

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

---

Marge McShane

Rensselaer Polytechnic Institute

Troy, NY, USA

[margemc34@gmail.com](mailto:margemc34@gmail.com)

- 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 Unpublished Ph.D. Dissertation, Princeton University.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!

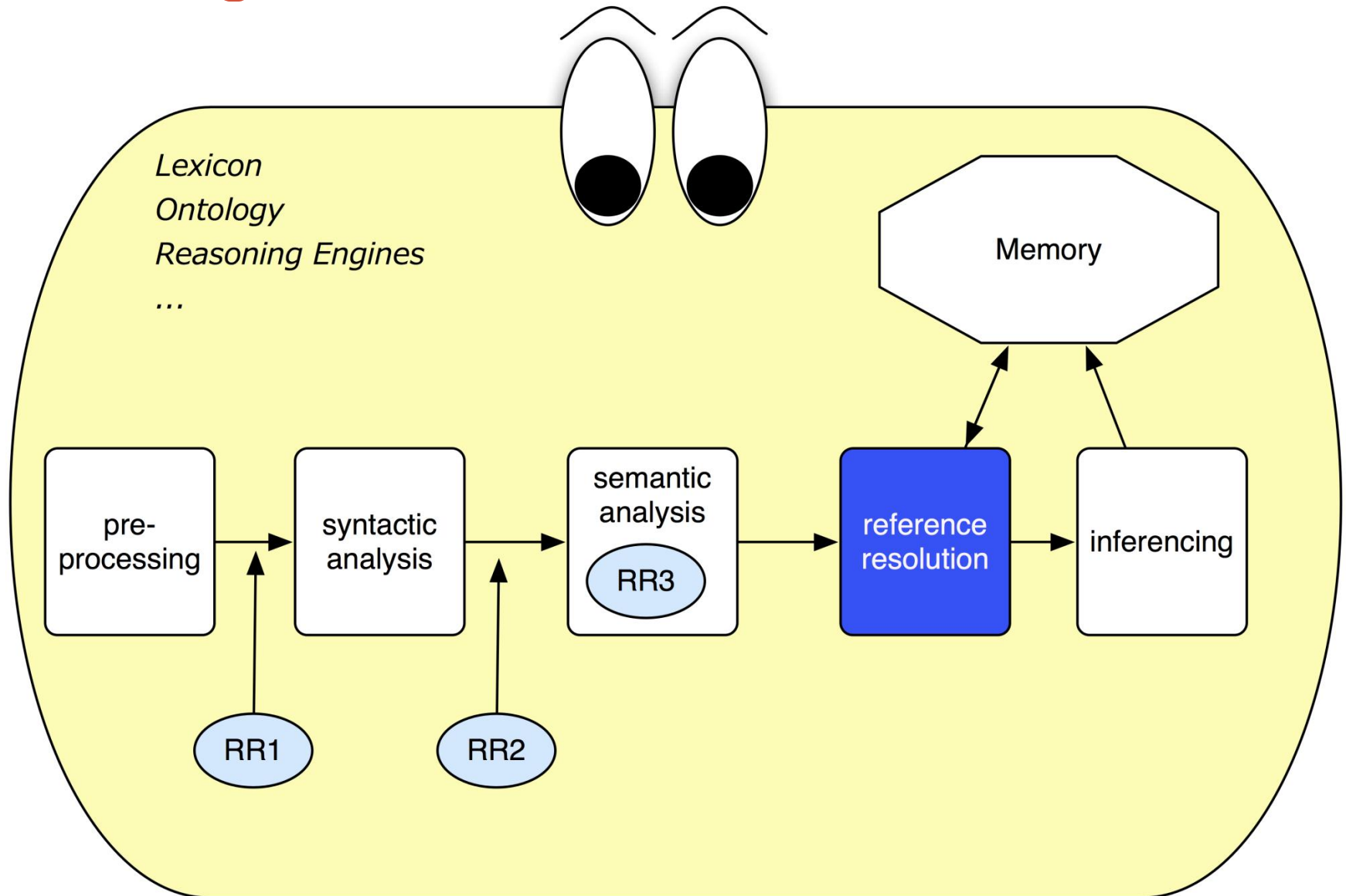
- Only covers NPs – not referential verbs
- Only covers single NP constituent coreferents
  - No clausal antecedents: It rained all night and the storm ruined my newly planted garden.
  - No split NP coreferents: Once our cat got used to our new dog they became the best of friends.

# 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



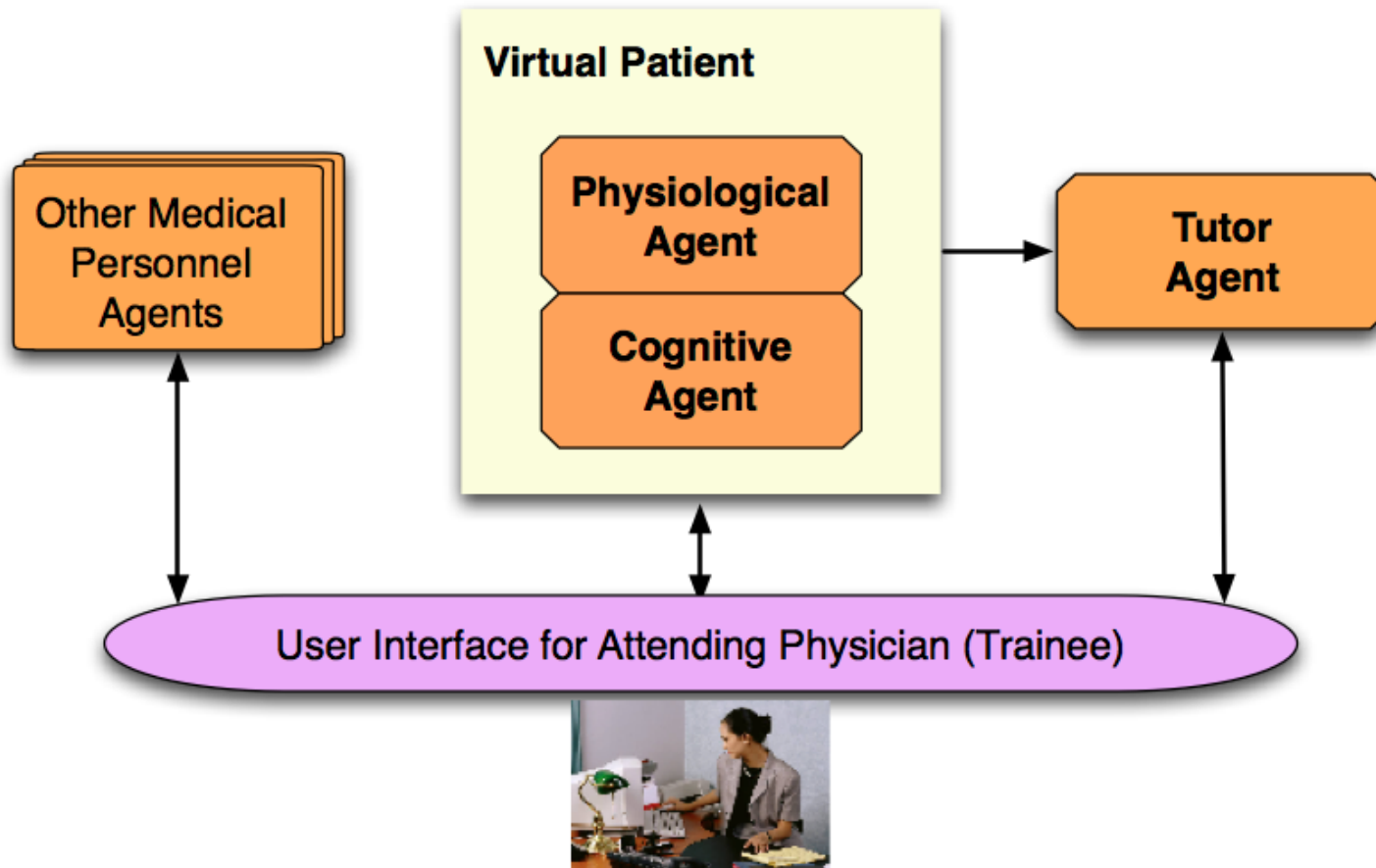
# OntoAgent



# 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



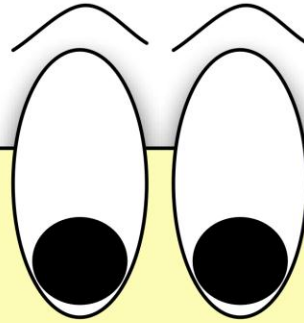
DOG-27

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**

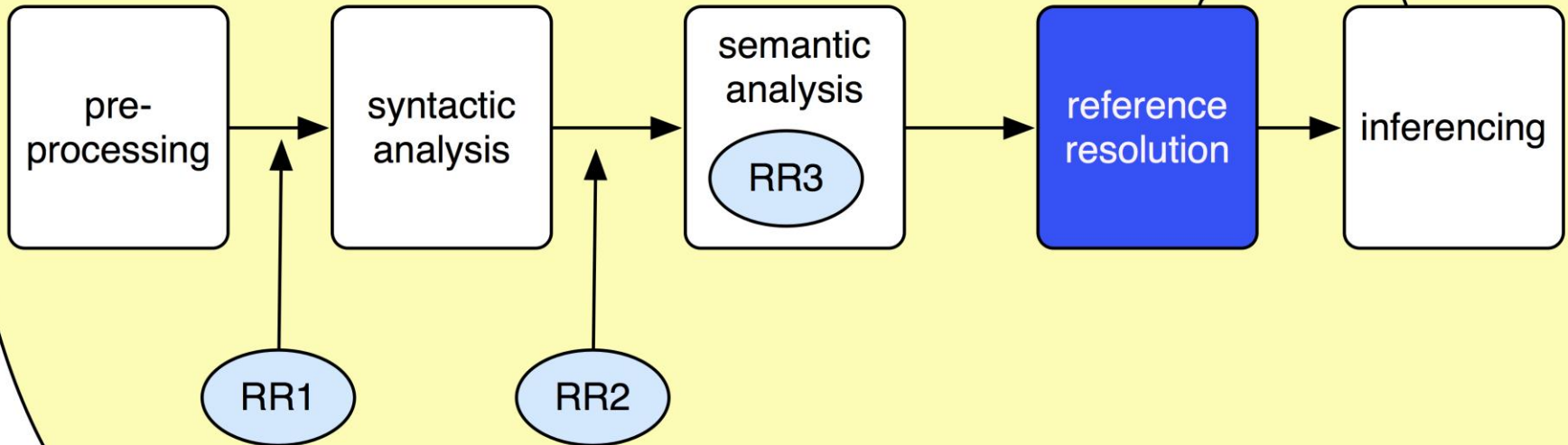
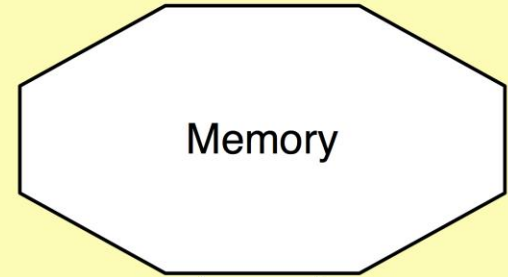
*etc., etc. !*

# 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

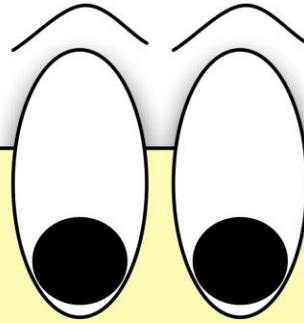
For Russian: same strategy.

# Why resolve so early?

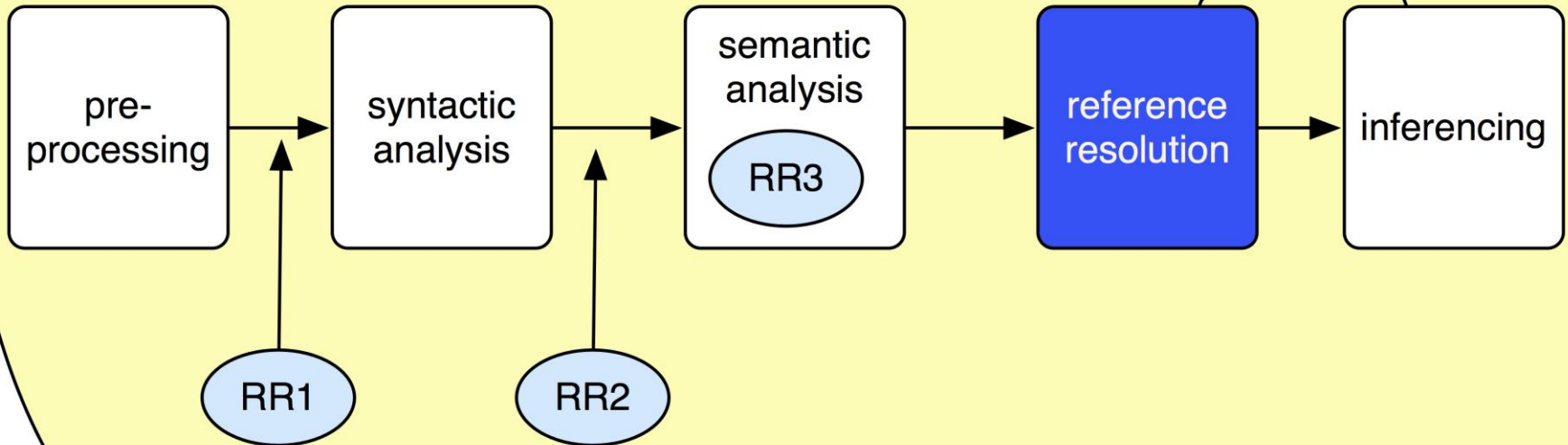
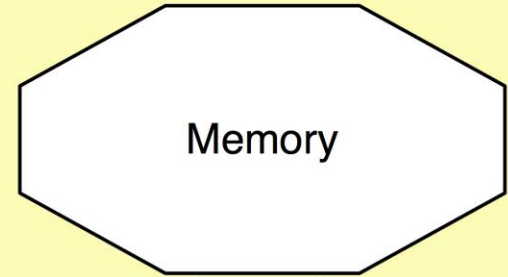
- Named entities are, of course, referring expressions.
- Knowing the semantic class of entities can guide lexical disambiguation
  - I saw Dr. Jones yesterday (CONSULT)
  - I saw Niagara Falls yesterday (VISUAL-EVENT)

# 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*  
*Ontology*  
*Reasoning Engines*  
...



# 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 2<sup>nd</sup> 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

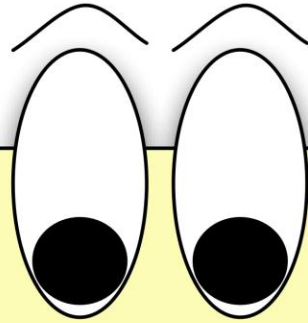
- Detection of some instances of subject ellipsis and direct object ellipsis
  - using lexically recorded selectional constraints
  - can work at this early stage only if all senses of a word have the same syntactic expectations
- 1. «Лошади мои стоят у калитки. Не провожайте [e]» (Чехов).
- 2. [The 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

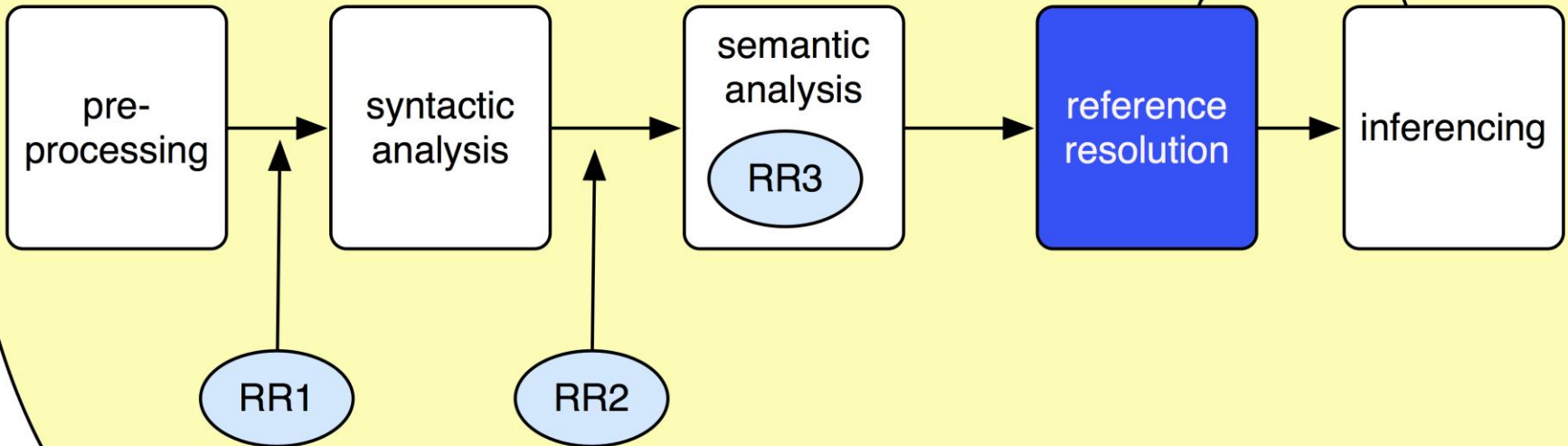
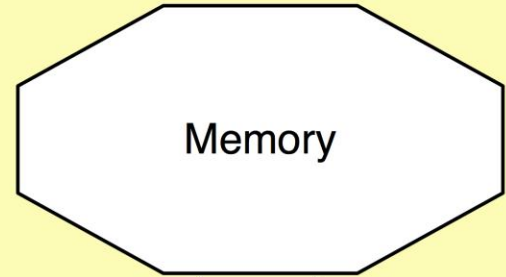
1. «Красное небо, уже начинает восходить луна, и я гнала лошадь, гнала [e]» (Чехов).  
...I drove that horse hard, drove [e]
2. «Я люблю мать, сильно люблю [e]...» (Чехов).  
I love my mother, love [e] very much
3. «Все они готовы съесть тебя, и съели бы [e] сегодня же, если бы не я» (Шварц).  
They 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.

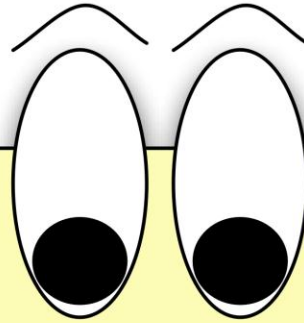
# More patterns in Russian

- 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 + (,) + a + NP + нет → a type of gapping construction
  - Лори любит кататься на коньках, а Лиза **нет**.

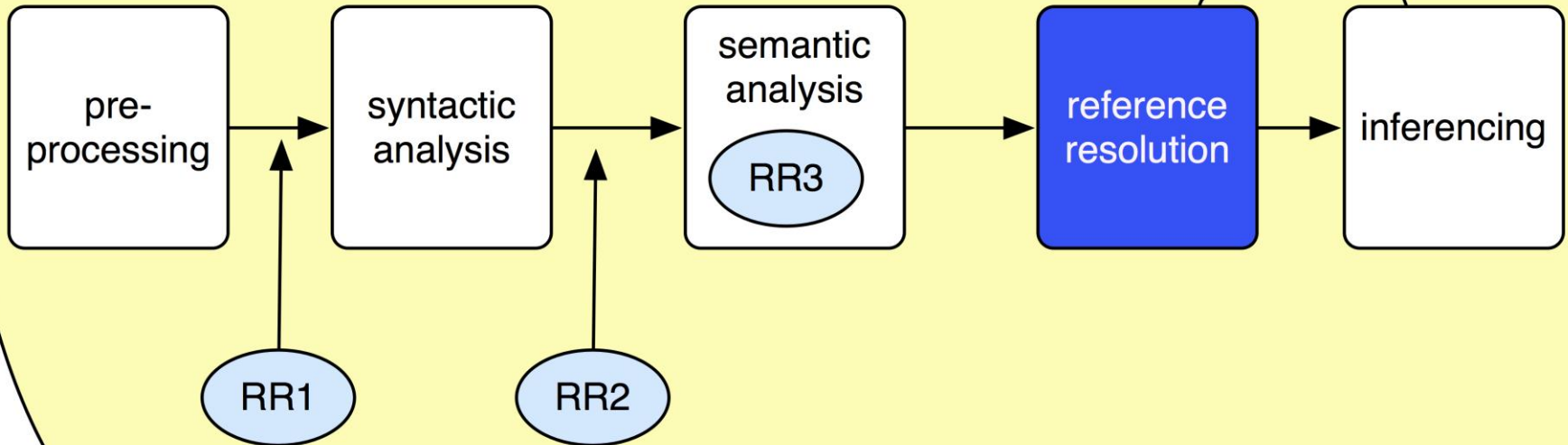
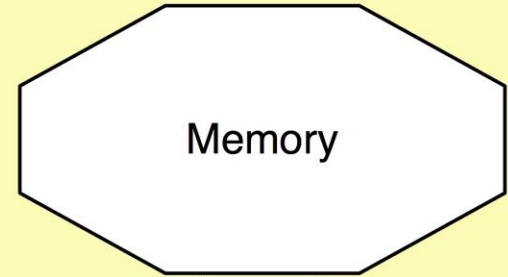
# Where we are now in the algorithm

- 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*  
*Ontology*  
*Reasoning Engines*  
...



# 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