

Sentence Comprehension

What's the problem?

- Thoughts are not necessarily linear

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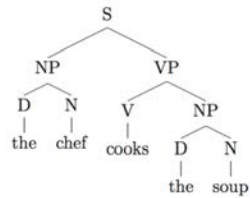
- Thoughts are not necessarily linear



What's the problem?

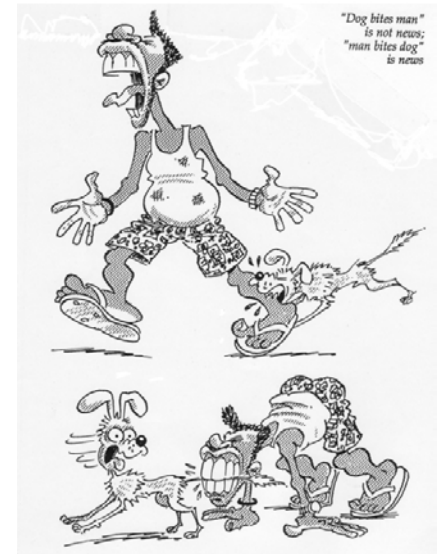
- Thoughts are not necessarily linear
- But words can only be spoken in a linear sequence to communicate those thoughts
- This non-linear to linear mapping is a *complicated* process reflected by the complexity of the *syntax* of language.

Syntax is



- Hierarchical
 - ◆ Beneath the linear sequence of words is a hierarchical structure that governs the relation between words, phrases, etc.
- Compositional
 - ◆ The meaning of a sentence is a function of the meaning of the words (morphemes) and their structural relations.

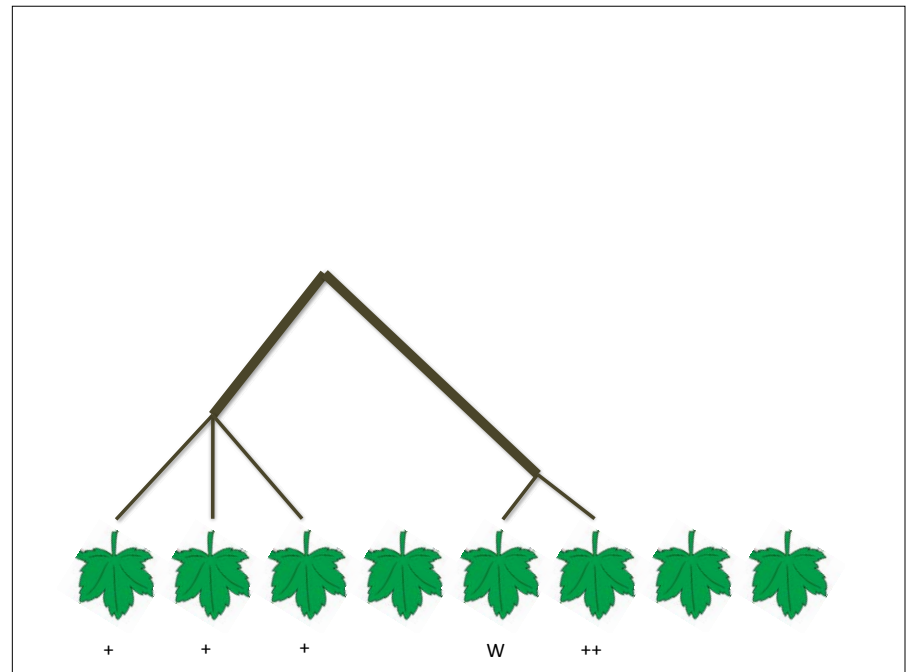
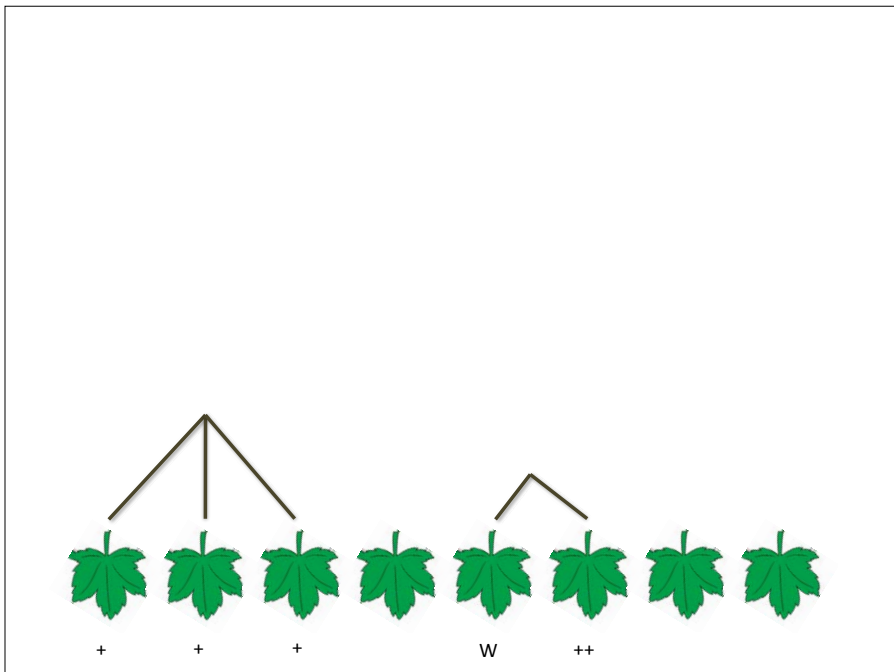
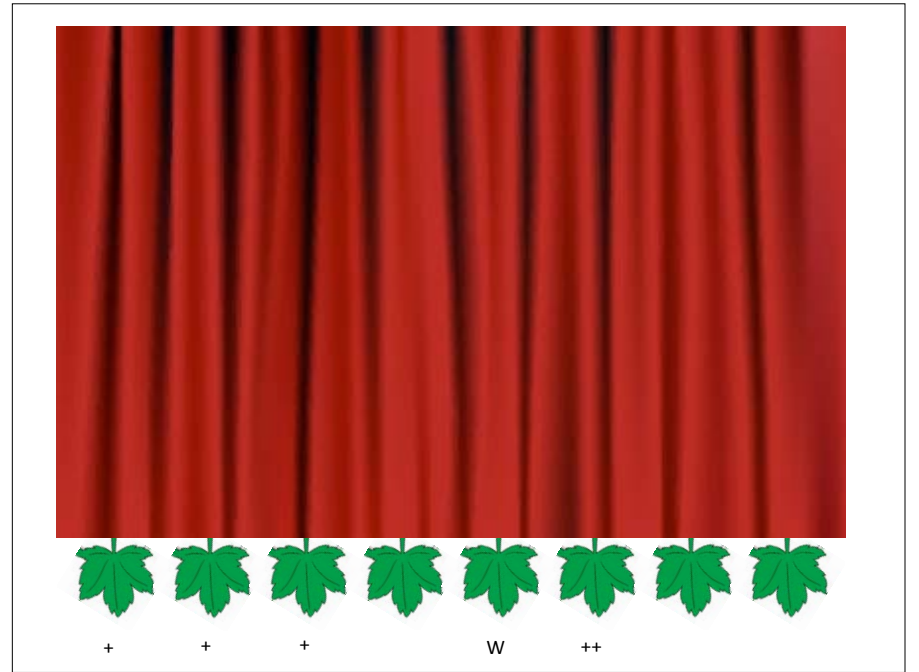
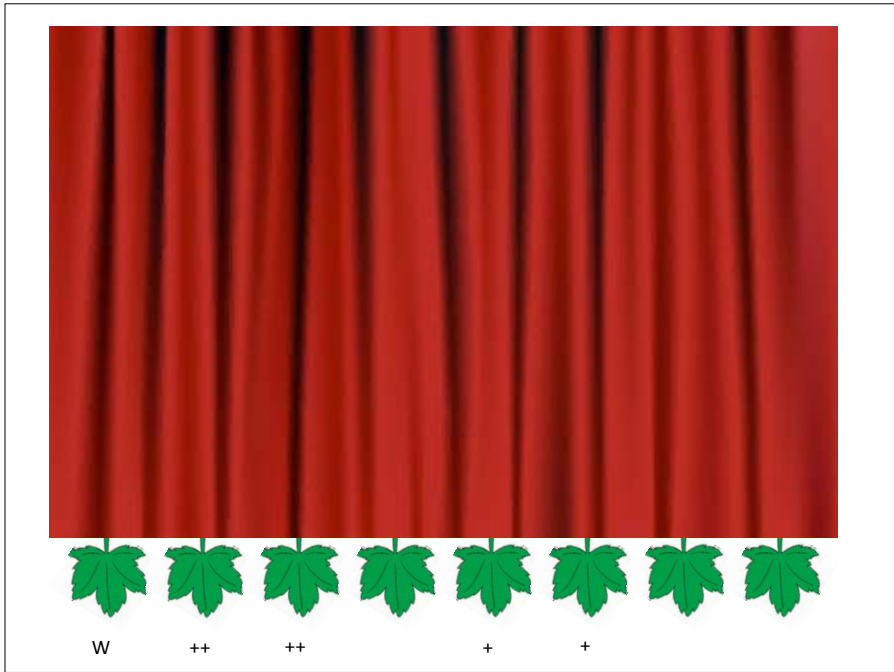
Compositionality:
Words + structure = meaning

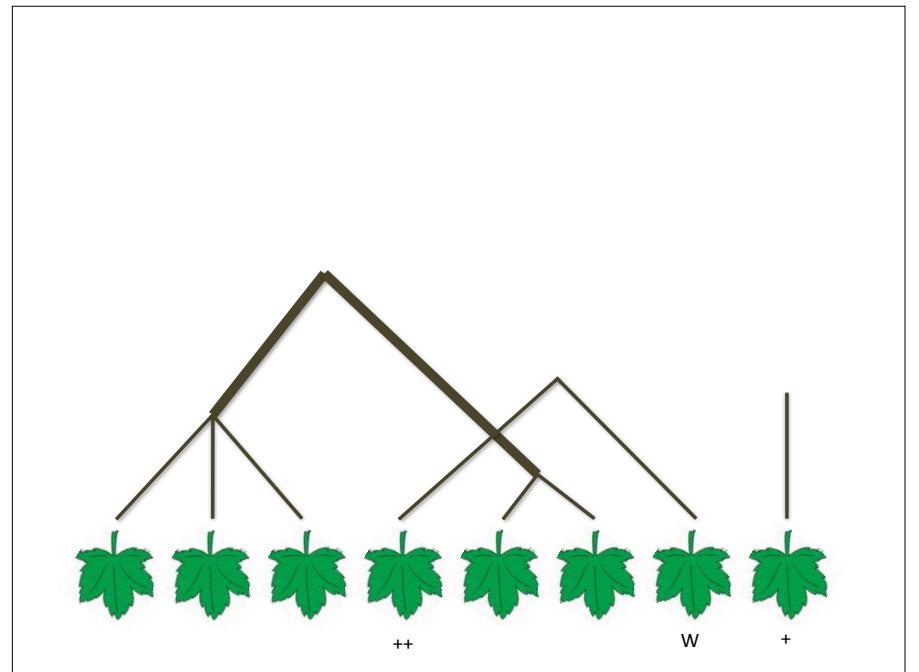
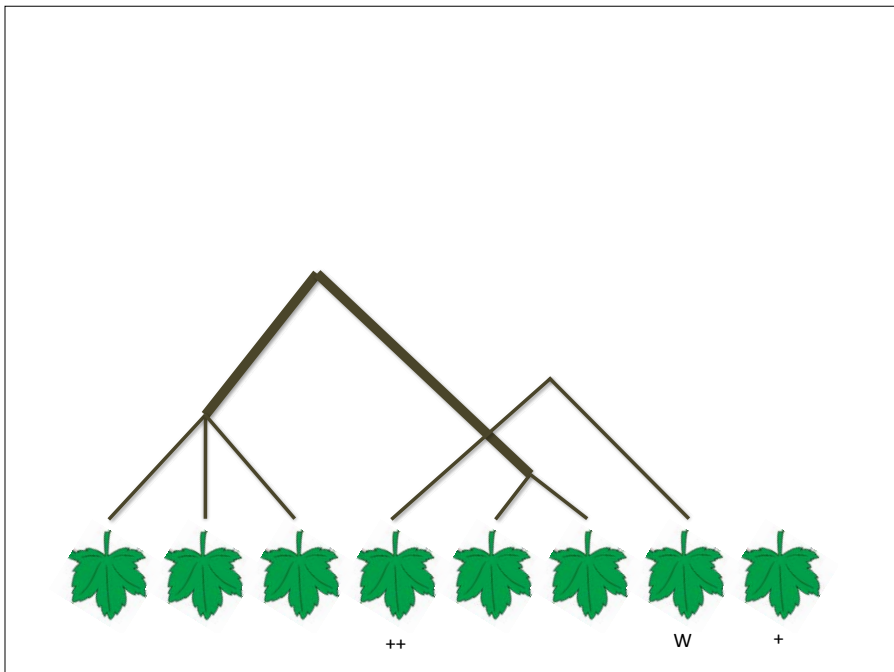
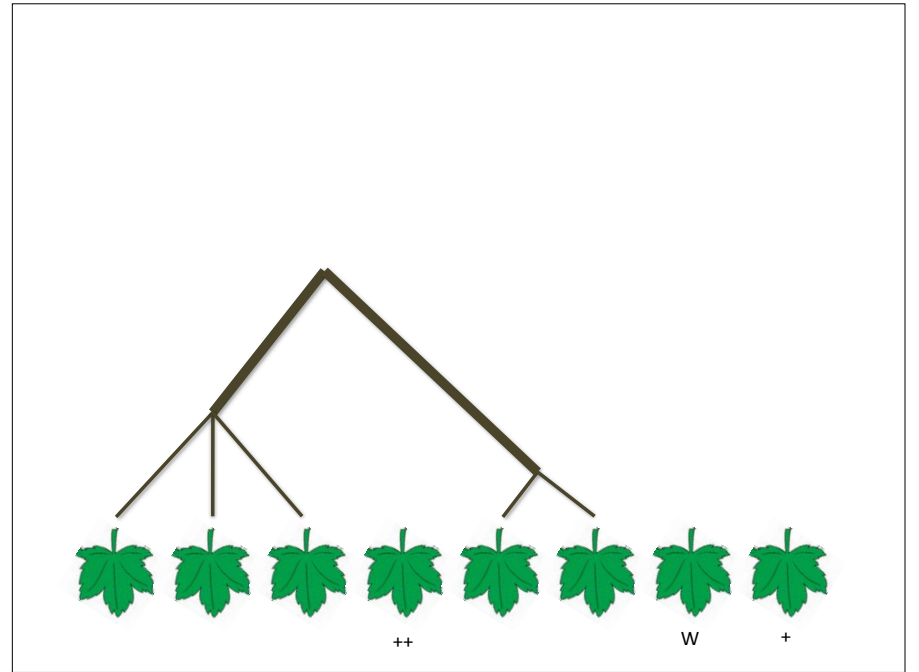
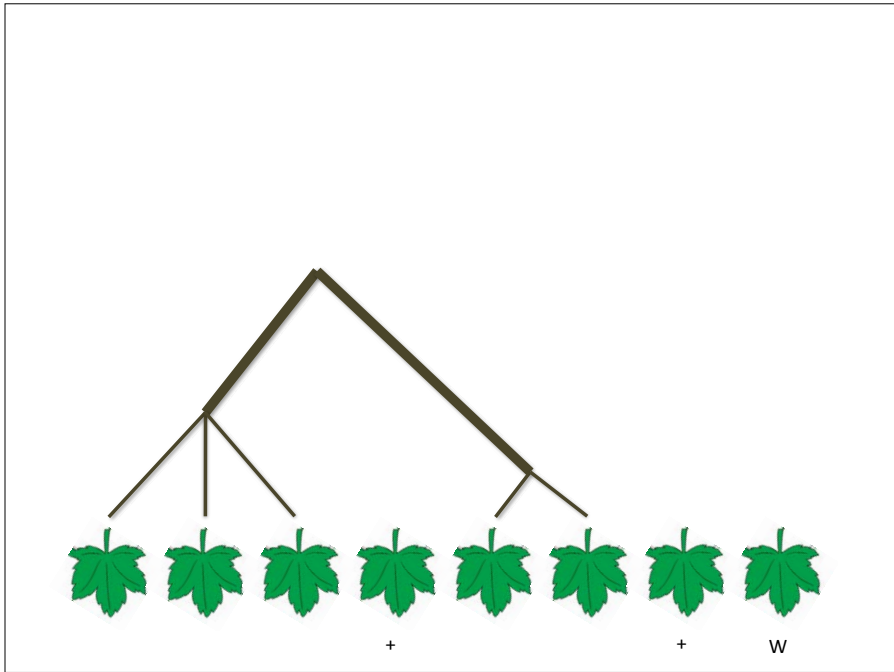


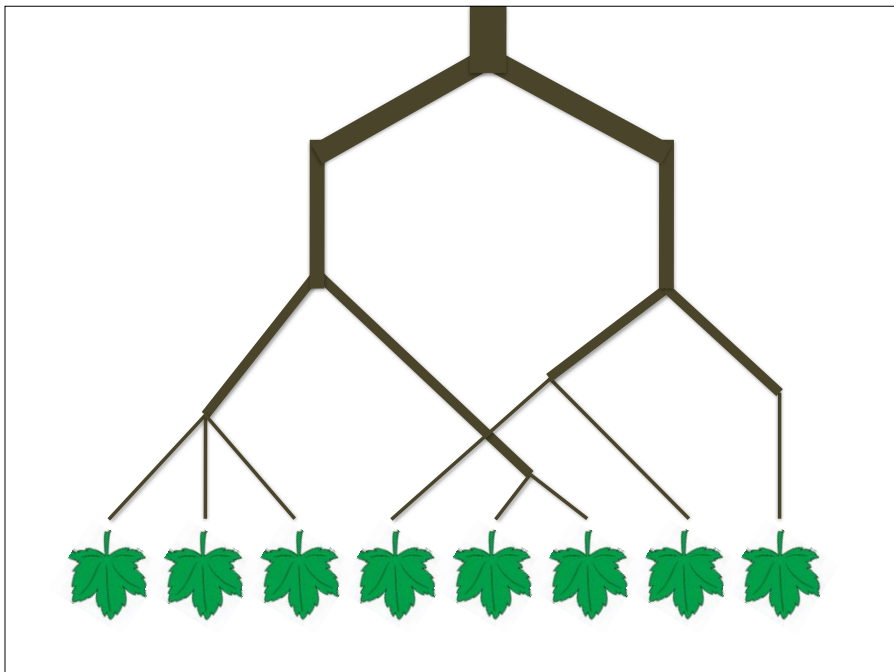
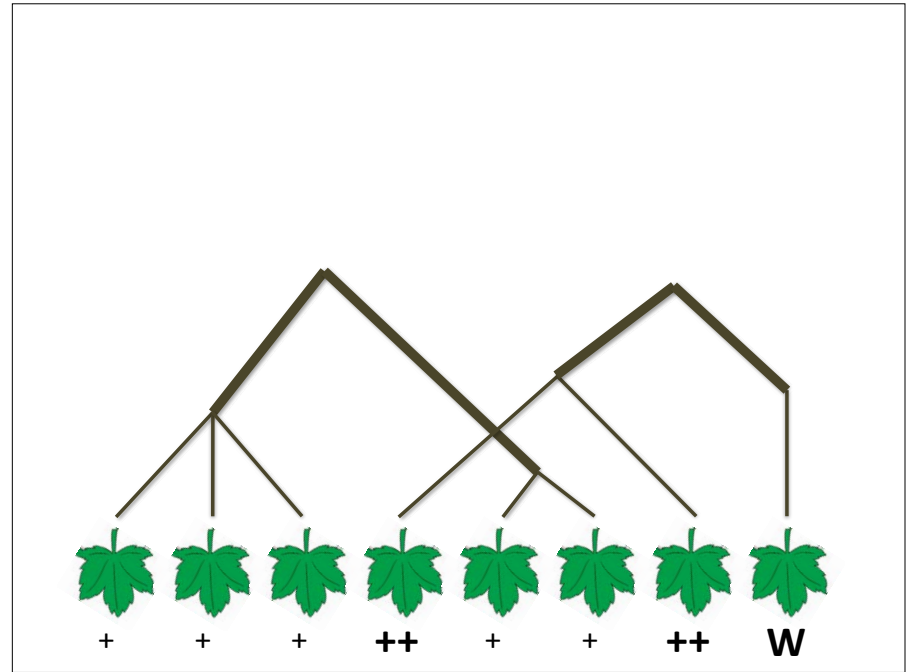
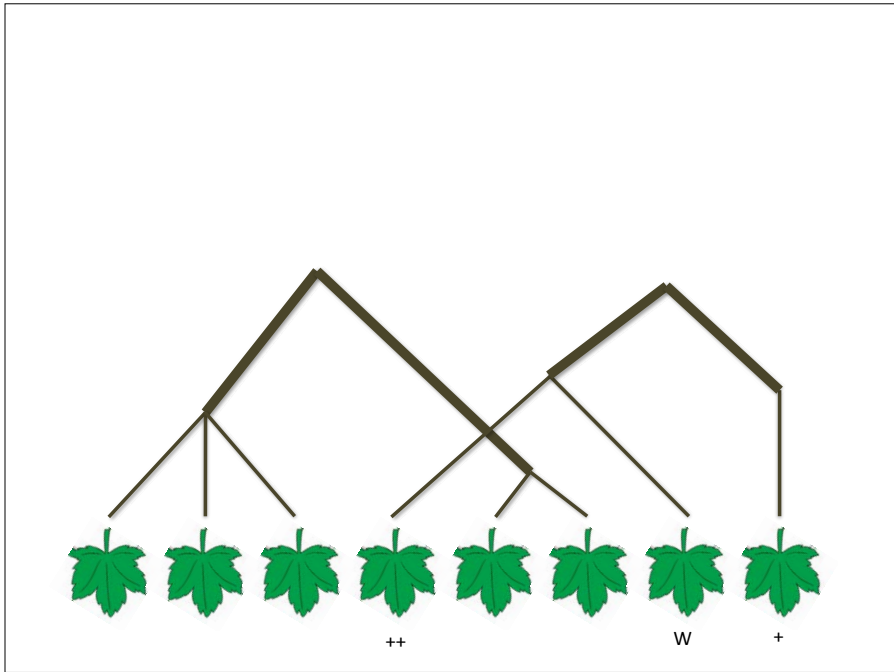
Hierarchical Structure
(digression)

What's behind the curtain?









The student in the hat is sleeping

The **students** in the hat ***is** sleeping
w

The student in the **hats** is sleeping
w

The student in the hats is sleeping

The Sentence Processing Problem

- How to recover the hierarchical sentence structure from a linear sequence of words?

↑
“parsing”

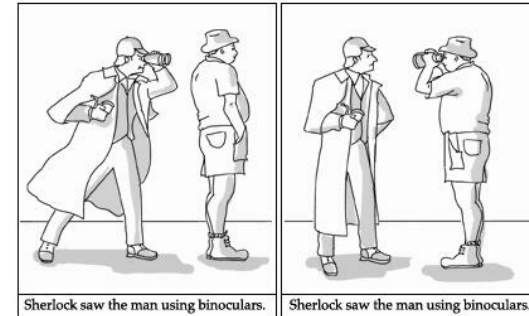
“The parser”: the mechanism that parses a sentences

The Sentence Processing Problem

- How to recover the hierarchical sentence structure from a linear sequence of words?
- Complications for the parser:
 - ♦ Ambiguity: there is often more than one way parse a sentence
 - ♦ We hear sentences incrementally, which means partial information, which means even more ambiguity

Ambiguity

Sherlock saw the man using binoculars



Ambiguity

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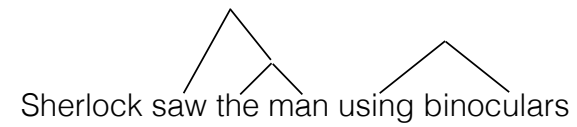
Ambiguity

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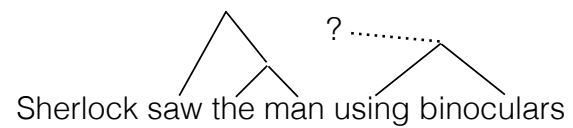
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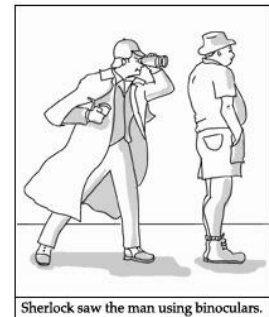
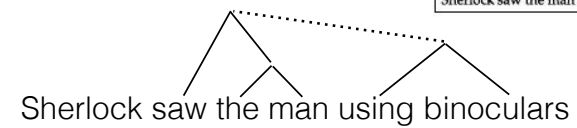
Sherlock saw the man using binoculars



Ambiguity

Attach to the verb phrase

Sherlock saw the man using binoculars



Ambiguity



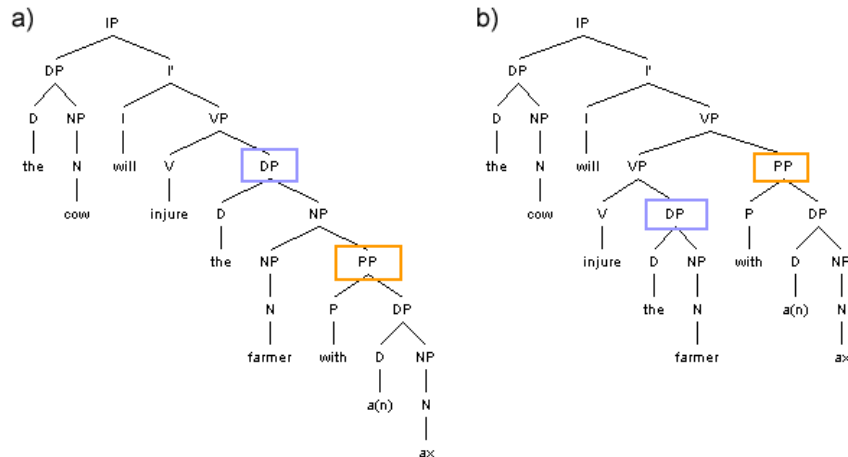
Attach to the noun phrase

Sherlock saw the man using binoculars

Enraged Cow Injures Farmer With Ax

A man was injured on Saturday when he attempted to milk his cow. The man said he had almost filled his bucket when the cow dipped her head into the hay and came up with an ax head in her mouth. As the man stood up to leave the cow jerked her head sharply and the ax head pierced his left calf causing him to fall to the ground. The cow then picked up the ax handle and proceeded to beat him with it. The man said the cow followed him back to the house beating him and causing a fracture in his right shoulder. The man is currently in intensive care with moderate blood loss and three broken ribs, the cow is yet to be found.

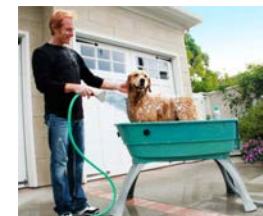
Who's got the ax?



Incremental Parsing Creates Local Ambiguities

- Incremental parsing: building structure as the words are encountered

As the man bathed the dog...



Incremental Parsing Creates Local Ambiguities

- Incremental parsing: building structure as the words are encountered

As the man bathed the dog decided to join him.

Incremental Parsing Creates Local Ambiguities

- Incremental parsing: building structure as the words are encountered

As the man bathed the dog decided to join him.



Do we really parse incrementally?

- Yes. The fact that we are sometimes misled by local ambiguities tells us that we are building syntactic structures on the fly.

Clap when you are ready for the next word

-----.

The _____.

_____ cat _____.

_____ chased _____.

_____ the _____.

_____ dog _____.

_____ down _____.

_____ the _____.

_____ street.

The cat chased the dog down the street.

(This demonstrates the "self-paced reading" paradigm.)

The -----

--- complex -----

houses

married

and

single



----- soldiers -----

----- and -----

----- their -----

----- families -----

Adj N
The **complex houses** married and single soldiers and their families
N V

Adj N
The **complex houses** married and single soldiers and their families
N V


- This is a *local ambiguity*
- If we waited until the end of the sentence to parse it, there would be no ambiguity.

- Disambiguation point
- Reading times increase when parsing error is noted

Sentences like this are called
Garden Path Sentences

Adj N
The **complex houses** married and single soldiers and their families
N V

Idiom: To be “led down the garden path” is to be deceived.



-----?

Who _____
_____?

_____ had _____
_____?

_____ the _____
_____?

_____ little _____
_____?

_____ girl _____
_____ ?

_____ expected _____
_____ ?

_____ US _____
_____ ?

_____ to _____
_____ ?

_____ sing
_____?

_____ those _____?

_____ stupid _____?

_____ French _____?

_____ songs ____?

_____ for?

Filled-gap effect

- Reading times increase at the *predicted* gap when the gap is “filled”

Who had the little girl expected us to sing those stupid French songs for?

Who had the little girl expected ____ to sing those stupid French songs?

- More evidence for “active”, predictive, incremental parsing

Filled-gap effect

- Reading times increase at the *predicted* gap when the gap is “filled”

Who had the little girl expected

- Structure is ambiguous at this point: gap could be filled by “who” or not.
- Leads to a mini garden path.
- More evidence for “active”, predictive, incremental parsing

Methods for studying sentence processing

- Self-paced reading
- Eye-tracking (during reading)
- ERPs
- Visual world paradigm

Parsing Models

- The “Garden Path” model
- Constraint-based models
- Good enough parsing

All seek to explain why one reading of an ambiguous sentence is preferred over another.

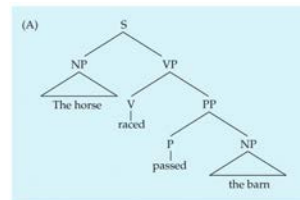
The Garden Path Model

When a structural ambiguity is encountered:

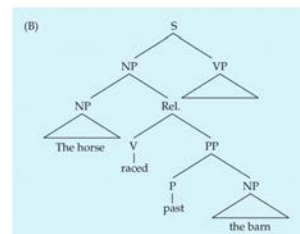
- Parser computes only one structure—*serial computation*
- The computed structure is determined by syntactic complexity alone (not frequency, semantics, or other factors)—*a modular system*
- Garden paths = wrong structure computed, which requires reanalysis

The Garden Path Model

the horse raced past the barn fell



Less complex



More complex

Constraint-Based Models

- Motivated by the observation that several factors beyond sentence structure alone affected garden paths.

1. Thematic relations
2. A verb's syntactic frame
3. Frequency
4. Context

Constraint-Based Models

1. Thematic relations

Verbs are relational

—> *kick* implies a kicker and a kickee

The horse kicked the cowboy.

—> *give* implies a giver, a gift, and a recipient

The clown gave his nose to the monkey.

Relations are often semantically constrained

—> *kick* implies an animate kicker


? The rock kicked the cowboy

Constraint-Based Models

1. Thematic relations

The pirate buried in the sand was lost forever.

Usually causes garden path




Constraint-Based Models

1. Thematic relations

The treasure buried in the sand was lost forever.

Reduces the garden path tendency
(‘treasure’ can’t bury something)



Constraint-Based Models

2. A verb's syntactic frame

Verb's differ in terms of the number of relations they specify (or "arguments" or "roles" they take)

- *sleep*: 1 role — Jake slept
- *kick*: 2 roles — Jake kicked the toy
- *give*: 3 roles — Jake gave the toy to the child

Constraint-Based Models

2. A verb's syntactic frame

Verb's also differ in terms of what kind of structures can satisfy these roles

- *sleep* = "intransitive" = does not take a direct object NP
→ *Jake slept the car
- *kick* = "transitive" = needs a direct object NP
→ *Jake kicked to school
→ *Jake kicked that he was wrong
- *give* = "ditransitive" (aka dative) = needs 2 objects NP (one can be in a PP)
→ Jake gave the child a toy
→ *Jake gave the child
- *think* = "sentential complement" = takes a whole sentence as it's object
→ Hillary thinks that Jake gave the child a toy
→ *Hillary thinks the child a toy

And many verbs fall into more than one category
I *ate* the sandwich (transitive) — I *ate* already (intransitive)

Constraint-Based Models

2. A verb's syntactic frame

Verb's also differ in terms of what kind of structures can satisfy these roles

- **This information affects how sentences are processed**

While the girl ate the chicken left

vs.

While the girl slept the chicken left

Constraint-Based Models

3. Frequency

- For verbs that fall into more than one syntactic frame category, they are often biased toward one due to the frequency of usage of that frame

Accept

George accepted the gift ← more common
George accepted that he should leave ← less common

- And for words that are ambiguous between, for example, noun and verb readings, which can lead to structural ambiguities, one reading is often more frequent.

The university plans to raise tuition was protested by students. (plan=N)
The university plans to raise tuition yet again. (plan=V)

Constraint-Based Models

3. Frequency

- The structure that gets built is typically the one that is most common.
- This is not predicted by the Garden Path model.

Constraint-Based Models

4. Context

The horse raced past the barn fell.

Constraint-Based Models

4. Context

Farmer Bill and Farmer John were racing their horses through the field. Farmer Bill rode his horse along the fence, while Farmer John raced his horse past the barn. Suddenly, the horse raced past the barn fell.

Constraint-Based Models

4. Context

Grammatical constructions are often selected during speaking for a communicative reason. E.g., what if I started my very first lecture with this statement:

- The treasure buried by the pirates was lost.

Constraint-Based Models

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Grammatical constructions are often selected during speaking for a communicative reason. E.g., what if I started my very first lecture with this statement:

- *The* treasure *buried by the pirates* was lost.

Implies shared knowledge of a specific treasure. cf. "A treasure..."

Implies shared knowledge of more than one treasure, one of which was buried by pirates.

Constraint-Based Models

4. Context

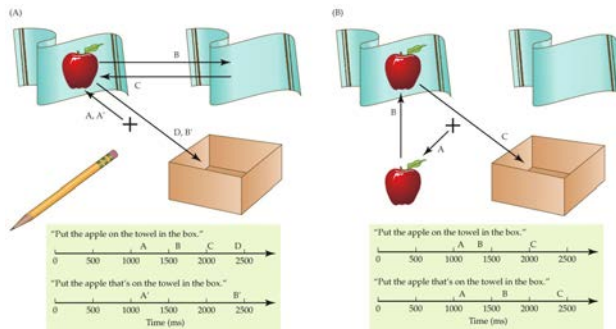
The horse [that was] raced past the barn fell.

Implies shared knowledge of more than one horse, one of which was raced past the barn.

Since these sentences are presented in isolation, there is no "other horse" in the readers mind, and therefore s/ he builds the most appropriate structure for the (lack of) context

Constraint-Based Models

4. Context



Put the apple *on the towel* in the box.

The visual context on the right "licenses" the PP modifier.

Constraint-Based Models

- Motivated by the observation that several factors beyond sentence structure alone affected garden paths.
- Propose that the parser uses all these factors to arrive that the *most likely* structure given the available information.
- Typically assume that multiple possible structures are considered in *parallel*.
- Typically assume an *interactive*, non-modular architecture.

“Good Enough” Parsing

A plane crashed on the border of the Syria and Turkey, which led to a number of political complications. For example, on question was where to bury the survivors? Do you think they should have been buried in Syria, Turkey, their country of citizenship or their region of ethnic heritage? Do you religion impacted the decision?

“Good Enough” Parsing

Dallas is the capital of what state?

“Good Enough” Parsing

Dog attacks have been on the rise in inner city LA and city leaders have demanding action. Animal control is now responding. Indeed, after a dangerous pitbull was bitten by a man, authorities seized the animal and euthanized it.

“Good Enough” Parsing

While the woman bathed the baby played with her husband .

“Good Enough” Parsing

How many animals of each type did Moses take into the ark?

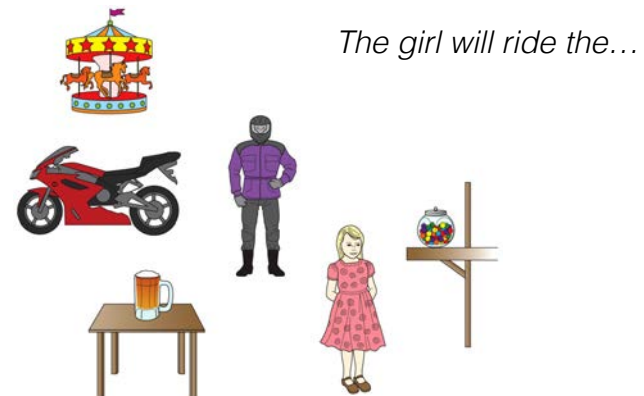
“Good Enough” Parsing

Did the woman bathe the baby?

“Good Enough” Parsing

- Several variants of “good enough” parsing
- Basic idea: we don’t necessarily analyze sentence structure (or word meaning) all that deeply. Instead we use context, etc., to get the gist and often ignore or smooth out the details.
- We use heuristic shortcuts to make inferences, not necessarily a detailed analytic process.
- **Prediction** is a central notion in this approach. We use context to predict sentence/word meaning/structure. Much of the work is done via prediction (“top down” processing) rather than input driven (“bottom up”) processing.

“Good Enough” Parsing



“Good Enough” Parsing

