Cognitive modeling for formal semantics

The organization of DRSs in declarative memory

Adrian Brasoveanu & Jakub Dotlačil

AC 2019

Goal

- A cognitively realistic parser that builds semantic representations (DRSs)

Goal

- A cognitively realistic parser that builds semantic representations (DRSs)
  - it builds DRSs incrementally, in real time
  - it does semantic (truth-value) evaluation

Goal

- A cognitively realistic parser that builds semantic representations (DRSs)
  - it builds DRSs incrementally, in real time
  - it does semantic (truth-value) evaluation
- The parser can model reaction times

The modeled reaction time data (Anderson 1974)

Participants studied 26 facts about person-location pairs:

(1) a. A hippie is in a park.
b. A captain is in a park.
c. A hippie is in a town.

- Each person concept – used 1, 2 or 3 times
  - e.g., *hippie* is used 2 times in (1)
- Each location concept – used 1, 2 or 3 times
  - e.g., *town* is used once in (1)

In the test phase, participants had to accept targets (learned facts) and reject foils (novel facts)

- Their reaction times measured

Generalizations

(*i.*) fastest recall for facts whose concepts were used only once

(*ii.*) reaction time increases when concepts used more often

(*iii.*) reaction time approximately equal for targets (true sentences) and foils (false sentences)

Our semantic parser

Incremental construction of DRSs modeled in the ACT-R cognitive architecture.

- the result is one DRS with three sub-DRSs, e.g.:

A hippie is in a town.

$$\begin{bmatrix} \text{DREF}: & 1 \\ \text{PRED}: & \textit{hippie} \\ \text{ARG1}: & 1 \end{bmatrix}$$

$$\begin{bmatrix} \text{DREF}: & 2 \\ \text{PRED}: & \textit{town} \\ \text{ARG1}: & 2 \end{bmatrix}$$

$$\begin{bmatrix} \text{PRED}: & \textit{in} \\ \text{ARG1}: & 1 \\ \text{ARG2}: & 2 \end{bmatrix}$$

Accounting for the generalizations

$$\begin{bmatrix} \text{DREF}: & 1 \\ \text{PRED}: & \textit{hippie} \\ \text{ARG1}: & 1 \end{bmatrix}$$

$$\begin{bmatrix} \text{DREF}: & 2 \\ \text{PRED}: & \textit{town} \\ \text{ARG1}: & 2 \end{bmatrix}$$

$$\begin{bmatrix} \text{PRED}: & \textit{in} \\ \text{ARG1}: & 1 \\ \text{ARG2}: & 2 \end{bmatrix}$$

- Semantic (truth) evaluation: fact/DRS retrieval from memory

Accounting for the generalizations

$$\begin{bmatrix} \text{DREF}: & 1 \\ \text{PRED}: & \textit{hippie} \\ \text{ARG1}: & 1 \end{bmatrix}$$

$$\begin{bmatrix} \text{DREF}: & 2 \\ \text{PRED}: & \textit{town} \\ \text{ARG1}: & 2 \end{bmatrix}$$

$$\begin{bmatrix} \text{PRED}: & \textit{in} \\ \text{ARG1}: & 1 \\ \text{ARG2}: & 2 \end{bmatrix}$$

- Semantic (truth) evaluation: fact/DRS retrieval from memory
- Spreading activation captures context effects on memory
  - if I need to slice some bread, the knife location comes to mind

Accounting for the generalizations

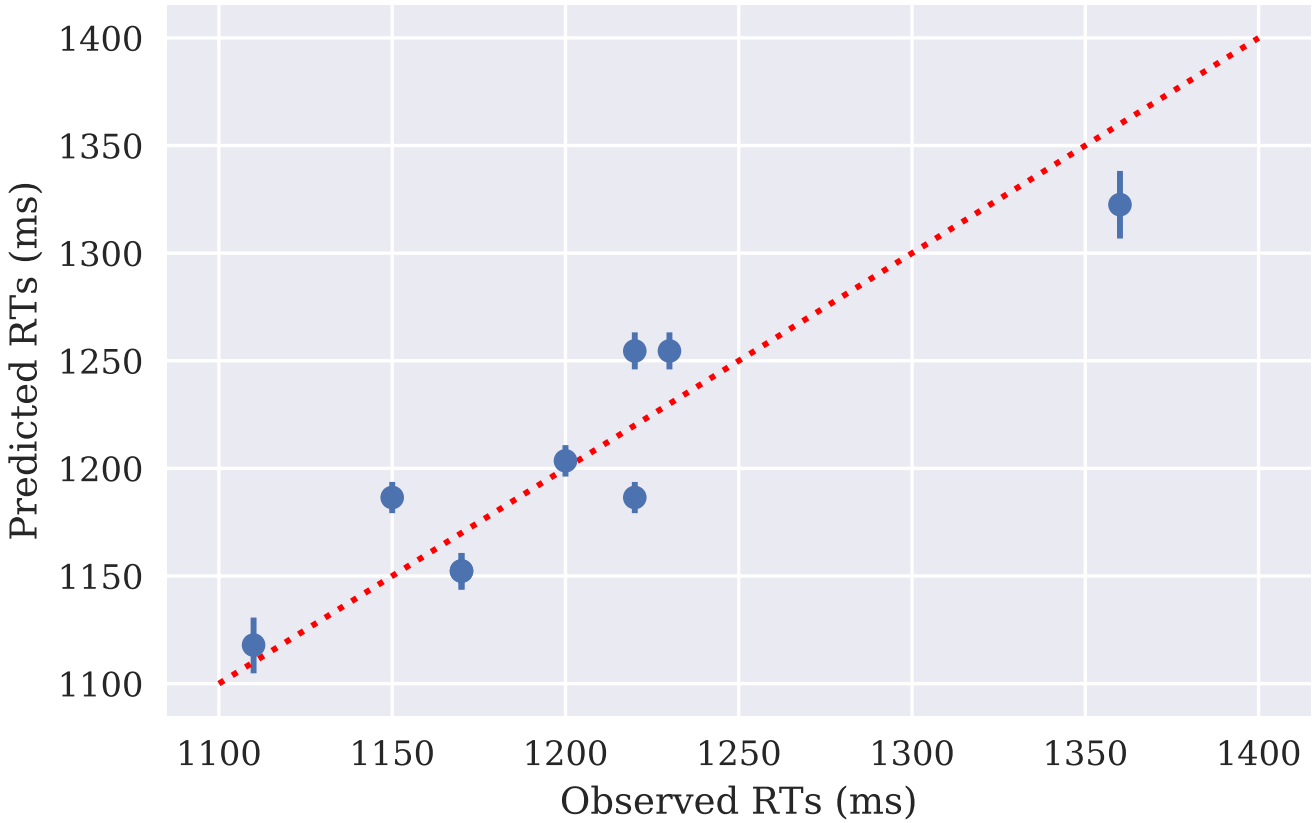
$$\begin{bmatrix} \text{DREF}: & 1 \\ \text{PRED}: & \textit{hippie} \\ \text{ARG1}: & 1 \end{bmatrix}$$

$$\begin{bmatrix} \text{DREF}: & 2 \\ \text{PRED}: & \textit{town} \\ \text{ARG1}: & 2 \end{bmatrix}$$

$$\begin{bmatrix} \text{PRED}: & \textit{in} \\ \text{ARG1}: & 1 \\ \text{ARG2}: & 2 \end{bmatrix}$$

- Semantic (truth) evaluation: fact/DRS retrieval from memory
- Spreading activation captures context effects on memory
  - if I need to slice some bread, the knife location comes to mind
- Spreading activation from sub-DRSs to learned facts in memory models reaction times in Anderson (1974)
- Poster and paper provide details

Results



Demos:

- `https://people.ucsc.edu/~abrsvn/demo_hippie_in_town_1.mp4`
- `https://people.ucsc.edu/~abrsvn/demo_hippie_in_town_2.mp4`

COGNITIVE MODELING FOR FORMAL SEMANTICS

Adrian Brasoveanu Jakub Dotlačil

1. INTRODUCTION

1. We outline the structure of a cognitively realistic semantic parser that incrementally constructs semantic representations (DRSs)
2. The parser composes and integrates semantic interpretations on-line
3. The parser evaluates new semantic representations relative to a model (database of known facts) stored in memory
4. The parser can model RT data and can predict the 'fan effect'

- https://people.ucsc.edu/~abrsvn/demo_hippie_in_town_1.mp4
- https://people.ucsc.edu/~abrsvn/demo_hippie_in_town_2.mp4

2. FAN EFFECT (ANDERSON, 1974)

Participants studied facts about person-location pairs. 10 examples:

a. A lawyer is in a cave. **b.** A debutante is in a bank. **c.** A doctor is in a bank.
d. A doctor is in a shop. **e.** A captain is in a church. **f.** A captain is in a park.
g. A fireman is in a park. **h.** A hippie is in a park. **i.** A hippie is in a church.
j. A hippie is in a town.

- Each person concept – used 1, 2 or 3 times (=fan of 1, 2 or 3)
- Each location concept – used 1, 2 or 3 times (=fan of 1, 2 or 3)

In the test phase, participants had to accept targets (learned facts) and reject foils (novel facts)

Target RTs		location fan 1	2	3
person fan	1	1.11	1.17	1.15
	2	1.17	1.20	1.23
	3	1.22	1.22	1.36

Foil RTs		location fan 1	2	3
person fan	1	1.20	1.25	1.26
	2	1.22	1.36	1.47
	3	1.26	1.29	1.47

(*i.*) the effect of 1-fan (intercept) is about 1.2s

(*ii.*) latency is a non-additive function of fan: (1, 3)/(3, 1) faster than (2, 2)

(*iii.*) the fan effects are approximately equal for targets and foils

3. BASIC ACCOUNT

DRS consists of three sub-DRSs:

1. $\begin{bmatrix} \text{DREF}: & 1 \\ \text{PRED}: & \textit{hippie} \\ \text{ARG1}: & 1 \end{bmatrix}$
2. $\begin{bmatrix} \text{DREF}: & 2 \\ \text{PRED}: & \textit{town} \\ \text{ARG1}: & 2 \end{bmatrix}$
3. $\begin{bmatrix} \text{PRED}: & \textit{in} \\ \text{ARG1}: & 1 \\ \text{ARG2}: & 2 \end{bmatrix}$

After constructing the DRS, the parser checks whether a matching fact is present in the model (learned facts in declarative memory).
Recall of fact i from declarative memory: parallel search driven by activation A_i. A_i modulated by spreading activation from sub-DRSs j. (Free params are in red below.)

$$A_i \approx \sum_j W_j S_{ji} \quad (1)$$

$$S_{ji} = S - \log(\text{fan}_j) \quad (2)$$

$$\begin{aligned} T &= I + Fe^{-A_i} \\ &= I + F' \prod_j \text{fan}_j^{W_j} \\ &\quad (F' = Fe^{-\sum W_j S}) \end{aligned} \quad (3)$$

(*i.*) by I in (3)

(*ii.*) by $\prod_j \text{fan}_j^{W_j}$ in (3)

(*iii.*) by parallel search

4. INCREMENTAL DRS CONSTRUCTION AND SEMANTIC EVALUATION

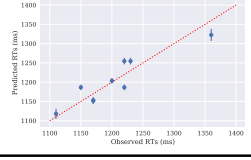
DRS construction as a set of production rules in ACT-R

Production rules: conditionalized actions

Left-corner parser interspersed with DRS construction; syntax and semantics built side by side

- $\boxed{1 \;\; \text{STILL-UNSPECIFIED-PREDICATE}(1)} \xrightarrow{\text{hippie}} \boxed{1 \;\; \text{hippie}(1)}$
- $\boxed{\text{in}(1, \_)} \Rightarrow \boxed{\text{IN}(1, 2)}$
- $\boxed{2 \;\; \text{STILL-UNSPECIFIED-PREDICATE}(2)} \xrightarrow{\text{town}} \boxed{2 \;\; \text{town}(2)}$

Evaluation as a recall from declarative memory.
Fan effect due to sub-DRSs built during incremental interpretation.
Parameter estimates obtained by embedding the parser in a Bayesian model.



Thank you!