Brain and Information
Synapse

Figure 1: Drawing of the visual cortex of the rat (S. Ramón y Cajal, 1889).
UNIPOLAR

MULTIPOLAR CELLS

BIPOLAR

Broca’s area

Pars opercularis

Primary Auditory cortex

Wernicke’s area

Motor cortex

Sensory associative cortex

Somatosensory cortex

Sensory associative cortex

Visual associative cortex

Visual cortex
PET scan of blood flow for 4 word tasks

Somatotopy of Action Observation

Fig. 4

- Foot Action
- Hand Action
- Mouth Action

The Brain - Functions
The Different Regions of the Brain

- The medulla controls heart rate, breathing, peristalsis, and reflexes such as sneezing.
- The hypothalamus controls temperature and water homeostasis. Also controlling the release of hormones by the pituitary gland.
- The thalamus is a relay station, integrating sensory input and channelling it to the sensory areas of the cerebrum.
- The cerebellum co-ordinates muscle movement and so controls balance, posture and movement.

Cortex

- Sensory Areas- these receive impulses via sensory neurones from receptors that detect the stimuli reaching the body. The skin has more receptors in some parts of the body than others
- Motor areas send impulses to skeletal muscles along nerve fibres passing down the brain stem and spinal cord. As with the sensory areas the part of the body is represented by an area of the motor cortex
- Association areas make decisions and send impulses through the motor areas
Visual cortex

Classic Cytoarchitectonic Map of Brodmann (1909)

Classical name for visual cortex: Areas 17, 18, 19
Visual Field and the Human Visual System

The visual field represented in its projection to the retina demonstrates how the lens of the eye inverts the image being viewed. Up is inverted down and right is represented on the left. Signals from the right retinas (left visual field) of both eyes travel through the optic nerve, optic tract, and optic radiations to the primary visual cortex in the right hemisphere. Signals from the left retinas (right visual field) travel to the left hemisphere. Primary visual cortex lies in the colored area along the calcarine sulcus. Colors show how the different sectors of the visual fields map on to primary visual cortex.

Cortex
Graphical representation
Receptive Fields of Lateral Geniculate Nucleus

Examples of receptive fields of brain cells

1. Response to light in center of cell’s field
2. Response to light in periphery of cell’s field

Diagram showing receptive field, center, and surround with activity of neuron and average activity.
Receptive Fields in Retinal Bipolar and Ganglion Cells

Receptive Fields of Lateral Geniculate and Primary Visual Cortex
Face Cells in Monkey

Computational Model of Object Recognition
(Riesenhuber and Poggio, 1999)
Hierarchical Template Matching:
Fukushima & Miyake (1982)’s Neocognitron

- Image passed through layers of units with progressively more complex features at progressively less specific locations.
- Hierarchical in that features at one stage are built from features at earlier stages
Mapping Human Striate Cortex (V1) with Positron Emission Tomography (PET)

• Checkerboards were used to present stimuli to different parts of the visual fields. The leftmost checkerboard is a foveal stimulus, the middle one presents a stimulus close to the fovea (parafoveal), and the rightmost one is a peripheral stimulus that surrounds the parafovea from 5.5 to 15°.
• Stimuli could also be presented to the upper quadrant (e.g., rightmost stimulus) or the lower quadrant (e.g., middle stimulus). (Courtesy of Posner and Raichle).

Checkerboard Stimuli and Calcarine Sulcus Activation

The foveal stimulus presented in the center of the visual field activated calcarine cortex most posteriorly and at the midline, the middle parafoveal stimulus stimulated calcarine cortex more anteriorly at the midline, and the rightmost more peripheral stimulus produced the most anterior activations at the midline.

Stimulation of the upper and lower halves of the visual field reliably produces areas of activation below (left) and above (right) the calcarine sulcus.
Extensive Interconnections Between Systems Identified in Primate Brain
Separation and Integration of Function

Areas of the monkey visual system (shown previously on unfolded cortex) are heavily interconnected.

Dorsal ("Where") and Ventral ("What") Visual Streams in Monkey

Parietal (Dorsal) and Temporal (Ventral) Processing Streams

Areas MT and V4 in the Macaque Brain
Dorsal (“Where”) and Ventral (“What”) Visual Streams in Human (PET)

Dorsal (where) pathway shown in green and blue and Ventral (what) pathway shown in yellow and red serve different functions. (Courtesy of Leslie Ungerleider).

Retinal and Thalamic Precursors of the Dorsal and Ventral Visual Pathways

Magnocellular (dorsal) and parvocellular (ventral) pathways from the retina to the higher levels of the visual cortex are separate at the lower levels of the visual system. At higher levels they show increasing overlap.
Object Recognition

- What is Object Recognition?
  - Segmentation/Figure-Ground Separation:
  - Labeling an object [The focus of most studies]
  - Extracting a parametric description as well

- Object Recognition versus Scene Analysis
  - An object may be part of a scene or
  - Itself be recognized as a “scene”
Shape perception and scene analysis

- Shape-selective neurons in cortex
  - Coding: one neuron per object
  - or population codes?
- Biologically-inspired algorithms for shape perception
- Visual memory: how much do we remember of what we have seen?
- The world as an outside memory and our eyes as a lookup tool

Four stages of representation (Marr, 1982)

1) pixel-based (light intensity)
2) primal sketch (discontinuities in intensity)
3) 2 ½ D sketch (oriented surfaces, relative depth between surfaces)
4) 3D model (shapes, spatial relationships, volumes)
Models of Object Recognition

- Transform & Match:
  - First take care of rotation, translation, scale, etc. invariances
  - Then recognize based on standardized pixel representation of objects.

Biederman: Recognition by Components

Biederman et al. (1991 – )

“geons”: units of 3D geometric structure
Recognition by components  
(Biederman, 1987)

- **GEONS**: geometric elements of which all objects are composed (cylinders, cones, etc). On the order of 30 different shapes

- Skips 2 ½ D sketch: Geons are directly recognized from edges, based on their nonaccidental properties (i.e., 3D features that are usually preserved by the projective imaging process)

---

Geons
Standard View on Visual Processing

- Image specific
- Supports fine discrimination
- Noise tolerant

visual processing

representation

- Image invariant
- Supports generalization
- Noise sensitive

Potential difficulties

A. Structural description not enough, also need metric info

B. Difficult to extract geons from real images

C. Ambiguity in the structural description: most often we have several candidates

D. For some objects, deriving a structural representation can be difficult

Figure 1: Conceptual problems with structural representations. A. Structural descriptions cannot be acquired by metric information, to represent differences among commonly encountered categories. The inclusion of metric details reduces the ability of structural methods to deal with novel objects. B. A picture of a New York City street corner with dog cars and a stroller object, which, as Edelman [3] suggests, may be described as such following a structural description in the visual cortex. At present, there is no reliable method for mapping a pre-made image into a collection of detected primitives (e.g. cars, curves, etc.) from which S&G's geons are constructed. Thus although a carefully engineered system such as that described in [2] can form a structural description of the line drawing of a candle object, the goal of deriving such a description directly from an image remains elusive. C. Even in simple tasks, e.g. object recognition, where the figure is readily separable from the ground, the distinction of structural description is problematic. The difficulty is coming from the possibility to assign multiple structural descriptions to the same image. D. In some tasks, coming up even with one structural description is problematic, how does one represent a shoe in terms of S&G's geons [??]
Eye Movements

- **Saccadic Movement**
  - fixation point to fixation point
  - dwell period: 200-600 msec
  - saccade: 20-100 msec

- **Smooth Pursuit Movement**
  - tracking moving objects in visual field

- **Convergent Movement**
  - tracking objects moving away or toward us
For example Attneave showed that a picture of a cat can be simplified by replacing all lines of low curvature with straight lines, as shown below, without adversely affecting the recognizability of the cat.

- In other words, the lines of low curvature represent redundant information, which therefore need not be explicitly stored in memory.

Biederman gives further evidence for this notion by showing that a cup remains recognizable after removal of its lines of low curvature, whereas it becomes unrecognizable after removal of its points of high curvature and line intersections.
Information Content of Contours

- Information associated with a contour is not uniformly distributed
- Experiment
  - Ask subject to place a number of fixed points on a blank sheet of paper so that they provide best approximation of a curve
  - People tend to place the points in the same relation
  - Histogram, number of subjects that placed points into these segments

If only six points were available, a person would most likely place them as shown (approximate the curve best)
- Illusion of the cat remains if large portions of the line segments are erased
- The information is concentrated in the neighborhood of the points of extreme curvature

Measurement on a circle
- First measurement the length is $S(\alpha)$, the more exact measurement is $S(\beta)$
Information Gain

- Length of arc of a circle of radius r subtended by an angle Θ is \( S(\Theta) = r \Theta \) if Θ is measured in radians
  - \( S(\alpha) = \alpha r \)
  - \( S(\beta) = \beta r \)

- \( I = \log_2(\frac{S(\alpha)}{S(\beta)}) = \log_2(\frac{\alpha}{\beta}) \) bits

- Information is always a relative quantity
- Information gained from the measurement of an interval must always be considered relative to some prior measurement

- **But** for direction and the angles that correspond to them, the situation is different
- We know a *priori* that the angle measure of a direction must lie between 0 and 2\(^*\pi\)

\[ S(\Theta) = r \Theta \]
Let be $\alpha = 2\pi$ the a priori knowledge (one “measurement”)

Let be $\beta$ a measurement

$I(\beta) = \log_2(\alpha / \beta) = \log_2(2\pi / \beta)$ bits

We need only one measurement!

Example

If $\beta = \pi$ the angle is a straight line and the information content is

- $I(\pi) = \log_2(2\pi / \pi) = \log_2(2) = 1$ bits

The measurement has specified that the observed direction lies in one half-of the planes
If $I(\pi /2) = 2$ bits
If $I(\pi /4) = 3$ bits
Smaller angles correspond to greater information

Information and contour

A contour is subdivided into short segments of equal length for some initial point $P$ to some final point $Q$
Each segmenting point (excluding P and Q) can be thought as the vertex of an angle formed with two neighboring points.

$A0A'$ is such an angle $\beta$.

Associated with that angle is its measure of information given by $I(\beta)$.

For each successive pair of angles along the path from $P$ to $Q$ prescribes the gain or loss of information passing from one angle to the next.
Example

- As we move in small steps from \(P\) to \(0\) along \(P0\) we see that each angle whose corresponding information is 1 bit.
- The information gain is passing from one straight line to the next, it is \(I(\pi) - I(\pi) = \log_2(\pi / \pi) = 0\), since the angle remains unchanged.
- When the right angle at vertex 0 is reached, there is a positive gain of information \(\log_2(\pi / (\pi/2)) = 1\) bit.
- At the next step, passing from right angle to the straight angle there is an information loss \(\log_2((\pi/2)/\pi) = -1\) bit.

- The right angle is the only place where the contour is curved, changes its direction.
- At the point of extreme curvature, the information is concentrated.
- Corners yield the greatest information.
- More strongly curved points yield more information.
Information content of a contour is concentrated in the neighborhood of points where the absolute value of the curvature is a local maximum.