Language

• Just another set of input/output paths.
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• Levels: phonemes/letters, words, phrases, sentences, paragraphs, and beyond.
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- Just another set of input/output paths.
- Levels: phonemes/letters, words, phrases, sentences, paragraphs, and beyond.
- Huge combinatorial power: distributed reps over time!
Overview of Models

- Distributed lexicon (ortho, phono, sem): reading & dyslexia.
- Orthography to phonology in reading: *regularities and exceptions*.
- Semantics to phonology and past tense overregularizations.
- Semantic representations from word co-occurrences.
- Sentence-level processing and the sentence gestalt.
Biological Substrates of Language

Frontal

Broca's

Wernicke's

Temporal

Parietal

Occipital
Phonology Features: Vowels

<- front | back ->

1 2 3 4 5 6 7

^ +---------------------+

u 1 E--A_ U
p 2 \ i --\ u |__hi_\^
3 \ e \ --Y-- / O
d \ \ \ \ \ /-

o 4 \ \ \ ^ / \--o
w 5 @ -I- W |__lo_v__
n \ \ / |
v 6 ----- a ------+

lips round/flat, long/short
**Phonology Features: Consonants**

place where airflow is restricted:
labial, labio-dental, dental, alveolar, palatal, velar, glottal

manner in which restricted:
plosive, fricative, semi-vowel, liquid, nasal

vocalized, not vocalized

<table>
<thead>
<tr>
<th>Phon</th>
<th>Examples</th>
<th>Loc</th>
<th>Mnr</th>
<th>Vce</th>
</tr>
</thead>
<tbody>
<tr>
<td>/p/</td>
<td>pit</td>
<td>lb</td>
<td>ps</td>
<td>−</td>
</tr>
<tr>
<td>/b/</td>
<td>bit</td>
<td>lb</td>
<td>ps</td>
<td>+</td>
</tr>
<tr>
<td>/m/</td>
<td>mit</td>
<td>lb</td>
<td>ns</td>
<td>+</td>
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<td>/t/</td>
<td>tip</td>
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<tr>
<td>/d/</td>
<td>dip</td>
<td>al</td>
<td>ps</td>
<td>+</td>
</tr>
<tr>
<td>/n/</td>
<td>nick</td>
<td>al</td>
<td>ns</td>
<td>+</td>
</tr>
<tr>
<td>/k/</td>
<td>cat</td>
<td>vl</td>
<td>ps</td>
<td>−</td>
</tr>
<tr>
<td>/g/</td>
<td>get</td>
<td>vl</td>
<td>ps</td>
<td>+</td>
</tr>
</tbody>
</table>
Language Questions

• What general processes are involved in reading, and how do these sometimes fail (e.g., in dyslexia)?
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• How are we able to read “cat”, “yacht”, and “nust”? 
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- How do we go beyond words to sentences?
Phonological: nonwords ("nust") impaired.

Deep: phono + semantic errors ("dog" as "cat") + visual errors ("dog" as "dot").

Surface: nonwords OK + semantic access impaired + difficulty reading exception words ("yacht") + visual errors.
Cleanup self-connections.
20 concrete (more features), 20 abstract.
Simulating Dyslexia

<table>
<thead>
<tr>
<th>Layer(s) lesioned</th>
<th>Dyslexia Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comp Sem</td>
<td>Surface</td>
</tr>
<tr>
<td>Comp Dir</td>
<td>Deep</td>
</tr>
<tr>
<td>OS_Hid</td>
<td>Surface</td>
</tr>
<tr>
<td>SP_Hid</td>
<td>Surface</td>
</tr>
<tr>
<td>OP_Hid</td>
<td>Phonology</td>
</tr>
<tr>
<td>OS_Hid + Comp Dir</td>
<td>Deep</td>
</tr>
<tr>
<td>SP_Hid + Comp Dir</td>
<td>Deep</td>
</tr>
<tr>
<td>OP_Hid + Comp Sem</td>
<td>Surface</td>
</tr>
</tbody>
</table>

Diagram showing layers and connections.
Semantic Pathway Lesions, Intact Direct

Concrete

Abstract

SP_Hid

OS_Hid

SP_Hid

OS_Hid

Visual
Vis + Sem
Semantic
Blend
Other

Errors

Lesion Proportion

0.0 0.2 0.4 0.6 0.8

0 5 10 15 20

0 0.2 0.4 0.6 0.8
Direct Pathway Lesion

![Graph showing errors in Visual, Vis + Sem, Semantic, Blend, and Other categories for Concrete and Abstract concepts with and without Sem.](image-url)
• Distributed reps (not localized to one region).

• Interactive (not modules), leads to interesting divisions of labor.
Language Questions

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Regularities & Exceptions: A Continuum

Regularities in pronunciation are often partial, context dependent:
Regularities & Exceptions: A Continuum

Regularities in pronunciation are often partial, *context dependent*: bint
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*i* in *mint, hint*.. vs *mind, find*.. except: *pint*
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Exceptions are extreme of context dependent.
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Seidenberg & McClelland (1989) used extremely context dependent *wickelfeatures*: _think_ = _th, thi, hin, ink, and nk_
Regularities & Exceptions: A Continuum

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PMSP used hand-coded context independent inputs (+ some conjunctions).
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PMSP used hand-coded context *independent* inputs (+ some conjunctions).

*Need a range of context dependency for regulars and exceptions.*
Reading as Object Recognition

Tradeoff between dependence & independence similar to object recognition: need invariance but also need to bind features.
Reading Model
Nonword Performance

Regularity tests (Glushko): bint → /bint/

Pseudo-homophones (McCann & Besner):
phoyce → /fYs/, choyce → /CYs/

Matched regularity/exception cases (Taraban):
High freq: poes → /pOz/, goes → /gOz/, does → /d^z/
Low freq: mose → /pOs/, poes → /pOz/, lose → /lUz/

<table>
<thead>
<tr>
<th>Nonword Set</th>
<th>Model</th>
<th>PMSP</th>
<th>People</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glushko regulars</td>
<td>95.3</td>
<td>97.7</td>
<td>93.8</td>
</tr>
<tr>
<td>Glushko exceptions raw</td>
<td>79.0</td>
<td>72.1</td>
<td>78.3</td>
</tr>
<tr>
<td>Glushko exceptions alt OK</td>
<td>97.6</td>
<td>100.0</td>
<td>95.9</td>
</tr>
<tr>
<td>McCann &amp; Besner ctrls</td>
<td>85.9</td>
<td>85.0</td>
<td>88.6</td>
</tr>
<tr>
<td>McCann &amp; Besner homoph</td>
<td>92.3</td>
<td>n/a</td>
<td>94.3</td>
</tr>
<tr>
<td>Taraban &amp; McClelland</td>
<td>97.9</td>
<td>n/a</td>
<td>100.0¹</td>
</tr>
</tbody>
</table>
Language Questions

- What general processes are involved in reading, and how do these sometimes fail (e.g., in dyslexia)? *Distributed lexicon* (*ortho, phono, sem*)

- How are we able to read “cat”, “yacht”, and “nust”? *Range of context dependent reps & continuum of regularity-exception*.

- Why do kids say “I goed to school” *after* first saying “I went”?

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Past Tense

Simple production model: semantics to phonology, with inflections:

- Phonology
- ed
  - (strong correlation)
- Semantics
  - past tense
Past Tense: U-Shaped Curve

This is the interesting target developmental phenomenon:

Overregularization in Adam

Eventual correct performance assumed
U-Shaped History

Initially: separate, overzealous rule system.
U-Shaped History

Initially: separate, overzealous rule system.

Then: Rumelhart & McClelland, U-shaped curve based on network processing of regularities.
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Later: Plunkett et al., etc, manipulate enviro in graded way.
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Later: Plunkett et al., etc, manipulate enviro in graded way.

Problem: backprop is gradient descent!
U-Shaped Model in Leabra

Interactivity, competition & Hebbian learning produce network that is in dynamic balance between reg & irreg mappings.

Small tweaks can shift it one way or the other! (priming model).
The Past Tense Model

Phonology

Hidden

Semantics
# The Past Tense Model

<table>
<thead>
<tr>
<th>Inflection</th>
<th>Reg sfx</th>
<th>Regular/Irregular examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Base</strong></td>
<td>–</td>
<td>I walk to the store daily.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I go to the store daily.</td>
</tr>
<tr>
<td><strong>Past</strong></td>
<td>-ed</td>
<td>I walked to the store yesterday.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I went to the store yesterday.</td>
</tr>
<tr>
<td><strong>3rd pers sing</strong></td>
<td>-s</td>
<td>She walks to the store daily.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>She goes to the store daily.</td>
</tr>
<tr>
<td><strong>Progressive</strong></td>
<td>-ing</td>
<td>I am walking to the store now.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I am going to the store now.</td>
</tr>
<tr>
<td><strong>Past participle</strong></td>
<td>-en</td>
<td>I have walked to the store before.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I have gone to the store now.</td>
</tr>
</tbody>
</table>
Past Tense Results

(a) Overregularization in Leabra

(b) Overregularization in Bp
Past Tense Results

**Early Correct Responding**

<table>
<thead>
<tr>
<th></th>
<th>Bp</th>
<th>L H0</th>
<th>L H001</th>
<th>L H005</th>
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</thead>
<tbody>
<tr>
<td>Responses</td>
<td>25</td>
<td>75</td>
<td>50</td>
<td>100</td>
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</tbody>
</table>

**Total Overregularizations**

<table>
<thead>
<tr>
<th></th>
<th>Bp</th>
<th>L H0</th>
<th>L H001</th>
<th>L H005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overregularizations</td>
<td>200</td>
<td>150</td>
<td>100</td>
<td>50</td>
</tr>
</tbody>
</table>

Legend:
- White: To 1st OR
- Gray: To 2nd OR
Language Questions

- What general processes are involved in reading, and how do these sometimes fail (e.g., in dyslexia)? Distributed lexicon (ortho, phono, sem)

- How are we able to read “cat”, “yacht”, and “nust”? Range of context dependent reps & continuum of regularity-exception.

- Why do kids say “I goed to school” after first saying “I went”? Dynamic balance between regular & exception mapping.

- How do words come to mean anything?

- How do we go beyond words to sentences?
How Do Words Come to Mean Anything?

- What Gives Words Their Meaning?
- Where Does this Meaning Come From?
What Gives Words Their Meaning? Distributed Semantics

Semantics is distributed across specialized processing areas.
Model: Correlational Semantics

Hebbian learning to encode structure of word co-occurrence.

Same idea as:

- V1 receptive field learning: learn the strong correlations.
- Latent Semantic Analysis (LSA) (but avoids “blobs” of PCA).
## Multiple-Choice Quiz

<table>
<thead>
<tr>
<th></th>
<th>0. neural activation function</th>
<th>1. transformation</th>
<th>2. bidirectional connectivity</th>
<th>3. cortex learning</th>
<th>4. object recognition</th>
<th>5. attention</th>
<th>6. weight based priming</th>
<th>7. hippocampus learning</th>
<th>8. dyslexia</th>
<th>9. past tense</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>spiking rate code membrane potential pt</td>
<td>emphasizing distinctions collapsing diffs</td>
<td>amplification pattern completion</td>
<td>error driven task based hebbian model</td>
<td>gradual feature conjunction spatial invar</td>
<td>competition inhibition selection binding</td>
<td>A long term changes learning</td>
<td>A fast arbitrary details conjunctive</td>
<td>A surface deep phonological reading problem</td>
<td>A overregularization shaped curve</td>
</tr>
<tr>
<td>B</td>
<td>interactive bidirectional feedforward</td>
<td>error driven hebbian task model based</td>
<td>competition inhibition selection binding</td>
<td>error driven task based</td>
<td>error driven task based hebbian model</td>
<td>gradual feature conjunction spatial invariance</td>
<td>B active maintenance short term residual</td>
<td>B slow integration general structure</td>
<td>B speech output hearing language nonwords</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>language generalization nonwords</td>
<td>spiking rate code membrane potential pt</td>
<td>language generalization nonwords</td>
<td>language generalization nonwords</td>
<td>amplification pattern completion</td>
<td>spiking rate code membrane potential pt</td>
<td>C fast arbitrary details conjunctive</td>
<td>C error driven hebbian task model based</td>
<td>C fast arbitrary details conjunctive</td>
<td></td>
</tr>
</tbody>
</table>
Sentences

Traditional approach:

Alternative approach:

Distributed reps of sentence meaning: The sentence Gestalt!

Parallel to object recognition issues: 3D structural model vs. distributed reps that distinguish different objects.
Toy World

People: busdriver (adult male), teacher (adult female), schoolgirl,

Actions: eat, drink, sit, spread, kiss, give, hit, throw, drive, rise,

Objects: spot (the dog), steak, soup, ice cream, crackers, jelly, iced tea, cool aid, spoon, knife, finger, rose, bat (animal), bat (baseball),

Locations: kitchen, living room, shed, and park,

Syntax: Active & Passive, phrases.
Network
## Tests

<table>
<thead>
<tr>
<th>Task</th>
<th>Sentence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Role assignment</td>
<td></td>
</tr>
<tr>
<td>Active semantic</td>
<td>The schoolgirl stirred the kool-aid with a spoon.</td>
</tr>
<tr>
<td>Active syntactic</td>
<td>The busdriver gave the rose to the teacher.</td>
</tr>
<tr>
<td>Passive semantic</td>
<td>The jelly was spread by the busdriver with the knife.</td>
</tr>
<tr>
<td>Passive syntactic</td>
<td>The teacher was kissed by the busdriver.</td>
</tr>
<tr>
<td>(control)</td>
<td>The busdriver kissed the teacher.</td>
</tr>
<tr>
<td>Word ambiguity</td>
<td>The busdriver threw the ball in the park.</td>
</tr>
<tr>
<td></td>
<td>The teacher threw the ball in the living room.</td>
</tr>
<tr>
<td>Concept instantiation</td>
<td>The teacher kissed someone (male).</td>
</tr>
<tr>
<td>Role elaboration</td>
<td>The schoolgirl ate crackers (with finger).</td>
</tr>
<tr>
<td></td>
<td>The schoolgirl ate (soup).</td>
</tr>
<tr>
<td>Online update</td>
<td>The child ate soup with daintiness.</td>
</tr>
<tr>
<td>(control)</td>
<td>The pitcher ate soup with daintiness.</td>
</tr>
<tr>
<td>Conflict</td>
<td>The adult drank iced-tea in the kitchen (living-room).</td>
</tr>
</tbody>
</table>
Gestalt Representations

SG Gestalt Patterns

Y

16.00 -
15.00 -
14.00 -
13.00 -
12.00 -
11.00 -
10.00 -
9.00 -
8.00 -
7.00 -
6.00 -
5.00 -
4.00 -
3.00 -
2.00 -
1.00 -
0.00 -

0.00  2.00  4.00  6.00  8.00

X
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- Why do kids say “I goed to school” after first saying “I went”? Dynamic balance between regular & exception mapping.

- How do words come to mean anything? Statistics of co-occurrence.

- How do we go beyond words to sentences? Sentence gestalt.