What do hidden representations learn?

Plaut and Shallice (1993)

- Mapped orthography to semantics (unrelated similarities)
- Compared similarities among hidden representations to those among orthographic and semantic representations (over settling)

- Hidden representations “split the difference” between input and output similarity

Other animals don’t like onions (but primates do)

- No correlation for “specific” weights because inputs vary
- No correlation for “more general” weights because output varies
- Only intermediate “general” weights build up due to correlations
Progressive deterioration in semantic dementia

**a** Picture naming responses for JL

<table>
<thead>
<tr>
<th>Item</th>
<th>Sept. 91</th>
<th>March 92</th>
<th>March 93</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bird</td>
<td>+</td>
<td>+</td>
<td>Animal</td>
</tr>
<tr>
<td>Chicken</td>
<td>+</td>
<td>+</td>
<td>Animal</td>
</tr>
<tr>
<td>Duck</td>
<td>+</td>
<td>Bird</td>
<td>Dog</td>
</tr>
<tr>
<td>Swan</td>
<td>+</td>
<td>Bird</td>
<td>Animal</td>
</tr>
<tr>
<td>Eagle</td>
<td>Duck</td>
<td>Bird</td>
<td>Horse</td>
</tr>
<tr>
<td>Ostrich</td>
<td>Swan</td>
<td>Bird</td>
<td>Animal</td>
</tr>
<tr>
<td>Peacock</td>
<td>Duck</td>
<td>Bird</td>
<td>Vehicle</td>
</tr>
<tr>
<td>Penguin</td>
<td>Duck</td>
<td>Bird</td>
<td>Part of animal</td>
</tr>
<tr>
<td>Racoon</td>
<td>Chicken</td>
<td>Chicken</td>
<td>Dog</td>
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</table>

**b**

<table>
<thead>
<tr>
<th>Feature type</th>
<th>DB</th>
<th>DC</th>
<th>IF</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brown</td>
<td>0.1</td>
<td>0.2</td>
<td>0.3</td>
<td>0.4</td>
</tr>
<tr>
<td>Black</td>
<td>0.5</td>
<td>0.6</td>
<td>0.7</td>
<td>0.8</td>
</tr>
<tr>
<td>Red</td>
<td>0.9</td>
<td>1.0</td>
<td>1.1</td>
<td>1.2</td>
</tr>
<tr>
<td>Yellow</td>
<td>1.3</td>
<td>1.4</td>
<td>1.5</td>
<td>1.6</td>
</tr>
<tr>
<td>Green</td>
<td>1.7</td>
<td>1.8</td>
<td>1.9</td>
<td>2.0</td>
</tr>
</tbody>
</table>

**c** IF’s delayed copy of a camel

**d** DC’s delayed copy of a swan

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Rumelhart and Todd (1993)

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Semantic hierarchy

Progressive differentiation in development
Progressive differentiation of concepts

Internal representations

Perceptual to conceptual shift
Semantic memory

Unitary, amodal semantic system
- General conceptual knowledge abstracted from a large number of individual episodes or experiences (Tulving, 1972).
- Mediates among multiple input and output modalities
- Can be selectively impaired by brain damage, usually to the anterior temporal lobes (Warrington, 1975).

Challenges
- Modality-specific effects in semantic priming
- Category- and modality-specific semantic deficits
- Modality-specific naming disorders (e.g., optic aphasia)

Challenges to unitary semantics account

Post-semantic lesion
- No basis for sensitivity to input modality

Semantic lesion
- Would impair visual gesturing and non-visual naming

Pre-semantic lesion
- Would impair visual gesturing (and other measures of comprehension)
  - But might be preserved relative to naming due to privileged access (Caramazza et al., 1990)

Alternative view of semantic organization

Multiple modality-specific semantic systems (Beauvois, 1982; Lhermitte & Beauvois, 1973; Shallice, 1987; Warrington, 1975)

Optic aphasia

Selective impairment in visual object naming
- Brain damage to left medial occipital lobe (visual cortex and underlying white matter)
- Not visual agnosia—relatively preserved visual gesturing and other tests of visual comprehension
- Not general anomia—relatively preserved naming from other modalities (e.g., touch, spoken definitions)
- Relatively preserved naming of actions associated with visually presented objects (Manning & Campbell, 1996)

<table>
<thead>
<tr>
<th>Study</th>
<th>Visual Naming</th>
<th>Visual Gesturing</th>
<th>Tactile Naming</th>
<th>Action Naming</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lhermitte &amp; Beauvois (1973)</td>
<td>73</td>
<td>100</td>
<td>91</td>
<td></td>
</tr>
<tr>
<td>Teixeira Ferreira et al. (1997)</td>
<td>53</td>
<td>95</td>
<td>81</td>
<td>75</td>
</tr>
<tr>
<td>Manning &amp; Campbell (1996)</td>
<td>27</td>
<td>75</td>
<td>90</td>
<td>67</td>
</tr>
<tr>
<td>Coslett &amp; Saffran (1989)</td>
<td>0</td>
<td>50</td>
<td>92</td>
<td></td>
</tr>
</tbody>
</table>

% Correct Performance

Analogous selective naming deficits have been observed for tactile input (Beauvois et al., 1978) and for auditory input (Denes & Semenza, 1975)

Problems
- Unparsimonious and post-hoc
- Poor accounts of acquisition, cross-modal generalization and priming
- No account of relative sparing of visual action naming
Current approach

- The semantic system operates according to connectionist/parallel distributed processing (PDP) principles:
  - **Processing**: Responses are generated by the interactions of large numbers of simple, neuron-like processing units.
  - **Representation**: Within each modality, similar objects are represented by overlapping distributed patterns of activity.
  - **Learning**: Knowledge is encoded as weights on connections between units, adjusted gradually based on task performance.

- Semantic representations develop a **graded degree of modality-specific specialization** in learning to mediate between multiple input and output modalities.

- Graded specialization derives from two factors:
  1. **Task systematicity**: Whether similar inputs map to similar outputs
     - Naming is an unsystematic task
  2. **Topographic bias**: Learning favors “short” connections (Jacobs & Jordan, 1992)
     - Mappings rely most on regions of semantics “near” relevant modalities

Tasks

- Naming objects from vision or touch
- Naming and gesturing action associated with objects from vision or touch

<table>
<thead>
<tr>
<th>Stimulus (Vision or Touch)</th>
<th>Task</th>
<th>Phonology</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vision</td>
<td>object</td>
<td>“bed”</td>
<td>-</td>
</tr>
<tr>
<td>Touch</td>
<td>action</td>
<td>“sleep”</td>
<td>⬤</td>
</tr>
</tbody>
</table>

Training procedure

- Object ($N = 100$), modality of presentation (Vision vs. Touch), and task (object vs. action) chosen randomly during training
- Activations clamped on appropriate input modality; network settled for 5.0 units of time ($\tau = 0.2$); error injected only over last time unit
- Error derivatives for each weight calculated by back-propagation-through-time adapted for continuous-time networks (Pearlmutter, 1989)
- **Weight changes scaled by Gaussian function** ($SD = 10$) of connection length (cf. Jacobs & Jordan, 1992)
- 110,000 total object presentations ($\approx 275$ per condition); all output activations on correct side of 0.5 for all objects and tasks
Semantic similarity

Mean correlations among pairs of semantic representations generated by each object in each input modality (note: relatedness is relative to visual categories).

- An object is most similar to itself regardless of modality of presentation (but cross-modal representations are not identical)
- Accounts for reduction in semantic priming with cross-modal presentation
Topographic lesions

Lesions applied to Vision $\Rightarrow$ Semantics connections
- Probability of removing each connection is a Gaussian function of the distance of unit from lesion location; $SD$ of Gaussian controls severity (1.5 below).

Effects of lesion location

Performance on visual naming and visual gesturing after lesions to Vision $\Rightarrow$ Semantics connections centered at each location (10 repetitions each; $SD = 1.5$).

Effects of lesion severity

- Highly selective impairment of visual object naming relative to visual gesturing and tactile naming
- Relative preservation of visual action naming

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<td></td>
</tr>
</tbody>
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Control simulation: No topographic bias

- Exact replication of simulation except without topographic bias

- Relative degrees of impairment due to differences in task systematicity

- Effect is not as large as in patients

Modality-specific impairment of grammatical categories

Selective impairment on nouns vs. verbs restricted to a particular input or output modality (Caramazza & Hillis, 1991; Hillis & Caramazza, 1995; Rapp & Caramazza, 1997)

- Patient HW (Caramazza & Hillis, 1991)
  - nouns > verbs in spoken output but not in written output

- Patient EBA (Hillis & Caramazza, 1995)
  - two lesions: left frontal and left temporal

Generating object names vs. action names

Performance after lesions to semantics ($SD = 2.0$).

Visual Object Naming  Visual Action Naming

- Generating names of actions associated with objects involves interactions with Action representations.

Modality-specific impairment of grammatical categories

Account 1: Modality-specific lexical representations divided by grammatical category
(Caramazza & Hillis, 1991; Hillis & Caramazza, 1995; Rapp & Caramazza, 1997)
Modality-specific impairment of grammatical categories

Account 2: Modality-specific access pathways divided by grammatical category (Rapp & Caramazza, 1997)

Modality-specific impairment of grammatical categories

Object naming – Action naming (white: nouns > verbs; black: verbs > nouns)

Incoming Lesions
Vision ⇒ Semantics (SD = 2.0)

Outgoing Lesions
Semantics ⇒ Phonology (SD = 1.5)

• Nouns depend more on semantics near Vision/Phonology; Verbs depend more on semantics near Action/Touch

• Lesions to incoming/outgoing connections produce modality-specific grammatical category impairments

Summary

• Differences in task systematicity and a topographic bias on learning produce a graded degree of modality-specific specialization within semantics.

⇒ The network does not develop separate modality-specific semantic systems—both visual and tactile input engage all of semantics.

• Damage to connections from vision to regions of semantics near phonology produces a highly selective visual naming deficit as observed in optic aphasia.

• The relative sparing of naming visual actions in optic aphasia results from the preserved support of action representations.

• Modality-specific impairments to nouns vs. verbs can arise from lesions to/from regions of semantics partially specialized for these grammatical classes.