Recap:
Defining the Modality of Sensation

- Proximal Stimulus
- Receptor Organ
- Afferent Tract
- Projection Area
Defining a Sensory Modality by Proximal Stimulation

- Vision: Rods, Cones in Retina
- Audition: Hair Cells in Cochlea
- Olfaction: Olfactory Epithelium
- Gustation: Taste Buds
- Touch: Cutaneous Receptors
- Temperature: Krause bulbs, Ruffini organs
- Pain: A-delta, C fibers
- Kinesthesia: Spindles, Golgi Organs
- Equilibrium: Hair Cells in Inner Ear
Problems for the Traditional View

• Non-Normative Stimulation
• Electrical Stimulation
  – Sensory Receptors
  – Sensory Nerves
The Doctrine of Specific Nerve Energies
Muller (1826)

- The Modality of Sensation is not Determined by the Proximal Stimulus.
- Each Sensory Nerve Reacts Differently to Stimulation.
- The Modality of Sensation is Determined by the Specific Nerve Activated by the Stimulus
Problems with the Original Doctrine

• No Specific “Nerve Energies”  
  – Adrian (1915)

• Electrical Stimulation of Projection Areas  
  – Penfield (1945)
The Doctrine of Specific Nerve Energies
Muller (1826), modified by Sperry (1945)

• Modality of sensation not determined by the proximal stimulus or the sensory receptor.

• Each sensory nerve reacts differently to stimulation.
  – *Muller*: Modality of sensation is determined by the activation of modality-specific nerves
  – *Sperry*: Modality of sensation is determined by the projection area to which the sensory impulse is delivered
Defining a Sensory Modality by Projection Area

- Vision: Primary Visual Area
- Audition: Primary Auditory Area
- Olfaction: Primary Olfactory Cortex
- Gustation: Primary Gustatory Cortex
- Touch: Primary Somatosensory Cortex
- Temperature: Somatosensory Cortex
- Pain: Somatosensory Cortex
- Kinesthesis: Somatosensory Cortex
- Equilibrium: Cerebellum
Qualities of Sensation
Boring (1953)

Intensity

• Vision
  – Brightness, Hue, Saturation

• Audition
  – Loudness, Pitch, Timbre

• Olfaction, Gustation
  – Flavor, Odor

• Touch
  – Roughness, Wetness (Pressure, Pain, Warmth)
The Psychophysical Principle

Every Psychological Quality of a Sensory Experience is Related to Some Physical Property of the Corresponding Stimulus
Qualities of Visual Sensation

• Hue
  – Wavelength
    465 nm
    495 nm
    570 nm
    700 nm

• Saturation
  – Amount of Gray
Qualities of Auditory Sensation
Seashore 1938; Howard & Angus (2006)

• Pitch
  – Frequency

• Timbre
  – Shape of Wave
    • Fundamental Frequency
    • Distribution of Harmonics
      – Flute, sine wave
        » Pure fundamental
      – Oboe, square wave
        » Fundamental + Odd harmonic
The Doctrine of Specific Fiber Energies

Helmholtz (1863, 1866), after Muller (1826)

Just as Every Modality of Sensation is Mediated by a Specific Neural System, so…

Within each Modality, Every Quality of Sensation is Mediated by a Specific Neural System
The Place Theory of Pitch

Helmholtz (1863); Bekesy (1960)

Wikipedia

Coat of Arms
Republic of Ireland

Oval Window

Higher Pitches

Lower Pitches
Duplex Theory of Pitch Perception
Wever & Bray (1930)

- **Place Principle**
  - Above 500-20,000 cps
- **Pure Frequency Principle**
  - Below 1,000 cps
- **Volley Principle**
  - 1,000 – 4,000 cps
The Problem of Color Vision
Newton (1704); Young (1802)

- 7 Million Shades of Color
  - Hue, Brightness, Saturation
  - Pantone: 3,039 Specific Colors
    - 300 Shades of Blue
The Search for Primary Colors
Young (1802); Maxwell (1855)

- 7 Primaries?
  - 4 Primaries?
  - 3 Primaries!

- Additive Mixture Adds Colors to Black
  - Subtractive Mixture Eliminates Colors from White

The Color Circle
Trichromatic Theory of Color Vision
Helmholtz (1856-1867), after Young (1802) and Maxwell (1855)

- Any Visible Color can be Produced by Mixing Three Primary Colors
- Three Kinds of Cones
  - “Red”
    - Long Wavelengths
  - “Green”
    - Medium Wavelengths
  - “Blue”
    - Short Wavelengths
Georges Seurat,
“Sunday Afternoon on the Island of La Grande Jatte” (1884-1886)
Art Institute of Chicago
Problems with the Trichromatic Theory

• Yellow as Pure Color
  – Not Mix of Red and Green

• Two Forms of Color Blindness
  – Monochromacy
    • Loss of All Color Sensitivity
  – Dichromacy
    • Protanopia
      – Loss of “Red” Receptors
    • Deuteranopia
      – Loss of “Green” Receptors

• Negative Afterimages
Keep Your Eyes Focused On This Image for 60-90 Seconds, Then Advance to the Next Slide
Walker Art Center, Minneapolis
Jasper Johns, “Target”
Jasper Johns, Moratorium (1969)
Fogg Art Museum, Harvard
Jasper Johns
*Flags* (1967-1968)
Metropolitan Museum of Art
The Opponent-Process Theory of Color Vision
Hurvich & Jameson (1957), after Hering (1878)

- On the Retina
  - Three Types of Cones
    - “Blue”, “Green”, “Red”
  - One Type of Rod
    - Light
- Antagonistic Pairs
  - Red-Green
  - Yellow-Blue
  - Black-White
Cortical Determinants of Sensory Quality

- **Auditory Pitch**
  - Tonotopic Organization of A1

- **Visual Hue**
  - Lateral Geniculate Nucleus
  - Area V8