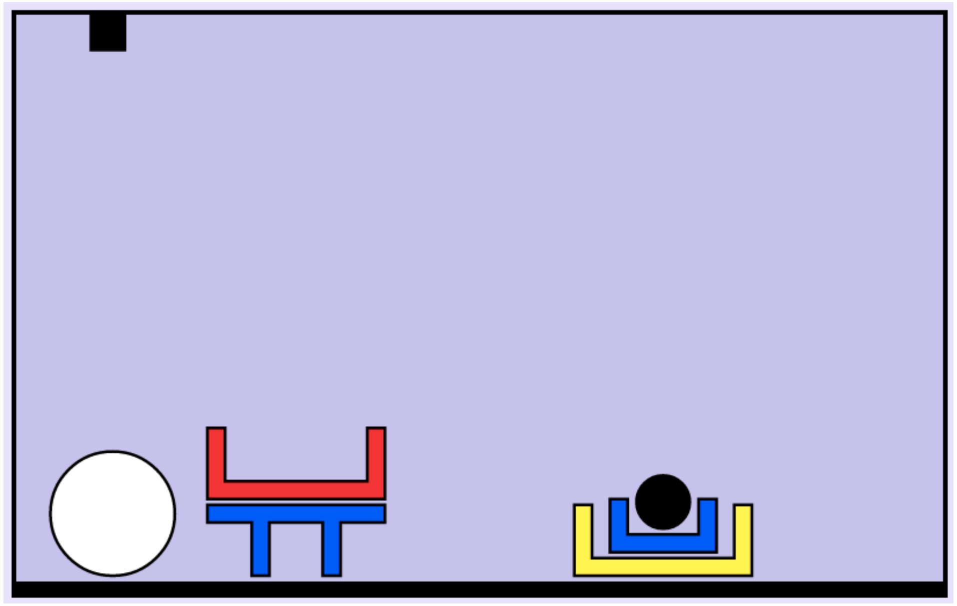
- "*put a ball in a box*" $\Rightarrow$ $inside(WhiteBall,RedBox) \lor inside(WhiteBall,YellowBox) \lor inside(BlackBall,RedBox) \lor inside(BlackBall,YellowBox) \lor inside(BlackBall,BlueBox)$

But impossible interperetations should be removed

- Note that we don't want the interpretation $inside(WhiteBall,BlueBox)$, because that violates the physical laws.

ONLY KEEP VALID INTERPRETATIONS

"*put the white ball in a box on the floor*"



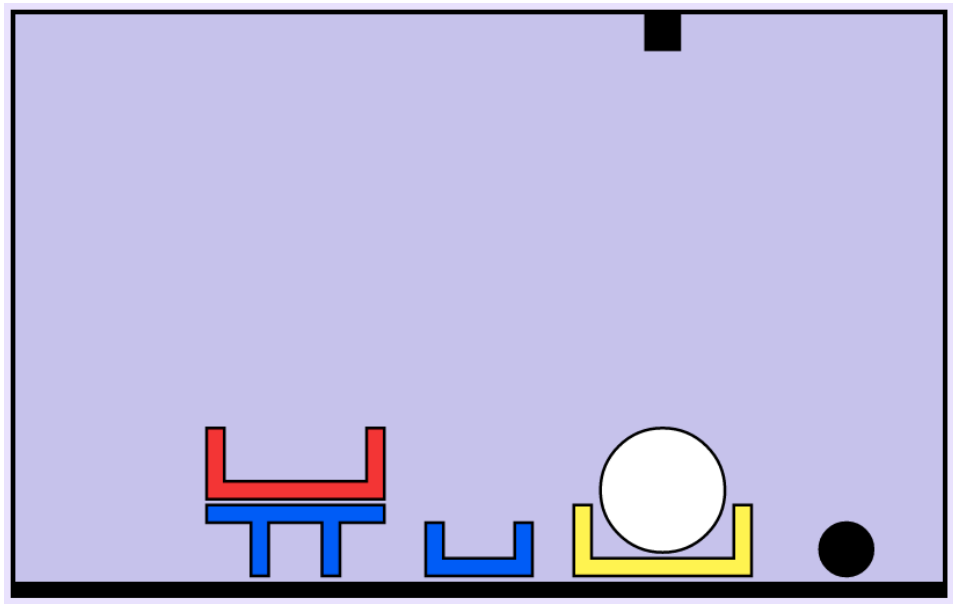
"*put the white ball in a box* ***that is*** *on the floor*" ⇒ *inside(WhiteBall, YellowBox)*

"*put the white ball* ***that is*** *in a box on the floor*" ⇒ There is no white ball in a box

“IN A BOX ON THE FLOOR”: NATURAL INTERPRETATION

inside(WhiteBall, YellowBox)

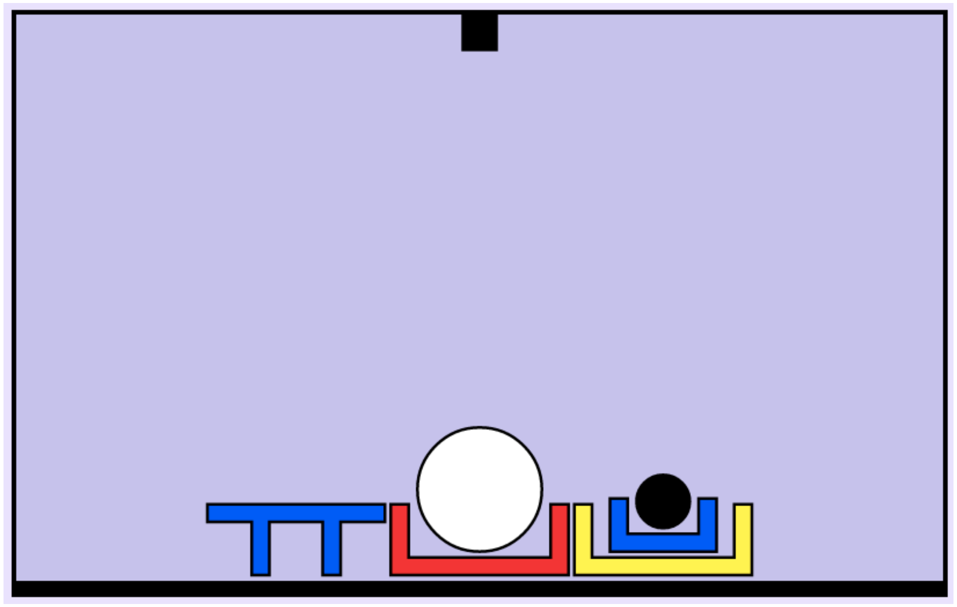
The yellow box is already on the floor: 17 actions to complete



“IN A BOX ON THE FLOOR”: ALTERNATIVE INTERPRETATION

$inside(WhiteBall, RedBox) \wedge on(RedBox, floor)$

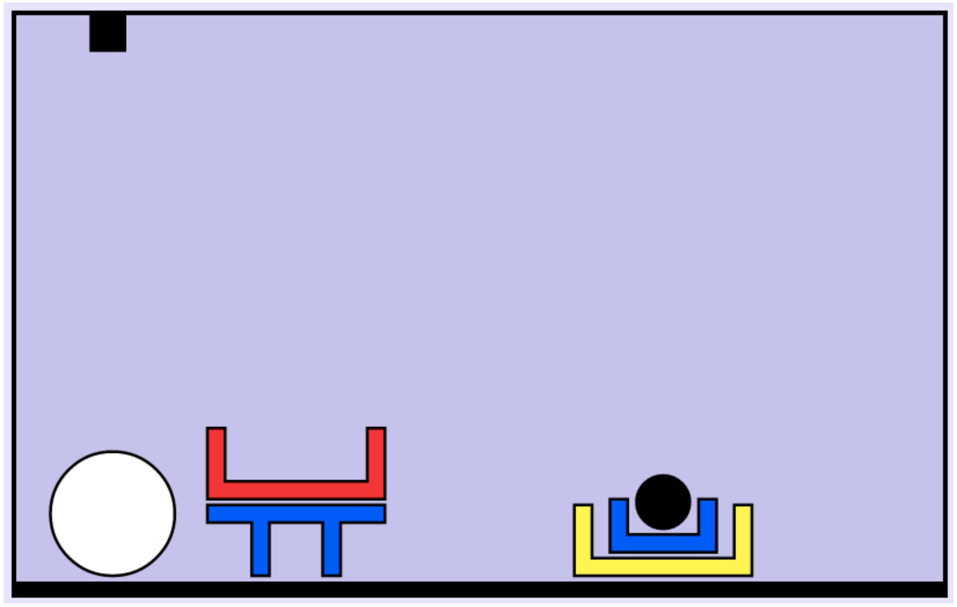
The red box can be placed on the floor first: 10 actions to complete



The red box is not on the floor at the start!

FINAL INTERPRETATION

"*put the white ball in a box on the floor*"



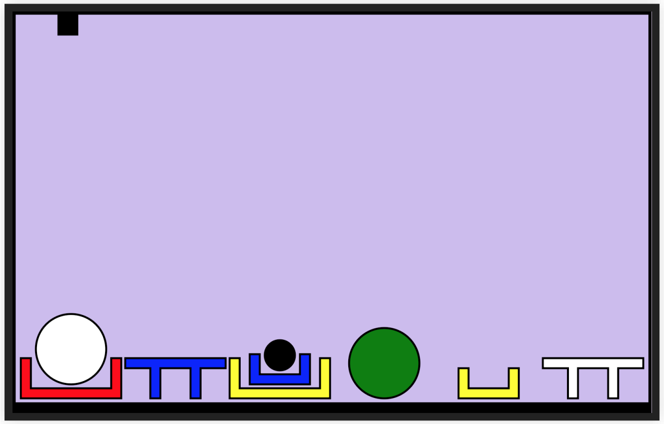
So, what should the final interpretation be?

inside(WhiteBall, YellowBox)

inside(WhiteBall, YellowBox) $\lor$ *(inside(WhiteBall, RedBox)* $\land$ *on(RedBox, floor))*

MORE COMPLEX SEMANTIC AMBIGUITY

"*put a ball right of a box in a box beside a table*"



Which object (i.e., which ball) should be placed where (i.e., beside or in which box, or beside which table)?

I.e., what should the goal be for each of the syntactic analyses?

"*put (a ball) right of ((a box in a box) beside a table)*"
"*put (a ball) right of (a box in (a box beside a table))*"
"*put (a ball right of a box) in (a box beside a table)*"
"*put ((a ball right of a box) in a box) beside (a table)*"
"*put (a ball right of (a box in a box)) beside (a table)*"

PHYSICAL LAWS

These are the physical laws that the interpreter and planner must check for:

- The floor can support at most N objects (beside each other).
- All objects must be supported by something.
- The arm can only hold one object at the time.
- The arm can only pick up free objects.
- Objects are “inside” boxes, but “ontop” of other objects.
- Balls must be in boxes or on the floor, otherwise they roll away.
- Balls cannot support anything.
- Small objects cannot support large objects.
- Boxes cannot contain pyramids, planks or boxes of the same size.
- Small boxes cannot be supported by small bricks or pyramids.
- Large boxes cannot be supported by large pyramids.

INTERPRETER TEST CASES

Each test case contains a *list of interpretations*, each interpretation is a string (a compact representation of a disjunction of conjunctions)

- if one parse gives several interpretations:

```
world: "small",
utterance: "take a blue object"
interpretations: ["holding(BlueTable) | holding(BlueBox)"]
```

- if several parses give interpretations:

```
world: "small"
utterance: "put a black ball in a box on the floor"
interpretations: ["inside(BlackBall, YellowBox)",
                  "ontop(BlackBall, floor)"]
```

TEST CASES: CONJUNCTIONS AND INVALID UTTERANCES

- The “all” quantifier gives rise to a conjunction:

```
world: "small"
utterance: "put all balls on the floor"
interpretations: ["ontop(WhiteBall, floor) & ontop(BlackBall, floor)"]
```

- If an utterance breaks the laws of nature:

```
world: "small"
utterance: "put a ball on a table"
interpretations: []
```

TEST CASES: MISSING INTERPRETATIONS

- There are some cases where the interpretation is missing:

```
world: "small"
utterance: "put a ball in a box on the floor"
interpretations: ["COME-UP-WITH-YOUR-OWN-INTERPRETATION"]
```

You should discuss these cases in your group and come up with good interpretations!