Two cortical visual systems (Ungerleider & Mishkin, 1982)

- **'WHERE' PATHWAY**
  - Dorsal stream
  - Parietal lobe

- **Primary visual cortex**
  - Occipital lobe

- **'WHAT' PATHWAY**
  - Ventral stream
  - Temporal lobe

Object recognition

(Distributed representations in state space)

Ventral pathway

Recognition as untangling object “manifolds”
Single neuron responses in inferotemporal cortex (IT)

Deep convolutional neural networks (CNNs)

Preserving identity across changes in viewing conditions

Learned features

Krizhevsky, Sutskever, and Hinton (2012, NIPS)
What does a deep network learn?

- Feedforward network: 40 inputs to 40 outputs via 6 hidden layers (of size 40)
- Random input patterns map to random output patterns \((n = 100)\)
- Compute pairwise similarities of representations at each hidden layer and compare to (correlate with) pairwise similarities of inputs and of outputs \((\Rightarrow \text{Representational Similarity Analysis})\)
- Network gradually transforms from input similarity to output similarity

Similarity of representations to neural representations in IT

Discrimination accuracy as a function of model complexity
Domain-specific cortical areas?

- **Visual Word-Form Area (VWFA)** (Petersen et al., 1992)
- **Fusiform Face Area (FFA)** (Kanwisher et al., 1999)
- **Parahippocampal Place Area (PPA)** (Epstein & Kanwisher, 1998)
- **Extrastriate Body Area (EBA)** (Downing et al., 2001)
- **Fusiform Body Area (FBA)** (Schwarzlose et al., 2005)

Faces and words: Homologous brain activation

**Faces (yellow)**

- Malach et al. (2002)
  \[x = 40, y = 55, z = 10\]

**Words**

- Cohen et al. (2000)
  \[x = 42, y = 57, z = 15\]

Faces and words: ERP (Rossion et al., 2003)
Faces and words: Impairments following brain damage

**Prosopagnosia**
- Visual recognition much poorer for faces vs. other objects
- Can be bilateral but right lesion suffices
- Rely on other cues for recognition

**Pure alexia**
- Impairment in word recognition in premorbidly literate adults
- Left occipitotemporal lesion
- No general language impairment
- Rely on sequential “letter-by-letter” strategy

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Computational principles of neural organization

**Representation are hierarchically organized**
The representation of information at each level, as a pattern of neural activity, **cooperates** with (i.e., mutually activates and reinforces) the representations of consistent information at lower and higher levels.

**Cooperation depends on available connectivity**
Connectivity is strongly constrained to minimize axon length (total volume); cooperating representations need to be close to each other.

**Inconsistent representations compete**
Representations of inconsistent information compete with each other to become active, and to become stronger through learning.

Interdependence of face and word processing (Plaut & Behrmann, 2011)
- As visual objects, faces and words are unrelated.
- However, both face and word recognition place extensive demands on **high-acuity visual information** from central vision (Malach et al.)
- Due to topographic constraints on neural organization, central visual information is **localized** in each hemisphere of the brain
- Both face and word representations need to be near central visual information to cooperate with it, but they compete with each other
- Words also need to cooperate with language-related representations (esp. phonology) which are typically left lateralized
- As a result, words become stronger in the left-hemisphere and faces become stronger in the right-hemisphere, but they are **mixed in both hemispheres** and therefore influence each other
Retinotopy and eccentricity: Early visual hierarchy

FFA is adjacent to central visual information (Malach et al., 2002)

Simulation (Plaut & Behrmann, 2011)

Stimuli: Faces
**Stimuli: Words**

- Bag
- Bed
- Beg
- Bet
- Bid
- Big
- Bit
- Bud
- But
- Dad
- Did
- Dig
- Dip
- Dog
- Dot
- Dug
- Mud
- Met
- Men
- Mat
- Map
- Man
- Mad
- Pad
- Pan
- Pen
- Pet
- Pig
- Pip
- Pop
- Pot
- Put
- Tag
- Tan
- Tap
- Ten
- Tin
- Tip
- Ton
- Top

**Stimuli: Houses**

- Houses

**Polar coordinates; Variation in scale**

- 34 faces, 9 houses, 40 words, varying in scale
- Input in polar coordinates (eccentricity, angle)

**Network architecture**

- Network diagrams showing different layers and connections for processing.
Lesioning method

- For each horizontal position (central to peripheral) in each hemisphere, remove three adjacent columns of intermediate (fusiform) units
- Measure recognition performance on faces, words and houses (across all scales)

Predictions

- **Domain generality**
  - Ventral temporal-occipital cortex should be involved in any fine-grained visual discrimination
- **Bilateral participation**
  - Unilateral lesions should impact both faces and words
- **Competition for representation**
  - Degree of face and word lateralization should be related within individuals
Neuropsychological data (Behrmann & Plaut, 2012)

- **Pure-alexic** patients with unilateral left-hemisphere lesions (n=4)
- **Prosopagnosic** patients with unilateral right–hemisphere lesions (n=3)

Face processing: Same-different judgements

Word processing: Lexical decision

Development of face and word lateralization (Dundas et al., 2012)
Effects of literacy on VWFA activation (Dehaene et al., 2010)

Computational principles of neural organization

Cooperation and competition among representations

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