We know quite a lot about the neural bases of the retrieval operations but very little about how the brain performs linguistic composition.

In particular, we know basically nothing about the neural bases of the **semantic combinatory operations**.

• Why?
The N400 violation paradigm

• The majority paradigm in the cognitive neuroscience of sentence-level semantics does not derive from, or relate to formal models of linguistic representation.

• Consequently, there does not exist body of research on the neural bases of semantic composition, as that operation is defined in linguistics.

• Instead, we have two (soon three) decades of research on so-called “semantic” violations.

  He spread the warm bread with socks. ← N400 ERP
  He spread the warm bread with butter.

• In terms of linguistic theory, these expressions do not violate the possibility of semantic composition, but rather, the plausibility of the resulting representation.
Well-formed but implausible meaning
• What are the neural bases of semantic composition?
  • This operation not necessarily affected by plausibility manipulations.
What kinds of mental objects are the meanings of sentences?

- What do you know when you know the meaning of a sentence?
- Standard view:
  - Knowing the meaning of a sentence =
    - Knowing what the world would need to be like in order for the sentence to be true =
    - Knowing the “truth conditions” of the sentence

- Example:
  - Knowing the meaning of *It is raining* is to know that this sentence is true if and only if
    - there is an event $e$ &
    - $e$ is a raining &
    - $e$ is in progress at a time $t$ &
    - $t$ includes the time of utterance
Sentence meanings

- In order to evaluate whether *It is raining* is in fact true, you consult your mental model of the world.

- If it includes a currently ongoing raining event, you judge the sentence to be true.
Compositionality

- Given that we can produce and understand sentences we’ve never encountered before, sentence meanings must be composed from the meanings their constituents in some *fairly transparent way*.

- Frege’s principle of compositionality:
  - The meaning of an expression is a function of the meanings of its parts and the way they are syntactically combined.
An informal illustration of a compositional mini-grammar
Natural language ontology

- We evaluate truth and falsity against a mental model of the world.

- So linguistic expressions will be descriptions of parts of that mental model.

- Every semantic theory needs to make assumptions about what kinds of things linguistic expressions are about.

- Ontology = a branch of metaphysics that studies what entities and what types of entities exist.
Natural language ontology

For our mini-grammar, let’s adopt the following assumption:

Our mental models of the world make a distinction between *individuals* such as *you, me, this computer, Washington Square Park*

and *eventualities* such as *laughing, loving, knowing, fighting* and so forth.

Most contemporary models of natural language meaning assume an ontology that includes at least eventualities (actions and happenings) and individuals (things).
Nouns, adjectives and verbs as basic building blocks of our compositional mini-grammar

- **Nouns & adjectives**: properties of individuals.
  - **cat**: the property of being a cat.
  - **happy**: the property of being happy.
  - **happy cat**: the property of being happy and a cat.
    - ‘happy cat’ is an example of **intersective modification**: a phrase such as ‘the happy cat’ picks out an individual that is both happy and a cat.
    - Not all modification is intersective: for example, ‘the alleged murderer’ does not pick out an individual that is alleged and a murderer.

- **Verbs**: properties of events (or states).
  - **laugh**: introduces an event into the discourse and asserts that the event is a laughing event.
  - **love**: introduces a state into the discourse and asserts that the state is a state of loving.
Predicates and arguments

- Something in our grammar needs to capture the fact that verbs cannot form sentences on their own (except in imperatives).
  - John threw the ball yesterday.
  - *Threw yesterday.
  - *John threw yesterday.
  - *Threw the ball yesterday.

- *Throw* is a *predicate* that takes two individuals as its *arguments*: an Agent (instigator of the action) and a Theme (affected participant).

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Agent & Theme = "thematic roles"
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- Capturing the incompleteness of *throw* without its arguments:
  It’s meaning involves two variables which must be substituted by descriptions of individuals.
A very informal illustration of how we might put together a sentence meaning with these assumptions ignoring many aspects of sentence meaning (such as tense, for example).
there exists an event such that it is a throwing event and it has John as its Agent and the unique (contextually determined) individual such that it has the property of being heavy and a rock as its Theme.
Cognitive neuroscience of semantic interpretation

- At the sentence level, still a heavily understudied domain.

- Hemodynamic research almost completely focused on the lexical level.
  - Further, experimental designs usually involve manipulation of metalinguistic judgments, such as evaluating the abstractness or concreteness of a target word (semantic task) vs. judging it for a phonological characteristic (phonological task).

- Electrophysiological research almost completely focused on the N400.
  - In a violation paradigm, a semantically unexpected word elicits an increased negativity peaking at around 400ms, as compared to a semantically congruous baseline.
N400 (Kutas & Hillyard)

He spread the warm bread with ___
Semantic anomaly, but not visual deviance (i.e., the capitalization), causes an N400.

Two ways to explain this effect:

i. Bread primes butter more than socks.

ii. Socks is harder to integrate into the sentence than bread.
Hypotheses about the N400

■ H1: Semantic integration
  □ The amplitude of the N400 reflects the effort of integrating the word into the current context.
  □ What is meant by “semantic integration” is not usually sharply defined in the ERP literature. Refers to a general notion of fitting meanings together.
  □ Also, the ERP literature does not usually explain why semantic expectedness and/or relatedness should affect semantic integration. It is not obvious why this should be the case.
  □ Linguistic theory would hold that once an unexpected/unrelated item has been accessed, composing it with the previous context should be just as easy as composing a quicker-to-access element.

■ H2: Lexical access
  □ The amplitude of the N400 reflects the ease of accessing the word.
  □ The ease of accessing the word depends on all the factors that affect lexical access
    ■ Priming by previous words.
    ■ Frequency.
    ■ The cloze probability of the word.
      □ Cloze probability: the percentage of individuals that continue a sentence fragment with that item in an offline sentence completion task.
Effect of lexical relatedness while cloze probability is constant (Federmeier & Kutas, 1999)

“They wanted to make the hotel look more like a tropical resort. So along the driveway they planted rows of _______ .”

- An N400 effect even though semantic expectancy is kept constant: *tulips* and *pines* are both unexpected. Lower N400 amplitude for pines because it’s a tree, like the predicted the category.
Effect of cloze probability while lexical relatedness is held constant (DeLong et al., 2005)

The day was breezy so the boy went outside to fly an airplane. The day was breezy so the boy went outside to fly a kite.

- Larger N400 for ‘an’ than for ‘a.’
  - These two elements mean the same thing, so their semantic relatedness or fit to the context is not varied.
  - Only their cloze probability differs:
    ‘kite’ is predicted and thus the determiner ‘a’ is predicted (since kite starts with a consonant). The N400 on ‘an’ reflects the pre-activation of ‘kite’.
N400 effects do not require a sentential context

- Low frequency words elicit larger N400s than high frequency words in lexical decision (Smith & Halgren, 1987).
  - In a sentential context this interacts with position: frequency effect only obtained early on in the sentence (Van Petten & Kutas, 1990).

- Semantically related targets (doctor - nurse) elicit smaller N400s than semantically unrelated targets outside a sentential context.

- Phonologically related targets (e.g.: fame - lame) elicit smaller N400s than phonologically unrelated targets outside a sentential context (Praamstra, Meyer, Levelt, 1994; Praamstra, Stegeman, 1993; Radeau et al., 1998).
... or even conscious access to the prime

- Proponents of the integration view have typically argued that N400 effects in priming paradigms are due to conscious matching of the target to the prime.
  - So “integration” here would no longer mean anything like semantic composition.

- However, semantic priming effects in the N400 have been reported even in masked priming, where the prime is not consciously perceived (e.g., Kiefer, 2002).
  - Here one cannot be “integrating” the target to the prime, as the prime hasn’t even been consciously perceived.
Relationship between the N400s in sentences vs. in word pairs?

- Topographically indistinguishable (Lau, Almeida, et al., 2009).
  - Used MEG, to gain better spatial resolution.
N400 interim summary

- There are several types of data that effectively rule out an integration view of the N400.

- However, this hypothesis continues to have a life in the field…