Syntax

- The study of how words are combined into sentences.
  - How to characterize the native speaker’s knowledge of what constitutes of well-formed, grammatical, expression in their language?

- Grammaticality ≠ Whether the sentence makes sense
  - Well-formed but nonsensical:
    - Colorless green ideas sleep furiously.
  - Ill-formed but perfectly interpretable:
    - I put the sweater on.
    - I put on the sweater
    - I put it on.
    - *I put on it.
How to study the internal structure of sentences?

- Core observation:
  - The order of words in sentences can be permuted in various ways.
  - But the grammar always treats certain combinations of words as units.
  - These units are called *constituents*.
  - The native speaker’s knowledge of how constituents combine with each other is described in *phrase structure rules*. 
Discovering constituency

*The boys ate burgers and fries.*

What did the boys eat _? Burgers and fries.
*What did the boys eat _ and fries? Burgers
Burgers and fries the boys ate _.
*Burgers and the boys ate _ fries.
*Burgers the boys ate _ and fries. (bad with a flat intonation)
Aspects of syntax

- **Syntactic realization of event participants** (who did what to whom?)
  - *The mouse chased the cat.*
  - *The cat was chased by the mouse.*

- **Agreement**
  - *These mice are cat-chasers.*
  - *These mice is cat-chasers.*
  - *These mouse are cat-chasers.*

- **Case**
  - I saw him. (accusative object)
  - I saw he*.

- **Displacement**
  - the senator who the reporter attacked _ quit.
Properties of *English* syntax

- All sentences must have a subject.
  - *Is raining*.

- Question words generally move to the front of the sentence.
  - *Who did you see ___?*
    - Some exceptions:
      - You did *what*?? (echo-question)
      - Who invited who to dinner? (multiple wh)

- Word order: Subject-Verb-Object.
  - *The mouse chased the cat.*
In order to find syntax in the brain, what should we look for?

- What are the real-time processes that serve to build syntactic structures?
  
  **Minimally:**
  - Composition.
  - Establishing dependencies between the surface position in which a constituent occurs and the site where it is interpreted.

  Object relative: **the senator** who the reporter attacked _ quit.
  Subject relative:**the senator** who _ attacked the reporter quit.
In order to find syntax in the brain, what should we look for?

- Case and agreement

  1. John saw him. vs.
  2. *John saw he. (case violation)
  3. Look how interesting this paper is. vs.
  4. *Look how interesting these papers is. (agreement violation)
Typical contrasts of functional imaging studies

- Words vs. sentences.
  - Goal: to find neural correlates of composition
  - A gross contrast, varies *everything* that distinguishes words from sentences.

- Hard vs. easy syntax.
  - Goal is to control for semantics while manipulating the difficulty of syntactic processing.
  - Danger/issue: hard syntax may engage different processing mechanisms from easy syntax.
The most heated debate:

- The role of Broca’s area in syntactic processing.
- Commonly thought of as the “syntax area” of the brain, partly based on aphasiology.
- But what does the evidence actually look like?
Stromswold et al. (1996): Broca’s area lights up for complex syntax

- A PET study contrasting center-embedded and right-branching structures.
- Center-embedded:
  The juice that the child spilled stained the rug.
- Right branching:
  The child spilled the juice that stained the rug.
A PET study contrasting center-embedded and right-branching structures.

Center-embedded:
*The juice that the child spilled ___ stained the rug.*

Right branching:
*The child spilled the juice that ___ stained the rug.*

Lots of psycholinguistic evidence that center-embedded structures are much harder to comprehend than right-branching structures.
Complex vs. simple sentences

Stromswold et al., 1996:

Center-embedded:

Center-embedded construction: The juice that the child spilled __ stained the rug

Right branching

Right branching construction: The child spilled the juice that __ stained the rug

- Blocked design.
Complex vs. simple sentences

Stromswold et al., 1996: Broca’s area

Fig. 2. Statistical parameter map (omnibus subtraction image) showing increased rCBF in the pars opercularis of the left hemisphere during judgments of semantic plausibility of sentences with center-embedded compared to right-branching relative clauses (condition 1 — condition 2).
PET Studies of Syntactic Processing with Auditory Sentence Presentation

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OBJECT CLEFT: It was the *juice* that the child enjoyed _ VS. 
SUBJECT CLEFT: It was the *child* that _ enjoyed the *juice*.

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**FIG. 1.** SPM image of the brain showing increased blood flow in Broca’s area when subjects processed auditorily presented cleft object compared to cleft subject sentences.
Broca’s activation due to syntax or…

- Increased working memory demands?
Localizing components of a complex task: sentence processing and working memory

Laurie A. Stowe, Cees A. J. Broere, Anne M. J. Paans, Albertus A. Wijers, Gijsbertus Mulder, Wim Vaalburg and Frans Zwarts

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Stowe et al.

VISUAL

(1) Syntactically simple sentences.

(2) Syntactically complex sentences

- containing embedded clauses
  - The boy who the doctor visited had contracted pneumonia.
- or complex listlike noun modifications
  - the long lacy white dress

(3) Ambiguous sentences contained ambiguities in which a word could be combined with the syntactic context in two ways

- e.g. The desert trains . . . usually are late (Noun)
  . . . its inhabitants to conserve their resources (Verb)
- There is evidence that in this sort of ambiguity both structures are constructed.
- The sentences remained ambiguous for at least four words, so that lexical information for construction of the meaning must be maintained for some time and two sets of phrase structures must also be maintained.
Effect of complexity: left posterior middle and superior temporal gyrus.

Stowe et al.
Stowe et al.

- Effect of ambiguity/working memory: Broca’s area & left insula.
Towards mechanism: Verbal working memory and articulatory rehearsal

- The decay of phonological information can be prevented by continuously articulating it subvocally (Baddeley’s “phonological loop”).

- Hypothesis:
  - Articulatory rehearsal aids the comprehension of syntactically complex sentences.
  - Broca’s area (as a production area) houses the articulatory rehearsal mechanism.
Rogalsky, Matchin & Hickok (2008): Does a secondary task of articulatory rehearsal suppress a complexity effect in Broca’s area?

**Behavioral data:** only object relatives significantly worsened by articulatory rehearsal

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**Effect of Concurrent Task on Sentence Comprehension**

- **Object relative**
- **Subject relative**
- **Passive**
- **Active**

Articulation vs. finger-tapping

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“Ba da ga da...ba da ga da”

“The man that the boy pushes is wearing a red shirt.”
Rogalsky, Matchin & Hickok (2008):
Does a secondary task of articulatory rehearsal suppress a complexity effect in Broca’s area?

- fMRI study: participants judge subject and object relatives for plausibility.
  - Object Relative: The money that the robber stole was in the bank vault.
  - Subject Relative: The robber that stole the money was in the bank vault.
  - Object Relative: #The robber that the money stole was in the bank vault.
  - Subject Relative: #The money that stole the robber was in the bank vault.
Rogalsky, Matchin & Hickok (2008): Does a secondary task of articulatory rehearsal suppress a complexity effect in Broca’s area?

Original Stromswold result:

- Articulatory rehearsal elevates the activation level of the subject relatives, such as that no OR vs. SR effect is observed. Under this secondary task, Broca’s activity is saturated.
- Evidence for articulatory rehearsal as a possible source of the syntactic “complexity” effect in Broca’s region.
Broca’s activation linked

- Complexity
- Working memory

Does Broca’s area “light up” for syntactic composition more generally?

- The hypothesis that it is the “syntax area” of the brain predicts that it should.
Sentences vs. word lists

NeuroReport 9, 2995–2999 (1998)

Localizing components of a complex task: sentence processing and working memory

Laurie A. Stowe, Cees A. J. Broere, Anne M. J. Paans, Albertus A. Wijers, Gijsbertus Mulder, Wim Vaalburg and Frans Zwarts

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Stimuli (visual):
Word lists (containing both open class and closed class items) vs.
sentences
Sentences vs. word lists

- Bilateral anterior temporal lobe activation (superior and middle temporal gyri).
Sentences vs. word lists

- Reading sentences - reading words activates left anterior temporal regions, not Broca’s area.
Sentences vs. word lists

Brain and Language 74, 289–300 (2000)

RAPID COMMUNICATION

Auditory Language Comprehension: An Event-Related fMRI Study on the Processing of Syntactic and Lexical Information

Angela D. Friederici, Martin Meyer, and D. Yves von Cramon

Max Planck Institute of Cognitive Neuroscience, Leipzig, Germany
## Sentences vs. word lists

<table>
<thead>
<tr>
<th></th>
<th>Semantics+</th>
<th>Semantics-</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The hungry cat chased the fast mouse.</td>
<td>The mumpfy folofel fonged the apole trecon.</td>
</tr>
<tr>
<td></td>
<td>The cook silent cat velocity yet honor.</td>
<td>The norp burch orlont kinker deftey glaunch legery.</td>
</tr>
</tbody>
</table>
Sentences vs. word lists

Normal speech

Real-word lists

Syntactic prose

Pseudoword list
Main effect of syntax in planum polare (anterior STG)

Normal speech

Real-word lists

Syntactic prose

Pseudoword list
Sentences vs. word lists
Sentences vs. words

- Sentences activate anterior parts of the temporal lobe either only in the LH or bilaterally.

  - Some evidence that precise localization may be modality dependent.

- Broca’s area does not light up for easy syntax

  - Thus BA not a likely locus of composition.
What exactly is manipulated in the sentence vs. word list contrast?

Factors other than the presence of syntax that’s varied in by +/-syntax contrast
- Tense
- Interpretation of event structure (e.g., we know the folofel is the agent of fonging the trecon)
- Etc..

This contrast is too gross for diagnosing basic composition.
Studying minimal phrases (Bemis & Pylkkänen, 2011)

- **Aim:** to vary the presence of composition in a maximally controlled way.
- **Composition task:** does the picture match the words?
- **List task:** does the picture match either of the preceding words?
Studying minimal phrases (Bemis & Pylkkänen, 2011)

- Just a single step of composition affects activity in the left anterior temporal lobe.
- No effects in Broca’s area.
Summary

- Broca’s area is still perhaps the brain region most strongly associated with syntax by the scientific community at large – yet the evidence for its participation in basic combinatory processes is thin at best.
- The left anterior temporal lobe our best current candidate for a region computing basic composition.