Lecture 19: Serial versus Parallel parsing
Left-corner, syntax first parsing

A left-corner parser combines both H-driven and D-driven parsing by using syntactic categories and phrase structure rules to parse the sentence.

A left-corner parser predicts that the **earliest stage** of sentence processing is driven by the **syntactic category** and **phrase structure rules**.

A left-corner parser predicts that **syntactic processing** precedes **semantic processing**.

**Lexical Access** occurs around **150ms - 200ms** after the onset of the word.

The **ELAN** occurs in response to phrase structure violations **150ms - 250ms** after the onset of the critical word.

The **N400** occurs in response to semantic violations **300ms - 500ms** after the onset of the critical word.
Ambiguity
**Word-level ambiguity**

**Ambiguity:** when there is more than one meaning for a word or sentence

Perhaps the simplest form of ambiguity is word-level ambiguity:

The specialist examined the *organ* carefully.

*organ*$_1$: a musical instrument

*organ*$_2$: a functional component of a living organism (e.g., liver)

What are the two meanings of this word? How do they affect the interpretation of this sentence?
Sentence-level ambiguity

**Ambiguity**: when there is more than one meaning for a word or sentence

John saw the man with binoculars.

*meaning*\(_1\)*: John used binoculars to see the man

*meaning*\(_2\)*: There was a man with binoculars, and John saw him

**Question 1**: How can we capture the two meanings for this one sentence in the theory of sentences that we’ve built so far?

**Question 2**: How does our parser deal with the fact that this sentence could have two meanings?
Two meanings = two structures

meaning\(_1\): John used binoculars to see the man

\[
\begin{align*}
\text{VP} & \rightarrow \text{V} \quad \text{DP} \quad \text{PP} \\
\text{DP} & \rightarrow \text{D} \quad \text{N} \\
\text{PP} & \rightarrow \text{P} \quad \text{N}
\end{align*}
\]

John saw the man with binoculars.

with binoculars is part of the VP, but not part of the DP.

So it modifies the verb saw.

meaning\(_2\): John saw a man who had binoculars

\[
\begin{align*}
\text{VP} & \rightarrow \text{V} \quad \text{DP} \\
\text{DP} & \rightarrow \text{D} \quad \text{N} \quad \text{PP} \\
\text{PP} & \rightarrow \text{P} \quad \text{N}
\end{align*}
\]

John saw the man with binoculars.

with binoculars is part of the DP

So it modifies the noun the man.
Sentence-level ambiguity

Question 1: How can we capture the two meanings for this one sentence in the theory of sentences that we’ve built so far?

Answer 1: We can capture the two meanings with two distinct syntactic structures, based on different phrase structure rules:

$$VP \rightarrow V \; DP \; PP \quad \text{or} \quad VP \rightarrow V \; DP$$
$$DP \rightarrow D \; N \quad \text{or} \quad DP \rightarrow D \; N \; PP$$

Question 2: How does our parser deal with the fact that this sentence could have two meanings?

Well, if there are different phrase structure rules to choose from, then it must make a choice. So we need to figure out how it approaches those choices.
Serial or Parallel
Serial versus Parallel Parsing

Serial Parsing: The parser only entertains one syntactic structure at a time. In other words, it chooses one phrase structure rule and follows it. If that structure turns out to be incorrect based on later evidence (words encountered later), then the structure is abandoned and the sentence is re-parsed.

Parallel Parsing: The parser entertains multiple syntactic structures at a time. In other words, it follows both phrase structure rules simultaneously. As more evidence is encountered, the incorrect structures will be eliminated leaving only the correct structure.

What we need to do is figure out what the predictions of these two approaches would be, and see which one is correct. And to do that, we are going to refine the idea of ambiguity.
Global versus Local Ambiguity

**Global Ambiguity:** A sentence is globally ambiguous if the entire sentence (global is a metaphor for “all” or “full”) has two structures.

John saw the man with binoculars.

**Local Ambiguity:** A sentence is locally ambiguous if there is a point in the sentence where two structures are possible, but the full sentence only has one possible structure.

While the men hunted the deer ran through the woods

- VP → V
- or
- VP → V DP

This is where you know it must be the first option, otherwise the sentence would be ungrammatical.
Local Ambiguity is the key!

**Serial Parsing:** The parser only entertains one syntactic structure at a time. In other words, it chooses one phrase structure rule and follows it. If that structure turns out to be incorrect based on later evidence (words encountered later), then the structure is abandoned and the sentence is re-parsed.

**Parallel Parsing:** The parser entertains multiple syntactic structures at a time. In other words, it follows both phrase structure rules simultaneously. As more evidence is encountered, the incorrect structures will be eliminated leaving only the correct structure.

Global ambiguity can’t help us tease these two approaches apart because it doesn’t contain any information that will lead the parser to correct an incorrect parse -- because both parses are correct!

Local ambiguity does provide information later in the sentence that will lead the parser to correct an incorrect parse -- because only one parse is correct!
Prediction 1: illusory ungrammaticality

Serial Parsing: The parser only entertains one syntactic structure at a time.

Parallel Parsing: The parser entertains multiple syntactic structures at a time.

Prediction 1: If the parser is serial, then we should be able to find locally ambiguous sentences that appear to be ungrammatical because the first parse is the incorrect one.

If the parser is parallel, then all sentences with at least one grammatical parse should appear to be grammatical because all parses are considered simultaneously, so there is always at least one grammatical parse under consideration.
Garden Path Sentences

The horse raced past the barn fell

The horse ridden past the barn fell

The ungrammatical structure

The grammatical structure
Prediction 1: illusory ungrammaticality

**Serial Parsing:** The parser only entertains *one syntactic structure* at a time.

**Parallel Parsing:** The parser entertains *multiple syntactic structures* at a time.

**Prediction 1:** If the parser is *serial*, then we should be able to find locally ambiguous sentences that appear to be ungrammatical because the first parse is the incorrect one.

The existence of “garden path sentences” suggests that the parser is serial, because these sentences do appear to be ungrammatical after the first parse:

*The horse raced past the barn fell.*

*The boat floated down the river sank.*
Prediction 2: Extra processing difficulty

**Serial Parsing:** The parser only entertains **one syntactic structure** at a time.

**Parallel Parsing:** The parser entertains **multiple syntactic structures** at a time.

**Prediction 2:** If the parser is **serial**, then there should be no difference between ambiguous and unambiguous sentences in terms of processing difficulty because they both require the construction of only one structure.

If the parser is **parallel**, then ambiguous sentences should be more difficult to process than unambiguous sentences, because ambiguous sentences require the construction of multiple structures, whereas unambiguous sentences only require the construction of a single structure.
Measuring processing difficulty with reading times

Self-paced reading is a task in which the subject reads a sentence one word at a time. The subject controls the rate of presentation of each word by pressing a button when they want to see the next word. By measuring the amount of time between button presses, we get a measure of how long it takes to read each word. 

more time = more difficulty

Let’s say this is the sentence that you want the subject to read:

This is an example sentence.

What they would see on their screen is this:

---- -- -- ------- --------.

Then they would press a button every time they want to see a word:

This is an example sentence.

And the computer measures the time between button presses
We can also do it with Eye Tracking

**Eye tracking** is a method in which the subject is asked to read sentences on a screen while a tiny camera records 1) where the subject’s eye is looking, and 2) how long the eye was looking there.

In eye tracking, the entire sentence is on the screen at once, so the subject doesn’t have to push any buttons:

This is an example sentence.

Instead, the camera tells us how long the person looks at each word by measuring the amount of time that the eye looks at each position!

**more time = more difficulty**
Does ambiguity lead to more difficulty?

A local ambiguity:

The psychology students found the book was written poorly in the book store.

No ambiguity:

The psychology students found that the book was written poorly.

It must be the subject of an embedded sentence because that introduces embedded sentences!
Does ambiguity lead to more difficulty?

**A local ambiguity:**

The psychology students found the book was written poorly.

**No ambiguity:**

The psychology students found that the book was written poorly.

The two theories predict different results for a comparison of the reading time at the book:
Does ambiguity lead to more difficulty?

A local ambiguity:

The psychology students found the book was written poorly.

No ambiguity:

The psychology students found that the book was written poorly.

The two theories predict different results for a comparison of the reading time at the book:

There is no difference in reading times for local ambiguities, which suggests that the parser only entertains one structure at a time.
The parser appears to be serial

**Serial Parsing:** The parser only entertains one syntactic structure at a time.

**Prediction 1:** If the parser is serial, then we should be able to find locally ambiguous sentences that appear to be ungrammatical because the first parse is the incorrect one.

**Prediction 2:** If the parser is serial, then there should be no difference between ambiguous and unambiguous sentences in terms of processing difficulty because they both require the construction of only one structure.

Both of the predictions made by a serial parser appear to be empirically true, suggesting that the parser does not entertain multiple structures when faced with local ambiguity.
Lexical access is parallel, Sentence processing is serial

Recall that the process of **lexical access** compares multiple candidates simultaneously, using evidence that unfolds over time to increase the activation of the correct lexeme:

This is **not** the way that sentence processing works. The parser chooses a **single candidate structure**, and pursues that structure until it finds evidence that the choice was mistaken.

The horse raced past the barn **fell**.

The boat floated down the river **sank**.