НАЦИОНАЛЬНЫЙ ИССЛЕДОВАТЕЛЬСКИЙ УНИВЕРСИТЕТ

# Dependency grammar and dependency parsing

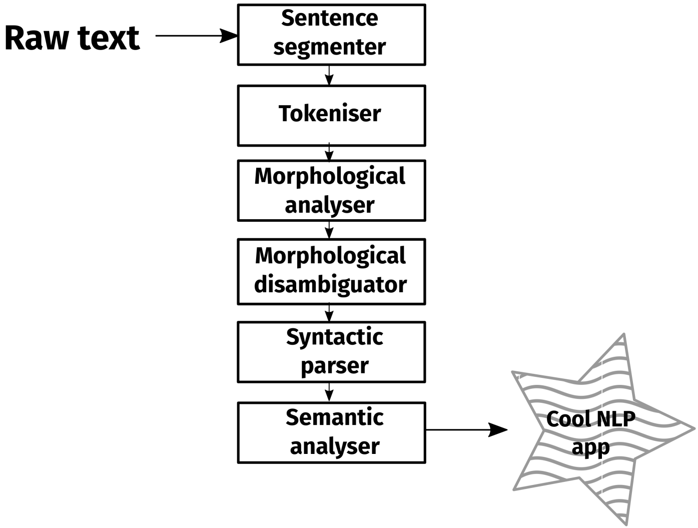
Francis M. Tyers

ftyers@hse.ru
https://www.hse.ru/org/persons/209454856

Национальный исследовательский университет
«Высшая школа экономики» (Москва)

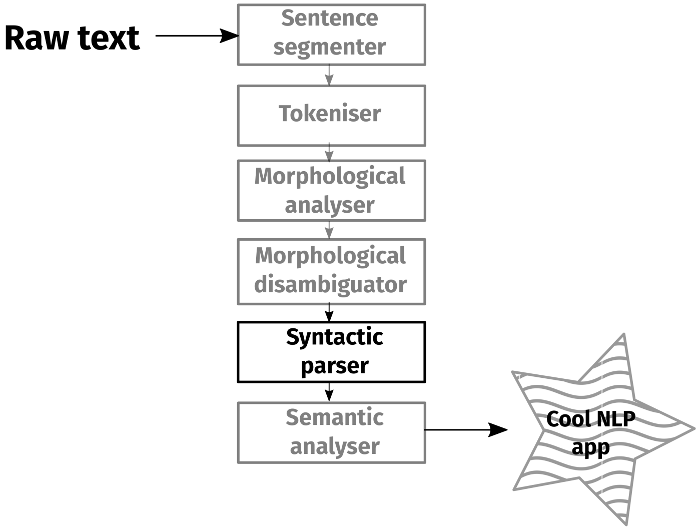
10 сентября 2018 г.

# Pipeline



Raw text
Sentence segmenter
Tokeniser
Morphological analyser
Morphological disambiguator
Syntactic parser
Semantic analyser
Cool NLP app

# Pipeline



Raw text
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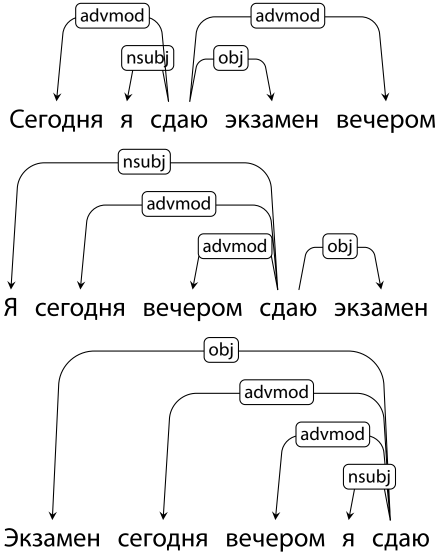
# Motivating example

*Сегодня я сдаю экзамен вечером*
*Я сегодня вечером сдаю экзамен*
*Экзамен сегодня вечером я сдаю*

**Bigrams**
я сдаю, сдаю экзамен
вечером сдаю, сдаю экзамен
я сдаю, сдаю EOS

- Generalise over linear order
- Generalise long-distance

# Motivating example




**Bigrams**

я сдаю, сдаю экзамен

Я сдаю, сдаю экзамен

я сдаю, сдаю экзамен

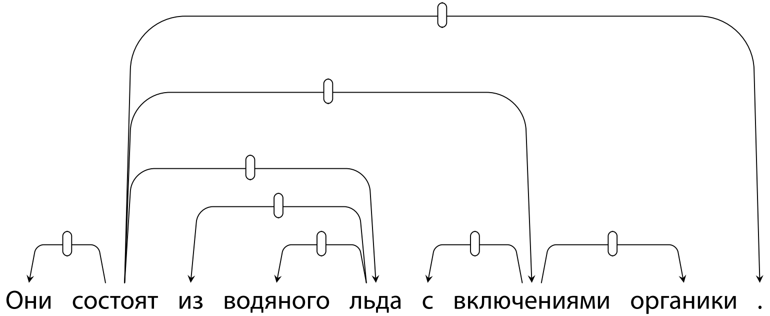
# Dependency syntax

- Word based
- No non-terminals
- Words are linked by one-way binary relations
- Relations may be typed or untyped

# Dependency structure

Они состоят из водяного льда с включениями органики .

# Dependency structure



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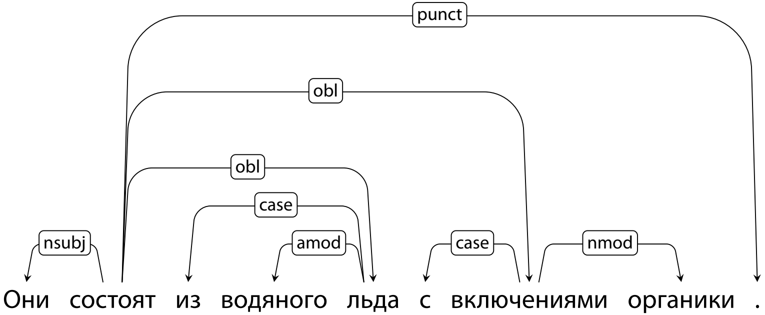
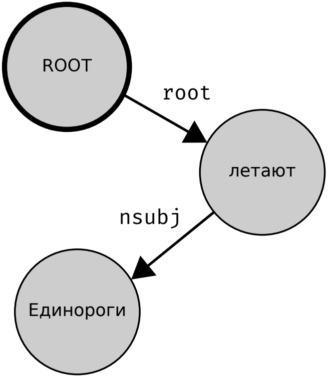


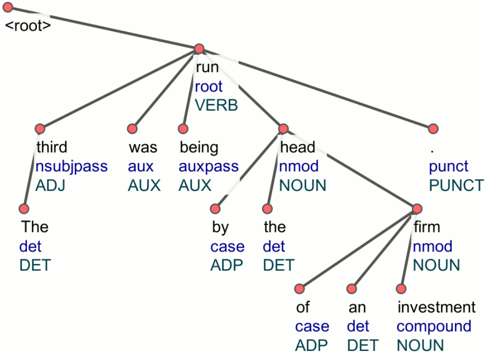

- Labels describe functional relations

# Terminology

| Superior | Inferior |
|---|---|
| Head | Dependent |
| Governor | Modifier |
| Regent | Subordinate |
| Mother | Daughter |
| Parent | Child |

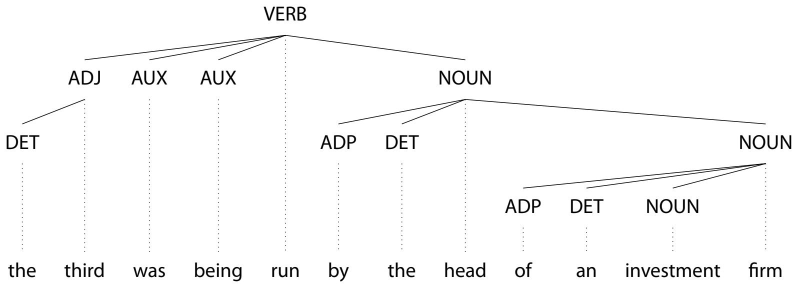


# Notational variants



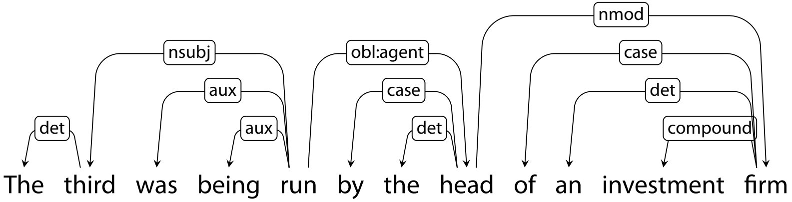

- Prague style

# Notational variants



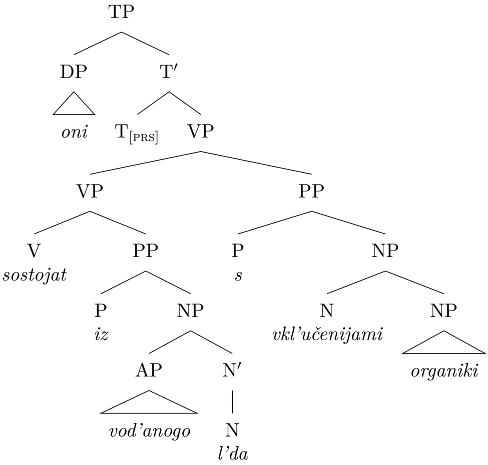

- «I wish I were a phrase-structure parse» style

# Notational variants




- Most familiar style

# Phrase structure



# Comparison

Dependency structures explicitly represent:

- head–dependent relations (directed arcs)
- functional categories (arc labels)

Phrase structures explicitly represent:

- phrases (non-terminal nodes)
- structural categories (non-terminal labels)

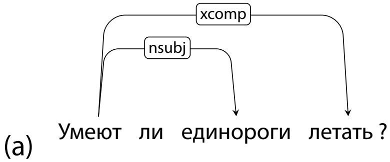
# Heads and dependents

- Criteria for a syntactic relation between a head *H* and a dependent *D* in a construction *C* (Zwicky, 1985)[1]
    1. *H* determines the syntactic category of *C*; *H* can replace *C*
    2. *H* determines the semantic category of *C*; *D* specifies *H*
    3. *H* is obligatory, *D* may be optional
    4. *H* selects *D* and determines optionality of *D*
    5. The form of *D* depends on *H* (agreement or government)
    6. Linear position of *D* is specified with reference to *H*
- An issue:
    - Syntactic (and morphological) versus semantic criteria

[1] Zwicky, A. (1985) "Heads" *Journal of Linguistics*, 21:1–29

# Some fuzzy cases

- **Complex verb groups** (auxiliary–main verb)
- Subordinate clauses (complementiser–verb)
- Coordination (coordinator–conjuncts)
- Adpositional phrases (adposition–nominal)
- Punctuation



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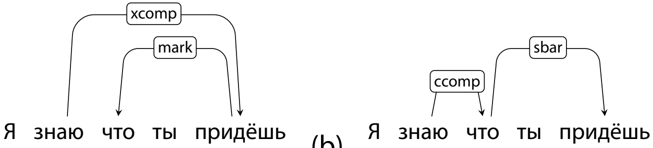
(a) (b)



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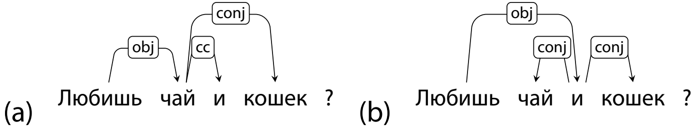

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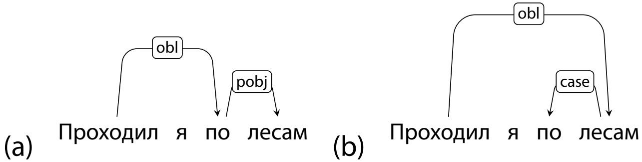

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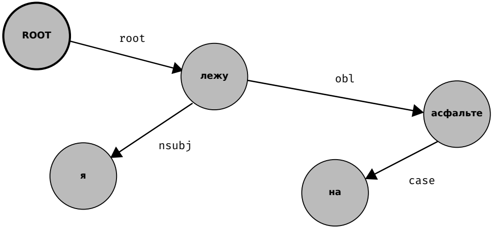
- Adpositional phrases (adposition–nominal)
- **Punctuation**

# Dependency graphs



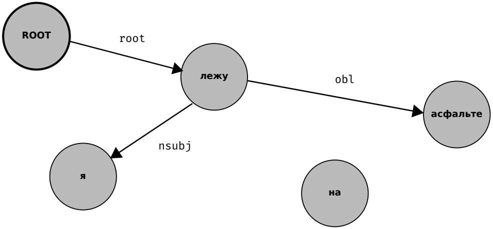

A dependency graph, *G*

- a set of *V* nodes, $V = \{0, 1, 2, 3, 4\}$
- a set of *A* arcs, $A = \{0 \rightarrow 2, 2 \rightarrow 1, 2 \rightarrow 4, 4 \rightarrow 3\}$
- a linear precedence order $<$ on *V*

Labelled graphs:

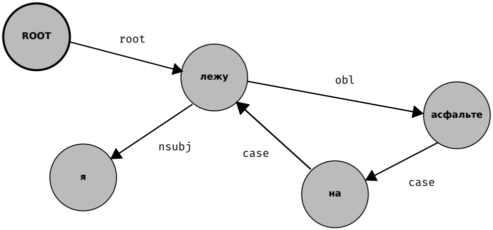
- Nodes in *V* are labelled with word forms (and annotation)
- Arcs in *A* are labelled with dependency types

# Conditions




- **Connectedness**: The syntactic structure must be complete, every word must be covered by the structure
- **Acyclicity**: The structure must be hierarchical, no cycles,
- **Single-headedness**: Each word must have at most one head

# Conditions

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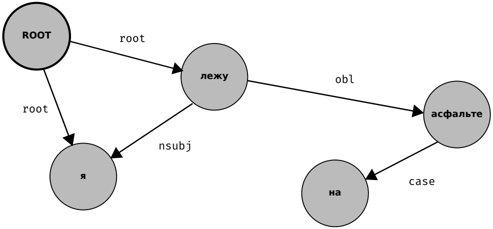


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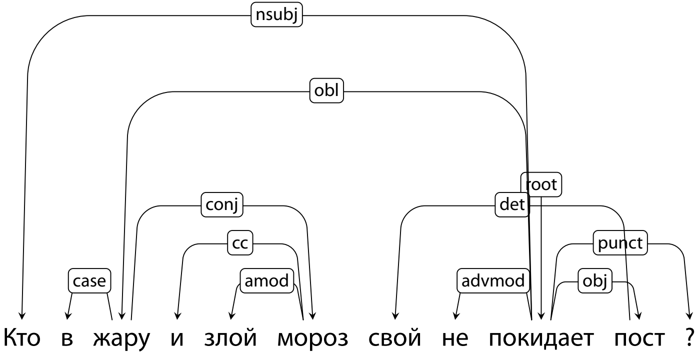
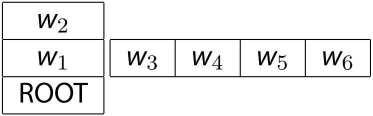
# Projectivity

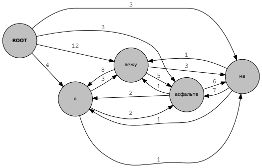



- Projectivity = no crossing arcs
- Non-projective → more complex to parse

**Transition-based**




**Graph-based**



# Transition-based

# General idea

**Parsing is:**

- A sequence of elementary operations
- A classifier is learnt to predict the sequence

# Components

**Data structures:**

- Stack:
  - Starts as containing only the ROOT
- Buffer
  - Starts as containing the full sentence
- Arcs
  - Starts as empty

**Operations:**

- SHIFT: Take the word on top of the buffer and put it on the stack
- LEFT-ARC: Make the word at the top of the stack the head of the word below it
  - Then remove the word at the top
- RIGHT-ARC: Make the word second from top the head of the word above it
  - Then remove the second from top word

# Example

ROOT Мы пошли домой

| **Stack** | **Buffer** |
|---|---|
| ROOT | Мы пошли домой |

# Example

**SHIFT**

ROOT Мы пошли домой

| **Stack** | **Buffer** |
|---|---|
| ROOT Мы | пошли домой |

# Example

**SHIFT**

ROOT Мы пошли домой

| **Stack** | **Buffer** |
| --- | --- |
| ROOT Мы пошли | домой |

# Example

**LEFT-ARC**

ROOT Мы пошли домой

| **Stack** | **Buffer** |
|---|---|
| ROOT пошли | домой |

# Example

**SHIFT**

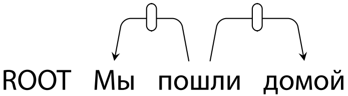
ROOT Мы пошли домой

**Stack** **Buffer**

ROOT пошли домой

# Example

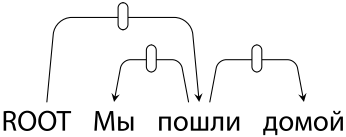
**RIGHT-ARC**




| **Stack** | **Buffer** |
| --- | --- |
| ROOT пошли | |

# Example

**RIGHT-ARC**




| **Stack** | **Buffer** |
|---|---|
| ROOT | |

# Configurations

A **configuration** is a snapshot of the state of the parser at a given time.

- A stack: Representing the word(s) currently being processed
- A buffer: Representing the remaining words
- A set of arcs representing a (partial) tree

We can conceive parsing as transitioning from one configuration to another via an operation.

# Oracle

How do we get the sequence of operations?

**Deterministic algorithm:**

- LEFT-ARC: Configuration has arc from the top of stack to the word below
- RIGHT-ARC: Configuration has arc from the of the stack to the first word in the input buffer
  - In addition: The dependent must have no dependents of its own
- SHIFT: All other cases

# Oracle

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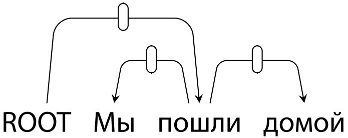
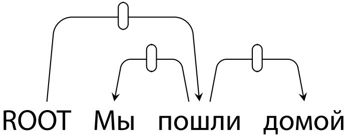
# Parsing with an oracle




| Stack | Buffer |
|---|---|
| ROOT | Мы пошли домой |

- Is there an arc from the first word in the buffer to the top of the stack?
  - (Мы, ROOT)
- Is there an arc from the top of the stack to the first word in the buffer?
  - (ROOT, Мы)
- $\rightarrow$ then SHIFT

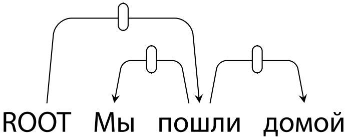
# Parsing with an oracle




| Stack | Buffer |
|---|---|
| ROOT Мы | пошли домой |

- Is there an arc from the first word in the buffer to the top of the stack?
  - (пошли, Мы) — YES, LEFT-ARC
- Is there an arc from the top of the stack to the first word in the buffer?
  - (Мы, пошли)

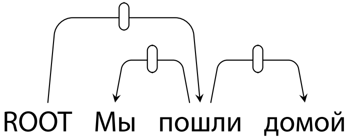
# Parsing with an oracle




| Stack | Buffer |
|---|---|
| ROOT | пошли домой |

- Is there an arc from the first word in the buffer to the top of the stack?
  - (пошли, ROOT)
- Is there an arc from the top of the stack to the first word in the buffer?
  - (ROOT, пошли) – YES, but *пошли* still has dependents
- $\rightarrow$ then SHIFT

# Parsing with an oracle




| Stack | Buffer |
|---|---|
| ROOT пошли | домой |

- Is there an arc from the first word in the buffer to the top of the stack?
  - (домой, пошли)
- Is there an arc from the top of the stack to the first word in the buffer?
  - (пошли, домой) – YES, and *домой* has no dependents
  - $\rightarrow$ RIGHT-ARC

# Training data

The “only” training data required is a treebank.

- Collection of sentences annotated for dependency structure
- Universal dependencies: 67 languages, 100s of treebanks

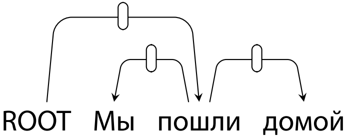
Data trains a classifier to predict a transition from a configuration.

# Training data

http://universaldependencies.org

| | | |
|---|---|---|
| Afrikaans | 1 | 49K |
| Ancient Greek | 2 | 414K |
| Arabic | 3 | 1,042K |
| Bambara | 1 | <1K |
| Basque | 1 | 121K |
| Belarusian | 1 | 8K |
| Bulgarian | 1 | 156K |
| Buryat | 1 | 10K |
| Cantonese | 1 | <1K |
| Catalan | 1 | 531K |
| Chinese | 4 | 153K |
| Coptic | 1 | 11K |
| Croatian | 1 | 197K |
| Czech | 5 | 2,222K |
| Danish | 1 | 100K |
| Dutch | 2 | 310K |
| English | 6 | 576K |
| Erzya | 1 | <1K |
| Estonian | 1 | 106K |
| Finnish | 3 | 377K |
| French | 6 | 1,099K |
| Galician | 2 | 164K |
| German | 2 | 313K |
| Gothic | 1 | 55K |
| Greek | 1 | 63K |
| Hebrew | 1 | 161K |
| Hindi | 2 | 375K |
| Hungarian | 1 | 42K |
| Indonesian | 2 | 147K |
| Irish | 1 | 23K |
| Italian | 4 | 436K |
| Japanese | 3 | 402K |
| Kazakh | 1 | 11K |
| Korean | 5 | 97K |
| Kurmanji | 1 | 10K |
| Latin | 3 | 491K |
| Latvian | 1 | 90K |
| Lithuanian | 2 | 5K |
| Maltese | 1 | 2K |
| Marathi | 1 | 3K |
| Naija | 1 | 12K |
| North Sami | 1 | 26K |
| Norwegian | 3 | 625K |
| Old Church Slavonic | 1 | 57K |
| Persian | 1 | 152K |
| Polish | 2 | 214K |
| Portuguese | 3 | 570K |
| Romanian | 2 | 239K |
| Russian | 3 | 1,226K |
| Sanskrit | 1 | 1K |
| Serbian | 1 | 86K |
| Slovak | 1 | 106K |
| Slovenian | 2 | 170K |
| Spanish | 3 | 1,004K |
| Swedish | 3 | 195K |
| Swedish Sign Language | 1 | 1K |
| Tagalog | 1 | <1K |
| Tamil | 1 | 9K |
| Telugu | 1 | 6K |
| Thai | 1 | 23K |
| Turkish | 2 | 74K |
| Ukrainian | 1 | 100K |
| Upper Sorbian | 1 | 10K |
| Urdu | 1 | 138K |
| Uyghur | 1 | 15K |
| Vietnamese | 1 | 43K |

# Features




| Stack | Buffer |
|---|---|
| ROOT пошли | домой |

Features indexed by address (in stack or buffer) and attribute name.

**Traditional:**

- (Stack[0], Form) = пошли
- (Buffer[0], Form) = домой
- (Stack[0], UPOS) = VERB
- (Stack[1], Form) = ROOT

**Indicator:**

- Combinations of such features, e.g.
  - (Stack[0], Form) = пошли & (Buffer[0], UPOS) = ADP

Can return NULL.

# Features begone!

Instead of all of those features, what do people do nowadays?

- Use embeddings
  - For words, POS tags, characters, features etc.

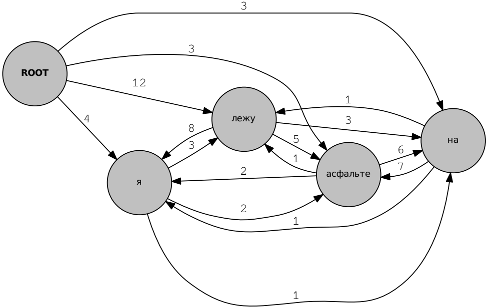
Why? Defining features is easy enough, but defining all those indicator features is tiresome.

# Extensions

- **Labelled parsing**: Instead of having three transitions, the LEFT-ARC and RIGHT-ARC transitions are expanded for the number of labels,
  - e.g. $\text{LEFT-ARC}_{\text{nsubj}}$
- **Non-projective parsing**: Add an extra transition which “swaps” adjacent nodes

# Graph-based

# Basic model




- Represent sentence as directed graph
- Score every edge
- Running the spanning tree algorithm

# Compared to transition based

**The old intuitions:**

- transition based: greedy decisions
  - $\rightarrow$ worse on long distance deps
- graph based: global optimisation, but local indep assumptions

With neural methods, these apply less.

# Scoring

Where do the scores come from ?

- The score of a tree is sum of all arcs in the tree
- The score of an arc is the linear combination of features and weights

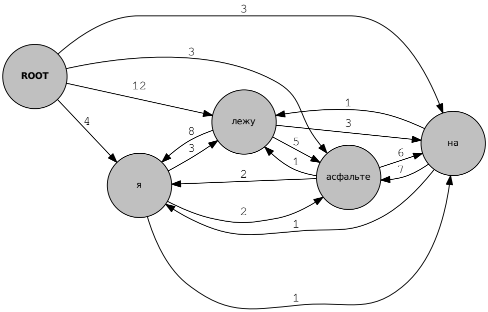
How about the features ?

- Similar to those used in transition-based parsing:
  - e.g. word form, lemma, POS of head and dependent
  - the dependency relation, direction of relation, etc.

# Maximum spanning tree

- Higher score
- Contains all nodes
- Each node has at most one incoming edge
- Originates from a single, predefined root

# Dense graph




- Links between all nodes
- Except the root

# Chu-Liu-Edmonds

- For each node in the graph
  - pick the incoming arc with the highest weight.
  - if this makes a tree $\rightarrow$ it's the MST
- Otherwise:
  - For each cycle
    - contract the cycle
    - find the incoming arc with highest weight
    - remove incompatible arcs in the cycle
  - repeat

# Chu-Liu-Edmonds

**function** MAXSPANNINGTREE($G$=($V$,$E$), *root*, *score*) **returns** *spanning tree*

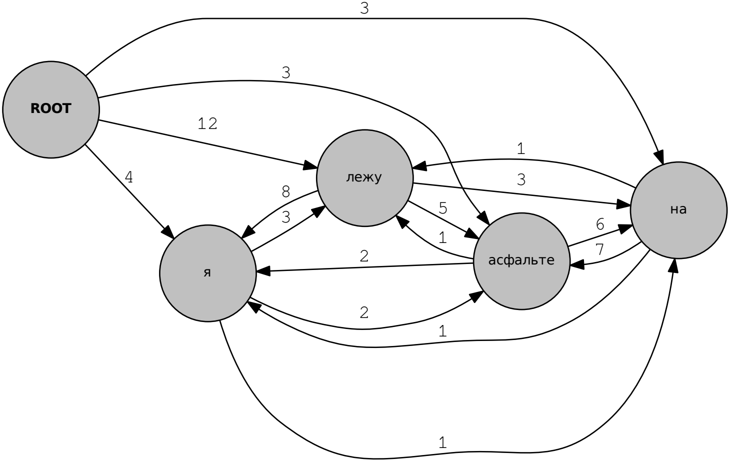
```
F ← []
T' ← []
score' ← []
for each v ∈ V do
   bestInEdge ← argmax_{e=(u,v)∈E} score[e]
   F ← F ∪ bestInEdge
   for each e=(u,v) ∈ E do
      score'[e] ← score[e] − score[bestInEdge]

   if T=(V,F) is a spanning tree then return it
   else
      C ← a cycle in F
      G' ← CONTRACT(G, C)
      T' ← MAXSPANNINGTREE(G', root, score')
      T ← EXPAND(T', C)
      return T
```

**function** CONTRACT($G$, $C$) **returns** *contracted graph*

**function** EXPAND($T$, $C$) **returns** *expanded graph*

# Example



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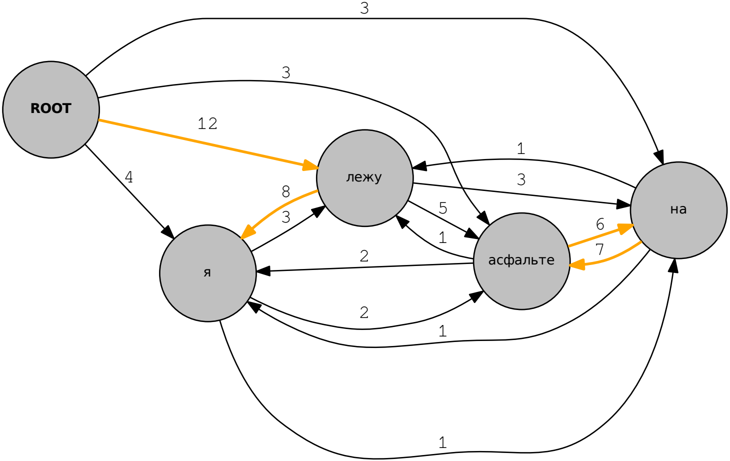

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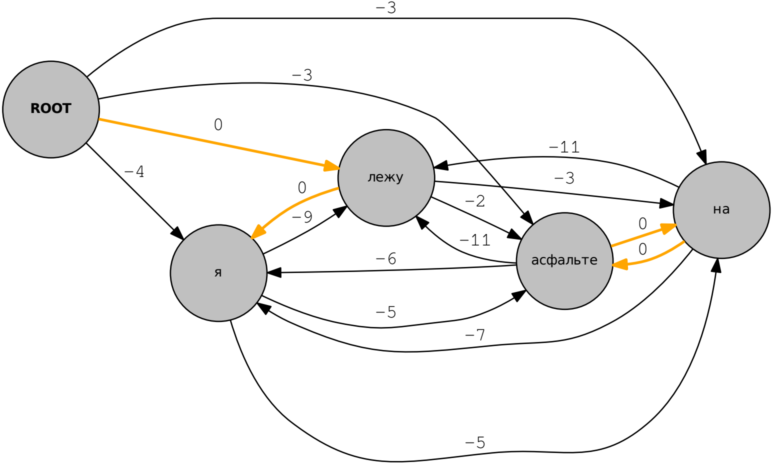
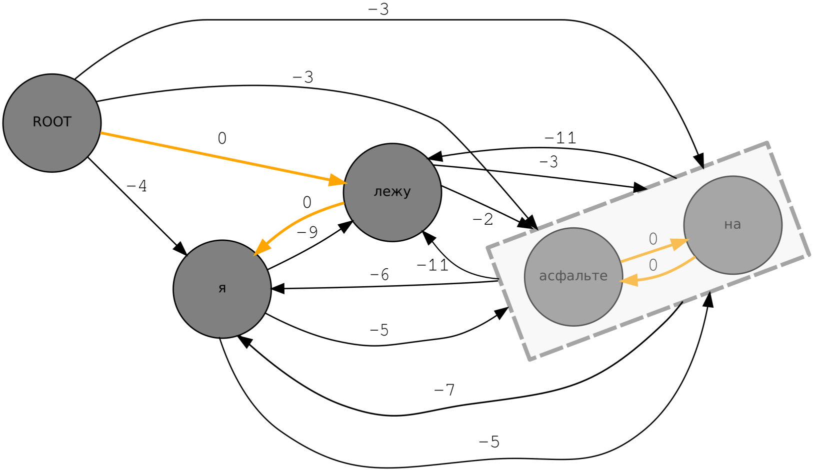
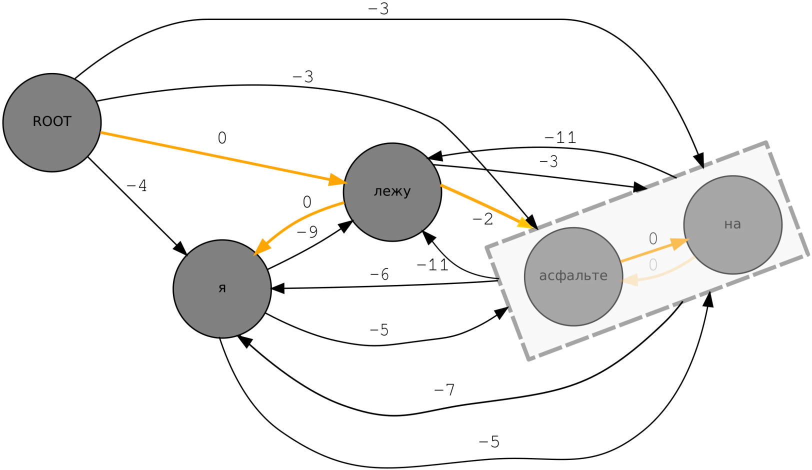


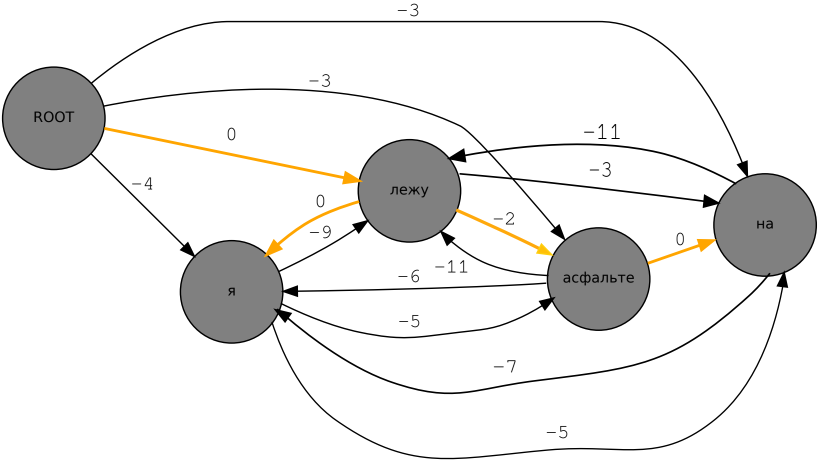
# Example



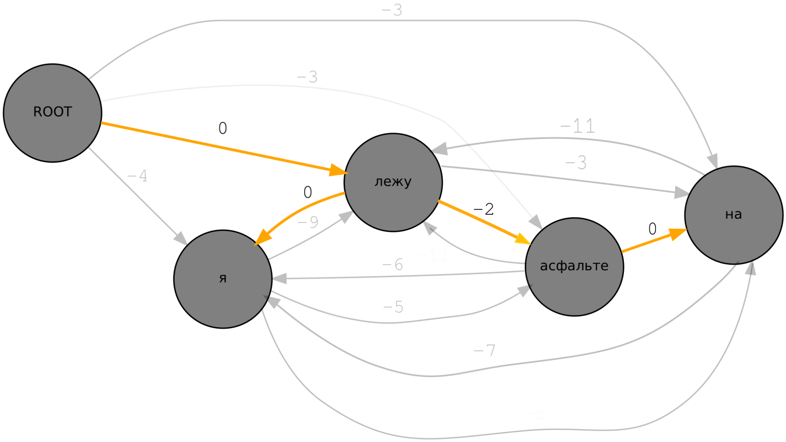
# Example



# Example



# Example



# Training

Training is online, like perceptron algorithm:

- Set some random initial weights
- Parse a sentence
- If the parse matches, do nothing,
- otherwise: find the features in the incorrect parse that aren't in the reference and lower the weights

# Parsers

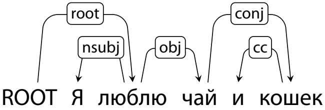
**Modern:**

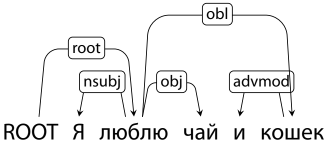
- UDPipe `http://github.com/ufal/udpipe`
- SyntaxNet `https://github.com/tensorflow/models/tree/master/research/syntaxnet`
- BiST `https://github.com/elikip/bist-parser`
  - Both MST and transition variants
- Stanford Parser `https://nlp.stanford.edu/software/nndep.html`

**Historical:**

- MaltParser
- MSTParser

# Evaluation

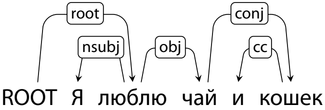


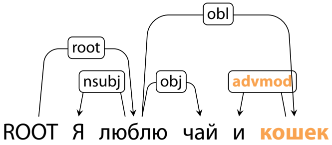




**Simple evaluation:**

- Unlabelled attachment score, **UAS**: correct heads/total heads
- Labelled attachment score, **LAS**: (correct heads+labels)/total heads

# Evaluation




**Simple evaluation:**

- Unlabelled attachment score, **UAS**: correct heads/total heads
- Labelled attachment score, **LAS**: (correct heads+labels)/total heads

LAS $3/5 = 60\%$

UAS $4/5 = 80\%$

# Shared tasks

- CoNLL 2006 (13 langs: ar, cs, bg, da, de, es, ja, nl, pt, sl, sv, tr, zh)
- CoNLL 2007 (10 langs: ar, ca, cs, el, en, eu, hu, it, tr, zh)
- CoNLL 2008: + semantic dependencies (English)
- CoNLL 2009: + semantic dependencies (ca, cs, de, en, es, ja, zh)
- ICON 2009 (Hindi, Bangla, Telugu)
- ICON 2010 (Hindi, Bangla, Telugu)
- SPMRL 2013 (9 languages: ar, de, eu, fr, he, hu, ko, pl, sv)
- SPMRL 2014 (9 languages: ar, de, eu, fr, he, hu, ko, pl, sv)
- VarDial 2017 (cross-lingual: cs-sk, sl-hr, da/sv-no)
- CoNLL 2017 (45 languages + surprise + end-to-end parsing)
- CoNLL 2018 (?? languages, end-to-end parsing)

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- **CoNLL 2017 (45 languages + surprise + end-to-end parsing)**
- **CoNLL 2018 (?? languages, end-to-end parsing)**

# CoNLL 2017

| | | |
|---|---|---|
| 1. | Stanford (Stanford) | 76.30 ± 0.12 |
| 2. | C2L2 (Ithaca) | 75.00 ± 0.12 |
| 3. | IMS (Stuttgart) | 74.42 ± 0.13 |
| 4. | HIT-SCIR (Harbin) | 72.11 ± 0.14 |
| 5. | LATTICE (Paris) | 70.93 ± 0.13 |
| 6. | NAIST SATO (Nara) | 70.14 ± 0.13 |
| 7. | Koç University (İstanbul) | 69.76 ± 0.13 |
| 8. | ÚFAL – UDPipe 1.2 (Praha) | 69.52 ± 0.13 |
| 9. | UParse (Edinburgh) | 68.87 ± 0.14 |
| 10. | Orange – Deskiñ (Lannion) | 68.61 ± 0.13 |
| 11. | TurkuNLP (Turku) | 68.59 ± 0.14 |
| 12. | darc (Tübingen) | 68.41 ± 0.13 |
| 13. | BASELINE UDPipe 1.1 (Praha) | 68.35 ± 0.14 |
| 14. | MQuni (Sydney) | 68.05 ± 0.13 |
| 15. | fbaml (Palo Alto) | 67.87 ± 0.13 |
| 16. | LyS-FASTPARSE (A Coruña) | 67.81 ± 0.13 |
| 17. | LIMSI-LIPN (Paris) | 67.72 ± 0.14 |
| 18. | RACAI (București) | 67.71 ± 0.13 |
| 19. | IIT Kharagpur (Kharagpur) | 67.61 ± 0.14 |
| 20. | naistCL (Nara) | 67.59 ± 0.15 |
| 21. | Wanghao-ftd-SJTU (Shanghai) | 66.53 ± 0.14 |
| 22. | UALING (Tucson) | 65.24 ± 0.13 |
| 23. | Uppsala (Uppsala) | 65.11 ± 0.13 |
| 24. | METU (Ankara) | 61.98 ± 0.14 |
| 25. | CLCL (Genève) | 61.82 ± 0.13 |
| 26. | Mengest (Shanghai) | 61.33 ± 0.14 |
| 27. | ParisNLP (Paris) | 60.02 ± 0.14 |

# CoNLL 2017

## ru_syntagrus

| | | | |
|---|---|---|---|
| 1. | Stanford (Stanford) | software1 | 92.60 |
| 2. | C2L2 (Ithaca) | software5 | 90.03 |
| 3. | IMS (Stuttgart) | software2 | 89.80 |
| 4. | HIT-SCIR (Harbin) | software4 | 89.77 |
| 5. | NAIST SATO (Nara) | software1 | 89.31 |
| 6. | UParse (Edinburgh) | software1 | 89.18 |
| 7. | Uppsala (Uppsala) | software1 | 88.04 |
| 8. | LATTICE (Paris) | software7 | 87.90 |
| 9. | LyS-FASTPARSE (A Coruña) | software5 | 87.55 |
| 10. | Orange – Deskiñ (Lannion) | software1 | 87.10 |
| 11. | fbaml (Palo Alto) | software1 | 86.83 |
| 12. | ÚFAL – UDPipe 1.2 (Praha) | software1 | 86.80 |

## en

| | | | |
|---|---|---|---|
| 1. | Stanford (Stanford) | software1 | 82.23 |
| 2. | HIT-SCIR (Harbin) | software4 | 79.94 |
| 3. | C2L2 (Ithaca) | software5 | 79.64 |
| 4. | LATTICE (Paris) | software7 | 78.91 |
| 5. | IMS (Stuttgart) | software2 | 78.71 |
| 6. | NAIST SATO (Nara) | software1 | 77.93 |
| 7. | fbaml (Palo Alto) | software1 | 77.57 |
| 8. | Orange – Deskiñ (Lannion) | software1 | 77.51 |
| 9. | ÚFAL – UDPipe 1.2 (Praha) | software1 | 77.25 |
| 10. | MQuni (Sydney) | software2 | 76.81 |
| 11. | TurkuNLP (Turku) | software1 | 76.68 |
| 12. | UParse (Edinburgh) | software1 | 76.42 |

# CoNLL 2018

| | |
|---|---|
| 15th April | Training and development data will be released. |
| 30th April | Baseline parsing models will be released. |
| 30th April | Test data available in TIRA. Test phase starts. |
| 26th June | Test phase ends. |
| 28th June | Results will be announced. |
| 10th July | Submission of system description papers. |

There is a Vyshka team!

**Ace the exam!**