Production and Transmission of Light

- Measurement
- Light and color production
  - Pigments, interference, scattering, bioluminescence
- Transmission through the environment
- Optimal hue, contrast, shading
Properties of light signals

• Brightness
  – Intensity of reflected (or self-generated) light (units = radiance)
  – Function of surface structure and range of wavelengths reflected
• Spectral composition (color)
  – Hue (dom. wavelength) and chroma (saturation)
• Spatial characteristics
  – Size, shape, color pattern of body structure
  – Position and posture of sender
• Temporal characteristics
  – Variability in the above characteristics
Color Spectra

- **Hue**
- **Chroma**

**Brightness = Intensity**
Color

Color results from selective absorption/reflectance

White = all colors reflect  Black = all colors absorb
Color has 3 dimensions

Color systems are based on human color perception

Brightness = radiance
Sources of color

• Pigments
  – Molecules which selectively absorb photons of some wavelengths and transmit others
  – Size of molecule affects wavelength absorption
  – Short chain molecules require high energy (short wavelengths) for excitation

• Structural colors
  – Interference
  – Scattering
Pigments (absorption spectra are inverse of reflectance spectra)

Benzene absorbs UV

Carotene absorbs blue and transmits green, yellow and red
Come in different lengths

Pterins: yellows and oranges found in insects

Verdins create blue-green color in bird egg shells

Porphyrsins: iron = hemoglobin, magnesium = chlorophyl, copper = turacin
Carotenoids in widowbirds and bishops

Note tail vs color, comes from diet

Badges of status in Collared widowbirds
Pryke et al 2001 Anim Behav 62:695-704
Pterins

Photos from www.butterflies.com
Porphyryins

Schalow’s turaco

Great frigatebird

Bird photos from <i-bird.com>
Melanin and Guanine

• Melanin
  – Large protein that absorbs all wavelengths and, therefore, appears black
  – Present in skin and hair of mammals, chitin of many insects
  – Coat color variants are caused by temporal regulation of melanin production during hair follicle growth, e.g. agouti phenotype: dark-light-dark

• Guanine
  – Forms platelets that reflect all wavelengths
  – Found in fish scales, appear silver
Status badges in Harris sparrows

1. Male. He stayed in the flock but suffered a significantly higher rate of attack.
2. Female. She left the flock and travelled alone, where she tended to be attacked less often than before.
3. Male. He often travelled alone or on the edge of the flock and suffered a significantly higher rate of attack.
4. Male. The only bird to show an improvement in status, he stayed in the flock, where he tended to be attacked less often than before.
Structural colors are caused by interference

Color depends on the reflection angle from feathers
Interference

- Created by layer of wax or keratin over feather, scale, etc.
- Positive interference (waves in phase) results at a certain thickness ($x$) refractive index ($n$) and angle of incidence for a given wavelength
- Refractive layer may be underlain with melanin to absorb non-reflecting wavelengths
Interference in feathers

- Constructive interference enhanced by stacking refracting layers
- Found in hummingbirds and peacocks and some butterfly wings
Beetles coat melanin with wax
Color by Scattering

Wild-type

Mutant color type

Mutant color types

Wild-type
Temporal modulation of color: chromatophores

Fish

Iridiophores contain platelets that reflect some wavelengths

Lizards

Cephalopods
Cuttlefish have chromatophores
Chameleons can change color
Temporal modulation of color: bioluminescence

Bioluminescence is common among marine organisms, especially deep-sea fishes.

Figure 8.10  The luciferin of the firefly Photinus. The active part of all luciferins is the COOH terminal group, which in the excited state (indicated by *) forms a double-bonded CO group allied with a system of conjugated double bonds in the rest of the molecule. One photon is released.
Bioluminescence in squid

- Created by symbiotic *Vibrio* bacteria
- Used for counter-illumination to downwelling moonlight

Jones & Nishiguchi, 2004, Marine Biology 144: 1151-1155
See [http://www.lifesci.ucsb.edu/~biolum/organism/squid.html](http://www.lifesci.ucsb.edu/~biolum/organism/squid.html)
Reception of light signals

- Receiver always receives veiling atmospheric light, reflected signal, and reflectance from background
- Must distinguish signal (Qr) from noise (Qv and Qb)
Habitat Transmission

• Color brightness of an object depends on wavelengths of available light
• Amount and spectral composition of available light can differ by habitat
• In terrestrial habitats, light spectra is influenced by angle of Sun, weather, vegetation
• Expect animals to utilize colors appropriate for habitats
Light intensity variation

<table>
<thead>
<tr>
<th>Situation</th>
<th>Intensity * (Photons cm(^{-2}) s(^{-1}) nm(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full sunlight</td>
<td>(10^{14})</td>
</tr>
<tr>
<td>Overcast daylight</td>
<td>(10^{13})</td>
</tr>
<tr>
<td>Twilight</td>
<td>(10^{11})</td>
</tr>
<tr>
<td>Moonlight</td>
<td>(10^{8})</td>
</tr>
<tr>
<td>Clear moonless night (starlight + airglow)</td>
<td>(10^{6})</td>
</tr>
<tr>
<td>Overcast moonless night</td>
<td>(10^{5})</td>
</tr>
<tr>
<td>Full sunlight at 1000 m in clear ocean waters</td>
<td>(10^{6})</td>
</tr>
</tbody>
</table>

* Spectral density near 500 nm (Lythgoe 1979, 4–6; Brines and Gould 1982).
Color filtering by habitat

Spectra in forest

Colors in white light

Green colors are enhanced in forest
Light reflectance
Guppy Color Patterns

Guppy Gallery
The male guppies depicted in this simulation only begin to demonstrate the vast range of colors and patterns expressed by wild guppies. Below are some examples of wild guppies, both males and females, from Trinidad and South America.

Click on a guppy to get more information. Click on the "Predators," "Guppies," or "Habitat" buttons to get more info on these themes.

Light attenuation

- Light attenuation follows inverse square law which is independent of wavelength
- Scattering and absorption, however, increase as wavelength decreases

<table>
<thead>
<tr>
<th>Environment</th>
<th>300</th>
<th>400</th>
<th>500</th>
<th>600</th>
<th>700</th>
<th>800</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure air</td>
<td>7.0 km</td>
<td>22 km</td>
<td>55 km</td>
<td>120 km</td>
<td>220 km</td>
<td>370 km</td>
</tr>
<tr>
<td>Clean air</td>
<td>3.8 km</td>
<td>5.0 km</td>
<td>6.0 km</td>
<td>6.7 km</td>
<td>7.4 km</td>
<td>7.9 km</td>
</tr>
<tr>
<td>Moderate fog</td>
<td>50 m</td>
<td>50 m</td>
<td>50 m</td>
<td>50 m</td>
<td>50 m</td>
<td>50 m</td>
</tr>
<tr>
<td>Pure water</td>
<td>?</td>
<td>23 m</td>
<td>28 m</td>
<td>5.4 m</td>
<td>2.0 m</td>
<td>0.49 m</td>
</tr>
<tr>
<td>Ocean</td>
<td>?</td>
<td>1–10 m</td>
<td>1–15 m</td>
<td>1–5 m</td>
<td>1–2 m</td>
<td>?</td>
</tr>
</tbody>
</table>

Signal detection

• Senders must produce a signal that contrasts from background using brightness, color, pattern or movement
• Can adopt countershading or reverse counter shading for crypsis or conspicuousness
• Visual systems often exaggerate contrast to detect objects in background
Signal contrast varies with habitat

Phylloscopus warblers

(A) (B) (C) (D) (E)
## Optimal signal and background hues

### Table 8.2 Optimal signal hue in different environments and backgrounds.

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Available light illumination level (hue)</th>
<th>Background hue</th>
<th>Optimal signal color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Night</td>
<td>Low (gray)</td>
<td>Black</td>
<td>White, biolumin</td>
</tr>
<tr>
<td>Open ocean, lake</td>
<td>Low to med. (blue)</td>
<td>Blue</td>
<td>Yellow</td>
</tr>
<tr>
<td>Marine reef</td>
<td>High (blue)</td>
<td>Blue</td>
<td>Red, yellow</td>
</tr>
<tr>
<td>Freshwater streams</td>
<td>Low to high (yellow-green)</td>
<td>Yellow-green</td>
<td>Blue, red</td>
</tr>
<tr>
<td>Tropical forest</td>
<td>Med. (green)</td>
<td>Green</td>
<td>Red</td>
</tr>
<tr>
<td>Temperate forest</td>
<td>Med. to high (green)</td>
<td>Yellow-green</td>
<td>Purple</td>
</tr>
<tr>
<td>Broadleaf litter</td>
<td>Med. (green)</td>
<td>Yellow</td>
<td>Blue</td>
</tr>
<tr>
<td>Forest tree trunk</td>
<td>Med. (green)</td>
<td>Orange</td>
<td>Blue-green</td>
</tr>
<tr>
<td>Grass, bush, marsh</td>
<td>High (white)</td>
<td>Yellow-green</td>
<td>Blue</td>
</tr>
<tr>
<td>Dried grass, old field</td>
<td>High (white)</td>
<td>Yellow</td>
<td>Blue</td>
</tr>
<tr>
<td>Sand dune</td>
<td>High (white)</td>
<td>Orange</td>
<td>Blue-green</td>
</tr>
<tr>
<td>Sky</td>
<td>High (white)</td>
<td>Blue</td>
<td>Black</td>
</tr>
<tr>
<td>Water surface</td>
<td>High (white)</td>
<td>Blue</td>
<td>Black or white</td>
</tr>
<tr>
<td>Low sun angle</td>
<td>Low, (purple)</td>
<td>Dark</td>
<td>White, yellow</td>
</tr>
</tbody>
</table>

*Source: After Hailman 1979 and Lythgoe 1979.*
Pattern contrast
Shape enhancement

Conspicuous

Hooded merganser
Palometa
Monarch butterfly
Mourning-cloak
Oscellated frogfish
Black margate

Cryptic

Dascyllus
Caluella
Rhacophorus
Polygonia
Counter and reverse shading