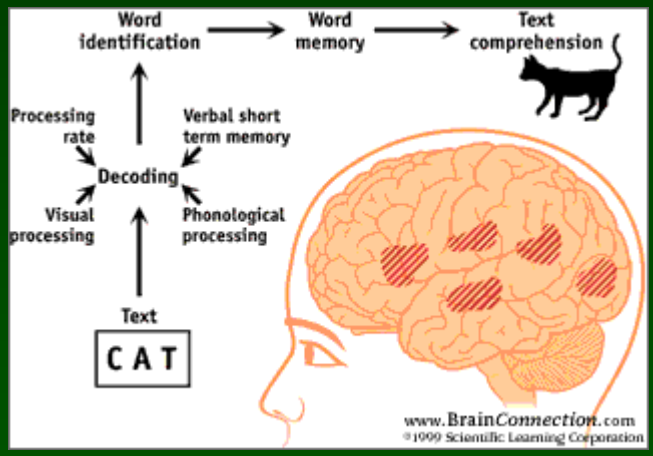
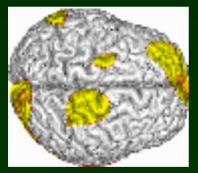
Selected topics in cognitive neuroscience & biomodeling

L13. Language



Włodzisław Duch
Neurocognitive Laboratory & Dept. of Informatics
Nicolaus Copernicus University, Poland
Google: Wlodek Duch

What it will be about



1. How are the words and concepts represented in the brain?
2. Model of speech and reading.
3. Language impairments.
4. Gestalt of sentences
5. Advanced models of meaning.
6.

Oct. 6, most important date in the XXI century?

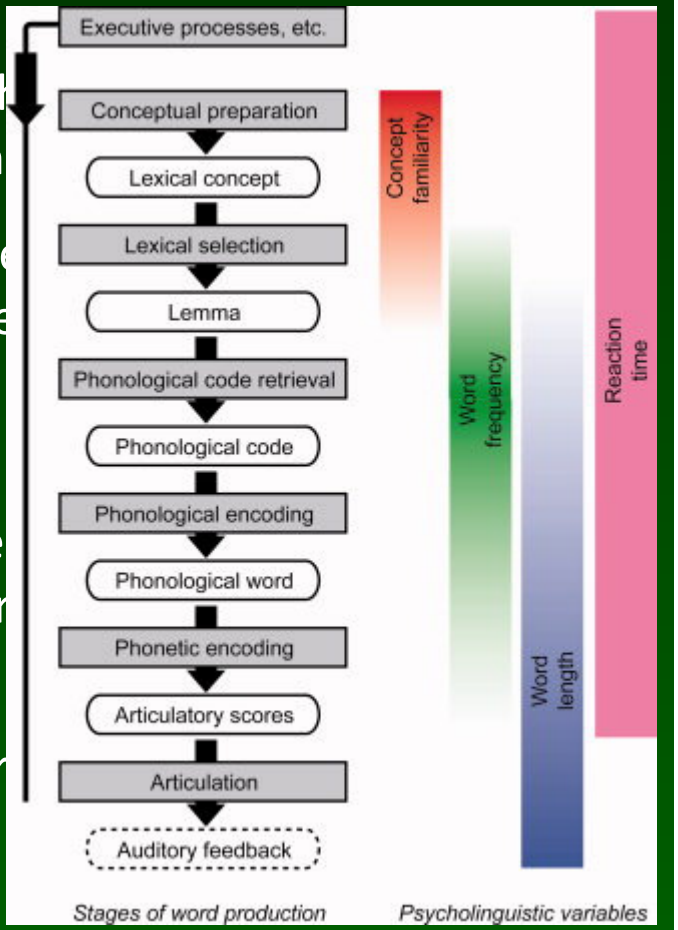
Symbolic representations in the brain

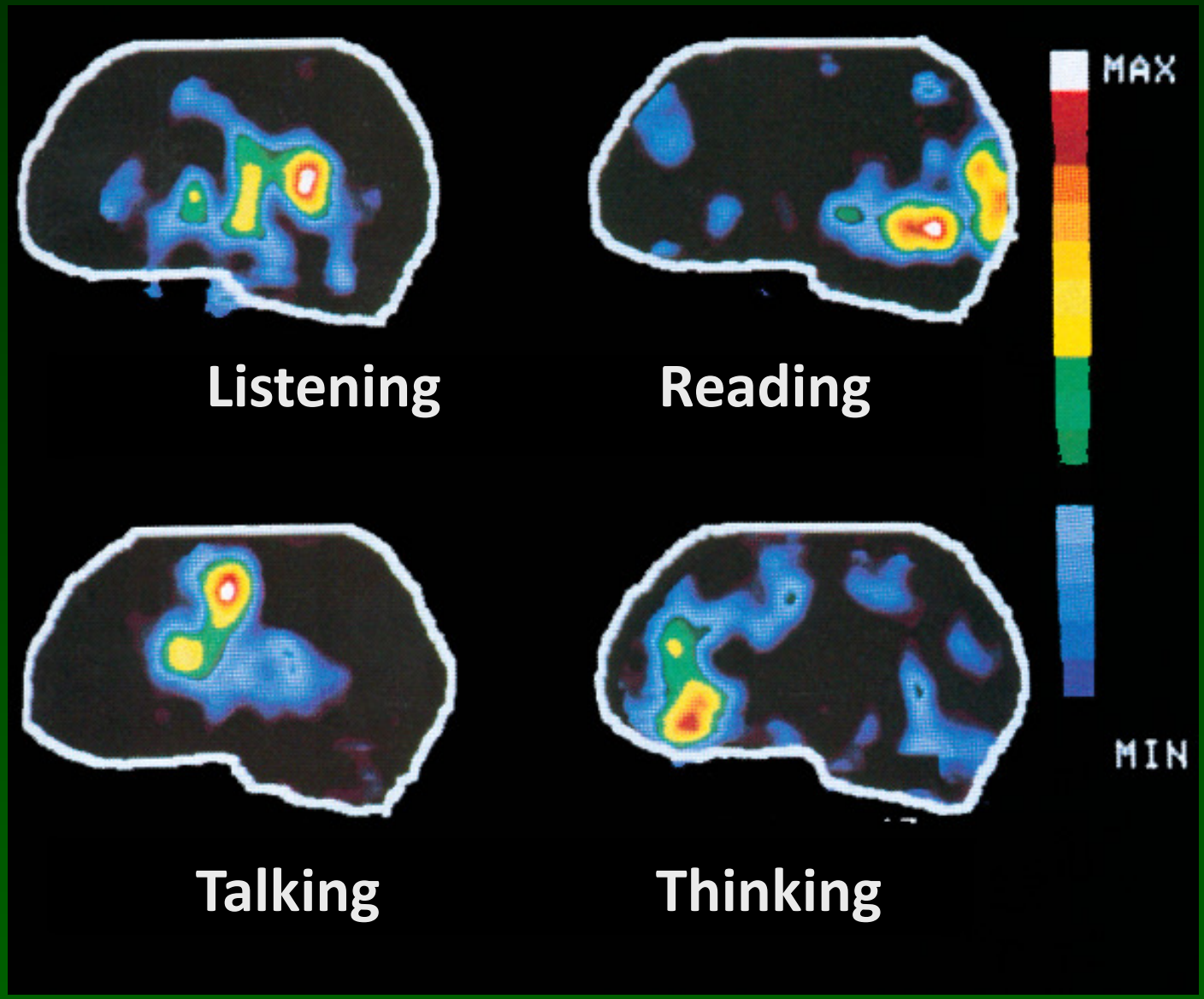
Mechanisms must be the same, all that we have in th
neurons and biochemical processes, only outputs an

Understanding speech requires many processing leve
(elementary sounds, phonemes), phonology (syllable
concepts (words), understanding concepts, phrases,
stories.

Reading requires visual perception of glyphs, graphe
creating information in the brain that may then inter
stream.

Understanding language requires associative memor
spreads neural activation to all brain areas.





All these areas are active, this is only contrast showing only specific activity.

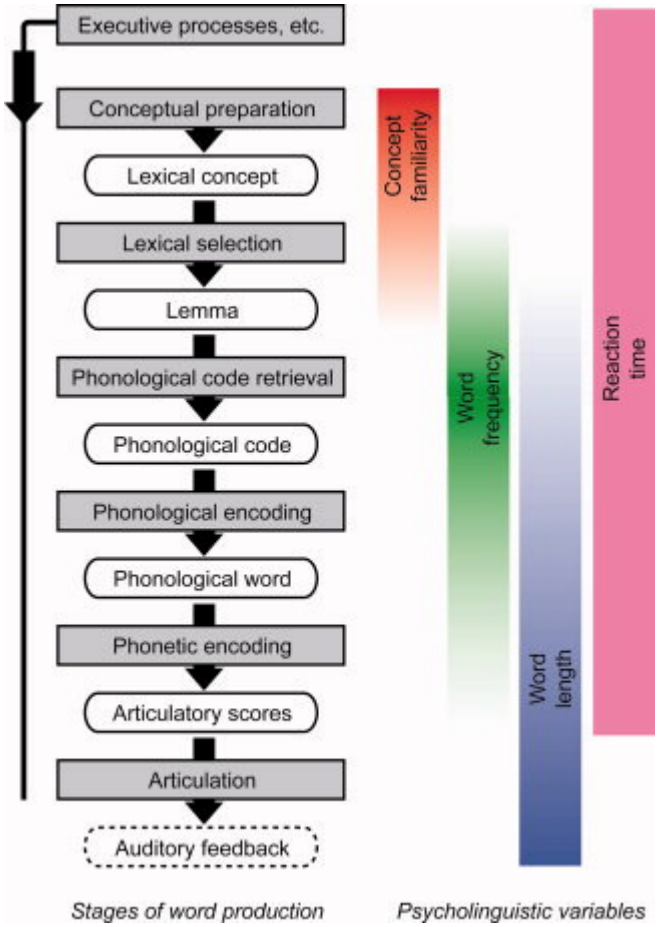
Symbolic representations in the brain

Mechanisms must be the same, all that we have in the brain are spiking neurons and biochemical processes, only outputs and inputs may differ.

Understanding speech requires many processing levels: phonetic encoding (elementary sounds, phonemes), phonology (syllables), selecting lexical concepts (words), understanding concepts, phrases, sentences, episodes, stories.

Reading requires visual perception of glyphs, graphemes, word-forms, creating information in the brain that may then internally enter the auditory stream.

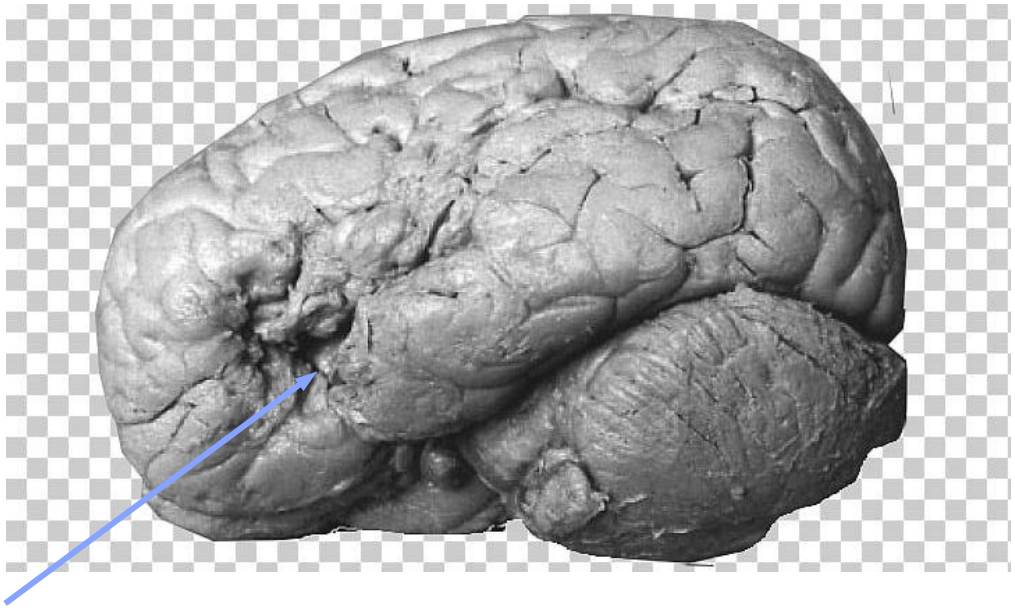
Understanding language requires associative memory and this process spreads neural activation to all brain areas.



Broca's area

Pierre Paul Broca (*1824-1880)* discovered the region in the brain responsible for speech production.

In 1861 he studied a patient with epilepsy who lost ability to speak.



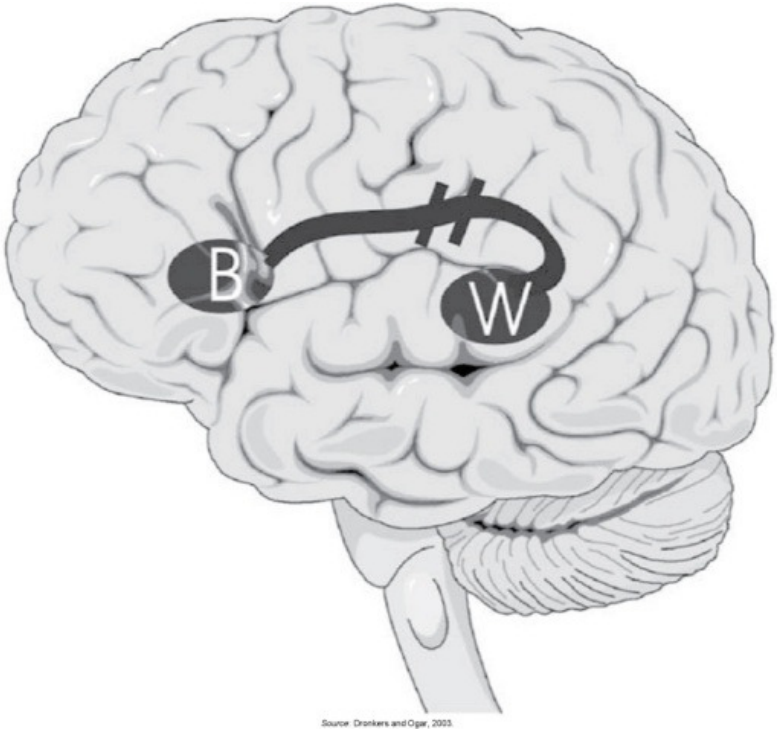
On the patient's death Broca performed autopsy and found damage to the posterior part of the third frontal convolution in the left hemisphere. He associated it to the production of speech.

Much of what we know about brain was first discovered by studying various brain lesions: mechanical, strokes, cancer tumors.

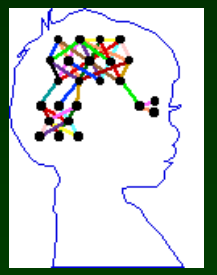
Wernicke's area

- Wernicke's area (W), in the left upper part of the temporal lobe, is the most important area for language understanding.
- Carl Wernicke (1848-1905) published his finding shortly after Broca's work.
- The two areas are connected with arcuate fasciculus (AF), a bundle of axons.

  Speech comprehension => production.
- Damage (in or near this region) leads to:
  - Broca's area (B): Expressive aphasia.
  - Wernicke's area (W): Receptive aphasia.
  - AF fibers between B & W: disconnection or conduction aphasia (repetition).



Words in the brain



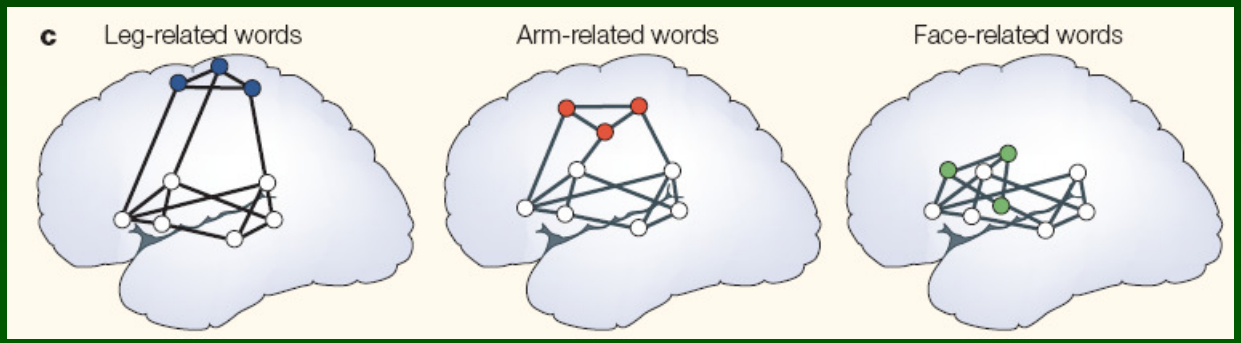
Psycholinguistic experiments show that most likely categorical, phonological representations are used, not the acoustic input.

Acoustic signal => phoneme => words => semantic concepts.

Phonological processing precedes semantic by 90 ms (from N200 ERPs).

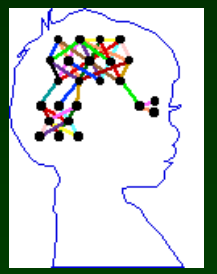
F. Pulvermuller (2003) The Neuroscience of Language. On Brain Circuits of Words and Serial Order. Cambridge University Press.

Action-perception networks inferred from ERP and fMRI



Left hemisphere: precise representations of symbols, including phonological components; right hemisphere? Sees clusters of concepts.

Words in the brain



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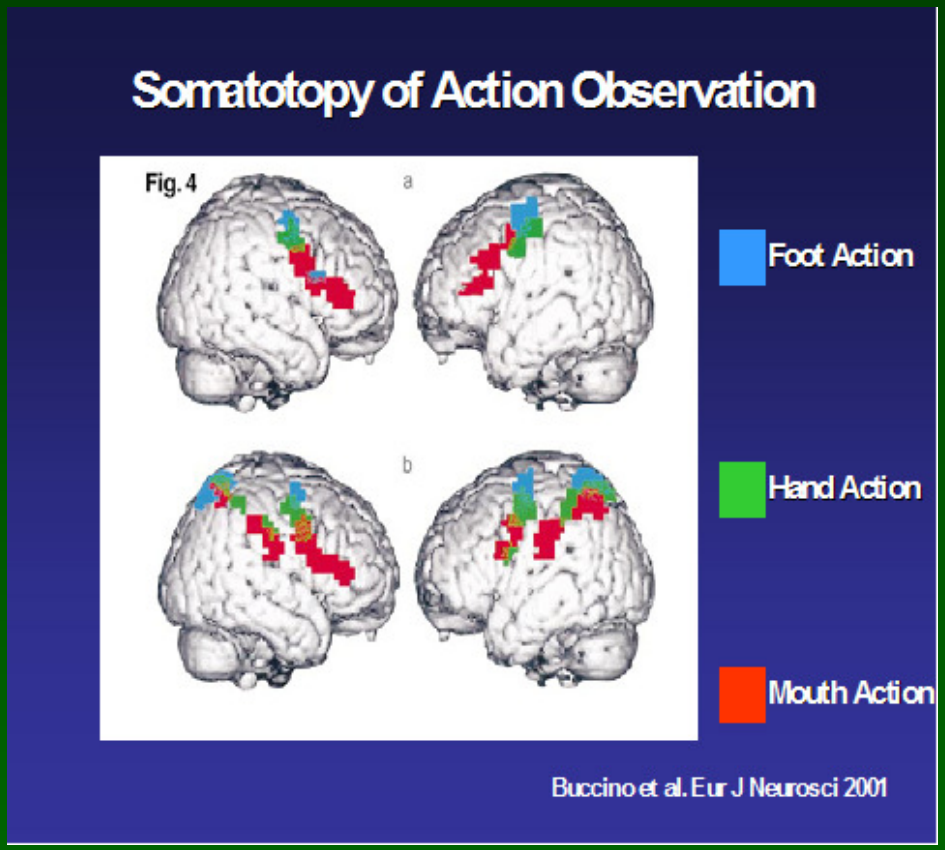
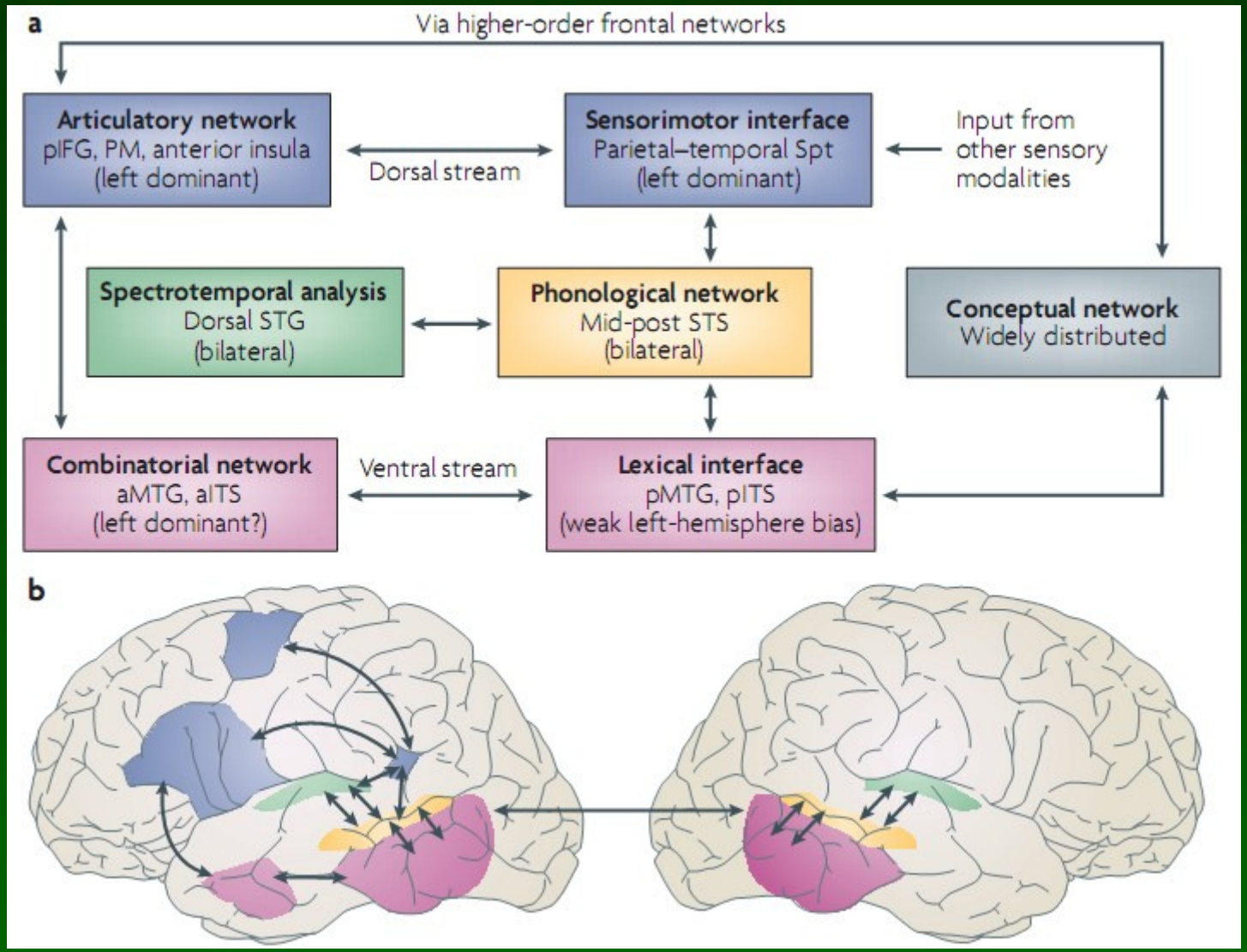


Anatomy of language



Neuroimaging words

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- Clear differences between fMRI brain activity when people read, think or view about different nouns.
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- Although individual variance is significant similar activations are found in brains of different people, a classifier may still be trained on pooled data.
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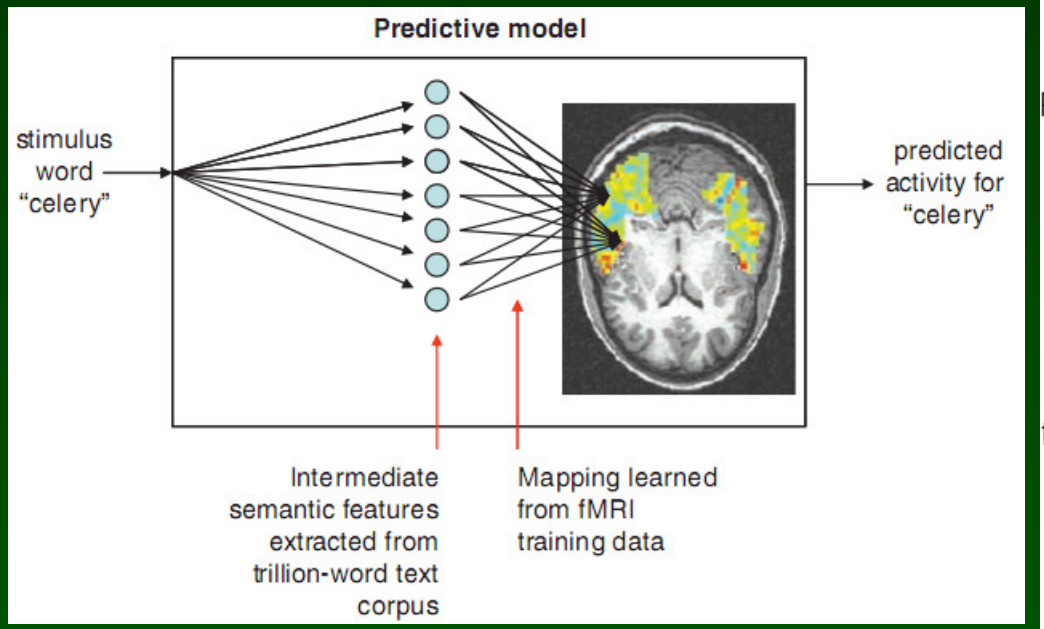
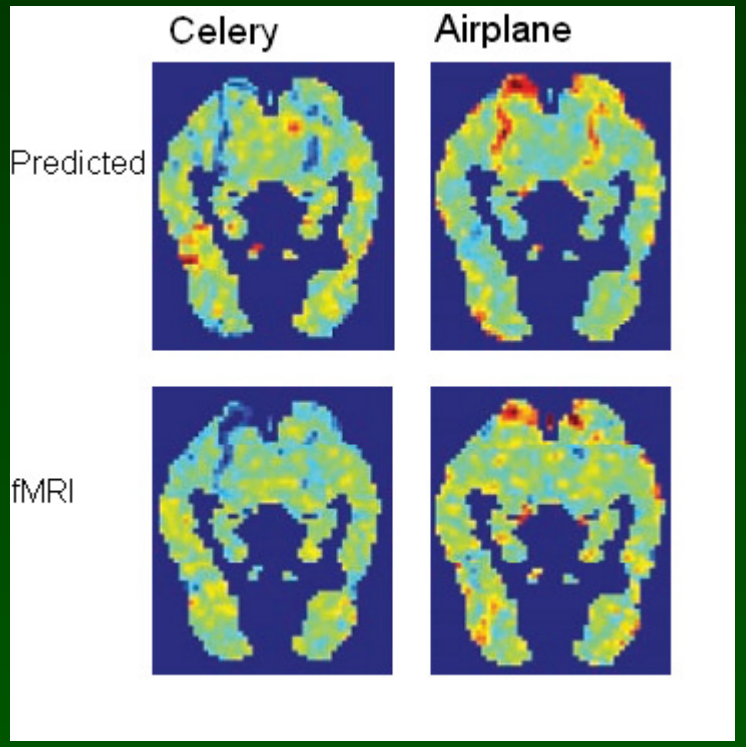




Fro each word S create semantic vector V(S), calculating correlation of this word with 25 selected features, in a big lexical corpus (10^{12}).

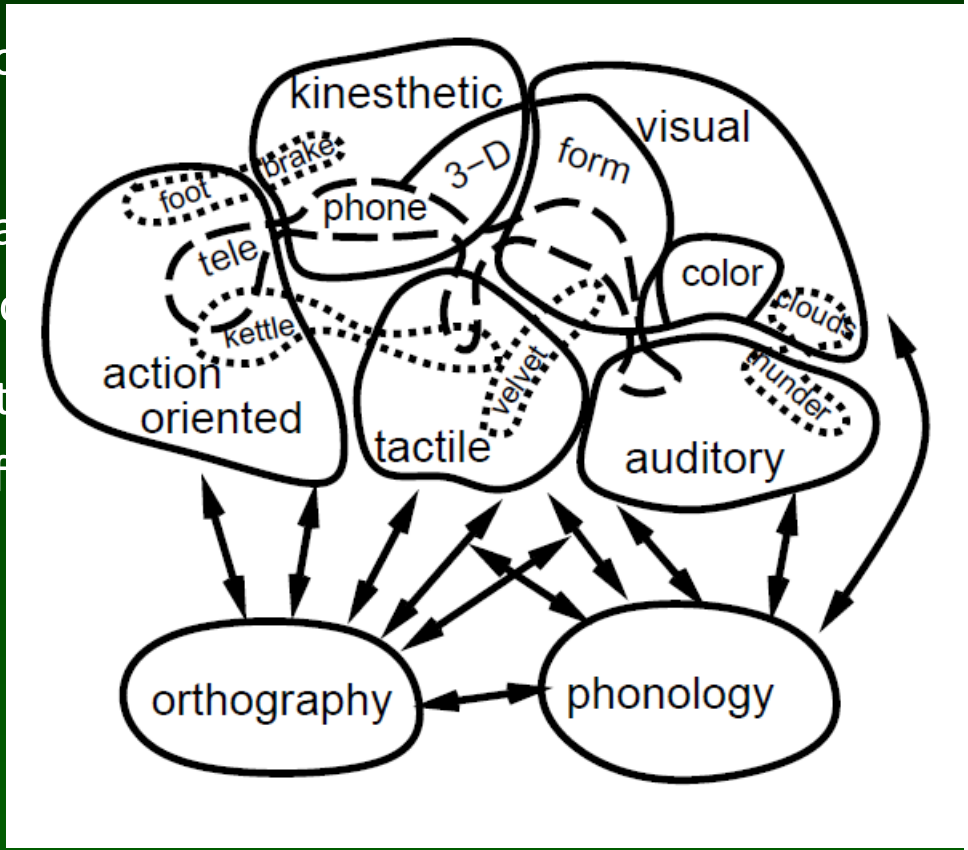
Map V(S) vectors to fMRI scans (~30.000 voxels), take 58 for training and predict additional 2 as test. Average accuracy is 77%, errors are reasonable.

Word semantics

The meaning of concepts is a result of c
many brain areas.

Simplest model: strong Hebbian correla
strong correlations between elements

Latent Semantic Analysis (LSA) is in fact
showing most common combination of
documents; this can be modeled using
PCA.



Nicole Speer et al.

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Meaning of concepts is always slightly different, depending on the context, but still may be clustered into relatively small number of distinct meanings.

Meaning = distribution of brain activity, predisposing the brain to make associations and actions.

A

Clause	Cause	Character	Goal	Object	Space	Time
...[Mrs. Birch] went through the front door into the kitchen.	●				●	
Mr. Birch came in	●	●			●	
and, after a friendly greeting,	●					●
chatted with her for a minute or so.	●					●
Mrs. Birch needed to awaken Raymond.		●				
Mrs. Birch stepped into Raymond's bedroom,			●		●	
pulled a light cord hanging from the center of the room,				●		
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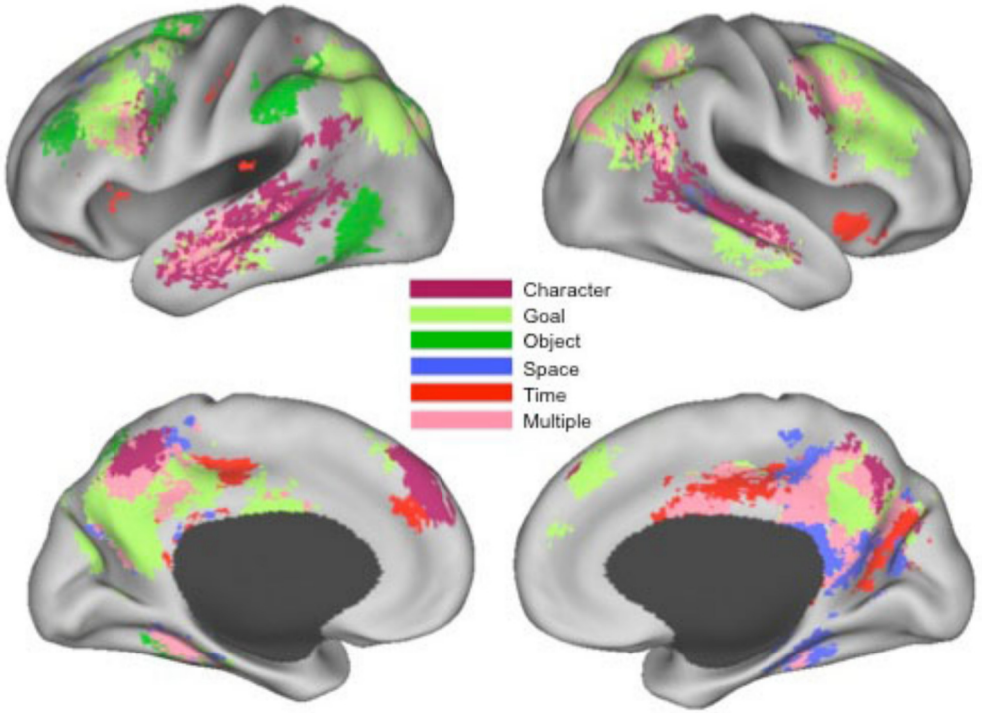
"Raymond, wake up."						
With a little more urgency in her voice she spoke again:						
Son, are you going to school today?						
Raymond didn't respond immediately.		●				●
He screwed up his face			●			
And whimpered a little.						

B



Segmenting experience

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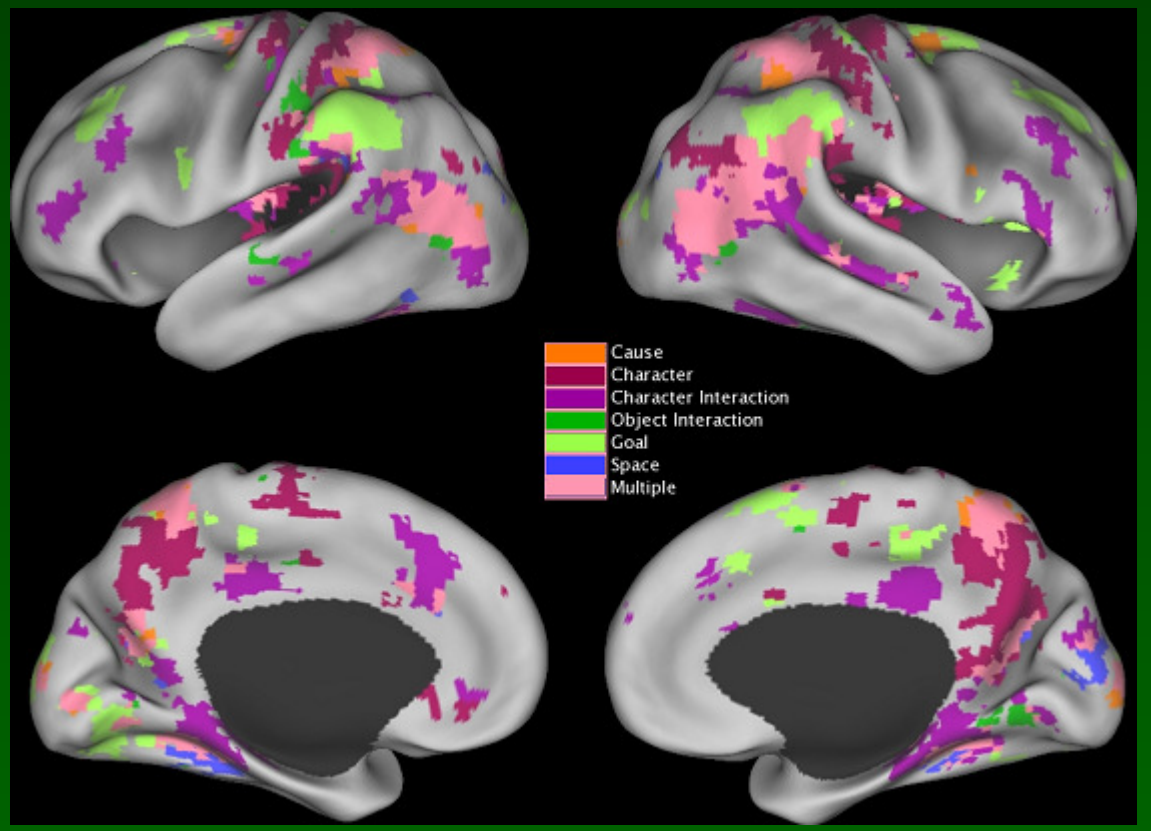
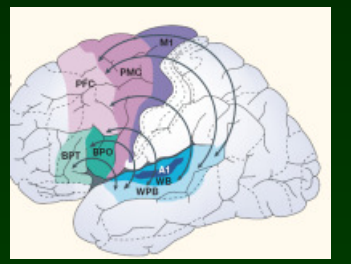
Automatic segmentation of experience is the basis of perception, facilitates planning, memory, association of information.

Transitions between segments result from important observations in the current episode, entering new objects, places, goals, interactions, like in a movie.



Computational creativity



- Start from keywords priming phonological representations in the auditory cortex; spread the activation to concepts that are strongly related.
- Use inhibition in the winner-takes-most to avoid false associations.
- Find fragments that are highly probable, estimate phonological probability.
- Combine them, search for good morphemes, estimate semantic probability.

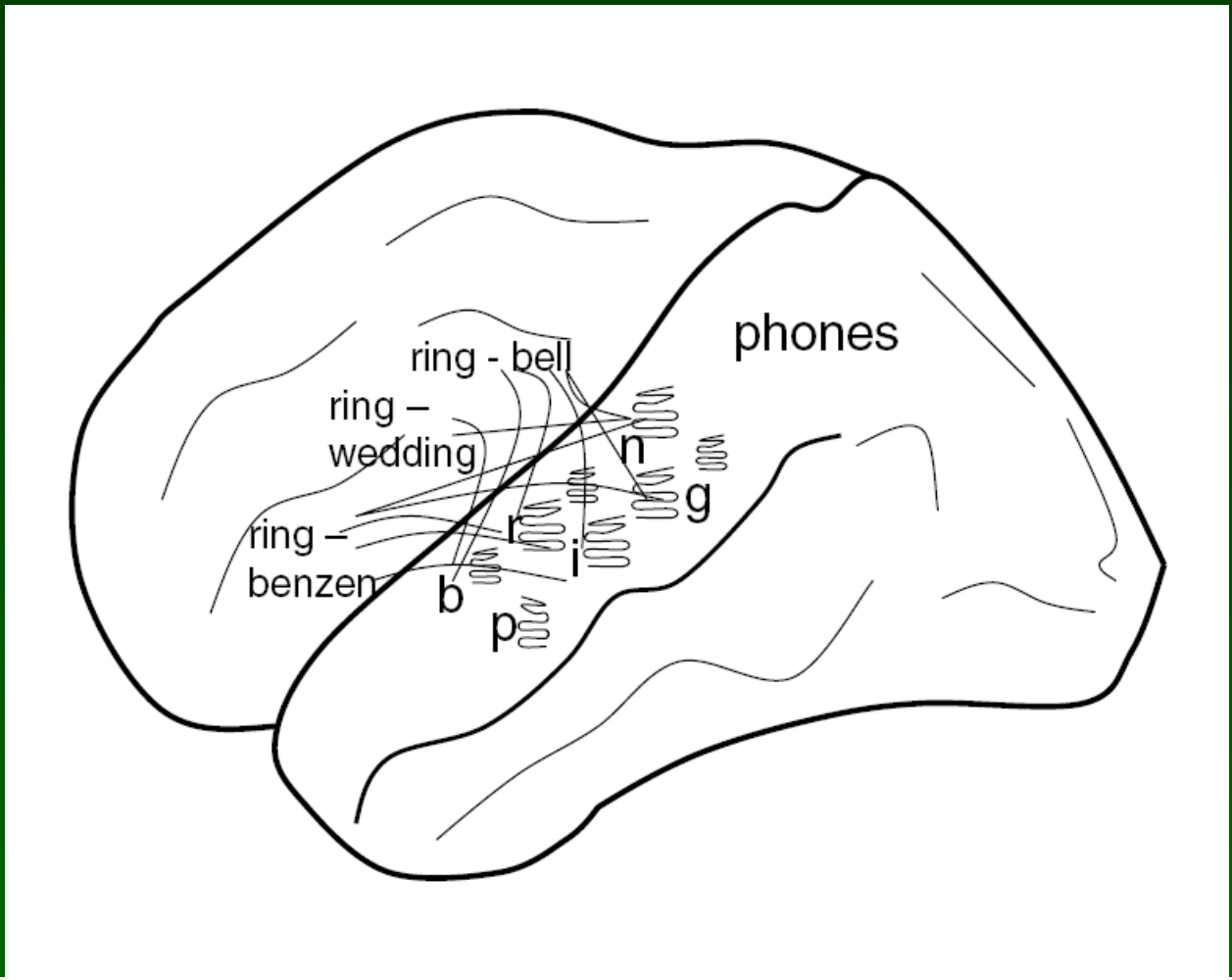
Creating novel words by **Random Variation Selective Retention** (RVSR): construct words from combinations of phonemes, pay attention to morphemes, flexion etc.

Creativity = space + imagination (fluctuations)
+ filtering (competition)

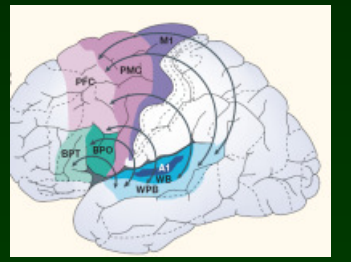
Space: neural tissue providing space for infinite patterns of activations.
Imagination: many chains of phonemes activate in parallel both words and non-words reps, depending on the strength of synaptic connections.
Filtering: associations, emotions, phonological/semantic density.

Ring your brain

- Context will decided which semantics to attach to r-i-n-g series of phonemes that you hear or letters that you read.



Creativity with words



The simplest testable model of creativity:

- create interesting novel words that capture some features of products;
- understand new words that cannot be found in the dictionary.

Model inspired by the putative brain processes when new words are being invented starting from some keywords priming auditory cortex.

Phonemes (allophones) are resonances, ordered activation of phonemes will activate both known words as well as their combinations; context + inhibition in the winner-takes-most leaves only a few candidate words.

Creativity = network + imagination (fluctuations) + filtering (competition)

Imagination: chains of phonemes activate both word and non-word representations, depending on the strength of the synaptic connections.
Filtering: based on associations, emotions, phonological/semantic density.

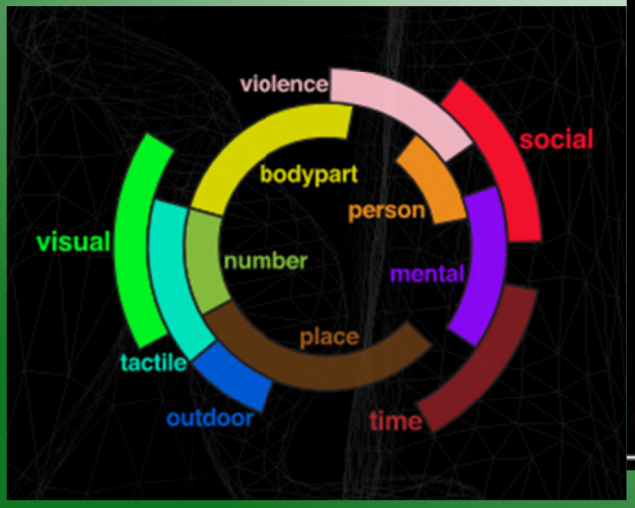
discoverity = {disc, disco, discover, verity} (discovery, creativity, verity)
digventure ={dig, digital, venture, adventure} new!
Check the BrainGeneserver and invent some good passwords today!

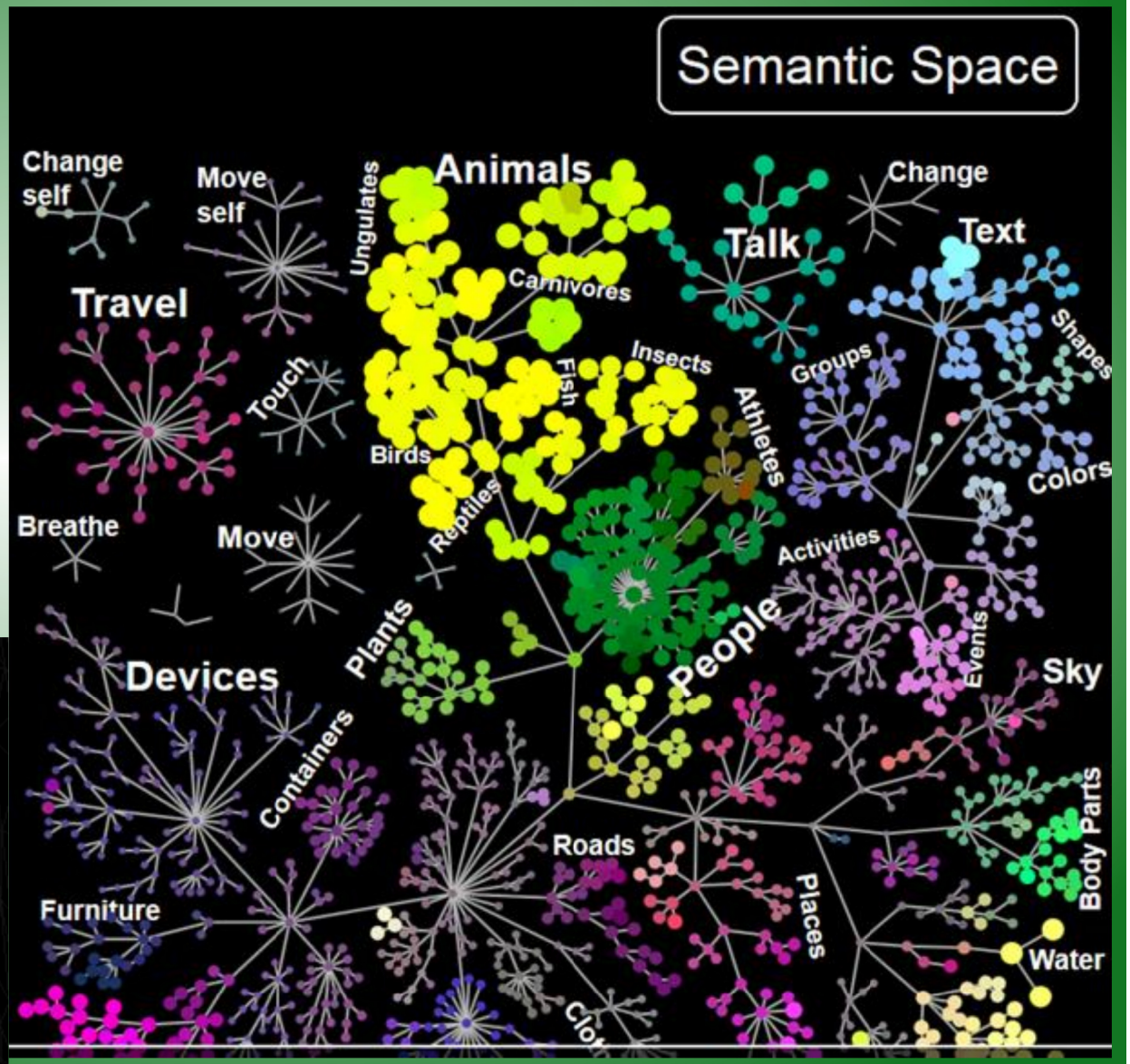
Some language related Q/A

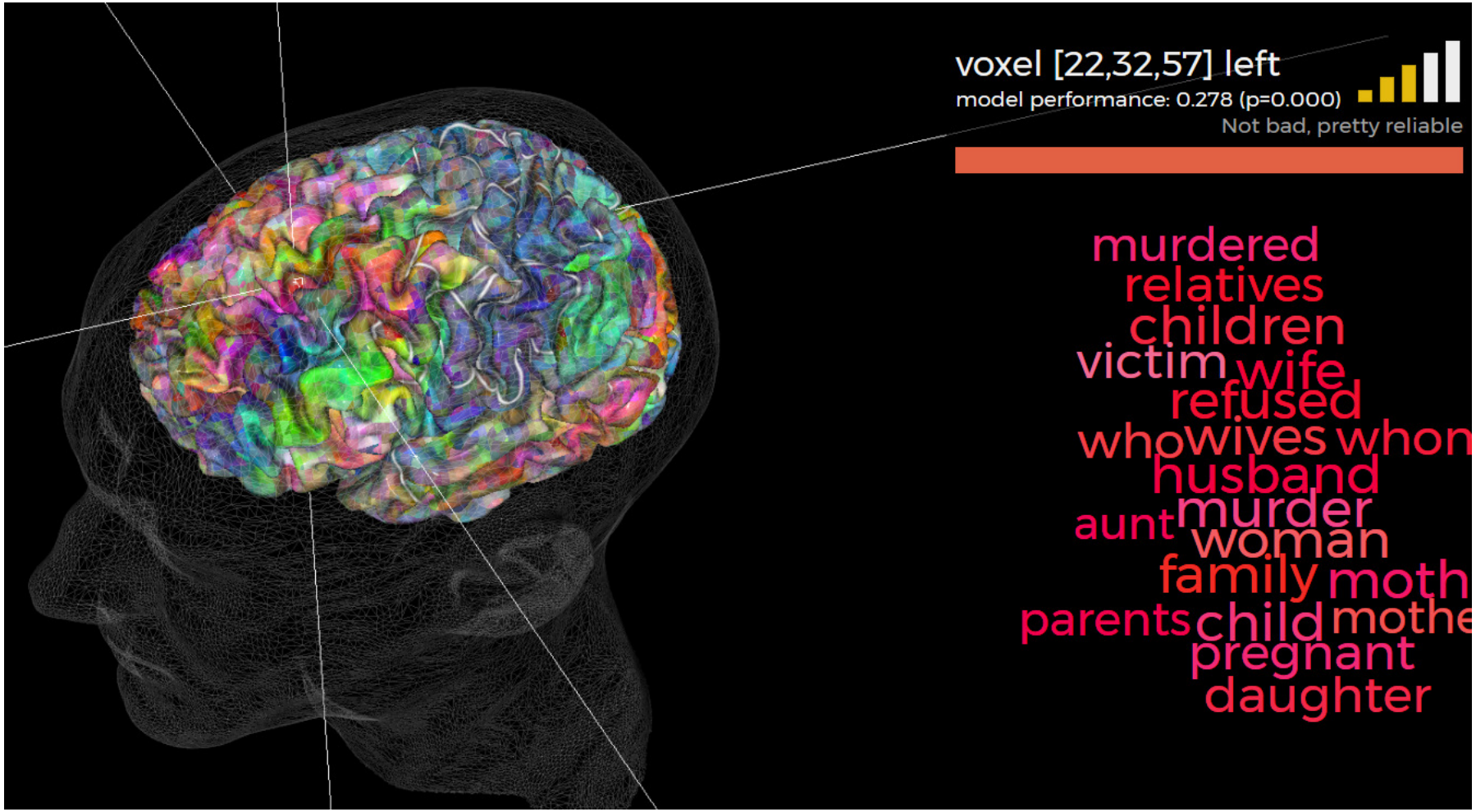
- What brain processes are involved in reading and why they sometimes fail (dyslexia)?
  Lexical representations are distributed, there are interactions between recognition of letters, orthographical, phonological and semantic layers.
- What is the difference between reading proper words like *cat, yacht*, and non-words like *nust*?
  Context-activated representations form continuum between regular and exceptional words, showing word-frequency effects.
- Why children first learn correctly and than say *I goed* instead of *I went*?
  There is dynamical balance between mapping regular and irregular forms.
- Where does the meaning of the words come from? Co-occurence statistics with other words, and embodiment in sensory related brain activations.
- How to understand the meaning of sentences? With the gestalt model.
- How to use it in large scale natural text understanding? It is still an open question … a job for you!

Semantic neuronal space

1700 words in the semantic space are grouped by similarity. Words activate specific ROIs, similar words create similar maps of brain activity. Video or audio stimuli, fMRI 60.000 voxel). Gallantlab,Berkeley.







Each voxel responds usually to many related words, whole categories.

http://gallantlab.org/huth2016/

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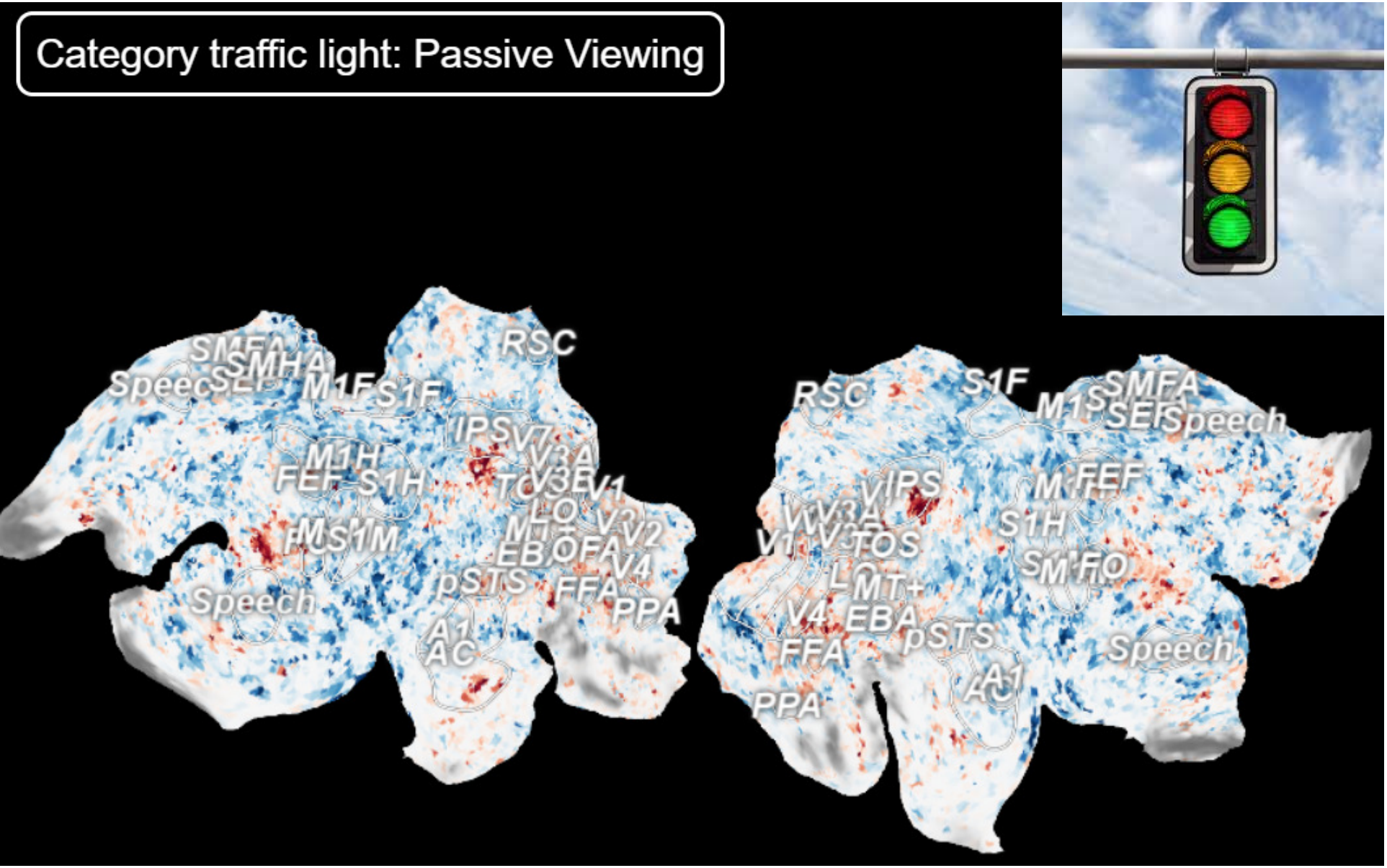
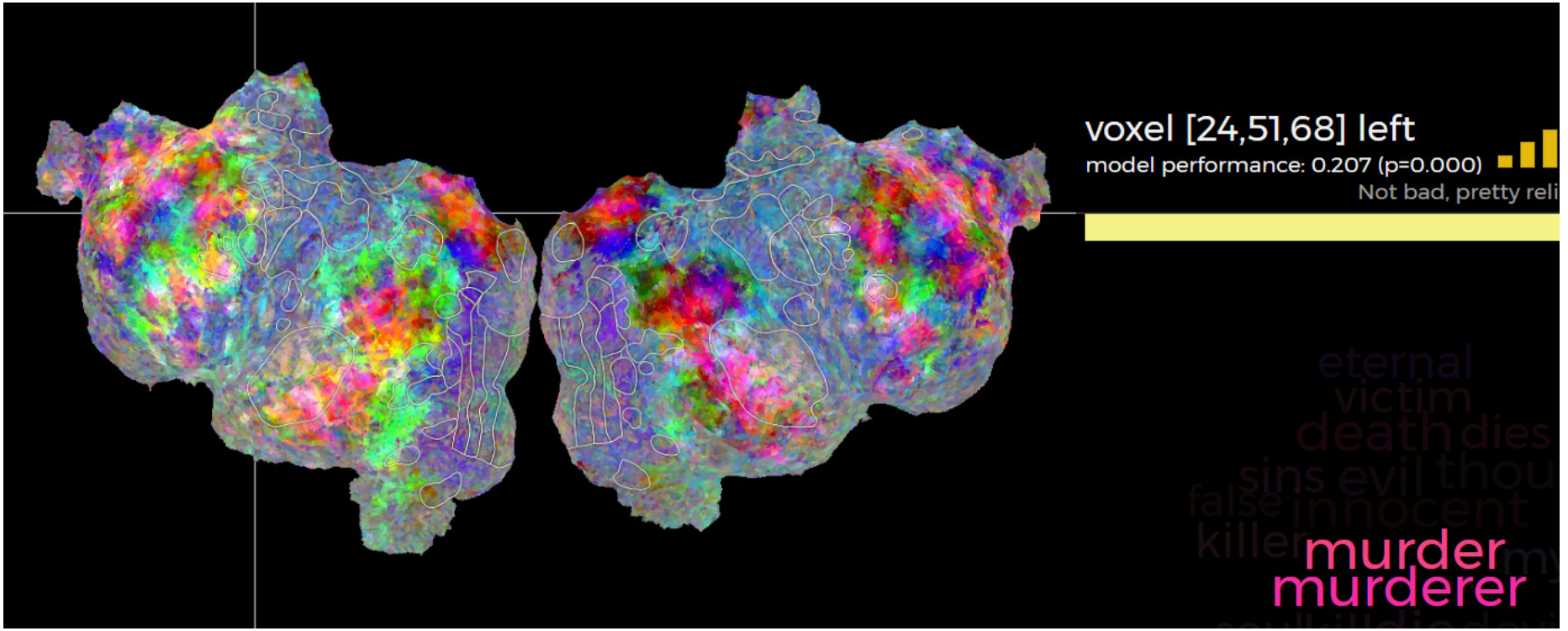
Interpretation for simple objects is easy: IPS – visual attention, V4 – color, AC – object recogniton.





Whole fMRI activity map for the word “murder” shown on the flattened cortex.

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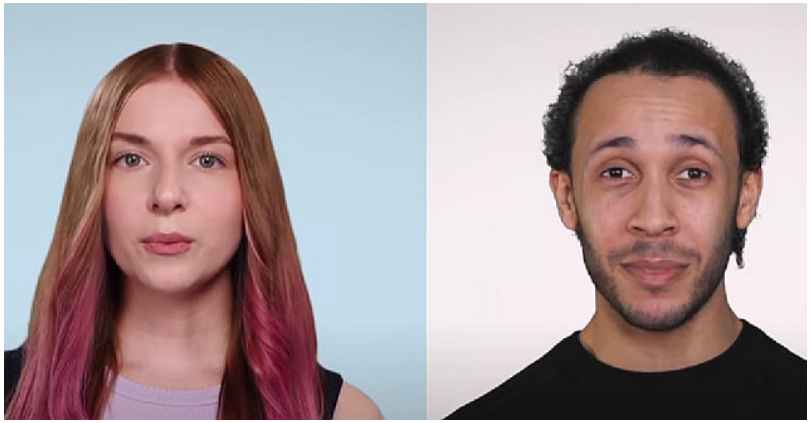
Power of imitation!

Two avatars discussing (GPT-3)



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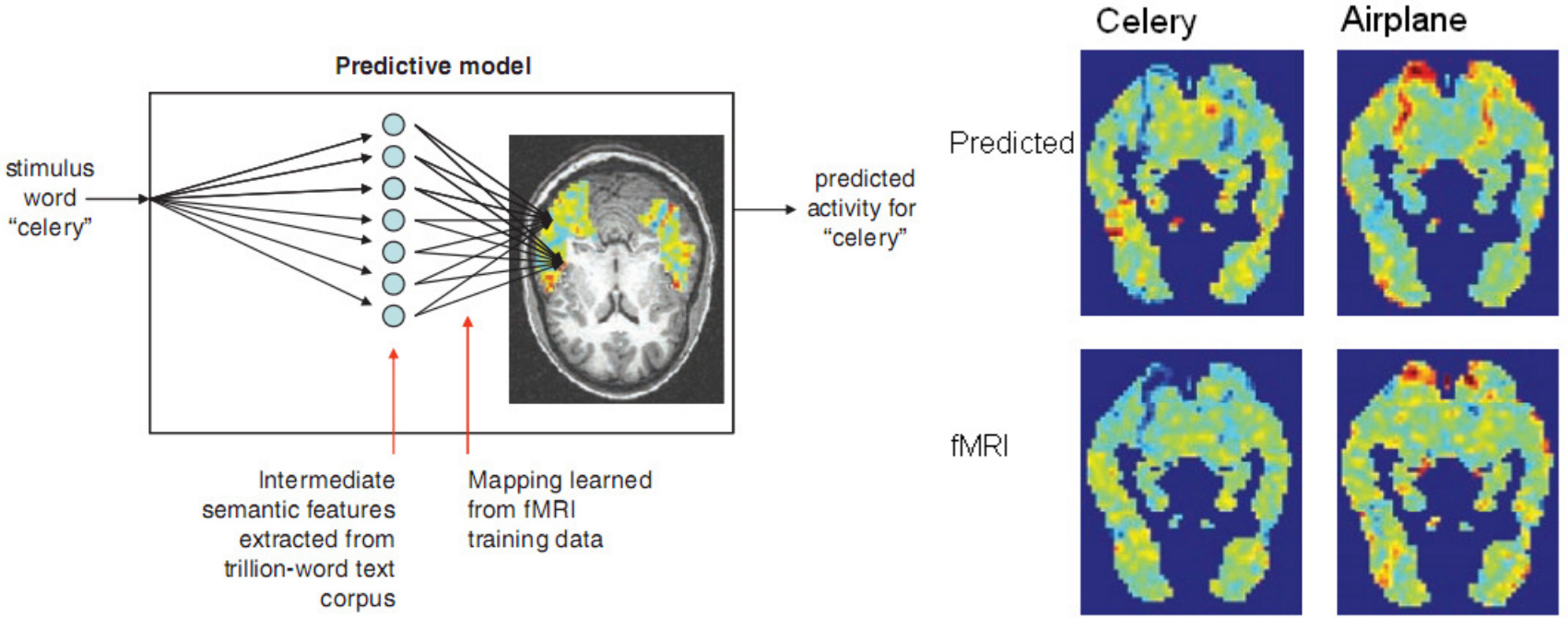

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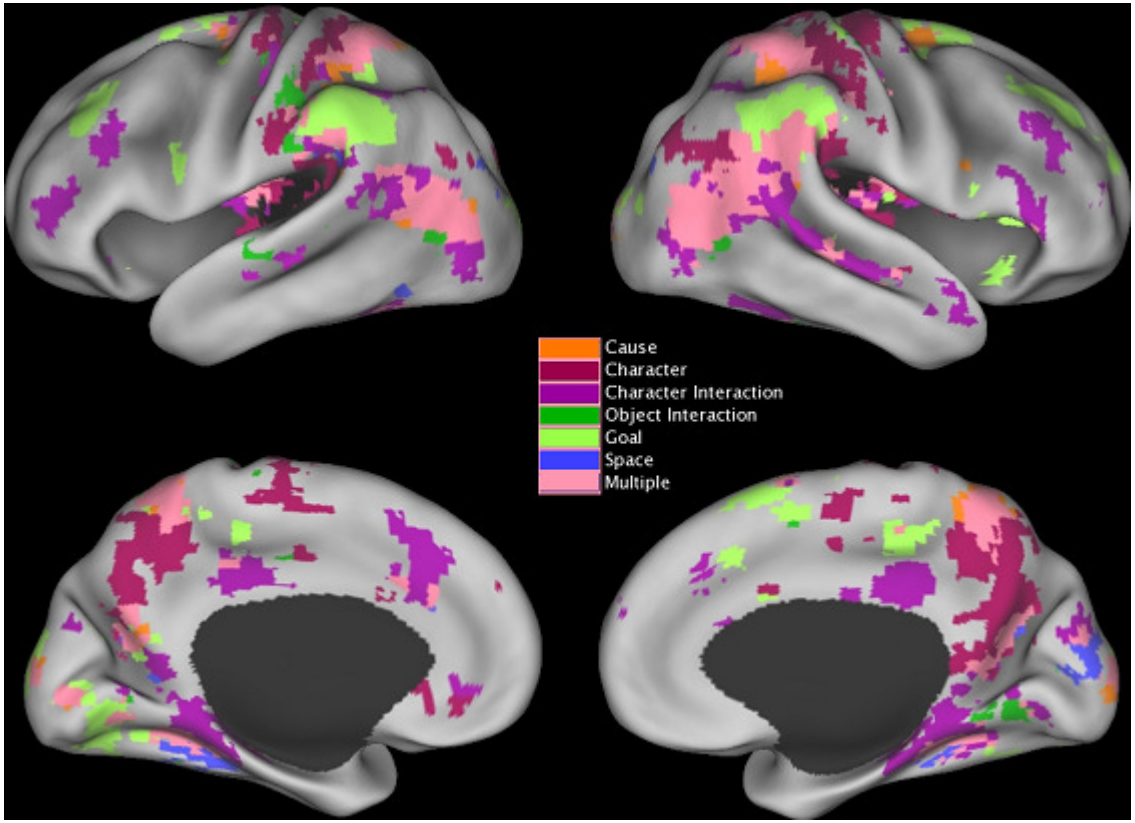

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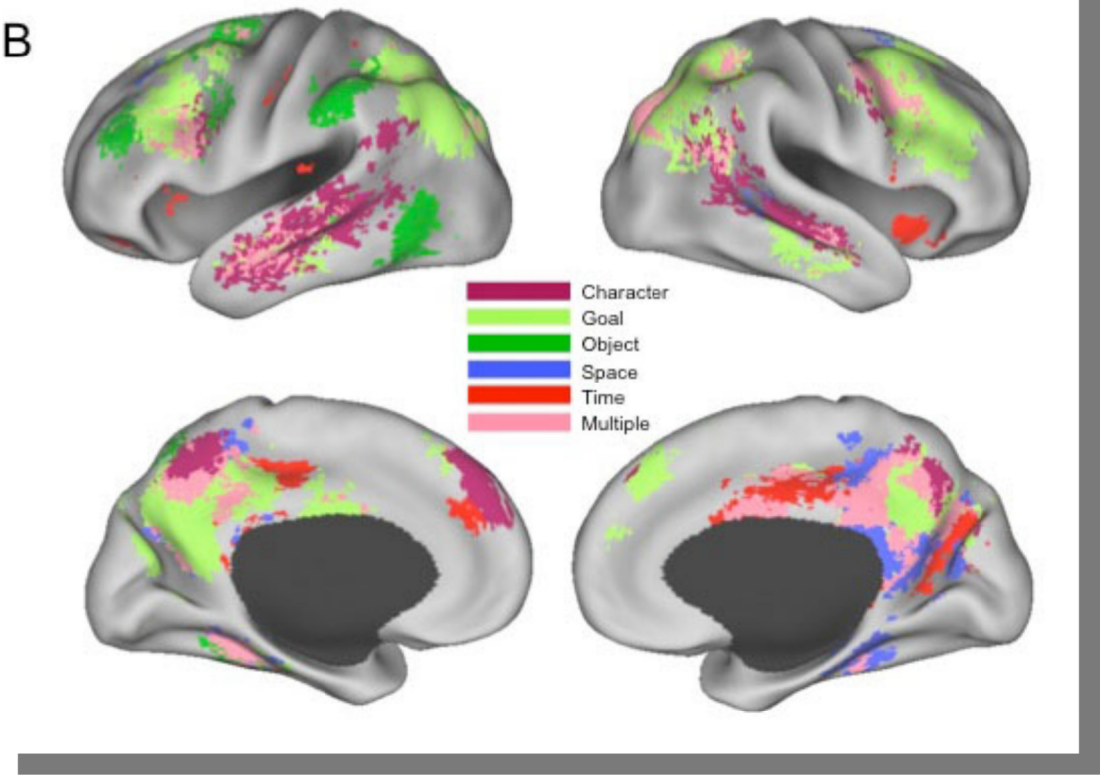

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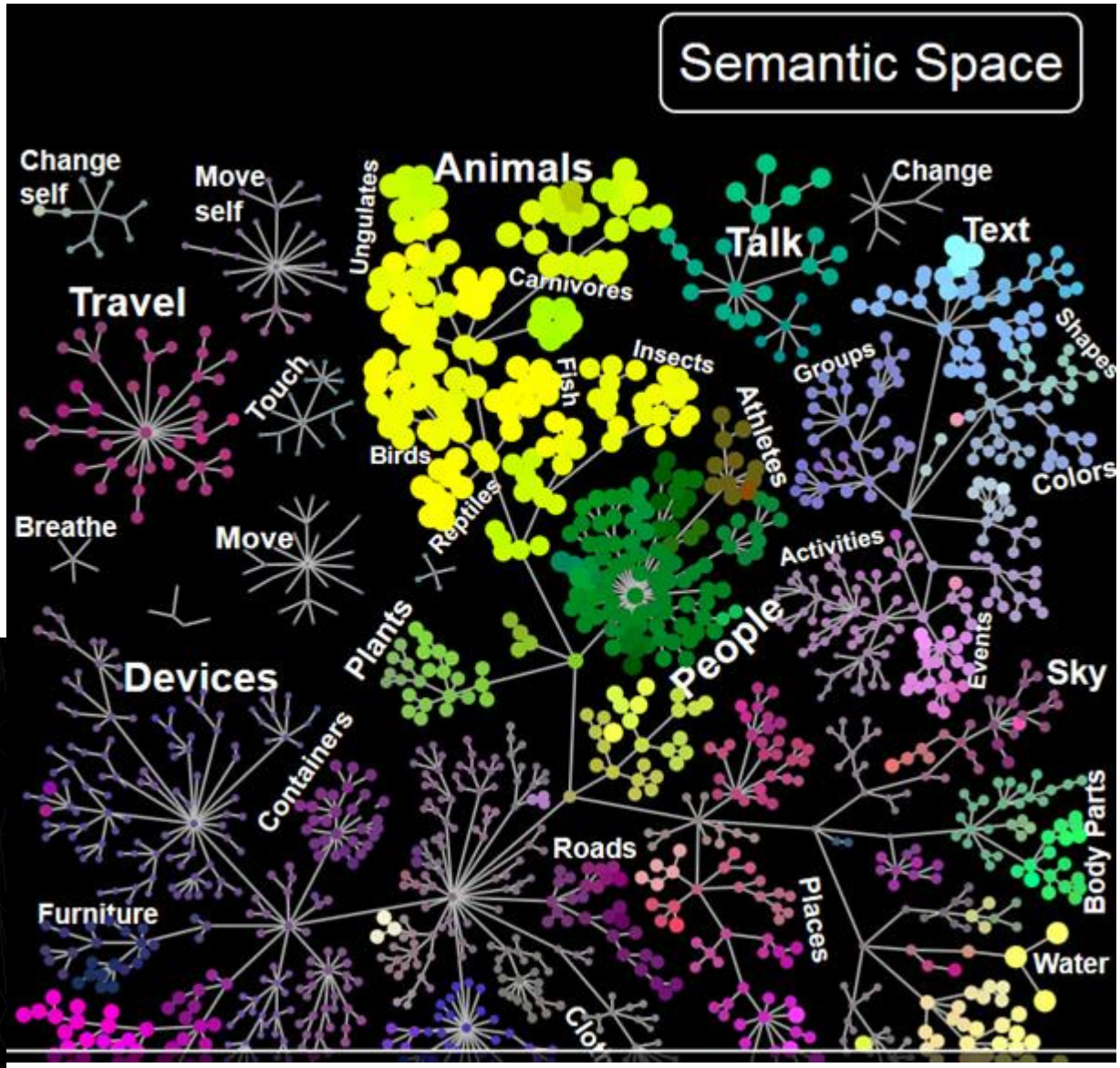

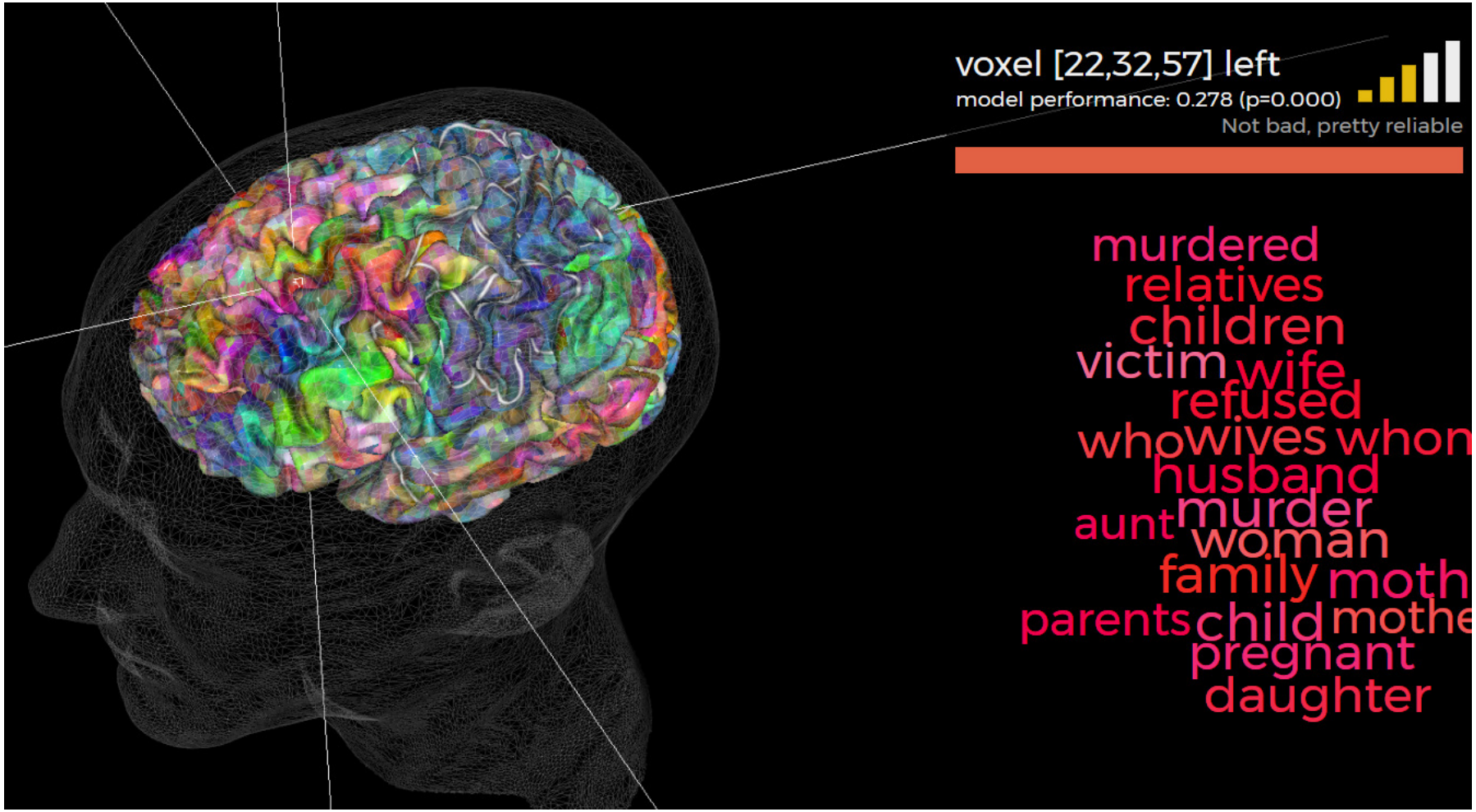

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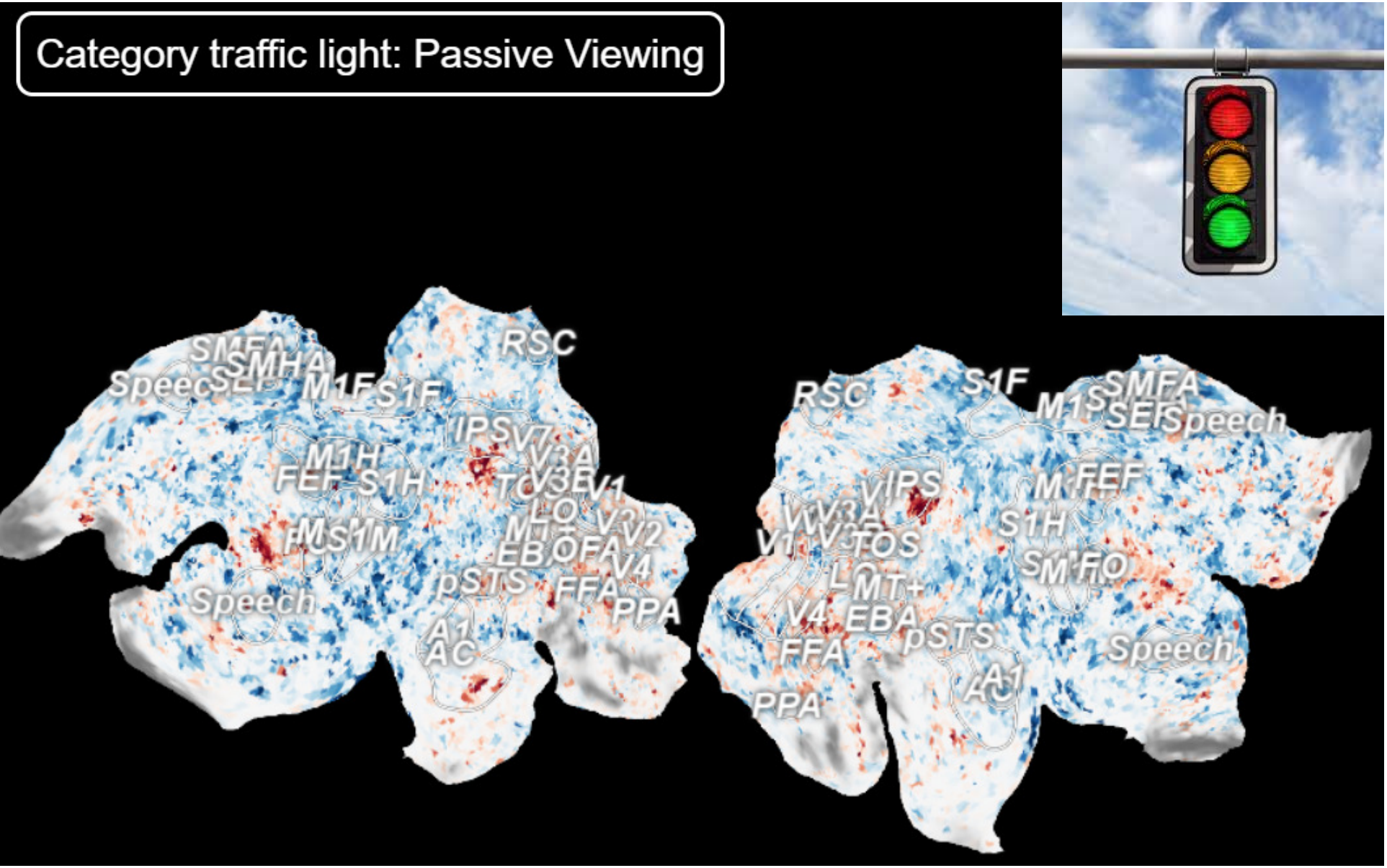

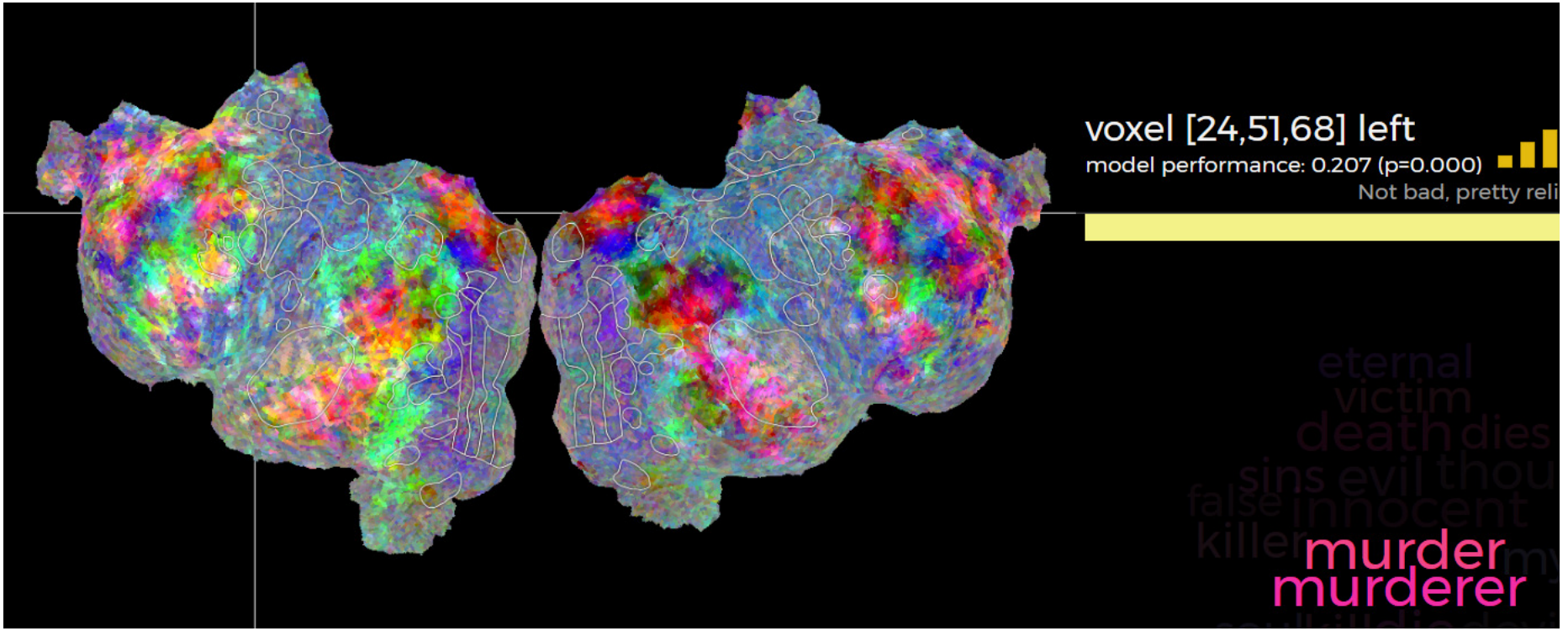

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