Word Processing

Based on: Chapter 3 of the Traxler textbook

Main Questions

1. How do we mentally represent word forms and meanings?

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2. How are those representations organized?
3. How do we access words in memory?
4. What are the neural events that support word processing?
5. What parts of the brain are involved in storing and accessing word meanings?

Mental Representation: Approaches

1. Sense vs Reference

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2. Lexical semantics: Words as lexical entries with features

Mental Representation: Approaches

1. Sense vs Reference
2. Lexical semantics: Words as lexical entries with features
3. Semantic network: Words as nodes in a graph

Sense vs Reference

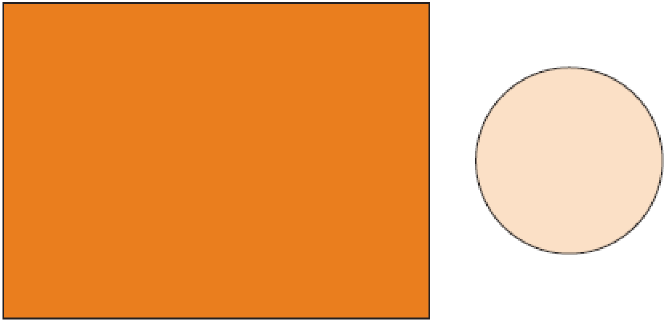

Figure:

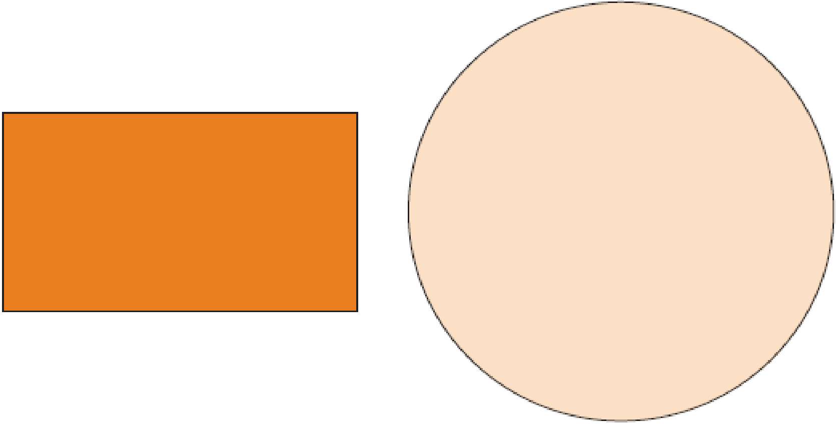

Figure:

Lexical semantics

- Based on introspection

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- Mental lexicon has entries for words
- Grammatical category (noun, verb, adjective, adverb etc)

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- Mental lexicon has entries for words
- Grammatical category (noun, verb, adjective, adverb etc)
- Information about word combination (adjective+noun; adverb+verb)

Lexical semantics of *cat*

Figure:

Core features: has fur, has claws, mammal

Problems with lexical semantics

- Does the meaning of *cat* include it can breathe?

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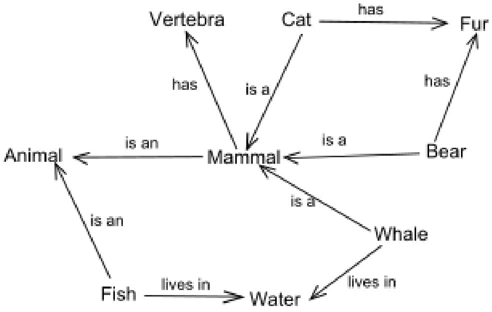
- Does the meaning *cat* include it is larger than a tomato but smaller than a car?
- Or are these retrieved from long term memory?
- What about 3-legged cats?

Semantic network



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Semantic network

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- No need to link every concept with every other concept
- *bear* $--> $ *mammal* $-->$ *animal*
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- This helps conserve memory resources

Evidence: Psychology experiments (lexical decision and naming tasks)

Lexical Naming Task

- Participants presented with a list of words

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- They read out aloud the words as quickly as they can
- Time to say target word measures time to retrieve word from the lexicon

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- Reaction time is the primary index of performance

Lexical decision figures are courtesy: Sidharth Ranjan

DOCTOR

Yes

No

Toctor

Yes

No

FLOOP

Yes

No

SKERN

Yes

No

NURSE

Yes

No

exacerbated

Yes

No

CLOCK	Yes
DOCTOR	Yes
TOCTOR	No
FLOOP	No
SKERN	No
NURSE	Yes
BANK	Yes
PLIM	No
exacerbated	Yes
Coercion	Yes

Where do you Stand?

Lexical Decision Experiments: Key findings

- Words recognized faster than non-words

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- Priming speeds responses

Priming

Presenting *Stimulus1* first helps people respond to *Stimulus2* subsequently (Meyer and Schvaneveldt 1971)

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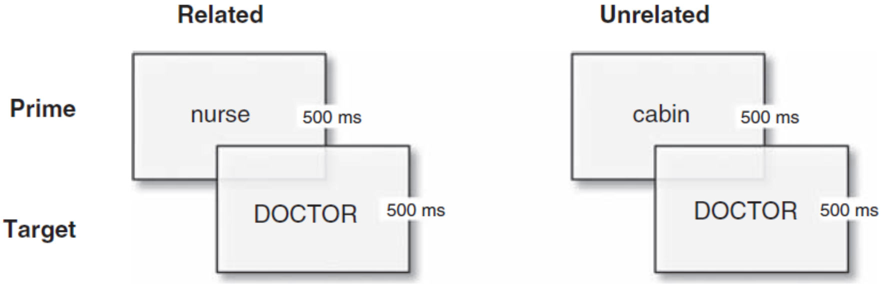

Varieties of Priming

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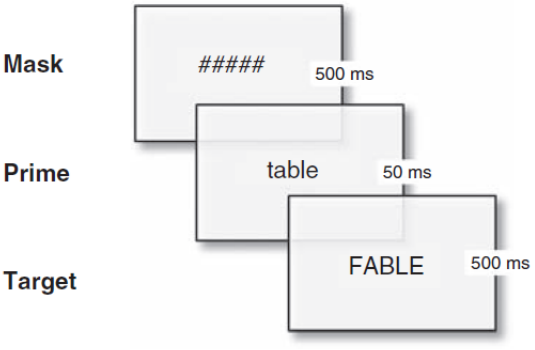
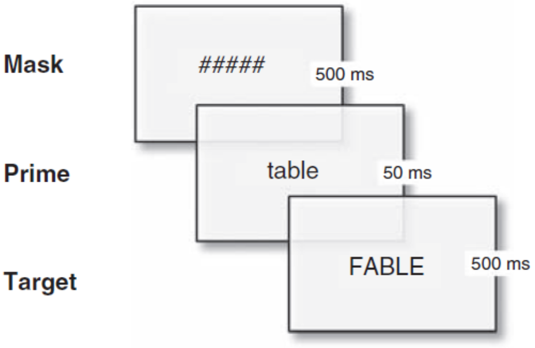
- **Masked priming**

Masked Priming



Masked Priming



Even short duration primes can induce faster lexical decisions

Example

Question: Are both words legitimate words of the English language? **(Yes/No)**

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Type of Stimulus Pair					
Top String	**Bottom String**	**Correct Response**	**Sample Stimuli**	**Mean RT (ms)**	**Mean Percentage Errors**
Word	Associated word	Yes	Nurse–doctor	855	6.3
Word	Unassociated word	Yes	Bread–doctor	940	8.7
Word	Nonword	No	Book–marb	1,087	27.6
Nonword	Word	No	Valt–butter	904	7.8
Nonword	Nonword	No	Cabe–manty	884	2.6

Figure:

Activation

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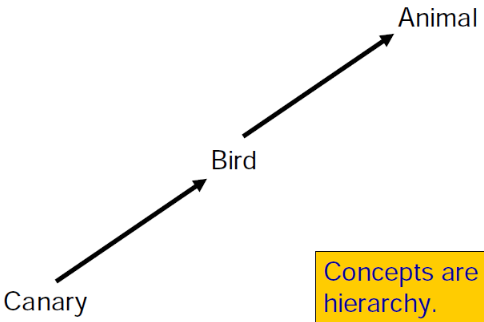
- By measuring relative amounts of priming, it may be possible to infer *how* particular forms or meanings are related

Collins and Quillian's (1969) Hierarchical model of semantic memory



Concepts are organized in a hierarchy.

Figure:

Spread of Activation

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- It diminishes further as it goes

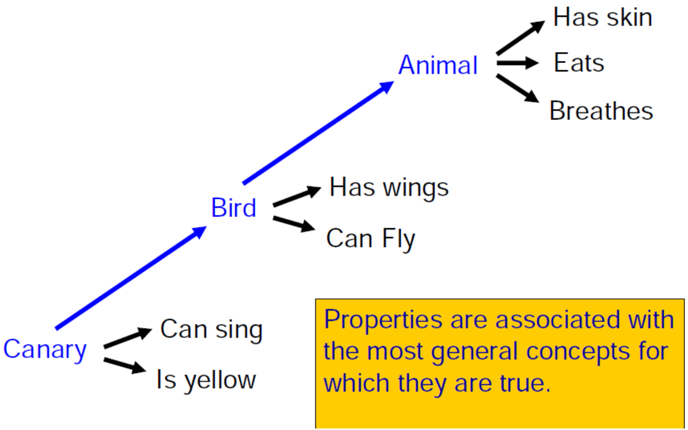

Animal
Has skin
Eats
Breathes
Bird
Has wings
Can Fly
Canary
Can sing
Is yellow
Properties are associated with the most general concepts for which they are true.

Figure:

Do canaries have skin?

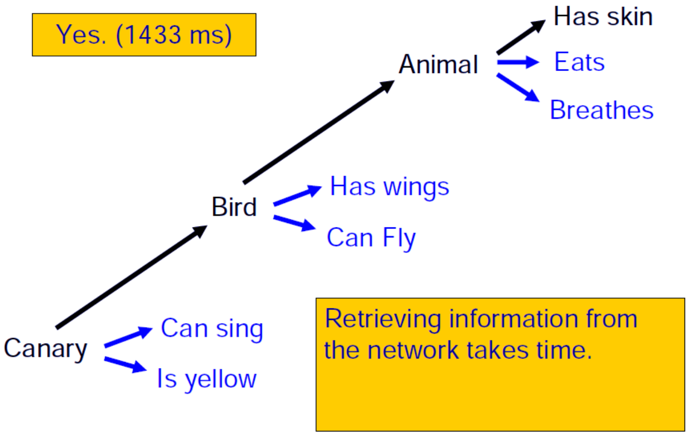


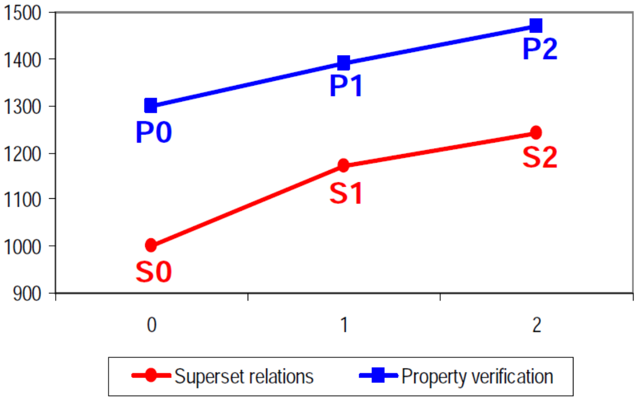
Figure:

Experiment

The participants were asked to evaluate the truth value of sentences

Level	Superset	Property
0	A canary is a canary (S0)	A canary is yellow (P0)
1	A canary is a bird (S1)	A canary can fly (P1)
2	A canary is an animal (S2)	A canary breathes(P2).

Results



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Properties of Activation

Semantic Network originated in Artificial Intelligence / Translation (Richens '56)

Spreading activation is simple representation of neuron behavior:

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- Diminishes / decays
- Varies with familiarity

Activation and familiarity

Reaction times may differ by familiarity (Collins & Loftus 74)

- stimuli: *a canary is a bird?* / *an ostrich is a bird?*
- measure: *yes* / *no* reaction time

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- Suggest network has weights: low weight ! delay, high weight ! quick

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Evidence from strategic priming study (Neely 1977)

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- *arm* primes *leg*

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- *arm* primes *leg*
- *arm* does not prime *sparrow*

Activation diminishes

Evidence from mediated priming studies (Balota & Lorch 1986)

- *lion*, *tiger* and *stripes*

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- *lion*, *tiger* and *stripes*
- *lion* activates *tiger*
- *tiger* activates *stripes*
- But, *lion* does not activate *stripe* as much

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- Co-occurence measured using quantitative metrics like Hyperspace Analogue to Language (HAL) and Latent Semantic Analysis (LSA)

Co-occurence

Co-occurrences in sentences/texts as features:

- *violin* co-occurs with *orchestra* a lot

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- holds even if *violin* and *cello* do not ever co-occur!

Figure: Cello player

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- *investment* co-occurs with *bank* a lot

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- *river* co-occurs with *bank* a lot
- *investment* co-occurs with *bank* a lot
- *river* and *investment* must be similar! (nope)

Evidence for Associative Activation

Rhodes and Donaldson (2008) conducted an Event Related Potential (ERP) study

- Associative relation: *fountain-pen*

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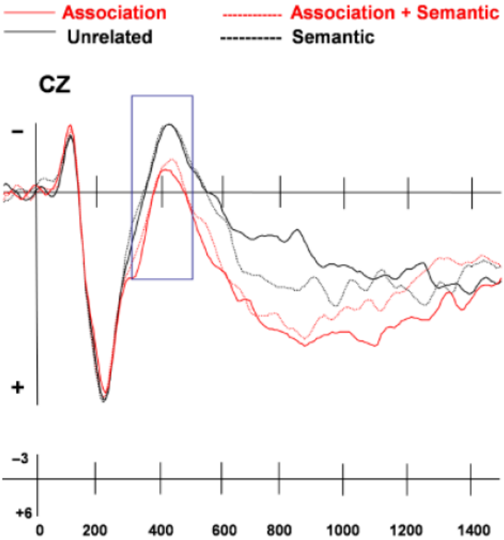
- Semantic and Associative relation: *dog-cat*
- Semantic relation: *bread-cereal*
- Unrelated: *beard-tower*

ERP results


Association
Association + Semantic
Unrelated
Semantic
CZ
−
+
−3
+6
0
200
400
600
800
1000
1200
1400

Summary of results

N400 effect: Negative-going deflection that peaks around 400 milliseconds after start of stimulus

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N400 effect: Negative-going deflection that peaks around 400 milliseconds after start of stimulus

- Assoc+ (Sem+/-) elicits similar N400, Assoc- (Sem+/-) doesn't
- Unrelated and assoc- (sem+/-) produced similar effects

Symbol Grounding Problem

- Are mental symbols for words grounded in any physical reality?
- Is the mind a system for computing symbols?

Chinese Room Argument

John Searle's article *Minds, Brains, and Programs* (1980)

- Imagine you do not know Chinese

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  - Rulebook says: *four*

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- Imagine you do not know Chinese
- You have a rulebook connecting Chinese symbols to other Chinese symbols
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  - Rulebook says: *four*
- Originally intended to argue against Strong AI, where computers have minds

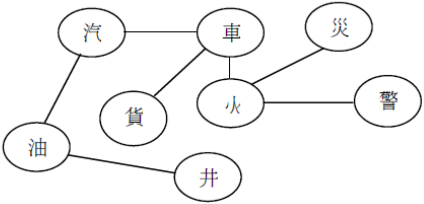

Figure:

Embodied Semantics

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  - Tucker & Ellis (2001)
  - Glenberg & Kaschak (2002)
  - Pulvermuller et al., 2005

Grasp type during visual object recognition

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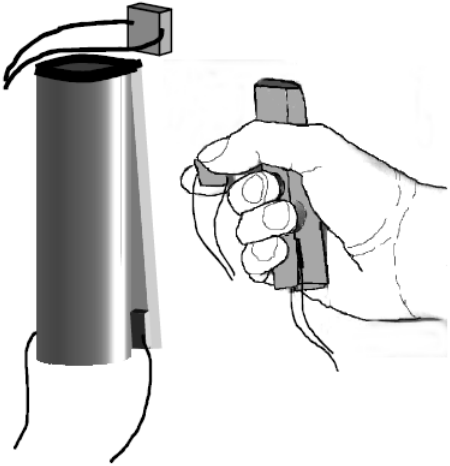
Grasp type during visual object recognition

Tucker & Ellis (2001)

- Tested interaction between word meaning and motor responses
- **Task**: Read a word and judge whether object is natural or man-made
  - Power grip response faster for large objects: *shovel*, *rake*
  - Precision grip response faster for small objects: *pen*, *forks*



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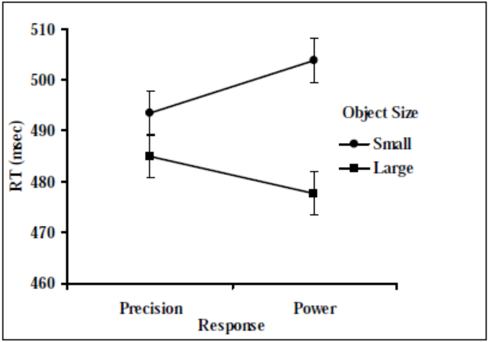
510
500
490
480
470
460
RT (msec)
Object Size
Small
Large
Precision
Power
Response

Figure:

Grounding Language in Action

Glenberg & Kaschak (2002)

- Participants made plausiblity judgements:

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  - *He pushed air* (Nonsense)

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  - *He opened the drawer* (Towards body)
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  - *He pushed air* (Nonsense)
  - *He pulled air* (Nonsense)
- Response measured using 3 buttons (close, mid, far)

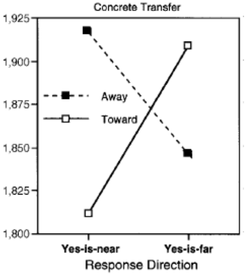
Concrete Transfer
1,925
1,900
1,875
1,850
1,825
1,800
Away
Toward
Yes-is-near
Yes-is-far
Response Direction

Figure:

Transcranial Magnetic Stimulation (TMS) experiment

Pulvermuller et al 2005

- Powerful magnetic stimulation is generated close to scalp

Transcranial Magnetic Stimulation (TMS) experiment

Pulvermuller et al 2005

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- TMS stimulation to hand/foot areas of motor cortex

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- Right hemisphere stimulation did not affect decision times that much

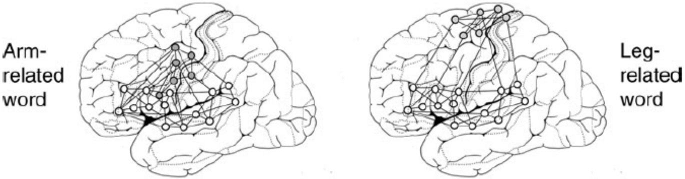

Figure:

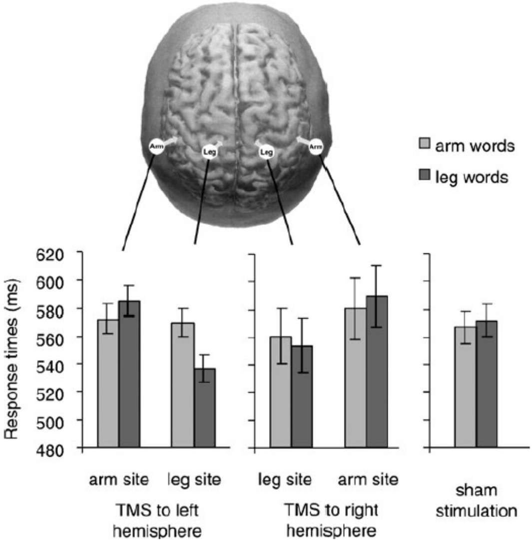
Arm
Leg
Leg
Arm
arm words
leg words
Response times (ms)
620
600
580
560
540
520
500
480
arm site
leg site
TMS to left hemisphere
leg site
arm site
TMS to right hemisphere
sham stimulation

Figure:

Mirror Neurons

- Neurons for mental stimulation of actions (processing verbs)

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- These mirror the neurons stimulated while performing actions

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- Studied in detail using monkeys

Mirror Neurons

Neurons in Macaque monkeys frontal lobes (*area F5*) that

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Existence of mirror neurons in monkeys was established by invasive single-cell recording techniques


Activity!
monkey
does action
Activity!
monkey
sees action

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Mirror neurons not confirmed in humans

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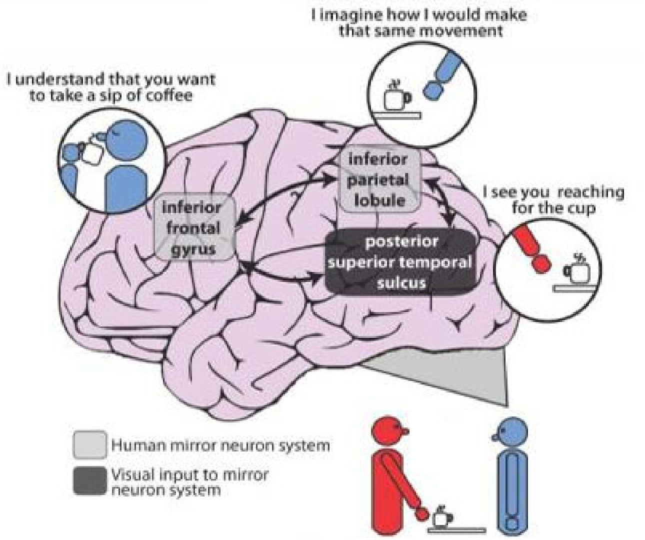
I imagine how I would make that same movement
I understand that you want to take a sip of coffee
inferior parietal lobule
inferior frontal gyrus
I see you reaching for the cup
posterior superior temporal sulcus
Human mirror neuron system
Visual input to mirror neuron system

Indirect Evidence for Mirror Neurons

1. Neuroimaging data: fMRI

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- (/ta/, /da/) caused activity in different part of motor cortex
- Listening and production trials activated same areas of the brain!

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- When listening to speech sounds involving tongue movements, TMS to motor cortex induces potential in tongue
- Motor-evoked potentials at tongue also obtained when TMS is applied and people watch videos of other people talking

Mirror Neurons: Alternative Proposals

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- Alternatively, this could be a way to verify that a speech sound was heard correctly
- Covertly produce own version of the speech sound and compare the two examples

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- So semantic network theory is the most accepted approach these days

Lexical Access

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- Word recognition is influenced by context: words can be recognized sooner in context than in isolation.

Importance of Context

I eat fish but dont enjoy chi-
Did you give the toys to the chi-

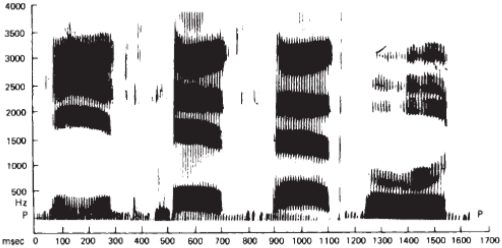

Figure: Spectrograms for *heed, head, had, and whod*

Why is this challenging?

Time Course of Lexical Access

Close shadowing task (Marslen-Wilson 1973):

- **task**: repeat sentences
- **stimuli**: spoken sentences (normal rate, about 5 syllables per sec)
- **measure**: time lag in repeating sentence
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Only 3/132 mistakes violated grammatical constraints

Gating task (Grosjean 1980):

- **task**: listening to parts of words and completing them
- **stimuli**: fragments of spoken words with/without context
- **measure**: length of fragment at which word can be identified
- **results**: subjects can identify words in 200ms w/ context, 300ms isolated

Shows context helps within 200ms.
Recgnition point: *tres***p***ass*, *ora***n***ge*

Word-monitoring task (Marslen-Wilson & Tyler 1980):

- **stimuli**: target word +
  The church was broken into last night.
  Some thieves stole most of the **lead** *off the roof*
- **measure**: reaction time to detect: identical word *lead* and *lead* rhyme (form) *bread* and *lead*
  category (sem) *metal* and *lead*
- **results**: Identical (273ms); Rhyme (419ms); Category (428ms)

Models of Lexical Access

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   -Cohort model (Marslen-Wilson 1987)
3. Third generation
   -Distributed cohort model (Gaskell & Marslen-Wilson 2002)
   -Distributed feature model (Elman 2004)

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1. Understand how humans learn and process language
2. Use computers to understand how humans process language

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Bottom-up Processing

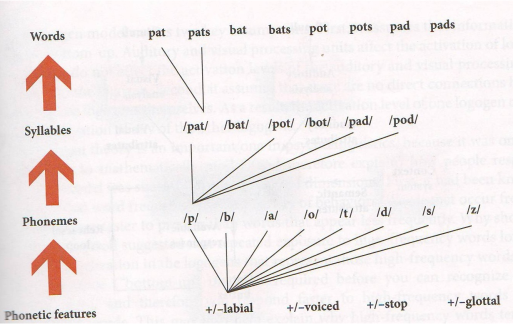

Figure:

Bottom-up vs Interactive models

Purely bottom-up models:

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Interactive models (bottom-up + top-down):

- constraints flow down (hypothesized units to observations) as well as up
- TRACE

(There are no purely top-down models)

Logogen Model (Morton 1969)

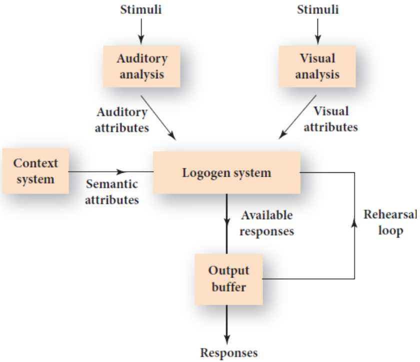

Figure:

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- The first logogen to reach a certain threshold of activation is recognized.

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- Predictions about word frequency, word association priming

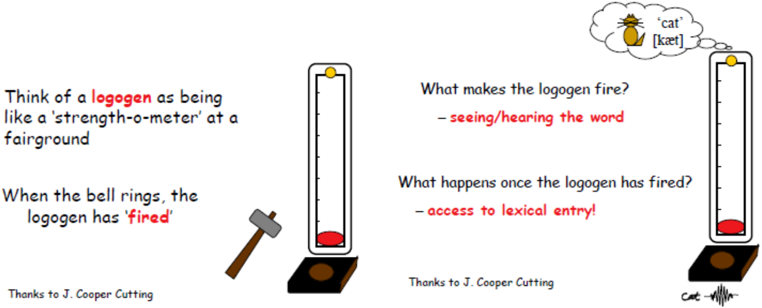
Think of a logogen as being like a 'strength-o-meter' at a fairground
When the bell rings, the logogen has 'fired'
Thanks to J. Cooper Cutting
'cat'
[kæt]
What makes the logogen fire?
– seeing/hearing the word
What happens once the logogen has fired?
– access to lexical entry!
Thanks to J. Cooper Cutting
Cat

Figure:

Activation Threshold

- *cat* is more frequent than *cot*
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Activation Threshold

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- So *cat* has lower activation threshold
- Repeated exposure (i.e. high frequency words) lowers threshold
- Explain why high frequency words are easier to recognize in noisy conditions

Frequency and Reaction Times (Foss 1969)

Task: React when you encounter **/b/** in the following sentences:

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- *The* **travelling** *bassoon player found himself without funds in a strange town* (41.5 per million)
- *The* **itinerant** *bassoon player found himself without funds in a strange town* (1.5 per million)

Figure:

Key Assumptions

1. Information flow is strictly bottom-up
2. No direct connections between logogens

Frequency Ordered Bin Search or FOBS (Taft & Forster 1975)

- Word forms are organized into bins

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- Words with more frequent roots are processed faster than words with less frequent roots

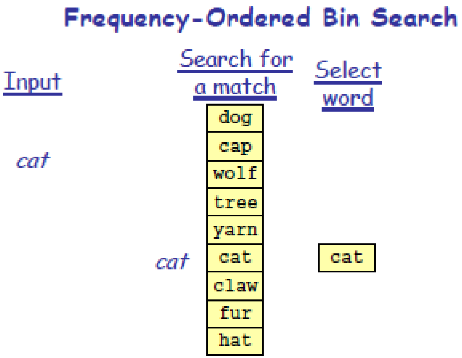
Frequency-Ordered Bin Search
Input
Search for a match
Select word
cat
dog
cap
wolf
tree
yarn
cat
cat
claw
fur
hat
cat

Figure:

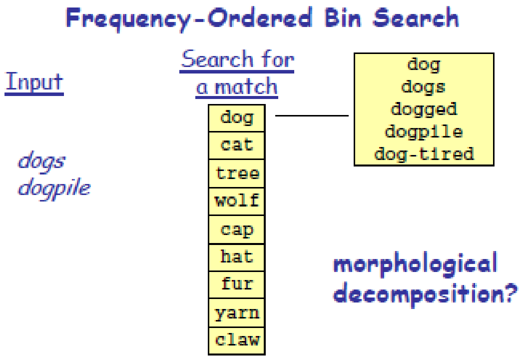
Frequency-Ordered Bin Search
Input
dogs
dogpile
Search for
a match
dog
cat
tree
wolf
cap
hat
fur
yarn
claw
dog
dogs
dogged
dogpile
dog-tired
morphological
decomposition?

Figure:

Prediction: Morphological Decomposition

Unlucky=un + luck+ y

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  arson-son (NO PRIMING)
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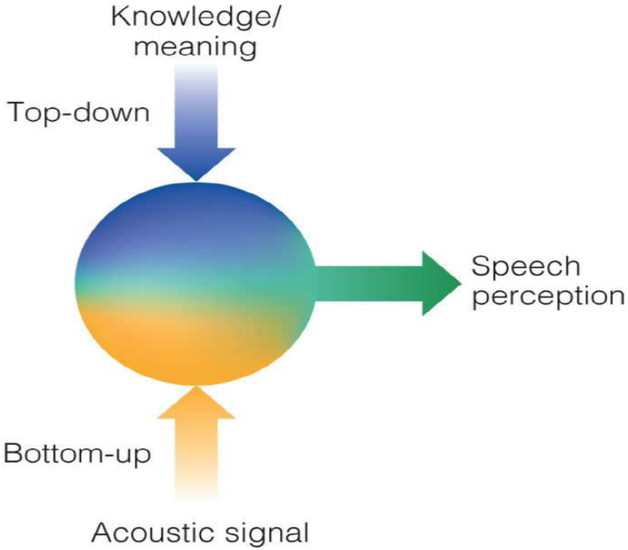
  Prime word exposure duration is manipulated
  doctor prime *nurse* (long prime duration)
  apartment prime *apart* (short prime duration)
  apartment - *apart* (NO PRIME at longer prime duration)

Top-down vs. Bottom-up Processing



Phoneme Restoration Effect (Warren 1971)

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- *The bill was sent to the legi_lature*
- Participants thought whole word was present. The /s/ was mentally restored!

It was found that the _eel was on the orange.
It was found that the _eel was on the shoe.

2nd Generation Model: TRACE Architecture

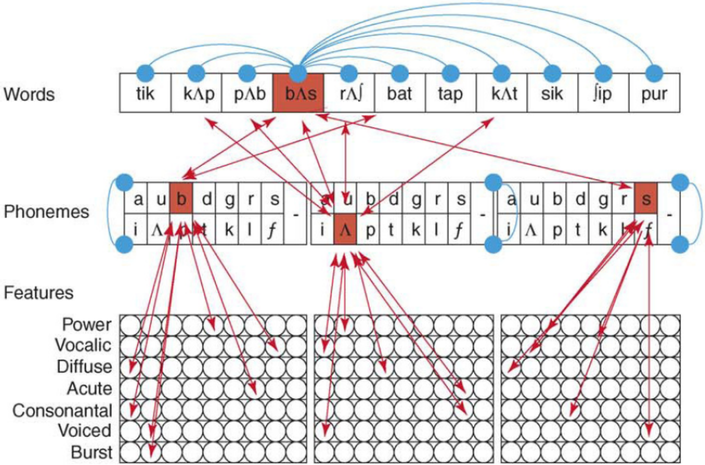
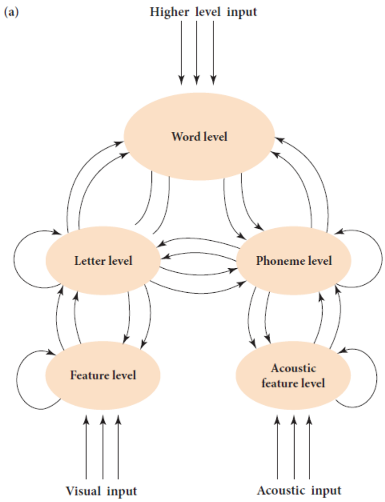


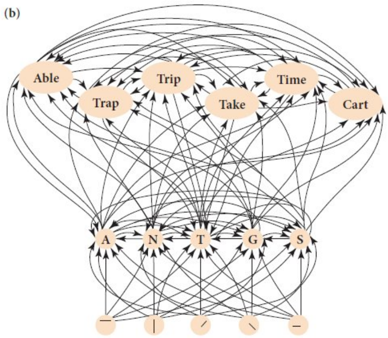
Figure: Spoken word processing

http://maglab.psy.uconn.edu/jtrace/

TRACE Features



TRACE: Written Word Processing



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- Connectionist model
- Three types of connectivity:
  1. Feed forward excitatory connections from input to features, features to phonemes, and phonemes to words
  2. Lateral (i.e., within layer) inhibitory connections at the feature, phoneme and word layers
  3. Top-down feedback excitatory connections from words to phonemes

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- Connectionist model
- Three types of connectivity:
  1. Feed forward excitatory connections from input to features, features to phonemes, and phonemes to words
  2. Lateral (i.e., within layer) inhibitory connections at the feature, phoneme and word layers
  3. Top-down feedback excitatory connections from words to phonemes
- Cascaded activation
- Explains word superiority effects and degraded/noisy input

Word Superiority

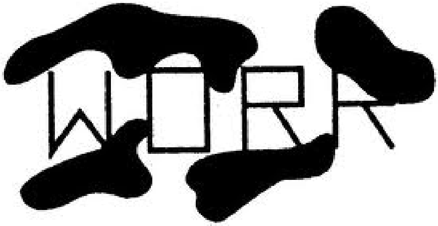
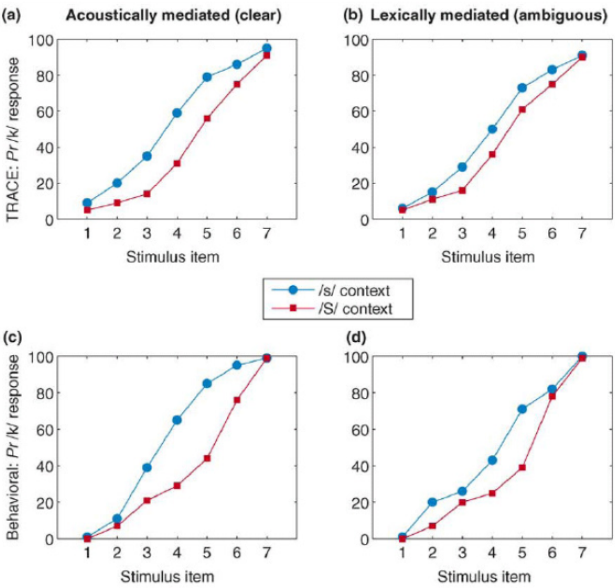


Figure:

Figure:

TRACE vs. Actual human data



COHORT Model

Participants hear: [s ..]

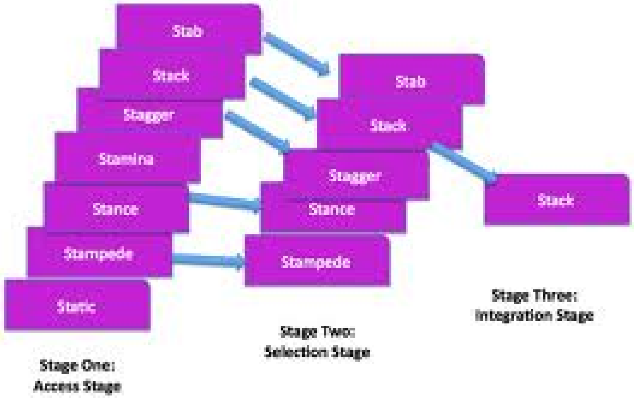


Figure: Access, Selection, Integration

Recognition Point

- (English) You hear [t], activate *tree*, *title*, *trespass*, *took*, *treadle* ....

Recognition Point

- (English) You hear [t], activate *tree, title, trespass, took, treadle* ....
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- At any point, if context ruled out other competitors, we could have settled on **trespass** earlier

Initial phoneme (about 150 ms) used to activate consistent words

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- Activated words form a cohort

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That are no longer consistent are eliminated, until only one word is left (the Uniqueness Point) this word is recognized.

Evidence supporting COHORT

Priming experiment (Marslen-Wilson and Zwitserlood 1989)

- *cap***t***ain* vs. *cap***t***ive*

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Further Evidence supporting COHORT

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  - Fluent restorations most likely in final syllable

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5. TRACE prediction: *pone* can activate *bone*
6. But COHORT predicts no activation (correct)

Third Generation: Distributed Feature Model

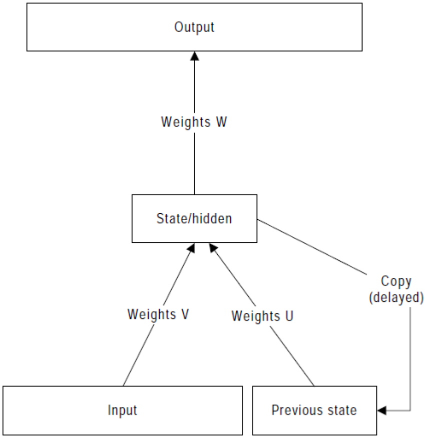

Figure: Simple Recurrent Network (SRN)

Properties of SRN

- Words represented as a pattern of neural activity across a multi-layered network

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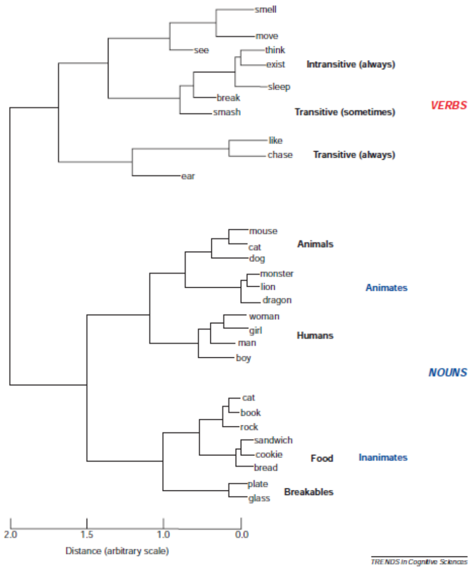
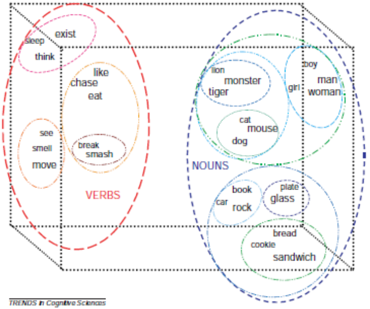
SRN Clusters



SRN Semantic Space



Lexical Ambiguity

- *They can fish*

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- *We serve retired people*

Lexical Ambiguity

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- *We serve retired people*
- *The pope married my sister*

The panda walks into the bar.

- *It eats shoots and leaves.*

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- *It eats, shoots and leaves.*

Context and ambiguity

- *The fisherman went to the* **bank**

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- *The fisherman went to the* **bank**
- *The thief went to the* **bank**

Exclusive vs. Exhaustive Access

To identify the correct meaning of an ambiguous word:

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Exclusive vs. Exhaustive Access

To identify the correct meaning of an ambiguous word:

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- Exhaustive access: All meanings of the word activated; Context cues kick in after

Evidence for Exhaustive Access

Seidenberg et al., 1982: Target words *listen/insect* provided immediately

1. *The spy swept the room looking for concealed* **bugs**

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No time difference depending on context!

Stimulus Offset Asynchrony (SOA)

Target words *listen/insect* provided after a gap of 250-500ms

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- Sentence1 on previous slide primes *listen*
- Sentence2 on previous slide primes *insect*

Figure: Ambiguity Experiment

Types of Lexical Ambiguity

1. **Biased**: Dominant and subordinate meanings
   This can is made of **tin**
   I bought a **tin** *of beans*

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Context and Ambiguity (Rayner & Pollatsek 1989)

Neutral context

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- Both meanings activated! (longer fixation duration compared to unambiguous words like *animals*)

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Results replicated using a neuroimaging experiment (Mason & Just)

Reordered Access Theory (Duffy et al., 1989)

2 factors: Dominance & Context

- More frequent meanings easier to access compared to less frequent ones
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- Like TRACE, competition amongst representations
- Biased: Dominant meaning triumphs
- Balanced: Competing representations take long to process
- Context also plays a role

Summary: Context and Ambiguity

1. **Balanced ambiguous words**: Neutral context (slow), Biased context (fast)
2. **Biased ambiguous words**: Neutral context (fast), Biased context (fast-dominant; slow-subordinate)

Neural Basis of Lexical Representation and Access

- Linguistic + World knowledge combine to confer meaning
- Wide spread left lateralization though right hemisphere also plays a role

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- Linguistic + World knowledge combine to confer meaning
- Wide spread left lateralization though right hemisphere also plays a role
- Differences in processing of *a crack* vs. *to crack*

Side view of left hemisphere

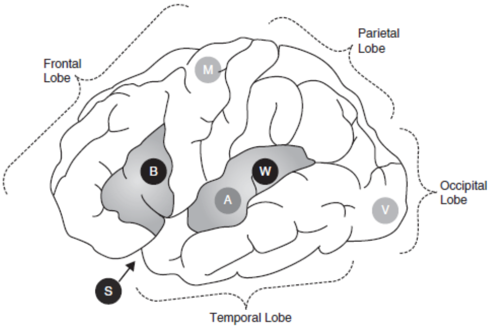


Figure:

- **B**: Broca's area
- **W**: Wernicke's area
- **M**: Motor processing
- **A**: Auditory processing
- **V**: Visual processing

Neural Responses

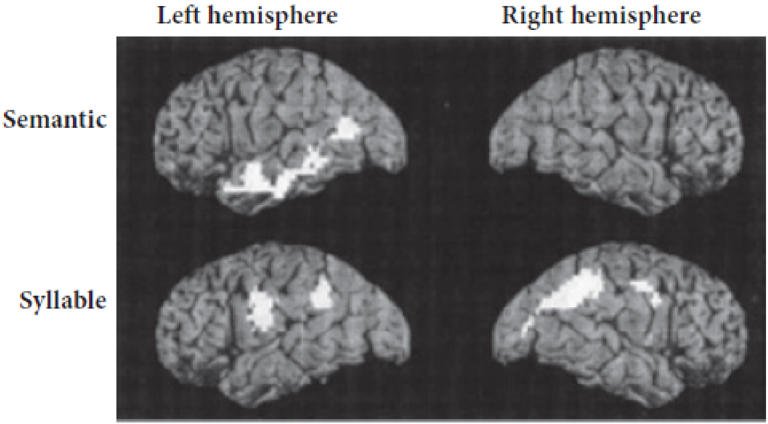


Figure: Semantic judgment task (top) and a phonological judgment task (bottom)

Event Related Potential (ERP) studies

- **Martin et al., 1996**: Different activations for pictures of animals and tools
- **Nobre et al., 1997**: Concrete (*cat, dog, table*) vs. Function words (*between, because, where*)

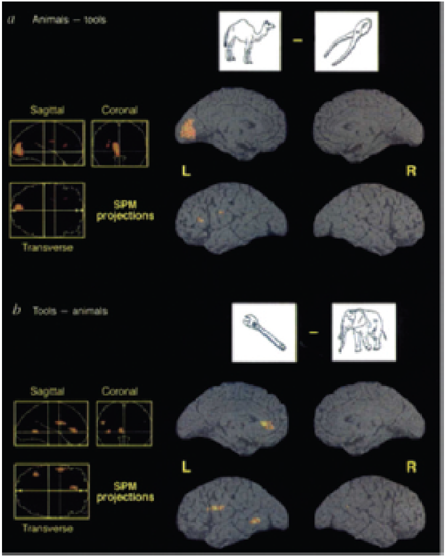


Figure: Top half: Greater occipital lobe activity during animal naming; Bottom half shows greater inferior frontal lobe activity during tools

fMRI data for abstract versus perceptual properties of animals (shown in orange; Goldberg, Perfetti, Fiez, & Schneider, 2007

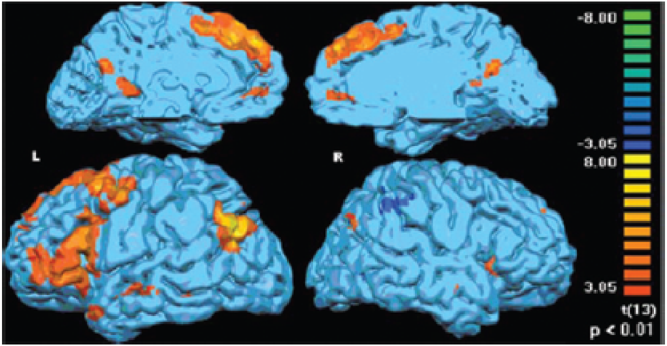
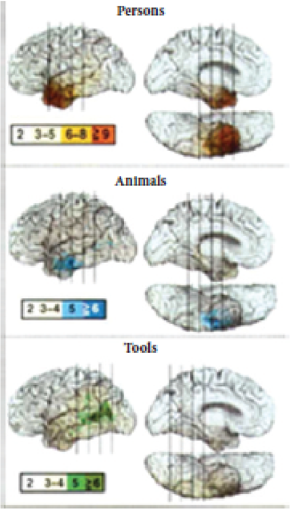


Figure: Questions that tapped visual features of animals led to increased activity in right parietal lobe (dark blue)

Lesionperformance correlations from Damasio, Grabowski, Tranel, Hichwa, & Damasio (1996)



Memory Representations

1. Localized
2. Distributed Memory Representations

Localized

- Semantic memory divided into separate categories (Caramazza & Hillis 1991; Pinker 1994)
- Evidence: Brain injury can result in loss of conceptual knowledge of tools

Category specific deficit

Patients suffering from specific production and comprehension disorders:

- Words corresponding to living vs. non-living things
- Nouns vs. verbs
- Artificial vs. Natural objects

Caramazza & Hillis 1991

	N	H.W. Total errors (%)	H.W. Semantic errors (%)	S.J.D. Total errors (%)	S.J.D. Semantic errors (%)
Spoken output					
Reading	296	53	73	2	0
Naming	60	63	81	2	0
Written output					
Dictation	296	0	0	13	64
Naming	60	0	0	50	100

Figure: HW: Left parietal region stroke; SJW: Left temporal region

Distributed Memory Representations

- Concepts encoded as *Hebbian* groups of neurons
- When one cell component gets active, it fires other components

Distributed Memory Representations

- Concepts encoded as *Hebbian* groups of neurons
- When one cell component gets active, it fires other components
- Nouns related to visual objects represented in visual neurons
- Verbs represented in both visual and motor neurons

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Pulvermuller (1999) says

- Such assemblies form when different groups of neurons are active at the same time

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- Sound will similarly activate perceptual and functional representations associated with the name

Criticism of Localization

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- Degradation of semantic knowledge is not all or nothing

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- Judgements to discriminate between different concepts fired anterior part of temporal lobe
- Questions that tapped shared features were not associated with greater signal intensity in the anterior temporal lobes
- Complex features and combinations of features supported by more anterior regions
- But without a dissociation between living and non-living categories in terms of where in the brain associated information is stored.

Assumption of Distributed Knowledge

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Assumption of Distributed Knowledge

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1. Word *cat* activates a wide variety of brain regions
2. How can we have a problem with just animals or with just tools?

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- Living things have properties that tend to be highly correlated
- Non-living things are also more likely to have multiple distinguishing features than living things

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- Discriminating living things is to pick out the few, highly specific discriminating features
- from among the larger number of highly correlated common features

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