Topics

• Part I: Resolution
  – On the film
  – On the print
  – On the slides
  – In television

• Part II: Color, shading, and prints
  – Contrast, color, and the Zone System
  – Lens design
  – Digital and conventional photography
  – The portal: scanning and scanners
Negative Films

• Black and white
  – Film contrast is about 0.7
  – Standard print paper contrast is about 1.4
  – Special paper contrasts vary from about 0.5 to 2.5 for solving special problems

• Color negatives have a standard
  – Film contrast is 0.5
  – Paper contrast is 2.0
Color Negative Film

- Print quality is the requirement
- Problems are
  - Spectral sensitivity of the layers to pure blue, green, and red
  - Spectral purity of the dyes for yellow, magenta, and cyan
- Design is
  - Allow a color cast (the familiar orange)
  - Accept a low contrast in the negative
Spectral Sensitivity Curves

From Kodak
Publication E-2328
Bright Sun Film GA
(Gold 100 color negative film)

Effective Exposure: 1/25 second
Process: C-41
Densitometry: Status M
Density: 0.2 above D-min

LOG SENSITIVITY

WAVELENGTH (nm)

*Sensitivity = reciprocal of exposure (erg/cm²) required to produce specified density

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Spectral Dye Density Curves

From Kodak
Publication E-2328
Bright Sun Film GA
(Gold 100 color
negative film)
Characteristic Curves

Exposure: Daylight
Process: C-41
Densitometry: Status M

From Kodak
Publication E-2328
Bright Sun Film GA
(Gold 100 color
negative film)
Print Paper and Color Slides

• Special requirements
  – Highlights must be clear to be white or project brightly
  – Overall color cast must be neutral
  – Contrast must be near 1.0

• Color slide film Contrast is about 1.1

• Prints
  – Reversal paper contrast is about 1.0
  – Color print paper contrast is about 2.0
The Trade Space

• Dynamic range limits
  – Dye density range is the image dynamic range
  – Density range of 1.8 is minimum for high quality prints and slides

• Resolution versus speed
  – High speed needs thicker emulsion
  – Thicker emulsion means lower resolution

• Grain is the noise floor for resolution
Quality and the Trade Space: Color Negatives

• Quality is the only objective
• Trade space issues
  – Color purity
    » In the color-sensitive layers
    » In the dyes formed in the development process
  – Grain, sensitivity, and resolution
• Results
  – High quality color
  – Good speed, fine grain, high resolution with technology advances
Quality and the Trade Space: Prints From Color Negatives

• Objectives
  – Quality
  – Bright whites and dark blacks
• Trade space issues
  – Color purity in sensitivity and dyes
  – Consistent color balance from black to white
• Results
  – High quality color
  – Speed-grain trade available to consumer
Quality and the Trade Space: Color Slides

• Objectives
  – Quality
  – Transparent whites
  – Dark blacks

• Problems are
  – Color purity in sensitivity and dyes
  – Grain, sensitivity, and resolution

• Results
  – Good to excellent quality color
  – Highest speeds, good grain, good resolution
Quality and the Trade Space: Prints From Color Slides

• Objectives
  - Quality
  - White whites
  - Dark blacks

• Problems are
  - Color purity in sensitivity and dyes
  - Grain, sensitivity, and resolution

• Results
  - Good quality color
  - Different character than prints from negatives
Color and Digital Photography

• Color Purity
  - Light recording – Limited only by filtration quality, a trade with “film speed”
  - Digital output – unlimited, cross-color coupling in sensitivity is reduced with software

• Linearity
  - Essentially perfect, limited by electrical leakages
  - Bounded
    » Below by shot noise
    » Above by saturation
Problems in Digital Photography

- **Resolution**
  - Focal plane pixel count – limited by CCD gate density
  - Each pixel is only one color – resolution is 1/3 that indicated by focal plane pixel count
  - Exception – emerging Foveon technology

- **Color**
  - Dyes in photo printers are the limitation
  - Dye design simpler than film and paper dyes

- **Exposure latitude**
When Smaller Is Better

• Smaller focal plane
  – Trade space for lens is friendlier
  – Faster lenses for given performance
  – Wider zoom range for given performance
  – Higher resolution for given speed

• Digital photography
  – Smaller focal planes, better lenses at present
  – Focal planes are getting bigger
  – An experimental 21 MPX focal plane is bigger than a 35 mm image
Lens Design

• Goal: Make optical distance to a flat focal plane equal across the aperture
• A curve fitting problem in these variables
  – Wavelengths 0.4 to 0.7 microns
  – Angle of incidence == position on the focal plane
  – Object distance (conjugate)
  – Zoom
• Solution must be near optimal at all useful f/stops
The Lens Trade Space

- Diffraction limited resolution is the goal
- Goals are $\frac{1}{4}$ wavelength variation in effective optical length of collimated light to a point on the focal plane
- Variables in the curve fitting problem
- Reflections and flare
- Optical absorption in the glass
Examples of Lenses

• Single wavelength, single point, single conjugate diffraction limiting
  - Single element
  - Any glass
  - Aspherical lens surfaces for fast lens

• Two wavelength – achromats
  - Two elements
  - Glasses with different dispersion (crown, flint)

• Three wavelengths – apochromats
Lens Aberrations

• **Blooming**
  - Difference in focal plane distance with distance from center of lens
  - Occurs anywhere on image plane

• **Astigmatism**
  - Difference in focal length and focal plane distance with position on lens plane
  - Occurs off-axis

• **Coma**
  - Difference in focal length with position on image plane
Lens Distortions

- Pincushion – focal length shorter off-axis
- Barrel – focal length longer off-axis
  - Fish-eye effect is intentional barrel distortion
- Focal plane curvature
  - The main fit parameter in the lens design problem
  - Sometimes intentionally done to match film curvature
- Fish-eye lenses
  - Originally conceived for comet searches
  - Stereographic projection equalizes exposure over the focal plane – no cosine falloff
Lens Technologies

• Lower dispersion glasses
  – Achromat trade space friendlier
  – Achromat performance similar to apochromats

• Aspherical lens surfaces
  – Faster high-quality lenses

• Multiple layer coatings
  – Lower reflections over spectrum – less flare, lower light loss
  – Less coloration in transmitted light
Focal Plane Size

• Larger focal plane
  – Longer focal lengths for equivalent coverage
  – Larger lens surfaces with $\frac{1}{4}$ wavelength tolerances
  – Volume of glass proportional to cube of focal plane width

• Result of reducing focal plane size
  – More variety in lenses
  – Faster lenses
  – Wider zoom ranges
The Zone System

• A Zone is
  - A one-stop (factor of two) variation in exposure
  - A measure of brightness in the scene
  - A measure of brightness in the print

• Zones
  - Zone I is total blackness
  - Zone VIII is total whiteness
  - Print zones are II to VII
  - Mid-range is Zone V
# 8-Bit Digital Zones

<table>
<thead>
<tr>
<th>Zone</th>
<th>Value</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>VII</td>
<td>128 – 255</td>
<td>White, with detail</td>
</tr>
<tr>
<td>VI</td>
<td>64 – 127</td>
<td>Sky, bright colors</td>
</tr>
<tr>
<td>V</td>
<td>32 – 63</td>
<td>Mid-tones</td>
</tr>
<tr>
<td>IV</td>
<td>16 – 31</td>
<td>Darker colors</td>
</tr>
<tr>
<td>III</td>
<td>8 – 15</td>
<td>Shadows, with color</td>
</tr>
<tr>
<td>II</td>
<td>0 – 7</td>
<td>Black, with detail</td>
</tr>
</tbody>
</table>
Scanning and Originals

• Prints from negatives or slides
  – Highlights and shadows flattened by the characteristic curve of the paper dyes
  – Loss of color fidelity through imperfect sensitivity and density curves
  – Changes in color balance with zone

• Color slides
  – No flattening of contrast in shadows
  – Otherwise, same problems as prints

• Color negatives – color balance changes with zone
Conclusions

• Conventional photography
  – Here to stay for awhile in niche applications
  – The vacuum tube technology analogy

• Digital photography
  – Still an emerging technology
  – Just now really competitive with conventional techniques
  – Superior potential for color fidelity, resolution, cost
  – Extremely large prints impractical just now

• Scan the negative or slide if available
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