

A MULTI-FACETED APPROACH TO REFERENCE RESOLUTION IN ENGLISH AND RUSSIAN

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- Narrow topic – reference resolution
 - How can we enable intelligent agents to **detect** and **fully resolve** all referring expressions?
- Broad topic – holistic natural language understanding (in the OntoSem framework)
 - Working on subproblems within a context of trying to solve the whole problem
- What is the whole problem?
 - Enabling intelligent agents to understand language with the proficiency of people
- A compelling desideratum
 - To reuse knowledge resources and processing and reasoning engines across agents, languages, and applications

History

Russian-English lexicography →

Ellipsis in Russian and Polish →

Computational Linguistics (OntoSem) →

Agent Modeling (OntoAgent) →

Reference resolution in English →

Reference resolution in Russian (and beyond)

Ellipsis is Slavic, descriptively

- McShane, M. 2005. **A Theory of Ellipsis**. Oxford; New York: Oxford University Press.
- McShane, M. 1998. **Ellipsis in Slavic: The Syntax-Discourse Interface**. Unpublished Ph.D. Dissertation, Princeton University.
- McShane, M. 1999. **Predictive rules of direct object ellipsis in Russian**. Formal Approaches to Slavic Linguistics, The Seattle Meeting 1998, ed. K. Dziwirek, et al. 329–348. Ann Arbor, Michigan: Michigan Slavic Publications.
- McShane, M. 1999. **The ellipsis of accusative direct objects in Russian, Polish and Czech**. Journal of Slavic Linguistics 7, 45–88.
- McShane, M. 2000. **Verbal ellipsis in Russian, Polish and Czech**. Slavic and East European Journal 44, 195–233.
- McShane, M. 2000. **Hierarchies of parallelism in elliptical Polish structures**. Journal of Slavic Linguistics 8:, 83–117.
- McShane, M. 2009. **Subject ellipsis in Russian and Polish**. Studia Linguistica 63(1) 2009, pp. 98–132.

Reference, computationally

- McShane, M., Nirenburg, S. & Beale, S. 2005. **Semantics-based resolution of fragments and underspecified structures**. *Traitement Automatique des Langues* 46, 163–184.
- McShane, M., Beale, S. & Nirenburg, S. 2004. **OntoSem methods for processing semantic ellipsis**. Proceedings of the HLT/NAACL 2004 Workshop on Computational Lexical Semantics.
- McShane, Marjorie, Stephen Beale and Sergei Nirenburg. 2010. **Reference resolution supporting lexical disambiguation**. Proceedings of the Fourth IEEE International Conference on Semantic Computing, Carnegie Mellon University, Pittsburgh, PA, Sept. 22-24.
- McShane, Marjorie, Sergei Nirenburg, Stephen Beale. 2011. **Reference-related memory management in intelligent agents emulating humans**. In: Langley P, editor. *Advances in cognitive systems. Papers from the AAIL fall symposium*. AAIL technical report FS-11-01. Menlo Park, CA: AAIL Press. 2011. p. 232-239.
- McShane, M., Nirenburg, S., Beale, S., Johnson, B. 2012. **Resolving elided scopes of modality**. *Advances in Cognitive Systems* 2 (2012) 95-112.
- McShane, M. Submitted. Ms. **Predicting reference resolution**.

Reference Resolution Is...

... all about memory

- Creating **anchors** for new referring expressions in memory
 - **A bird** flew into the room.
- Adding new information to existing anchors in memory
 - A bird flew into the room and **it** seemed disoriented.

Compare with the “co-reference resolution task”

- Only links strings – no anchor in memory; no cross-textual cases.
- Semantics-free
- Only covers precise coreference

No “bridging”: I walked into my kitchen and the window was open.

No set/member: The team played well except for the goalie.

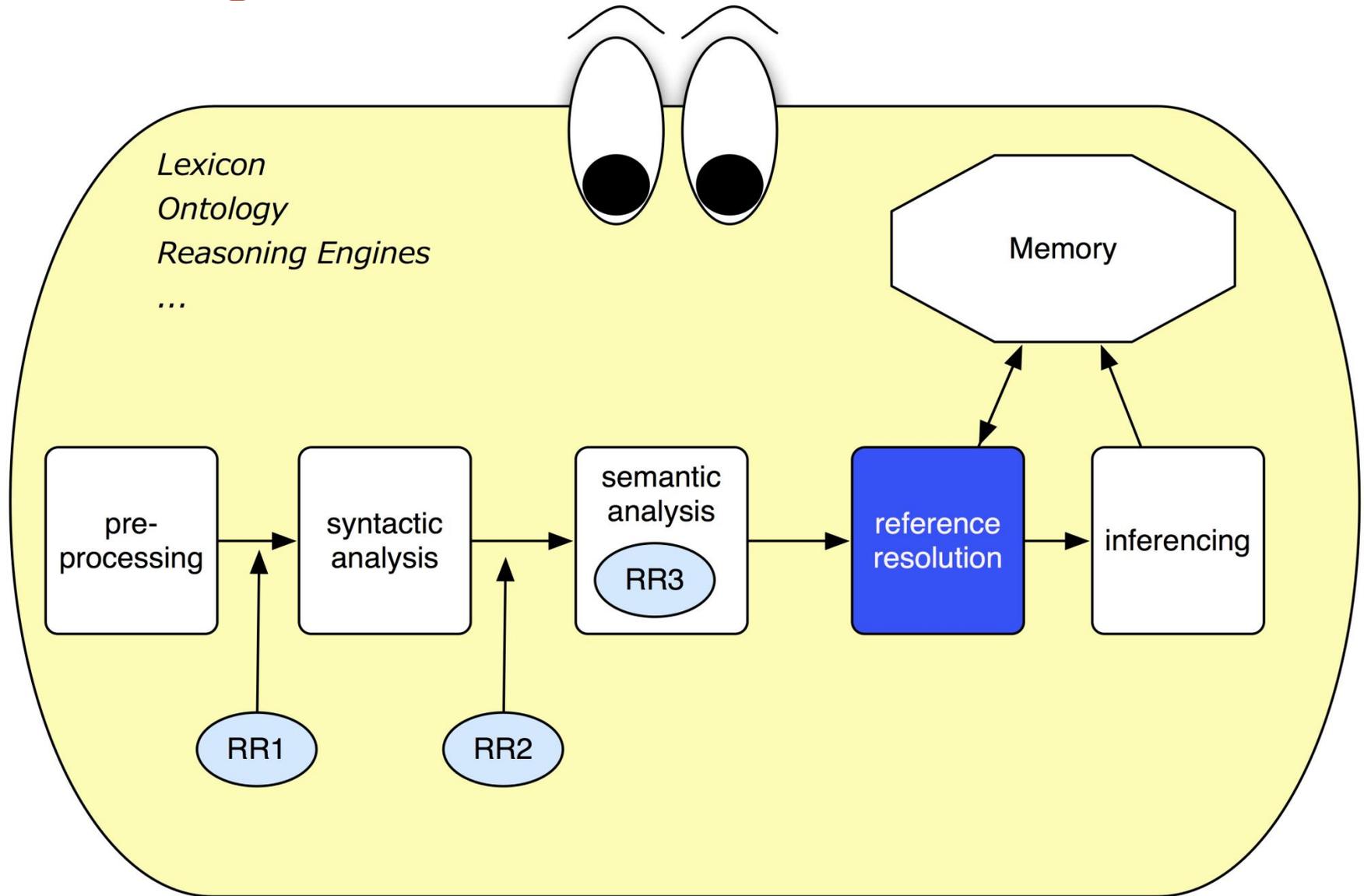
No generic/concrete: Jan has a pony and I want one too!

- Only covers NPs – not referential verbs
- Only covers single NP constituent coreferents
 - No clausal antecedents: It rained all night and the storm ruined my newly planted garden.
 - No split NP coreferents: Once our cat got used to our new dog they became the best of friends.

A task made in heaven for ML methods

- The down side: not a realistic proxy for the actual task
 - Little coverage of phenomena
 - Typically, a perfectly annotated corpus is required for training AND evaluation

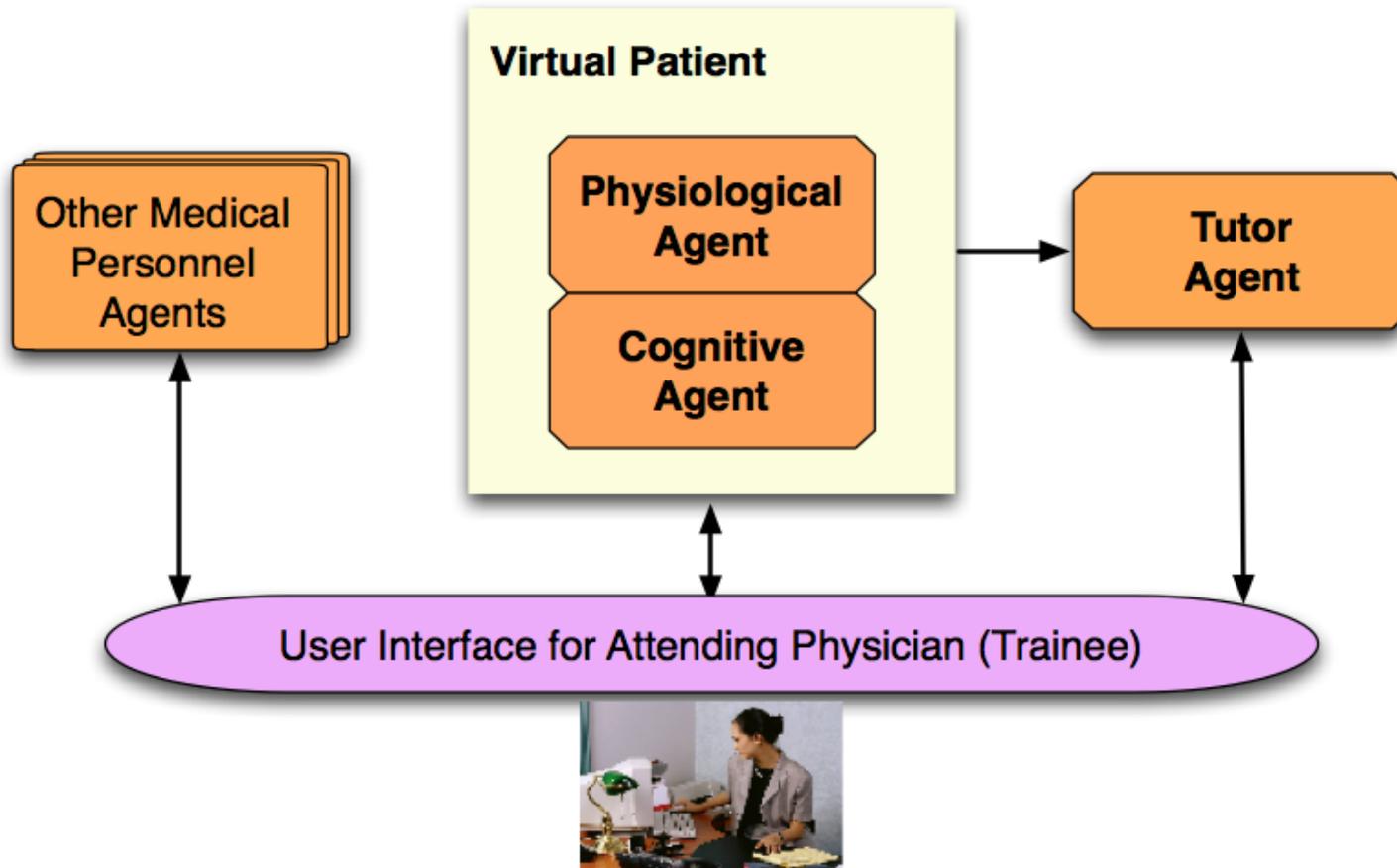
OntoAgent



OntoAgent

- Multi-functional intelligent agents that collaborate with people in applications
- Ontological Semantics (OntoSem) approach to semantic analysis
 - Originally for interlingual machine translation
 - Largely language-independent
- Trying to model *what* people do, not necessarily *how* they do it
- Incorporate expectations, world knowledge (domain choice; AI)
- Balance near-term utility with long-term goals
- Balance theoretical desiderata with practical constraints

Maryland Virtual Patient



Semantic Analysis for Intelligent Agents

- Interpreting input using unambiguous ontological metalanguage
 - play: PLAY-MUSICAL-INSTRUMENT, PLAY-SPORT, etc.!
- Making all relevant language-oriented inferences
 - detecting indirect speech acts, metaphors, etc.
- Populating agent memory with the results of this analysis, which centrally involves reference resolution

Semantics and Reference

Вчера Саша играла как зверь и ____ занула к восьми часам.

Yesterday Sasha played like crazy and ____ fell asleep by 8:00.

When is yesterday?

Who is Sasha?

What kind of playing? (musical instrument? baseball?)

8 in the morning or the evening?

“зверь” is not a referring expression

Analysis is possible only in context

I'm talking to my mom on the phone on March 27, 2014:

Yesterday Sasha played like crazy and ___ fell asleep by 8:00.

Yesterday: March 26, 2014

Sasha: that dog →

played: ran, fetched her ball,
wrestled, chased squirrels, ...

like crazy: long and intensely

8:00: eight p.m.



Mindreading

- In saying this, I know that my mom knows:
 - the most important Sasha in my life
 - how Sash plays via observation and dialog
 - that it's atypical for her to fall asleep by 8:00, which makes this communication relevant

The whole point of any communication is to further populate the other person's or intelligent agent's memory.

If I (eventually) want my helper robot to go out and play with my dog in the rain, I want it to know that it should throw a ball, not take out a pack of cards and start dealing. It has to know what “dog playing” is.

What is “dog playing” ontologically?

- RECREATIONAL-EVENT
 - PLAY-SPORT
 - PLAY-AMUSEMENT
 - PLAY-ADULT
 - PLAY-DOG
 - PLAY-CHILD
 - PLAY-CHILD-AGE-2
 - PLAY-CHILD-AGE-2-JAPAN ; correspondence with Igor Boguslavsky
 - PLAY-CHILD-AGE-3
 - ...
- Why so much concept splitting?
 - Each concept needs to house a script
 - Cf. Ray Jackendoff -- if linguists don't treat all aspects of meaning, who will?

Ontological concept descriptions (what the agents knows about concepts)

PLAY-DOG

AGENT DOG

HAS-EVENT-AS-PART

PLAY-FETCH (AGENT DOG, HUMAN) (THEME STICK, BALL, FRISBEE)

CHASE (AGENT DOG) (THEME SQUIRREL, CHIPMUNK)

DIG (AGENT DOG) (THEME HOLE) (INSTRUMENT PAW)

WRESTLE-DOG (AGENT DOG (CARDINALITY > 1))

RUN (AGENT DOG)

SMELL (AGENT DOG) (THEME GRASS, TREE, DIRT, BUSH)

EFFECT HAPPINESS (DOMAIN DOG) (RANGE > .8)

DURATION default (> 10 MINUTE, < 2 (MEASURED-IN HOUR))

...

What is a sufficient meaning representation?

Sasha was playing

Option 1:

PLAY-AMUSEMENT-1 (AGENT DOG-1)

Option 2:

PLAY-DOG (AGENT DOG-1)

Does the choice come down to “easier”?

- Not necessarily.
- The word ‘play’ must be disambiguated anyway:
 - Yo-Yo Ma was playing PLAY-MUSICAL-INSTRUMENT (or PLAY-CELLO)
 - The Pittsburgh Penguins were playing PLAY-SPORT (or PLAY-ICE-HOCKEY)
 - Sasha was playing PLAY-AMUSEMENT (or PLAY-DOG)
 - Nikki was playing PLAY-AMUSEMENT (or PLAY-CHILD)
 - And then all the idioms: play for a fool; play a joke on; play into someone’s hands; etc.

Text Meaning Representations

Sasha played like crazy yesterday...

PLAY-DOG-435

AGENT

DOG-27

INTENSITY

1 ; scalar attribute; scale {0,1}

ABSOLUTE-TIME

MONTH 3, DAY 13, YEAR 2014

RELATIVE-TIME

< FALL-ASLEEP-271

and fell asleep by 8:00

FALL-ASLEEP-271

EXPERIENCER

DOG-27

ABSOLUTE-TIME

HOUR < 20:00, MONTH 3, DAY 13, YEAR 2014

RELATIVE-TIME

> PLAY-435

play-v1

def to play a musical instrument

example John is playing (his cello)

syn-struct

 subject (\$var1)

 v (\$var0)

 directobject (\$var2) (opt +)

sem-struct

 PLAY-MUSICAL-INSTRUMENT

 AGENT ^\$var1 (default MUSICIAN)* (sem HUMAN)*

 THEME ^\$var2 (default MUSICAL-INSTRUMENT)*

* constraints listed in the ontology

play-v2

def of dogs, to play doing dog-like things

example Fido is playing in the backyard

syn-struct

subject (\$var1)

v (\$var0)

sem-struct

PLAY-DOG

AGENT ^\$var1 (default DOG)*

* constraint listed in the ontology

play-v3

def of any animal, including humans

example Charlie is playing in the backyard

syn-struct

subject (\$var1)

v (\$var0)

sem-struct

PLAY-AMUSEMENT

AGENT ^\$var1 (default ANIMAL)*

- constraint listed in the ontology

A generic rule in the analyzer prefers more specific constraints over broader constraints.

Possible Memories of a Person/Agent who Knows This Dog: Fact Repository

PLAY-DOG-435

AGENT DOG-27
INTENSITY 1
ABSOLUTE-TIME MONTH 3, DAY 13, YEAR 2014
RELATIVE-TIME < FALL-ASLEEP-271

CHASE-12

AGENT DOG-27 ,DOG-14 ; Sasha and Natty
THEME SQUIRREL-10

DOG-WRESTLE-22

AGENT DOG-27, DOG-14

PLAY-FETCH-30

AGENT DOG-27, DOG-45

DIG-11

AGENT DOG-27, DOG-14

DESTINATION NATION-23

EFFECT CLEANLINESS (DOMAIN DOG-27, DOG-14) (RANGE < .2)

Ontological knowledge, from previous slide:

PLAY-DOG

HAS-EVENT-AS-PART CHASE, DOG-WRESTLE, PLAY-FETCH, DIG...

Mindreading after the utterance

- I can assume that my mom knows that Sasha was running and/or digging, wrestling, fetching
- If I asked her what she thought Sasha was doing, she would answer with some subset of those activities
- So should an intelligent agent

This depth of analysis is a big challenge
but not impossible.

Marrying practical with ambitious

- Our goal is to make progress over the long term on the fundamental issues of semantic analysis, including reference resolution with
 - no ceilings of results
 - useful interim results
 - no assumption that preconditions will be fulfilled by somebody else
- How?
 - Approach every problem from the point of view of overall text analysis
 - phenomena can be treated at any or multiple stages of analysis
 - all available engines can be applied
 - all available knowledge bases can be consulted

Reference Processing

Detection (all orange expressions are referring expressions)

Вчера Саша играла как зверь и ____ занула к восьми часам.

Yesterday Sasha played like crazy and ____ fell asleep by 8:00.

Resolution:

- Link objects and events to an established anchor, or create a new anchor, in the intelligent agent's memory.
- Resolve all relative expressions of time and place.
- Do this processing on semantic analyses of the text.

Resolution: grounding in agent memory



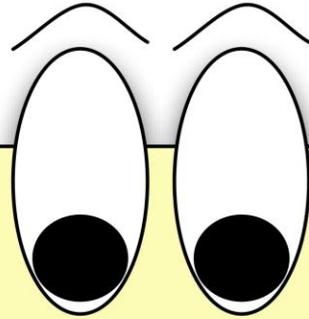
DOG-27

HAS-PERSONAL-NAME Sasha
HAS-FAMILY-NAME McShane
HAS-OWNER HUMAN-88
COLOR black, tan
WEIGHT 65 POUNDS
HAS-BIRTHDATE MONTH 8, DAY 13, YEAR 2009
AGENT-OF INGEST-71, CUDDLE-889, FETCH-204,
 DIG-336 {...}, **PLAY-DOG-435**
EXPERIENCER-OF STROKE-ANIMAL-EVENT-44,
 {...} **FALL-ASLEEP-271**

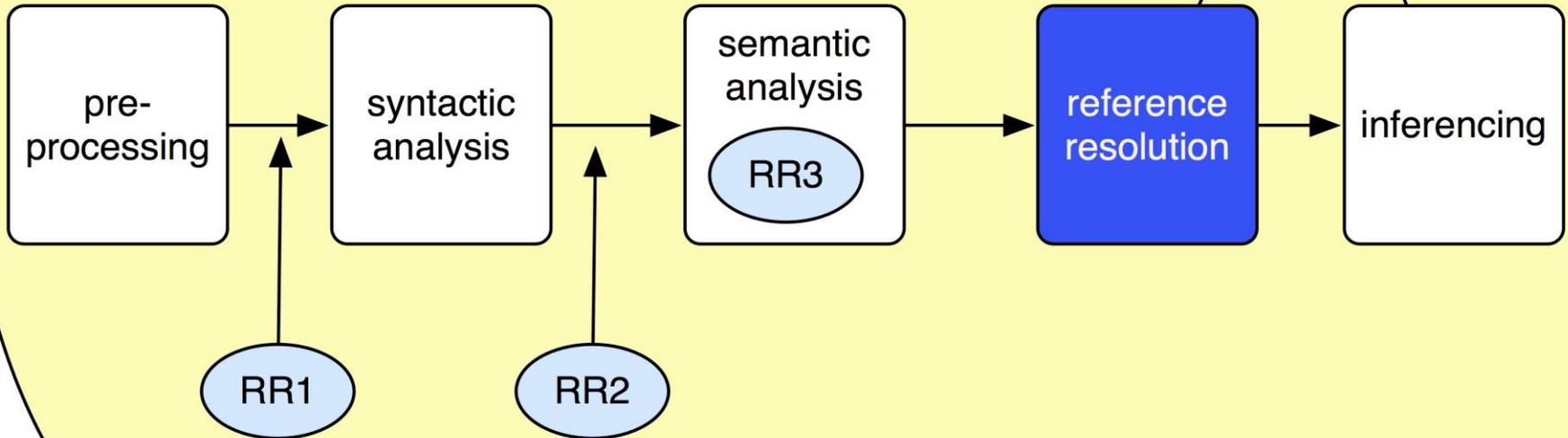
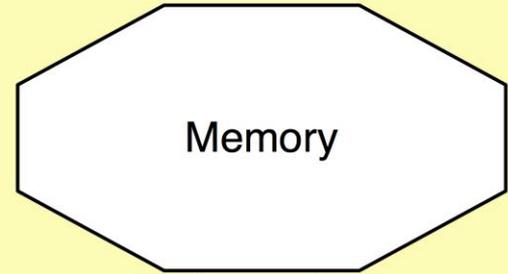
etc., etc. !

English → Russian

- The English system is under development
- Past multilingual work suggests direct applicability to any other language
 - Porting OntoSem lexicons to other languages: reuse sem-struct
 - Esp. useful for descriptive sem-structs (*overboard*, *recall (of product)*, anything with a meaning procedure, like *abovementioned*)
 - Research on reference and ellipsis in Russian and Polish
- I'll give some examples for Russian without claims about the current state of NLU for Russian



Lexicon
Ontology
Reasoning Engines
...



RR1: First reference engine

- Which aspects of reference detection and resolution can we carry out using ONLY the results of preprocessing?
 1. Some named entity semantic resolution
 2. Certain kinds of ellipsis detection

Named Entity Semantic Resolution

Input string: Army Capt. Patrick Horan

Stanford preprocessor output: syntactic grouping
(NP (NNP Army) (NNP Capt.) (NNP Patrick) (NNP Horan))

OntoSem output: semantic analysis

HUMAN-1

HAS-TITLE	Army Capt.
HAS-PERSONAL-NAME	Patrick
HAS-SURNAME	Horan

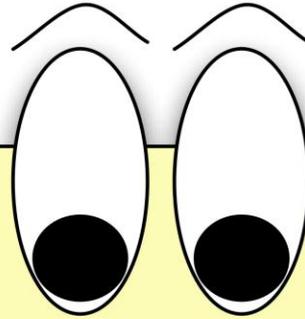
For Russian: same strategy.

Why resolve so early?

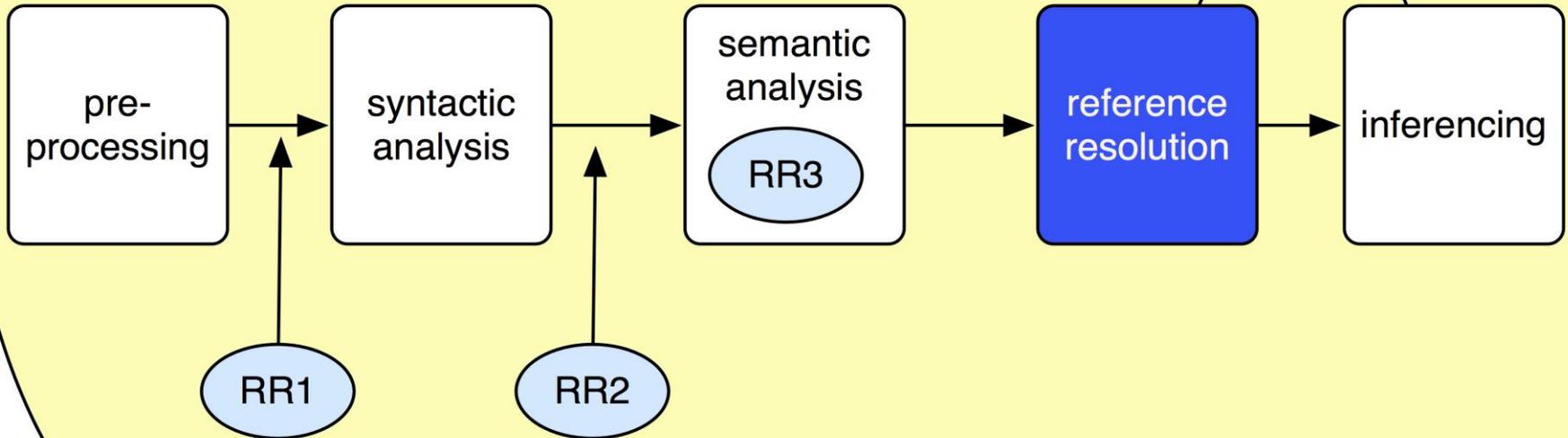
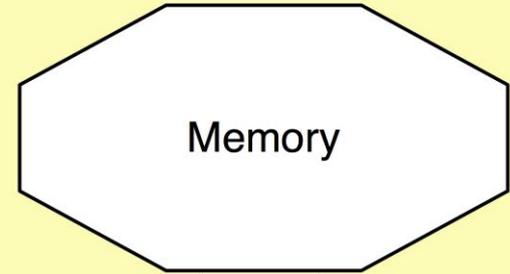
- Named entities are, of course, referring expressions.
- Knowing the semantic class of entities can guide lexical disambiguation
 - I saw Dr. Jones yesterday (CONSULT)
 - I saw Niagara Falls yesterday (VISUAL-EVENT)

Lightweight ellipsis detection

- Certain kinds of ellipsis can be detected in very “surfacy” ways: e.g., elided scopes of modality before hard discourse breaks
 - I wanted to run 10 miles if I could [e].
- Limited to hard discourse breaks (periods, semi-colons, colons).
 - Compare: I wasn't sure if I could, really, finish on time.
- Why do this: to help the parser!



Lexicon
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Syntactic Analysis

- From the syntactic parse, the system (RR2) detects several types of structures that are potentially elliptical and adds reference-oriented metadata to the current state of analysis to support further downstream processing.

E.g.,

- Gapping: Lori ate a sandwich and Mary [e], a salad.
- Unexpressed 2nd subject in VP conjunction structure: Tom had a sandwich and [e] went to work.

The case of gapping

- The Stanford parser treats gapping structures as conjoined nominals—essentially, appositives (simplifying the structure a bit)

Lori ate a sandwich and Mary [e], a salad

(NP (NP Mary) (NP a salad))

- This is incorrect, but it is *predictably* incorrect, which is great for us. The OntoSem analyzer:
 1. detects syntactic configurations that might indicate gapping
 2. copies the verbal string from the first conjunct
 3. adds metadata to the copied string that explicitly blocks instance-coreference, thus facilitating the later reference resolution task and
 4. reinterprets the incorrect NP coordinate structure as a clausal coordinate structure with a gap

Our gapping engine

This revised syntactic output is *much better* input to the semantic analyzer.

Applying this to Russian

- Gapping – similar to English
 - Коля съел бутерброд а Маша [e], салат.
- Detection of subject ellipsis in VPs – similar to English
 - Коля съел бутерброд и [e] отправился на работу.
- Detection of some cases of main verb ellipsis in subjectless sentences (and, possibly, clauses)
 - Я [e] домой.
 - I home-adv. ‘I’m heading home’
 - Я [e] в парк
 - I to park-ACC ‘I’m going to the park’

Applying this to Russian

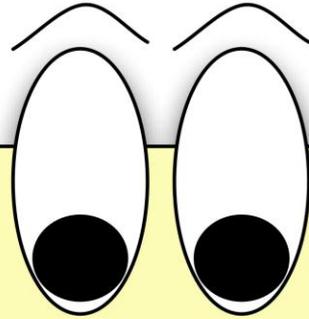
- Detection of some instances of subject ellipsis and direct object ellipsis
 - using lexically recorded selectional constraints
 - can work at this early stage only if all senses of a word have the same syntactic expectations
- 1. «Лошади мои стоят у калитки. Не провожайте [e]» (Чехов).
- 2. [The stepmother looking over the dresses Zolushka made] «У нас нет оснований отвергать твою работу. Помоги [e] одеться» (Шварц).
- 3. «Я из Москвы... [e] Учился в институт...» -- «[e] Исключили [e]?» – «Нет, [e] сам ушел» (Войнович).
- 4. «Вон! Все пошли вон! Расстроили [e] [e]! Обидели [e] [e]! [e] Всех переколю!» (Шварц)

Enhance confidence in expectations by incorporating expectation-driven rules using surfacey heuristics like lexical and syntactic repetition

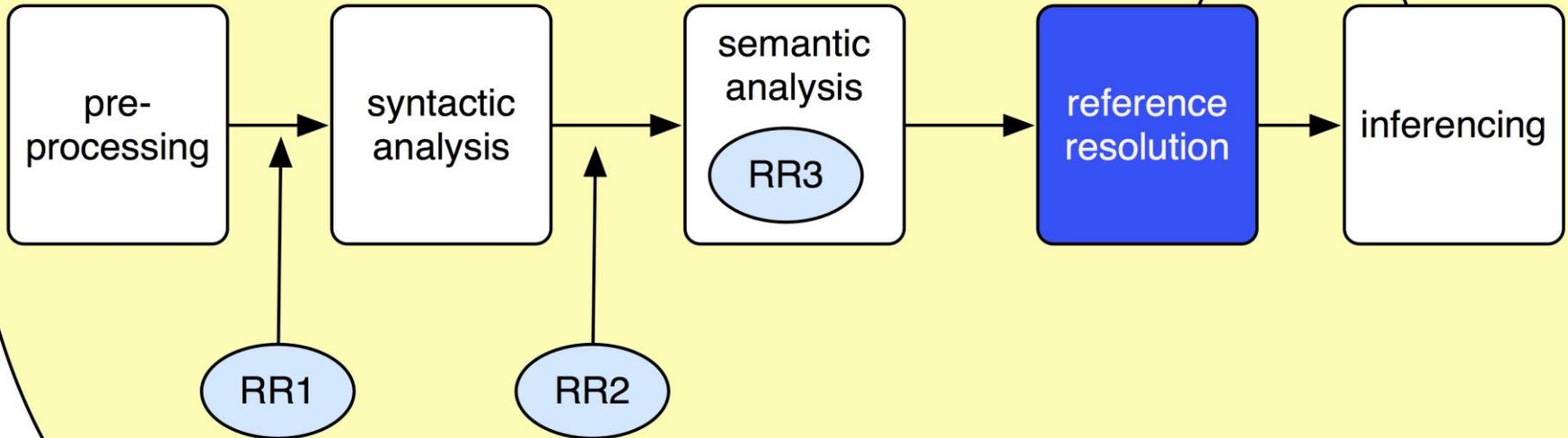
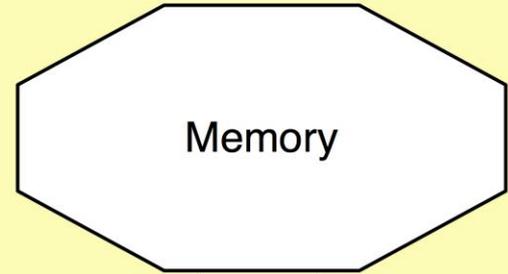
1. «Красное небо, уже начинает восходить луна, и я гнала лошадь, гнала [e]» (Чехов).
...I drove that horse hard, drove [e]
2. «Я люблю мать, сильно люблю [e]...» (Чехов).
I love my mother, love [e] very much
3. «Все они готовы съесть тебя, и съели бы [e] сегодня же, если бы не я» (Шварц).
They were all ready to eat you alive, and would have eaten [e] alive this very day were it not for me

Detection-only at this stage

- Detecting doesn't mean resolving.
- Ellipsis can be resolved to a specific entity or to a generalized group:
 - Горе никогда не убивает [e].
Grief never kills [e].
 - «Вам понадобились великаны... Они только в сказках хороши, а так они пугают [e]» (Чехов)
You needed giants... Only in fairy tales are they good; actually they scare [e]



Lexicon
Ontology
Reasoning Engines
...



Lexical detection of reference phenomena during basic semantic analysis (RR3)

- Non-referring expressions
 - Pleonastic it: **It** is raining; I find **it** funny that...
 - In idioms: Old Mr. Jones **kicked the bucket**.
- Elided events following modals and aspectuals
 - John finished **[e]** the book on Sunday.
 - John wants **[e]** that book.
- idiosyncratic verbs that permit event ellipsis:
 - I forgot **[e]** my keys.

For Russian

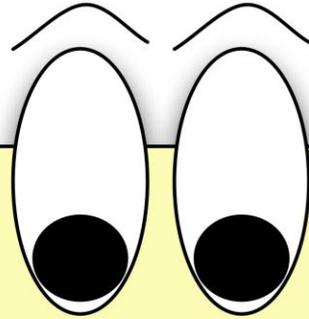
- Idioms (different inventory, same idea)
 - Черт его знает! (no devil, no him/it) ‘God only knows!’
- Detection of elided verbs is exactly the same as in English
 - Джон кончил [е] книгу в воскресенье.
 - Джон хочет [е] эту книгу.

More patterns in Russian

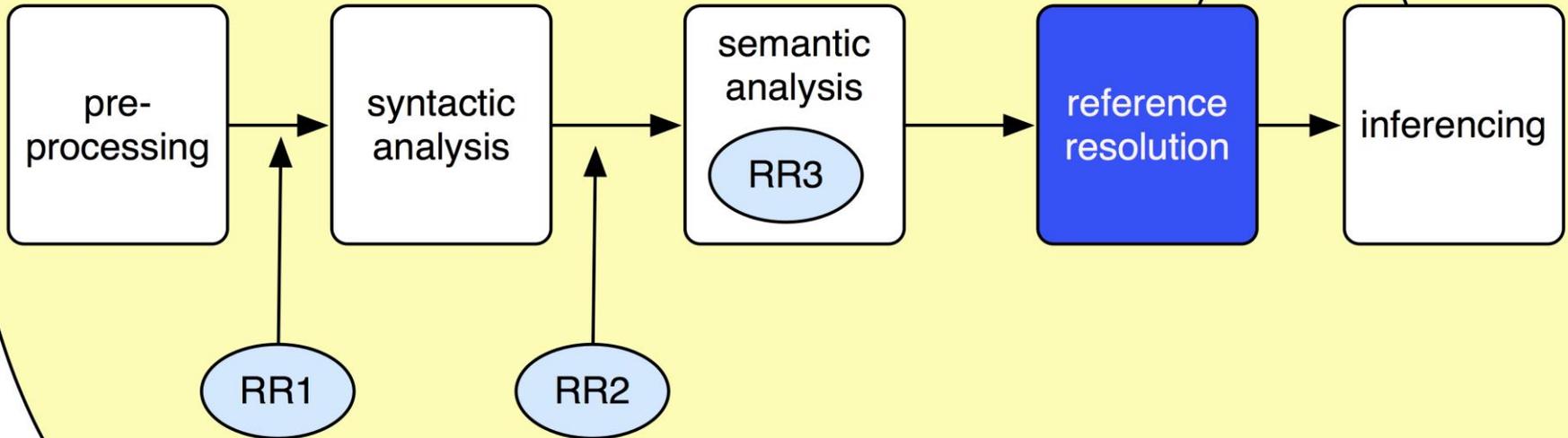
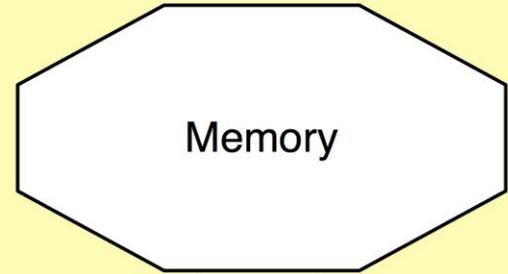
- NP + туда, сюда, directional PP → elided verb of motion
 - Маша в магазин
 - HUMAN-1
 - AGENT-OF MOTION-EVENT-1
 - MOTION-EVENT
 - DESTINATION STORE-1
- NP + не + об этом → elided verb of speech
 - Я не об этом.
- CL + (,) + а + NP + нет → a type of gapping construction
 - Лори любит кататься на коньках, а Лиза **нет**.

Where we are now in the algorithm

- Text meaning representations have been generated
- Some cases of ellipsis have been detected; some of those have already been resolved
- Some referring expressions have been partially treated: e.g., named entities (John Smith) have been analyzed but have not yet been linked to anchors in the memory of the text processing agent
- Non-referring expressions have been detected and will not be considered further (their meaning has already been folded into the text meaning representation).
- The agent now needs to link all referring expressions to its memory.



Lexicon
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...



Dedicated reference resolution module

- This is a very simplified, snapshot view of what the agent does (see the abovementioned paper for details)
 - Determine if each referring expression has a textual “sponsor”
 - it might be a coreferent: **Mary** is tired, **she** needs to get to bed.
 - it might represent a “bridging” relationship: When I walked in **my room** **the window** was open.
 - it might represent a set/member relationship: **Your team** is mostly good but **the goalie** is not so hot.
 - and so on (see McShane 2009 for discussion).

Types of Heuristic Evidence

- Semantic heuristics: we have TMRs as input
 - Ontological distance
 - Property-value unification
- Parallelism-oriented heuristics
 - Jeannine made a quilt: she knitted it out of scraps of yarn.
- Pragmatic heuristics: e.g., speaker changes
 - [Jay] I just made a killing on a stock deal!
 - [Gary] **That's** great!

Linking to Memory

- Seek, or establish new anchors for, all events and objects