НАЦИОНАЛЬНЫЙ ИССЛЕДОВАТЕЛЬСКИЙ
УНИВЕРСИТЕТ

Dependency grammar and dependency parsing

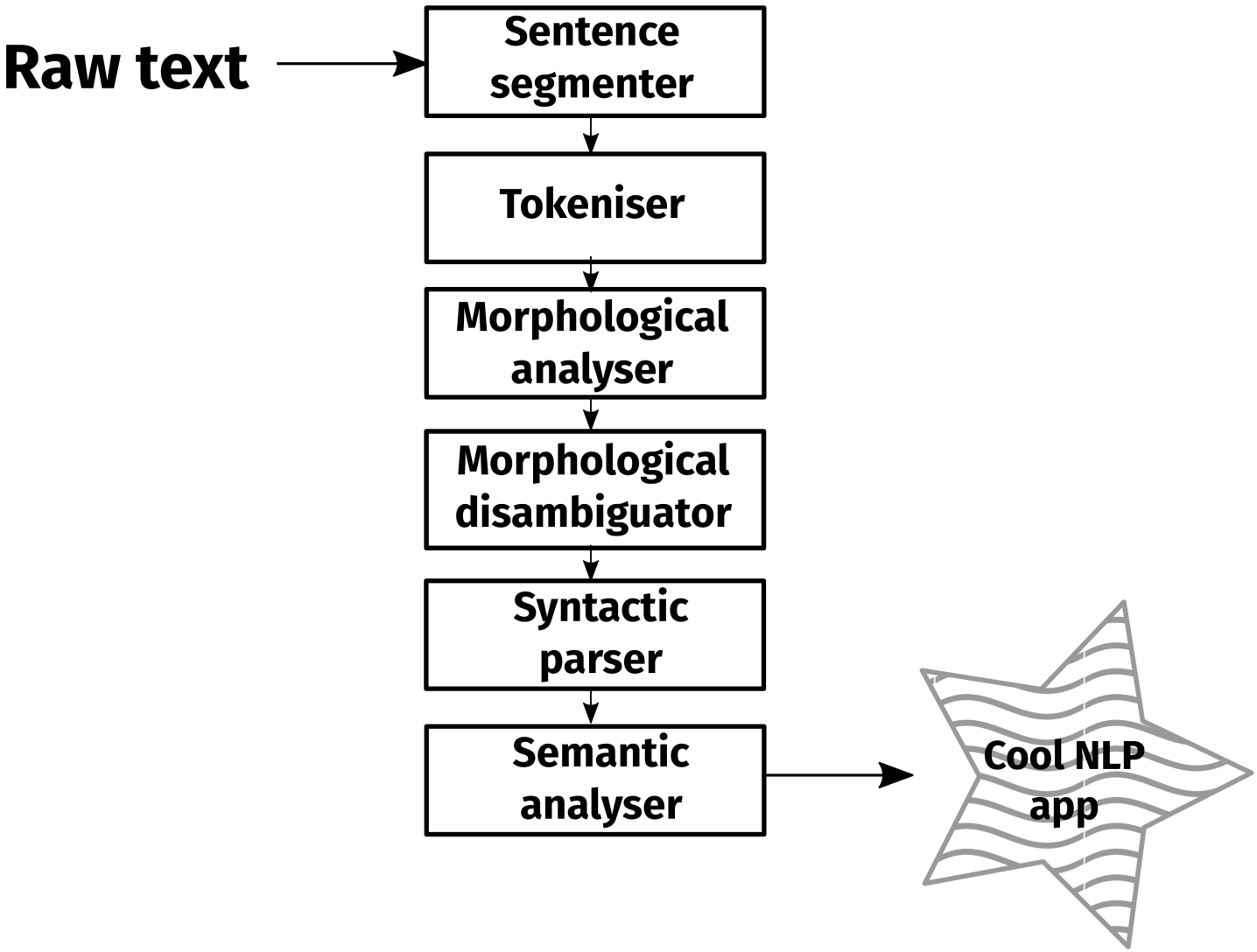
Francis M. Tyers

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

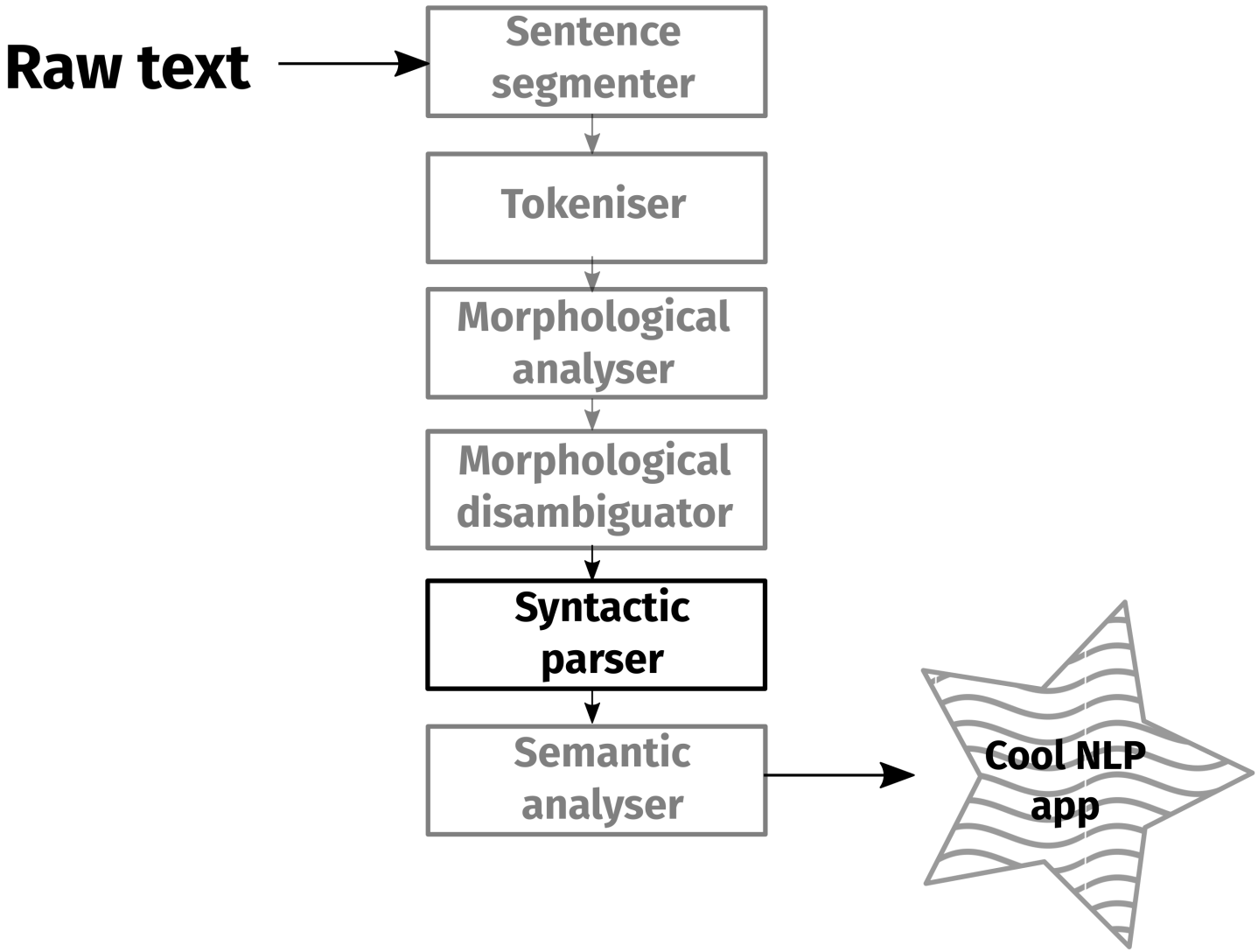
Национальный исследовательский университет
«Высшая школа экономики» (Москва)

27 марта 2018 г.

Pipeline


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

Pipeline


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

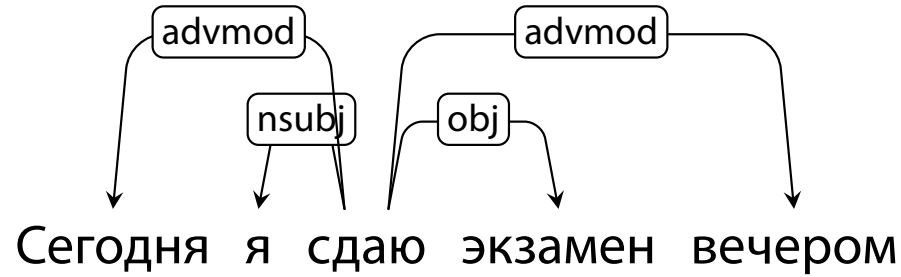
Motivating example

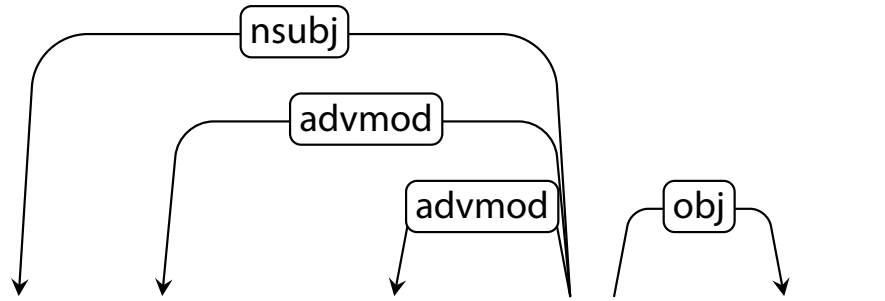
Сегодня я сдаю экзамен вечером
Я сегодня вечером сдаю экзамен
Экзамен сегодня вечером я сдаю

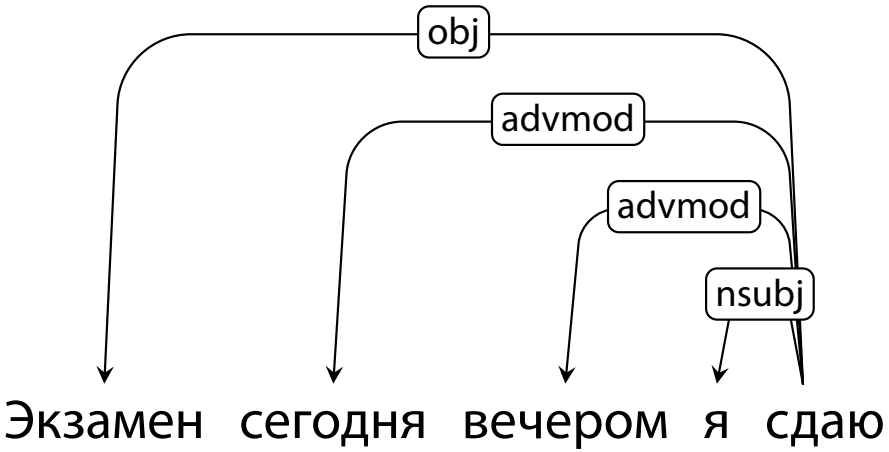
Bigrams
я сдаю, сдаю экзамен
вечером сдаю, сдаю экзамен
я сдаю, сдаю EOS

- Generalise over linear order
- Generalise long-distance

Motivating example







Bigrams

я сдаю, сдаю экзамен

Я сдаю, сдаю экзамен

я сдаю, сдаю экзамен

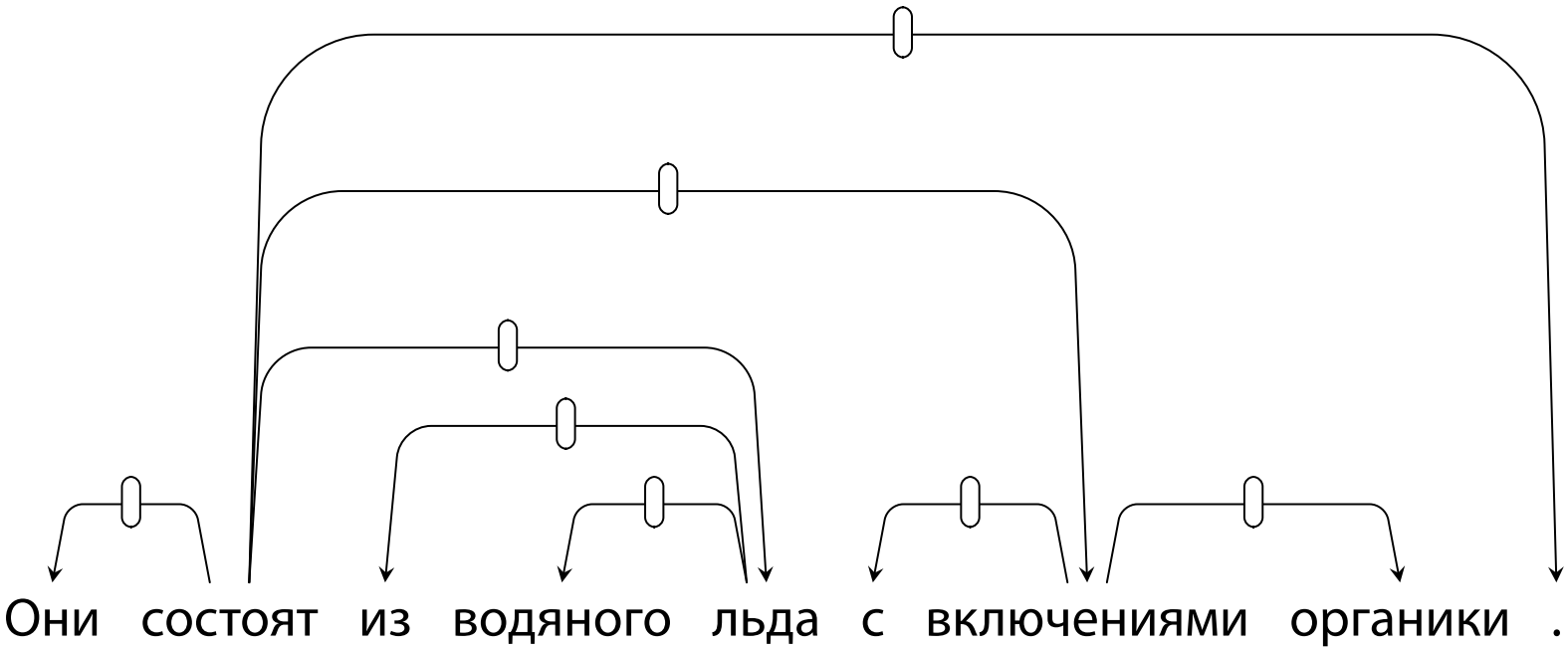
Dependency syntax

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

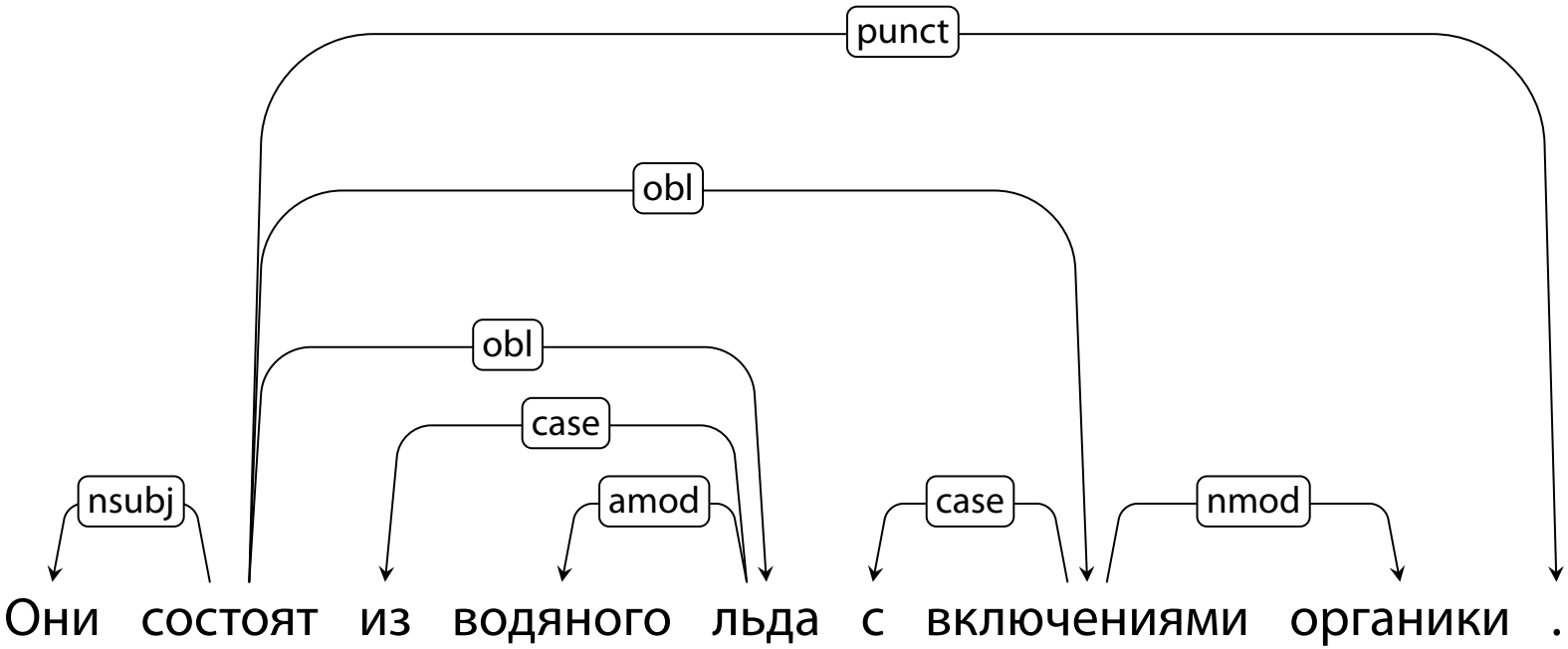
Dependency structure

Они состоят из водяного льда с включениями органики .

Dependency structure



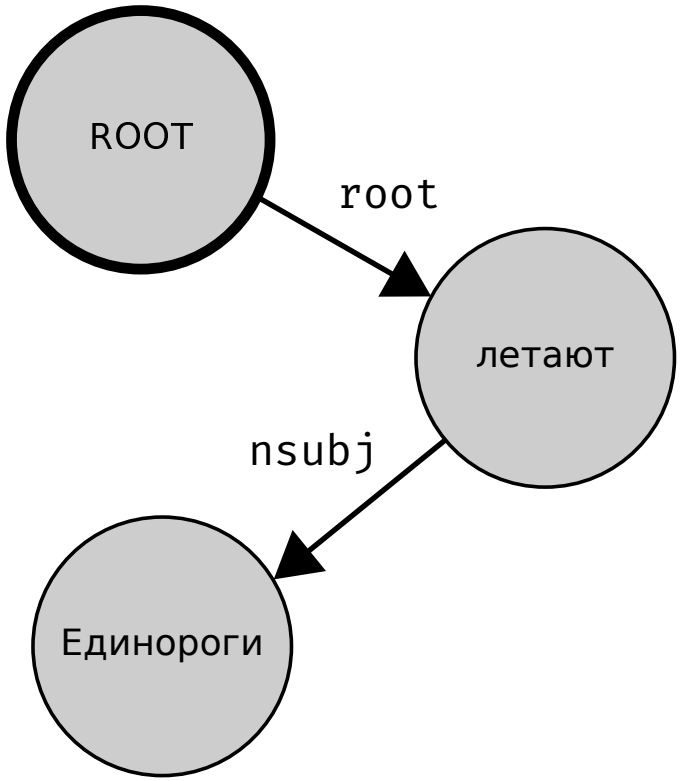
Dependency structure



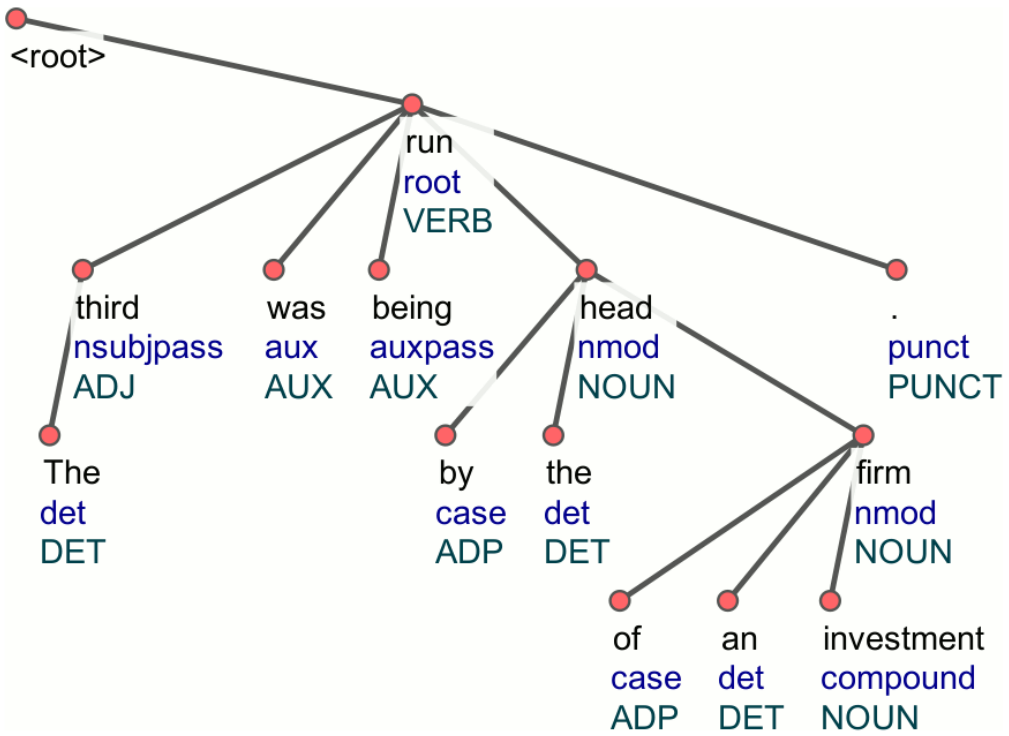
- Labels describe functional relations

Terminology

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

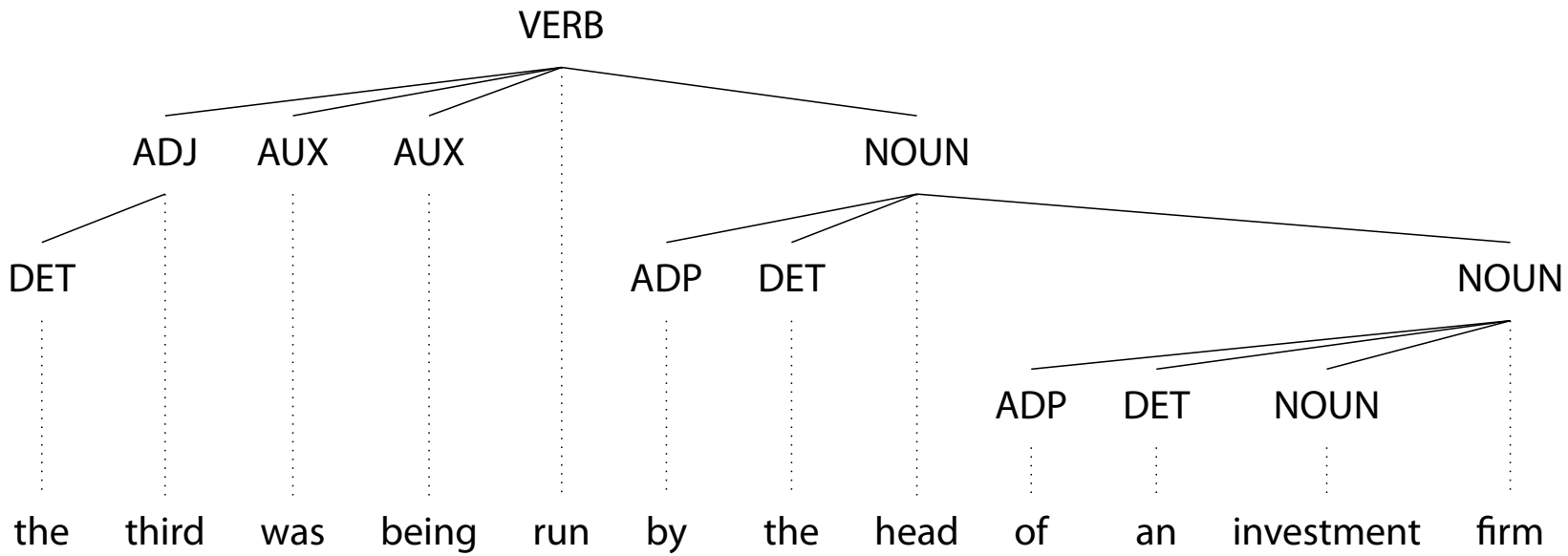


Notational variants



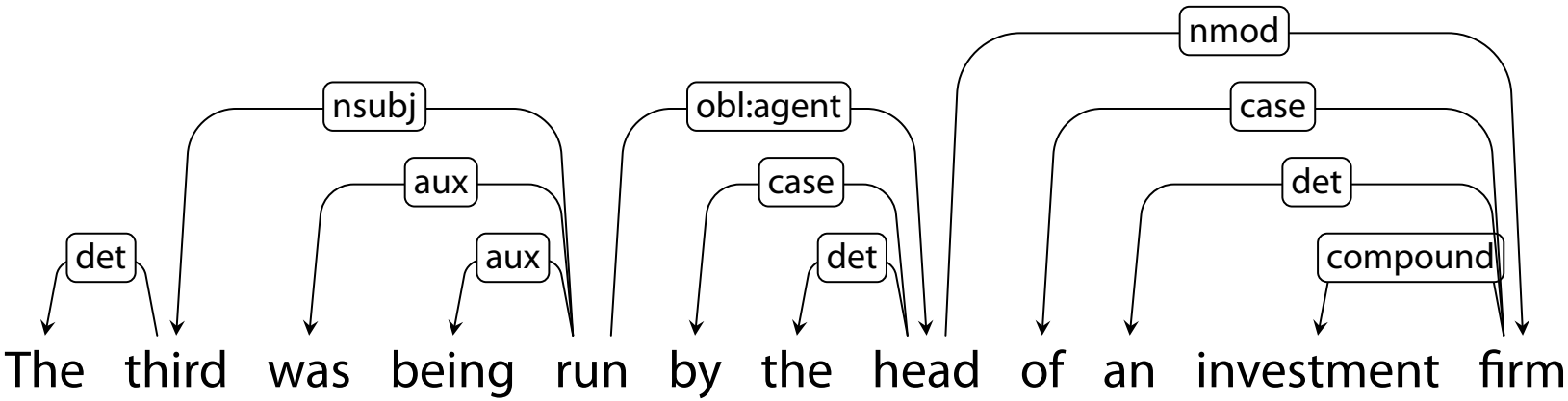
- Prague style

Notational variants



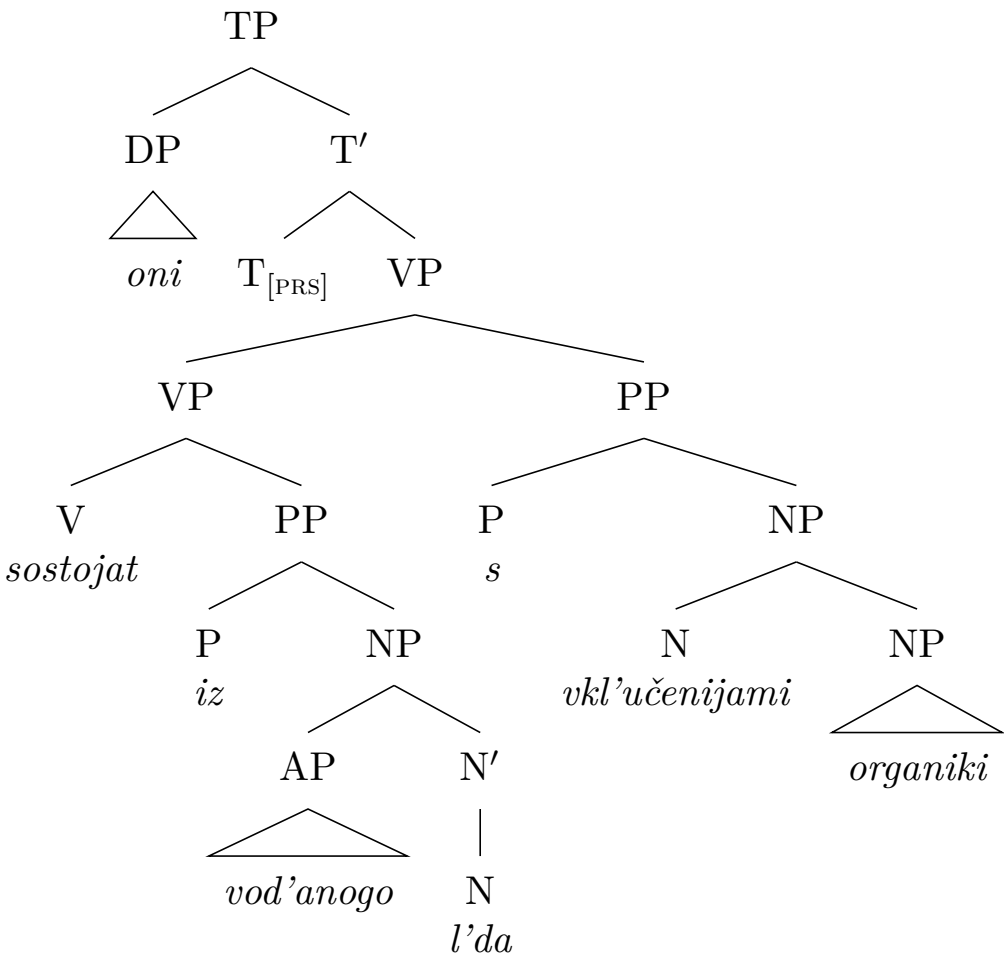
- «I wish I were a phrase-structure parse» style

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

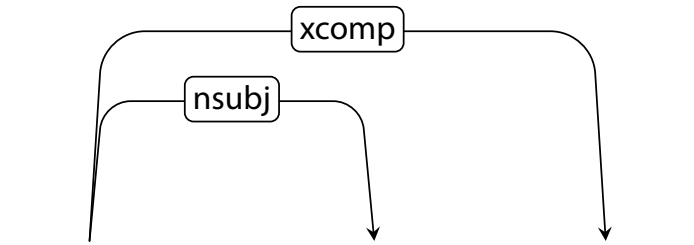
- Criteria for a syntactic relation between a head *H* and a dependent *D* in a construction *C* (Zwicky, 1985)[1]
  1. *H* determines the syntactic category of *C*; *H* can replace *C*
  2. *H* determines the semantic category of *C*; *D* specifies *H*
  3. *H* is obligatory, *D* may be optional
  4. *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

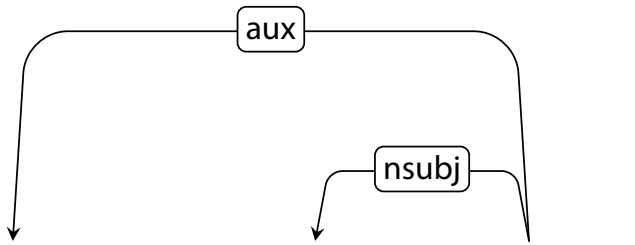
Some fuzzy cases

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

(a)



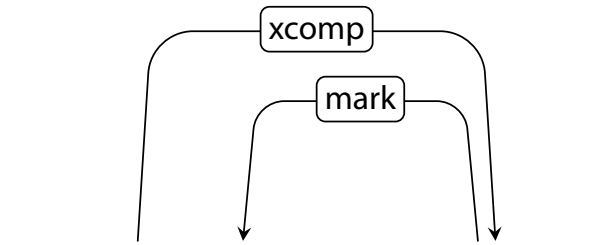
(b)



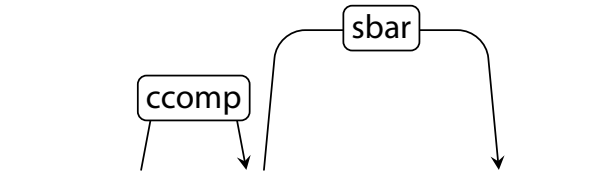
Some fuzzy cases

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

(a)



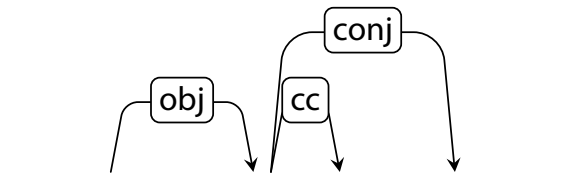
(b)



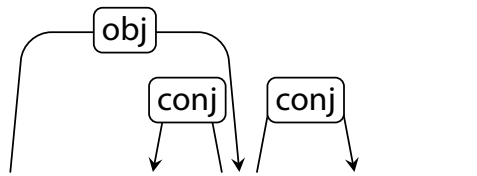
Some fuzzy cases

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

(a)



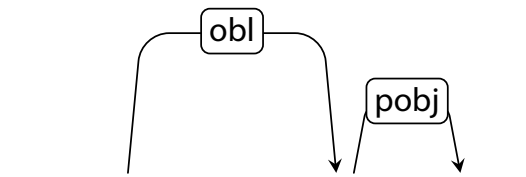
(b)



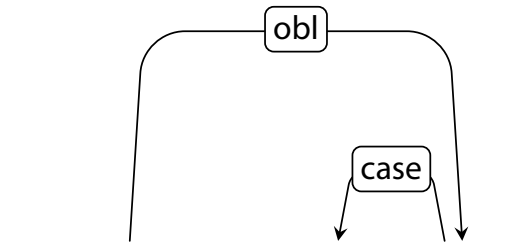
Some fuzzy cases

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

(a)



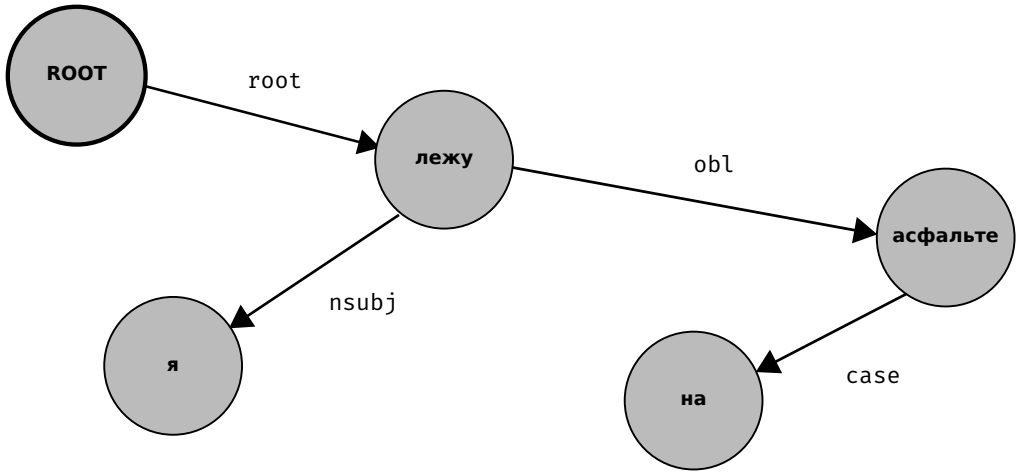
(b)



Some fuzzy cases

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

Dependency graphs



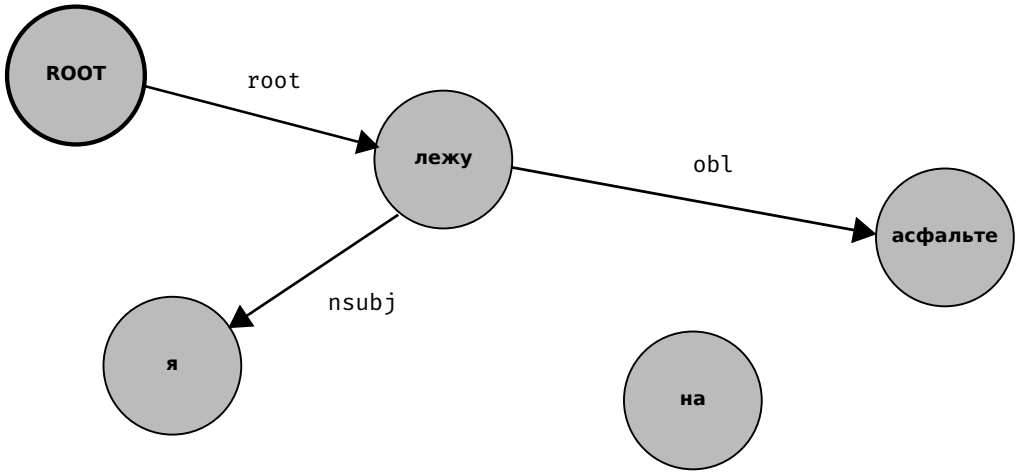
A dependency graph, *G*

- 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:

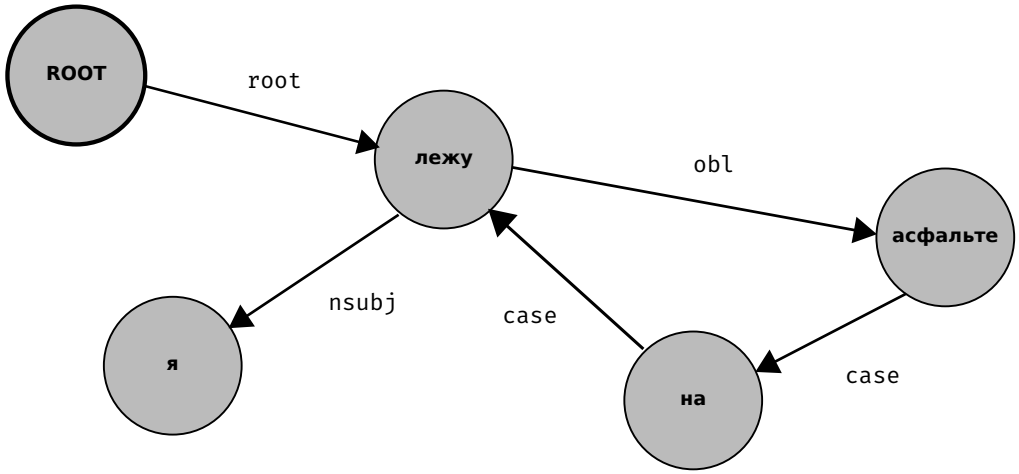
- Nodes in *V* are labelled with word forms (and annotation)
- Arcs in *A* are labelled with dependency types

Conditions



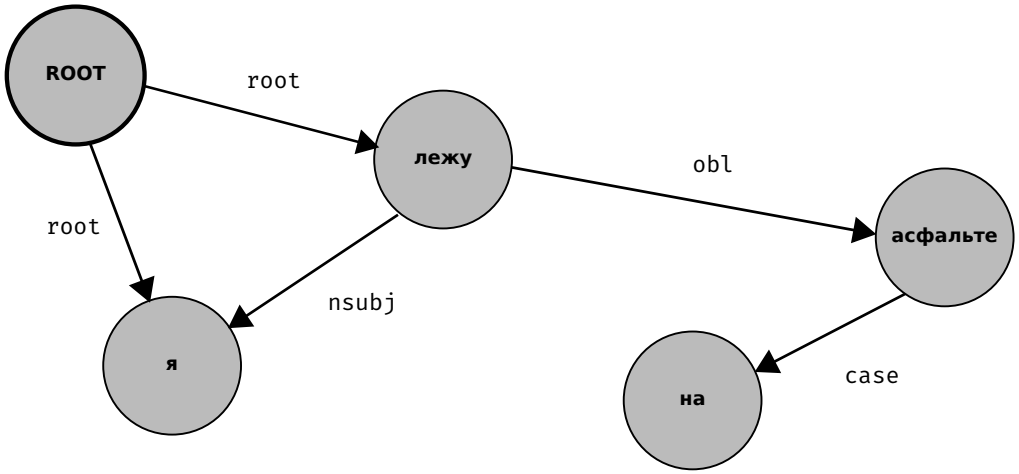
- **Connectedness**: The syntactic structure must be complete, every word must be covered by the structure
- **Acyclicity**: The structure must be hierarchical, no cycles,
- **Single-headedness**: Each word must have at most one head

Conditions



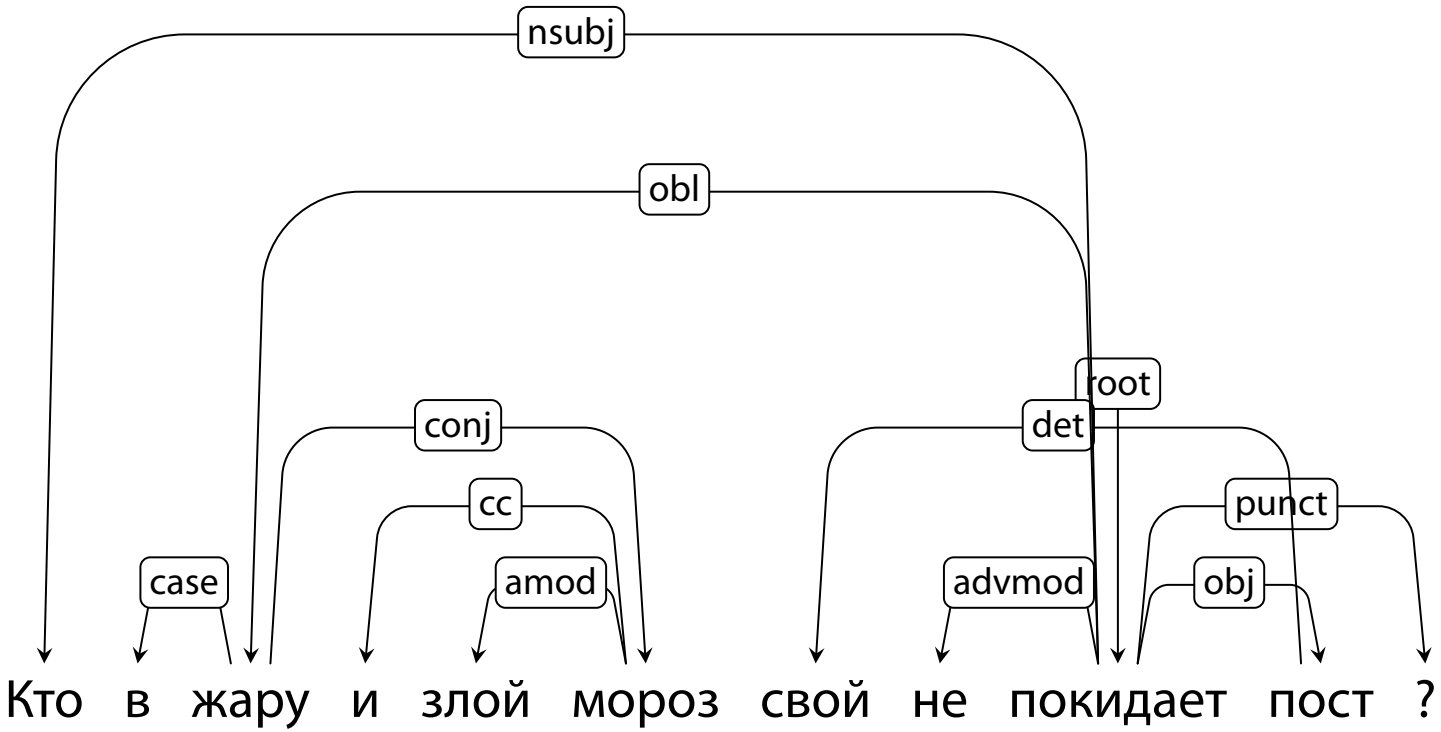
- **Connectedness**: The syntactic structure must be complete, every word must be covered by the structure
- **Acyclicity**: The structure must be hierarchical, no cycles,
- **Single-headedness**: Each word must have at most one head

Conditions



- **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

Projectivity

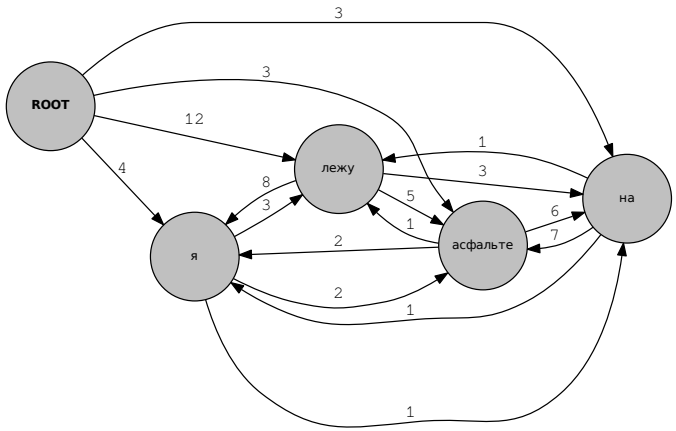


- Projectivity = no crossing arcs
- Non-projective $\rightarrow$ more complex to parse

Parsing methods

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

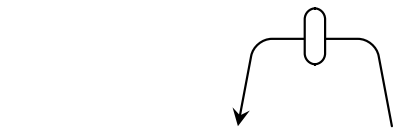
SHIFT

ROOT Мы пошли домой

Stack	**Buffer**
ROOT Мы пошли	домой

Example

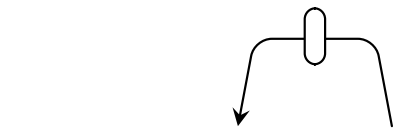
LEFT-ARC



Stack	**Buffer**
ROOT пошли	домой

Example

SHIFT

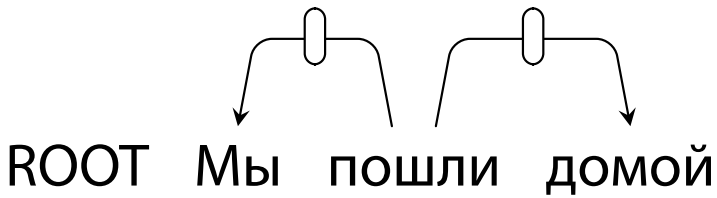


ROOT Мы пошли домой

Stack	**Buffer**
ROOT пошли домой	

Example

RIGHT-ARC

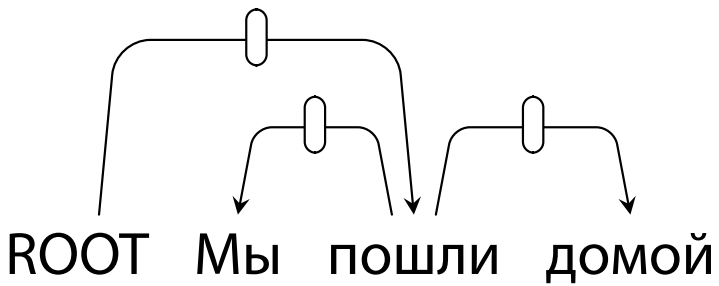


Stack **Buffer**

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

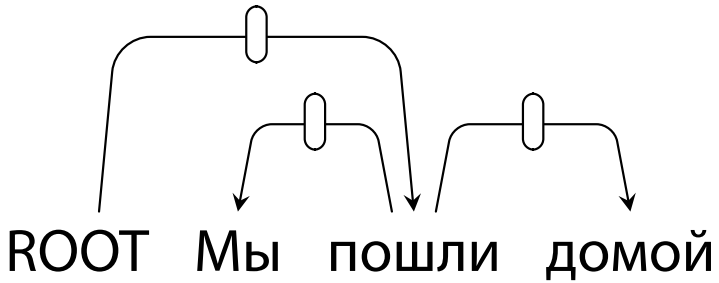
Oracle

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

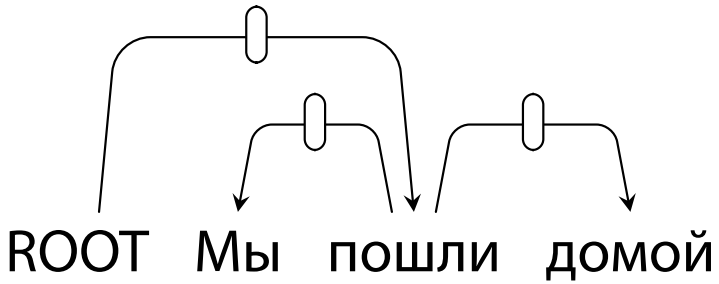
Parsing with an oracle



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

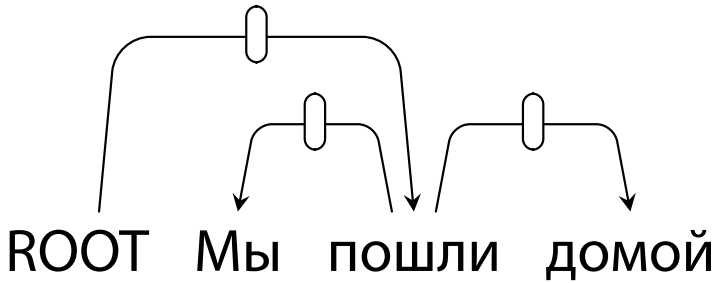
Parsing with an oracle



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)

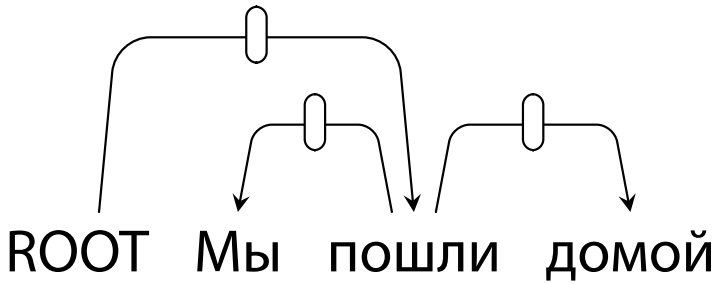
Parsing with an oracle



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.

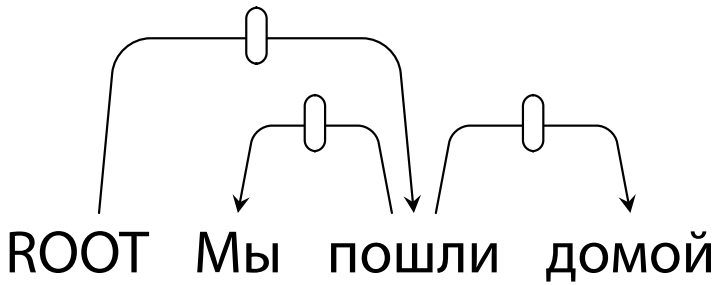
Training data

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

Can return NULL.

Indicator:

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

Features begone!

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

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

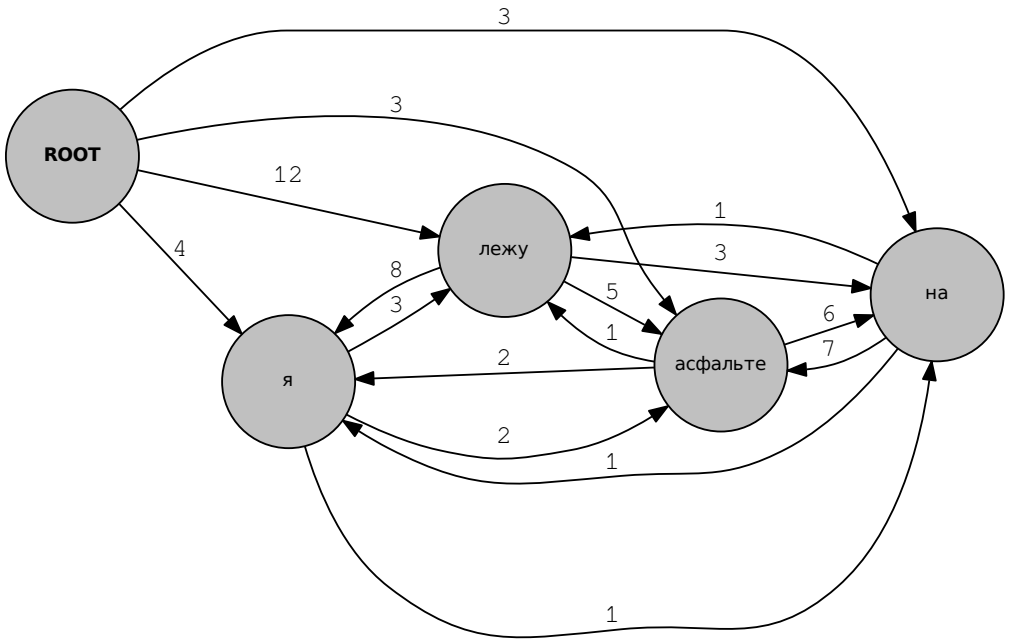
Why? Defining features is easy enough, but defining all those indicator features is tiresome.

Extensions

- **Labelled parsing**: Instead of having three transitions, the LEFT-ARC and RIGHT-ARC transitions are expanded for the number of labels,
  - e.g. 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

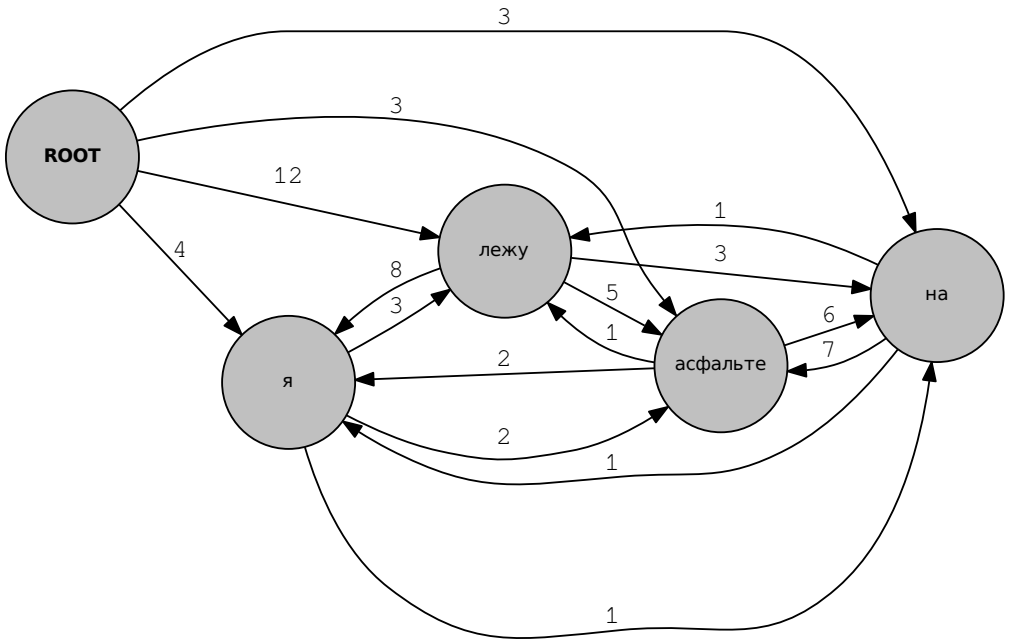
How about the features ?

- 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*

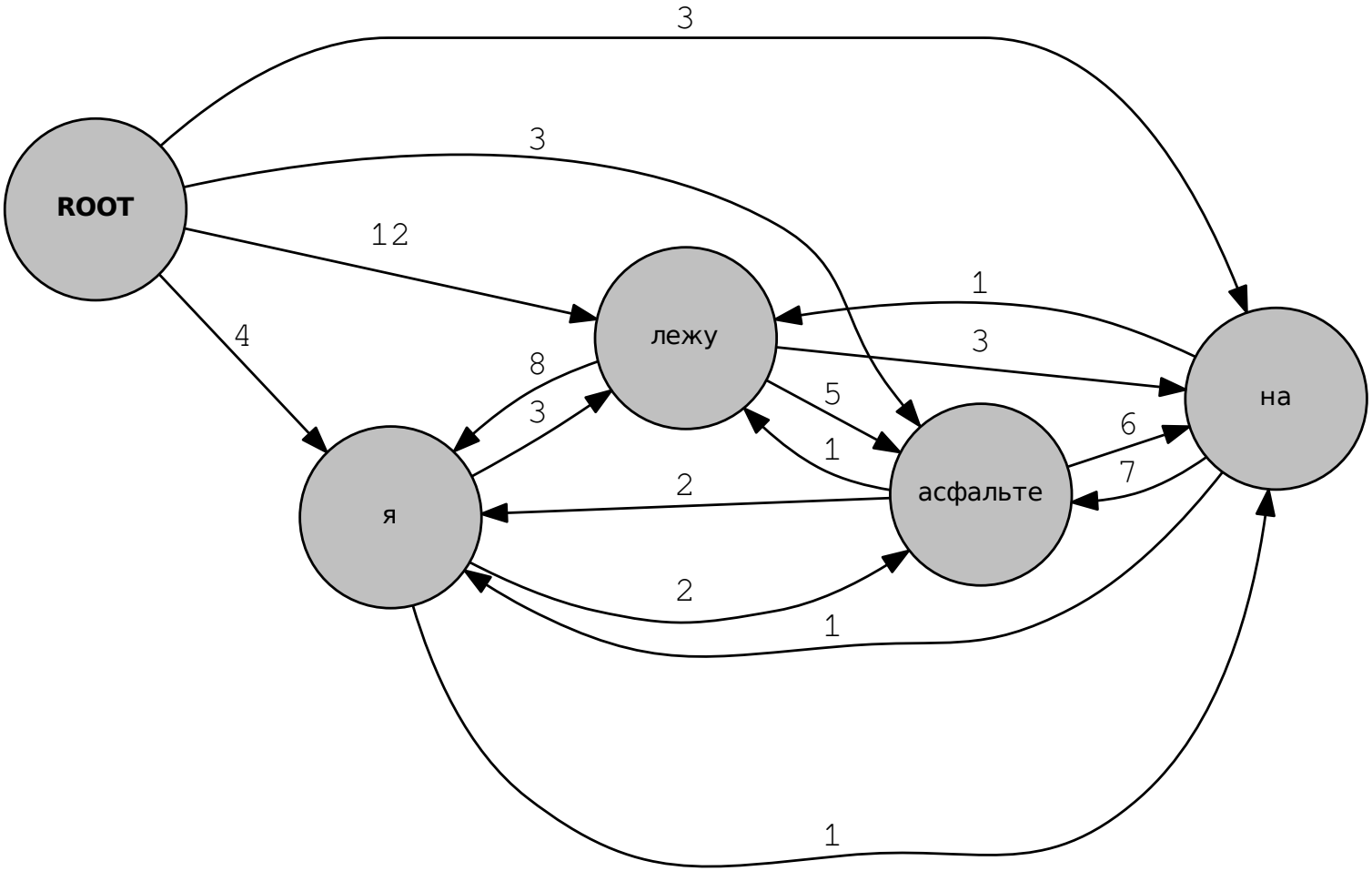
$F \leftarrow []$
$T' \leftarrow []$
$score' \leftarrow []$
for each $v \in V$ **do**
  $bestInEdge \leftarrow \text{argmax}_{e=(u,v) \in E}\ score[e]$
  $F \leftarrow F \cup bestInEdge$
  for each e=(u,v) $\in E$ **do**
    $score'[e] \leftarrow score[e] - score[bestInEdge]$

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

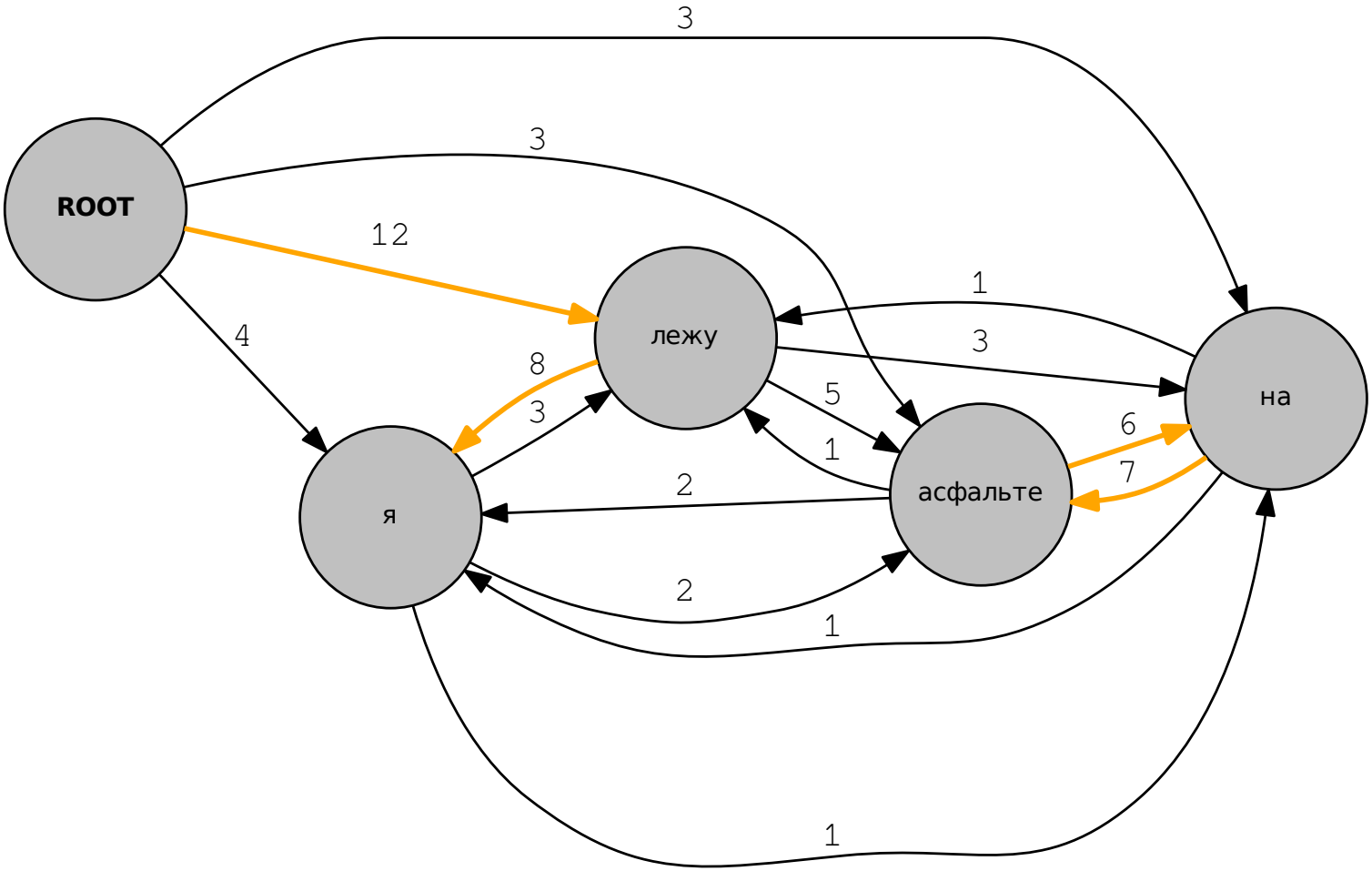
function CONTRACT(G, C) **returns** *contracted graph*

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

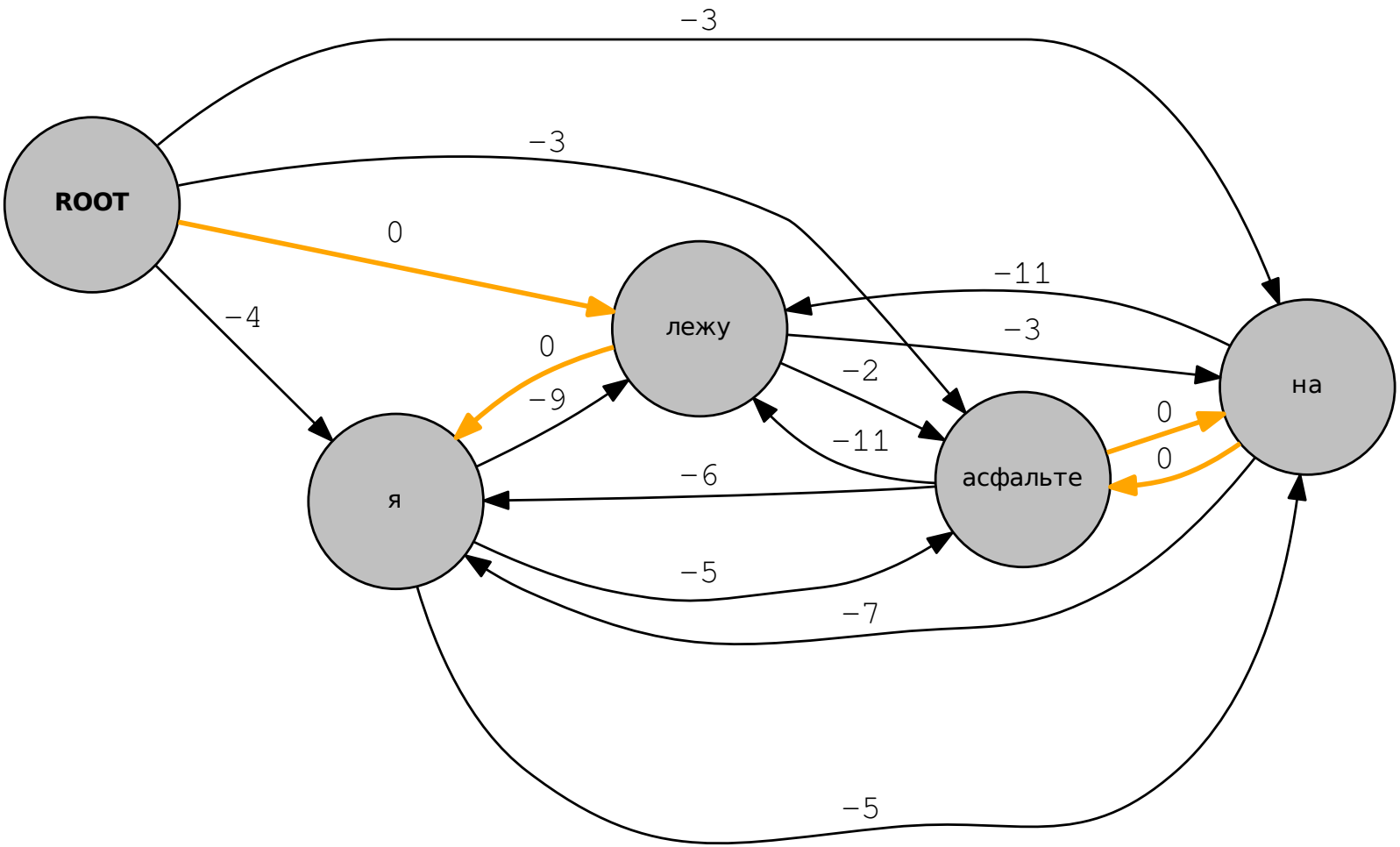
Example



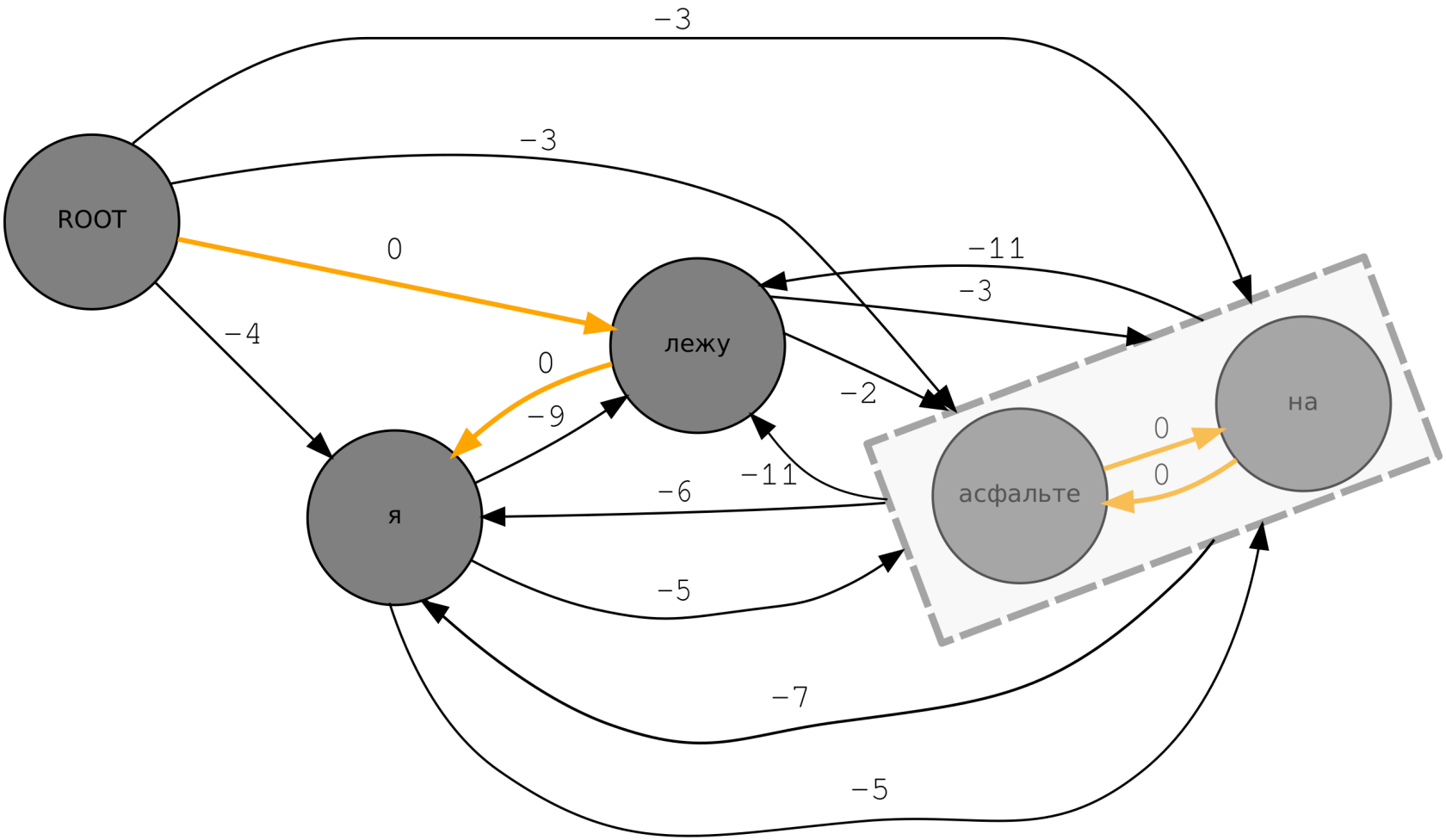
Example



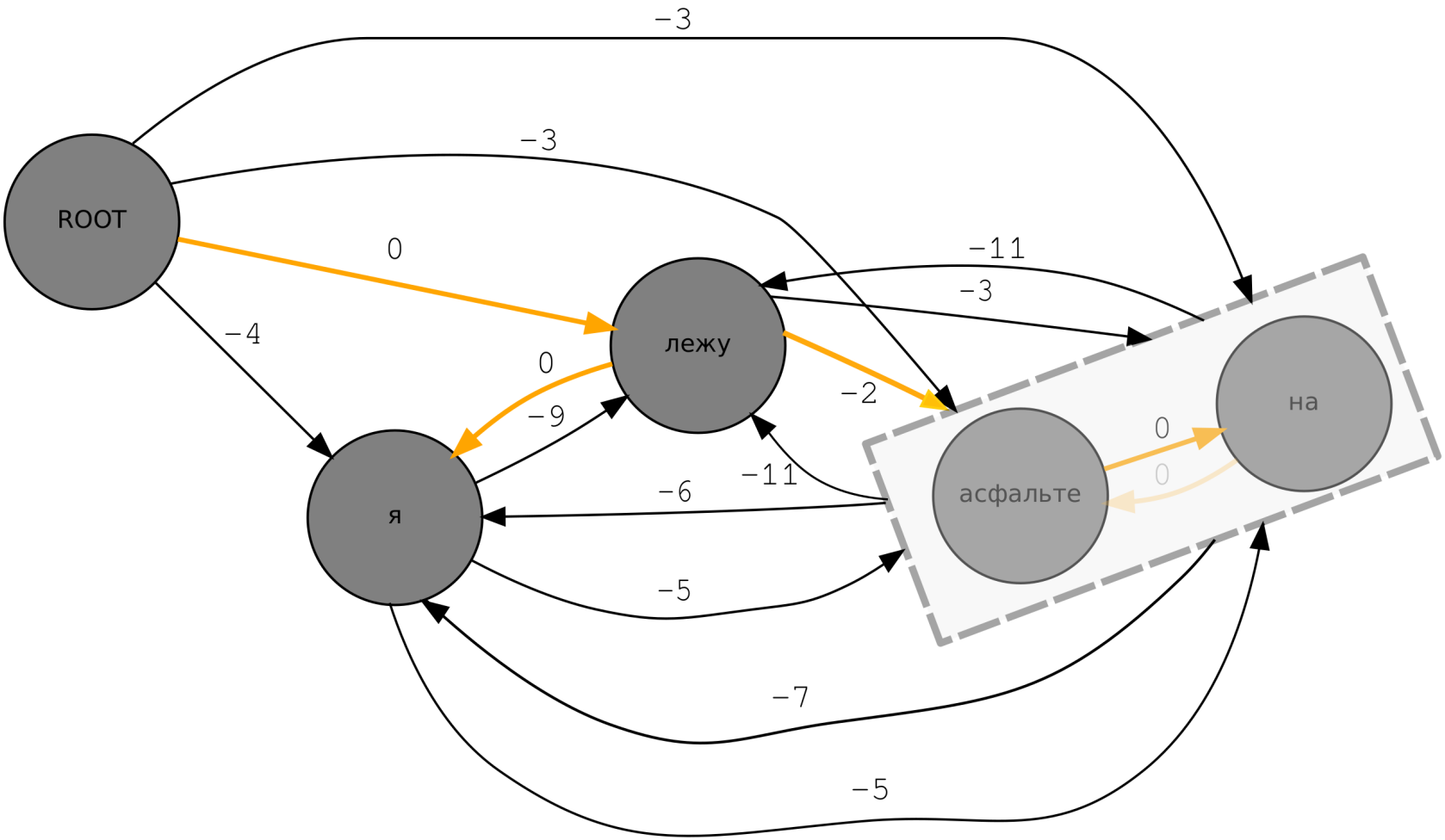
Example



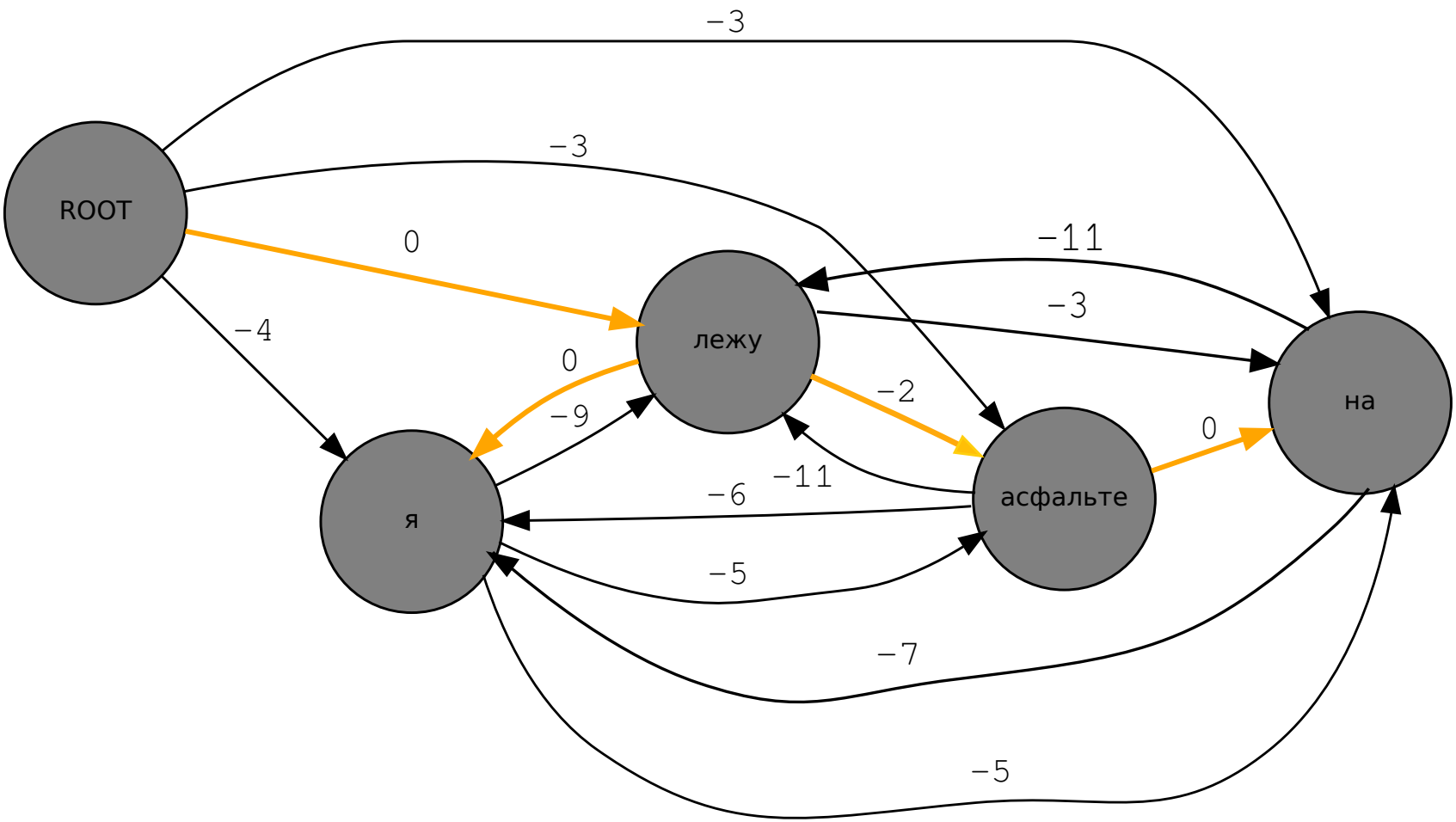
Example



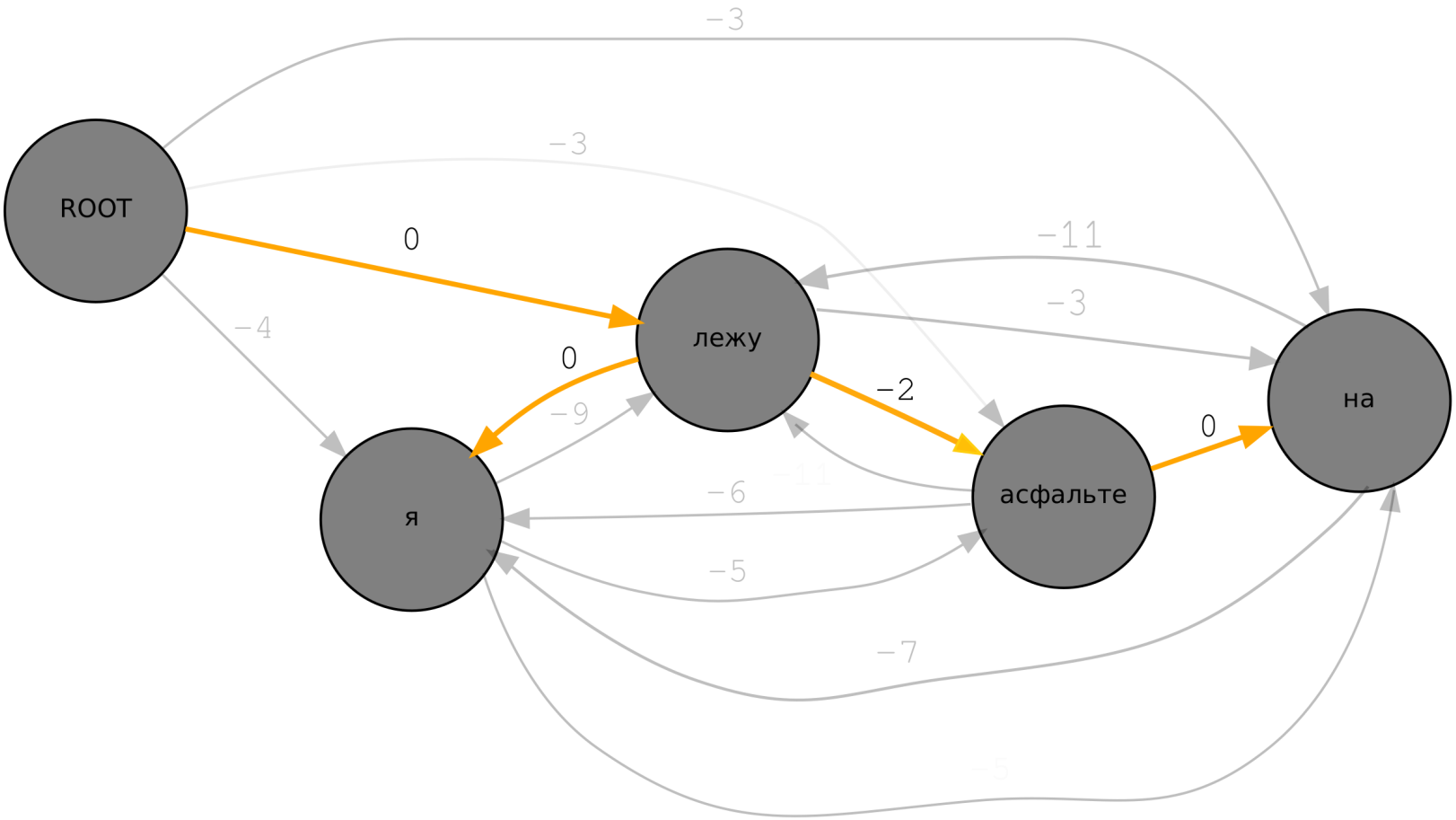
Example



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

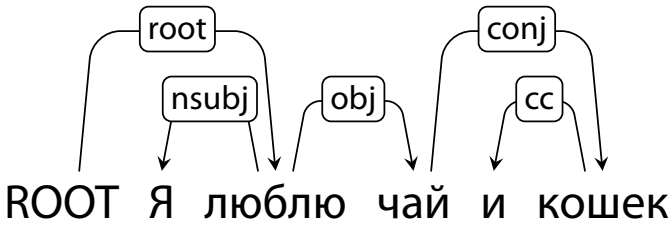
Modern:

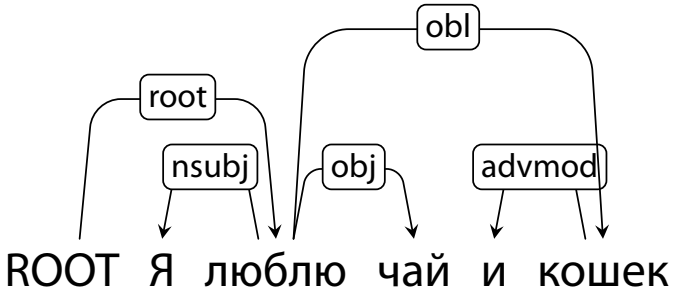
- UDPipe http://github.com/ufal/udpipe
- SyntaxNet https://github.com/tensorflow/models/tree/master/research/syntaxnet
- BiST https://github.com/elikip/bist-parser
  - Both MST and transition variants
- Stanford Parser https://nlp.stanford.edu/software/nndep.html

Historical:

- MaltParser
- MSTParser

Evaluation

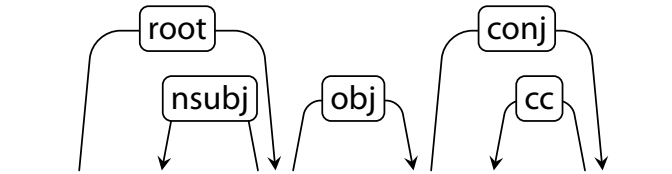


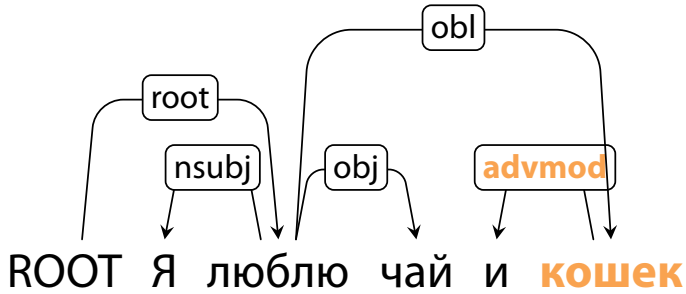


Simple evaluation:

- 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)

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)**

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

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!