The Neural Basis of Thought and Language

Week 14
• Final exam review session tonight
  - 6-8pm Evans 75
• Final in class next Tuesday, May 8th
• Be there on time!
• Format:
  - closed books, closed notes
  - short answers, no blue books
• Final paper due on bSpace on Friday, May 11
“Harry walked into the café.”
The HARRY construction

construction HARRY
subcase of Ref-Expr
form
  self_f.orth ← “Harry”
meaning: Harry

schema Harry
subcase of Human
  gender ← male
  name ← “Harry”
  address ← 42 Tall Elf Dr.
The CAFE construction

construction CAFE
  subcase of Ref-Expr
  form
    self_f.orth ← “cafe”
  meaning: Cafe

schema Cafe
  subcase of Building

schema Building
  subcase of Container
The INTO construction

construction INTO
subcase of Spatial-Relation form
self_f.orth ← “into”
meaning: Trajector-Landmark
  evokes Container as cont
evokes Source-Path-Goal as spg
  trajector ↔ spg.trajector
  landmark ↔ cont
  cont.interior ↔ spg.goal
  cont.exterior ↔ spg.source
The WALKED construction

construction WALKED
subcase of Motion-Verb
form
  self_f.orth ← “walked”
meaning: Walk
  self_m.aspect ← simple_past
The Spatial-Phrase construction

construction \text{SPATIAL-PHRASE}

constructional constituents

sr : Spatial-Relation
lm : Ref-Expr

form

\text{sr}_f \text{ before } \text{lm}_f

meaning

\text{sr}_m \text{ landmark } \leftrightarrow \text{lm}_m
The Directed-Motion construction

direction DIRECTED-MOTION

constructional

constituents

a : Ref-Exp
m: Motion-Verb
p : Spatial-Phrase

form

a_f before m_f
m_f before p_f

meaning

evokes Directed-Motion as dm
self_m.scene ↔ dm
dm.agent ↔ a_m
dm.motion ↔ m_m
dm.path ↔ p_m

schema Directed-Motion

 roles
agent : Entity
motion : Motion
path : SPG
What exactly is simulation?

- Belief update and/or X-schema execution
“Harry walked into the café.”
“Harry is walking to the café.”
“Harry is walking to the café.”
“Harry has walked into the wall.”
Perhaps a different sense of INTO?

construction INTO
subcase of spatial-prep form
  self, .orth ← “into”
meaning
  evokes Trajectory-Landmark as tl
  evokes Container as cont
  evokes Source-Path-Goal as spg
  tl.trajector ← spg.trajector
  tl.landmark ← cont
  cont.interior ← spg.goal
  cont.exterior ← spg.source

construction INTO
subcase of spatial-prep form
  self, .orth ← “into”
meaning
  evokes Trajectory-Landmark as tl
  evokes Impact as im
  evokes Source-Path-Goal as spg
  tl.trajector ← spg.trajector
  tl.landmark ← spg.goal
  im.obj1 ← tl.trajector
  im.obj2 ← tl.landmark
“Harry has walked into the wall.”
Map down to timeline

ready → start → ongoing → finish → done

consequence
Usage-based Language Learning

(Utterance, Situation)

Analyze

Partial Analysis

Comprehension

Constructions

Reorganize

Hypothesize

Acquisition

(Comm. Intent, Situation)

Generate

Utterance

Production
while <utterance, situation> available and cost > stoppingCriterion
    analysis = analyzeAndResolve(utterance, situation, currentGrammar);
    newCxns = hypothesize(analysis);
    if cost(currentGrammar + newCxns) < cost(currentGrammar)
        addNewCxns(newCxns);
    if (re-oganize == true)  // frequency depends on learning parameter
        reorganizeCxns();
Three ways to get new constructions

- Relational mapping
  - throw the ball

- Merging
  - throw the block
  - throwing the ball

- Composing
  - throw the ball
  - ball off
  - you throw the ball off

\[
\text{THROW} \quad \text{<} \quad \text{BALL}
\]
\[
\text{THROW} \quad \text{<} \quad \text{OBJECT}
\]
\[
\text{THROW} \quad \text{<} \quad \text{BALL} \quad \text{<} \quad \text{OFF}
\]
Minimum Description Length

- Choose grammar G to minimize $\text{cost}(G \mid D)$:
  - $\text{cost}(G \mid D) = \alpha \cdot \text{size}(G) + \beta \cdot \text{complexity}(D \mid G)$
  - Approximates Bayesian learning; $\text{cost}(G \mid D) \approx \text{posterior probability } P(G \mid D)$

- **Size of grammar** = $\text{size}(G) \approx 1/\text{prior } P(G)$
  - favor fewer/smaller constructions/roles; isomorphic mappings

- **Complexity of data given grammar** $\approx 1/\text{likelihood } P(D \mid G)$
  - favor simpler analyses
    (fewer, more likely constructions)
  - based on derivation length + score of derivation
Human Sentence Processing

Can we use any of the mechanisms we just discussed to predict reaction time / behavior when human subjects read sentences?
Good and Bad News

• Bad news:
  - No, not as it is.
  - ECG, the analysis process and simulation process are represented at a higher computational level of abstraction than human sentence processing (lacks timing information, requirement on cognitive capacity, etc)

• Good news:
  - we can construct bayesian model of human sentence processing behavior borrowing the same insights
Bayesian Model of Sentence Processing

- Do you wait for sentence boundaries to interpret the meaning of a sentence? No!

- As words come in, we construct
  - partial meaning representation
  - some candidate interpretations if ambiguous
  - expectation for the next words

- Model
  - Probability of each interpretation given words seen
  - Stochastic CFGs, N-Grams, Lexical valence probabilities
The cop arrested the detective.

Reduced Relative

The cop arrested by the detective.
The cop arrested the detective.

The cop arrested the detective by N-Gram.
SCFG + N-gram

Different Interpretations

Main Verb

Reduced Relative

The cop arrested the detective

The cop arrested by
Predicting effects on reading time

• Probability predicts human disambiguation
• Increase in reading time because of...
  - Limited Parallelism
    • Memory limitations cause correct interpretation to be pruned
    • *The horse raced past the barn fell*
  - Attention
    • Demotion of interpretation in attentional focus
  - Expectation
    • Unexpected words