The Moment of Meaning
The Moment of Meaning

Johan Bos

Joint work with:
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- Duc-Duy Nguyen
- Fabrizio Esposito
- Hessel Haagsma
- Johannes Bjerva
- Kilian Evang
- Lasha Abzianidze
- Malvina Nissim
- Mostafa Abdou
- Noortje Venhuizen
- Pierre Ludmann
- Rik van Noord
- Talita Antonio
- Valerio Basile
recognizing textual entailment, large annotated corpora, distributional semantics

Montague semantics

1970s

under-specification, automated inference

1980s

distribuKonal semanKcs

1990s

wide coverage semanKc parsers

2000s

under-­‐specificaKon, automated inference

2010s

recognizing textual entailment, large annotated corpora, distributional semantics

2020s

parsers for small fragments, dynamic semantics

1980s

dynamic semanKcs

2000s

Why Semantics?

① Future Language Technology requires semantic interpretation – “explainable NLP”
② Improve MT – contradiction checking
③ Semantics is fun because it is super-interdisciplinary
Nothing sucks like an Electrolux
Machine Translation

I saw two birds with a cat.

Ik zag twee vliegen in een kat.

2017: bad

2018: good
Machine Translation

I saw two birds with a cat.

Ik zag twee vliegen in een kat.

Dat neemt niet weg dat er problemen zijn.

That does not mean that there are problems.
**Explication**

**English:** The "Magpies", Newcastle United Football Club, have ...

**German:** Die "Elstern", **wie der** Newcastle United Football Club **auch genannt wird**, brachten ...

**Hyperonym – Hyponym**

**English:** ... have produced some of Britain’s finest **players**.

**German:** ... brachten einige der besten **Fußballspieler** Großbritanniens hervor.

**Co-Hyponym**

**English:** ... the chance to **taste a pint** of beer and have a chat with the locals

**German:** ... die Gelegenheit **ein Glas** Bier zu **trinken** und mit den Einheimischen zu plaudern.

**Simile**

**English:** ... passing through the ranks of the Ostyak (...) **like a scythe through standing grain**.

**German:** ... herüberwanderten und Otjaken (...) **buchstäblich niedermähten**.

**Anaphoric Expression**

**English:** Construction of the first floor (...) began on August 9, 1173. **This first floor** is ...

**German:** Der Bau der ersten Etage (...) begann am 9. August 1173. **Diese Etage** ist ...

**Numerical Expression (Langeveld 1986)**

**English:** That man is **not above** forty. (**e.g.** \( \leq 40 \))

**Dutch:** Die man is **nog geen** veertig. (**e.g.** \( < 40 \))
Meaning Banking
**Motivation**
- Integrate Lexical and Formal Sem.
- Gold-standard meanings
- Multi-lingual
- Resource for parsing/translation

**Method**
- Machine-produced, human-corrected
- Language-neutral annotation
- Use parallel corpora
- English first, annotation projection

**Results**
- Four languages
- WordNet/VerbNet/DRT
- Bronze/Silver/Gold data
- Easily available: pmb.let.rug.nl

**Discourse Representation Theory** (Kamp 1981)
This school was founded in 1650.

<table>
<thead>
<tr>
<th>x1</th>
<th>e1</th>
<th>t1</th>
</tr>
</thead>
<tbody>
<tr>
<td>school.n.01(x1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>time.n.08(t1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>YearOfCentury(t1, 1650)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>t1 &lt; now</td>
<td></td>
<td></td>
</tr>
<tr>
<td>found.v.01(e1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time(e1, t1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Theme(e1, x1)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Diese Schule wurde 1650 gegründet.

<table>
<thead>
<tr>
<th>x1</th>
<th>t1</th>
<th>e1</th>
<th>x2</th>
</tr>
</thead>
<tbody>
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<td>school.n.01(x1)</td>
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<td>(x1)</td>
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</tr>
</tbody>
</table>
Language-Neutral Linguistic Analysis

Segmentation: 1 tagset, 1 tokeniser (Elephant)
Parsing: 1 tagset, 1 parser (easyCCG)
Semantic Tagging: 1 tagset, 1 tagger
Boxing: 1 boxer
<table>
<thead>
<tr>
<th>Rule</th>
<th>Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X/Y$</td>
<td>$Y$ \rightarrow $X$</td>
</tr>
<tr>
<td>$X/Y$</td>
<td>$Y/Z$ \rightarrow $B$</td>
</tr>
<tr>
<td>$X/Y$</td>
<td>$Y/Z$ \rightarrow $Bx$</td>
</tr>
<tr>
<td>$(X/Y)/Z$</td>
<td>$Y/Z$ \rightarrow $S$</td>
</tr>
<tr>
<td>$Y$</td>
<td>$X/Y$ \rightarrow $&lt;B$</td>
</tr>
<tr>
<td>$Y/Z$</td>
<td>$X/Y$ \rightarrow $&lt;Bx$</td>
</tr>
<tr>
<td>$Y/Z$</td>
<td>$X/Y$ \rightarrow $&lt;Sx$</td>
</tr>
<tr>
<td>$X$</td>
<td>$Y/(Y\backslash X)$ \rightarrow $&gt;_T$</td>
</tr>
<tr>
<td>$X/Z$</td>
<td>$Y/(Y\backslash X)$ \rightarrow $&lt;_T$</td>
</tr>
</tbody>
</table>

**CCG**

Combinatory Categorial Grammar (Steedman 2000)
Deze school is opgericht in 1650.
Semantic Tagging

- 72 sem-tags divided into 13 classes
- Designed in a data-driven fashion
- POS-tagging not informative enough
- Includes named entity recognition
- Semantically motivated
- Language-neutral


Compositional Semantics ($\lambda$-DRT)
Projection with a Twist: EN → NL (PMB 19/0830)

Word alignment (Giza ++)

Copy, Merge & Split

**Copy:** transfer of category from source to target

**Merge:** two source categories merge into one target category (composition)

**Split:** one source category into two target categories (de-composition)

**Examples:**

- **Copy:**
  - X/Y Y/Z
  - X/Z

- **Merge:**
  - X

- **Split:**
  - X/X X

**Notes:**

- N/N: default
- N: value
- N: standaardbedrag

- NP: you
- (S\NP)/NP: have

- S/(S\NP): you

- S/NP: hai

- S_{[adj]}\NP: impossible

- (S/\NP)/(S/\NP): niet
  - S_{[adj]}\NP: mogelijk
Projection challenges – an example

PMB: 10/0864

: My eyes hurt.

: Meine Augen schmerzen.

: Ik heb pijn aan mijn ogen.

: Mi fanno male gli occhi.
Learning from translations

PMB: 59/1946
I do like ice cream.
Ich mag wirklich Eiscreme.

PMB: 68/2811
I do believe it’s called a leek.
Io credo davvero che si chiama porro.
Boxing Day
## DRS – Discourse Representation Structure

<table>
<thead>
<tr>
<th>x1</th>
<th>x2</th>
<th>x3</th>
</tr>
</thead>
<tbody>
<tr>
<td>08293641(x1)</td>
<td>15160774(x2)</td>
<td>02431950(x3)</td>
</tr>
<tr>
<td>ARG23(x2,1650)</td>
<td>(&lt;(x2,\text{now}))</td>
<td>ARG6(x3,x2)</td>
</tr>
<tr>
<td>ARG3(x3,x2)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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<td>t1 &lt; now</td>
<td>establish.v.01(e1)</td>
<td>Time(e1,t1)</td>
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</tr>
<tr>
<td>Theme(e1,x1)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
(e1 / establish-01
 :ARG1 (x1 / school)
 :time (t1 / date-entity
 :year 1650))
[e1 | establish-01
  :ARG1 [x1 | school]
  :time [t1 | date-entity
    :year 1650]]

e1 x1 t1

establish.v.01(e1)
  Theme(e1,x1)
  Time(e1,t1)
school.n.01(x1)
time.n.08(t1)
  YearOfCentury(t1,1650)
t1 < now
[e1 | establish-01(e1)  
 :ARG1 [x1 | school(x1)]  
 :time [t1 | date-entity(t1)  
 :year 1650]]
ARS

[e1 | establish-01(e1)
   ARG1(e1,x1) [x1 | school(x1)]
   time(e1,t1) [t1 | date-entity(t1)
               year(t1,1650)]]

DRS

<table>
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</tr>
</thead>
<tbody>
<tr>
<td>establish.v.01(e1)</td>
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<tr>
<td>YearOfCentury(t1,1650)</td>
</tr>
<tr>
<td>t1 &lt; now</td>
</tr>
</tbody>
</table>
DRS

[e1 x1 t1 |
  establish-01(e1)
  ARG1(e1,x1)
  time(e1,t1)
  school(x1)
  date-entity(t1)
  year(t1,1650)]

DRS

e1 x1 t1

  establish.v.01(e1)
  Theme(e1,x1)
  Time(e1,t1)
  school.n.01(x1)
  time.n.08(t1)
  YearOfCentury(t1,1650)

  t1 < now
96/2544 These headphones don’t work.

Show:  pointers  senses
DRS: context-sensitive

96/2544 These headphones don’t work.

Show:  ✔️ pointers  ✔️ senses

Most likely interpretation

41/2289: Tom is stuck in his sleeping bag.
<table>
<thead>
<tr>
<th></th>
<th>List of Phenomena (PMB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MWE nouns</td>
</tr>
<tr>
<td>2</td>
<td>MWE particle verbs</td>
</tr>
<tr>
<td>3</td>
<td>Named entities</td>
</tr>
<tr>
<td>4</td>
<td>Person gender</td>
</tr>
<tr>
<td>5</td>
<td>Literal names</td>
</tr>
<tr>
<td>6</td>
<td>Word senses WN</td>
</tr>
<tr>
<td>7</td>
<td>Thematic roles VN</td>
</tr>
<tr>
<td>8</td>
<td>Comparison op</td>
</tr>
<tr>
<td>9</td>
<td>Agent/Role nouns</td>
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<tr>
<td>10</td>
<td>Quantification</td>
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<td>11</td>
<td>Definite descriptions</td>
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<td>12</td>
<td>Pronouns</td>
</tr>
<tr>
<td>13</td>
<td>Possessives</td>
</tr>
<tr>
<td>14</td>
<td>Discourse relations</td>
</tr>
<tr>
<td>15</td>
<td>Numbers</td>
</tr>
<tr>
<td>16</td>
<td>Dates</td>
</tr>
<tr>
<td>17</td>
<td>Clock times</td>
</tr>
<tr>
<td>18</td>
<td>Decades</td>
</tr>
<tr>
<td>19</td>
<td>Scores</td>
</tr>
<tr>
<td>20</td>
<td>Negation</td>
</tr>
<tr>
<td>21</td>
<td>Never/always</td>
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<td>22</td>
<td>Disjunction</td>
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<tr>
<td>23</td>
<td>Conditionals</td>
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<tr>
<td>24</td>
<td>Past tense</td>
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<tr>
<td>25</td>
<td>Present tense</td>
</tr>
<tr>
<td>26</td>
<td>Future tense</td>
</tr>
<tr>
<td>27</td>
<td>Container nouns</td>
</tr>
<tr>
<td>28</td>
<td>Arithmetic</td>
</tr>
<tr>
<td>29</td>
<td>Modals &lt;&gt;</td>
</tr>
<tr>
<td>30</td>
<td>Modals [ ]</td>
</tr>
<tr>
<td>31</td>
<td>Spatial relations</td>
</tr>
<tr>
<td>32</td>
<td>Co-reference</td>
</tr>
<tr>
<td>33</td>
<td>Control</td>
</tr>
<tr>
<td>34</td>
<td>Coordination</td>
</tr>
<tr>
<td>35</td>
<td>Deictic pronouns</td>
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<tr>
<td>36</td>
<td>Reflexive pronouns</td>
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<td>37</td>
<td>Measures</td>
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<td>38</td>
<td>Noun compounds</td>
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<td>39</td>
<td>GPE Adjectives</td>
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<tr>
<td>40</td>
<td>Weather verbs</td>
</tr>
<tr>
<td>41</td>
<td>Questions</td>
</tr>
<tr>
<td>42</td>
<td>Imperatives</td>
</tr>
</tbody>
</table>
Drowning by Numbers
# Evaluating Meaning Representations

<table>
<thead>
<tr>
<th>Semantic Evaluation</th>
<th>Syntactic Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Check for logical equivalence</td>
<td>• Check matching tuples</td>
</tr>
<tr>
<td>• Use standard theorem provers for first-order logic</td>
<td>• Implementations:</td>
</tr>
<tr>
<td>(Blackburn &amp; Bos 2005)</td>
<td>• Allen et al. 2008</td>
</tr>
<tr>
<td>• Discrete Score:</td>
<td>• Smatch (Cai &amp; Knight 2013)</td>
</tr>
<tr>
<td>0 (no proof)</td>
<td>• Counter (van Noord et al. 2018)</td>
</tr>
<tr>
<td>1 (proof)</td>
<td>• Continuous Score:</td>
</tr>
<tr>
<td></td>
<td>0.00 (no matches)</td>
</tr>
<tr>
<td></td>
<td>0.XX (some but not all)</td>
</tr>
<tr>
<td></td>
<td>1.00 (perfect match)</td>
</tr>
</tbody>
</table>

Discrete Score:
- 0 (no proof)
- 1 (proof)

Continuous Score:
- 0.00 (no matches)
- 0.XX (some but not all)
- 1.00 (perfect match)
96/2544 These headphones don’t work.
Tom was moaning in pain.

Tom kreunde van de pijn.
# The Match

<table>
<thead>
<tr>
<th>Classic Boxer</th>
<th>Neural Boxer</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓ Tokenisation (Elephant)</td>
<td>✓ No tokenisation</td>
</tr>
<tr>
<td>✓ Syntactic parsing (EasyCCG)</td>
<td>✓ OpenNMT</td>
</tr>
<tr>
<td>✓ Semantic tagging</td>
<td>✓ 2 bi-LSTM layers</td>
</tr>
<tr>
<td>✓ Thematic role labelling</td>
<td>✓ 300 nodes</td>
</tr>
<tr>
<td>✓ Word sense disambiguation</td>
<td>✓ Naïve dropout: 0.2</td>
</tr>
<tr>
<td>✓ Pronoun resolution</td>
<td>✓ General attention</td>
</tr>
<tr>
<td>✓ Presupposition projection</td>
<td>✓ Beam size 10 during decoding</td>
</tr>
<tr>
<td>✓ Lambda calculus</td>
<td>✓ Coach: Rik van Noord</td>
</tr>
<tr>
<td>✓ Coach: Johan Bos</td>
<td>✓ Coach: Rik van Noord</td>
</tr>
</tbody>
</table>
Variables as nameless dummies (de Bruyn 1972)

### Input:

“She showers every morning”

### Output:

- $b_3$ REF $x_1$
- $b_3$ female “n.02” $x_1$
- $b_4$ REF $e_1$
- $b_4$ shower “v.03” $e_1$
- $b_4$ Agent $e_1$ $x_1$
- $b_4$ Time $e_1$ $x_2$
- $b_2$ REF $x_2$
- $b_2$ morning “n.01” $x_2$
- $b_0$ IMP $b_2$ $b_4$

### Using de Bruyn indexing

“She showers every morning”

- $0$ REF
- $0$ female “n.02” @0
- $1$ REF
- $1$ shower “v.03” @0
- $1$ Agent @0 @1
- $1$ Time @0 @-1
- $2$ REF
- $2$ morning “n.01” @0
- $3$ IMP $2$ $1$
Neural Boxer, character-based

Input: S,h,e,+s,h,o,w,e,r,s,+e,v,e,r,y,+m,o,r,n,i,n,g.

Output:

$0,+,$REF,| | |, $0,+,$f,e,m,a,l,e,+"n.02",+,@0,| | |,
$1,+,$REF,| | |, $1,+,$s,h,o,w,e,r,+"v.03",+,@0,| | |,
$1,+,$Agent,+,@1,+,@0,| | |, $1,+,$Time,+,@-1,+,@0,| | |,
$2,+,$REF,| | |,$2,+,$m,o,r,n,i,n,g,+"n.01",+,@0,| | |,
$3,+,$IMP,+,$2,+,$1,| |
<table>
<thead>
<tr>
<th>DRS parser</th>
<th>F-score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spar</td>
<td>40</td>
</tr>
<tr>
<td>Classic Boxer</td>
<td>74</td>
</tr>
<tr>
<td>Neural Boxer</td>
<td></td>
</tr>
<tr>
<td>Neural Boxer + silver data</td>
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<td>78</td>
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<tr>
<td>Neural Boxer + silver data</td>
<td>84</td>
</tr>
</tbody>
</table>

The Silence of the Lambdas
seq2seq, no spaces (only 5% decrease in F-score)

S,h,e,s,h,o,w,e,r,s,e,v,e,r,y,m,o,r,n,i,n,g,.  

$0,+,$REF, || ||,  
$0,+,$f,e,m,a,l,e,+,"n.02"$,+$,@0, || ||,  
$1,+,$REF, || ||,  
$1,+,$s,h,o,w,e,r,+,"v.03"$ + @0 || ||,  
$1,+,$Agent,+,@1,+,@0, || ||,  
$1,+,$Time,+,@-1,+,@0, || ||,  
$2,+,$REF, || ||,  
$2,+,$m,o,r,n,i,n,g,+,"n.01"$,+$,@0, || ||,  
$3,+,$IMP,+,$2,+,$1, || ||
Is NB learning recursive structures?

Tom’s cellphone rang and he answered it.

B4:[x1][male(x1),Name(x1,tom)]
B5:[x2][cellphone(x2),User(x2,x1)]
B2:[x3][ring(x3),Theme(x3,x2)]
B5:[x5][answer(x5),Agent(x5,x2),Patient(x5,x6)]
B7:[x6][entity(x6)]
B2:CONTINUATION B3 B4
Back to the Future
Results – the Moment of Meaning

- Meaning Banking
  - integrating lexical with formal semantics
  - Language-neutral semantic annotation
  - Multi-lingual (projection saves annotation time!)

- Meaning Interpretation
  - Semantic tagging
  - Neural semantic parsing outperforms traditional parsing
  - Still lots of stuff to explore
recognizing textual entailment, large annotated corpora, distributional semantics

Montague semantics

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under-specification, automated inference

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some stuff with neural networks

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2020s
Future

- Computational Semantics
  - We need other resources for inference (Poliak et al. 2018)
  - Explainable NLP (not just labels)
  - We need to think more “multilingual”

- Add meaning to MT
  - Verify translations with semantic parsing
  - MTL with semantic tagging as aux task?
  - Outperform BLEU
Shared Task on DRS parsing
IWCS, Gothenburg, 23-27 May 2019

DRS parsing in a nutshell

He played the piano and she sang.

DRS in clausal form:

- b0 DRS b1
- b2 REF x1
- b2 male "n.02" x1
- b1 REF e1
- b1 play "v.03" e1
- b1 Agent e1 x1
- b1 Theme e1 x2
- b3 REF x2
- b3 piano "n.01" x2
- b4 REF t1
- b4 time "n.08" t1
- b4 TPR t1 "now"
- b0 CONTINUATION b1 b5

System output:

- b0 DRS b5
- b6 REF x3
- b6 female "n.02" x3
- b5 REF e2
- b5 sing "v.01" e2
- b5 Agent e2 x3
- b5 Time e2 t2
- b7 REF t2
- b7 TPR t2 "now"
- b7 time "n.08" t2
- b1 Time e1 t1

DRS in box form:

- t1 b4
  - time.n.08(t1)
  - t1 < now

- t2 b7
  - time.n.08(t2)
  - t2 < now

- b1
  - play.v.03(e1)
  - Time(e1,t1)
  - Theme(e1,x2)
  - Agent(e1,x1)

- b5
  - sing.v.01(e2)
  - Time(e2,t2)
  - Agent(e2,x3)

CONTINUATION(b1,b5)

- b2
  - b1
  - male.n.02(x1)

- b3
  - piano.n.01(x2)

- b6
  - female.n.02(x3)
The End

pmb.let.rug.nl

competitions.codalab.org/competitions/20220
References