Computing Dynamic Meanings

Day 2: Introduction to syntactic and semantic parsing in ACT-R/*pyactr*

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Topic for today

- Parsing
- Is interpretation incremental?

  Altmann and Steedman, 1988; Marslen-Wilson, 1973, 1975; Tanenhaus et al., 1995; Trueswell et al., 1994
- If so, what does it tell us about (syntactic) parsing?

  Steedman, Stabler, Shieber & Johnson

Syntactic parsers are incremental

Garden-path or “garden-path-like” effects :

(1) a. The horse raced past the barn fell.
    b. The horse that was raced past the barn fell.

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(2) Trump urged to stop tweeting on Trump tower meeting.

(3) a. While she mended a sock fell on the floor.
    b. While she mended, a sock fell on the floor.

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(2) Trump urged to stop tweeting on Trump tower meeting.

(3) a. While she mended a sock fell on the floor.
    b. While she mended, a sock fell on the floor.

(4) a. The professor saw the students walked across the quad.
    b. The professor saw that the students walked across the quad.

Syntactic parsers are incremental

Garden-path or “garden-path-like” effects :

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(2) Trump urged to stop tweeting on Trump tower meeting.

(3) a. While she mended a sock fell on the floor.
    b. While she mended, a sock fell on the floor.

(4) a. The professor saw the students walked across the quad.
    b. The professor saw that the students walked across the quad.

(5) a. Put the apple on the towel into the box.
    b. Put the apple that is on the towel into the box.

Syntactic parsers are incremental

Garden-path or “garden-path-like” effects :

I. The horse raced past the barn fell.
II. While she mended a sock fell on the floor.
III. The professor saw the students walked across the quad.
IV. Put the apple on the towel into the box.

$\rightarrow$ syntactic parsing is incremental

Terminology

- locally/temporarily ambiguous sentences
- garden-path sentences

Marslen-Wilson (1975): shadowing

Normal sentence:

- The new peace terms have been announced. They call for the unconditional withdrawal of all the enemy forces.

Semantically anomalous sentence:

- The new peace terms have been announced. They call for the unconditional **universe** of all the enemy forces.

Marslen-Wilson (1975): shadowing

The word *withdrawal*/*universe*: disrupted in one of the syllables, or not disrupted

- 2nd syllable: *withdrawal* $\rightarrow$ *withdewal*
- 3rd syllable: *withdrawal* $\rightarrow$ *withdrawack*
- 2nd syllable: *universe* $\rightarrow$ *unopverse*
- 3rd syllable: *universe* $\rightarrow$ *unitierse*

Marslen-Wilson (1975): shadowing

- 2nd syllable: *withdrawal* $\rightarrow$ *withdewal*
- 3rd syllable: *withdrawal* $\rightarrow$ *withdrawack*

- Corrected often (27 cases)

- 2nd syllable: *universe* $\rightarrow$ *unopverse*
- 3rd syllable: *universe* $\rightarrow$ *unitierse*

- Hardly ever corrected (5 cases)

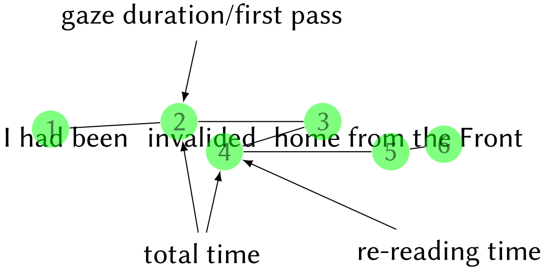
Marslen-Wilson (1975): shadowing

Item

The new peace terms have been announced. They call for the unconditional withdrawal/universe of all the enemy forces.

- Incremental interpretation, hence, restoration of disrupted words only in normal condition (in 2nd and 3rd syllables)
- Problems?

Eye-tracking & 80's ad 90's



Reduced-relative garden path

(6) The horse raced past the barn fell.

(7) The horse raced...

Main-clause >> reduced-relative clause

Minimal Attachment:
listeners/readers posit the smallest syntactic structures compatible with the input

Frazier, 1978

Closely-similar alternatives: J. Hale, 2011; Pritchett, 1988, 1992

Other possibilities: Bever, 1970; Gibson, 1991; J. Hale, 2001; Steedman, 2001

Ferreira and Clifton, (1986)

Interaction of semantic selectional restrictions and parsing

(8) a. The defendant examined **by the lawyer** turned out to be unreliable. (Animate Reduced)

b. The defendant that was examined **by the lawyer** turned out to be unreliable. (Animate Unreduced)

Ferreira and Clifton, (1986)

Interaction of semantic selectional restrictions and parsing

(8) a. The defendant examined **by the lawyer** turned out to be unreliable. (Animate Reduced)

b. The defendant that was examined **by the lawyer** turned out to be unreliable. (Animate Unreduced)

(9) a. The evidence examined **by the lawyer** turned out to be unreliable. (Inanimate Reduced)

b. The evidence that was examined **by the lawyer** turned out to be unreliable. (Inanimate Unreduced)

Ferreira and Clifton, (1986)

I. The Animate/Inanimate $[_V$ **examined** $]$ $[_{\text{disamb}}$ **by the lawyer** $]$
II. The Animate/Inanimate that was $[_V$ **examined** $]$ $[_{\text{disamb}}$ **by the lawyer** $]$

- First pass: Disamb – reduced slower than unreduced

Ferreira and Clifton, (1986)

I. The Animate/Inanimate $[_V$ **examined** $]$ $[_{\text{disamb}}$ **by the lawyer** $]$
II. The Animate/Inanimate that was $[_V$ **examined** $]$ $[_{\text{disamb}}$ **by the lawyer** $]$

- First pass: Disamb – reduced slower than unreduced

$\Rightarrow$ incremental interpretation does not affect parsing

Altmann and Steedman, (1988): NP/VP-attachment ambiguity

Context affects syntactic attachment

Target sentence:

(10) The burglar blew open the safe with...

Altmann and Steedman, (1988): NP/VP-attachment ambiguity

Context affects syntactic attachment

Target sentence:

(10) The burglar blew open the safe with...

a. ...the dynamite.

b. ...the new lock.

Altmann and Steedman, (1988): NP/VP-attachment ambiguity

Context affects syntactic attachment

Target sentence:

(10) The burglar blew open the safe with...

a. ...the dynamite.

b. ...the new lock.

(11) a. The burglar blew open [$_{NP}$ the safe with the N]

b. The burglar [$_{VP}$ blew open [$_{NP}$ the safe] with the N]

- more than one safe $\rightarrow$ NP-attachment supported
- just one safe $\rightarrow$ VP-attachment supported

Altmann et al. (1988): context influence

(12) NP-attachment support

a. A burglar broke into a bank carrying some dynamite. He planned to blow up a safe. Once inside he saw that there was a safe which had a new lock and a **safe** which had an old lock.

(13) VP-attachment support

a. A burglar broke into a bank carrying some dynamite. He planned to blow up a safe. Once inside he saw that there was a safe which had a new lock and a **strongbox** which had an old lock.

Altmann et al. (1988): context influence

(12) NP-attachment support

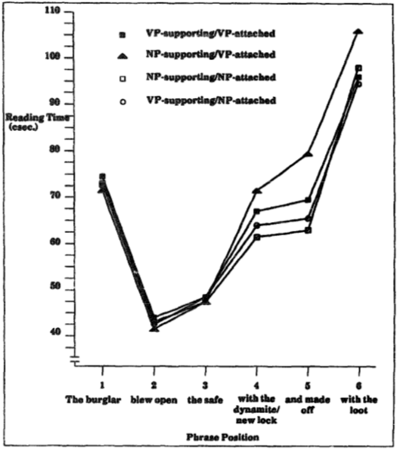
a. A burglar broke into a bank carrying some dynamite. He planned to blow up a safe. Once inside he saw that there was a safe which had a new lock and a **safe** which had an old lock.

(13) VP-attachment support

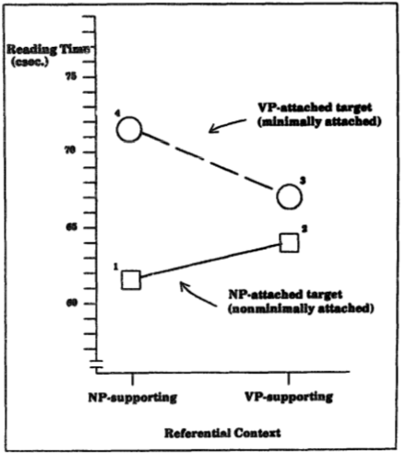
a. A burglar broke into a bank carrying some dynamite. He planned to blow up a safe. Once inside he saw that there was a safe which had a new lock and a **strongbox** which had an old lock.

The burglar /blew open /the safe /**with the dynamite (new lock)**/and...

Altmann et al. (1988): results



Altmann et al. (1988): results



Altmann et al. (1988)

explanation of results

NP-attachment >> VP-attachment

Late Closure:
if more than one phrase is compatible with the phrase P, parser attaches P to the most local phrase currently being processed

Frazier (1978)

(14) Jessie put the book Kathy was reading in the library...

Altmann et al. (1988)

explanation of results

(NP-attachment >> VP-attachment)× context

Principle of Parsimony:
A reading that carries fewer unsatisfied presuppositions will be favored over one that carries more.

Steedman, 2001

(15) The burglar blew open the safe with the ...

Tanenhaus et al. (1995): visual context

(16) Put the apple on the towel.

a. Put $[_{NP}$ the apple on the towel]

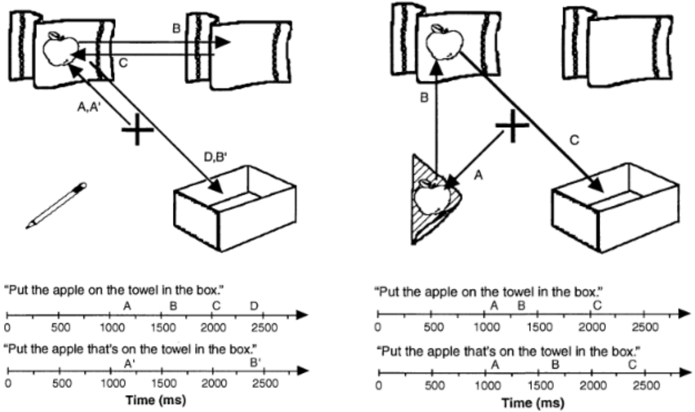
b. $[_{VP}$ Put $[_{NP}$ the apple] on the towel]

Experimental sentences:

(17) Put the apple on the towel in the box. (Locally Ambiguous)

(18) Put the apple that's on the towel in the box. (Locally Unambiguous)

Tanenhaus et al. (1995): visual context



Tanenhaus et al. (1995): visual context

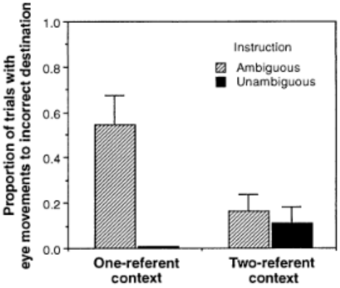


Fig. 3. Proportion of trials in which participants looked at the incorrect destination.

(19)	a.	Put the apple on the towel in the box.	(Ambiguous)
	b.	Put the apple that's on the towel in the box.	(Unambiguous)

Tanenhaus et al. (1995)

explanation of results

(NP-attachment $>>$ VP-attachment)$\times$ context

Principle of Parsimony:
A reading that carries fewer unsatisfied presuppositions will be favored over one that carries more. Steedman, 2001

(20) Put the apple on the towel in the box.

Interim summary

- Semantic information available to parser
- Semantic constraints incrementally used

  Altmann and Steedman, 1988; Tanenhaus et al., 1995
- Semantic constraints not incrementaly used

  Ferreira and Clifton, 1986

Trueswell et al. (1994)

Interaction of semantic selectional restrictions and parsing

(21) a. The defendant examined **by the lawyer** turned out to be unreliable. (Animate Reduced)

b. The defendant that was examined **by the lawyer** turned out to be unreliable. (Animate Unreduced)

Trueswell et al. (1994)

Interaction of semantic selectional restrictions and parsing

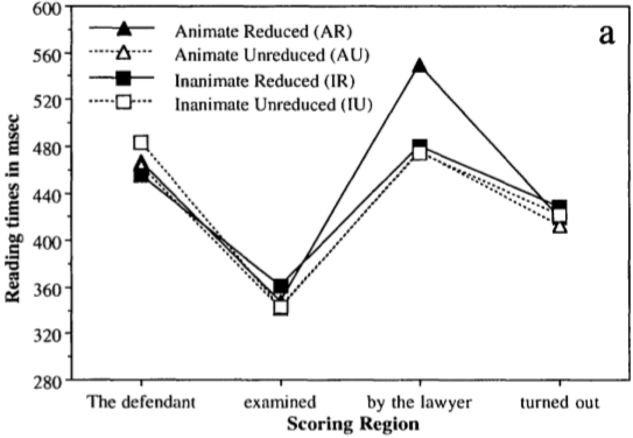
(21) a. The defendant examined **by the lawyer** turned out to be unreliable. (Animate Reduced)

b. The defendant that was examined **by the lawyer** turned out to be unreliable. (Animate Unreduced)

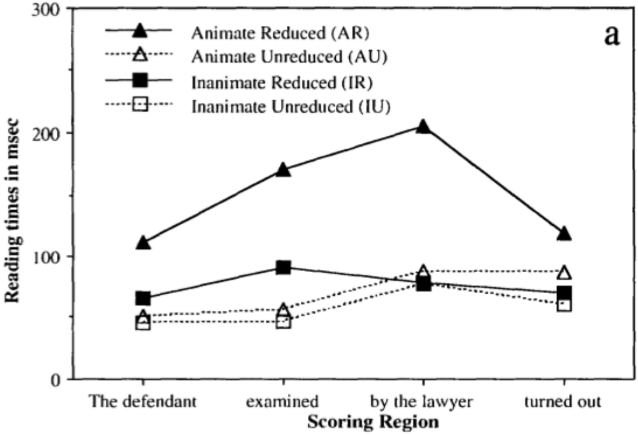
(22) a. The evidence examined **by the lawyer** turned out to be unreliable. (Inanimate Reduced)

b. The evidence that was examined **by the lawyer** turned out to be unreliable. (Inanimate Unreduced)

Trueswell et al. (1994):results



Trueswell et al. (1994):results



Eye-tracking & Trueswell et al. (1994)

explanation of results

- Main-clause >> reduced-relative clause (if both possible)
- Parser uses lexical information (selectional restrictions) to change preferences
- But what about Ferreira and Clifton, 1986?
- Ferreira and Clifton, 1986 – inanimate condition not always violating selectional restrictions:

Eye-tracking & Trueswell et al. (1994)

explanation of results

- Main-clause >> reduced-relative clause (if both possible)
- Parser uses lexical information (selectional restrictions) to change preferences
- But what about Ferreira and Clifton, 1986?
- Ferreira and Clifton, 1986 – inanimate condition not always violating selectional restrictions:
  The car towed from the parking lot...
  The meal brought to the highest priest...

Summary

- Evidence that lexical and contextual semantics can guide parser in syntax

  Altmann and Steedman, 1988; Marslen-Wilson, 1973, 1975; Tanenhaus et al., 1995; Trueswell et al., 1994

- Consequences?

Setting the stage

Theoretical considerations & parsing

Appendix: developments & refinements

Theoretical considerations

- Semantics (compositionality principle)
- Parsing (strong competence and rule-to-rule assumption)
- Parsers

Semantics – interpretation is productive

- We can interpret novel, previously unheard of sentences

Consequences:

- Interpretation is rule based (as opposed to memorized)
- Interpretation proceeds by building bigger blocks out of smaller blocks

What are the smaller blocks? What are the bigger blocks?

$\rightarrow$ Constituents

Understanding productivity

Principle of compositionality

The meaning of a complex expression is fully determined by its structure (syntax) and the meaning of its constituents (parts)

Stanford Encyclopedia of Philosophy

Assumptions about parsing

Strong competence (Bresnan and Kaplan, 1982)

There exists a direct correspondence between the rules of a grammar and the operations performed by the human language processor.

Rule-to-rule compositionality (Montague, 1973)

Each syntactic rule corresponds to a rule of semantic interpretation. ($\Rightarrow$ entities combined by syntactic rules must be semantically interpretable)

Grammar

I. $S \rightarrow NP\ VP$
II. $NP \rightarrow D\ N$
III. $NP \rightarrow NP\ VP$

the: D

book, opinion: N

IV. $PP \rightarrow P\ NP$
V. $VP \rightarrow V\ PP$
VI. $VP \rightarrow V$

fell: V

Grammar

I. S → NP VP

II. NP → D N

III. NP → NP VP

the: D

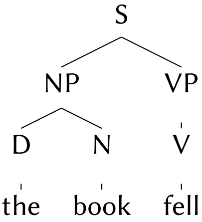
book, opinion: N

IV. PP → P NP

V. VP → V PP

VI. VP → V

fell: V



Parser: top-down

I. S $\rightarrow$ NP VP
II. NP $\rightarrow$ D N
III. NP $\rightarrow$ NP VP
IV. PP $\rightarrow$ P NP
V. VP $\rightarrow$ V PP
VI. VP $\rightarrow$ V

- **expand**: if the stack shows a symbol X on top, and the grammar contains a rule $X \rightarrow \alpha$ then replace the stack symbol X with the sequence of symbols α
- **scan**: if the stack shows one of the grammar's terminal symbols Y on top, and w, the current word being parsed, is of category Y, then remove w from the input and Y from the stack

J. T. Hale, 2014

ACT-R TD parser; initialize model

```python
import pyactr as actr
environment = actr.Environment(focus_position=(320, 180))

actr.chunktype("parsing_goal", "stack_top stack_middle\
    stack_bottom parsed_word task")
actr.chunktype("parse_state",
               "mother daughter1 daughter2")
actr.chunktype("word", "form cat")

parser = actr.ACTRModel(environment)
dm = parser.decmem
g = parser.goal
imaginal = parser.set_goal(name="imaginal", delay=0.05)
```

ACT-R TD parser; add lexical information into decl. memory

```
dm.add(actr.chunkstring(string="""
    isa     word
    form    evidence
    cat     N
"""))

g.add(actr.chunkstring(string="""
    isa         parsing_goal
    task        read_word
    stack_top   S
"""))
```

ACT-R TD parser; add rules

```
parser.productionstring(name="encode word", string="""
    =g>
    isa                 parsing_goal
    task                read_word
    =visual>
    isa                 _visual
    value               =val
    ==>
    =g>
    isa                 parsing_goal
    task                get_word_cat
    parsed_word        =val
    ~visual>
""")
```

ACT-R TD parser; add rules

```
parser.productionstring(name="retrieve category", string="""
    =g>
    isa             parsing_goal
    task            get_word_cat
    parsed_word     =w
    ==>
    +retrieval>
    isa             word
    form            =w
    =g>
    isa             parsing_goal
    task            match_category
""")
```

ACT-R TD parser; add rules

```
parser.productionstring(name="match category", string="""
    =g>
    isa             parsing_goal
    task            match_category
    ?retrieval>
    state           free
    buffer          full
    =retrieval>
    isa             word
    cat             =c
    ==>
    =g>
    isa             parsing_goal
    task            parsing
    parsed_word     =c
""")
```

ACT-R TD parser; add rules

```
parser.productionstring(name="expand: S ==> NP VP", string="""
    =g>
    isa         parsing_goal
    task        parsing
    stack_top   S
    stack_middle =s2
    ==>
    =g>
    isa         parsing_goal
    stack_top   NP
    stack_middle VP
    stack_bottom =s2
    +imaginal>
    isa         parse_state
    mother      S
    daughter1   NP
    daughter2   VP
""")
```

ACT-R TD parser; add rules

```
parser.productionstring(name="expand: NP ==> D N", string="""
    =g>
    isa          parsing_goal
    task         parsing
    stack_top    NP
    stack_middle =s2
    ==>
    =g>
    isa          parsing_goal
    stack_top    D
    stack_middle N
    stack_bottom =s2
    +imaginal>
    isa          parse_state
    mother       NP
    daughter1    D
    daughter2    N
""")
```

ACT-R TD parser; add rules

```
parser.productionstring(name="scan: word", string="""
    =g>
    isa         parsing_goal
    task        parsing
    stack_top   =y
    stack_middle =x
    stack_bottom =b
    parsed_word =y
    ==>
    =g>
    isa         parsing_goal
    task        press_space
    stack_top   =x
    stack_middle =b
    stack_bottom None
    parsed_word None
""")
```

ACT-R TD parser; add rules

```
parser.productionstring(name="press spacebar", string="""
    =g>
    isa             parsing_goal
    task            press_space
    stack_top       ~None
    ?manual>
    state           free
    ==>
    =g>
    isa             parsing_goal
    task            read_word
    +manual>
    isa             _manual
    cmd             'press_key'
    key             'space'
    ~imaginal>
""")
```

Parser: bottom-up

I. S $\rightarrow$ NP VP
II. NP $\rightarrow$ D N
III. NP $\rightarrow$ NP VP
IV. PP $\rightarrow$ P NP
V. VP $\rightarrow$ V PP
VI. VP $\rightarrow$ V

- **reduce**: if the top of the stack shows a sequence of symbols α, and there is a grammar rule $X \rightarrow \alpha$, then replace α on the stack with X.
- **shift**: if the current word of the sentence is w, push w on to the top of the stack.

J. T. Hale, 2014

ACT-R BU parser; initialize model

```
environment = actr.Environment(focus_position=(320, 180))

actr.chunktype("parsing_goal", "stack_1 stack_2 stack_3 sta
actr.chunktype("parse_state",
               "mother daughter1 daughter2")
actr.chunktype("word", "form cat")

parser = actr.ACTRModel(environment)
dm = parser.decmem
g = parser.goal
imaginal = parser.set_goal(name="imaginal", delay=0.05)
```

ACT-R BU parser; add rules

```
parser.productionstring(name="shift word and project it", string="""
        =g>
        isa          parsing_goal
        task         retrieving
        stack_1      =s1
        stack_2      =s2
        stack_3      =s3
        stack_4      =s4
        stack_5      =s5
        =retrieval>
        isa          word
        cat          =y
        ==>
        =g>
        isa          parsing_goal
        task         parsing
        stack_1      =y
        stack_2      =s1
        stack_3      =s2
        stack_4      =s3
        stack_5      =s4
        ~retrieval>""")
```

ACT-R BU parser; add rules

```
parser.productionstring(name="reduce: NP ==> D N", string="""
        =g>
        isa          parsing_goal
        task        parsing
        stack_1      N
        stack_2      D
        stack_3    =s3
        stack_4    =s4
        stack_5    =s5
        ==>
        =g>
        isa          parsing_goal
        stack_1    NP
        stack_2    =s3
        stack_3    =s4
        stack_4    =s5
        stack_5    None
        +imaginal>
        isa          parse_state
        mother       NP
        daughter1    D
        daughter2    N""")
```

ACT-R BU parser; add rules

```
parser.productionstring(name="press spacebar", string="""
    =g>
    isa             parsing_goal
    task            parsing
    ?manual>
    state           free
    ?imaginal>
    state           free
    ==>
    =g>
    isa             parsing_goal
    task            read_word
    +manual>
    isa             _manual
    cmd             'press_key'
    key             'space'
    ~imaginal>
""", utility=-10)
```

Parser: left-corner (eager)

I. S $\rightarrow$ NP VP

II. NP $\rightarrow$ D N

III. NP $\rightarrow$ NP VP

IV. PP $\rightarrow$ P NP

V. VP $\rightarrow$ V PP

VI. VP $\rightarrow$ V

- **project**: if the top of the stack is a symbol Y, and there is a grammar rule X $\rightarrow$ Y β whose right-hand side starts with Y, then replace Y with new symbols: an expectation for each of the remaining righthand side symbols, and a record that X has been found
- **project+complete**: if the top of the stack is Y, and right below it is an expectation [X], then replace both with the remaining expectations β
- **shift**: if the current word of the sentence is w, push w on to the top of the stack.

Resnik, 1992

ACT-R LC parser; add rules

```
parser.productionstring(name="project and complete: NP ==> D N", string
    =g>
    isa             parsing_goal
    stack_1         D
    stack_2         NP
    stack_3         =s3
    stack_4         =s4
    ==>
    =g>
    isa             parsing_goal
    stack_1         N
    stack_2         =s3
    stack_3         =s4
    stack_4         None
    +imaginal>
    isa             parse_state
    mother          NP
    daughter1       D
    daughter2       N
""")
```

ACT-R LC parser; add rules

```
parser.productionstring(name="project: NP ==> D N", string="""
    =g>
    isa             parsing_goal
    stack_1         D
    stack_2         =s2
    stack_2         ~NP
    stack_3         =s3
    stack_4         =s4
    ==>
    =g>
    isa             parsing_goal
    stack_1         N
    stack_2         NP
    stack_3         =s2
    stack_4         =s3
    +imaginal>
    isa             parse_state
    mother          NP
    daughter1       D
    daughter2       N
""")
```

Top-down:

- **expand**: if the stack shows a symbol X on top, and the grammar contains a rule $X \to \alpha$ then replace the stack symbol X with the sequence of symbols α
- **scan**: if the stack shows one of the grammar's terminal symbols Y on top, and w, the current word being parsed, is of category Y, then remove w from the input and Y from the stack

Bottom-up:

- **reduce**: if the top of the stack shows a sequence of symbols α, and there is a grammar rule $X \to \alpha$, then replace α on the stack with X.
- **shift**: if the current word of the sentence is w, push w on to the top of the stack.

Left-corner (eager):

- **project**: if the top of the stack is a symbol Y, and there is a grammar rule X $\to$ Y β whose right-hand side starts with Y, then replace Y with new symbols: an expectation for each of the remaining righthand side symbols, and a record that X has been found
- **project+complete**: if the top of the stack is Y, and right below it is an expectation [X], then replace both with the remaining expectations β
- **shift**: if the current word of the sentence is w, push w on to the top of the stack.

Parsers and interpretation

I. S $\rightarrow$ NP VP
II. NP $\rightarrow$ D N
III. NP $\rightarrow$ NP VP
IV. PP $\rightarrow$ P NP
V. VP $\rightarrow$ V PP
VI. VP $\rightarrow$ V NP

(23) The evidence examined by the doctor...

Summary

I. Bottom-up parsing coupled with compositionality predicts (the effect of) incremental interpretation too late

II. Top-down & left-corner parsing (with the standard theory of adjunction) predict that the decision happens before the disambiguating incremental interpretation

III. For top-down & left-corner parsers: Incremental interpretation has to be able to interpret incomplete constituents

Setting the stage

Theoretical considerations & parsing

Appendix: developments & refinements

Solution I: Steedman, 2001

- bottom-up parsing using Combinatory Categorial Grammar
- only constituents (well-formed syntactic objects) receive interpretation
- Interpretation becomes incremental due to extra composition rules

Notation of bottom-up parser

the:D   lawyer:N   examined:VBD   the:D   evidence:N

NP $\rightarrow$ D N   NP $\rightarrow$ D N

———

NP   NP

VP $\rightarrow$ VBD NP

———

VP

S $\rightarrow$ NP VP

———

S

Bottom-up parsing rule

Current rule

- If you have evidence for A and B and you have a rule $X \to A\ B$, postulate X

Extra rule (rule composition)

- Two rules: $X \to A\ B$, $B \to C\ Y$
- You have evidence for A and C (being empty counts as evidence)
- Postulate a new *rule*, $X \to Y$

Bottom-up parser with extra rule

the:D lawyer:N examined:VBD the:D evidence:N

NP $\rightarrow$ D N

———

NP

S $\rightarrow$ NP VP VP $\rightarrow$ VBD NP

———

S $\rightarrow$ NP NP $\rightarrow$ D N

———

S $\rightarrow$ N

———

S

Bottom-up parser with extra rule

The parser can parse incrementally:

(24) The woman that John saw...

The parser *cannot* parse incrementally:

(25) The woman that every man saw...

Demberg, 2012

Coordination as a constituency test:

(26) [books that every] and [journals that no] accordionist liked (?)

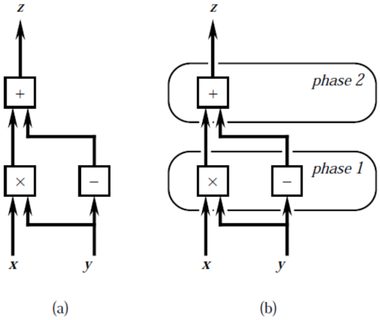
Solution II: Interpreting non-constituents is valid

Stabler, Shieber and Johnson

(27) The evidence examined...

- (27) is a non-constituent, but it can be interpreted (why should it not?)
- Dropping the strict mapping between syntax and semantics – enough for top-down and left-corner parser
- On bottom-up parser and adjunction: Shieber and Johnson, 1993

Asynchronous processing



(a) – asynchronous
(b) – synchronous
(b) – in some conditions disadvantaged:
$x = 1$, or $y = 0$

Circuit for computing: $z = xy + (-y)$

Summary

- top-down parsing, bottom-up parsing, left-corner parsing
- incremental interpretation and the limits with bottom-up parsing
- incremental interpretation and the interpretation of non-constituents

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