

The Neural Basis of Thought and Language

Week 14



Administrivia

- 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.”

Utterance



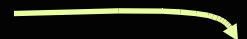
Analysis Process

Semantic Specification



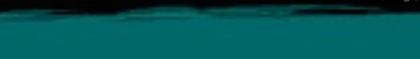
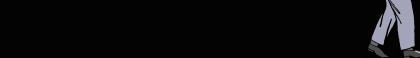
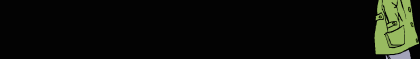
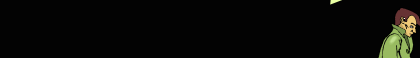
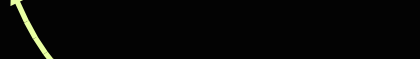
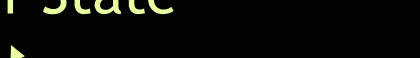
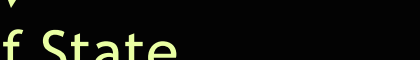
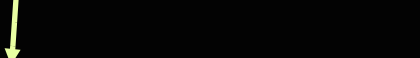
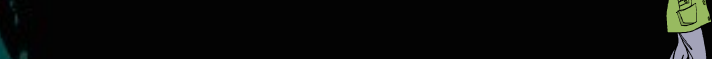
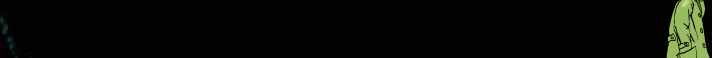
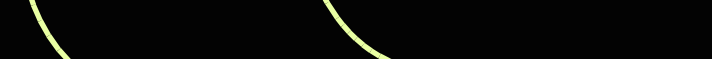
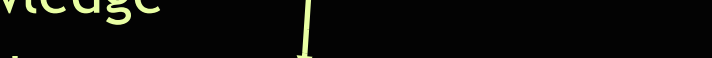
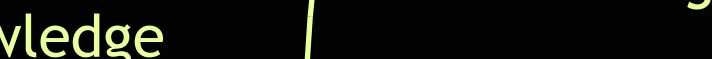
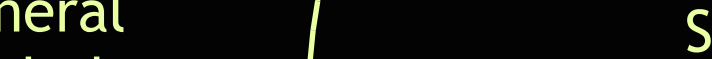
Simulation

Constructions



General Knowledge

Belief State



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

$\text{self}_f \text{.orth} \leftarrow \text{“into”}$

meaning: Trajector-Landmark

evokes Container as cont

evokes Source-Path-Goal as spg

trajector \leftrightarrow spg.trajector

landmark \leftrightarrow cont

cont.interior \leftrightarrow spg.goal

cont.exterior \leftrightarrow spg.source

The WALKED construction

construction WALKED

subcase of Motion-Verb

form

$\text{self}_f.\text{orth} \leftarrow \text{“walked”}$

meaning: Walk

$\text{self}_m.\text{aspect} \leftarrow \text{simple_past}$

The Spatial-Phrase construction

construction SPATIAL-PHRASE

constructional

constituents

sr : Spatial-Relation

Im : Ref-Expr

form

sr_f *before* Im_f

meaning

sr_m .landmark \leftrightarrow Im_m

The Directed-Motion construction

construction 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

$self_m.scene \leftrightarrow dm$

$dm.agent \leftrightarrow a_m$

$dm.motion \leftrightarrow m_m$

$dm.path \leftrightarrow p_m$

schema Directed-Motion

roles

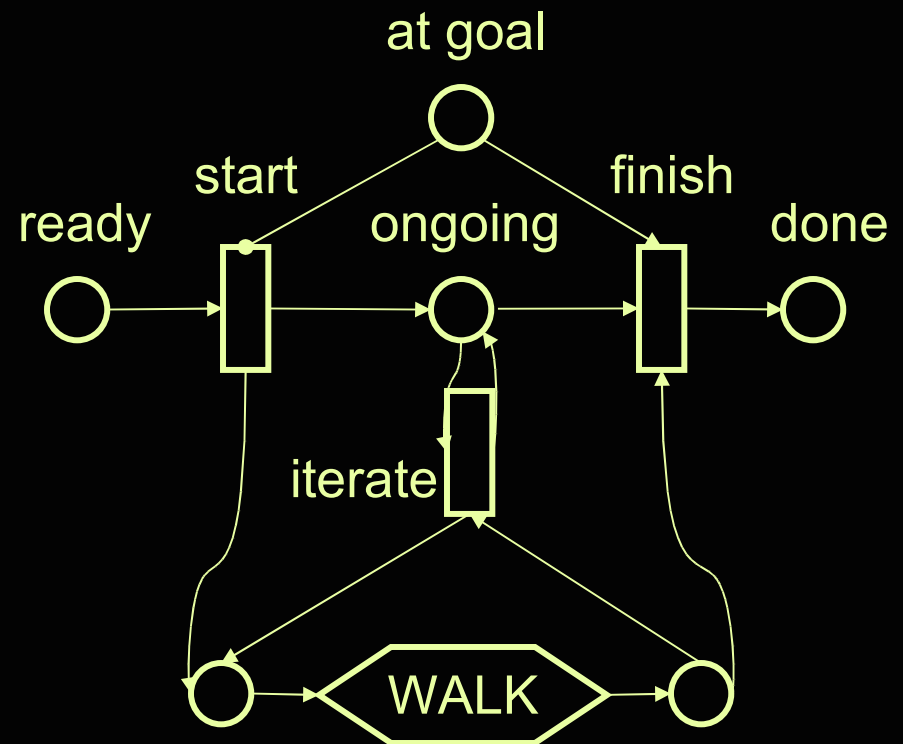
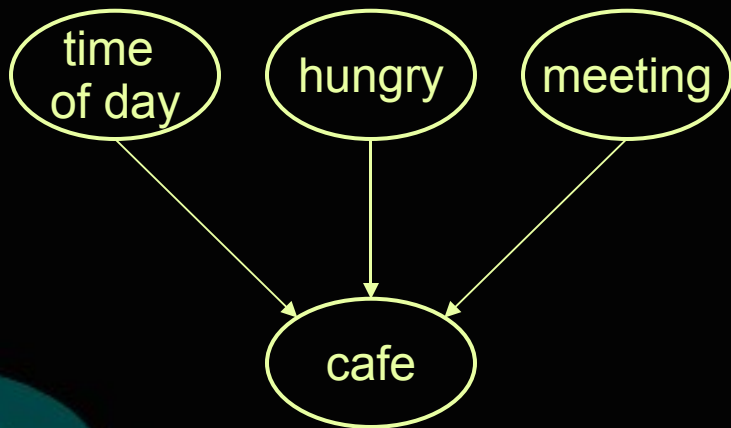
agent : Entity

motion : Motion

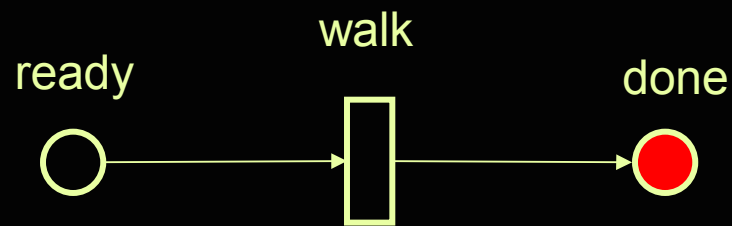
path : SPG

What exactly is simulation?

- Belief update and/or X-schema execution



“Harry walked into the café.”




walker=Harry


goal=cafe

“Harry is walking to the café.”

Utterance

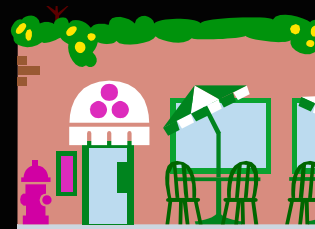


Analysis Process

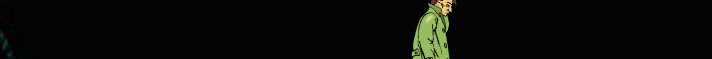
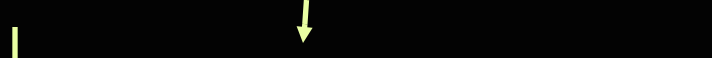
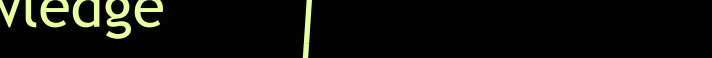
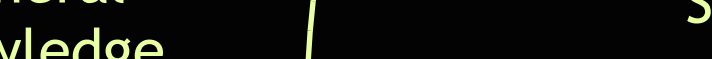
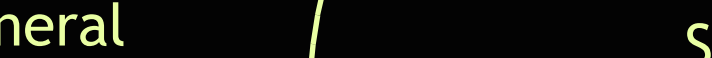
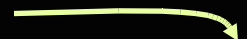
Semantic Specification



Simulation

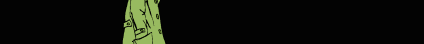
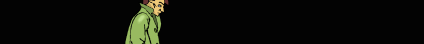
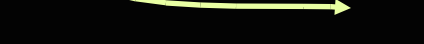
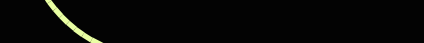
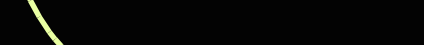
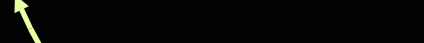
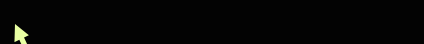
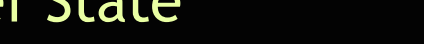
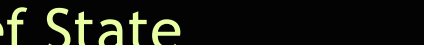
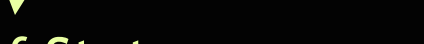


Constructions

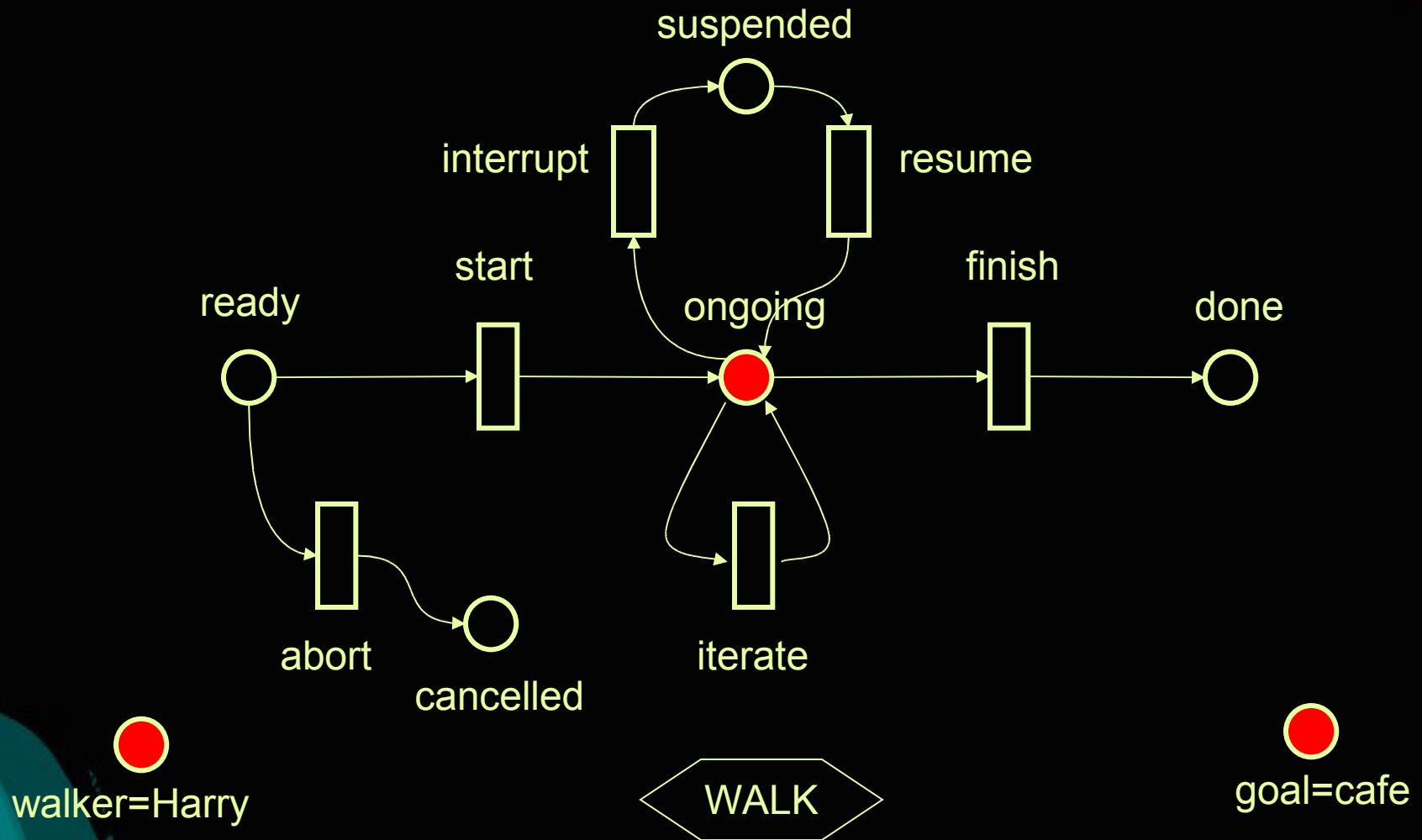


General Knowledge

Belief State



“Harry is walking to the café.”



“Harry has walked into the wall.”

Utterance

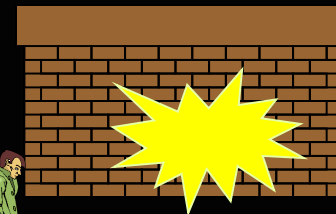


Analysis Process

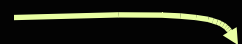
Semantic Specification



Simulation

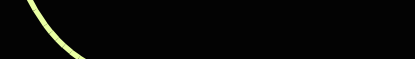
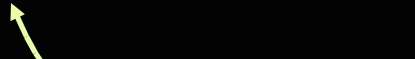


Constructions



General Knowledge

Belief State



Perhaps a different sense of INTO?

construction INTO

subcase of spatial-prep

form

self_f .orth ← “into”

meaning

evokes Trajector-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_f .orth ← “into”

meaning

evokes Trajector-Landmark as tl

evokes Impact as im

evokes Source-Path-Goal as spg

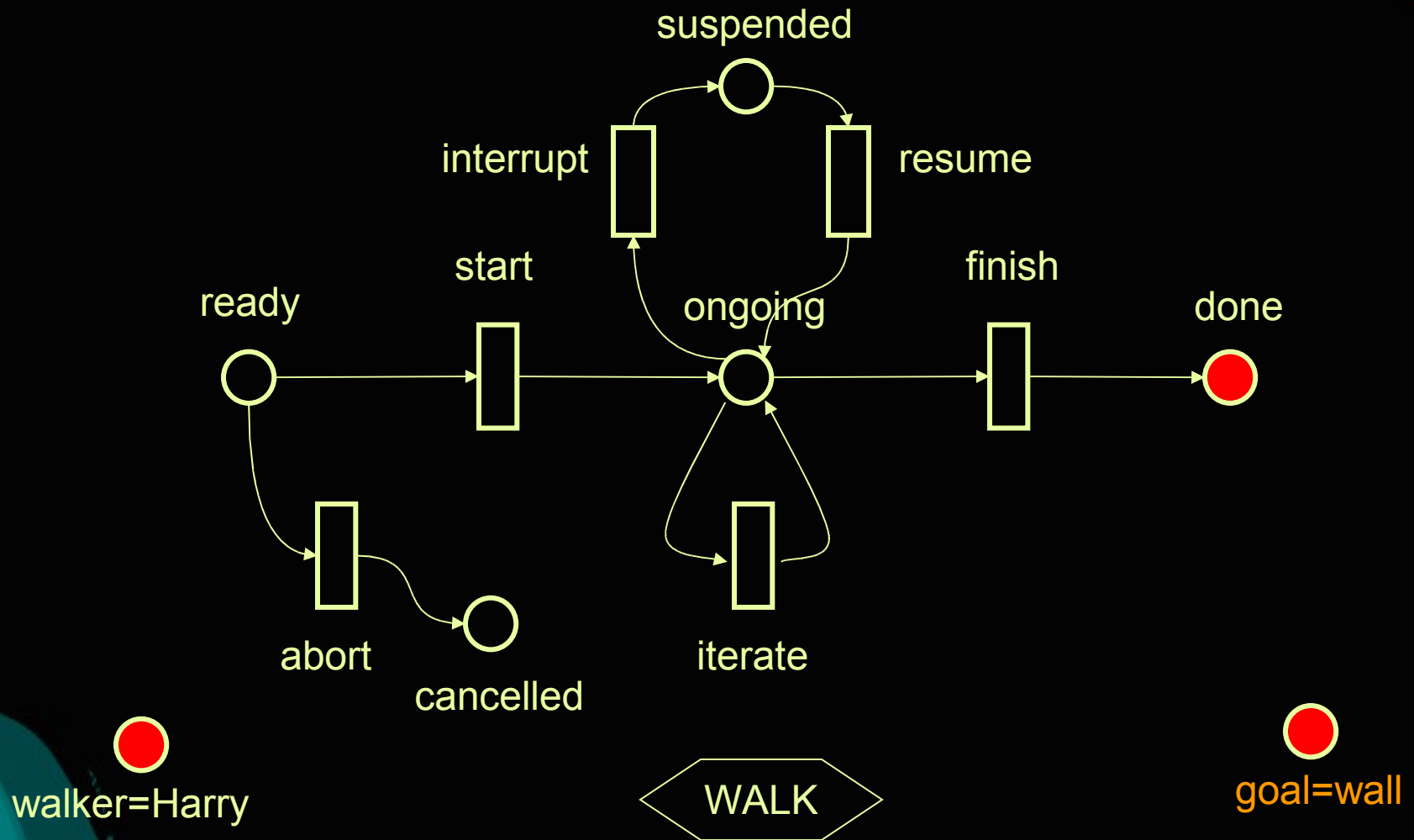
tl.trajector ↔ spg.trajector

tl.landmark ↔ spg.goal

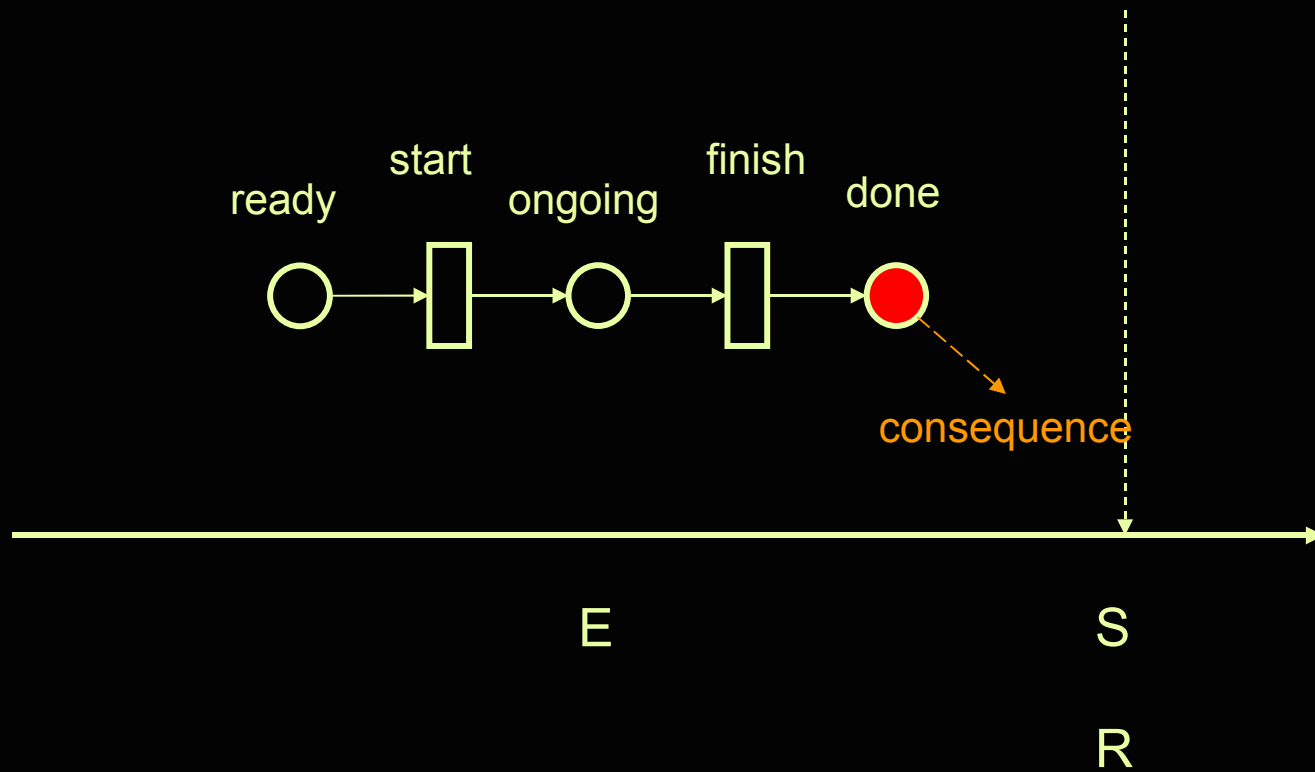
im.obj1 ↔ tl.trajector

im.obj2 ↔ tl.landmark

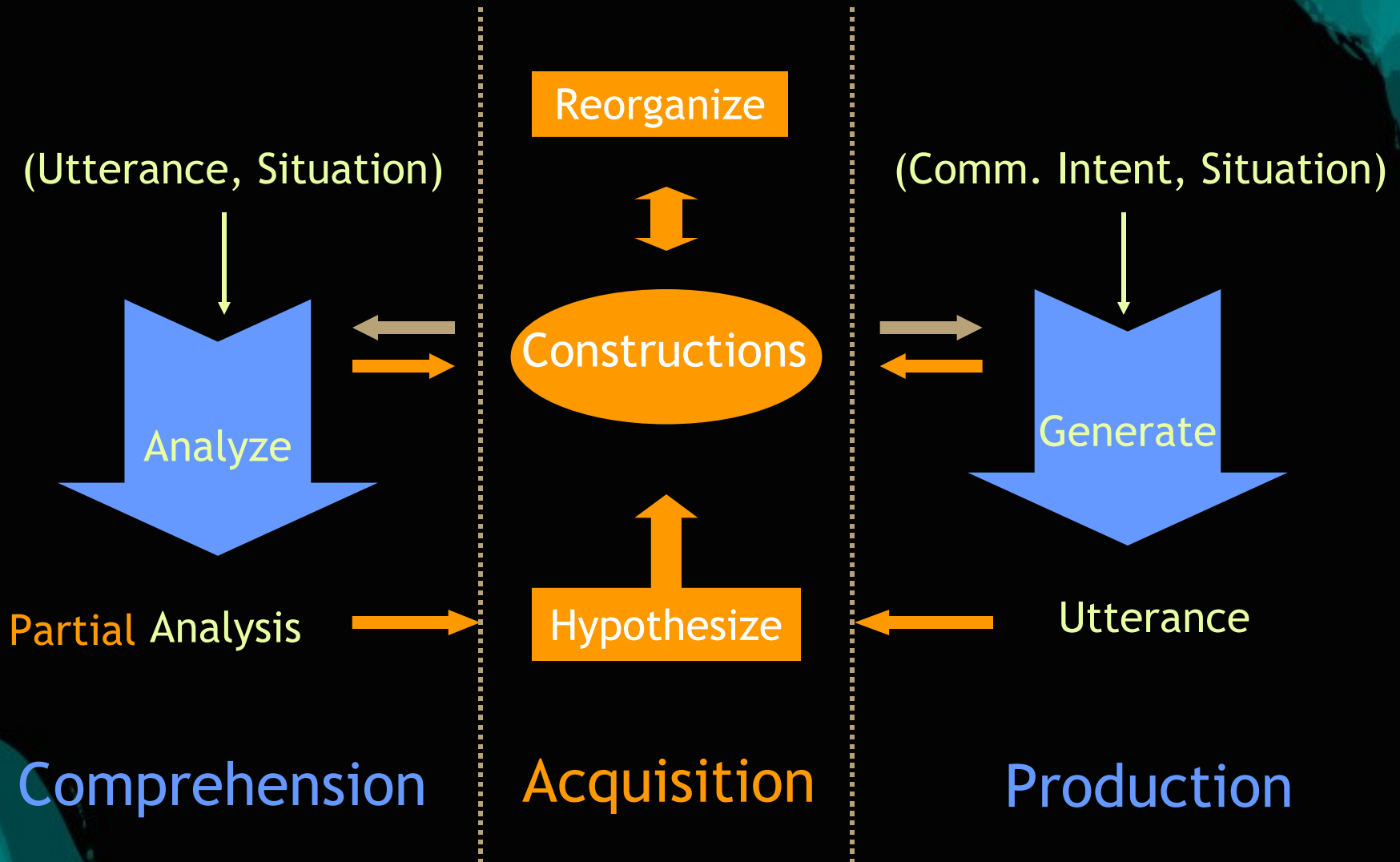
“Harry has walked into the wall.”



Map down to timeline



Usage-based Language Learning



Main Learning Loop

```
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-organize == true) // frequency depends on learning parameter
    reorganizeCxns();
```

Three ways to get new constructions

- Relational mapping

- **throw the ball**

} **THROW < BALL**

- Merging

- **throw the block**
- **throwing the ball**

} **THROW < OBJECT**

- Composing

- **throw the ball**
- **ball off**
- **you throw the ball off**

} **THROW < BALL < OFF**

Minimum Description Length

- Choose grammar G to minimize $\text{cost}(G | D)$:
 - $\text{cost}(G | D) = \alpha \cdot \text{size}(G) + \beta \cdot \text{complexity}(D | G)$
 - Approximates Bayesian learning;
 $\text{cost}(G | D) \approx \text{posterior probability } P(G | D)$
- **Size of grammar** = $\text{size}(G) \approx 1 / \text{prior } P(G)$
 - favor fewer/smaller constructions/roles; isomorphic mappings
- **Complexity of data given grammar** $\approx 1 / \text{likelihood } P(D | G)$
 - 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

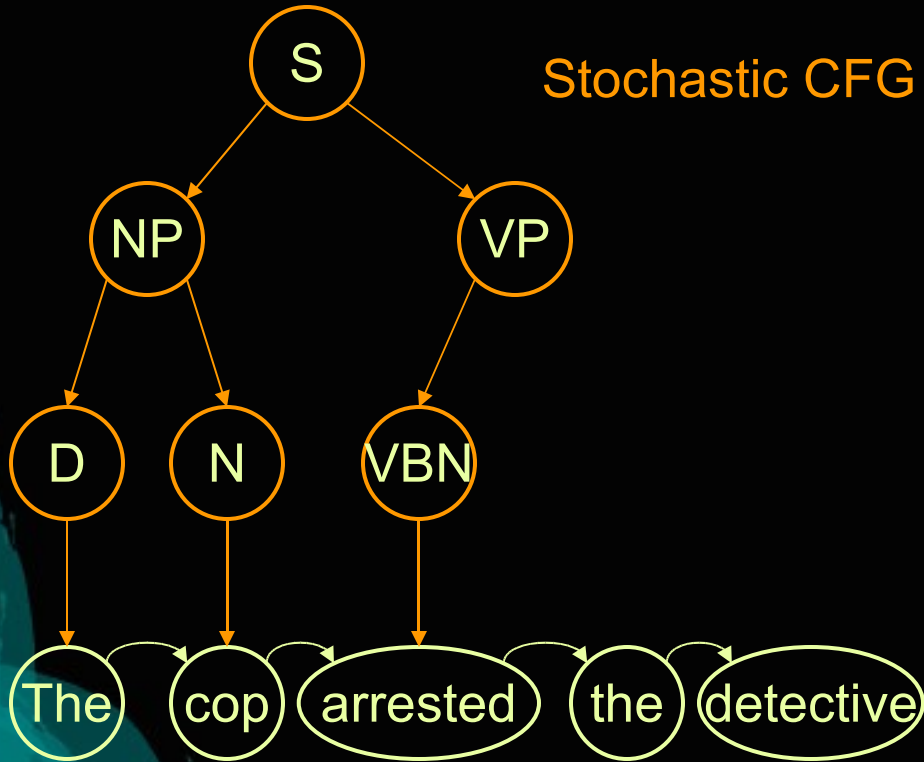
Bayesian Model of Sentence Processing

- 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

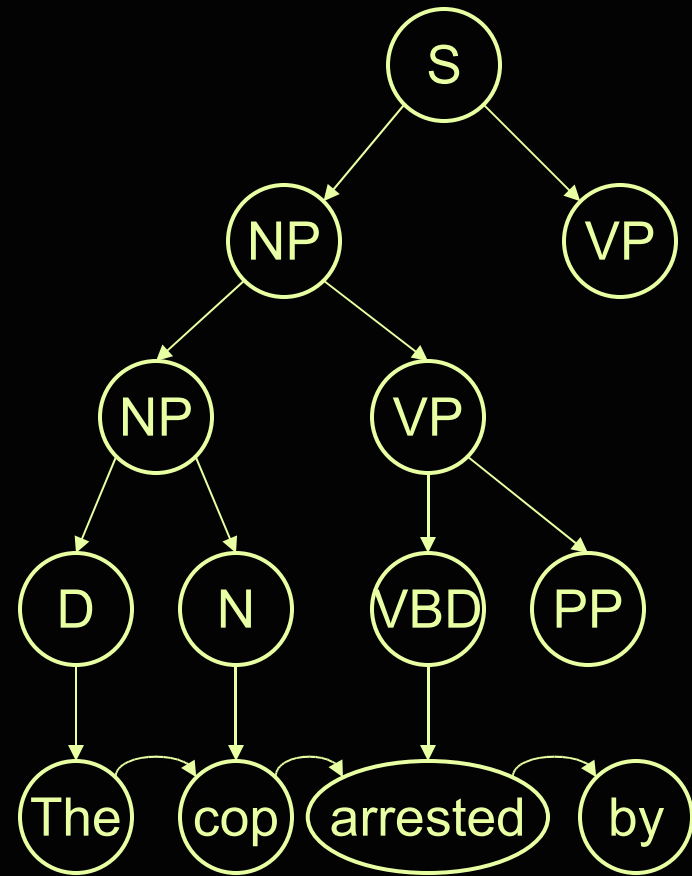
SCFG + N-gram

Main Verb

Stochastic CFG

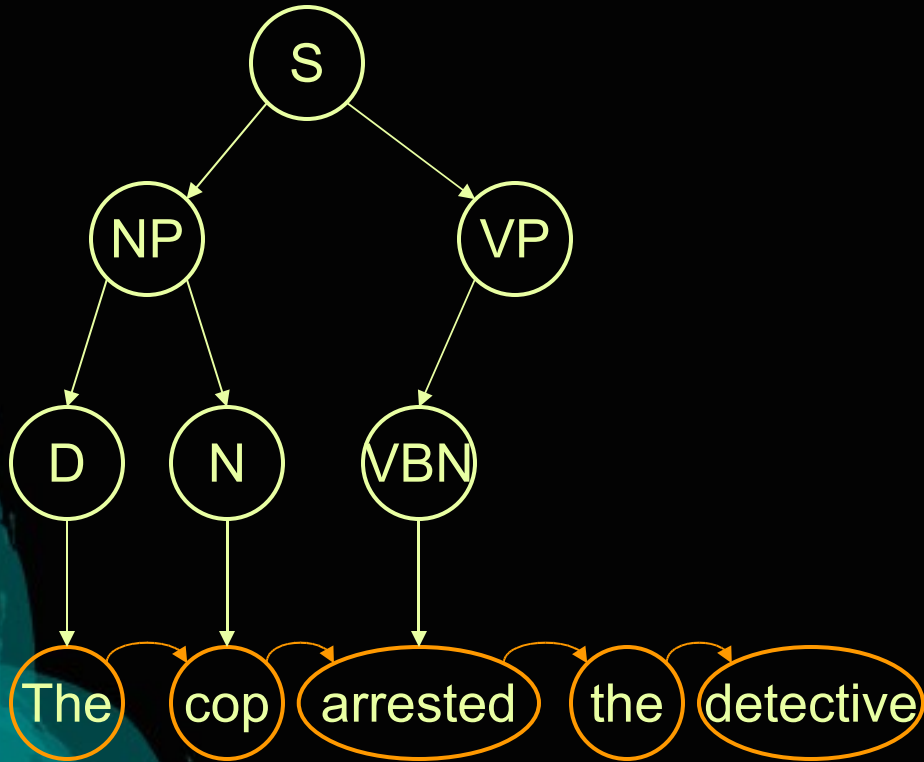


Reduced Relative



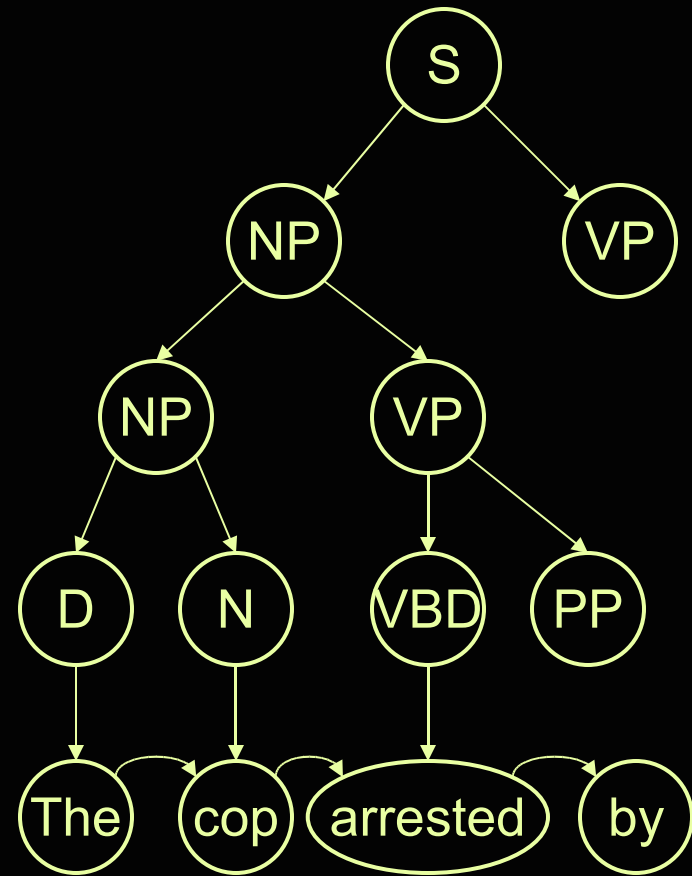
SCFG + N-gram

Main Verb



N-Gram

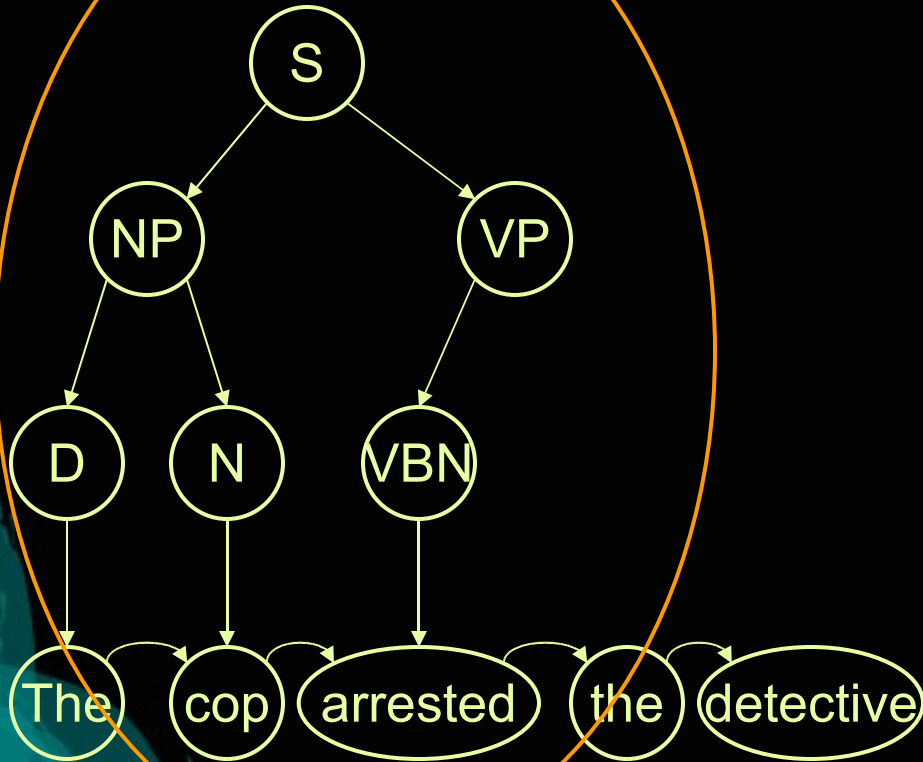
Reduced Relative



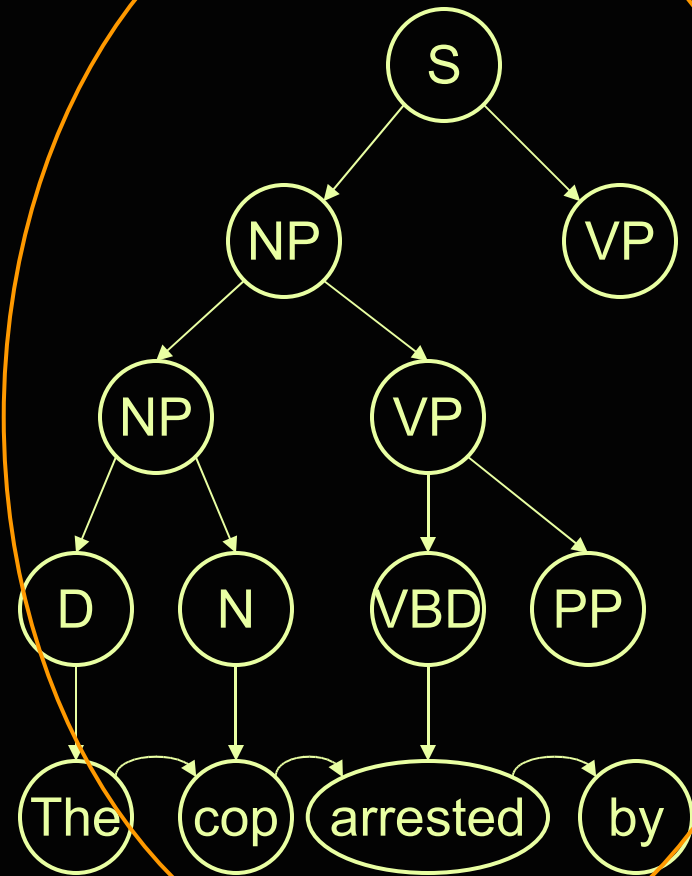
SCFG + N-gram

Different Interpretations

Main Verb



Reduced Relative



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