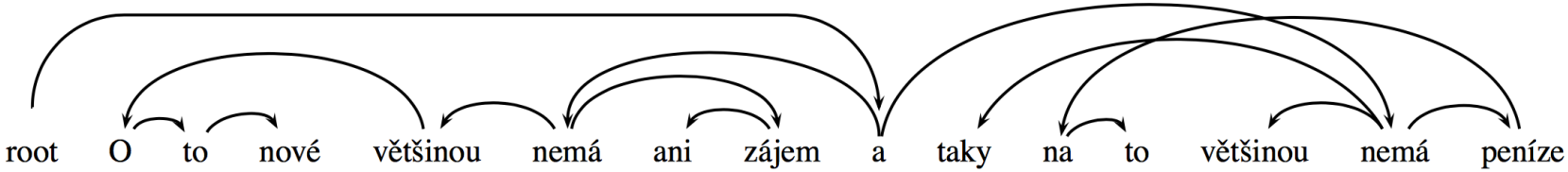



*He is mostly not even interested in the new things and in most cases, he has no money for it either.*

McDonald et al. 2006

# Natural Language Processing

Info 159/259

Lecture 16: Dependency syntax (Mar 15, 2022)

David Bamman, UC Berkeley

# Context-free grammar

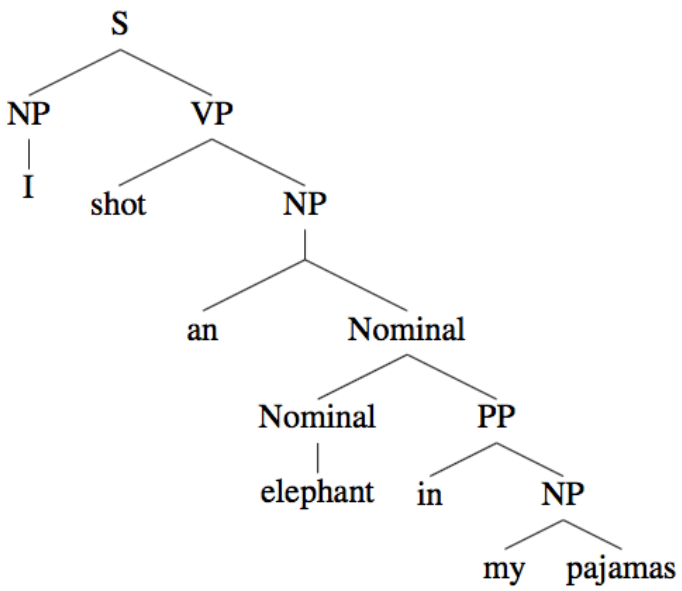
A context-free grammar defines how symbols in a language combine to form valid structures

| | | |
|---|---|---|
| NP | → | Det Nominal |
| NP | → | ProperNoun |
| Nominal | → | Noun \| Nominal Noun |
| Det | → | a \| the |
| Noun | → | flight |

non-terminals

lexicon/ terminals

# Constituents



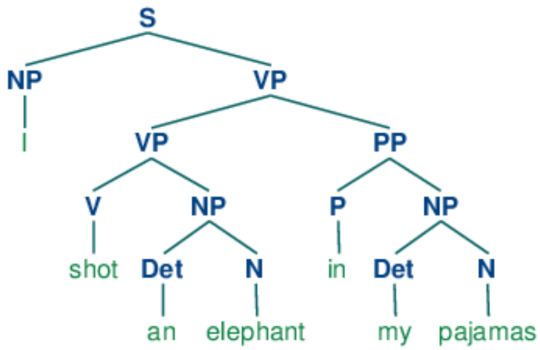

*Every* internal node is a phrase

- my pajamas
- in my pajamas
- elephant in my pajamas
- an elephant in my pajamas
- shot an elephant in my pajamas
- I shot an elephant in my pajamas

Each phrase could be replaced by another of the same type of constituent

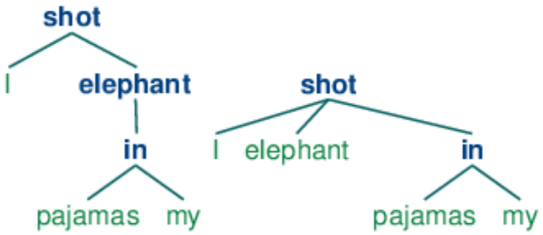
# Formalisms

## Phrase structure grammar
(Chomsky 1957)




two weeks ago

## Dependency grammar
(Mel'čuk 1988; Tesnière 1959; Pāṇini)

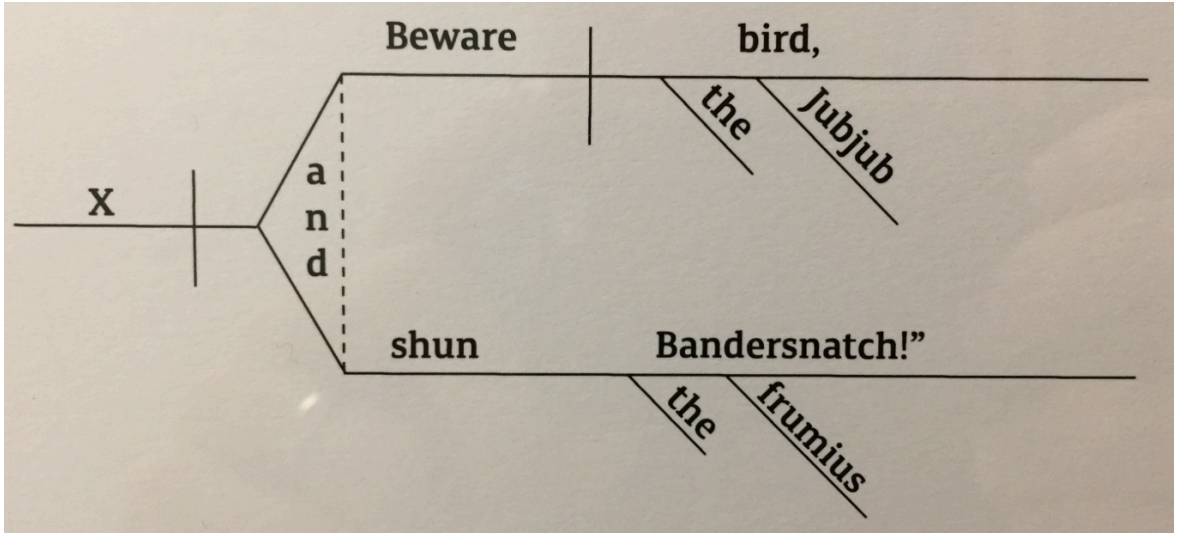



today

# Dependency syntax

- Sgall, Dependency-based formal description of language (1994)
- Mel'čuk, Dependency Syntax: Theory and Practice (1988)
- Tesnière, Éléments de syntaxe structurale (1959)
- Medieval theories of grammar (Covington 1984)
- Pānini grammar of Sanskrit (ca. 5th-century BCE)

# Dependency syntax



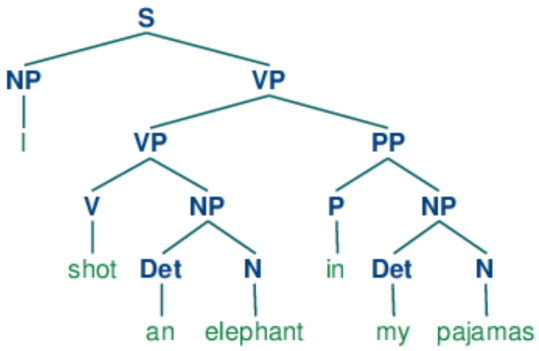

"Sentence diagramming"

# Dependency syntax

- “Between the word and its neighbors, the mind perceives connections, the totality of which forms the structure of the sentence. The structural connections establish dependency relations between the words. Each connection in principle unites a superior and an inferior term.”

Tesnier 1959; Nivre 2005

# Dependency syntax



- Dependency syntax doesn't have non-terminal structure like a CFG; words are directly linked to each other.

# Dependency syntax

- Syntactic structure = asymmetric, binary relations between words.

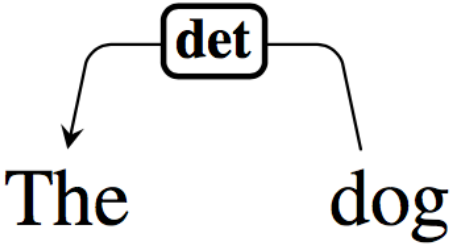
Tesnier 1959; Nivre 2005

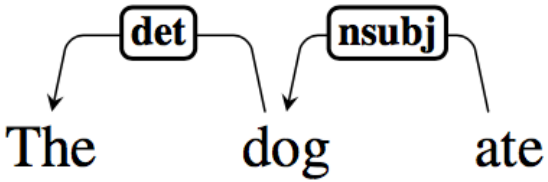
# Dependency

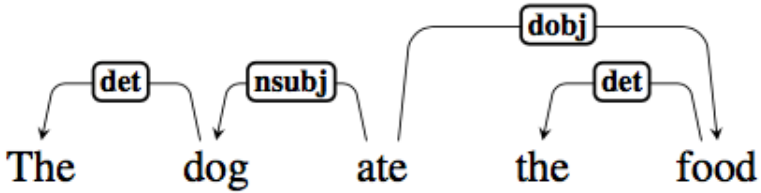
- How do we decide which of a pair of words is the head and which is the dependent?

# Dependency

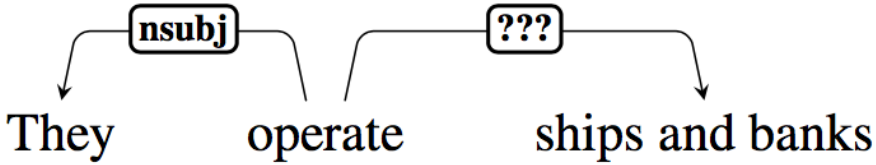
- Many (conflicting) frameworks:
  - Head determines the syntactic category of a construction
  - Head is obligatory; dependents are optional
  - Head selects dependents and determines whether the dependent is required
  - The form of the dependent depends on the head (e.g., agreement between nouns/verbs, adjectives/nouns)
  - The linear position of a dependent is specified with respect to the head.


det
The
dog


det
nsubj
The
dog
ate

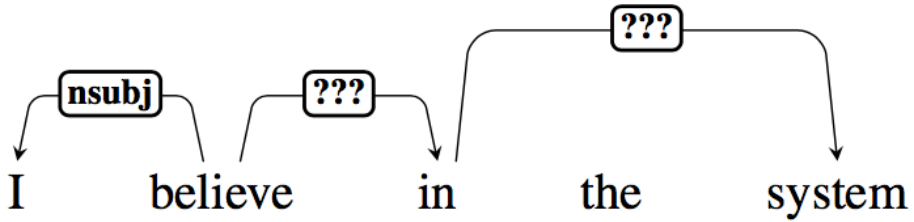

dobj
det
nsubj
det
The
dog
ate
the
food

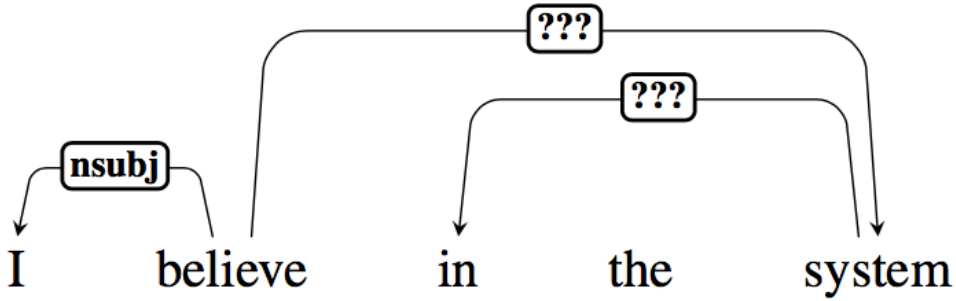
# Coordination




Nivre 2005

# Case marking prepositions




Nivre 2005

# Trees

- A dependency structure is a directed graph G = (V,A) consisting of a set of vertices *V* and arcs *A* between them. Typically constrained to form a tree:
    - Single root vertex with no incoming arcs
    - Every vertex has exactly one incoming arc except root (single head constraint)
    - There is a unique path from the root to each vertex in V (acyclic constraint)

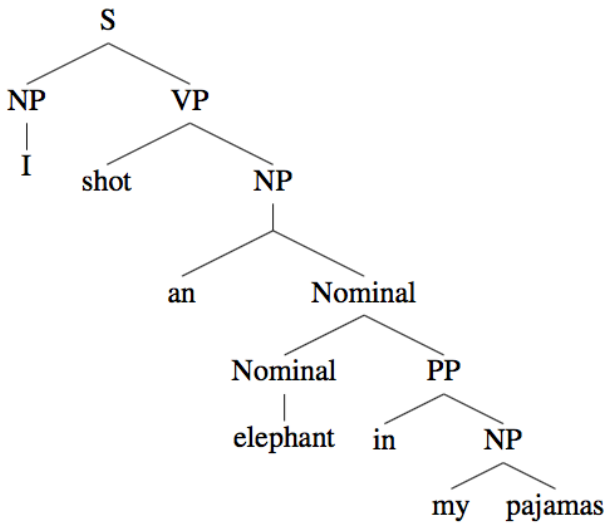
# Trees

- Unlike phrase-structure trees, dependency trees aren't tied to the linear order of the words in a sentence.
- Adding a constraint derived from the linear order of words in a sentence allows for more efficient parsing algorithms (as we'll see on Thursday).

# Word order

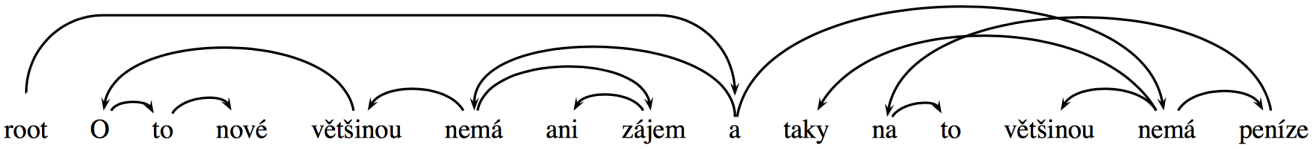
- Dependency relations belong to the structural order of a sentence, not the linear order.

- This is different from a phrase-structure tree, where the syntax is constrained by the linear order of the sentence (a different linear order yields a different parse tree).

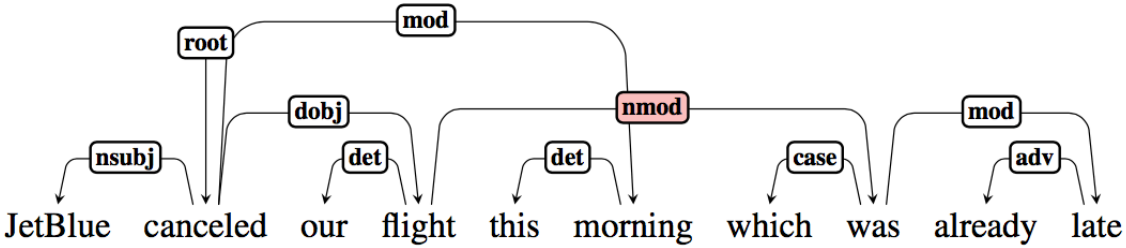



Tesnière 1959

# Free word order

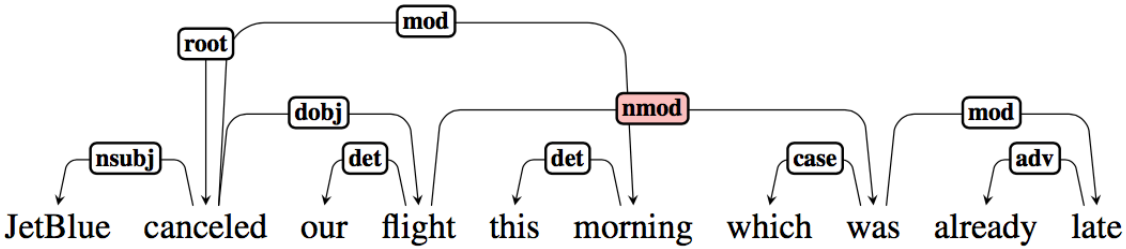



*He is mostly not even interested in the new things and in most cases, he has no money for it either.*



# Projectivity

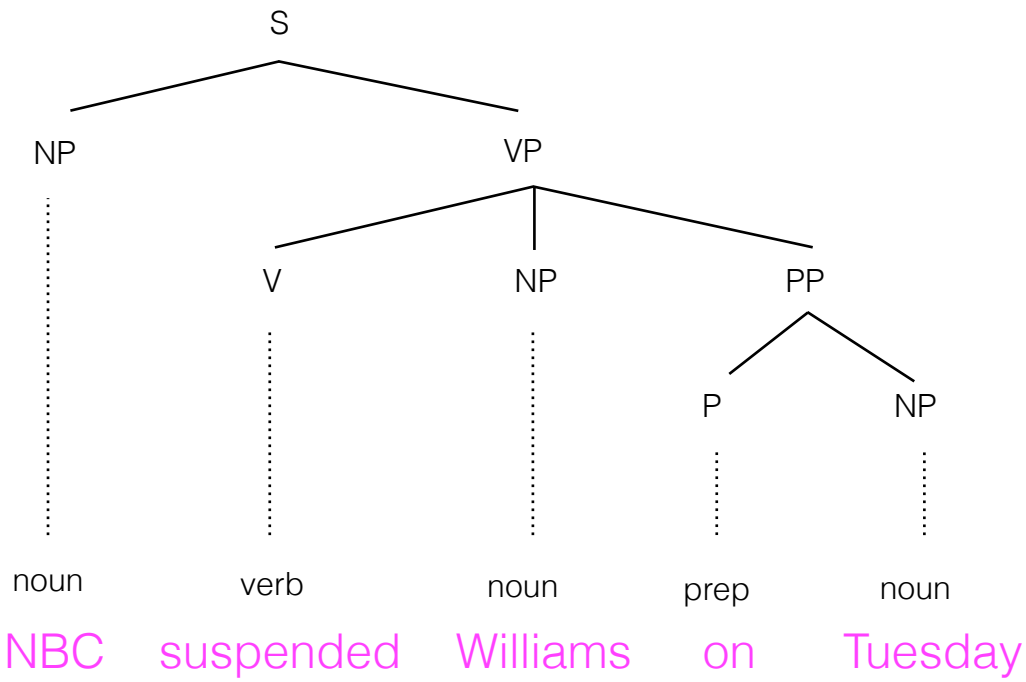
- An arc between a head and dependent is projective if there is a path from the head to every word between the head and dependent.



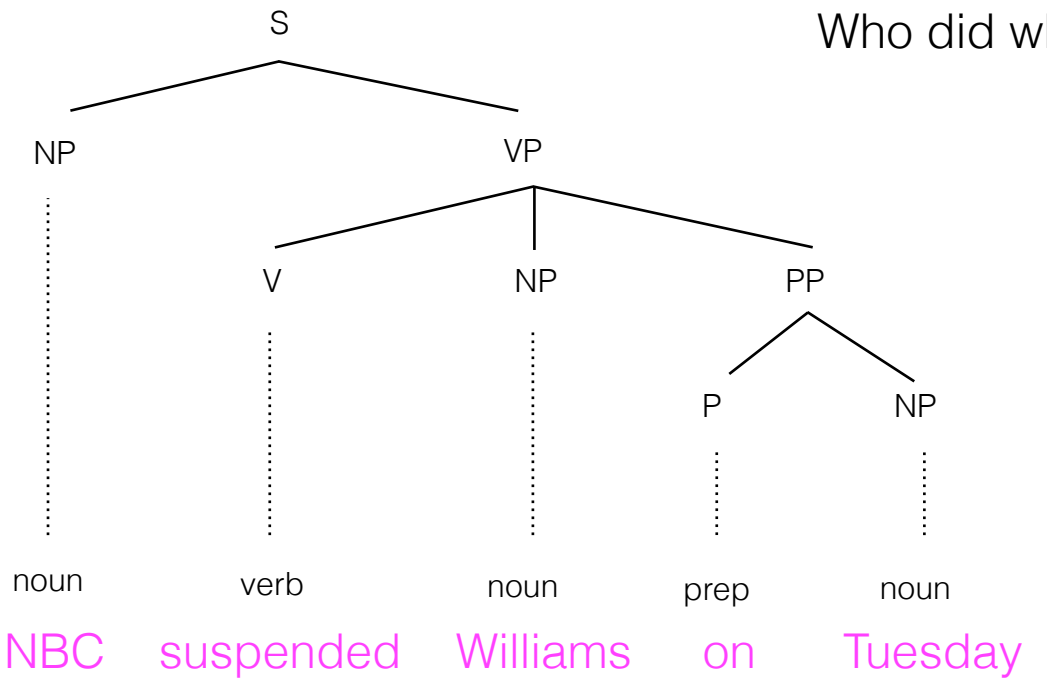
# Dependencies vs constituents

- Dependency links are closer to semantic relationships; no need to infer the relationships from the structure of a tree
- A dependency tree contains one edge for each word, no intermediate hidden structures that also need to be learned for parsing.
- Easier to represent languages with free word order.

Covington 2001

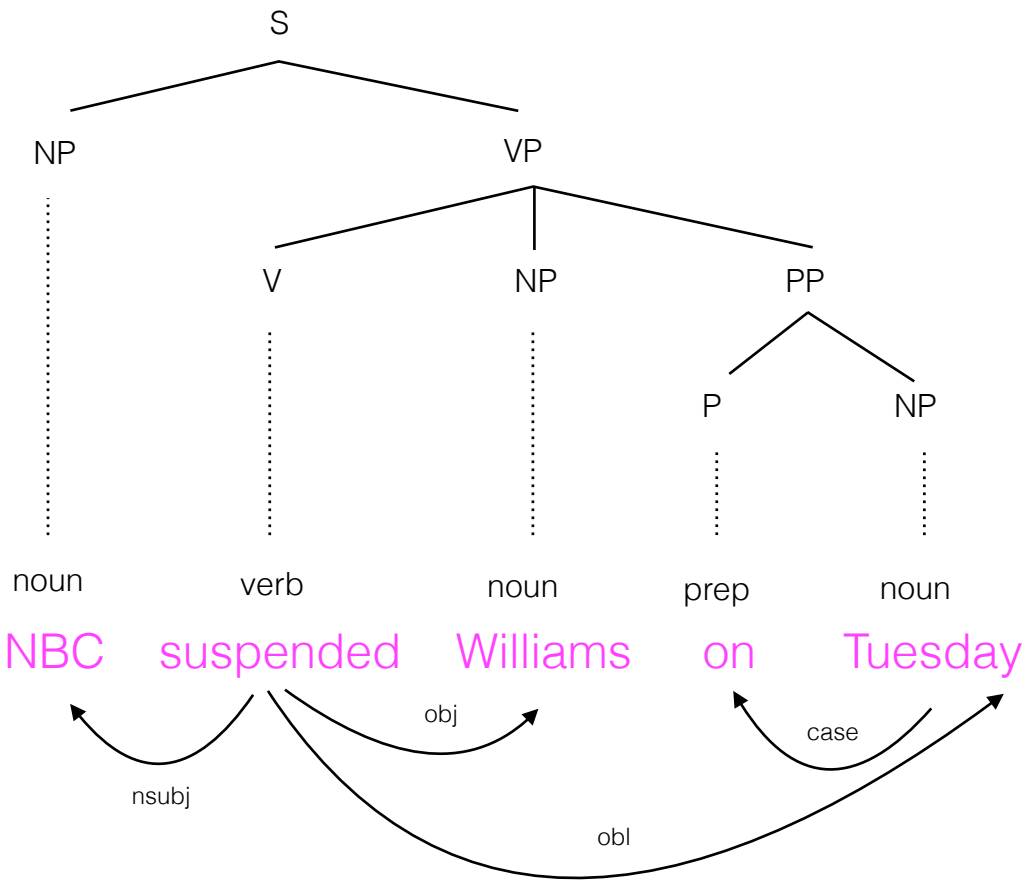

S
NP
VP
V
NP
PP
P
NP
noun
verb
noun
prep
noun
NBC
suspended
Williams
on
Tuesday

Who did what to whom?




subject: S → NP VP

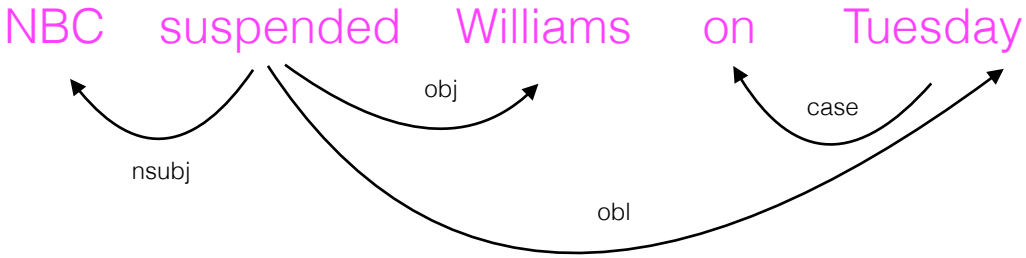
direct object: S → NP (VP → … NP … )


S
NP
VP
V
NP
PP
P
NP
noun
verb
noun
prep
noun
NBC
suspended
Williams
on
Tuesday
nsubj
obj
obl
case

# Dependency grammar

Captures binary relations between words

- nsubj(NBC, suspended)
- obj(Williams, suspended)



# Data

- NELL SVO triples (604 million nsubj+dobj relations from 230B words on the web

| | | | |
|---|---|---|---|
| police | found | five .030 bullets | 1 |
| police | found | seven dead rebels | 3 |
| police | found | two hidden cameras | 2 |
| police | found | wanders lover | 1 |
| police | found | 211 pounds | 4 |
| police | found | Marcia | 3 |
| police | found | bank draft | 1 |
| police | found | diskette | 2 |
| police | found | five marijuana plants | 3 |
| police | found | items used | 1 |
| police | found | judge | 5 |

# Dependency-Based Word Embeddings

Levy & Goldberg, ACL 2014

http://irsrv2.cs.biu.ac.il:9998/

| Target Word | BoW5 | BoW2 | Deps |
|---|---|---|---|
| batman | nightwing | superman | superman |
| | aquaman | superboy | superboy |
| | catwoman | aquaman | supergirl |
| | superman | catwoman | catwoman |
| | manhunter | batgirl | aquaman |
| hogwarts | dumbledore | evernight | sunnydale |
| | hallows | sunnydale | collinwood |
| | half-blood | garderobe | calarts |
| | malfoy | blandings | greendale |
| | snape | collinwood | millfield |
| turing | nondeterministic | non-deterministic | pauling |
| | non-deterministic | finite-state | hotelling |
| | computability | nondeterministic | heting |
| | deterministic | buchi | lessing |
| | finite-state | primality | hamming |
| florida | gainesville | fla | texas |
| | fla | alabama | louisiana |
| | jacksonville | gainesville | georgia |
| | tampa | tallahassee | california |
| | lauderdale | texas | carolina |
| object-oriented | aspect-oriented | aspect-oriented | event-driven |
| | smalltalk | event-driven | domain-specific |
| | event-driven | objective-c | rule-based |
| | prolog | dataflow | data-driven |
| | domain-specific | 4gl | human-centered |
| dancing | singing | singing | singing |
| | dance | dance | rapping |
| | dances | dances | breakdancing |
| | dancers | breakdancing | miming |
| | tap-dancing | clowning | busking |

# Universal Dependencies

## UD Treebanks

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Afrikaans | 49K | LF | – | | | | |
| Ancient Greek | 202K | LF | | | ✔ | | |
| Ancient Greek-PROIEL | 211K | LF | – | | ✔ | | |
| Arabic | 242K | LF | – | | ✔ | | |
| Arabic-NYUAD | 629K | LF | – | | ✔ | | |
| Arabic-PUD | 20K | LF | – | | | | W |
| Basque | 121K | LF | | | ✔ | | |
| Belarusian | 8K | LF | – | | ✔ | | |
| Bulgarian | 156K | LF | | ✔ | ✔ | | |
| Buryat | 10K | LF | – | | | | |
| Catalan | 530K | LF | | ✔ | ✔ | GPL | |
| Chinese | 123K | LF | | ✔ | ✔ | | W |
| Chinese-CFL | 7K | L | | | | | |
| Chinese-PUD | 21K | F | – | | | | W |
| Coptic | 4K | LF | | | ✔ | | |
| Croatian | 197K | LF | – | ✔ | ✔ | | W |
| Czech | 1,503K | LF | | ✔ | ✔ | | |

http://universaldependencies.org

# Universal Dependencies

- Developing cross-linguistically consistent treebank annotation for many languages

- Goals:
    - Facilitating multilingual parser development
    - Cross-lingual learning
    - Parsing research from a language typology perspective.

http://universaldependencies.org

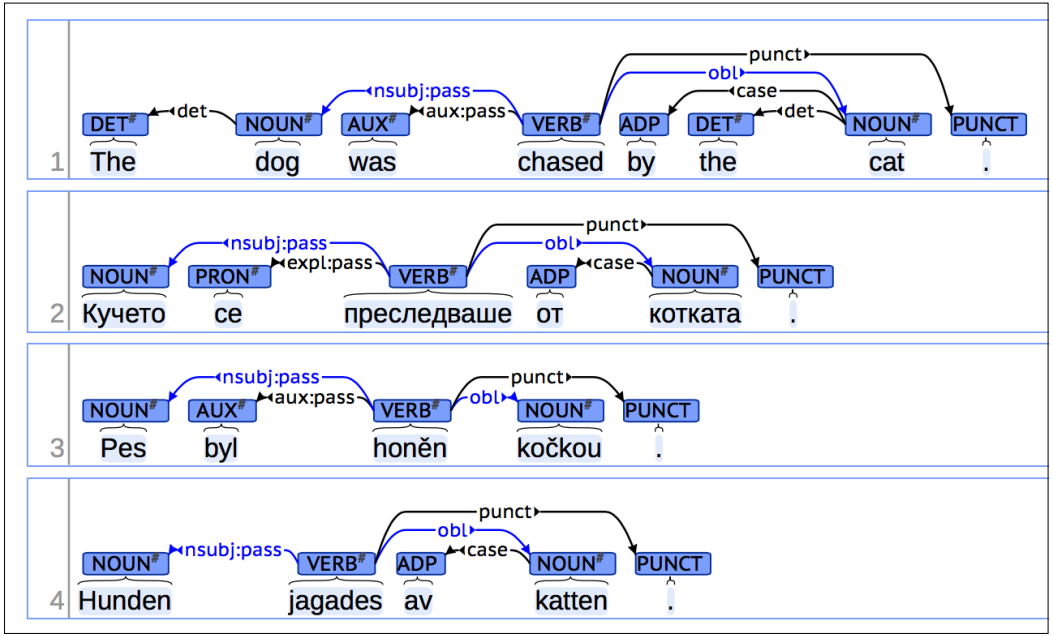
# Universal Dependencies

English

Bulgarian

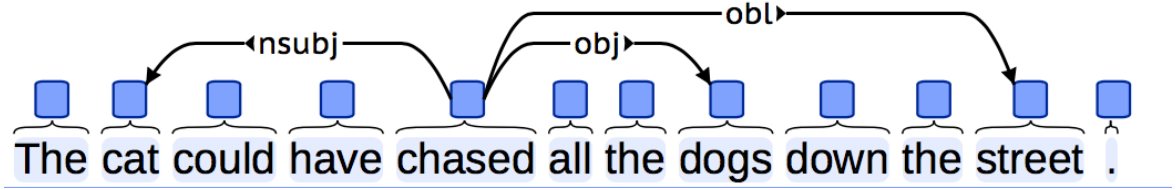
Czech

Swedish




http://universaldependencies.org

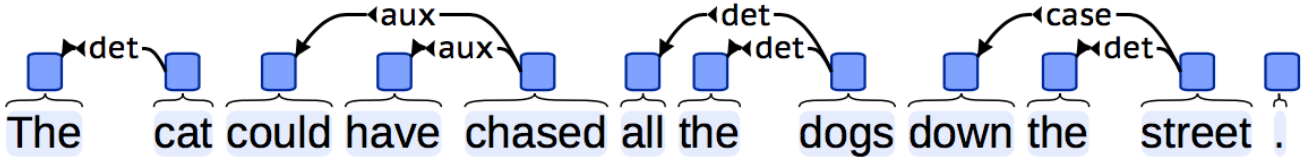
# UD Principles




Dependency relations mainly hold between content words.

http://universaldependencies.org/u/overview/syntax.html

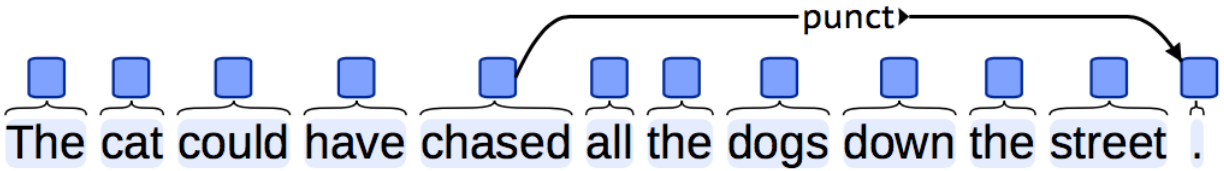
# UD Principles




Function words dependent on closest related content word

http://universaldependencies.org/u/overview/syntax.html

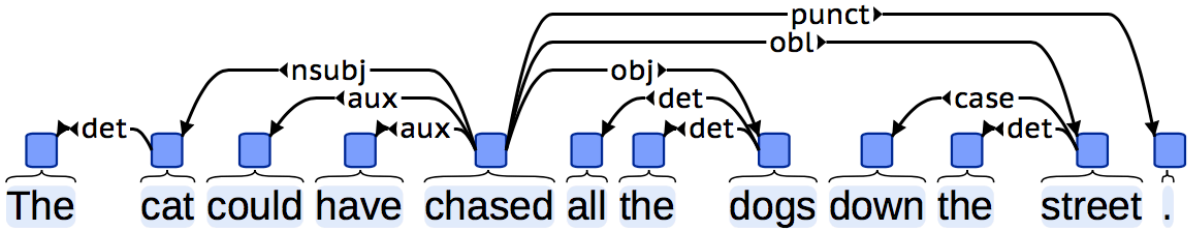
# UD Principles




Punctuation typically depends on phrasal head

http://universaldependencies.org/u/overview/syntax.html

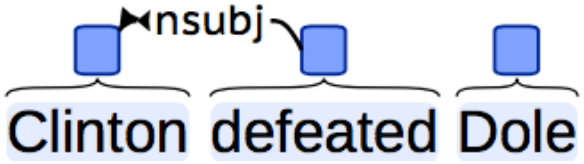
# UD Principles




http://universaldependencies.org/u/overview/syntax.html

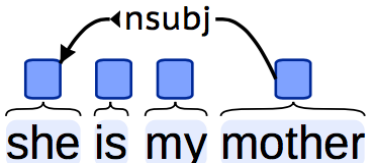
# nsubj

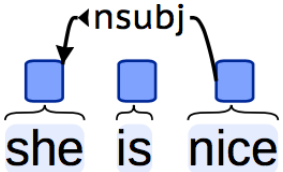
- Syntactic subject of active verbs

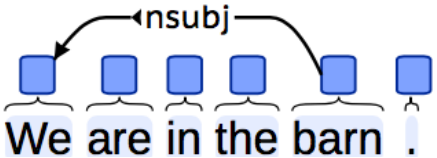


# nsubj

- When the verb is copular (nominal/adjective predicatives like “she is my boss”), the subject depends on the complement.

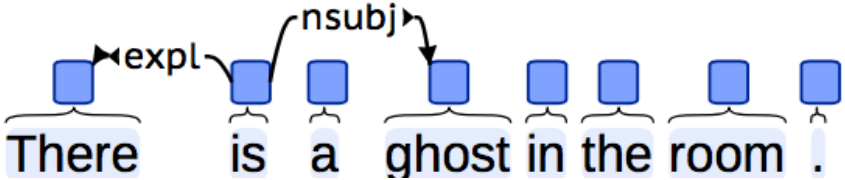


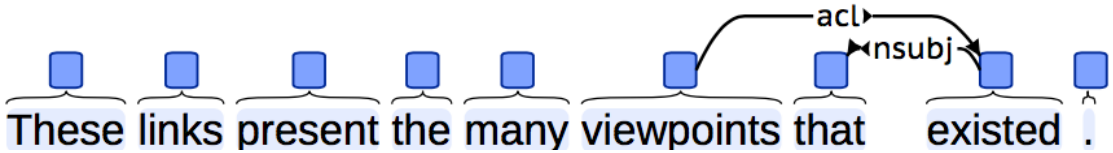
# nsubj

- Expletives



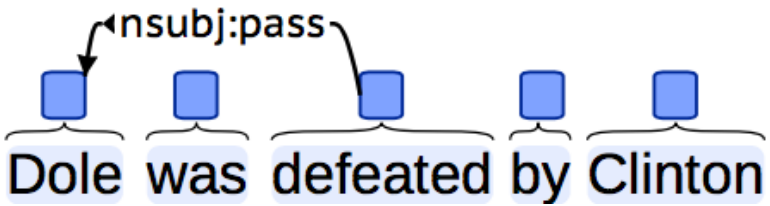
# nsubj

- Relative clauses with finite verbs also often have syntactic subjects expressed.



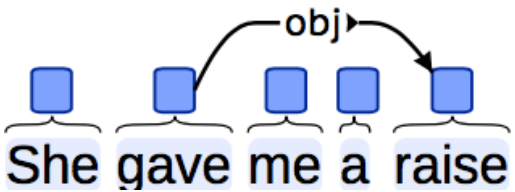
# nsubj:pass

- Syntactic subject of passive verbs



# obj

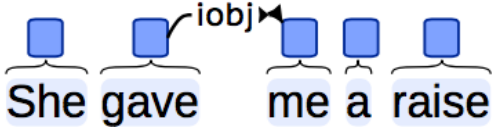
- Generally, the entity that is acted upon as the direct object of the predicate.




- Note the term for a direct object in older versions of Universal Dependencies (e.g., described in SLP3) is “dobj”.

# iobj

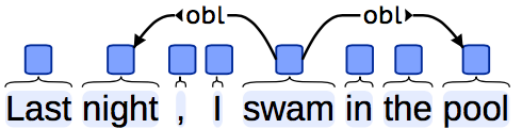
- Indirect object: recipients of ditransitive verbs of exchange (verbs requiring two objects)

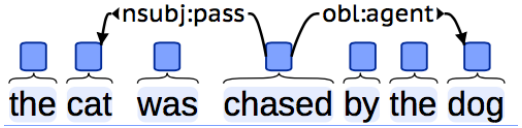


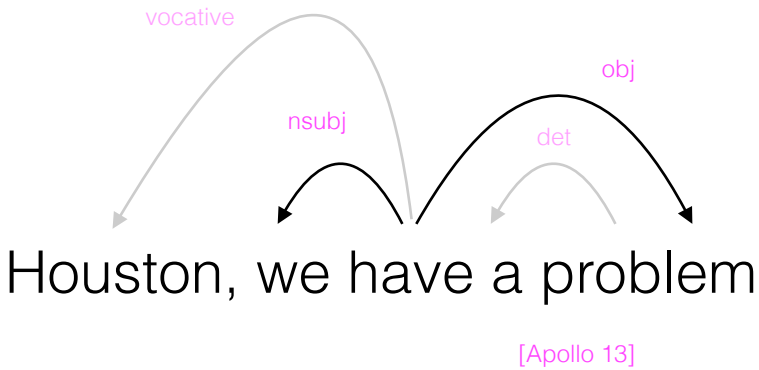

| nsubj | | iobj | obj |
|---|---|---|---|
| She | teaches | her daughters | math |
| She | told | her daughters | a story |

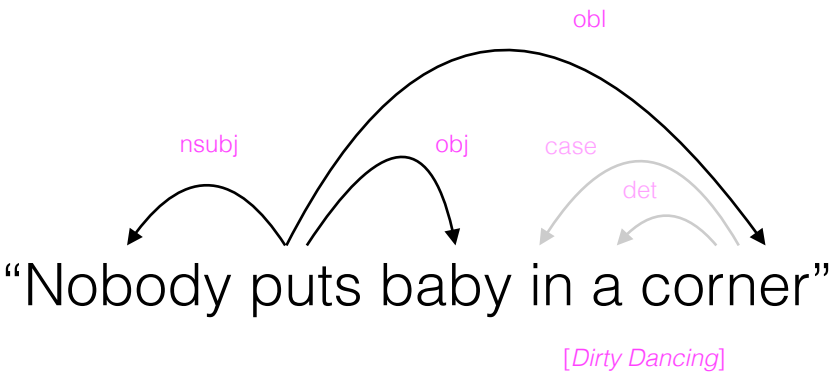
# obl

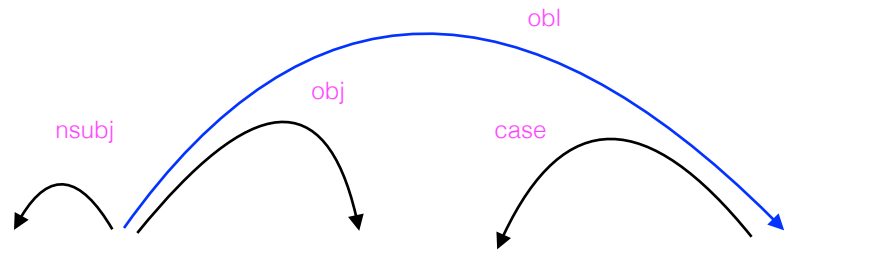
- Any nominal functioning as non-required argument or adjunct of a verb, including temporal and locational nominal modifiers and agents of passive verbs



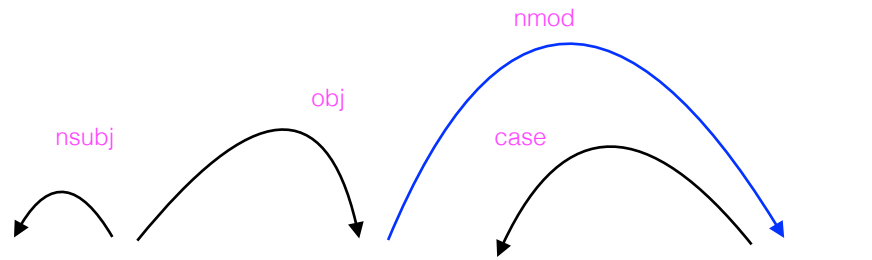




vocative
obj
nsubj
det
Houston, we have a problem
[Apollo 13]


obl
nsubj
obj
case
det
“Nobody puts baby in a corner”
[*Dirty Dancing*]



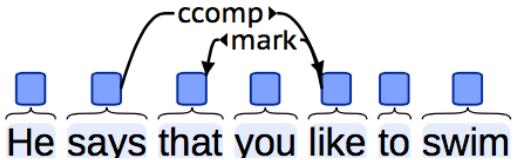

I shot an elephant in my pajamas

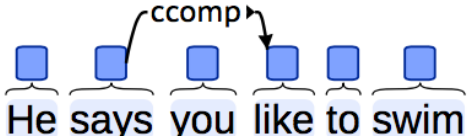



I shot an elephant in my pajamas

# ccomp

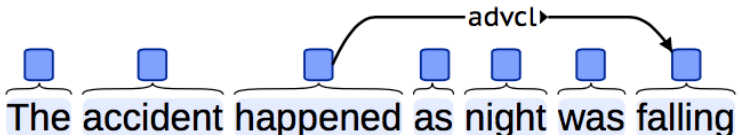
- Clausal complements, including dialogue

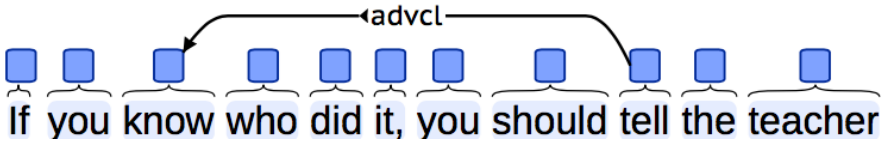


# advcl

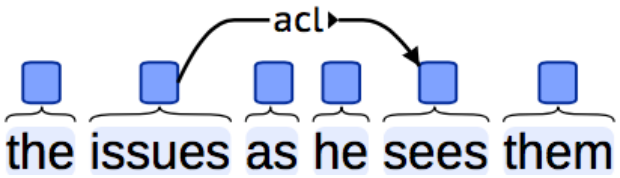
- A clause that modifies another predicate (temporal clauses, consequence, conditional clauses, purpose clauses)



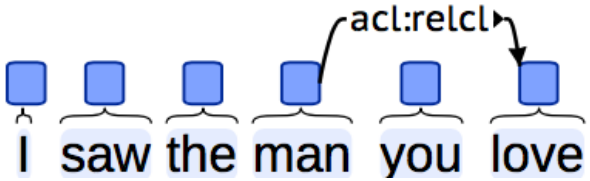
# acl

- Clausal modifier of a nominal, including relative clauses. The head verb of the embedded clause modifies the nominal it qualifies



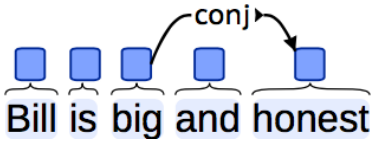
# acl:relcl

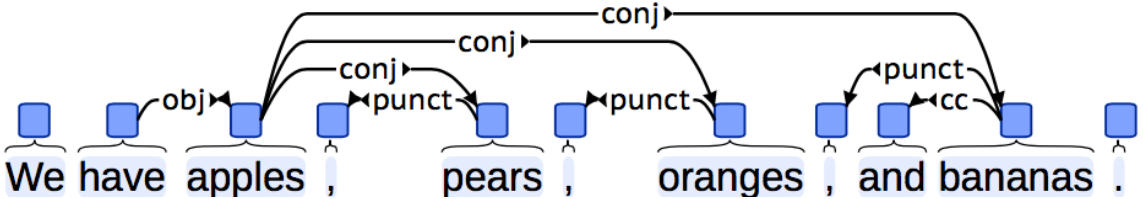
- Clausal modifier of a nominal, including relative clauses. The head verb of the embedded clause modifies the nominal it qualifies



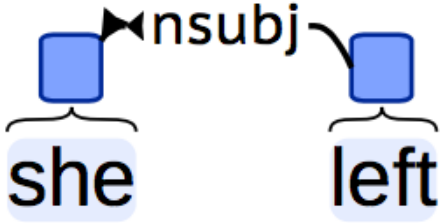
# conj

- The elements that are coordinated; the head is the first conjunct

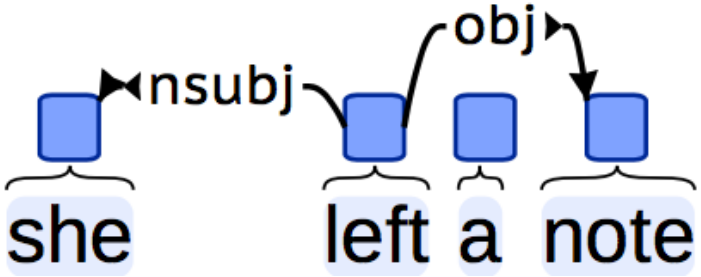


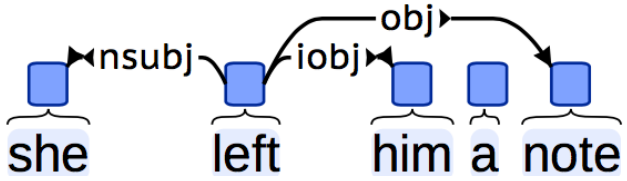
# Intransitive verbs

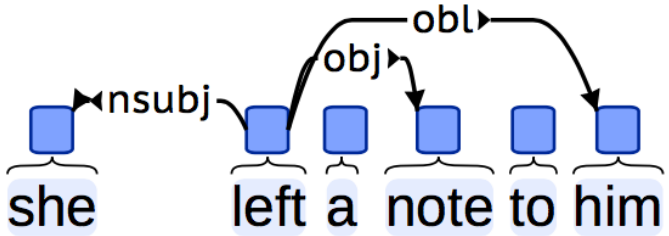


# Transitive verbs

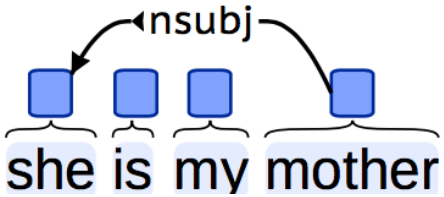


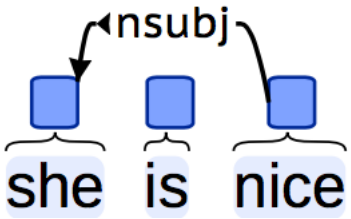
# Ditransitive verbs



# Nonverbal predication

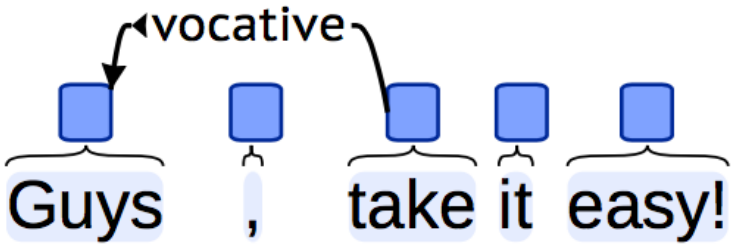


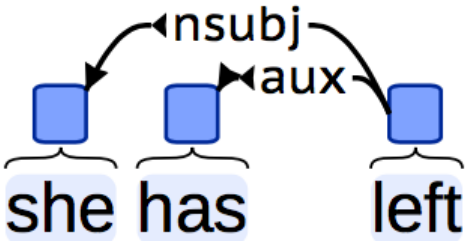
# Nonverbal predication

- Equation (aka identification): “she is my mother”
- Attribution: “she is nice”
- Location: “she is in the bathroom”
- Possession: “the book is hers”
- Benefaction: “the book is for her”
- Existence: “there is food (in the kitchen)”

# Vocatives

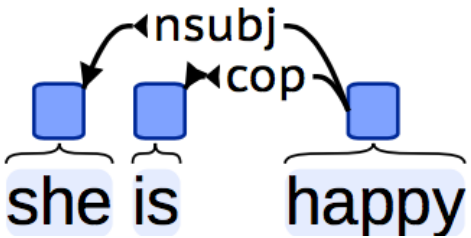


# Aux

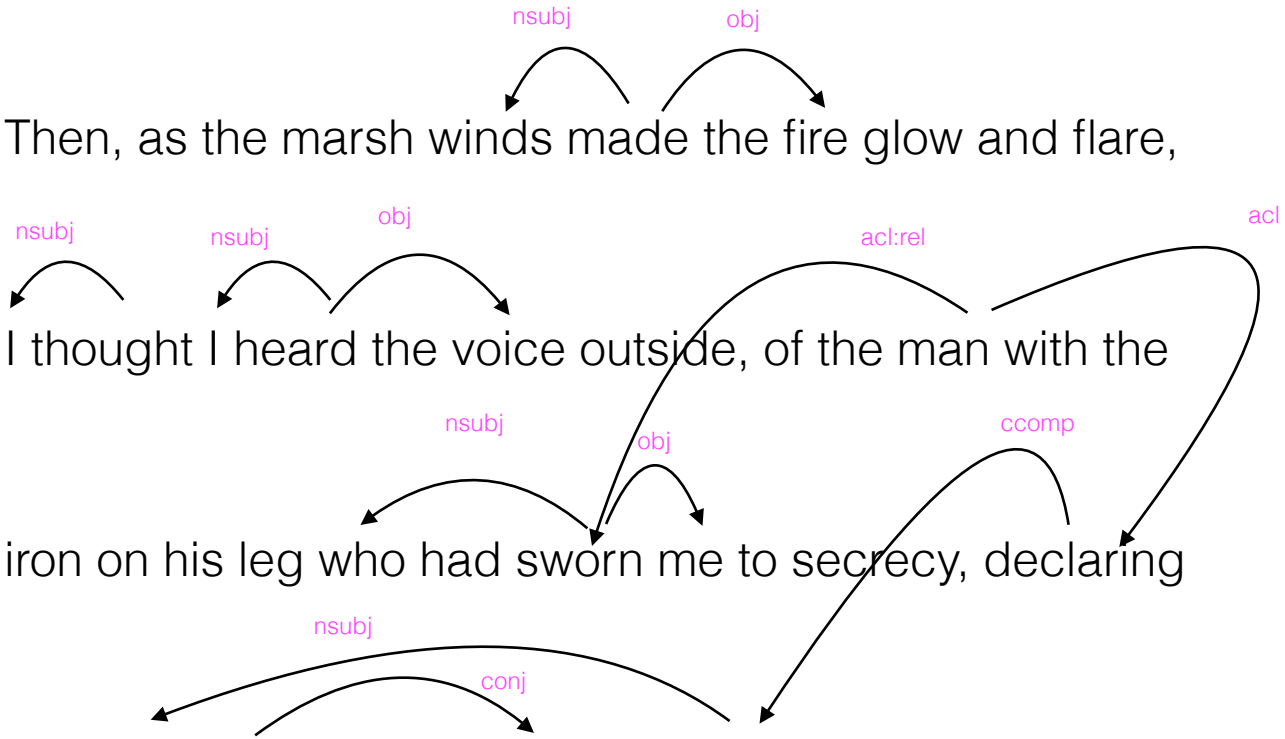



aux adds tense, aspect, mood, voice or evidentiality

# cop




cop links a non-verbal predicate to subject




[Great Expectations]

# Thursday

- Algorithms for dependency parsing
    - Shift-reduce parsing
    - Graph-based parsing