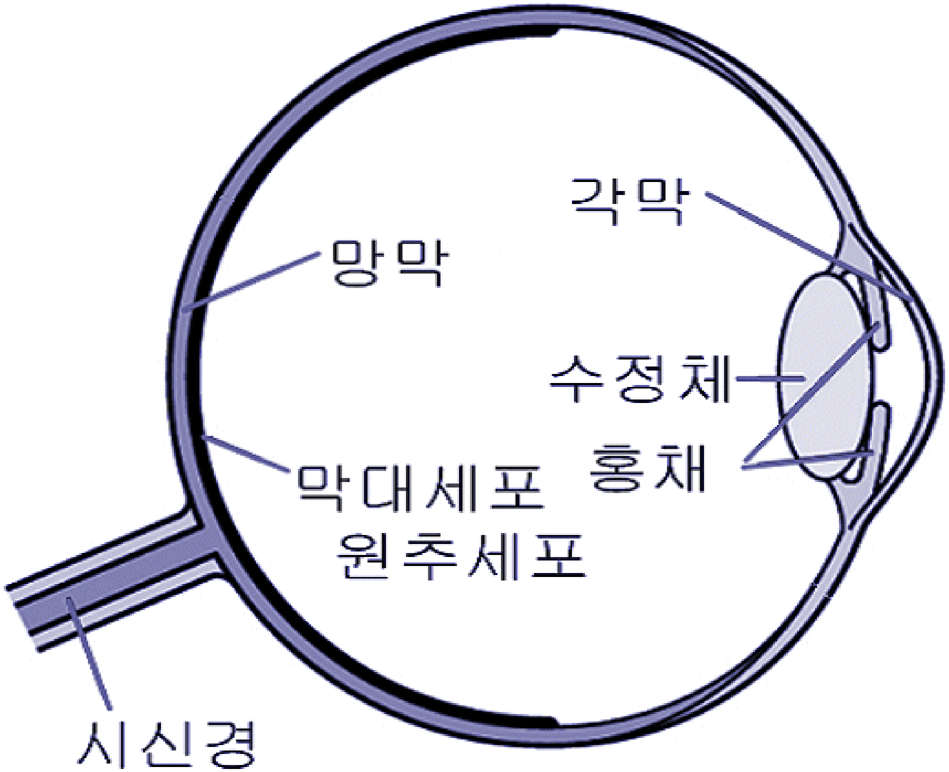
Visual Display

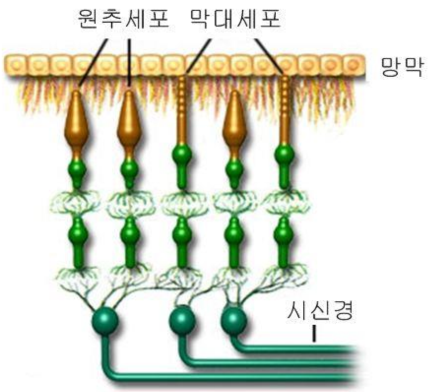
Slides adapted from various sources …

Human Eye

- 홍채: 빛의 양을 조절
- 수정체: 초점거리 조절



Rods and Cones



- **These two systems visual perception**

- **Rods - provide "scotopic" or low intensity vision (<u>명암인식, 어두운 빛 반응</u>)**
  - Provide our night vision ability for very low illumination (but no color),
  - Are distributed primarily in the <u>periphery of the visual field</u>.

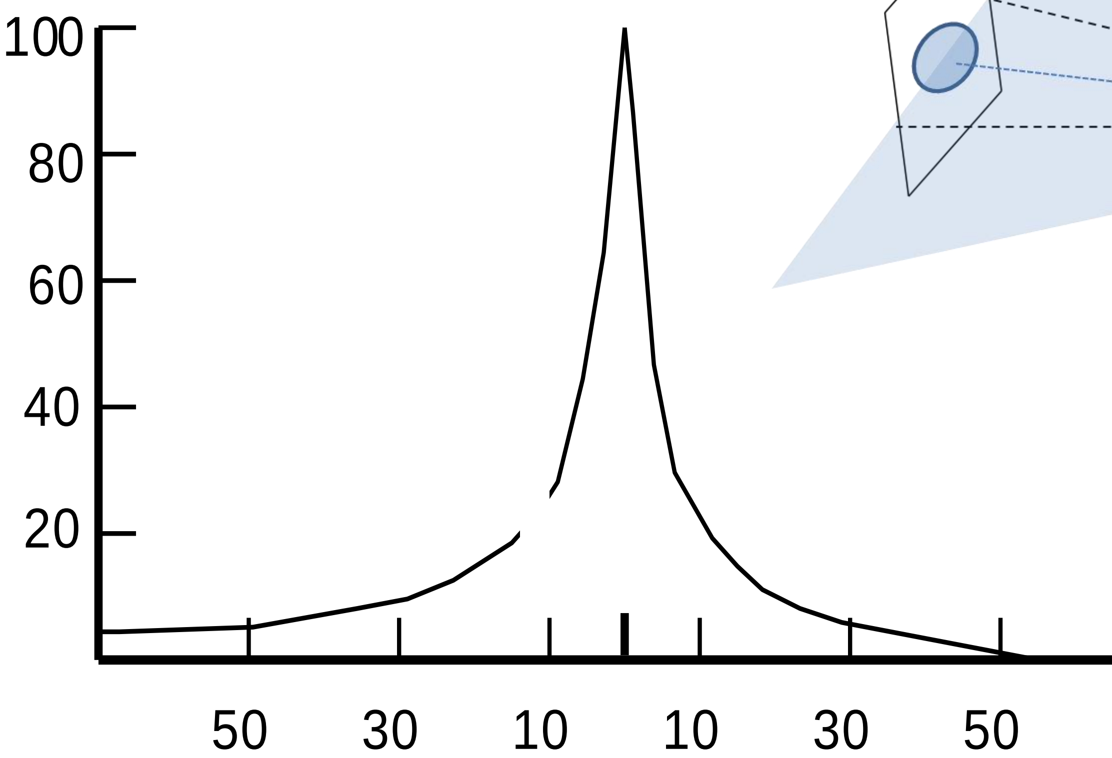
- **Cones - provide "photopic" or high acuity vision (<u>색상인식, 밝은 빛 반응</u>)**
  - Provide our day vision, high resolution images, color vision, by means of three types of cones (<u>concentrated in the fovea</u>):
    - "L" or red, long wavelength sensitive,
    - "M" or green, medium wavelength sensitive,
    - "S" or blue, short wavelength sensitive.

Then to the brain

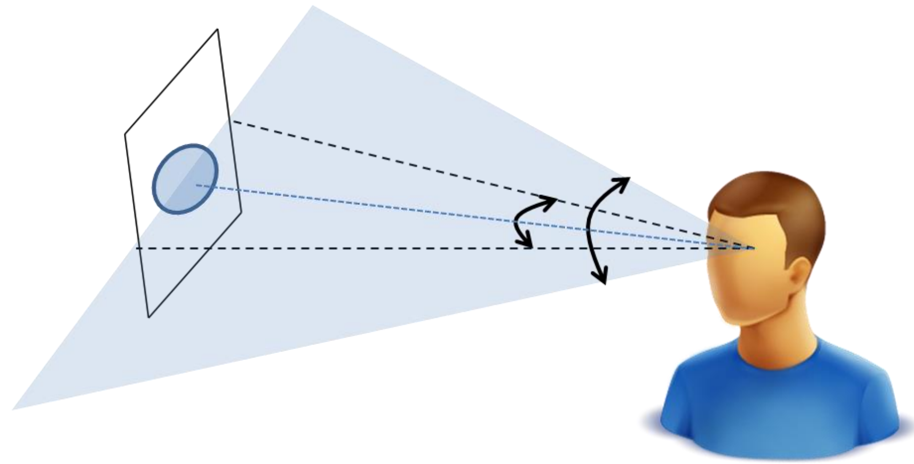
- **The ganglion nerve cells that collect and aggregate nerve impulses converge at the optic disk and form the optic nerve. At the optic disk there are no photoreceptor cells which creates a blind spot on the retina.**

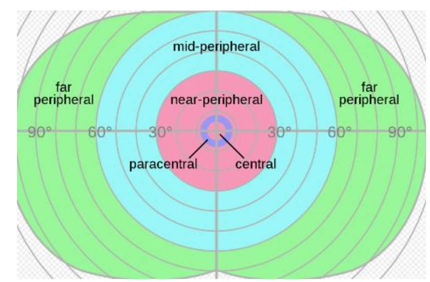
- **It is estimated that vision accounts for at least 40% of brain functioning.**

Acuity Distribution



Distance from Fovea (deg.)





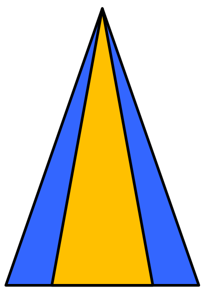
(a)

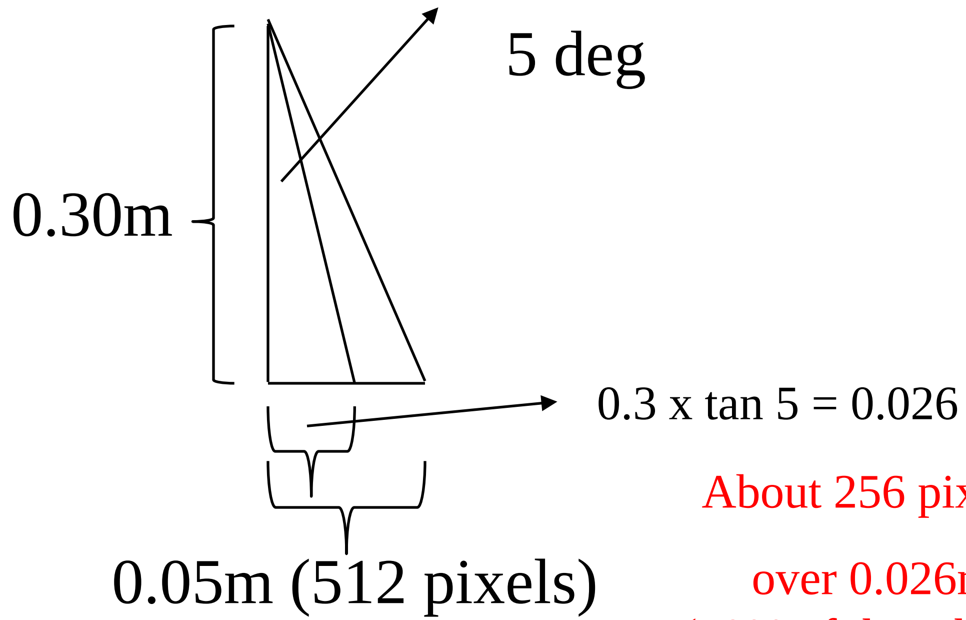
(b)

Smaller screen

Closer viewing distance

Relatively more area covered by foveal vision





About 256 pixels

over 0.026m
(50% of the whole)

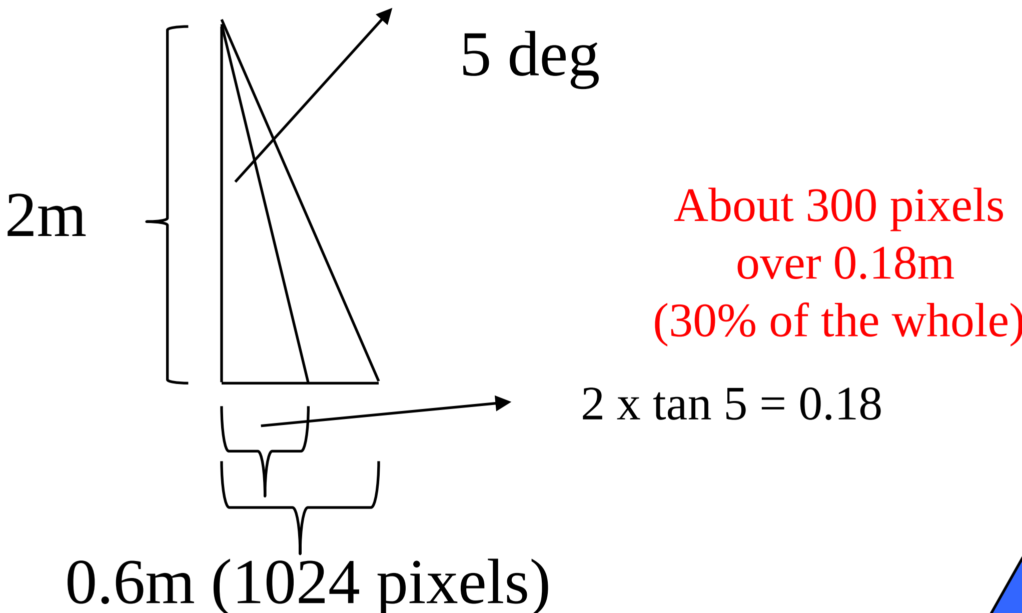
Small screen:

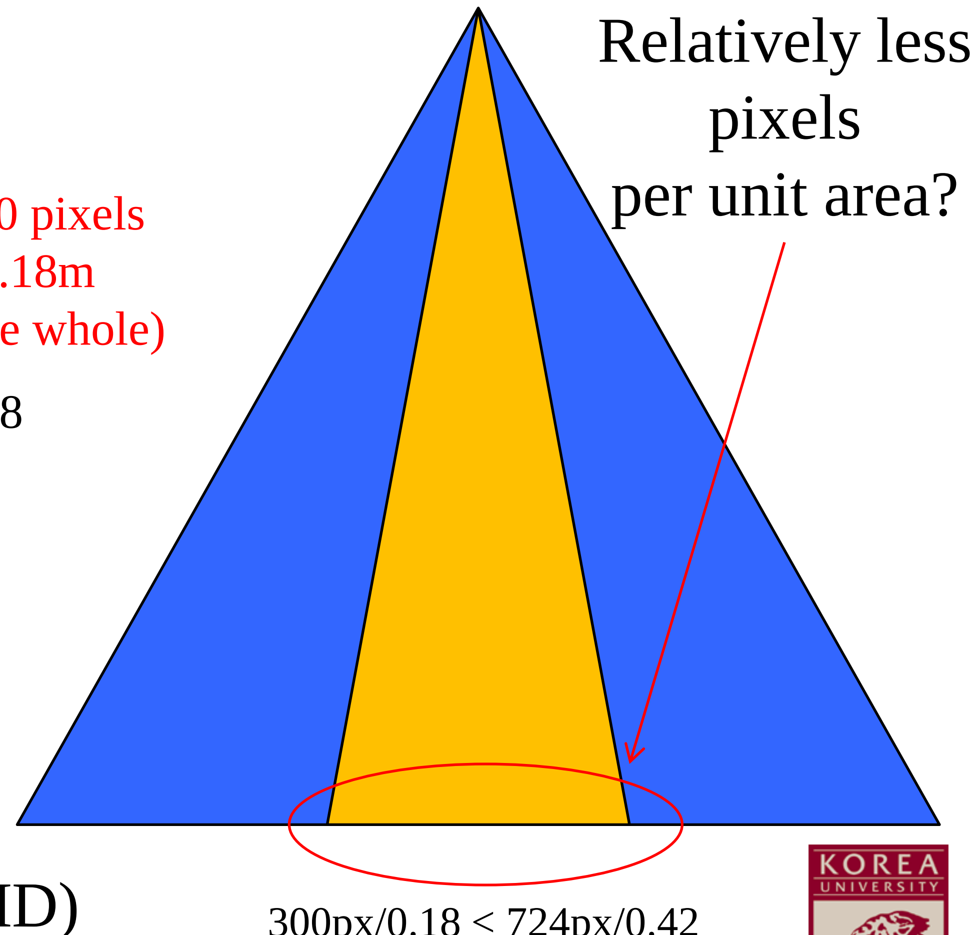
1024 / 10cm

Larger screen

Farther viewing distance

Relatively less area covered by foveal vision

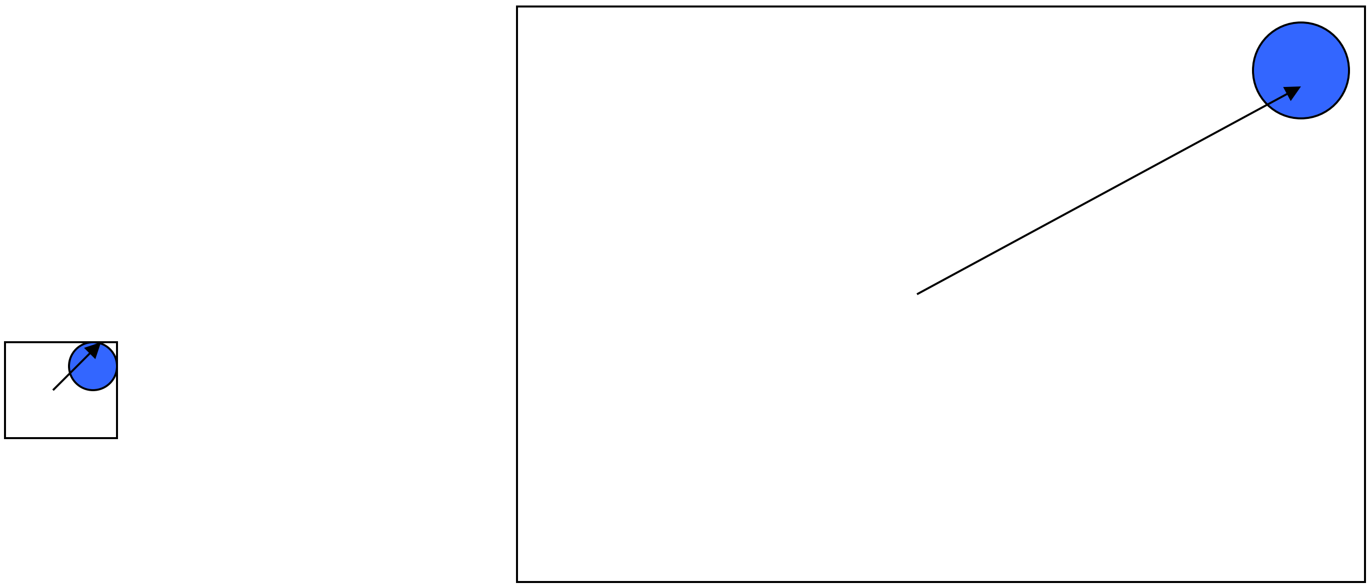




Large Screen:

2048 / 120cm (this is not even UHD)

How efficiently can we use each display?

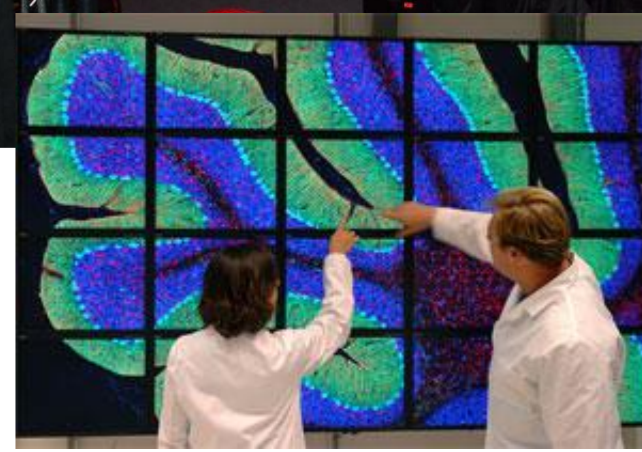


It will take approximately 2.5x as long to fixate targets at the edge of the big screen

Head movements accompany eye movements (~ > 25 deg)

Data walls (near immersion)

- **Stereo, no head tracking, wide screen**



Is it any good?

- If you are viewing from a far distance, will you perceive the details to the UHD?
- If you are viewing from a close distance, what good is the rest of the display?
- It is not even completely immersive …
- Need right resolution (and right cost)

Scale matters

While size is a relative thing,

absolute size sometimes matter

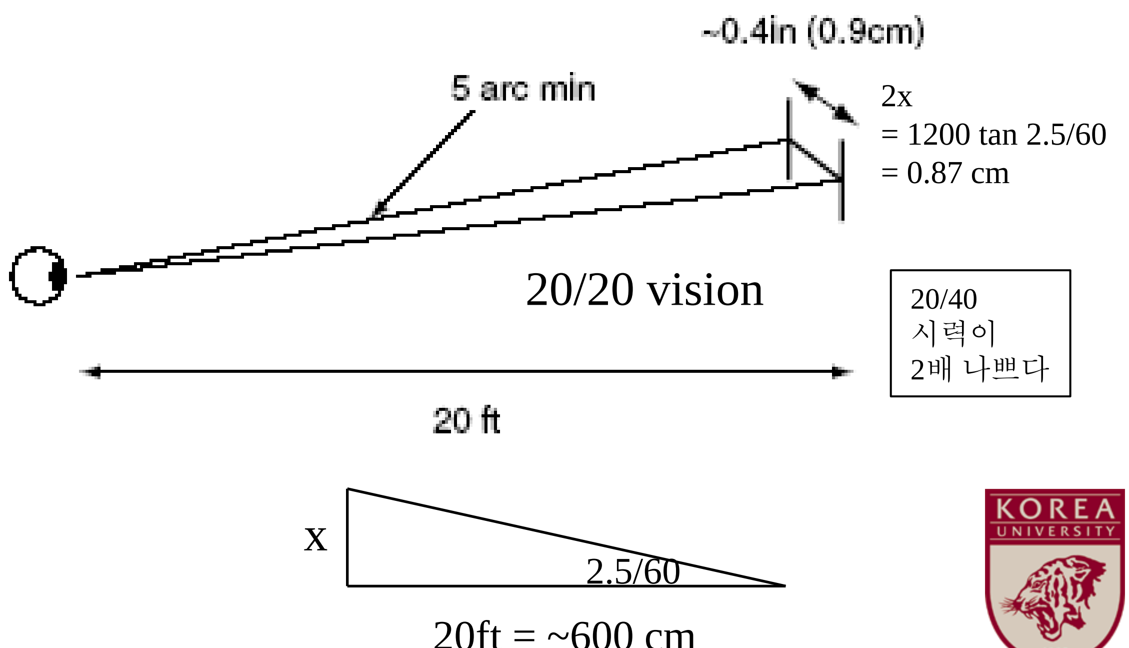
(i.e. absolute w.r.t. human scale,

remnants of evolution?)

Variability (with vision)

- Visual acuity problems: Minimum Lateral Length or Depth Human Eyes can perceive (Acuity drops at the Periphery)
  - Known to distinguish elements subtended by 1~5 arc min from 20 ft.

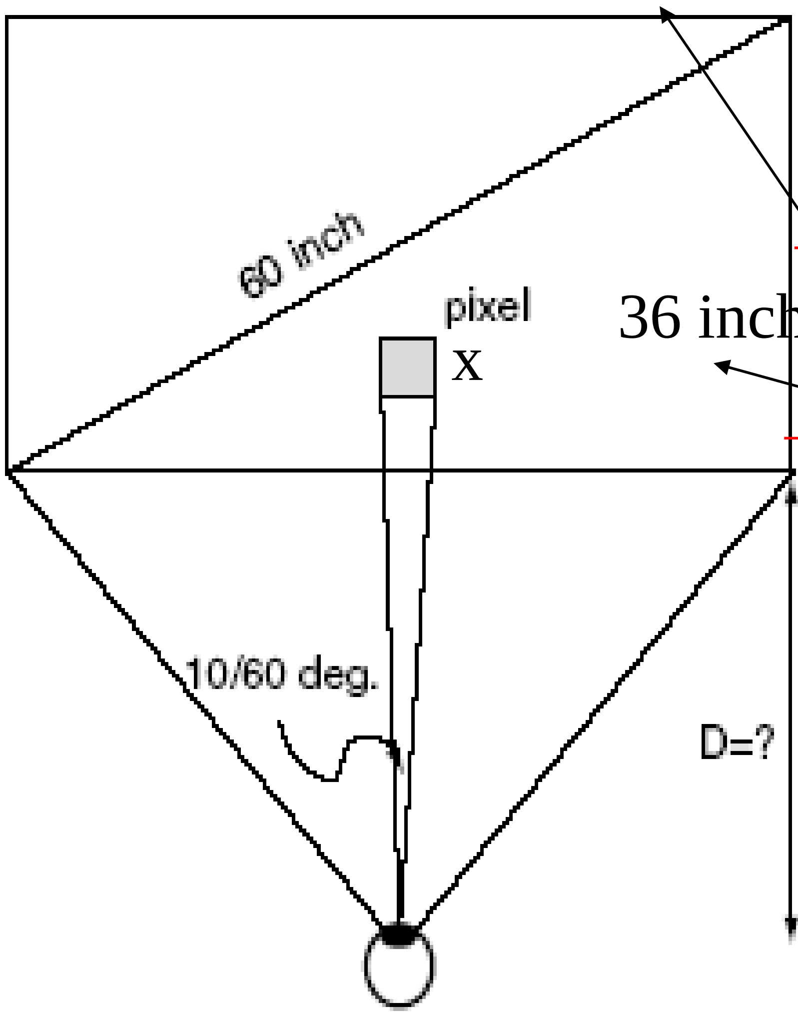
- Near vision
  (근시, 멀리 있는것이 안보임)
- Far vision
- Astigmatism
- Color-Blindness
- Contrast Sensitivity :



Display Parameters: **want to match eye and display parameters as close as possible**

- FOV (Field of View): Angle subtended by the viewing surface from a given observer location
  - Humans: 120H x 180V
  - Related to Spatial Resolution
  - Related to Angular Resolution
- Spatial Resolution: No. of pixels that can be displayed in unit area
- Pitch: How wide and Tall the Pixel is
- Angular Resolution: Visual angle the pixel subtends from a particular viewing distance
- Critical Flicker Frequency (~ 60 Hz)
- Refresh Rate (15 ~ 20 Hz)
- Brightness / Contrast
- Color

48 inch (117cm)



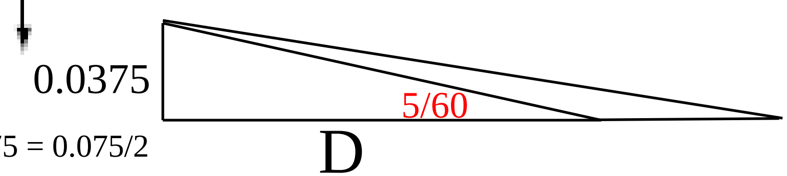
Given 60 inch project screen
Visual acuity assumed and required : 10 arc min
Resolution 640 X 480 → pitch = ~~0.09 inch.~~

~~Visual activity satisfied with D <~16 in.~~

The display's resolution is overly high for viewing ~~distance of over 16 inch.! (Can only distinguish up to pixel level with D less than 16 in.)~~

$$(640x)^2 + (480x)^2 = 60^2$$

$$x = 0.075 \text{ inch}$$



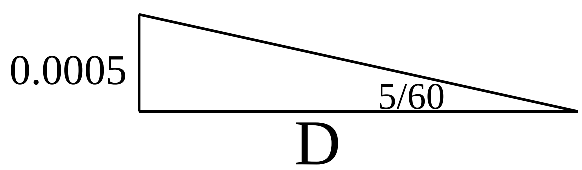
0.0375 = 0.075/2

D = 0.0375/tan(5/60) = 26 inch (very close …) = 65 cm
Beyond 65 cm, with give acuity, I cannot discern a single pixel (of 0.0375 size)

Larger display (100 inch / 245 cm) with higher resolution …

$$(2560x)^2 + (1920x)^2 = 100^2$$

$$x = 0.00098 \text{ inch}$$

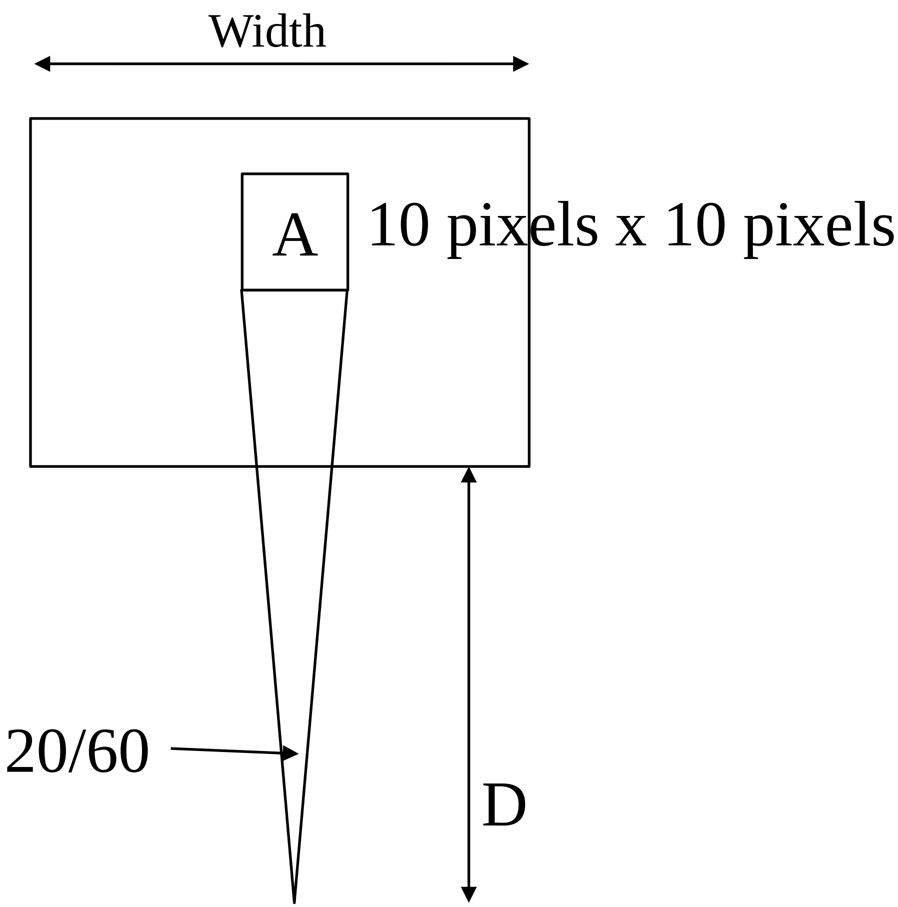


D = 0.0005/tan(5/60) = < 1 inch
Beyond 1 inch, you cannot discern a pixel

I can make out a pixel at less than 2.45 cm from the screen
→ Q: Do I need such resolution for this sized Display with such visual acuity?

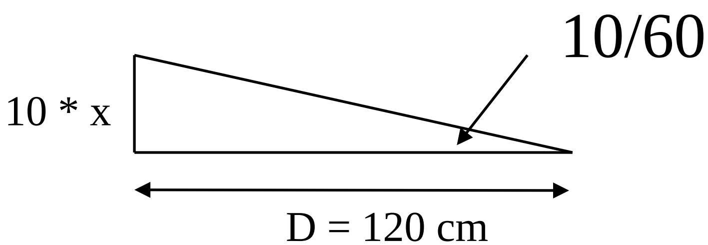
If D was 10 ft ~= 300 cm (let's say a normal viewing distance for 2m display)

Discernable Pitch with given visual acuity would be = D * tan 5/60 = 1.8 inch
Suppose 4000 pixels → 7200 inch screen = 2880 cm display from 3 m (gigantic)
Suppose 2000 pixels → 3600 inch screen = ~15m display … (still gigantic)
For 2m display then … 200 cm / (1.85 inch * 2.45 cm/inch) = 880 pixels …



20 arc min visual acuity
To discern a letter (rather than a pixel)

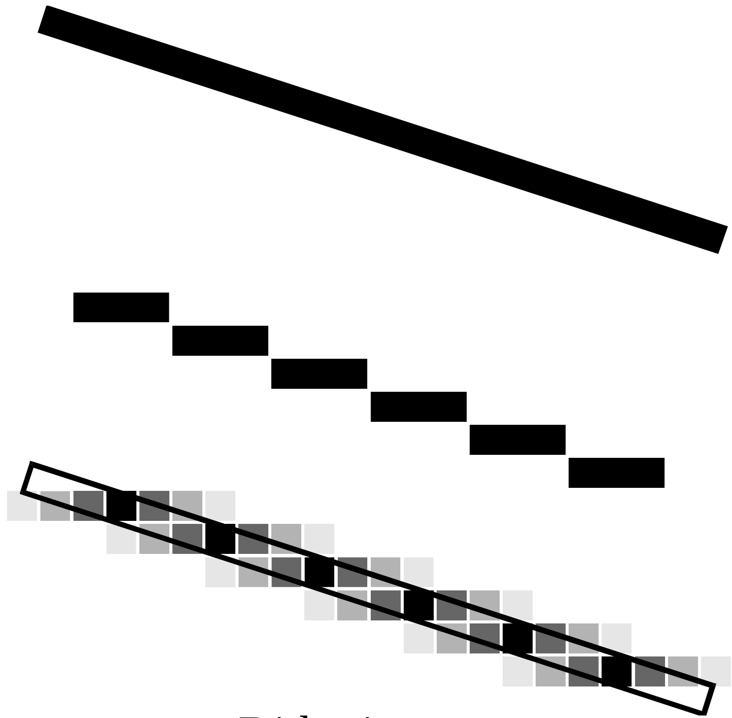
D = 120 cm = 1.2 m
Size of display?
Resolution: 2560 x 1920
x → size of pixel?



tan (1/6) = 10 * x / 120
x = tan (1/6) * 12 = 0.036 cm

Width = 2560 * x = 92 cm

Anti aliasing: Overcoming aliasing



Dithering

Nyquist Sampling Theorem

- **The ideal samples of a continuous function contain all the information in the original function if and only if the continuous function is sampled at a frequency greater than twice the highest frequency in the function**

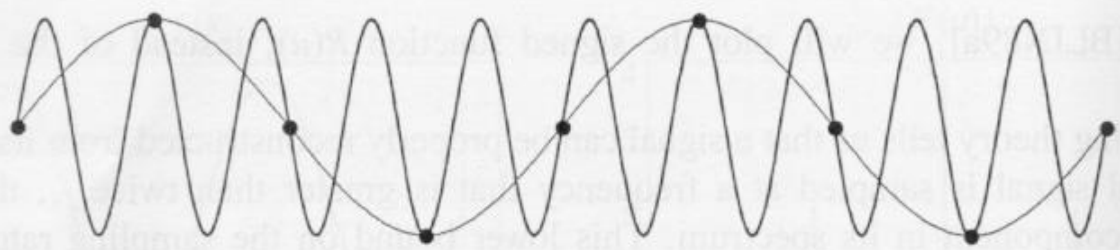
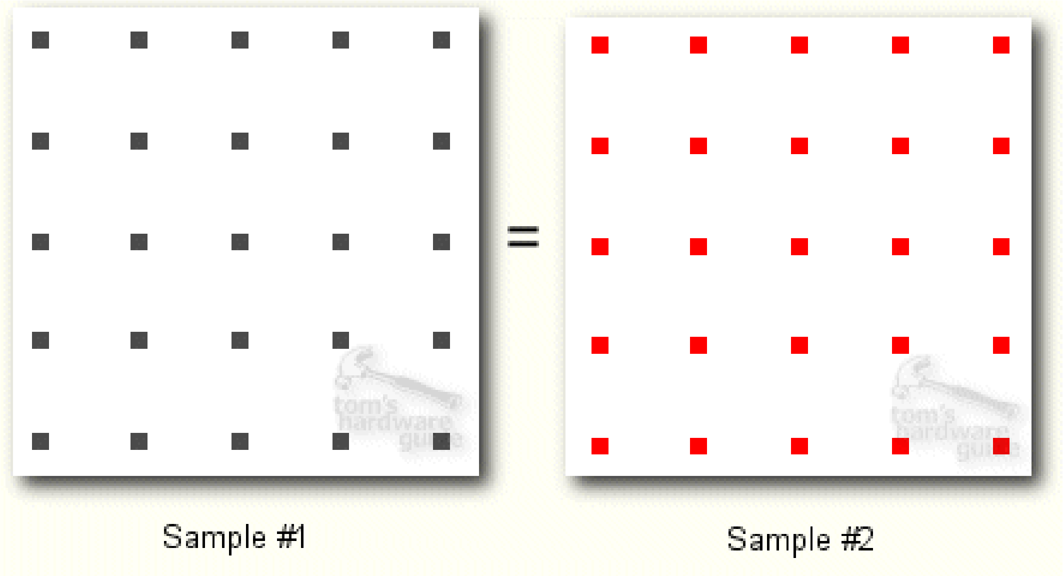


Fig. 14.17 Sampling below the Nyquist rate. (Courtesy of George Wolberg, Columbia University.)

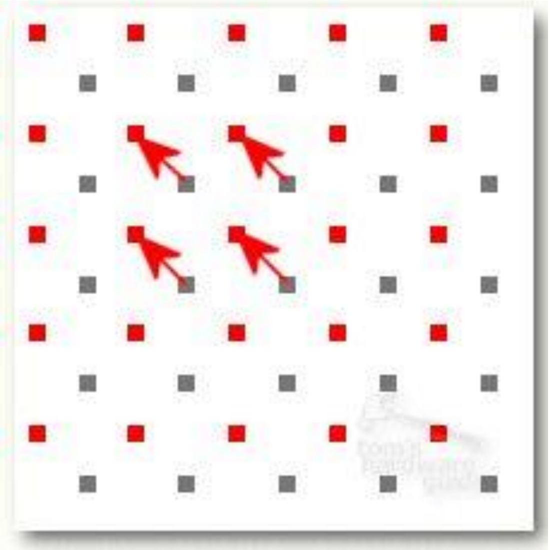
GeForce3

- **Multisampling**
  - After each pixel is rendered, write pixel value to two different places in frame buffer



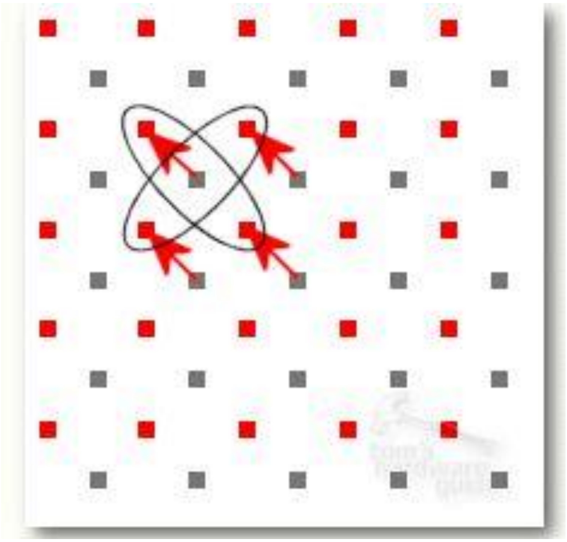
GeForce3 - Multisampling

- **After rendering two copies of entire frame**
  - Shift pixels of Sample #2 left and up by ½ pixel
  - Imagine laying Sample #2 (red) over Sample #1 (black)

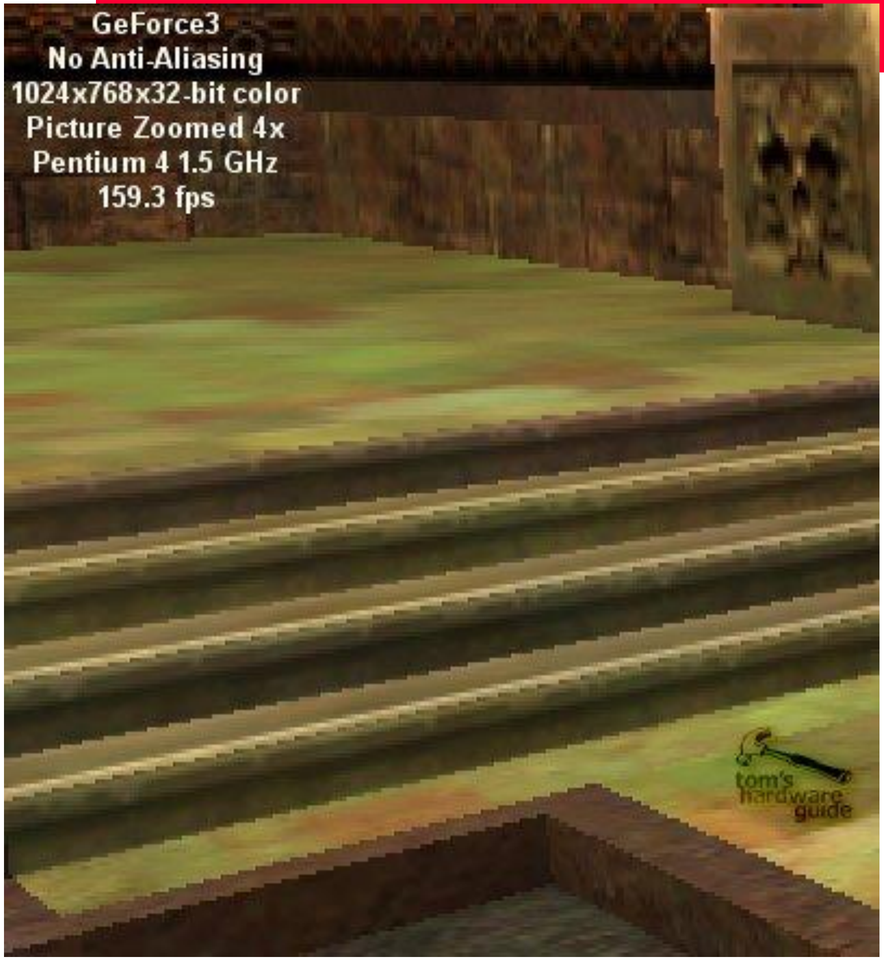


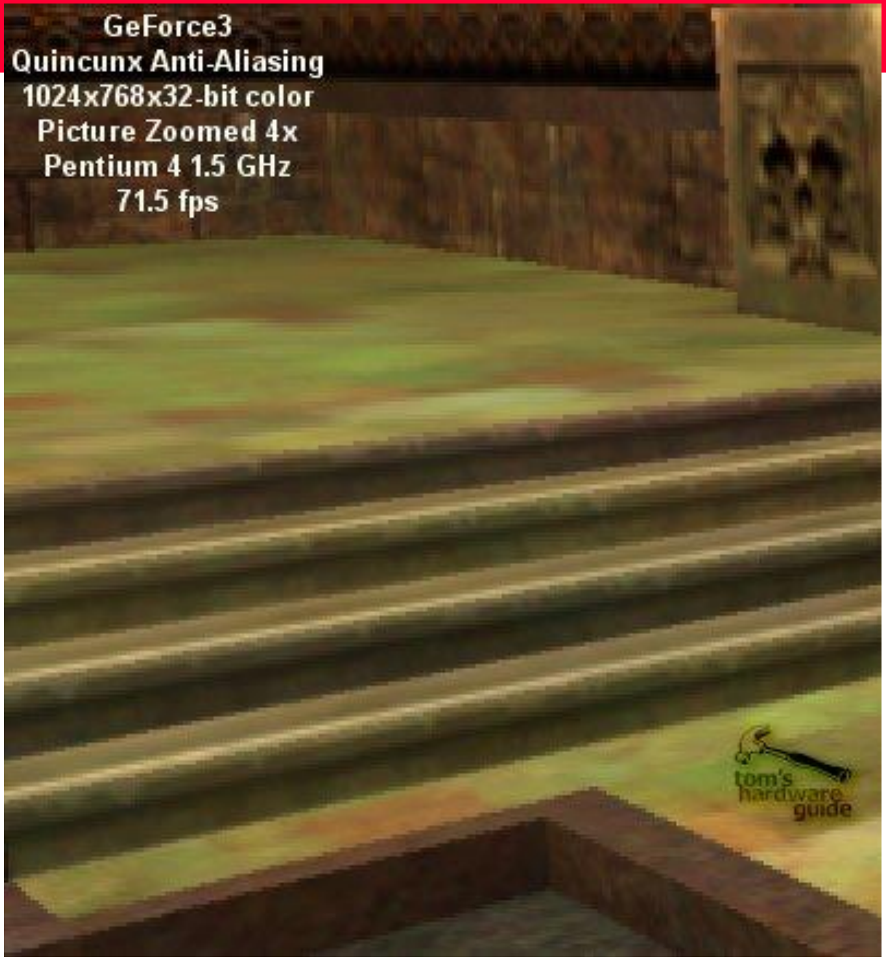
GeForce3 - Multisampling

- Resolve the two samples into one image by computing average between each pixel from Sample 1 (black) and the four pixels from
  Sample 2 (red) that are 1/ sqrt(2) pixels away



GeForce3 - Multisampling





- **No AA** **Multisampling**

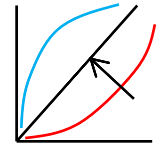
Light measurement

- **Luminance:**
  <u>Physical measurement</u> of the amt. of light in the environment: L

- **Brightness: Amount of <u>perceived</u> light**
  – Brightness = L^n
  – e.g. (in the dark) = $L^{1/3}$

- **Lightness: Perceived surface reflectance**

- **Monitor and Luminance**
  – $L = V^{\lambda}$ (Gamma parameter)
  – Gamma correction (set the relationship manually …)



y = kv (expect black)

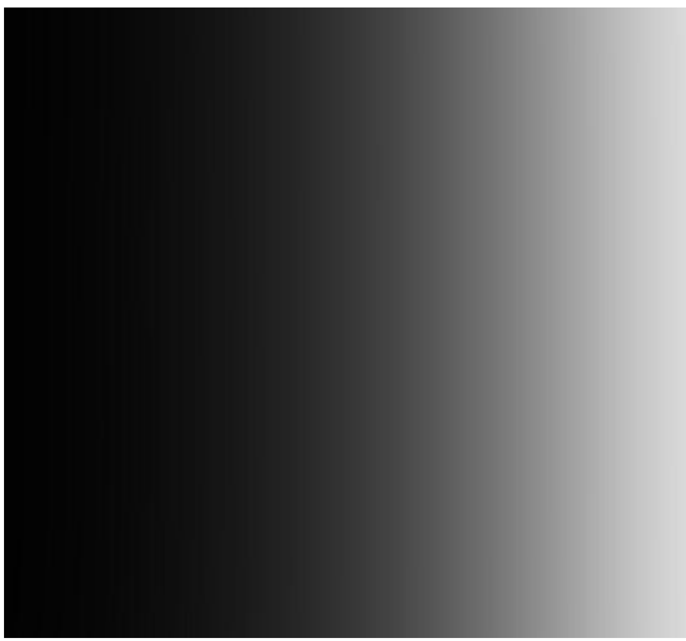
→ but perceived as blue

* v^n

→ perceived as linear

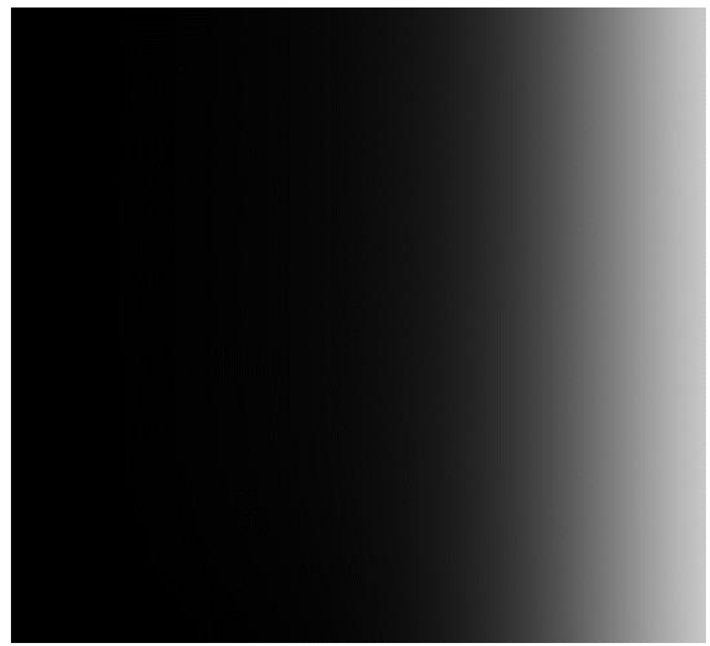
Gamma Correction

- 프로그래머의 기대치 대 실제 밝기
  - 회색도 128은 실제로 더욱 어둡게 나타남

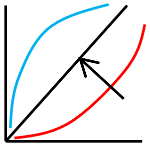


Perceptually what you expect (linearly changing brightness)

And what is outputted by linear voltage control



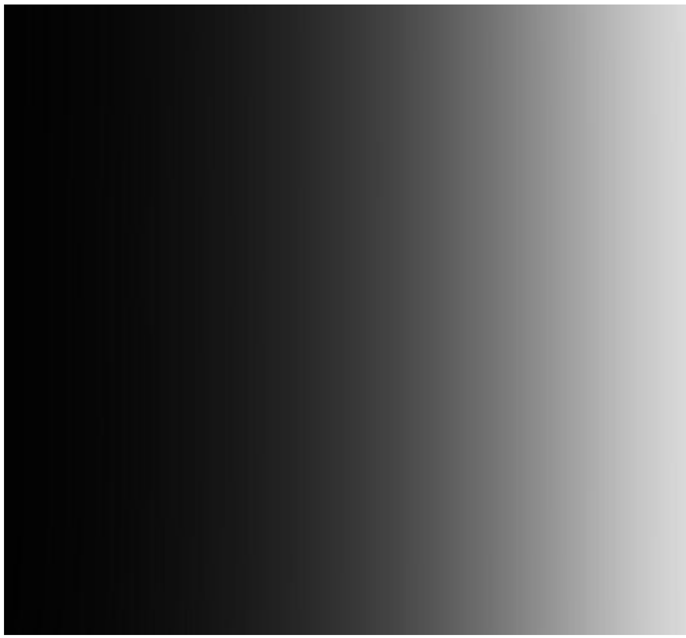
What you actually perceive



Gamma Correction

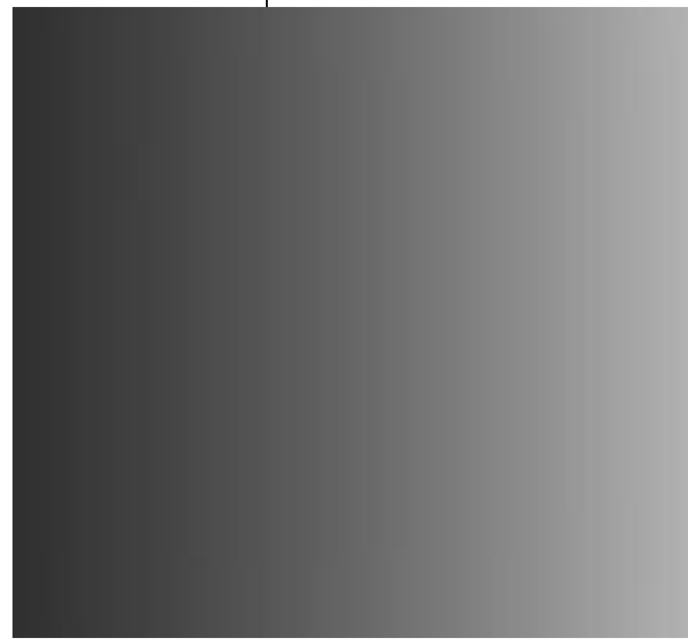
y = kv (expect black)
→ but perceived as blue

$* \, v^n$
→ perceived as linear

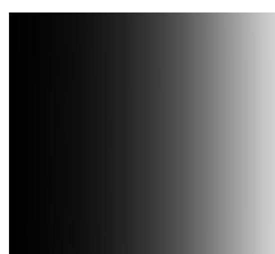


original output

$* \, v^n \quad =$



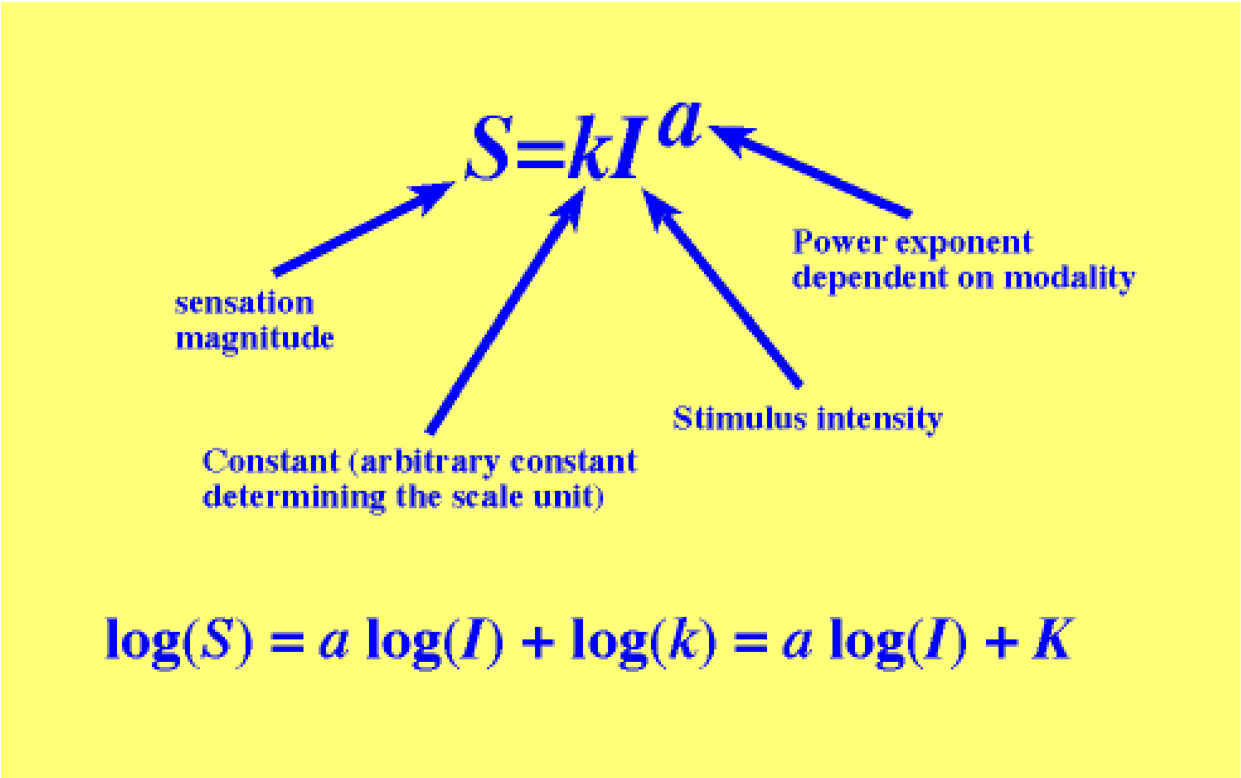
Changed output by gamma correction



Perceived as linear variation

Steven's power law

- Proposed relationship between the magnitude of a physical stimulus and its perceived intensity or strength.



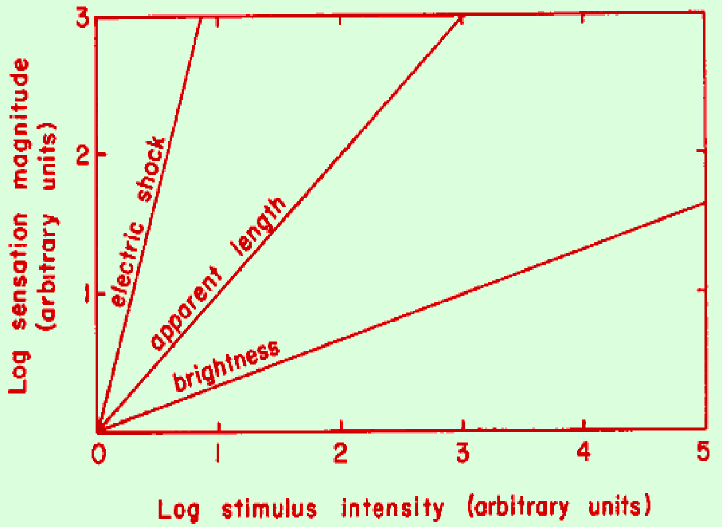


FIG. 8.3. Psychophysical magnitude functions for three perceptual continua. The linearity of the functions on double logarithmic coordinates indicates that sensation magnitude is a power function of stimulus intensity. The slope of the line corresponds to the exponent of the power function. The exponents for electric shock to the fingertips, line length, and the brightness of relatively large stimuli lasting about 1 sec are 3.5, 1.0, and .33, respectively.

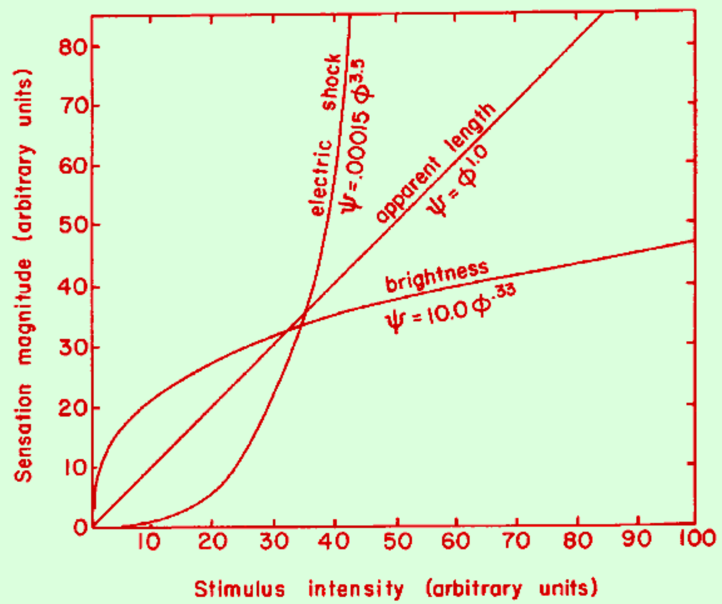
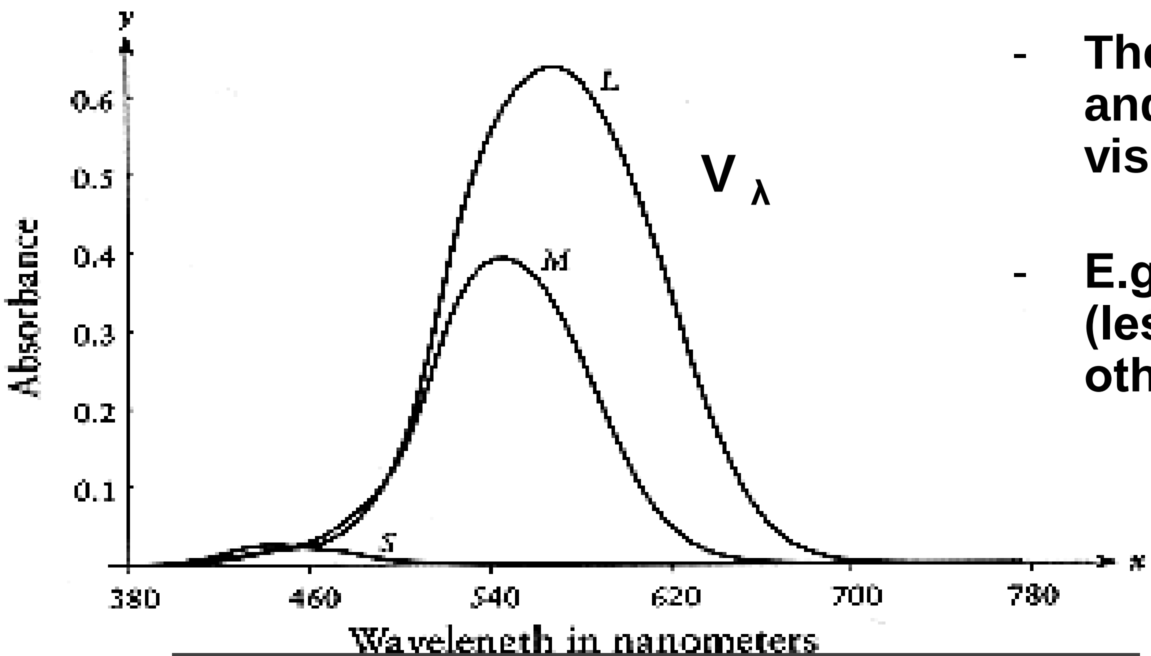
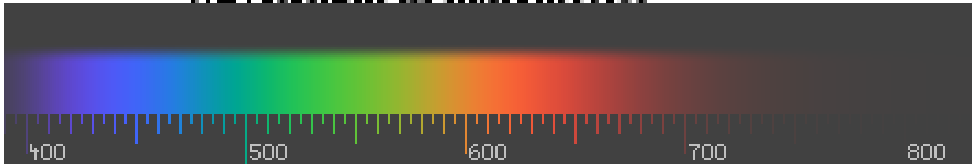


FIG. 8.4. Psychophysical magnitude functions for three perceptual continua plotted on linear coordinates. Each function is a power function. The form of the function is greatly influenced by the size of the exponent. An exponent of 1.0 corresponds to a linear function. An exponent less than 1.0 corresponds to a concave downward function, and an exponent greater than 1.0 corresponds to a concave upward function.

Cone Sensitivity Functions (also basis of color vision)





- There are both luminance and chromatic channel for visual info. processing
- E.g. don’t use blue text … (less sensitive … there are other reasons too …

three types: sensitivity functions peaks at different wavelengths (“red”, “green”, “blue”)

Luminance & Chrominance (color)

- The luminance channel is important since information presented in this channel is more likely to be perceived (by humans) vs. chrominance.

- The luminance channel yields better performance on spatial vision tasks for form, perception, and acuity and on temporal vision tasks for motion perception.

- The luminance channel dominates when resolving detail, required for reading small text or interpreting small symbols. For this reason, luminance contrast is more important in display design than color contrast.

Short wavelength sensitive cones

Blue text on a dark background
is to be avoided. We have very few
short-wavelength sensitive cones in
the retina and they are not very sensitive

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Blue text on a dark background
is to be avoided. We have very few
short-wavelength sensitive cones in
the retina and they are not very sensitive.
Chromatic aberration in the eye is also a
problem

Blue text on a dark background
is to be avoided. We have very few
short-wavelength sensitive cones in
the retina and they are not very sensitive

Luminance/Brightness Contrast

- Contrast between characters or symbols and their background is one of the most important determinants of readability. Recall, that our visual system works “more” by making comparisons--not by quantifying or measuring the amount of light.

- The greater the contrast, the greater the legibility of the display. The finer the detail present, the greater the luminance contrast required.

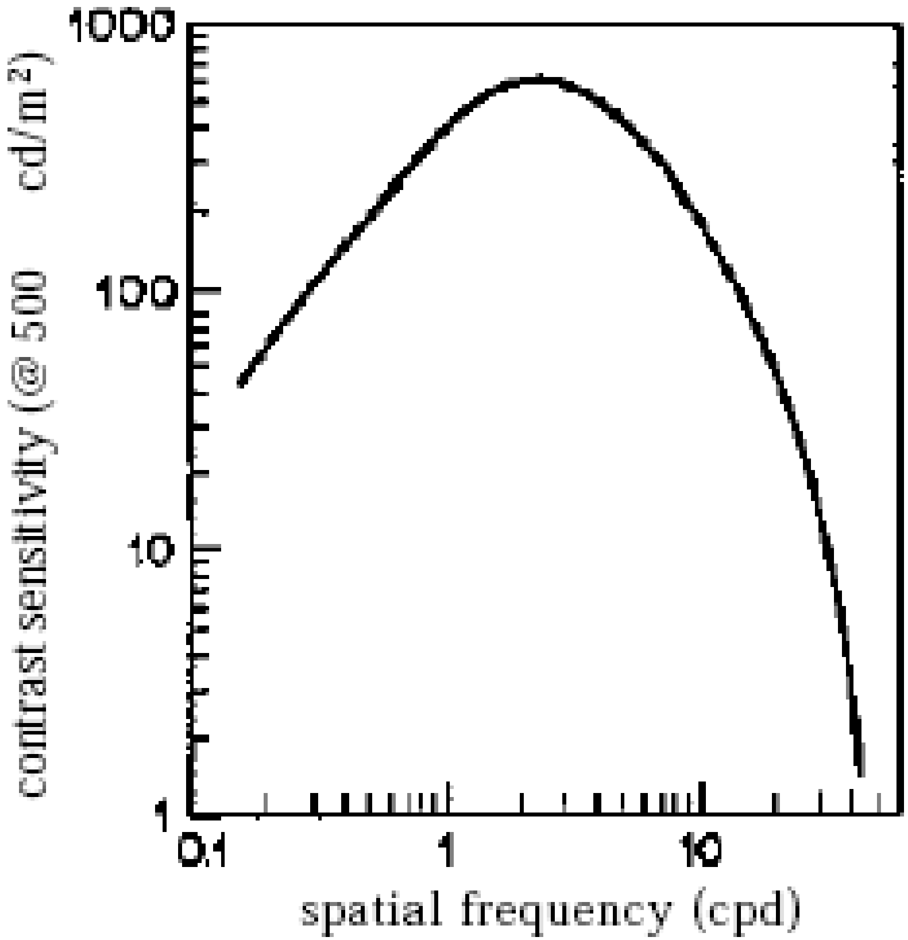
- Measurement: To determine contrast, luminance is measured with a photometer

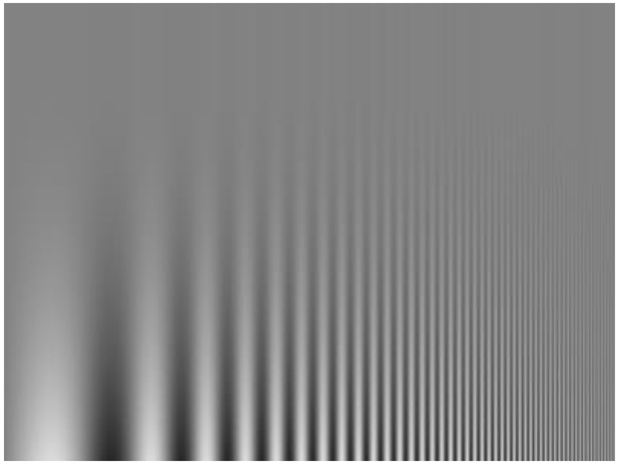
- Calculations: Luminance contrast and/or contrast ratio can be calculated using the various “contrast” formulas.

Luminance/Brightness Contrast

- E.g. this formula is used to measure contrast between an object such as a character or symbol and its background.
  - $(L_{object} - L_{background}) \;/\; L_{background}$
  - $(L_{max} - L_{min}) \;/\; (L_{max} + L_{min})$
- Recommended contrast ratios for general use computer displays (e.g. for symbols and text relative to background on self-luminous displays)
  - General Use
    - Minimum symbol contrast - 3:1
    - Preferred symbol contrast - 7:1 ~ 10:1
  - Air Traffic Control Display
    - Minimum contrast - 8:1

Contrast sensitivity



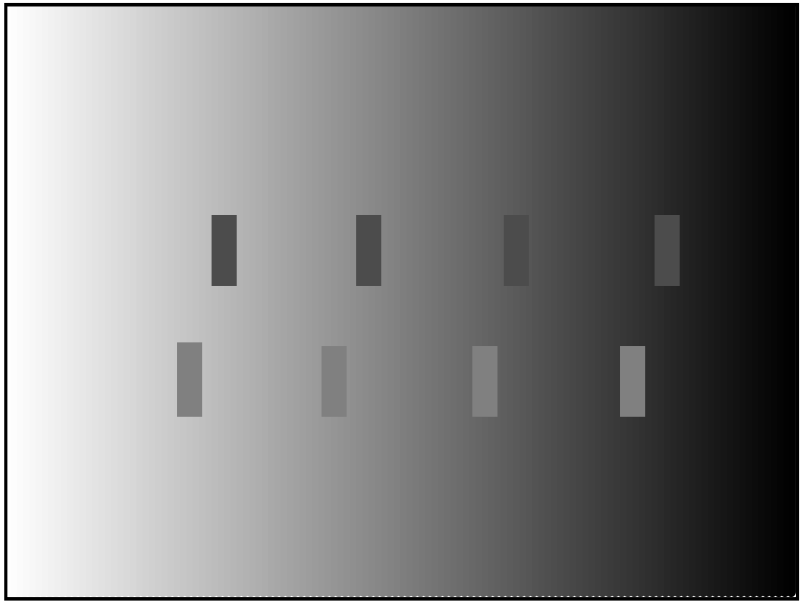


Contrast varies by the content

Simultaneous Contrast

Same gray patch looks lighter with darker background

(biological phenomenon, not psychological)



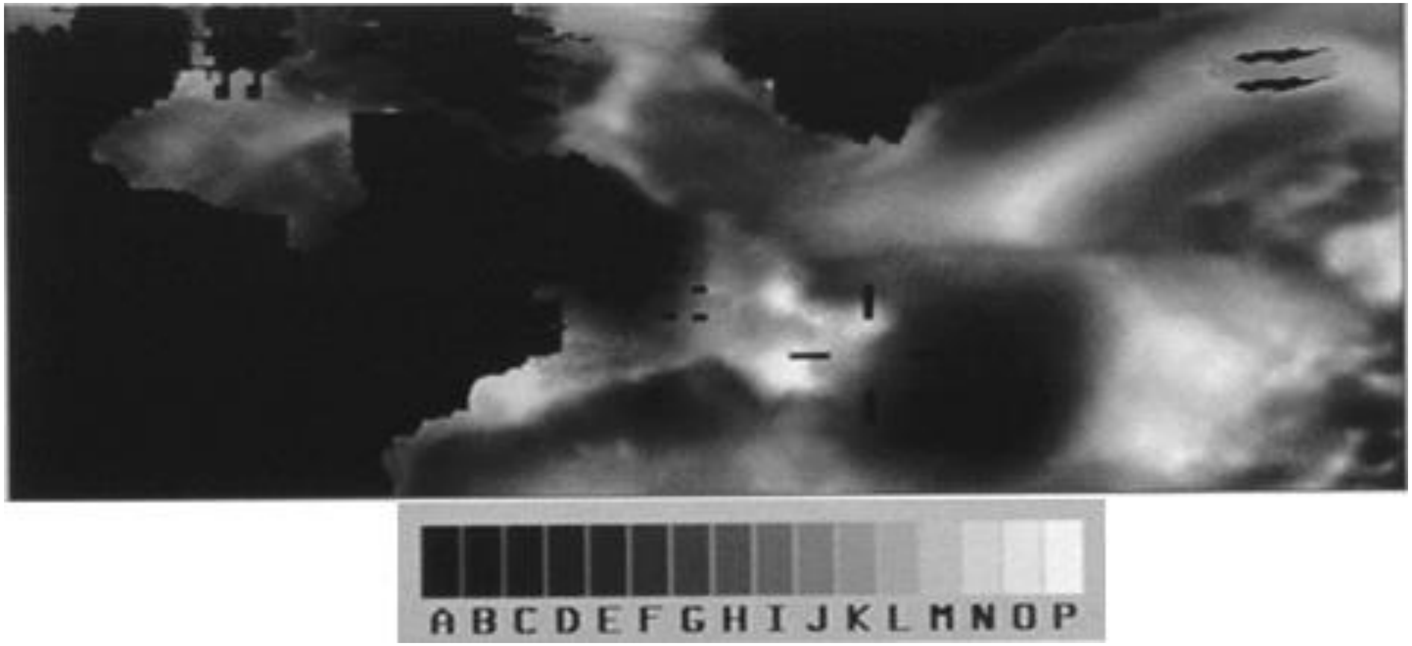
Upper row: all same brightness

Lower row: all same brightness

Another contrast variation by external factor

(background or environment)

Errors in Map Reading



The map and the code look different !

Lightness (or Luminance/Brightness) constancy

- **Luminance vs. Lightness**
  - Black paper under the sun outdoors: ~1000 candelas
  - White paper in an office: 50 candelas
  - White paper in a dark office < 50 candelas
  - Still we can tell black from white !

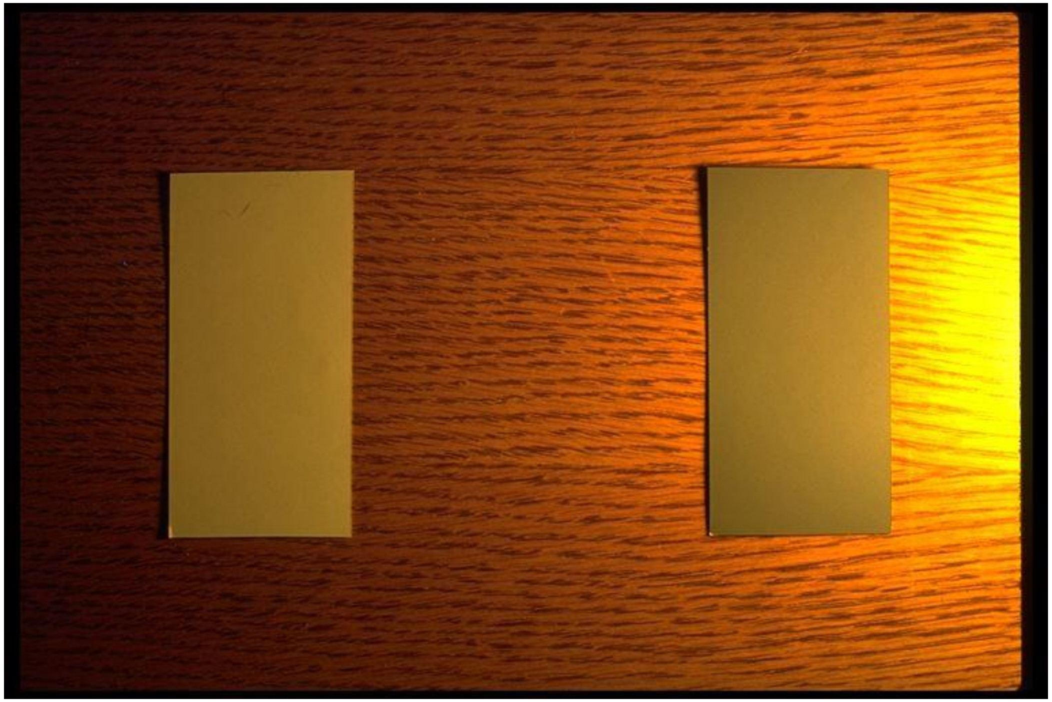
- **Humans tries to achieve "lightness constancy" despite env. condition**
  - Discounts illumination level

- **Mechanisms**
  - Adaptation
    - Photo-pigment is bleached and become less sensitive with great env. light
    - When darker, recovers (takes up to 30 min)
    - Lightness of surface is kept within range at least
  - Texture, shadow, light orientation etc.
  - Cognitive aspects

Constancy vs. Simultaneous Contrast

Paper near the lamp is gray, but reflects more light (should perceive it as similar to white)

Paper far from the lamp is white



But S. contrast makes it that gray paper look darker with brighter background (or white paper lighter with darker background)

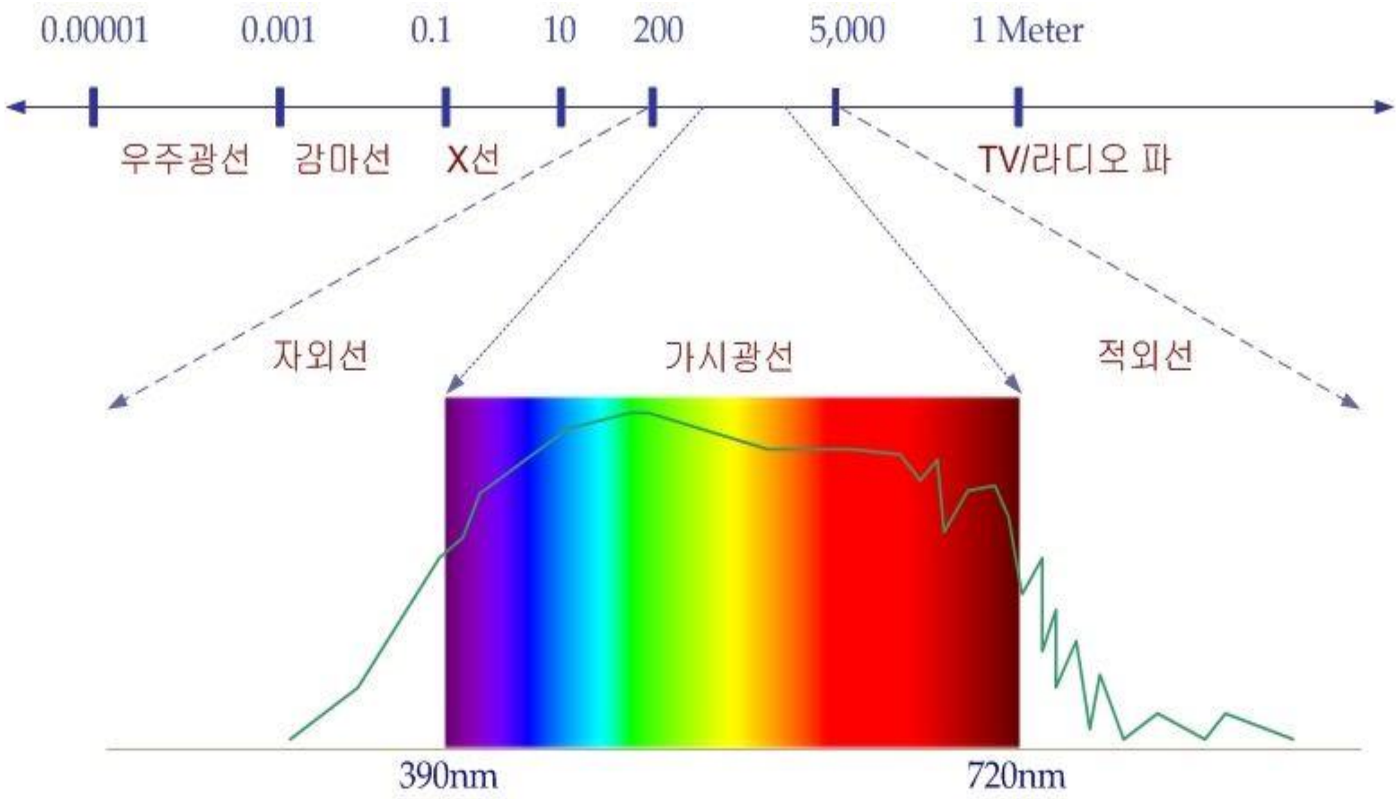
Summary

- **Humans can adapt and keep lightness (and color) constancy but help would be appreciated**

- **Contrast is important for selection of background and surrounds for visualization of information**

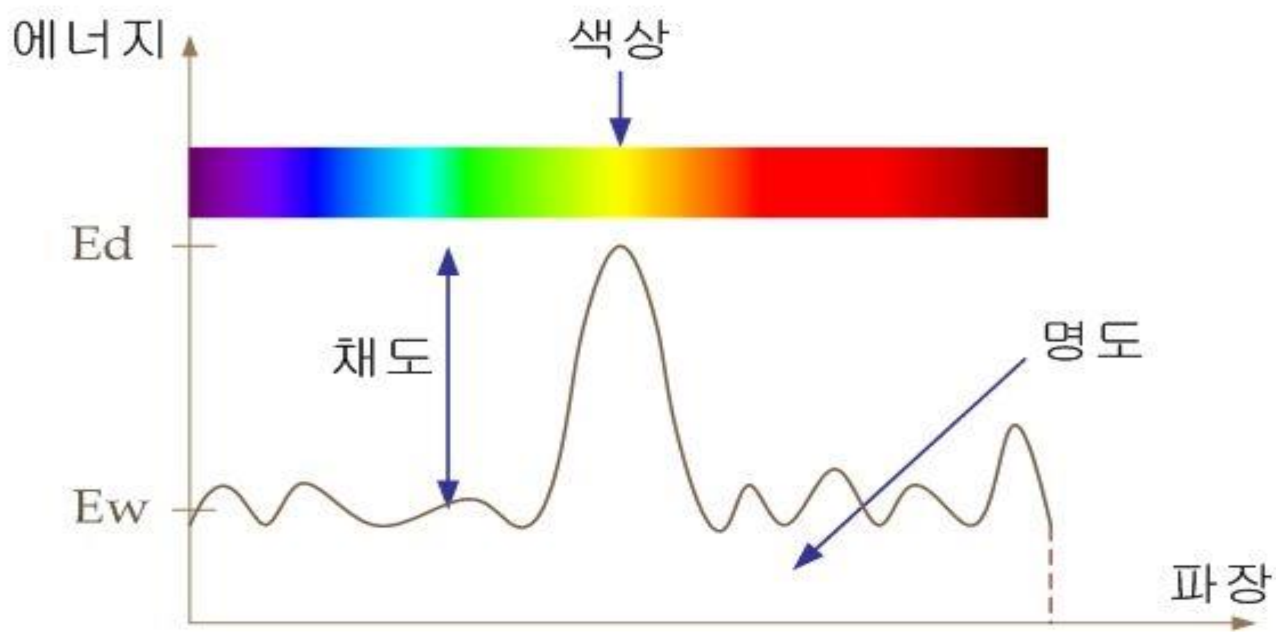
전자기파

- 주파수, 파장
- 가시광선의 파장: **390nm – 720nm**



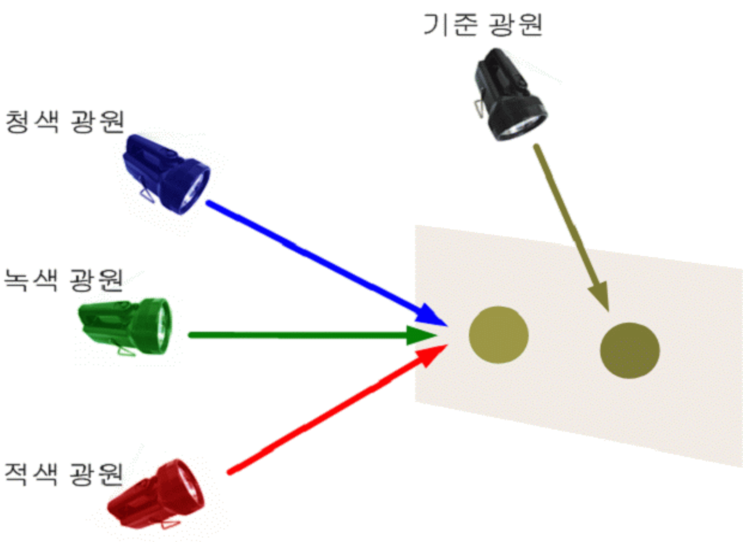
색상, 명도, 채도

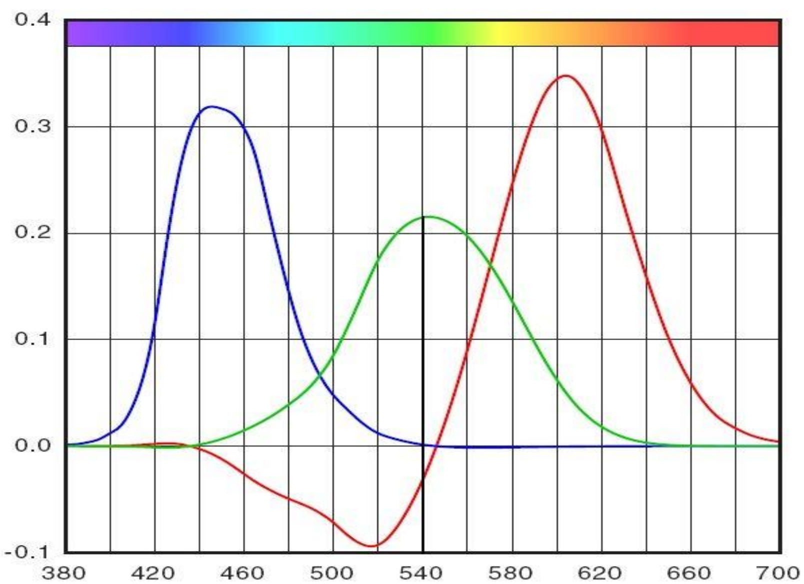
- **색상: 우세주파수의 색**
- **명도: 파형 아래의 면적**
- **채도: Ed – Ew**
  - 채도 증가: Ed 증가 또는 Ew 감소
  - Ew 감소: 명도 저하, 색상 인식이 어려움



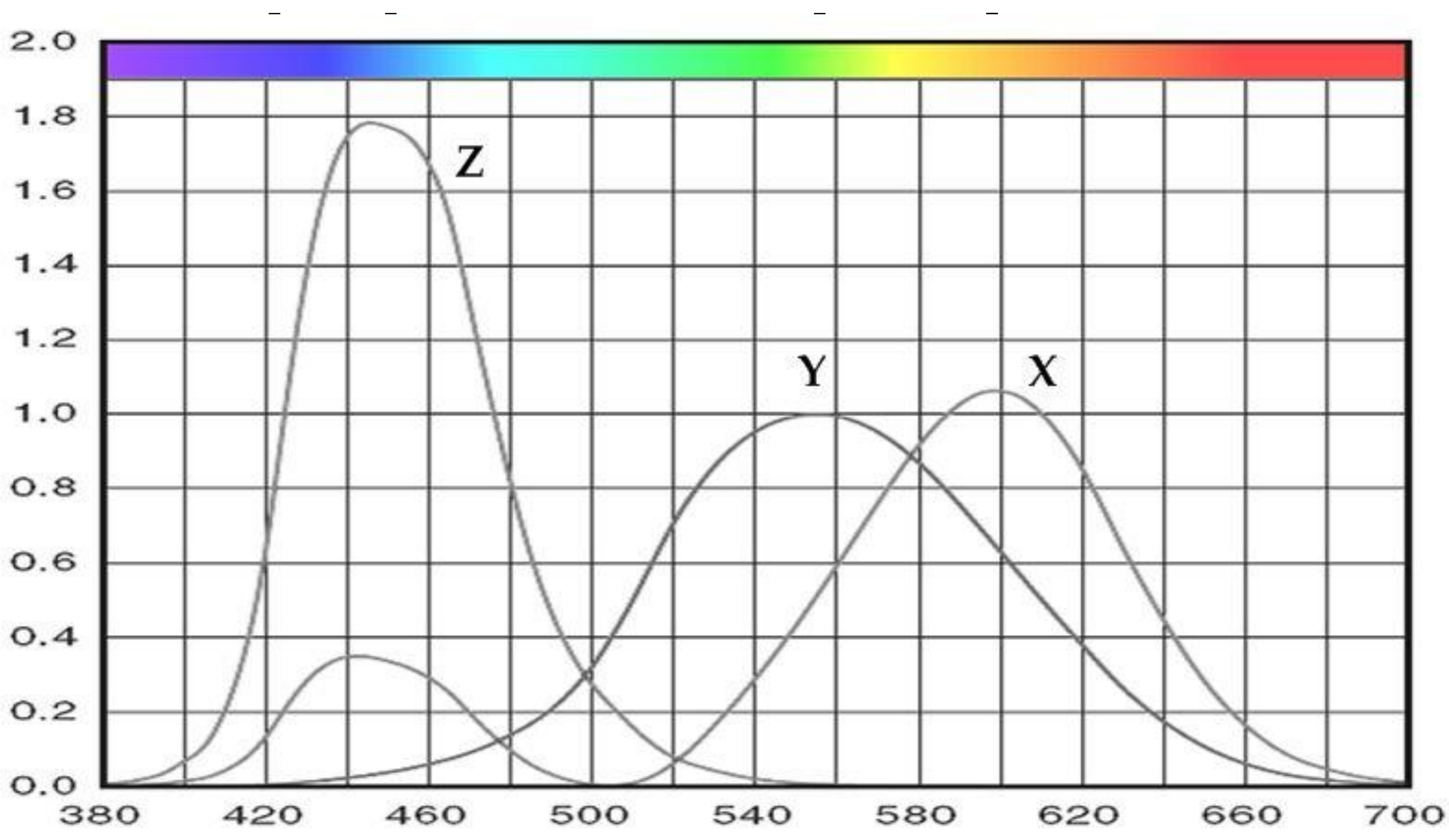
컬러 매칭

- **580 nm 황색 = 적색 광원(0.25) + 녹색광원(0.13) + 청색광원(0.0)**
- **500nm 근처에서 적색광원은 음의 값**
  - G, B를 합성한 색상에서 적색 성분을 빼야 함.
  - 현실적으로 불가능





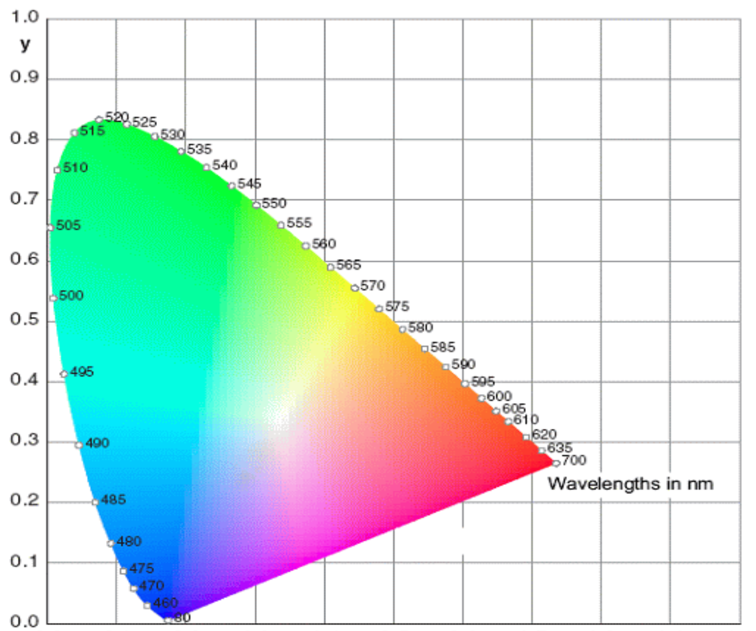
CIE 컬러 모델: color = f(X, Y, Z)

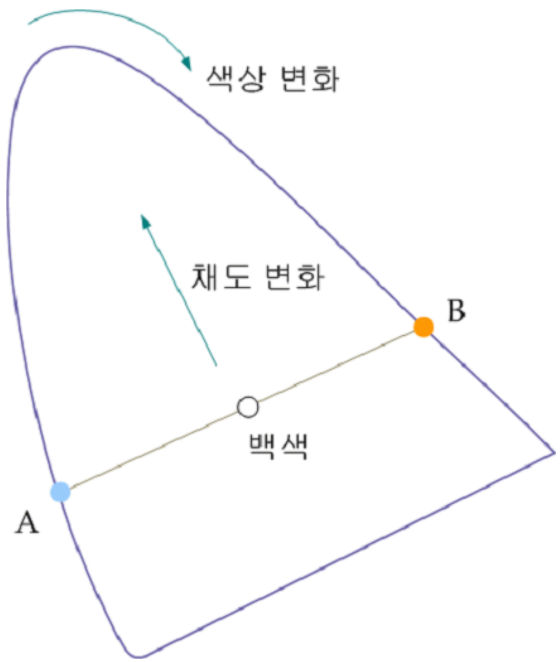


CIE 정규화 → color = g(x, y)

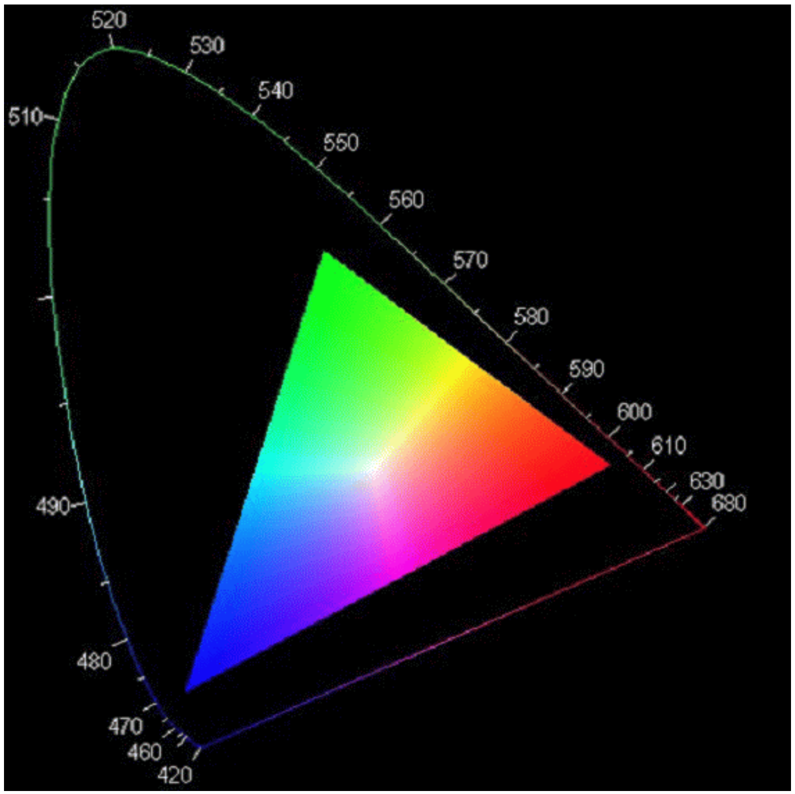
$x = X / (X + Y + Z)$ $y = Y / (X + Y + Z)$ $z = Z / (X + Y + Z)$

- **x+y+z = 1이 되도록 x, y, z를 설정**
- **x, y가 결정되면 z는 자동으로 결정됨: x, y의 함수로서 색을 표현**
  - CIE 색 범위
  - 순색(단일 파장): 경계선, 내부색: 순색의 혼합, 보색: 예. A와 B

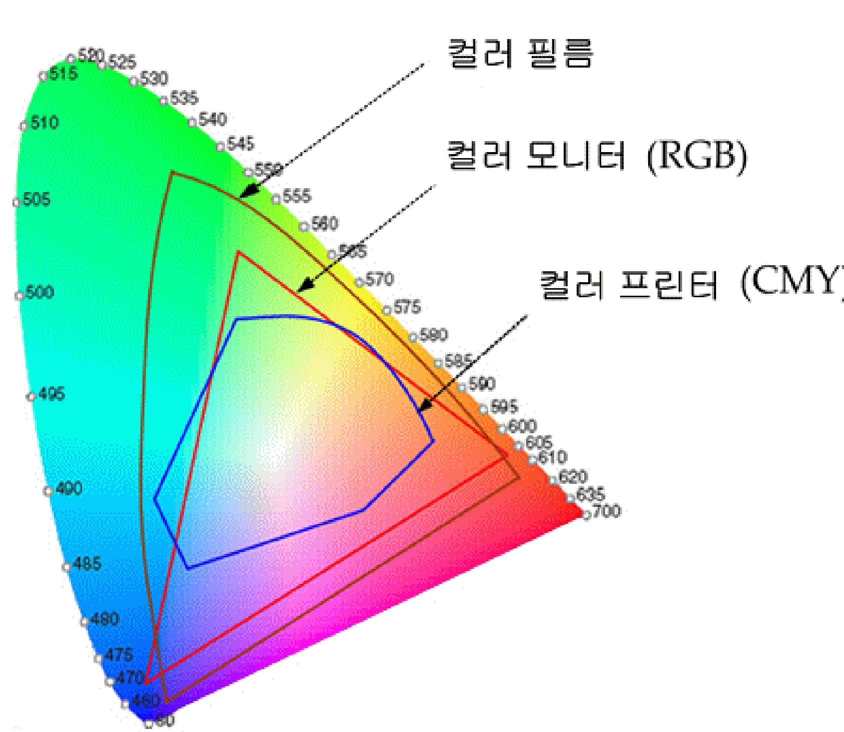




색 범위(Color Gamut)



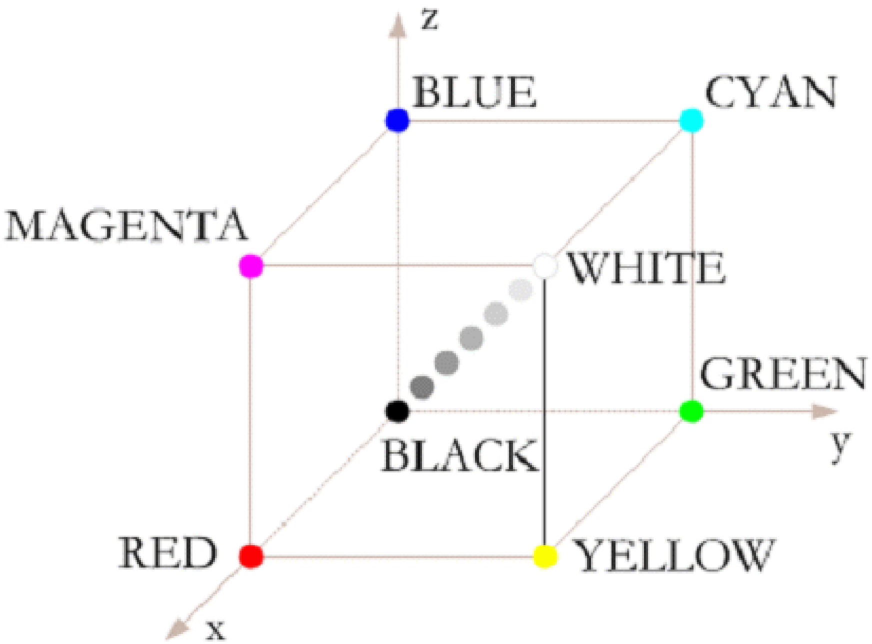
[그림 3-10] 컬러 모니터 색 범주

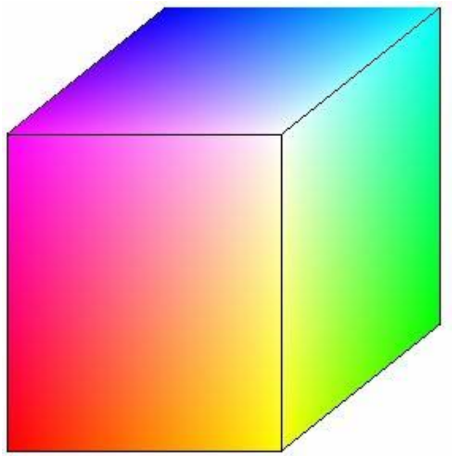


[그림 3-11] 출력 장비별 색 범주

RGB Color Model

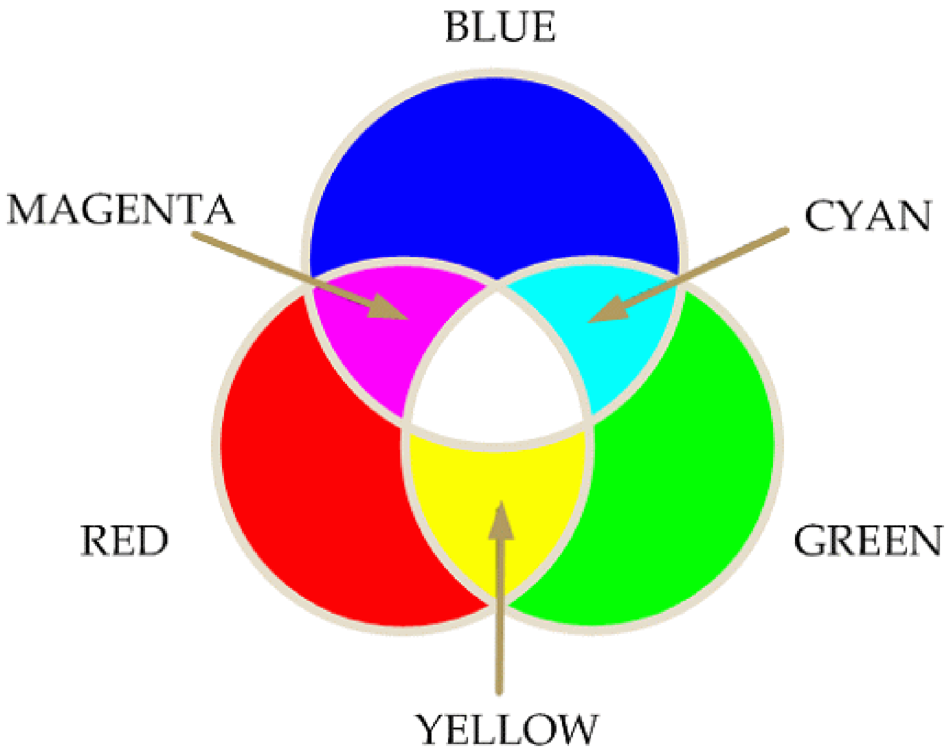
- 삼중 자극이론(Tri-Stimulus Theory)
  – 원추세포는 파장 630nm(빨강), 530 nm(녹색), 450nm(청색)에 가장 민감하게 반응





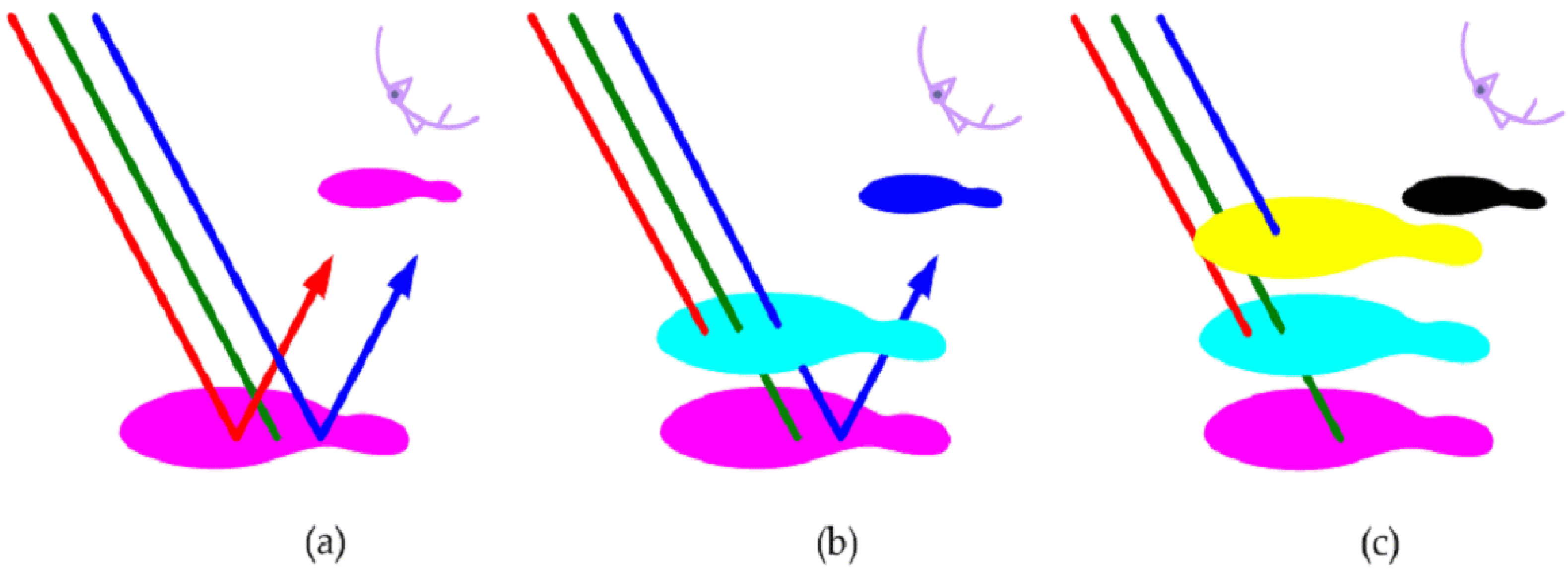
RGB Color Model

- **Additive**
  - 빛의 합성(예: 모니터)
  - R+G = Y, G+B = C, B+R = M
  - RGB의 보색은 CMY



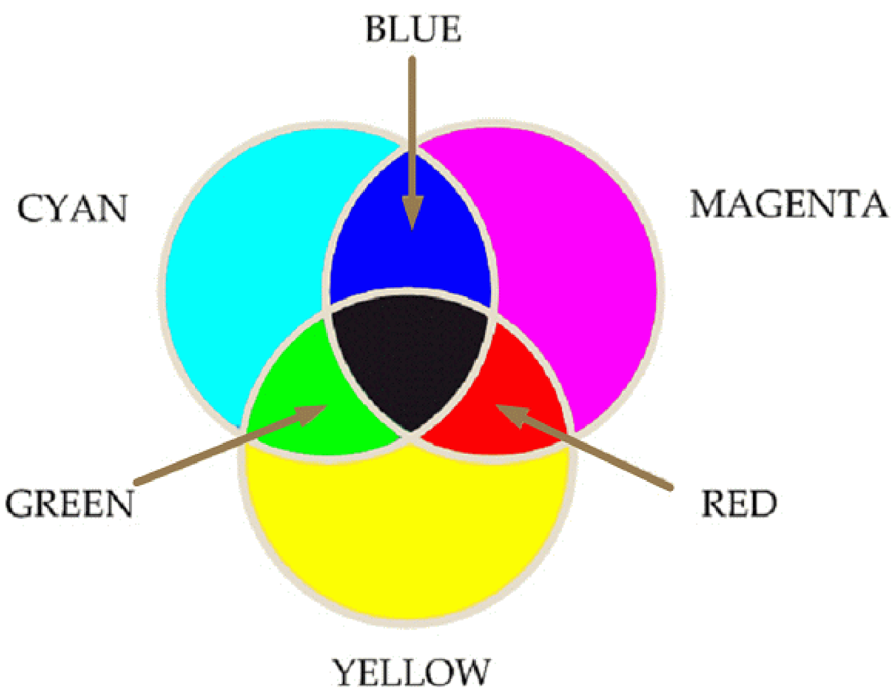
CMY Color Model

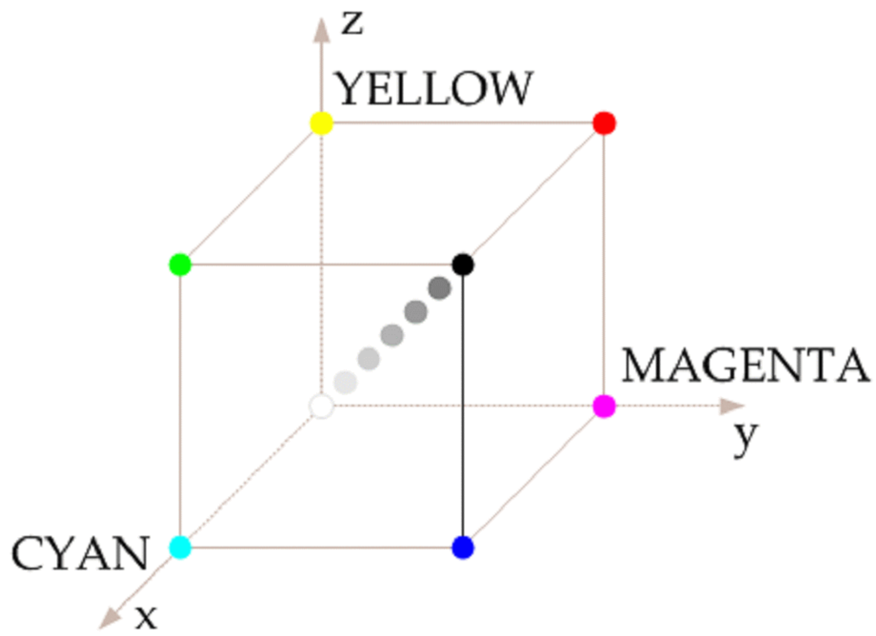
- **Subtractive**
  - 물감의 합성 (예: 프린터)
  - W - G(Complement of Magenta) = R + B = Magenta
  - (W - G) - R(Complement of Cyan) = Blue
  - (W - G - R) - B(Complement of Yellow) = Black



CMY Color Model

- RGB는 CMY의 합성으로 표현
- C+M+Y = Black   cf. R+G+B
- 물감의 삼원색은 CMY. 빨강노랑파랑이 아님.



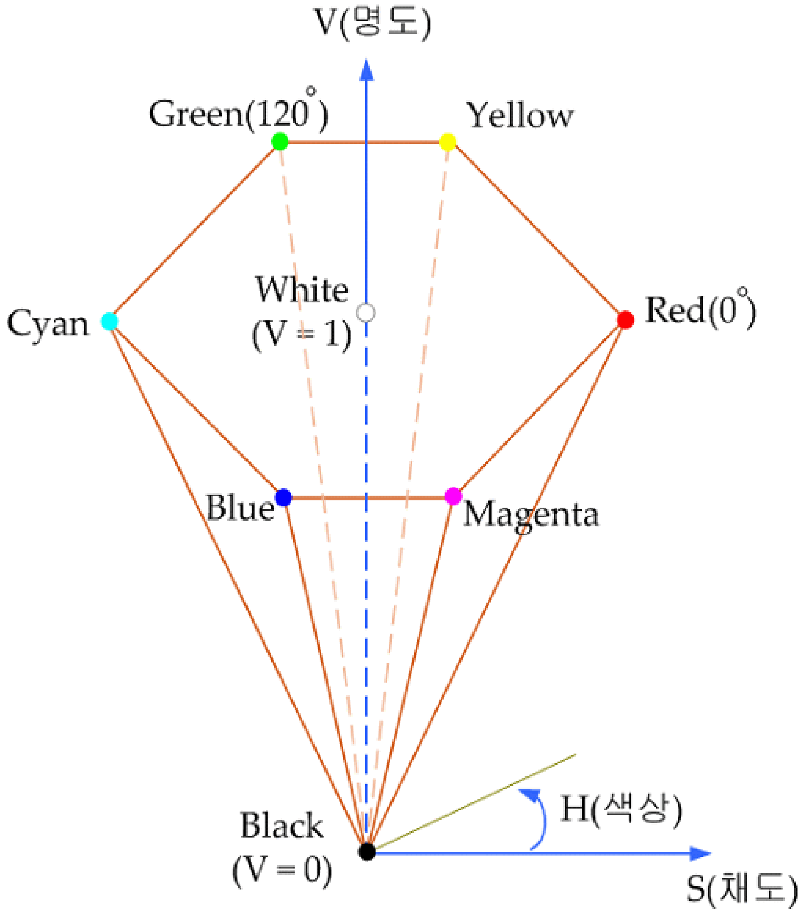


HSV Color Model

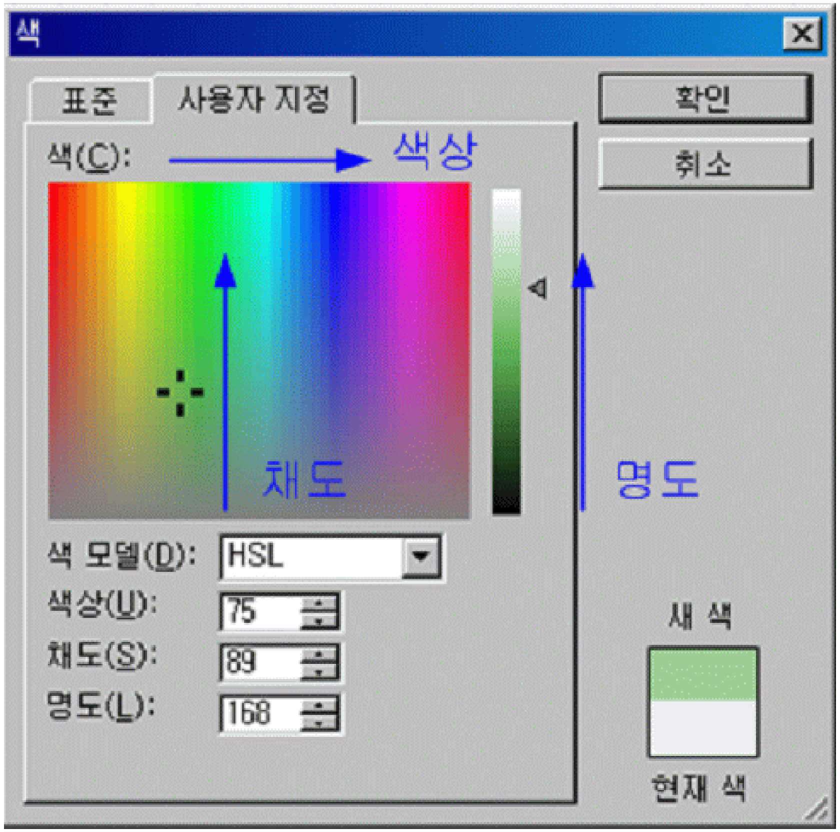
- **RGB 모델의 단점**
  - 직관적이지 않다. 보라색 = R, G, B 각각 얼마?
- **HSV(Hue, Saturation, Value)**
  - 또는 HSB(Hue, Saturation, Brightness)
  - 색상(Hue), 채도(Saturation), 명도(Value, Brightness)
  - 화가의 직관
    - 셰이드 = 어떤 색상에 흑색을 섞음. 채도와 명도를 동시에 낮춤.
    - 틴트 = 어떤 색상에 백색을 섞음. 채도는 낮추고 명도는 높임.

HSV Color Model

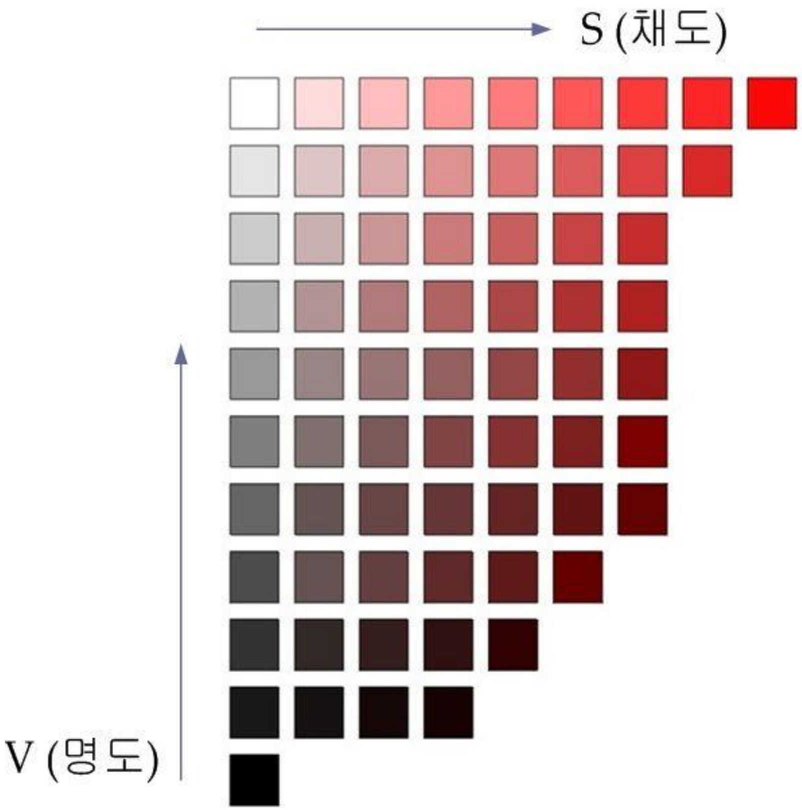
H	S	V	색
0	1.0	1.0	Red
120	1.0	1.0	Green
240	1.0	1.0	Blue
	0.0	1.0	White
		0.0	Black
90	0.5	0.25	



HSV Color Model



[그림 3-23] HSV 대화상자



[그림 3-24] HSV 단면

YUV

- **컬러 TV의 흑백 TV 호환성**
  - Y = 0.213R + 0.715G + 0.072G
  - Y' = 0.299R + 0.587G + 0.114B　　　　명도
  - U = 0.492 (B - Y')   V = 0.877 (R - Y')　　　색(색상, 채도)

- **디지털 TV**
  - Y'CbCr
  - Cb = (B - Y')/1.772 + 0.5   Cr= (R - Y')/ 0.402 + 0.5

- **NTSC TV 표준**
  - I는 주황-청색(Orange –Blue), Q는 자주-녹색(Purple-Green)축

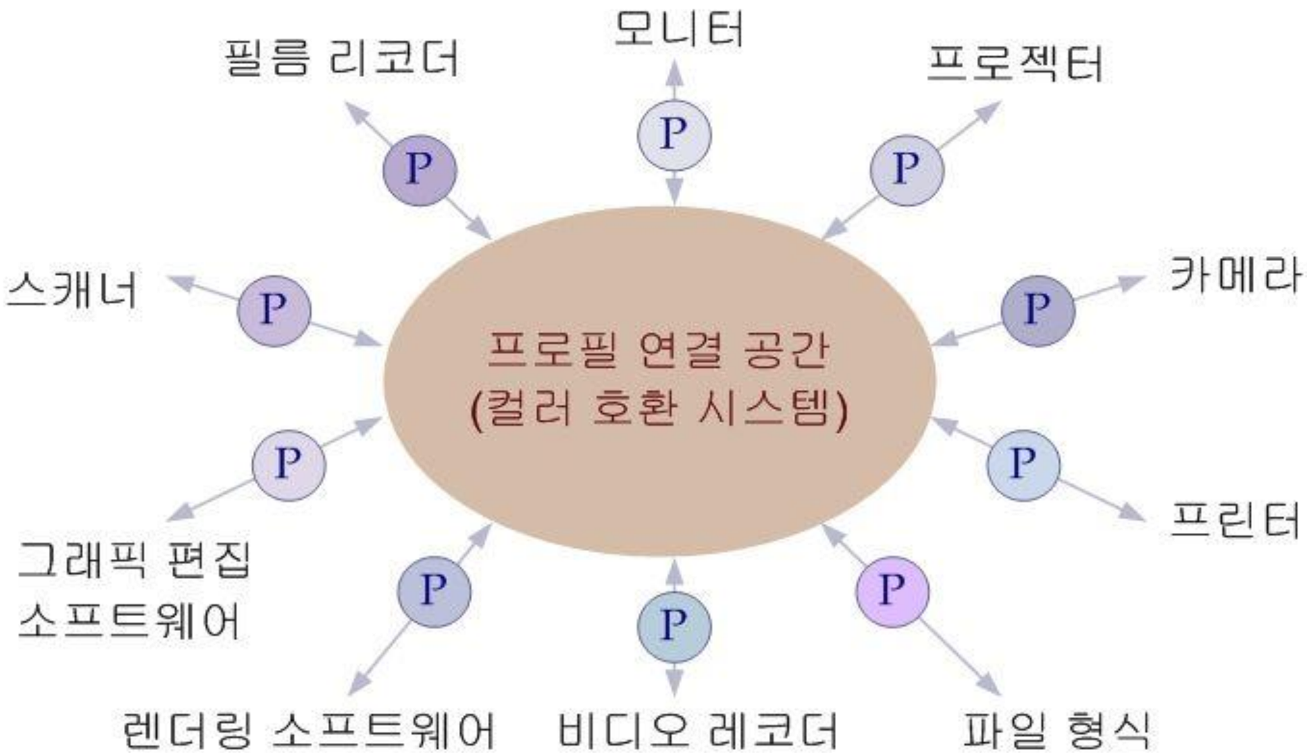
$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.275 & -0.321 \\ 0.212 & -0.523 & 0.311 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

CIE L*a*b*

- **웨버의 법칙**
  – 자극이 강할수록 상대적 감도는 낮아짐
  – 절대 명도 I일 때, 인지된 명도는 Log (I)에 비례
- **CIE 모델의 문제점**
  – 인지된 색차가 그림의 거리에 비례하지 않음
- **CIE의 변형**
  – 인지 컬러모델(Perceptual Color Model)
  – 인지된 색차가 맵상의 거리에 비례하도록

CMS(Color Management System)

- **컬러 호환성**
  - 컬러모델, 장비특성에 따른 오차를 최소화
  - 개별 장비의 컬러모델, 장비특성을 프로필 형태로 나타냄
  - 장비에 무관한 컬러공간으로 사상

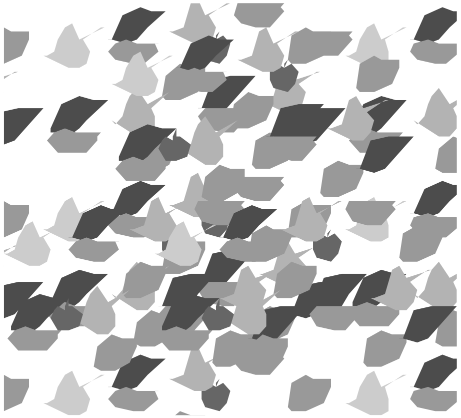
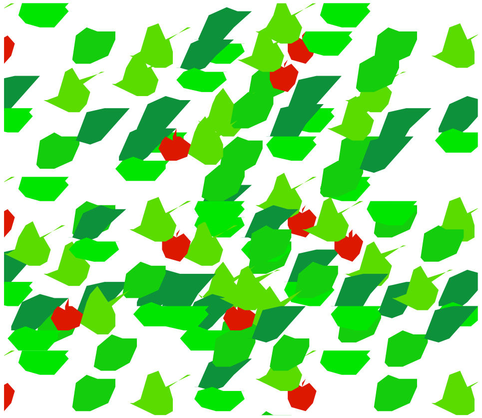


Color is irrelevant …

- **To perceiving object shapes**
- **To perceiving layout of objects in space**
- **To perceiving how objects are moving**

But, color is critical…

- **To help us break camouflage**
- **To judge the condition of objects (food)**
- **To determine material types**
- **Extremely useful for coding information**

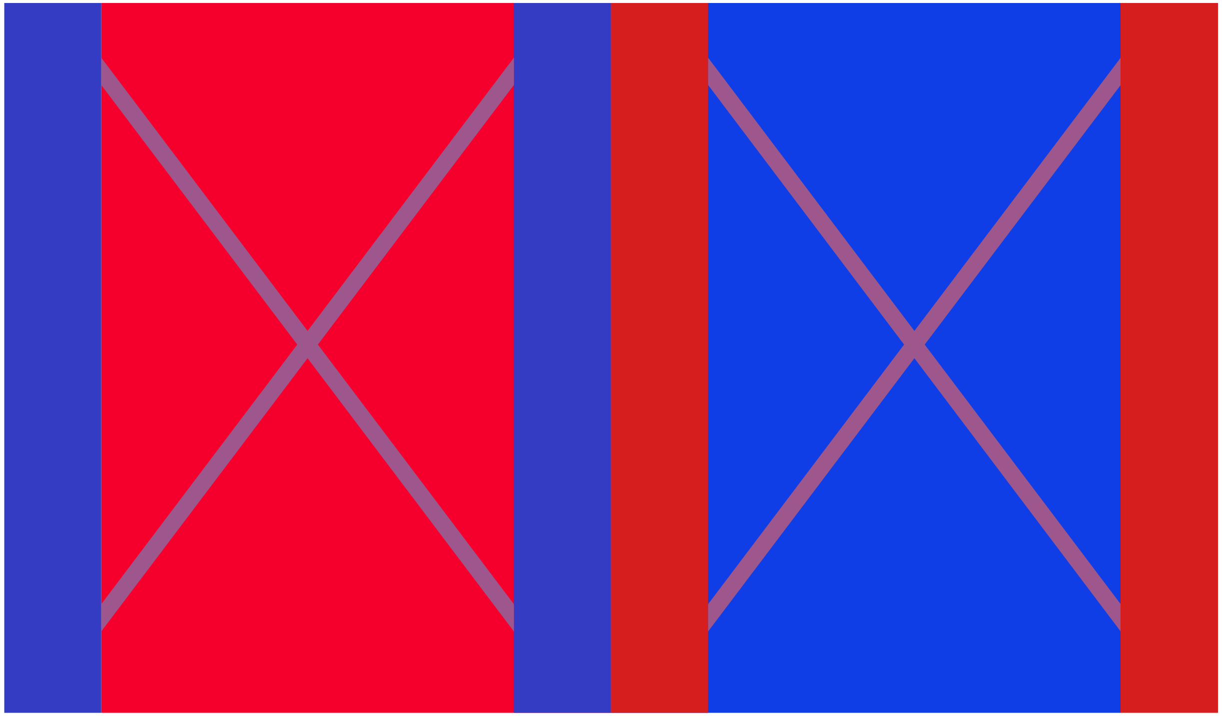
Implications

- **Chromatic channels are only capable of one third of the info carried out by the luminance channel**
  - Chromatic difference is not suitable for display kind of detail

Luminance contrast needed to see detail

3:1 recommended
10:1 idea for small text

Color contrast



Legibility	Black Background	White Background
Best	White	Black
	Yellow , Dark Yellow	Blue, Dark Blue
	Cyan , Dark Cyan	Red, Dark Red
Medium	Green, Dark Green	Magenta
	Magenta	Green, Dark Green
	Red, Dark Red	Cyan , Dark Cyan
Poorest	Blue, Dark Blue	Yellow , Dark Yellow
None		

Inappropriate Text Colors

- Beware of blue: Blue is inappropriate for discerning small shapes like alphanumeric characters, dots etc. on a dark background. However, blue is a good background color.
- Light greens are as well inappropriate as text colors on light backgrounds.

Blue	Blue	Red	Red	Green	Green
Blue	Blue	Red	Red	Green	Green

Lightness and Hue Differences

For readable text (or graphics) always provide a significant lightness difference between the information and the background (the acuity of the eye is much higher for lightness changes than for changes in hue and saturation).

Do	Do not
Black on White	Black on Dark Grey
Dark Grey on White	Middle Grey on Light Grey
Black on Light Grey	Dark Grey on Middle Grey

Discrimination on the basis of hue and/or saturation differences alone is not adequate in any situation where there is fine detail.

Do: Hue/Saturation and Lightness	Do not: Hue/Saturation Only
Blue on Cyan (Hue)	Blue on Cyan (Hue)
Blue on Blue (Saturation)	Blue on Blue (Saturation)

Guideline: Allow a contrast ratio of at least 5:1 between text and background (ISO 9241 demands at least 3:1, but 10:1 is preferred).

Maximum Lightness Difference	Little Lightness Difference
Black on White, Bold	**Blue on Green, Bold**
Black on White, Plain	Blue on Green, Plain
White on Black, Bold	**Green on Magenta, Bold**
White on Black, Plain	Green on Magenta, Plain

Blue Text on Red Background and Vice Versa

Do not use **blue** text on a **red** background or vice versa - the colors are seen at different depths.

Blue on Red	Red on Blue

Put Colored Text on Neutral Background

For maximum **legibility**, avoid colored text with colored background (the hue changes through color contrast or hue induction.)

-> Place colored text on a neutral background (white, black, or grey) or use black or white text on a colored background.

Do	Do not
Blue on Grey	Blue on Green
Black on Yellow	Black on Blue
White on Blue	White on Yellow

Rules for Choosing Black and White Text

- Background lightness between 0% and 20%: Use white text
- Background lightness between 40% and 100%: Use black text

Background Lightness	White Text	Black Text
20%	White	Black
50%	White	Black
80%	White	Black

Improving Color Consistency

Color **consistency** can be improved (if color is necessary, e.g. for a corporate color scheme) by using backgrounds which are desaturated and either of a closely similar hue to the text or, for increased contrast, of a complementary hue.

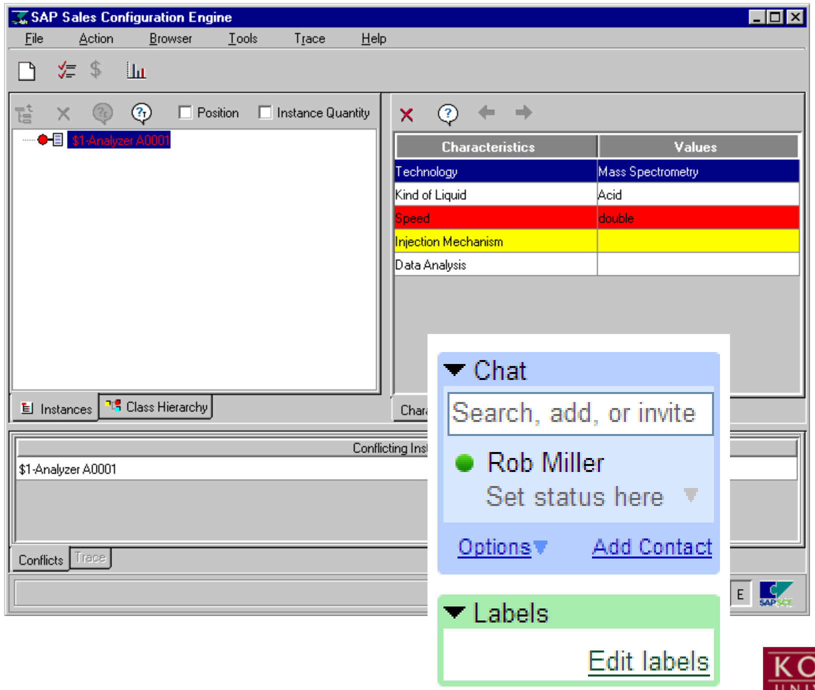
Similar Hue	Complementary Hue
Blue on Light Blue	Blue on Light Yellow
Red on Light Red	Red on Light Cyan
Green on Light Green	Green on Light Magenta

Avoid saturated colors

- In general, avoid strongly saturated colors - i.e., the colors around the outside edge of the HSV cone. Saturated colors can cause visual fatigue because the eye must keep refocusing on different wavelengths.
- They also tend to saturate the viewer's receptors (hence the name). One study found that air traffic controllers who viewed strongly saturated green text on their ATC (air traffic control) interfaces for many hours had trouble seeing pink or red (the other end of the red/green color channel) for up to 15 minutes after their shift was over.
- Use less saturated, "pastel" colors instead, which mix gray or white into the pure color.

Avoid saturated colors

- The examples on top use colors with high saturation; on the bottom, low saturation. Shades of gray have minimum saturation.



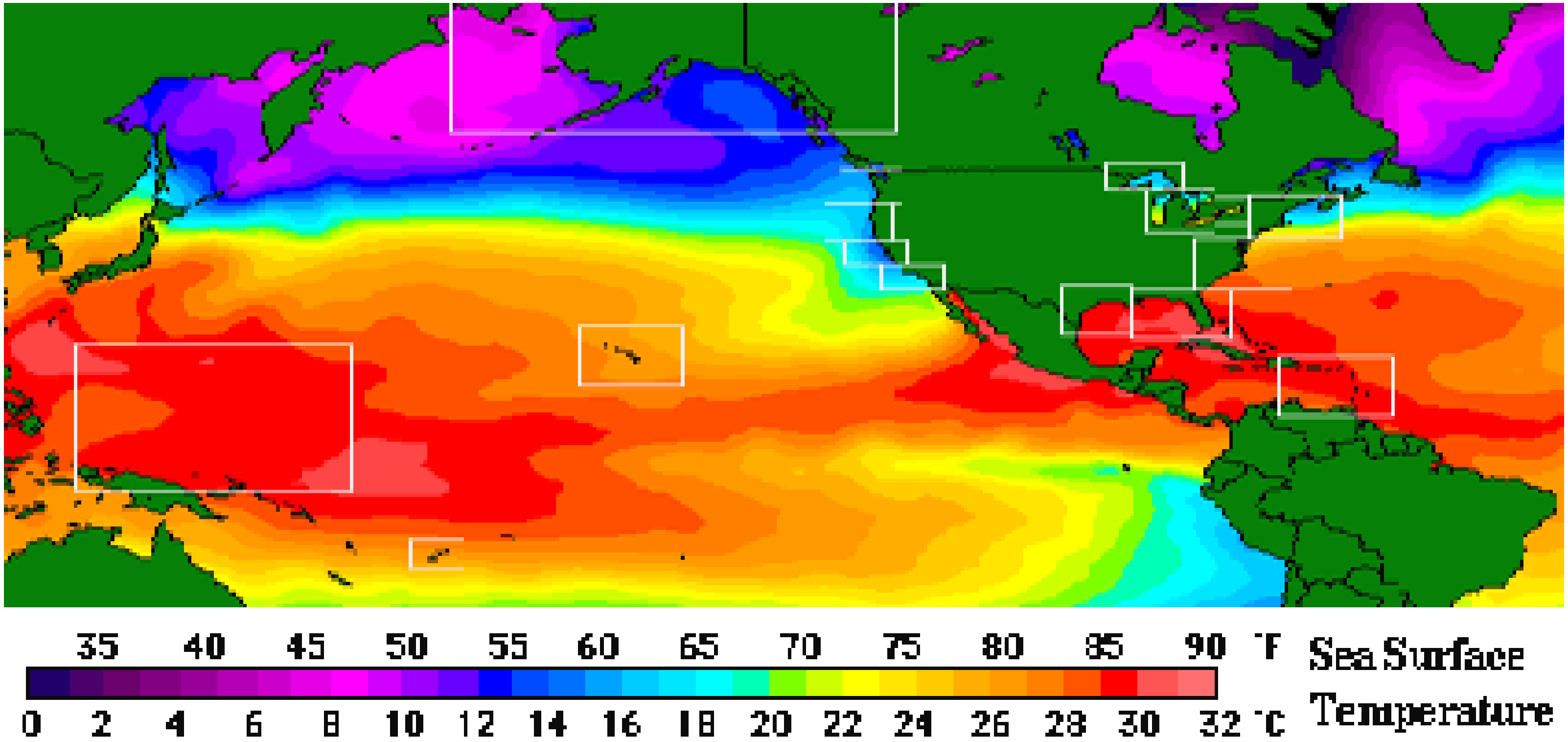
Types of data and coding

- Nominal (labeling)
- Ordinal (orderable, but not regular)
- Interval (meaningful step sizes)
- Ratio (Zero, ratios)

Color coding and memory

- Although human vision enables us to perceive differences among millions of colors, we have very poor color memory
- For this reason, the number of different colors used for coding on a display should be limited to between five and ten colors
- Humans are much better at performing “relative judgment” tasks in contrast to the “absolute judgment” task. One way to change a display from requiring absolute judgment to relative judgment is to incorporate a comparison scale (three dimensions … e.g. HSV, RGB, …)

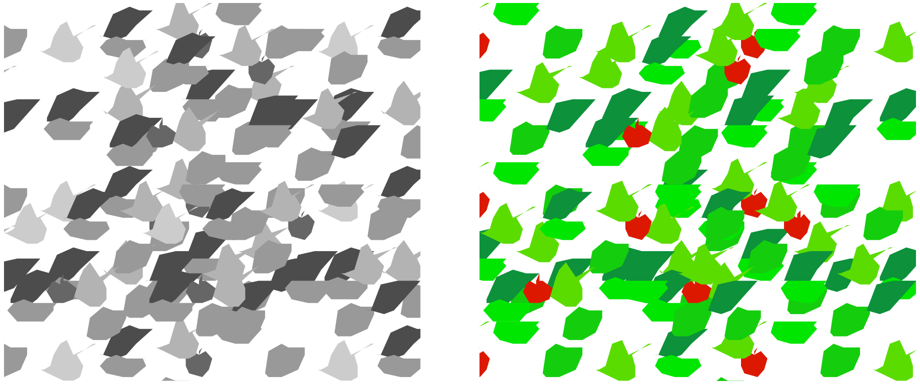
Color coding and memory

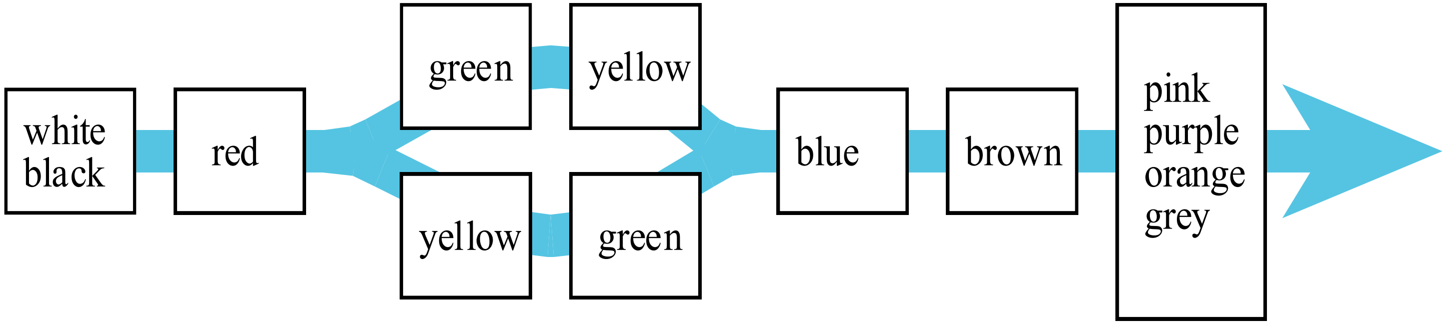


Color great for classification

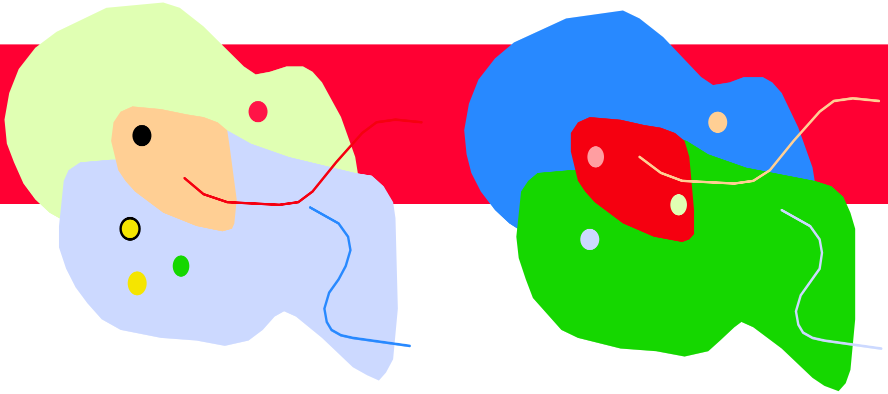
- **Rapid visual segmentation**
- **Color helps us determine type**
- **Only about six categories**

  (Magic Number ?)





Color coding



Large areas: low saturation

Small areas high saturation

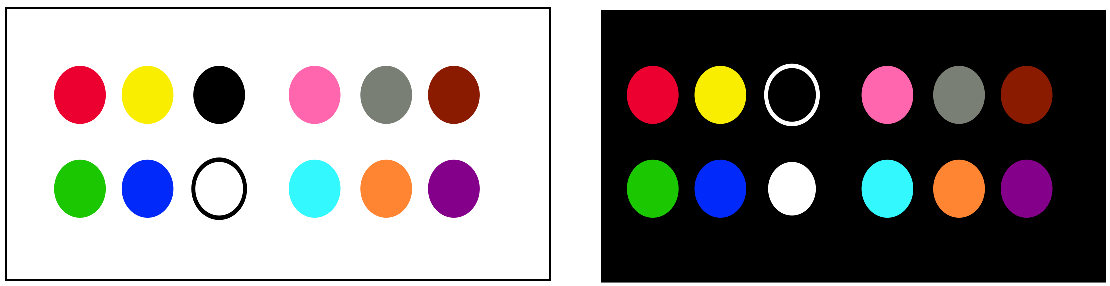
Break iso-luminance with borders

Must have luminance contrast with background to see details

The same rules apply to color coding text and other similar information. Small areas should have high saturation colors.

Large areas should be coded with low saturation colors

Color choices (for coding)

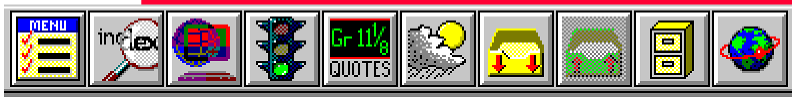


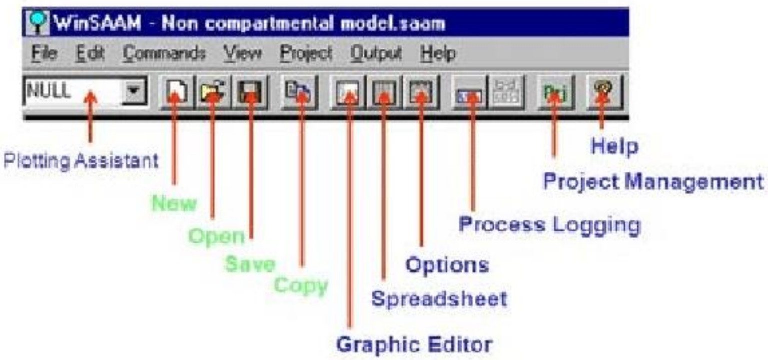
Which colors? (distinct and memorable)

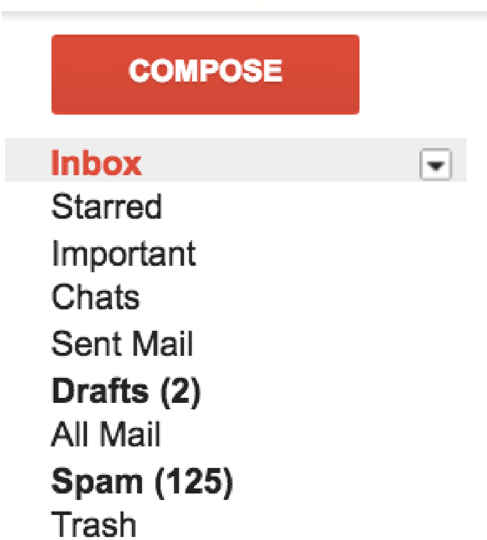
Recommended: Red, Green, Yellow, Blue, Black, White

Pink, Cyan, Gray, Orange, Brown, Purple

Also consider cultural aspect: “Red” is good or bad?







An interface with many colors appears more complex, more cluttered, and more distracting. Use only a small number of different hues.

The toolbar on top uses too many colors (many of them highly saturated), so none of the buttons stand out, and the toolbar feels hard to scan. In contrast, the toolbar at the bottom uses only a handful of colors. It’s more restful to look at, and the buttons that actually use color (like the Open File button) really pop out.

A simple and very effective color scheme uses just one hue (like blue or green, weakly saturated and in various values), combined with black, white, and shades of gray.

Examples: Color for classification

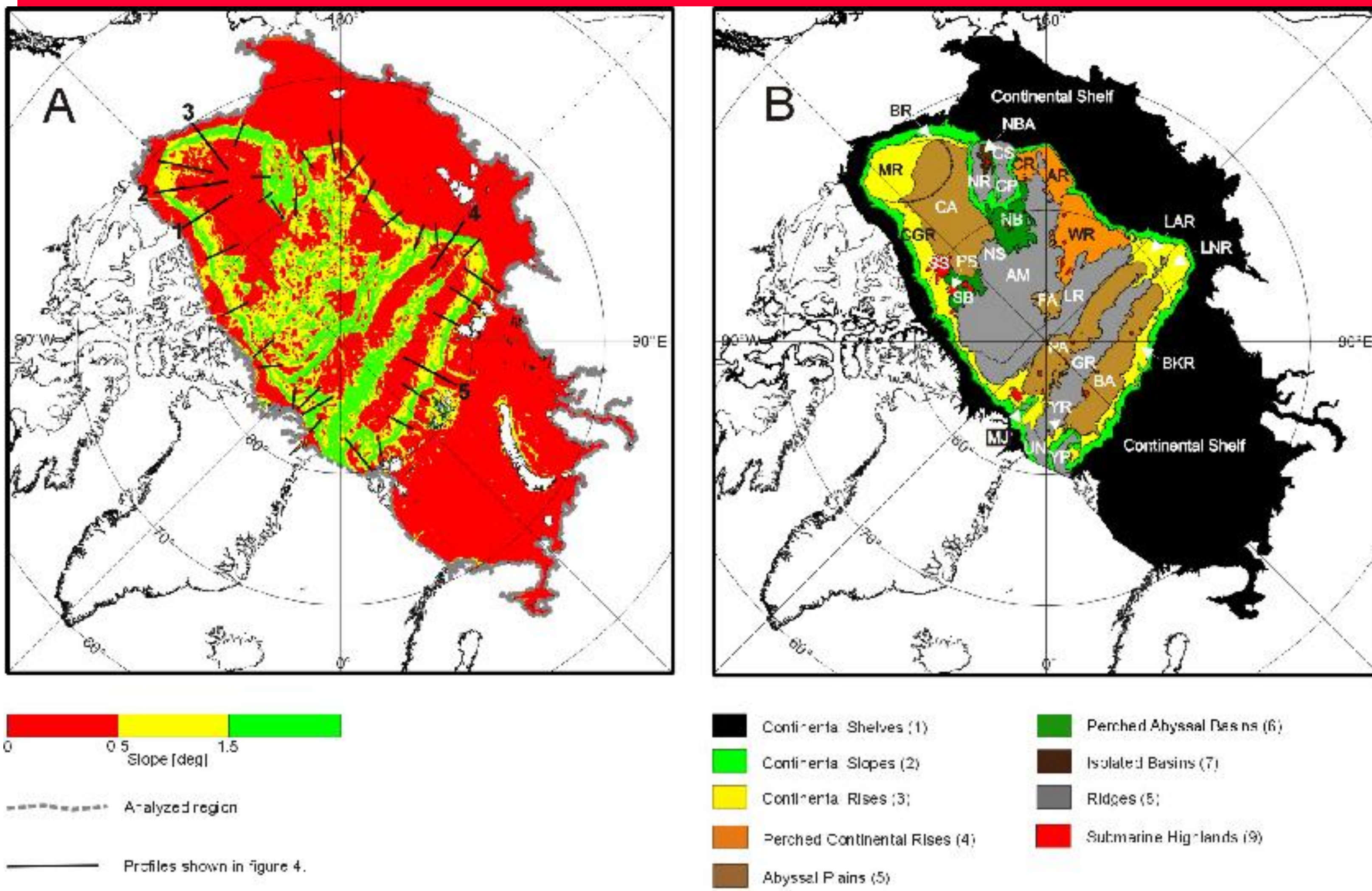


Figure 3A and B. Continuous scale (hue?) Classification (9 colors)

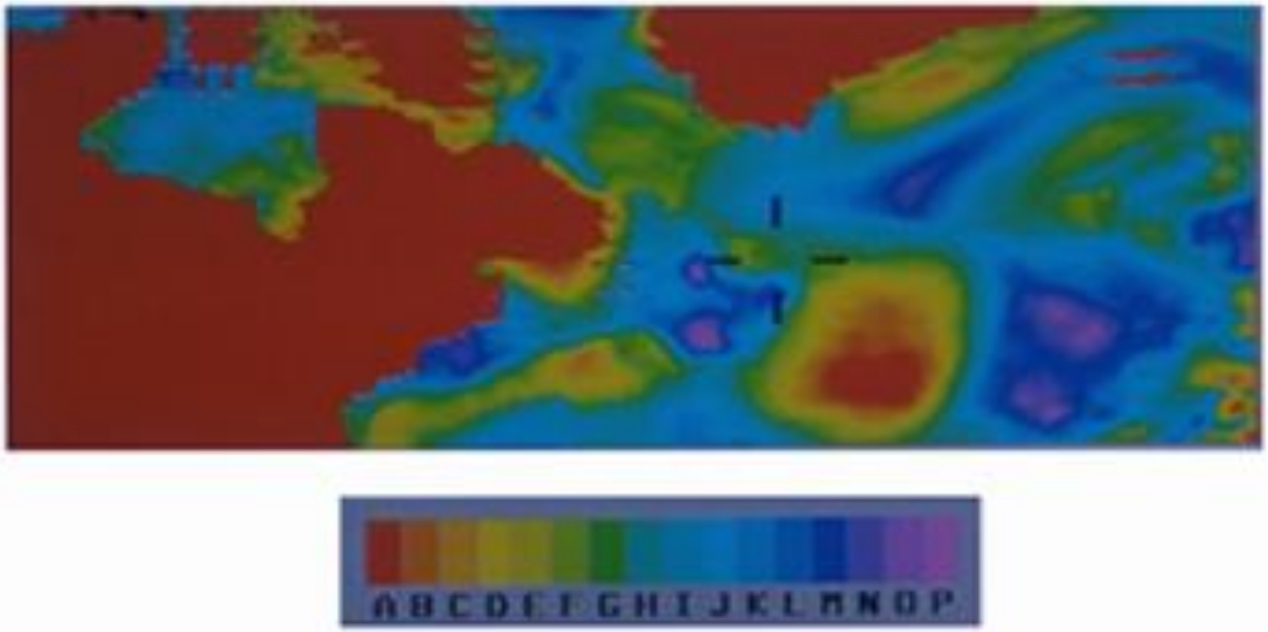
Ordinal data

- *Order*: ordered values should be represented by perceptually-ordered colors
- *Separation*: significantly different levels should be represented by distinguishable colors
- Can use uniform color spaces
- *Luminance:* good for showing form
- *Many hues:* useful for showing readable values

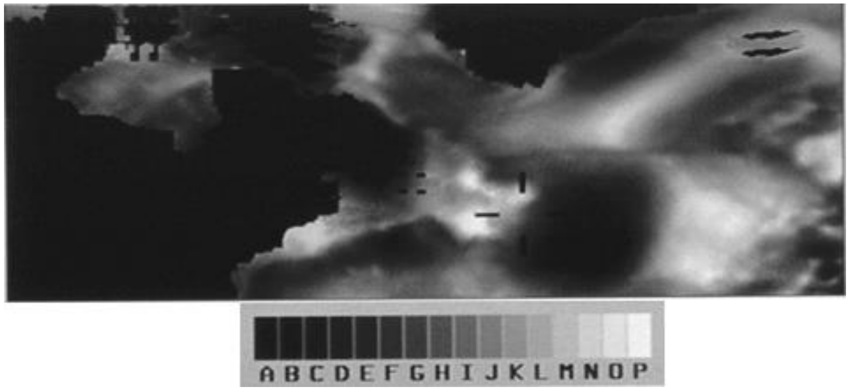
Ordinal Data: Pseudo-color sequences

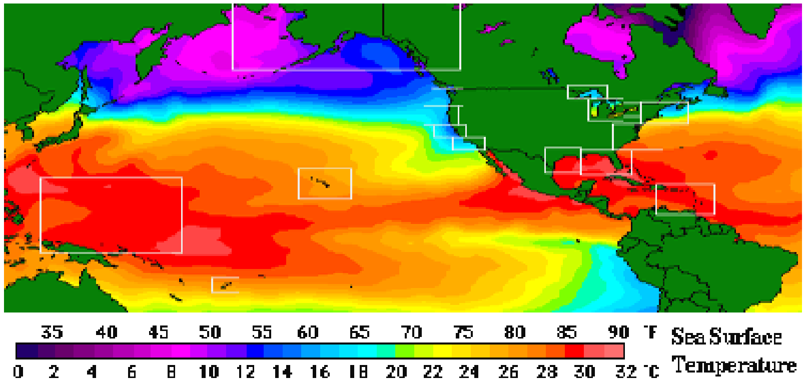
- One approach: Change a single color model component with other components held constant

- Examples
  - Grey scale
  - Saturation scale
  - Spectrum (hue, rainbow) scale

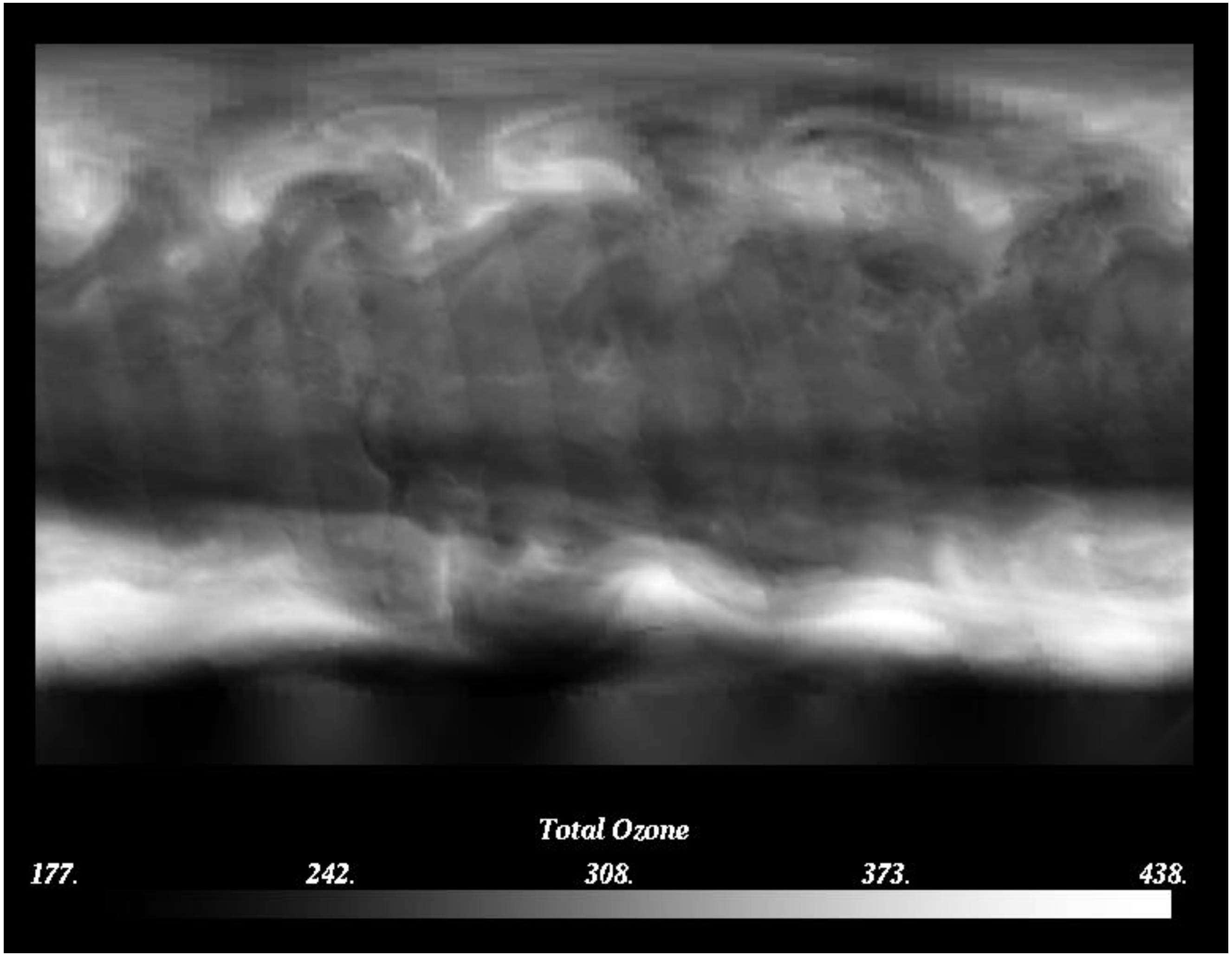


Pseudo color is just by the light spectrum … (no other good choice)?

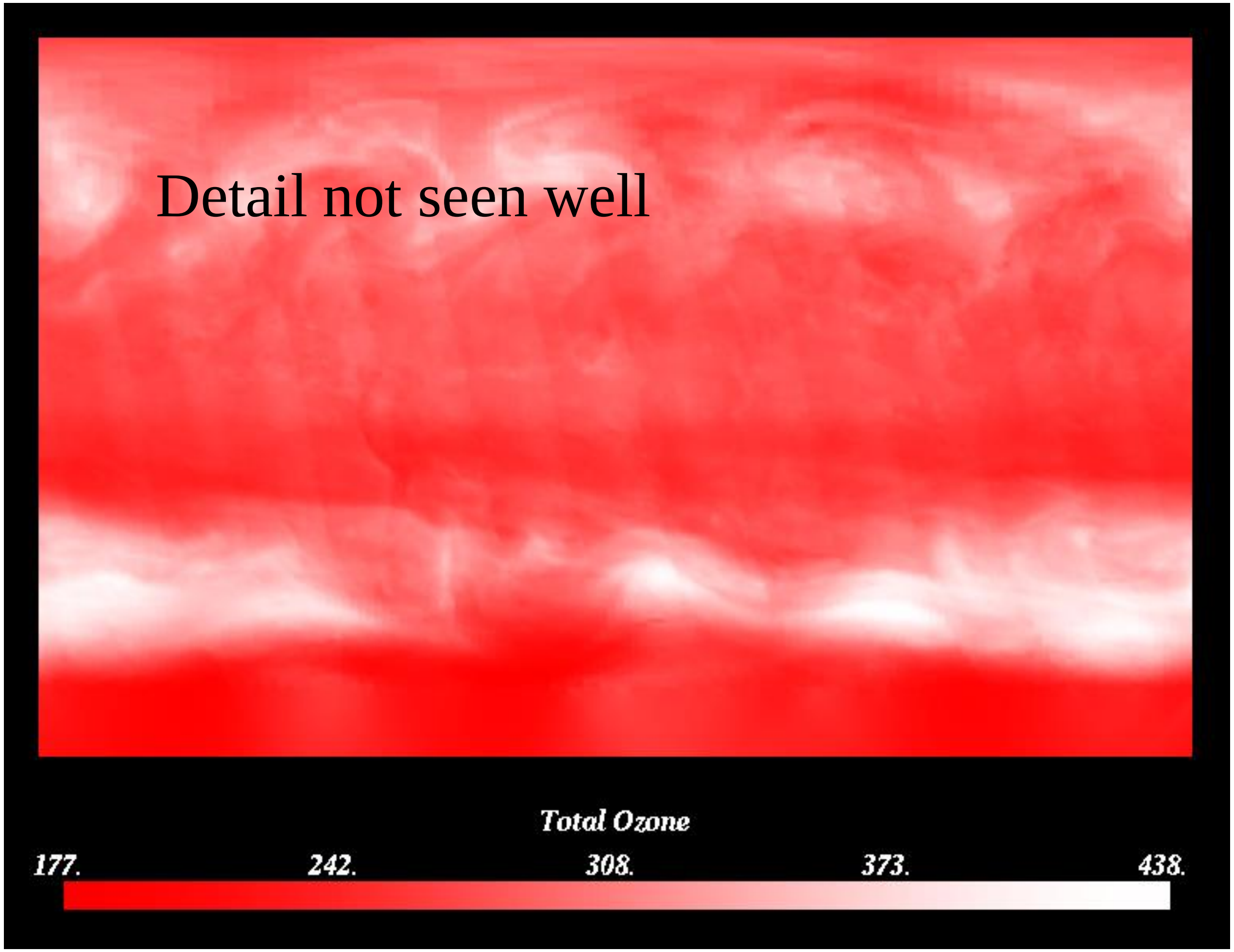




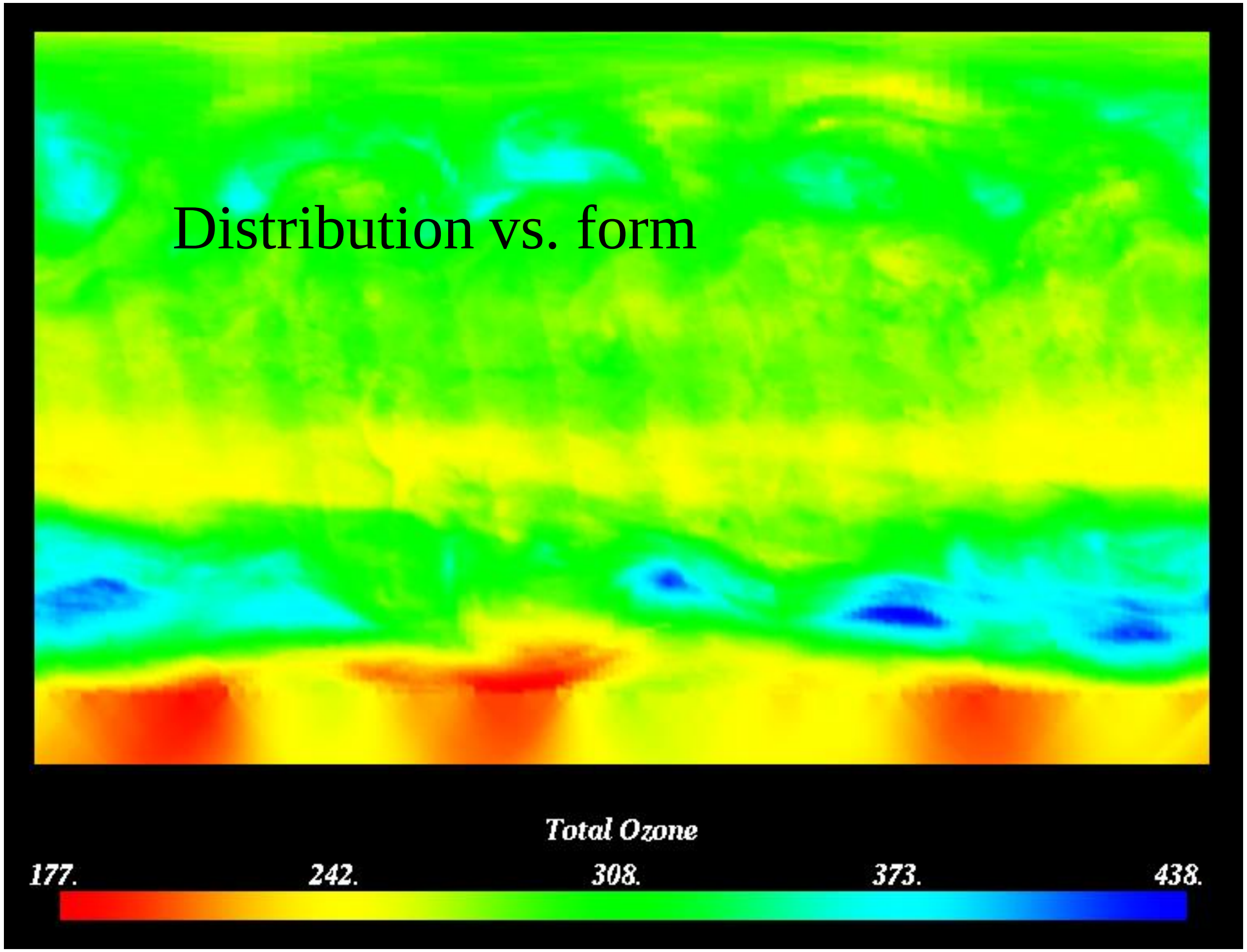
Luminance (Gray) Scale



Saturation Scale



“Pseudo” color scheme (hue)

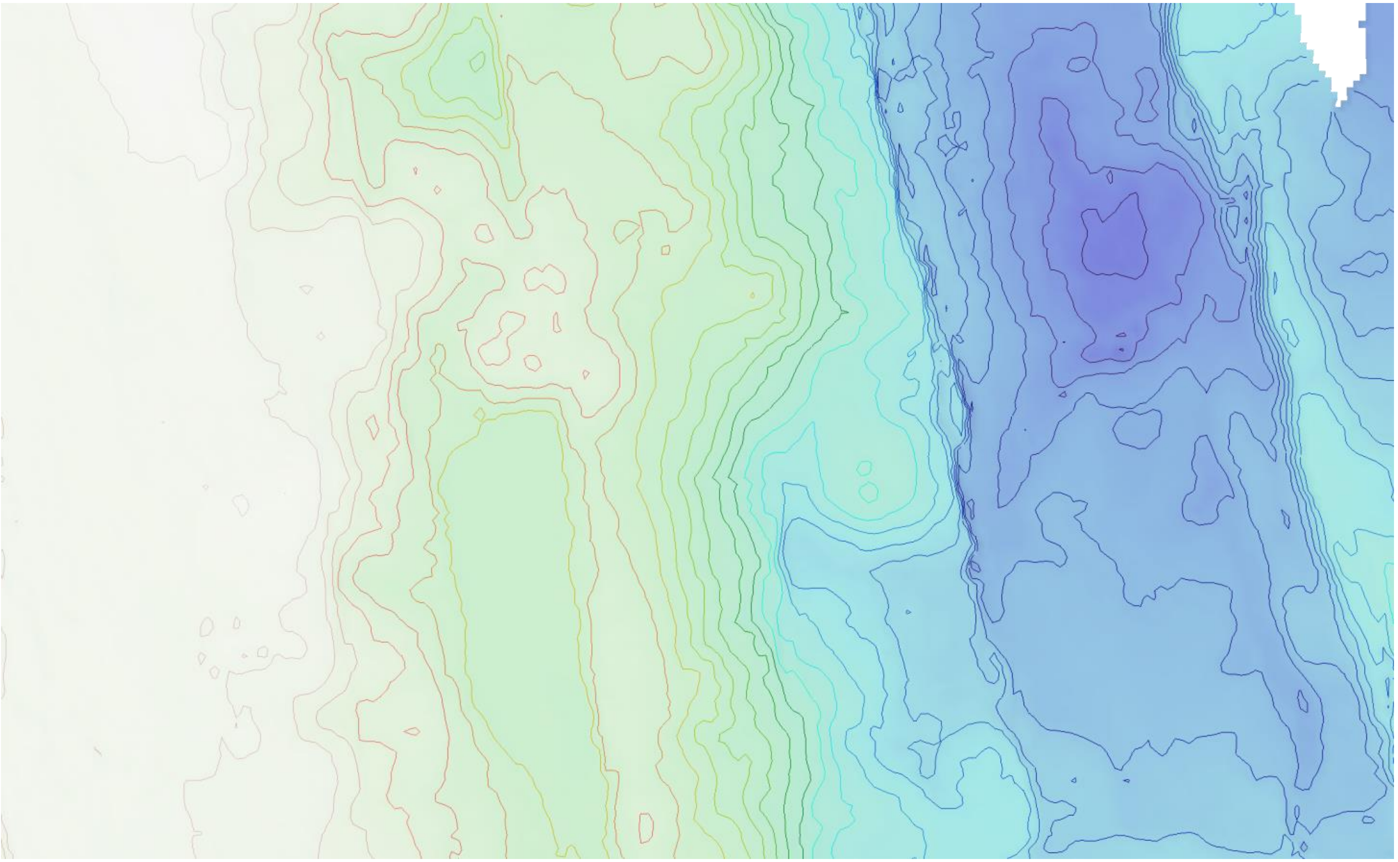


Interval sequences: Contour Lines and Color

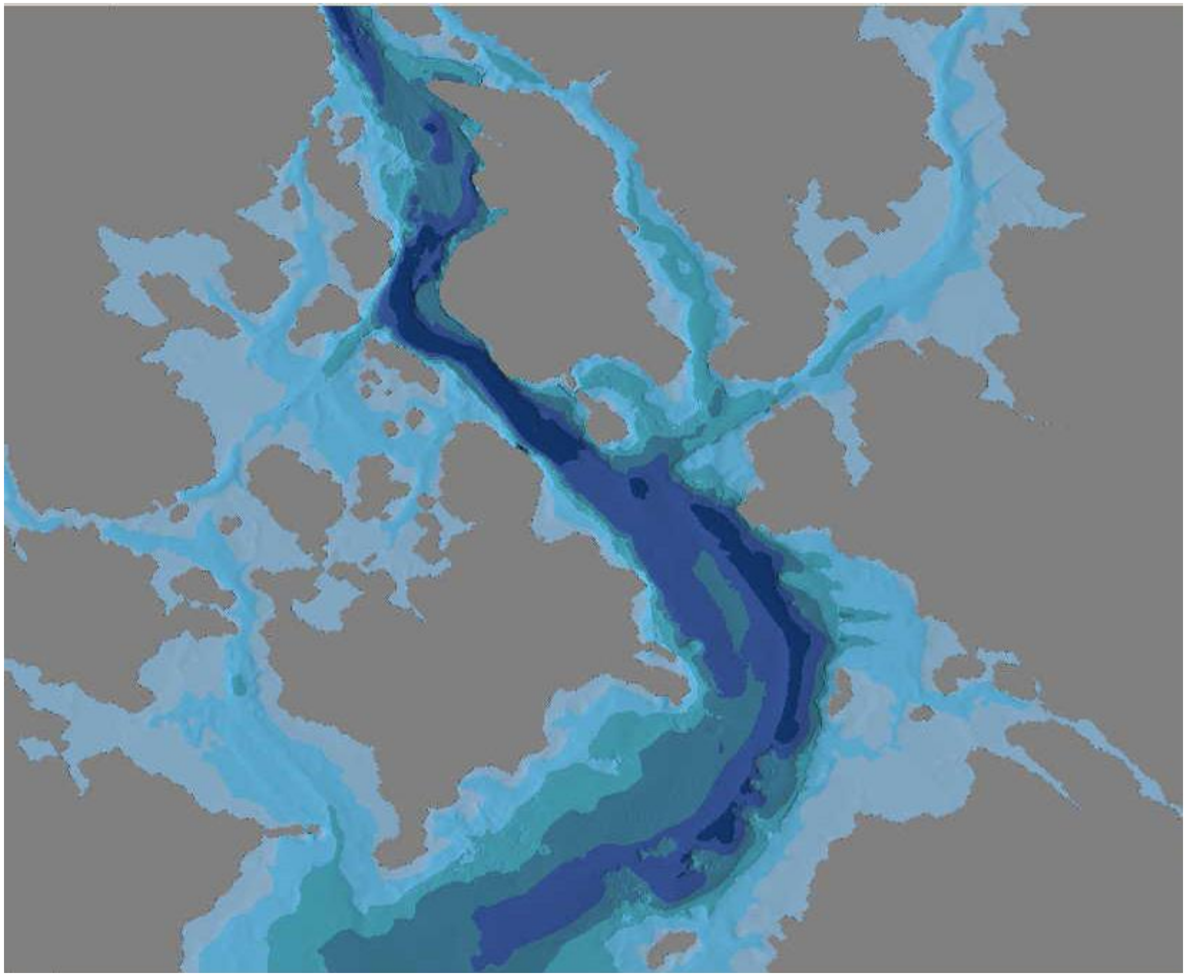
- Both indicate regions
  - Contour by showing the boundaries
  - Bands by showing the interiors

- Choice of spacing
  - Regular intervals to enable interval comparison
  - Specific values to highlight regions (sea level)

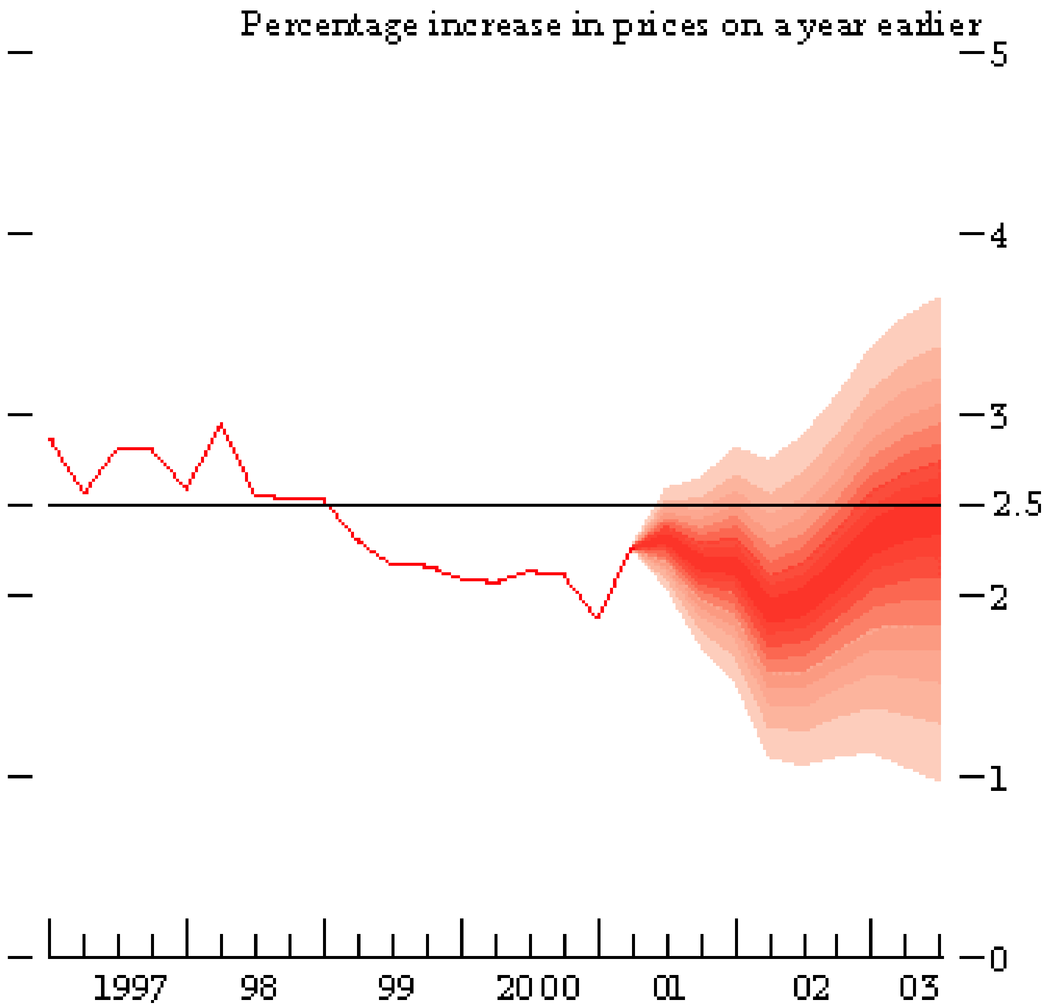
Interval – contours and color



Interval – step color (same hue / stepped by saturation)



Uncertainty – saturation …

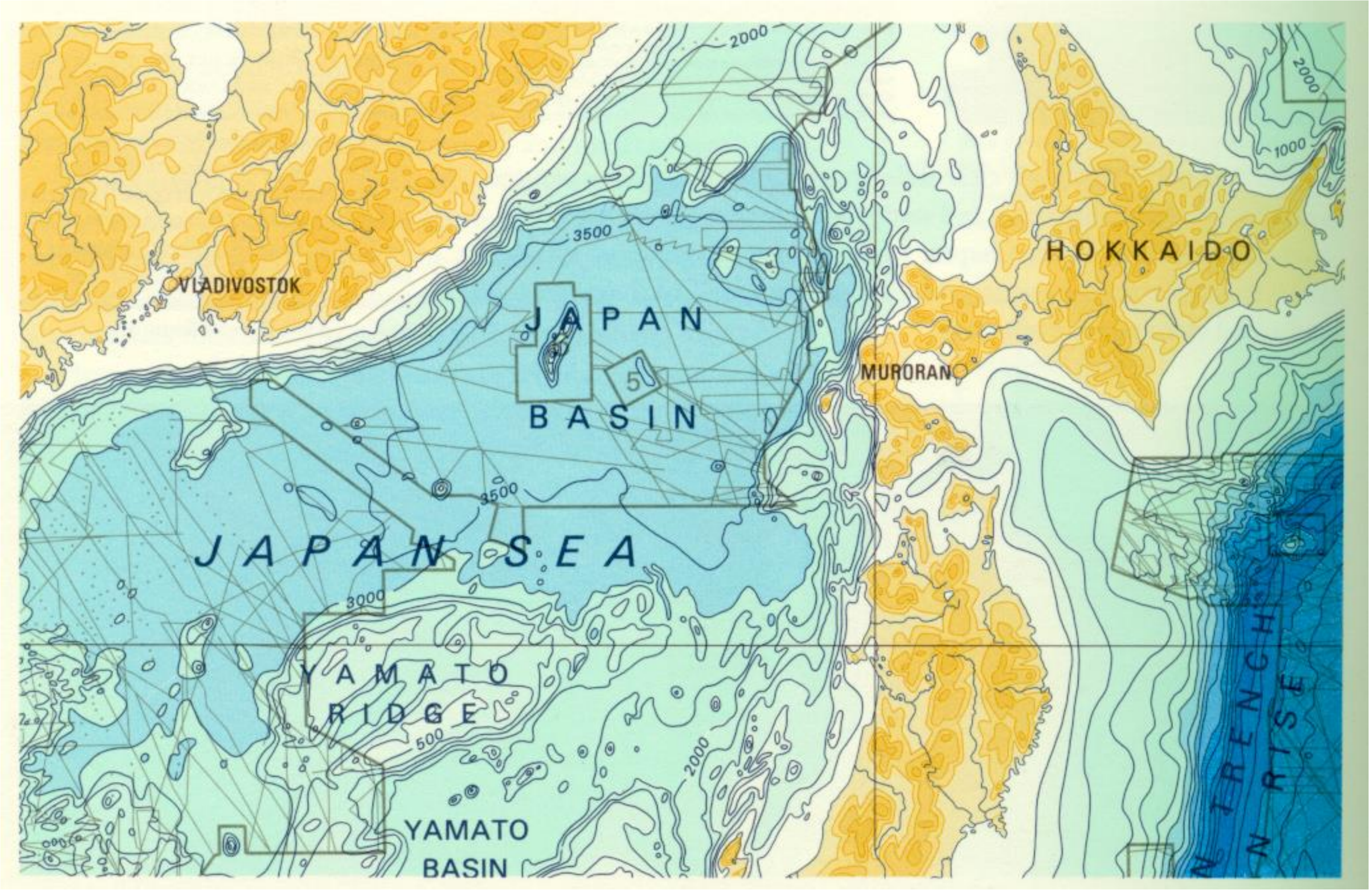


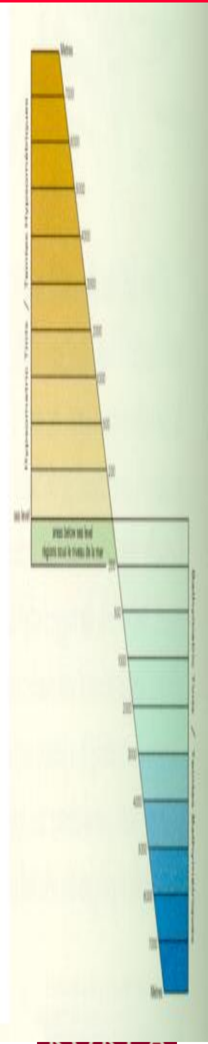
Ratio sequence

- **Represent neutral by neutral on opponent-color channels (bipolar)**
  - Representing “zero”
  - Double ended scale
- **In the next example – more like categorical (hue)**
  - Red: positive
  - Green: negative
  - Gray: neutral

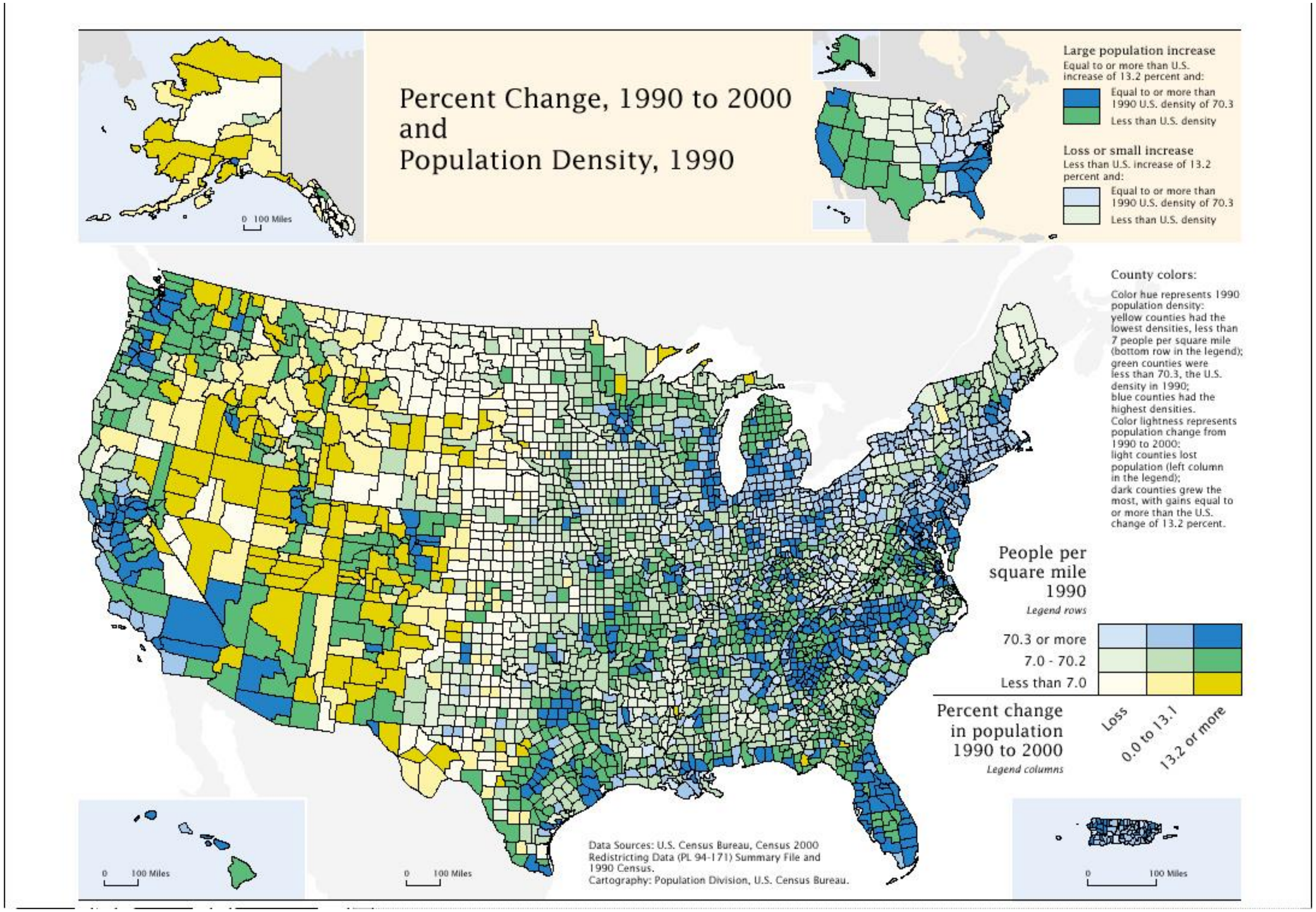
Double-Ended Income

Ordered (and double-ended)





Hue and saturation – Bivariate (multi-dim)



Take home messages

- Use luminance for detail, shape and form
- Use color for coding - few colors
- Minimize contrast effects
- Strong colors for small areas - contrast in luminance with background

Consider user

- **Color deficient viewers?**
  - Don’t depend on red-green differentiation
  - Use redundant scales
- **Application area conventions?**
  - Use familiar scales (or at least know when you’re not)
- **Color associations with variables?**
  - Use associated color

Murch's Rules on colors

- Avoid the simultaneous display of highly saturated, spectrally extreme colors.
- Pure BLUE should be avoided for text, thin lines, and small shapes.
- Avoid adjacent colors that differ only in the amount of BLUE.
- Older operators need higher brightness levels to distinguish colors.
- Colors change in appearance as the ambient light level changes.
- The magnitude of a detectable change in color varies across the spectrum.
- It is difficult to focus upon edges created by color alone.
- Avoid RED and GREEN in the periphery of large-scale displays.
- Opposite colors go well together.
- For color-deficient (*color blind*) observers, avoid single-color distinctions.

Color guideline (example)

- Use color conservatively. It may make it harder understand.

  More color is more information.
- Limit the number of colors. up to 4 on one display (7 total).
- Recognize the power of color as a coding technique It speeds recognition if differences

  e.g., new/old, OK/bad
- Ensure that color coding supports the task.
- Place color coding under user control allow users to turn color coding off.
- *Design for monochrome first* . Use color to enhance layout.
- Use color to help in formatting. e.g., physically close but different fields.
- Be consistent in color coding.

Color guideline (continued)

- Use standard, and apply throughout system.
- Be alert to common expectations about color. E.g. stop/go, hot/cold, forest/water
- Be alert to problems with common pairings need good contrast.
- Some pairs hard to focus on together (saturated red & blue)
- Some color clash … triggers color confusion (color blindness)(e.g., red/green)
- Use color changes to indicate status changes attention getting

  (green changing to red)
- Use color in graphic displays for greater information density

  (another dimension better than shading)
- Poor color use may be worse than no color.

Pre-attentive Features

- The visual systems pattern perception and recognition capabilities can be capitalized upon in display design.

- There are simple shapes and colors that are very rapidly processed and recognized. This processing is termed "pre-attentive" because it occurs automatically prior to conscious attention.

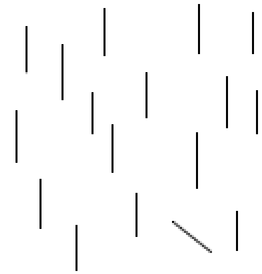
- We can use knowledge of pre-attentive processing in the design of visual displays to organize information for rapid recognition. Pre-attentively processed items are those that "pop-out" and segmentation effects in our perception.

Pre-attentive Features

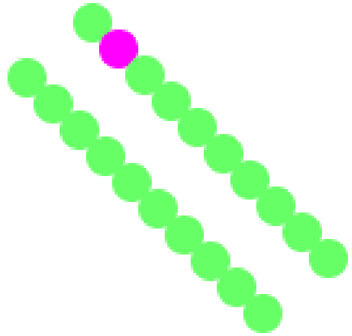
- A feature is considered pre-attentively processed if it can be recognized within a set of "distractors" in less than 10 m sec.

- Non-preattentively processed items take 40 msec per item or more. Pre-attentively processed features can be used in display design when we want the user to instantly (at a glance) extract information.

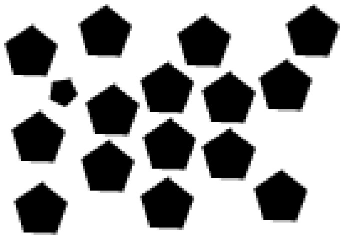
Pre-attentive Features



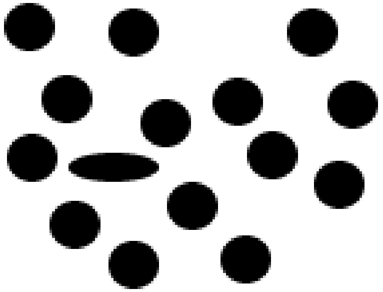
- Color - Color difference can make an item "pop-out" from surrounding items.



- Size - Size is easily pre-attentively processed.



- Shape - A difference in shape can be used to draw attention to an item.



- Orientation, Contrast/blur, Motion, Simple shading

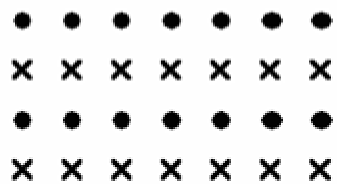
Pre-attentive Pattern (Static): Gestalt

- Proximity - Objects near each other tend to be perceived as a unit.

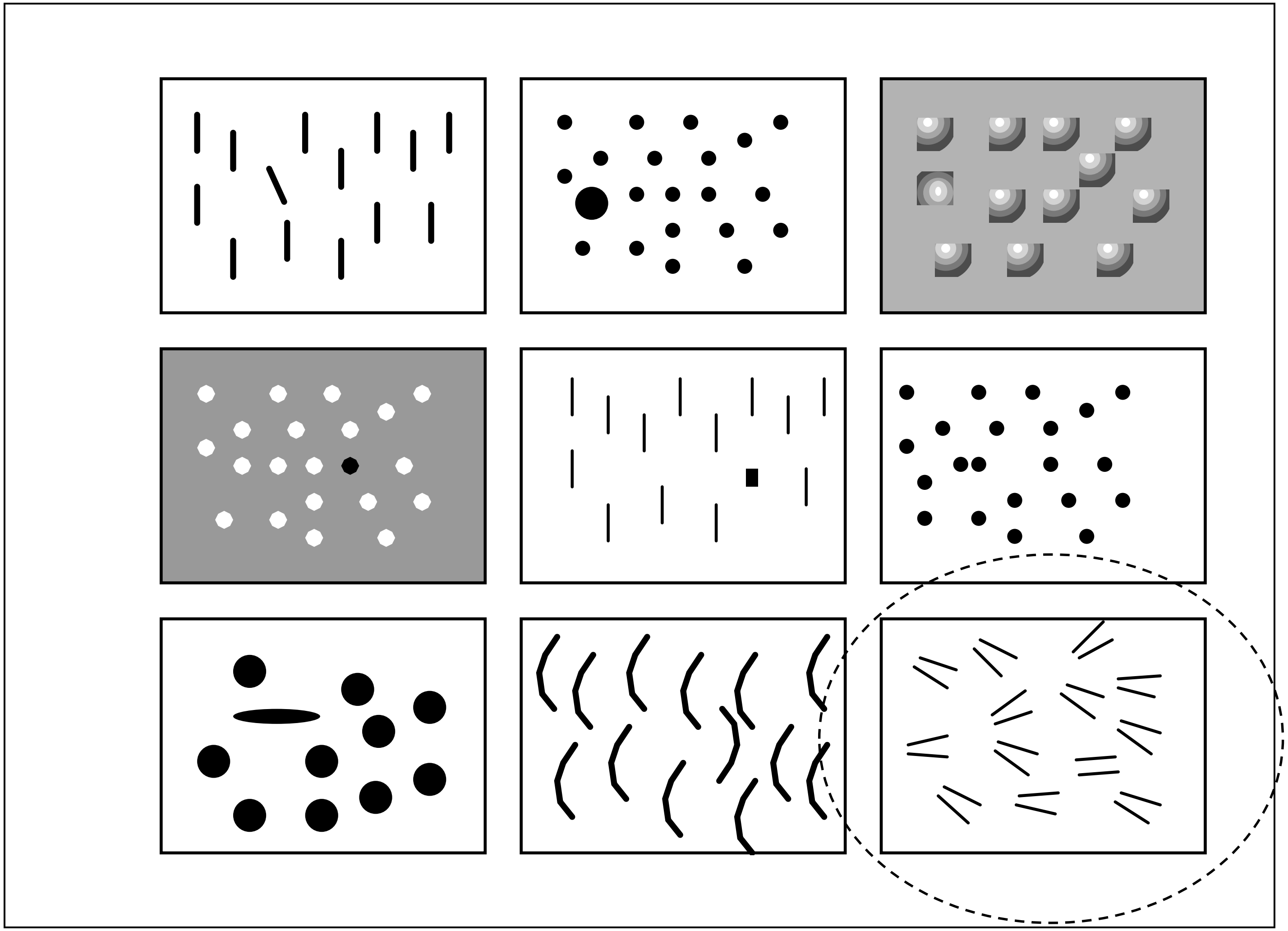
- Continuity - Objects arranged or connected by a smooth curve tend to be perceived as a unit.

- Closure - Figures with gaps tend to be perceived as closed complete figures.

- Similarity - Objects similar to each other tend to be perceived as a unit.



More Pre-Attentive examples



Laws of pre attentive display

- **Must stand out on some simple dimension**
  - color,
  - simple shape = orientation, size
  - motion,
  - depth

- **Lessons for highlighting – one of each**

- **Black art … ㅠㅠ**

Highlighting to make info. available to attention

Using color
<u>Using underlining</u>

A flying box leads attention

Blinking momentarily attracts attention

Motion elicits an orienting response

Adding is usually better than taking out
e.g. underline one word vs.
underline everything else

Interference

- When designing visual displays, we may wish to use pre-attentive properties to call attention to specific items or to emphasize categories.

- Color and shape are both pre-attentive properties; however, if distractors share features with the target item(s), interference can result.

- Also, color will usually dominate shape in grouping or categorizing display elements.

- Conjunction search is example of interference.

Conjunction search

- When combinations of pre-attentive features are used, care must be taken not to create a "conjunction" search condition, thus losing the pre-attentive advantage.

- Conjunction is the result of visual interference by equally, attention getting features.

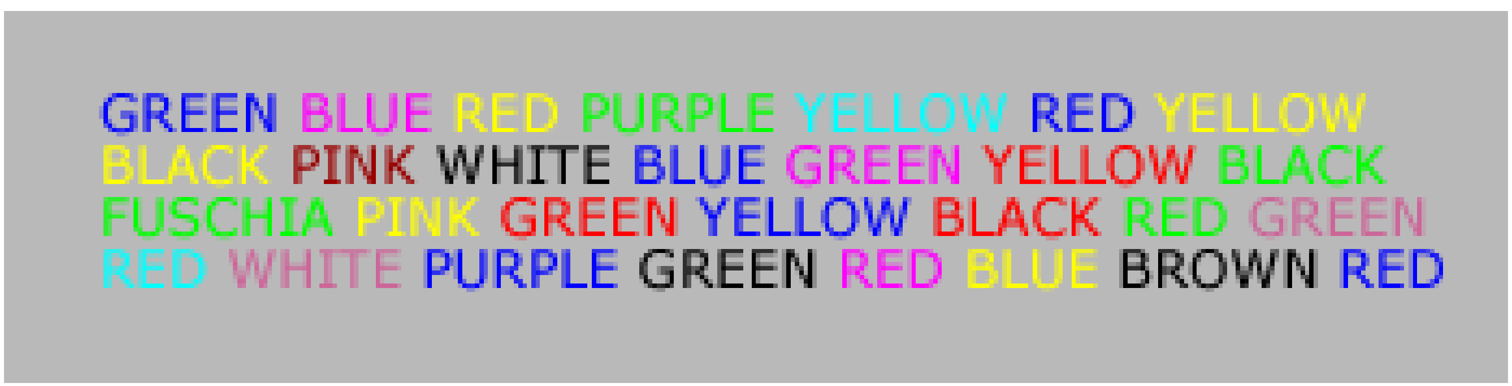
- Conjunction Search - Search for the red ellipse among the dark blue circles and ellipses. This is a conjunction search example, as each element must be scanned to find the red circle. It does not pre-attentively "pop-out."

- Pre-Attentive Search - Spatial grouping can be used to bring back pre-attentive features. The lower grouping is pre-attentive for the red ellipse.

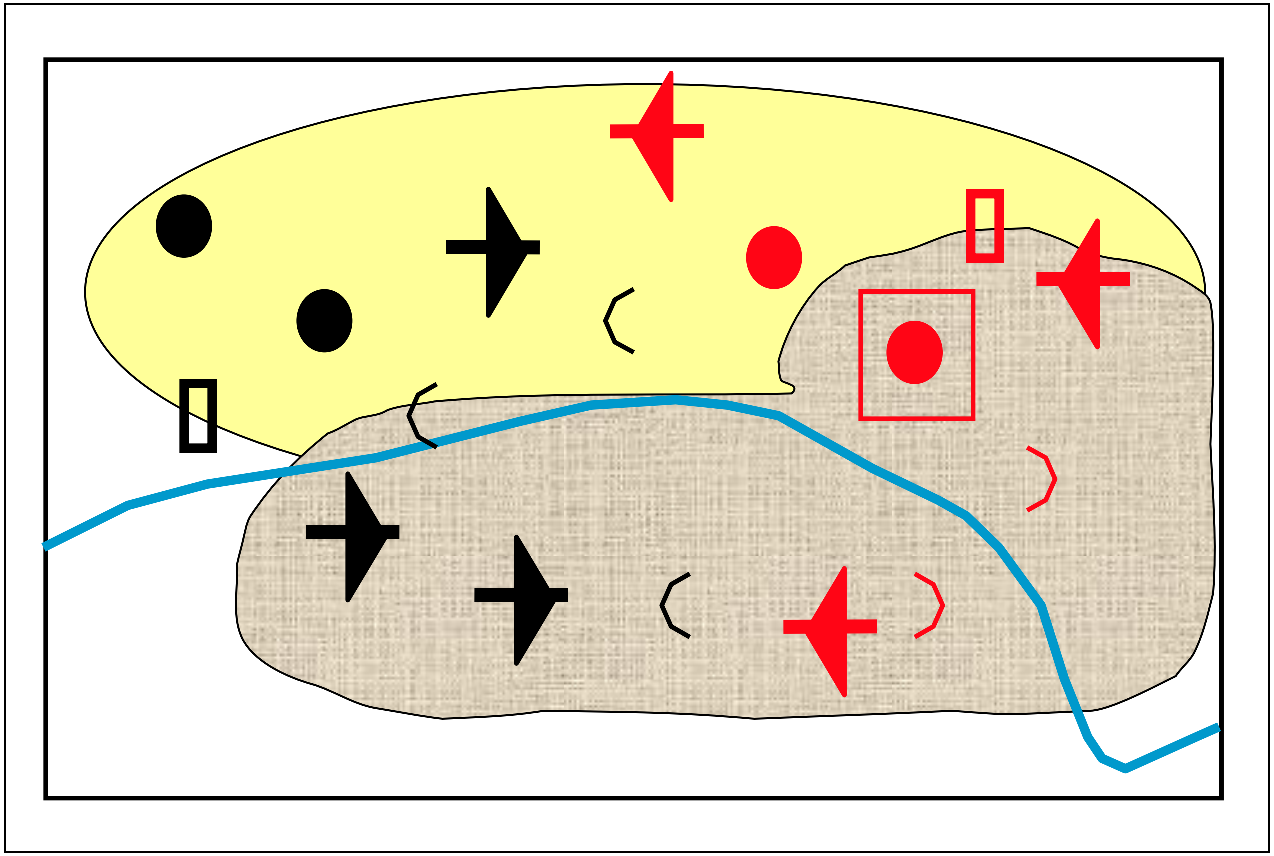
Interference

- Visual perception can conflict with verbal meaning, creating interference effects. This can cause displays to be difficult to use, can slow response time, or even lead to performance errors through misinterpretation.

- Stroop Effect - Count the number of times the word "RED" appears in this example. The verbal content conflicts with color perception.



Apply preattentive features to designing symbols/icons

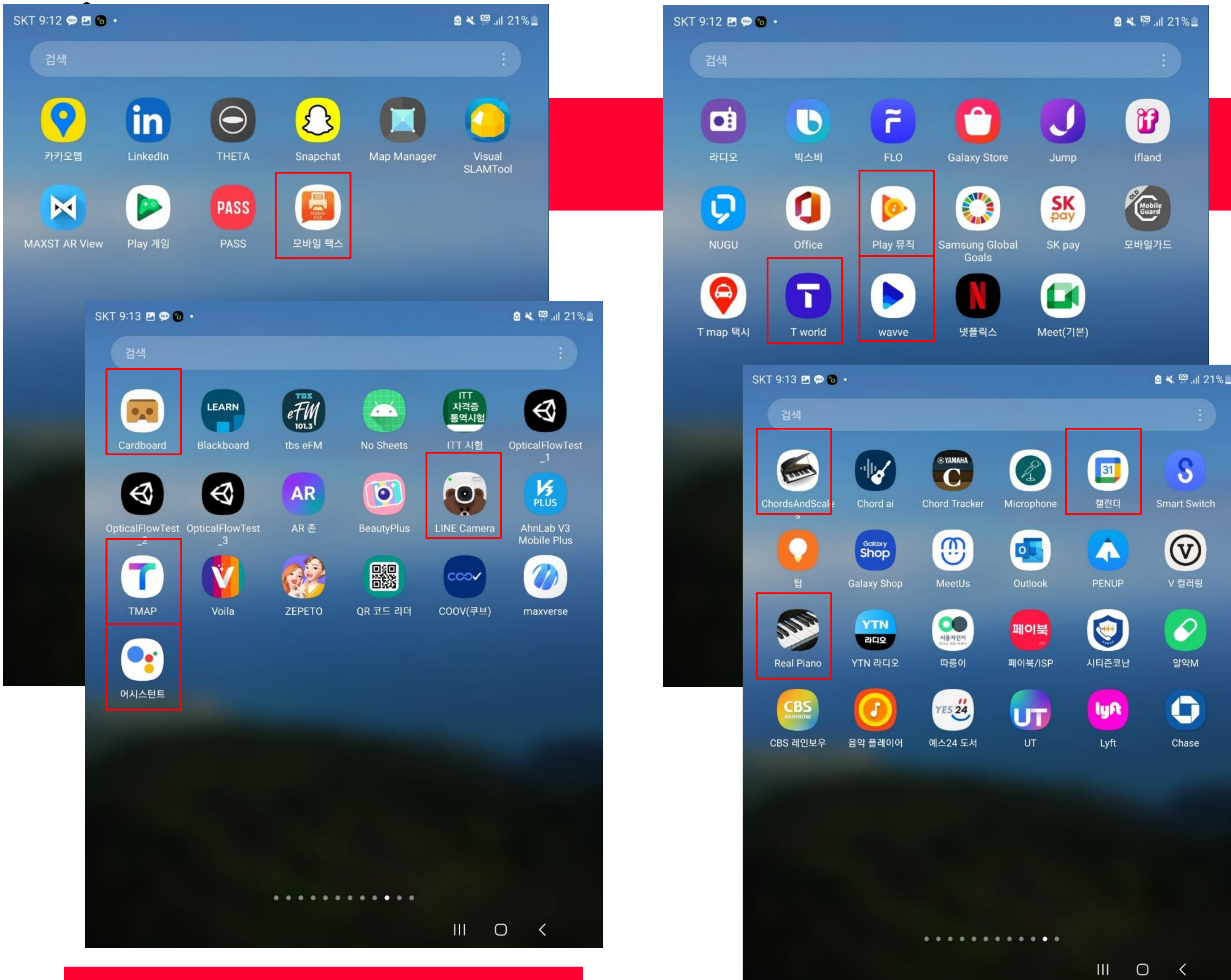


Red: hostile

Black: Friendly

Square:
  suspected

Different shapes:
  Airplane,
  Infantry, tank,
  building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Visual SLAMTool
MAXST AR View
Play 게임
PASS
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tbs eFM
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BeautyPlus
LINE Camera
AhnLab V3 Mobile Plus
TMAP
Voila
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Outlook
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V 컬러링
Real Piano
YTN 라디오
따릉이
페이북/ISP
시티즌코난
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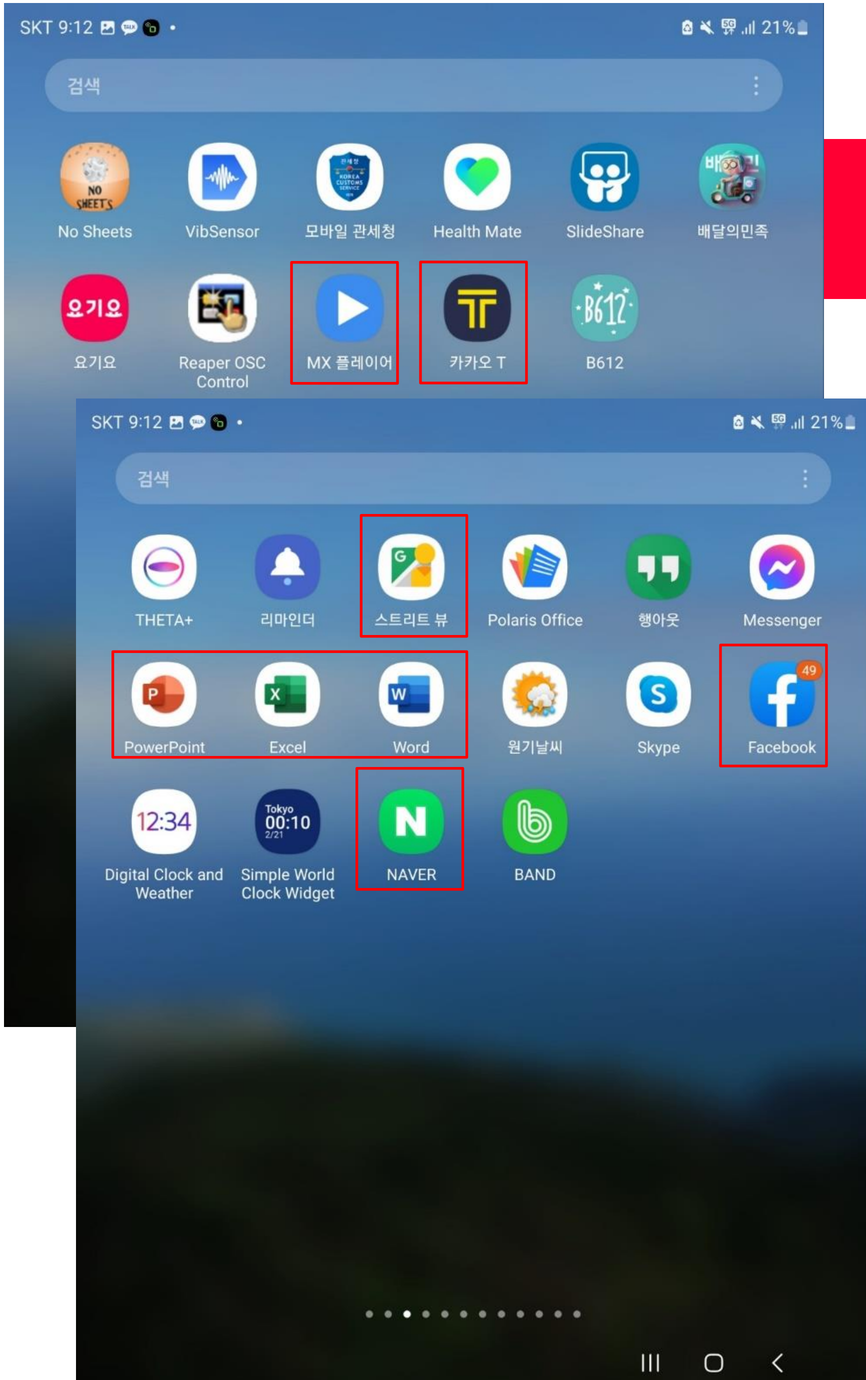
예스24 도서
UT
Lyft
Chase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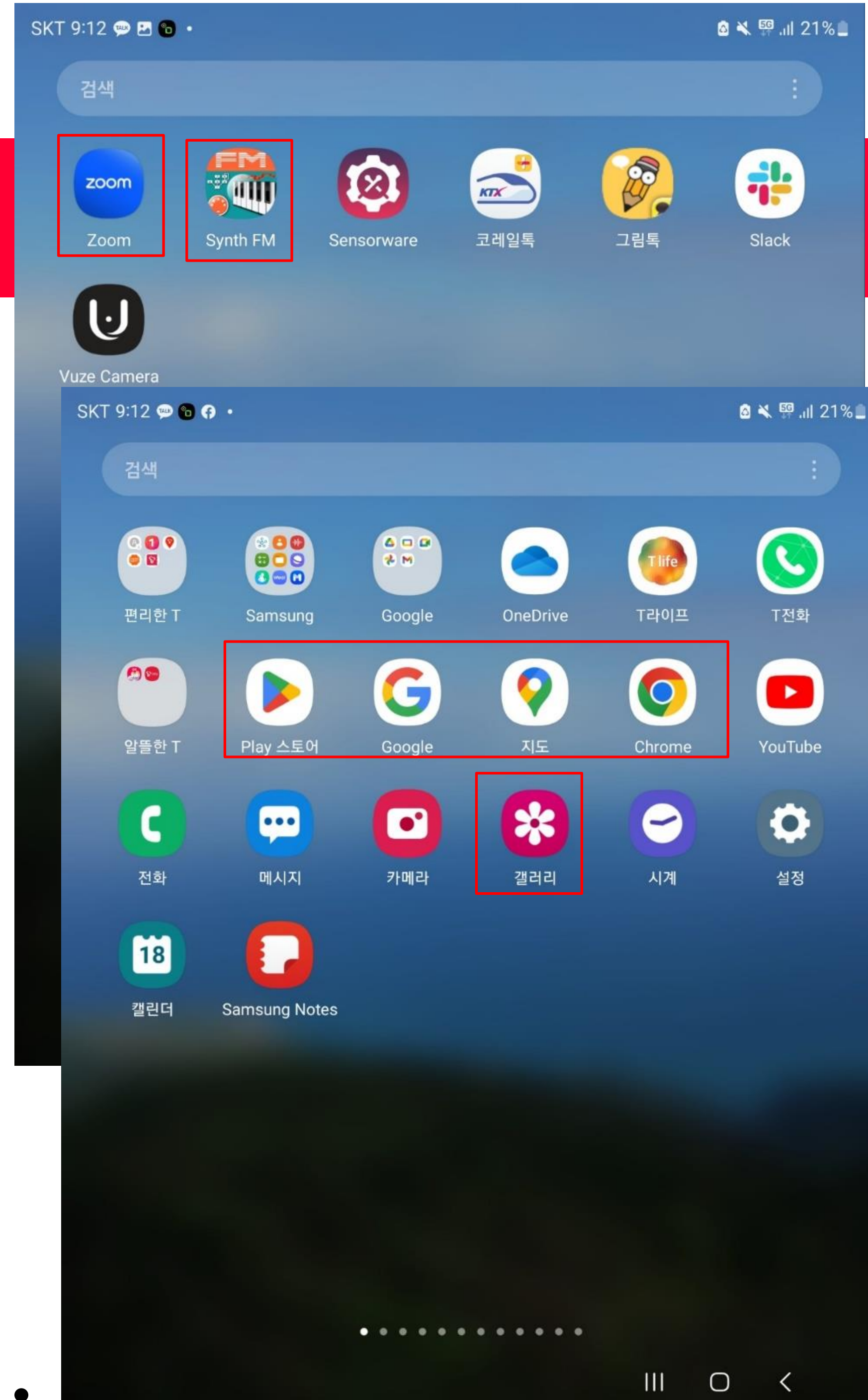
NAVER
BAND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지도
Chrome
YouTube
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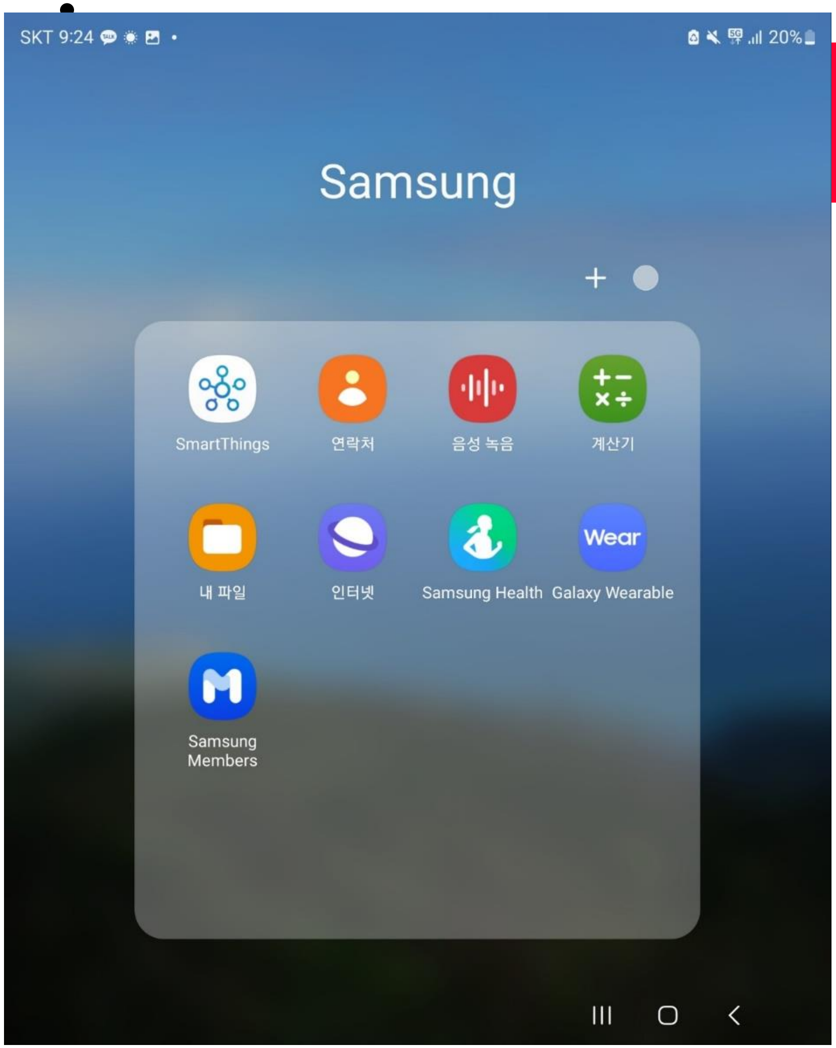
설정
캘린더
Samsung Notes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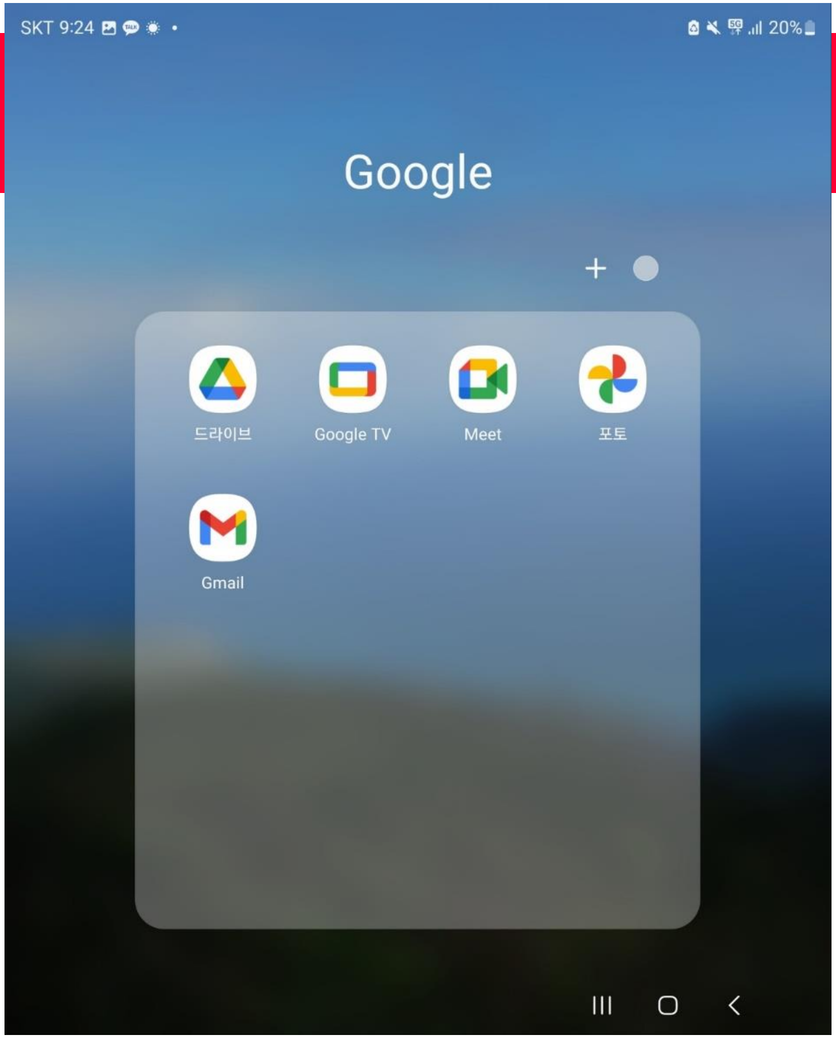
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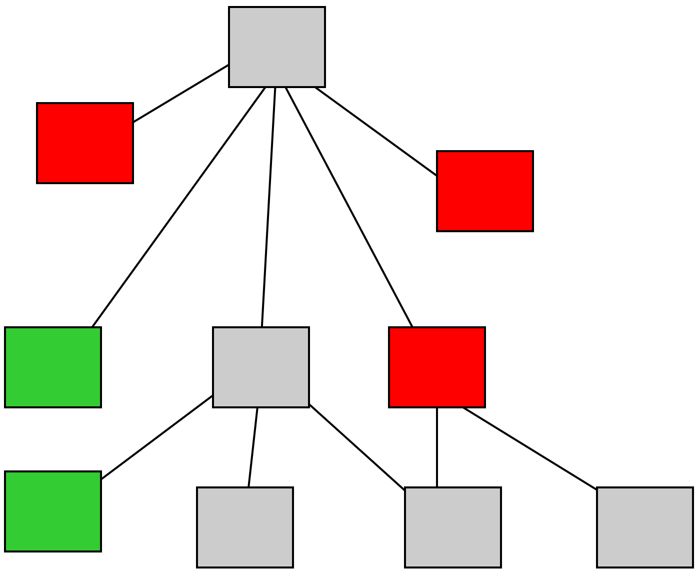
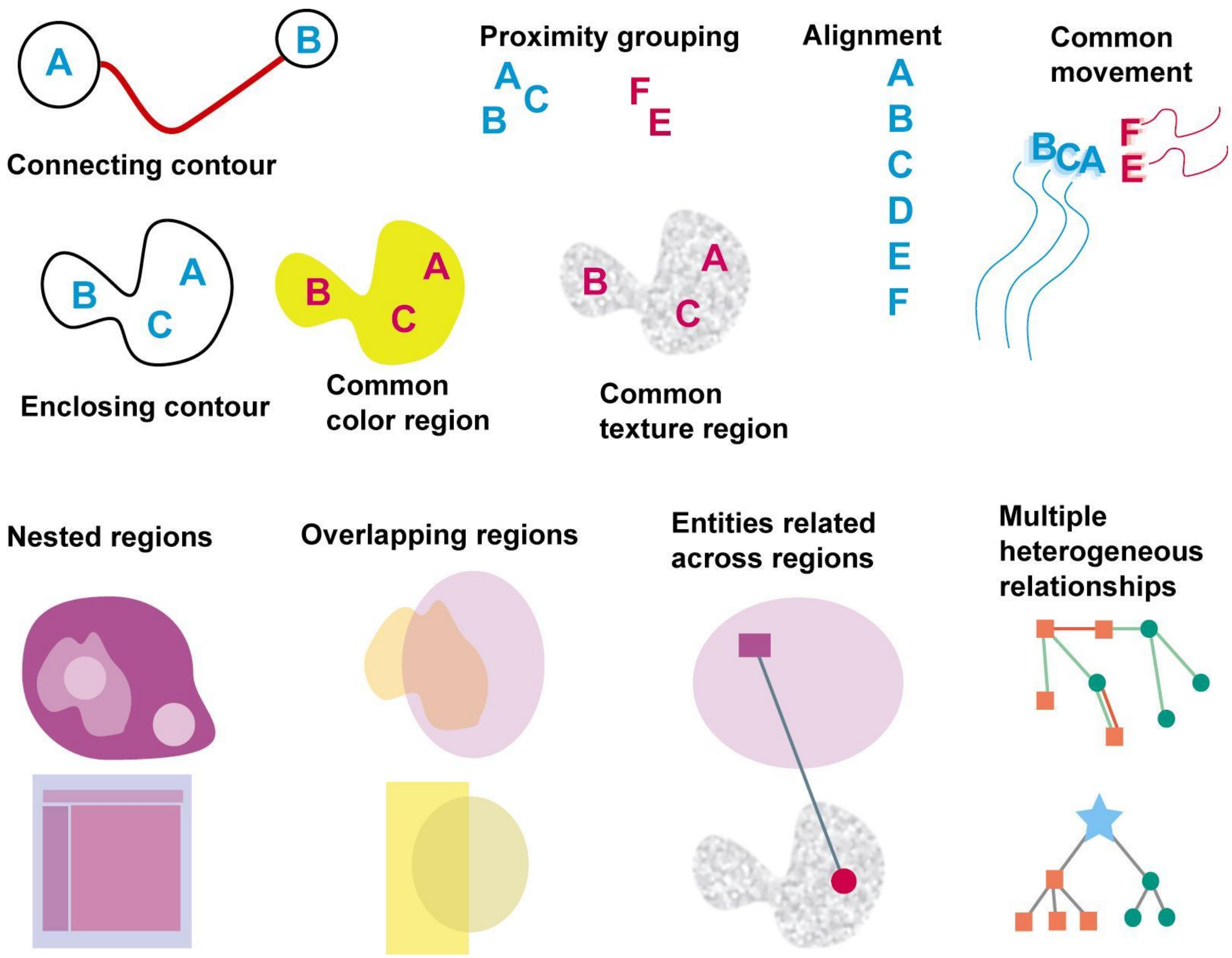
Cultural semantics

The fact that certain colors are special is because they are hard wired

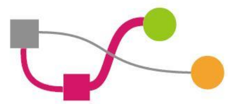
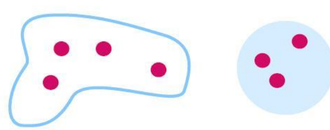
The meaning of those colors is culturally determined



Visual Grammar of diagrams/structure

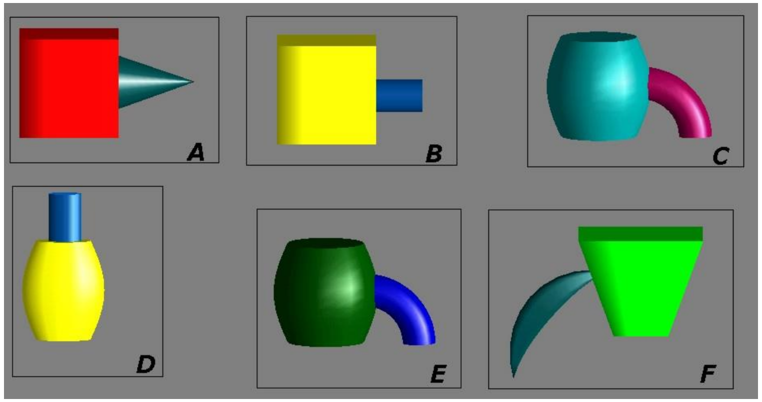


Semantics of structure

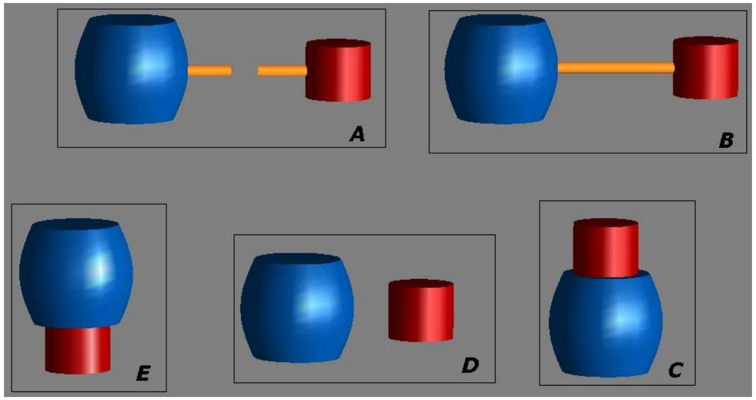
Graphical Code		Semantics
Shapes connected by contour		Related entities, path between entities
Thickness of connecting contour		Strength of relationship
Color and texture of connecting contour		Type of relationship
Shapes enclosed by a contour, or a common texture, or a common color		Contained entities. Related entities
Nested regions, partitioned regions		Heirararchical concepts
Attached shapes		Parts of a conceptual structure

Natural semantics

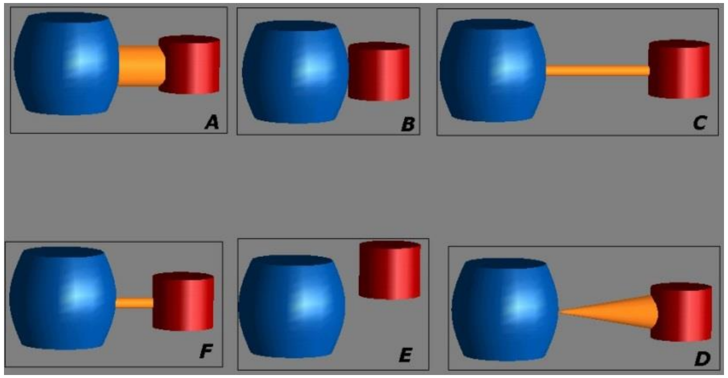
Instances



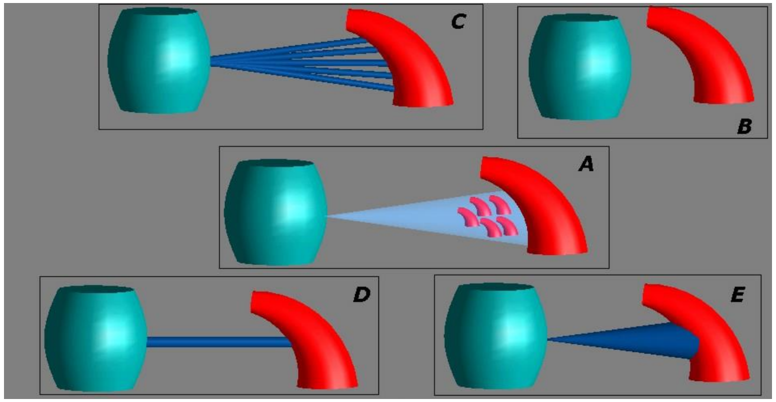
Dependency



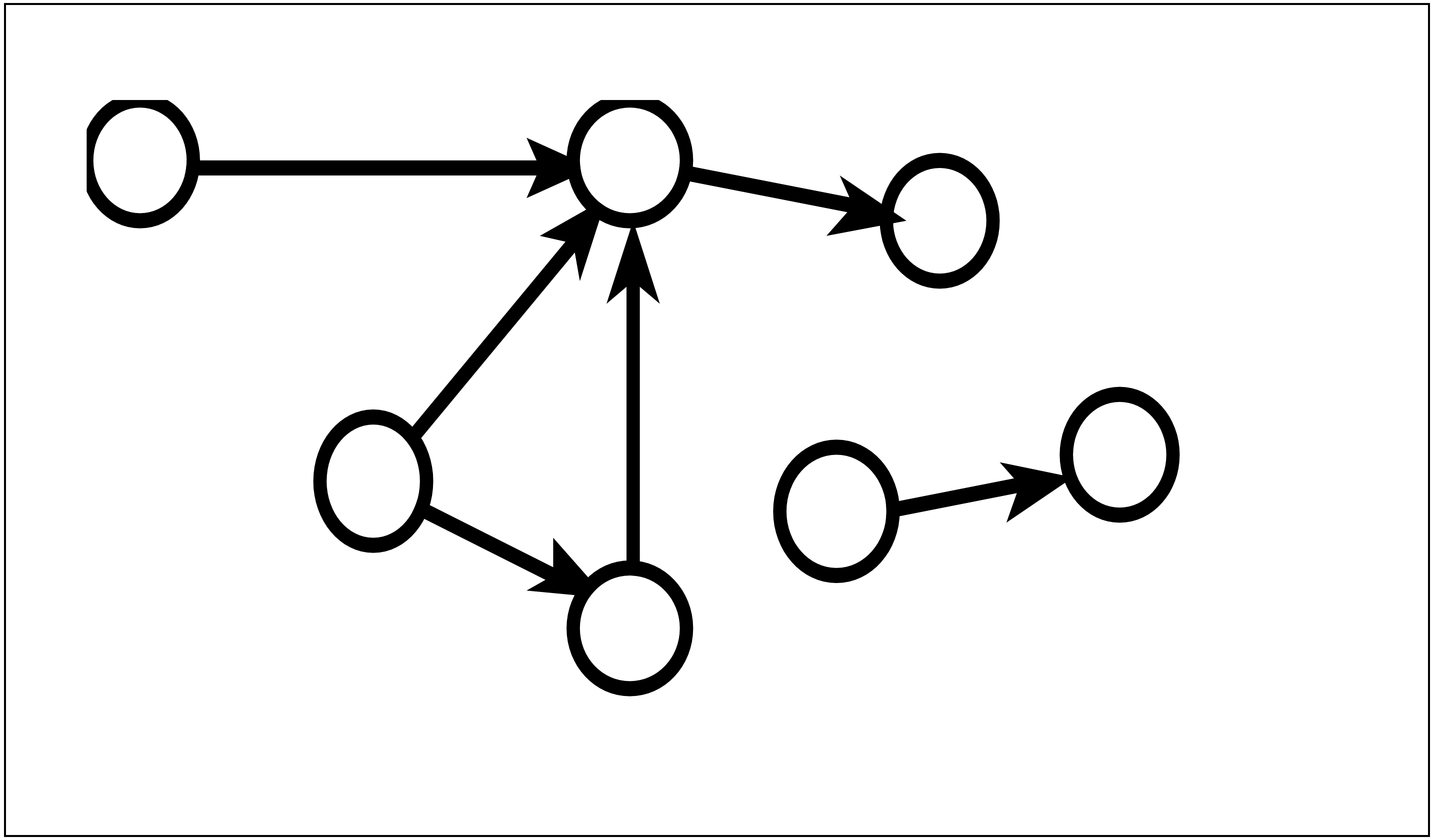
Strength of Relationship



Multiplicity

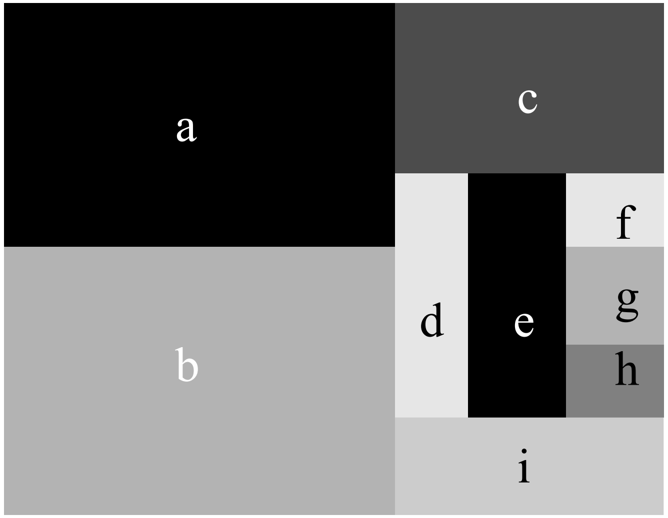


A causal graph

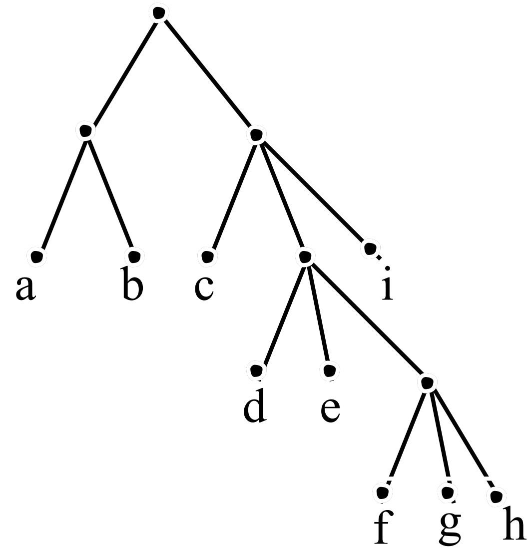


Treemaps and hierarchies

a

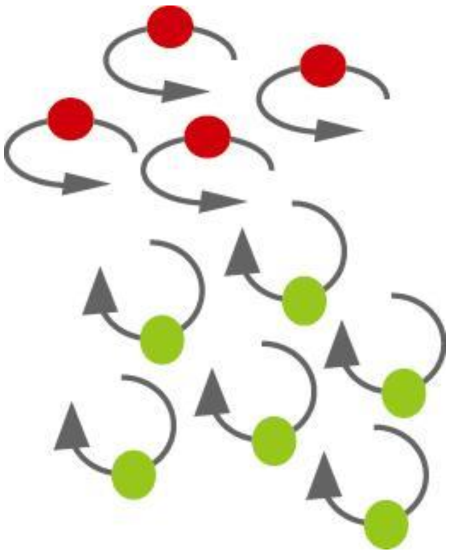


b



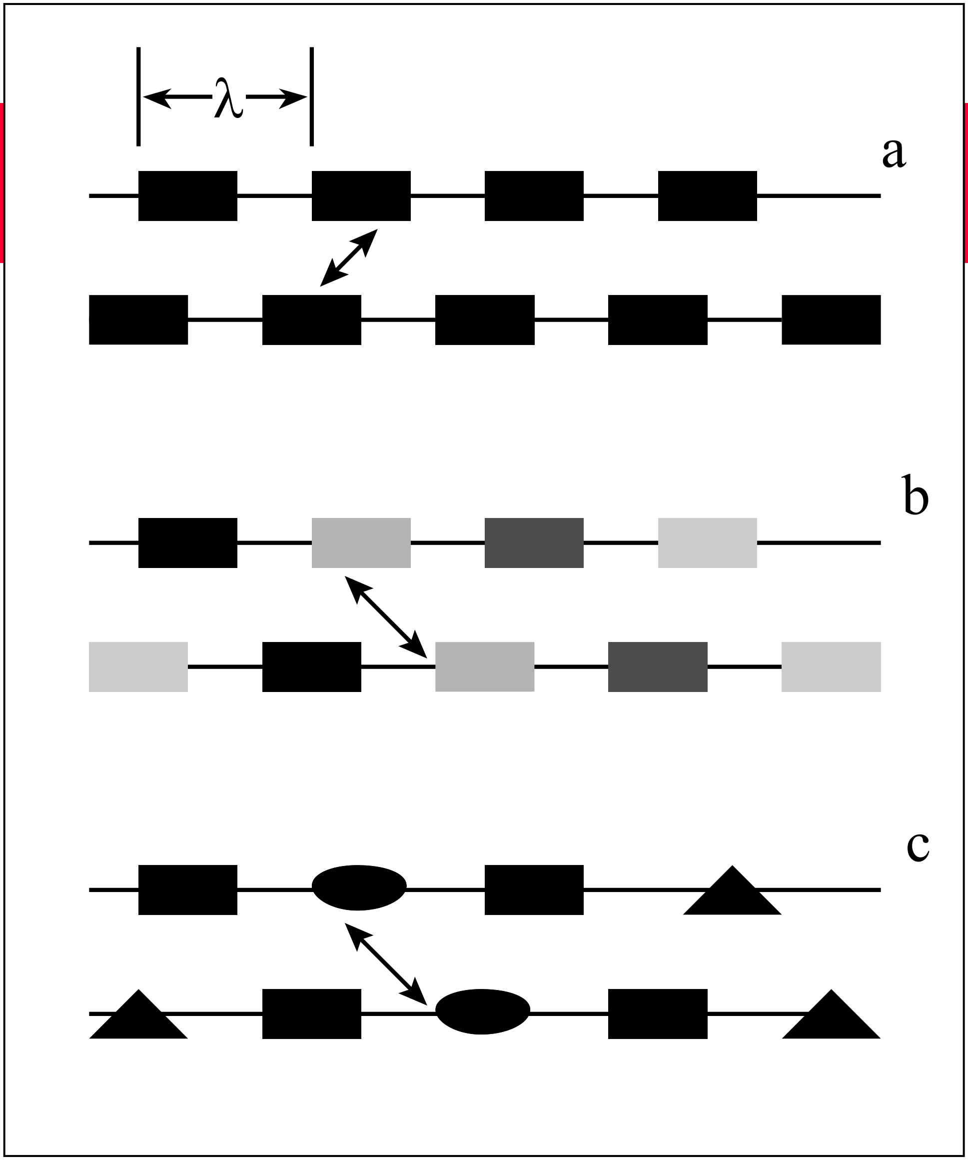
Motion patterns

- **Correlation between points:**
  - frequency, phase or amplitude
  - Result: phase is most noticeable

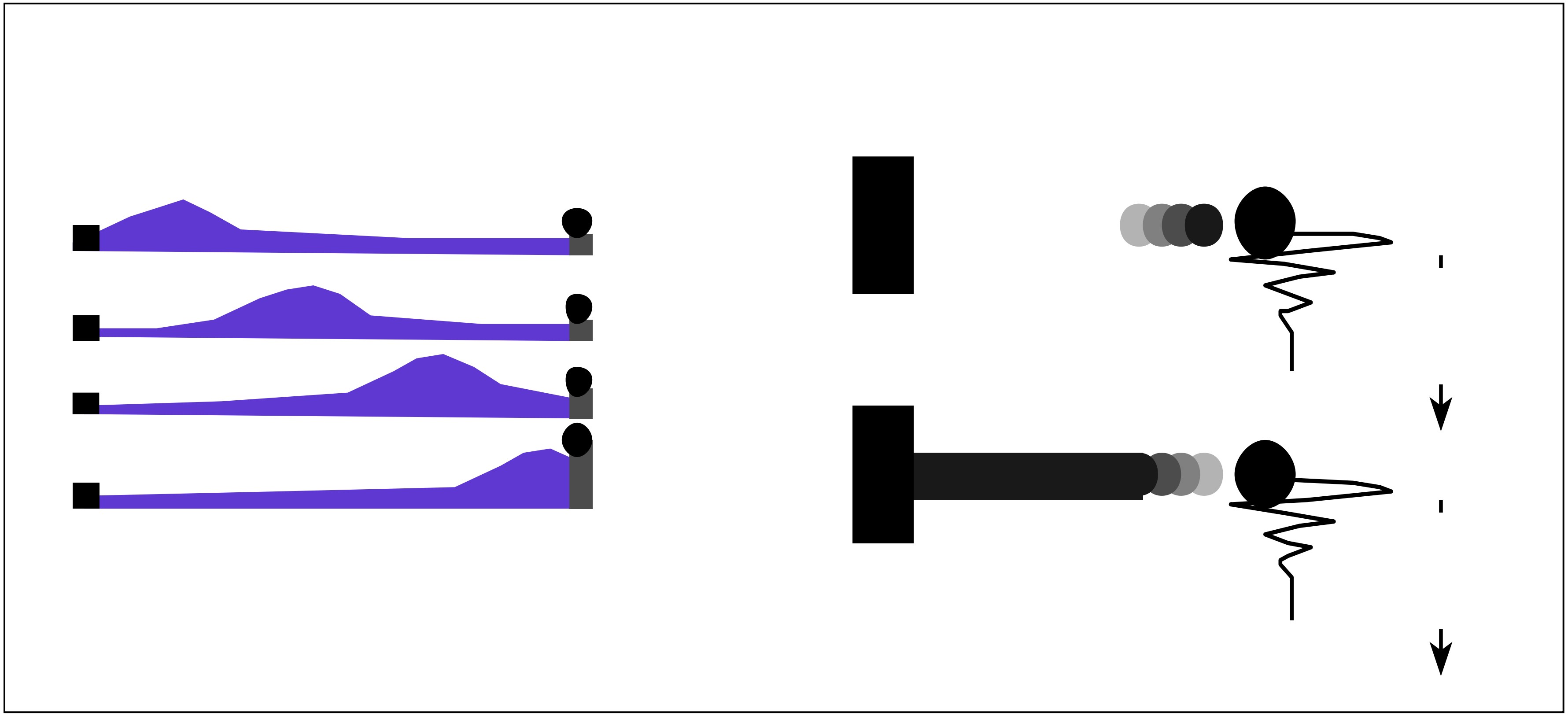


Motion patterns

- **Can show motions that are limited by the Frame Rate (e.g. mobile device)**

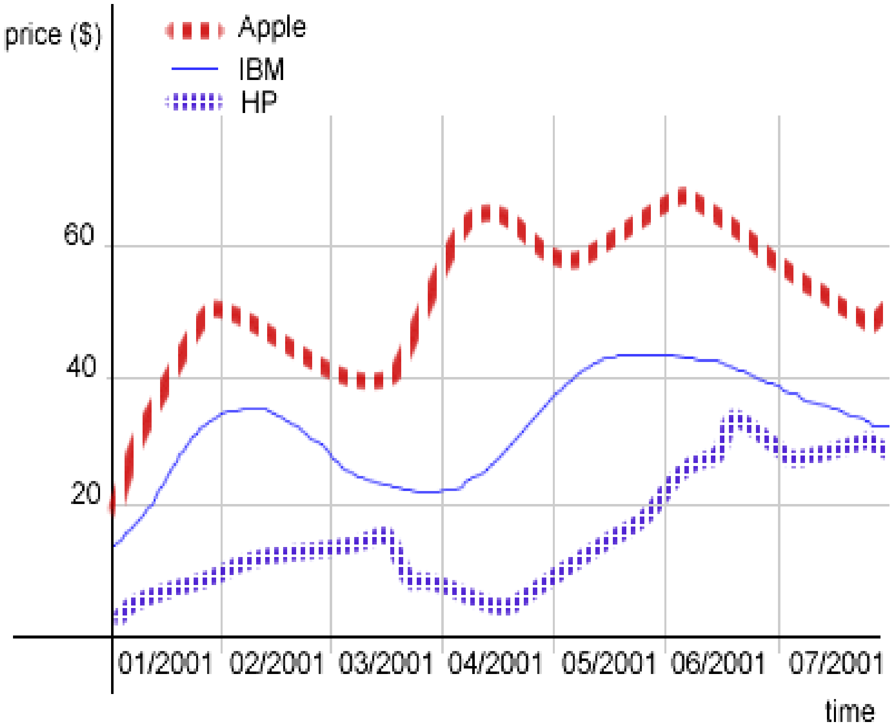


Visual Causal Vectors



Redundant Coding

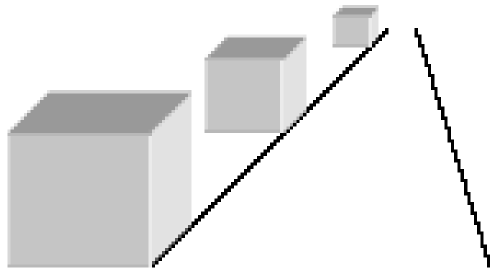
- Use color to group objects or draw attention (color coding)
- E.g. Line style (for those with vision deficiency)
- Symbols also (with small symbols, colors may be less discerning)



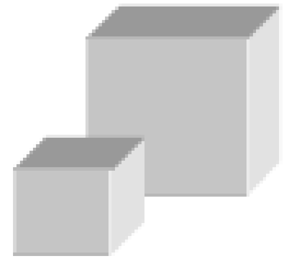
Psychological Depth Cues

- Perspective
- Motion Parallax: Differential angular velocity of objects at different depth from observer (close objects move more rapidly than far objects)
- Height in Field of View and Relative Size
- Occlusion and Texture Gradient
- Color and Haziness
- Shadows

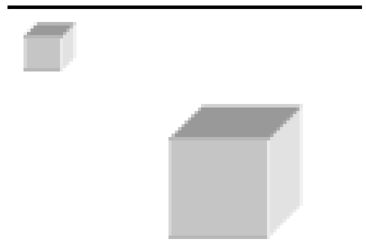
- Cues are usually additive



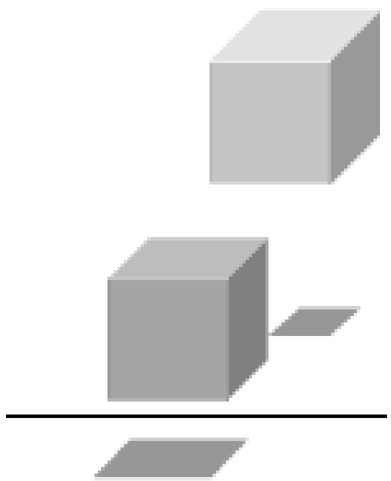
Perspective view



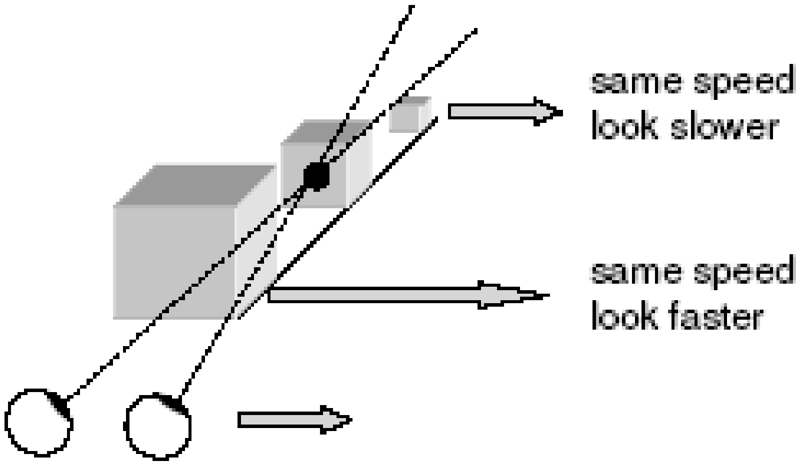
Object occlusion



Relative size

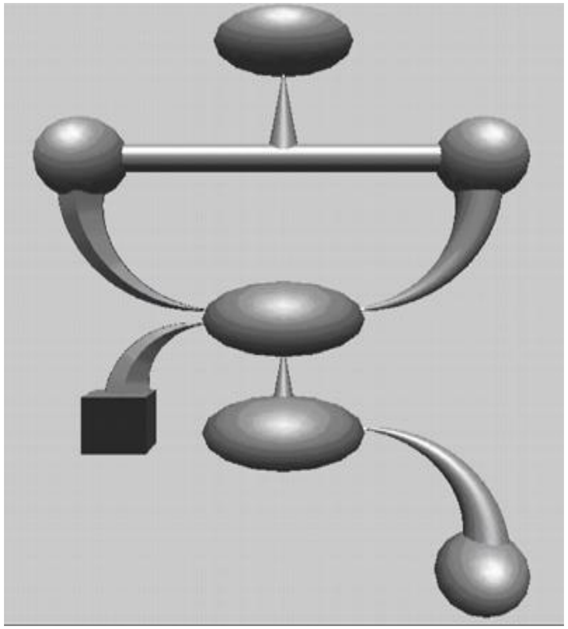


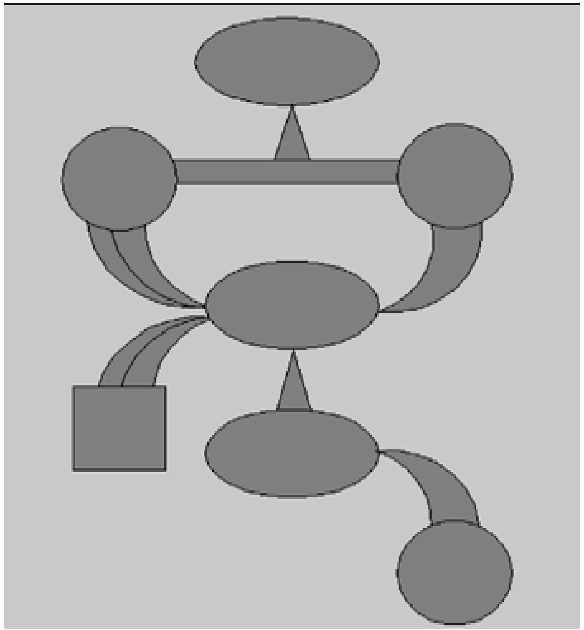
Shadow



Motion parallax

3D versus 2D





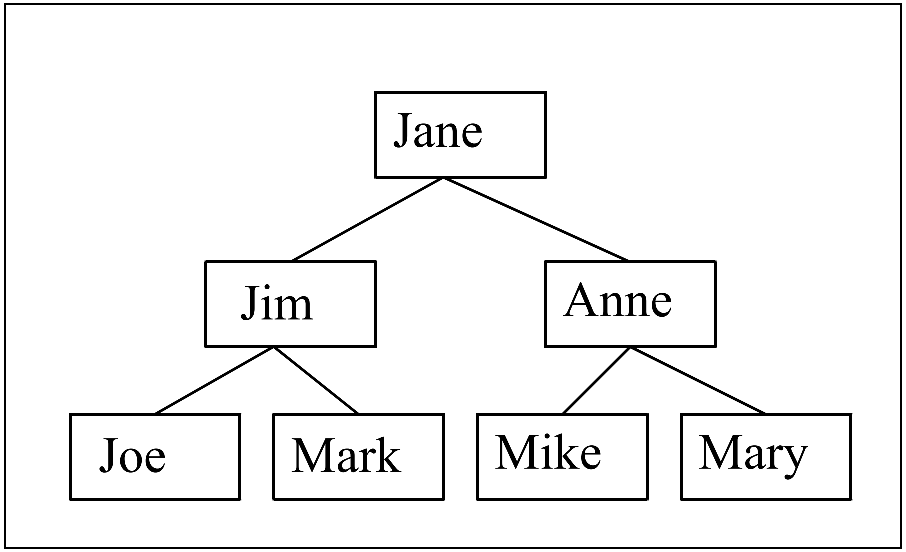
Less errors with 3D in general

Image and words

- Words for procedure, logic and abstract meanings
- Images for pattern and structure

Abstraction Pattern

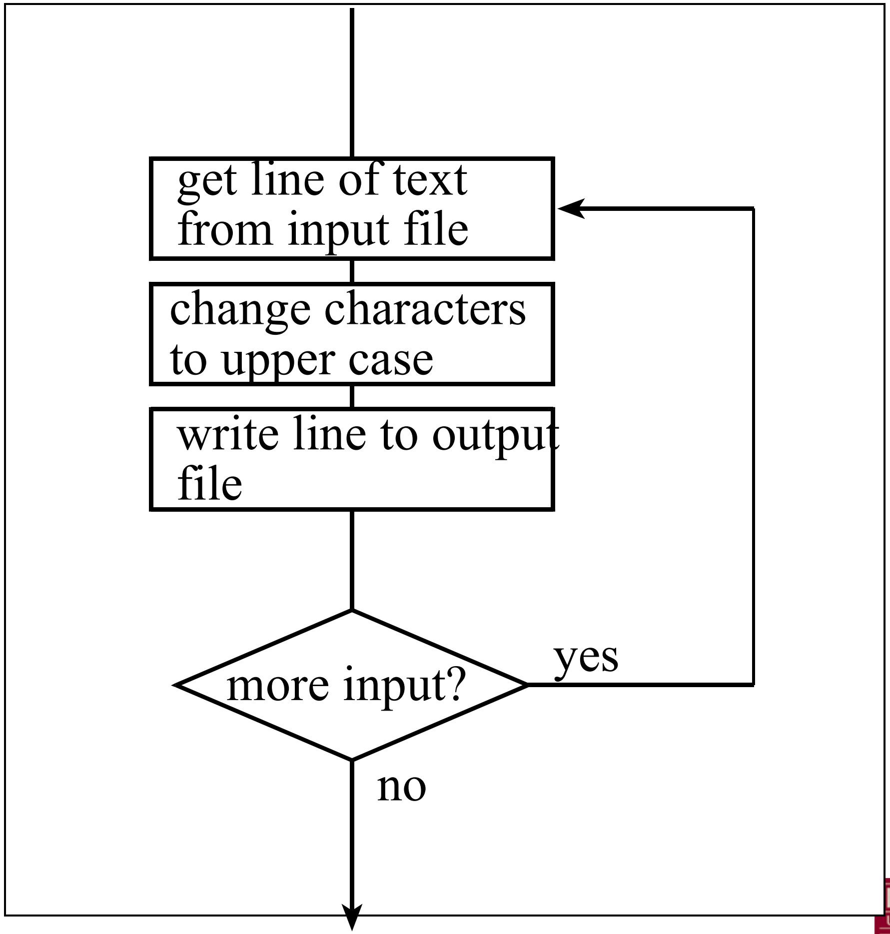
- Jane is Jim’s boss
- Jim is Joe’s boss
- Anne works for Jane
- Mark works for Jim
- Anne is Mary’s boss
- Anne is Mike’s boss



Visual and verbal pseudo-code

- **While letters in stack**
  - Take a letter
  - Put a stamp on it
  - Put it in the ‘out tray’

Visual programming languages have a history of failure

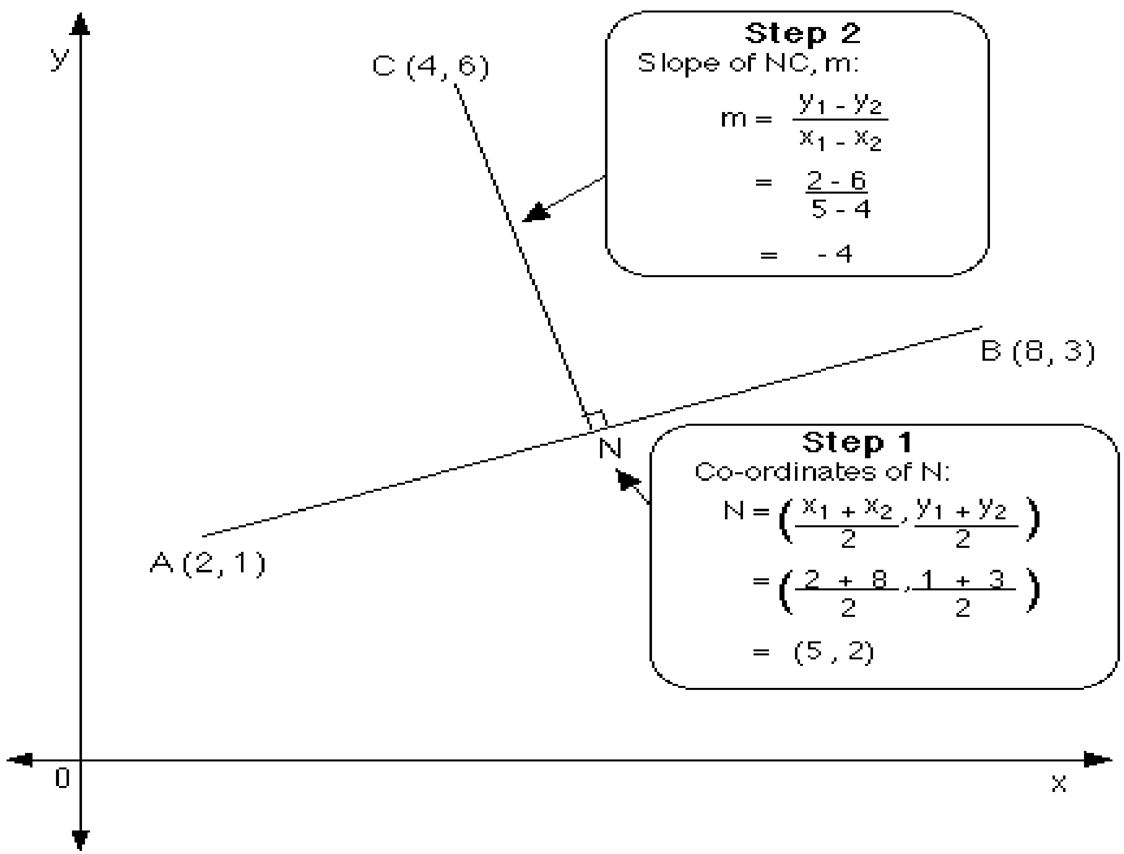


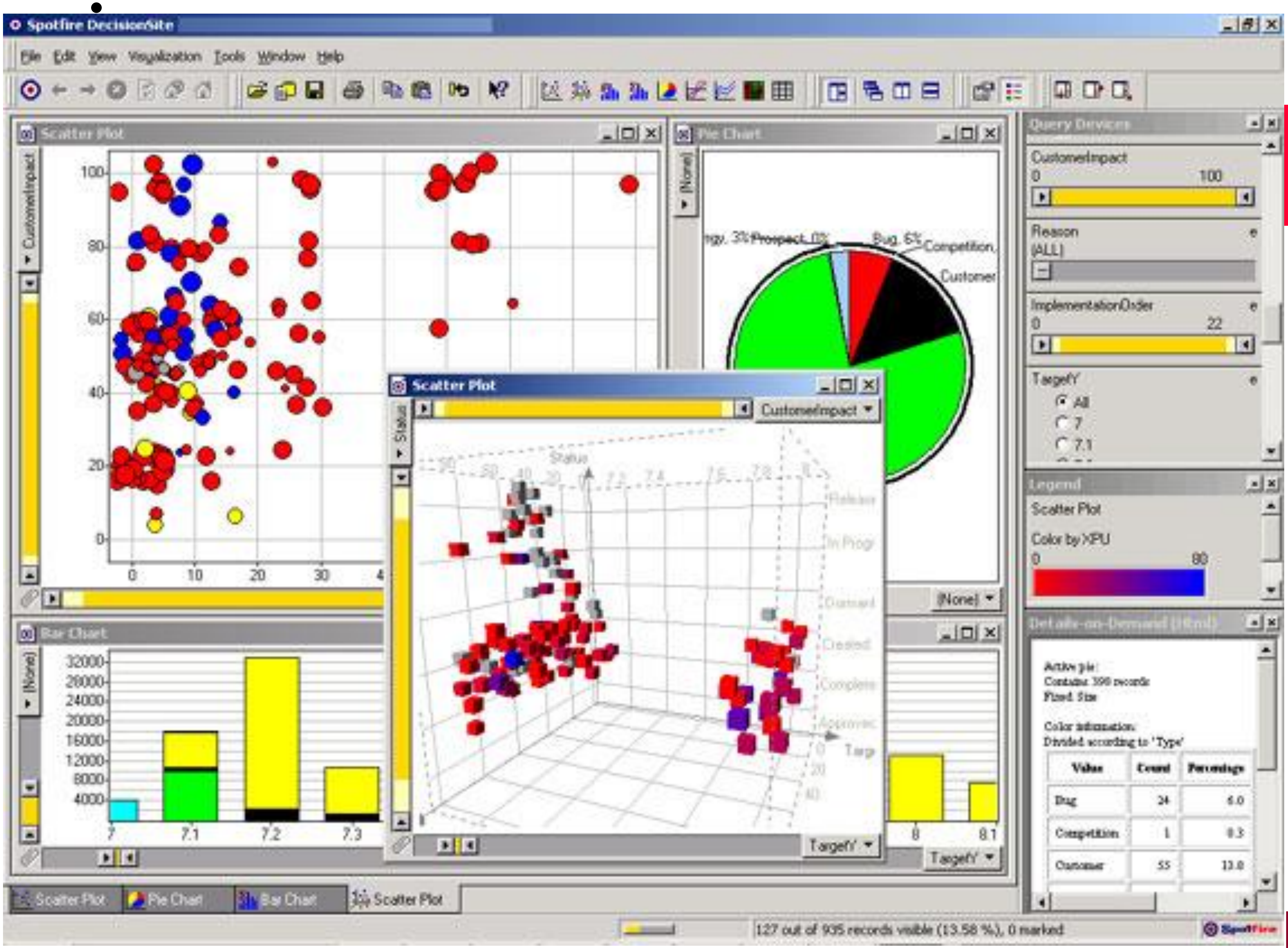
Data flow diagrams are defunct

Integrated pictures and words more effective

Problem

Find the co-ordinates of N, and the slope of the line NC, given that N is the mid-point on line AB.





Info Viz. (and interaction)