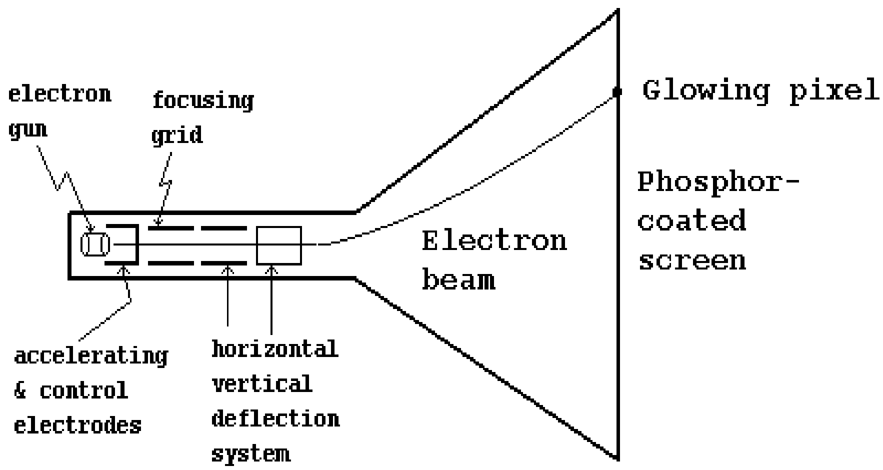
Computer Graphics Hardware

Graphics Hardware

- Display Devices
  - Vector Scan
    - Image stored as line segments (vectors) that can be drawn anywhere on display device
  - Raster Scan
    - Image stored as a 2D array of color values in a memory area called the frame buffer
    - Each value stored determines the color/intensity of an accessible point on display device
- Both based historically on CRT (TV)
  - Electron beam accelerated toward screen
    - focused
    - deflected
    - strikes phosphorescent material on screen

      -->pixel that glows

A Cathode Ray Tube (CRT)



A Pixel

- Visible point where electron beam hits screen
- Screen phosphors glow & fade
- Have a finite size
  - Not a mathematical point

Resolution

- Maximum number of pixels that can be plotted without overlap
- Expressed as: # horizontal X # vertical pixels
- Depends on:
  - phosphor used
  - focusing system (how small a point)
  - Speed/precision of deflection system
  - video memory size (raster scan)--as we'll see

Aspect Ratio

- Ratio of # of pixel columns to # of pixel rows
- Examples:
  - SVGA VESA mode 100h: 640 X 400, A.R. = 1.6
  - Standard Windows: 640 X 480. A.R. = 1.33
- **<u>Pixel Ratio</u>** (often called Aspect Ratio)
  - Ratio of pixel height to pixel width
  - Ratio of # of horizontal pixels to vertical pixels needed to produce equal length lines
  - For a square screen, A.R. = P.R.
  - If Pixel Ratio != 1, figures are distorted

Dot Pitch

- Minimum distance between centers of adjacent pixels of same color
- Should be less than 0.28 mm for sharp images
- For fixed sized screen
  - Decreasing distance between pixels ==> Increase Resolution
  - So dot pitch determines max resolution

Persistence

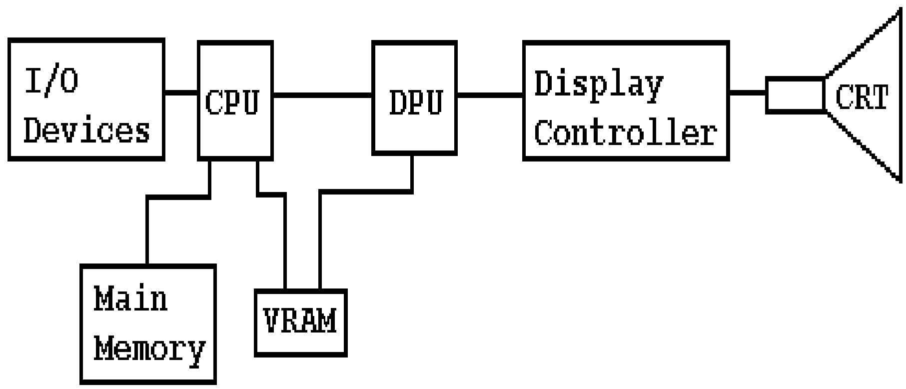
- After beam leaves a phosphor, it fades
- Definition of persistence:
  - Time to reduce initial intensity to 10% of original value
  - Value depends on type of phosphor (10 - 100 msec.)
- Finite persistence==>screen must be redrawn
  - Refresh rate determined by persistence
- Example: If persistence = 20 msec
  - 1st pixel on screen invisible after that time ==>
    - screen must be refreshed once every 20 msec
    - so refresh rate must be > 50 Hz.

- If refresh is too slow: flicker
- If refresh is too fast: shadowing (ghosting)

Graphics Hardware Systems

- CPU--Runs program in main memory
  - specifies what is to be drawn
- CRT--does the actual display
- Display Controller--Provides analog voltages needed to move beam and vary its intensity
- DPU—generates digital signals that drive display controller
  - (offloads task of video control to separate processor)
- VRAM--Stores data needed to draw the picture
  - Dual-ported (written to by CPU, read from by DPU)
  - Fast (e.g., 1000X1000, 50 Hz ==> 20 nsec access time!)
  - Also called Refresh Buffer or Frame Buffer
- I/O devices--interface CPU with user

A Computer Graphics Hardware System (General)



Flat-Panel Displays

- Technologies to replace CRT monitors
- Reduced volume, weight, power needs
  - Thinner: can hang on a wall
- Two categories
  - Emissive and non-emissive

Flat Panel Displays: Emissive Devices

- Convert electrical energy to light
- Plasma panels (gas-discharge displays)
  - Voltages fired to intersecting vertical/horizontal conductors cause gas to glow at that pixel
  - Resolution determined by density of conductors
  - Pixel selected by x-y coordinates of conductors
  - These are "raster" devices
- Other technologies
  - All require storage of x-y coordinates of pixels
  - Examples:
    - Thin-film electroluminescent dipslays
    - LEDs
    - Flat CRTs

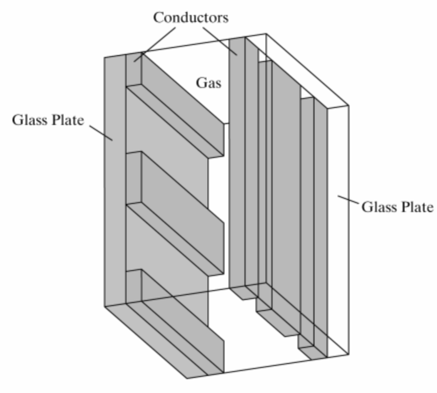


Figure 2-11
Basic design of a plasma-panel display device.

Computer Graphics with Open GL, Third Edition, by Donald Hearn and M.Pauline Baker.
ISBN 0-13-0-15390-7

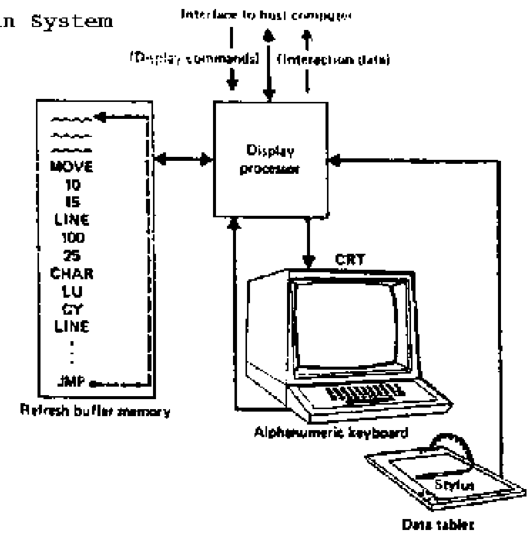
Flat Panel Displays: Non-emissive Devices

- Use optical effects to convert ambient light to pixel patterns
- Example: LCDs
  - Pass polarized light from surroundings through liquid crystal material that can be aligned to block or transmit the light
  - Voltage applied to 2 intersecting conductors determines whether the liquid crystal blocks or transmits the light
- Like emissive devices, require storage of x-y coordinates of pixel to be illuminated

Vector Scan Systems

- Also called random, stroke, calligraphic displays
- Images drawn as line segments (vectors)
- Beam can be moved to any position on screen
- Refresh Buffer stores plotting commands
  - So Frame Buffer often called "Display File”
  - provides DPU with needed endpoint coordinates
  - Pixel size independent of frame buffer
    - ==> very high resolution

Vector Scan System



Typical refresh display device. Display list in memory shows symbolic representation of plotting commands followed by values (e.g., *x, y* coordinates or characters).

Advantages of Vector Scan

- High resolution (good for detailed line drawings)
- Crisp lines (no "jaggies")
- High contrast (beam can dwell on a pixel==>very intense)
- Selective erase (remove commands from display file)
- Animation (change line endpoints slightly after each refresh)

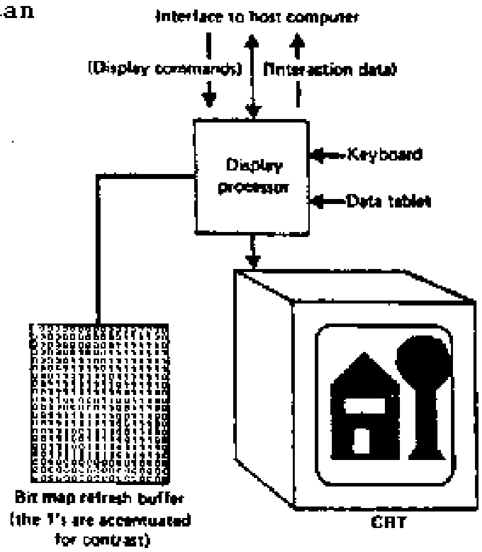
Disadvantages of Vector Scan

- Complex drawings can have flicker
  - Many lines
    - so if time to draw > refresh time ==> flicker
  - High cost--very fast deflection system needed
  - Hard to get colors
  - No area fill
    - so it's difficult to use for realistic (shaded) images
  - 1960s Technology, only used for special purpose stuff today

Raster Scan Systems (TV Technology)

- Beam continually traces a raster pattern
- Intensity adjusted as raster scan takes place
  - In synchronization with beam
  - Beam focuses on each pixel
  - Each pixel's intensity is stored in frame buffer
  - So resolution determined by size of frame buffer
- Each pixel on screen visited during each scan
  - Scan rate must be >= 30 Hz to avoid flicker

Raster Scan System



Typical raster graphics display showing house and tree.

Simplest system: one bit per pixel

– frame buffer called a bitmap

Gray Scale: N bits/pixel

– 2^N intensities possible

– memory intensive

- Example:1000 X 1000 X 256 shades of gray ==> 8 Mbits

Scan Conversion

- Process of determining which pixels need to be turned on in the frame buffer to draw a given graphics primitive
- Need algorithms to efficiently scan convert graphics primitives like lines, circles, etc.

Advantages of Raster Scan Systems

- Low cost (TV technology)
- Area fill (entire screen painted on each scan)
- Colors
- Selective erase (just change contents of frame buffer)
- Bright display, good contrast
  - but not as good as vector scan can be:
  - can't make beam dwell on a pixel

Disadvantages

- ✍ Large memory requirement for high resolution
  - (but cost of VRAM has decreased a lot!)
- ✍ Aliasing (due to finite size of frame buffer)
  - Finite pixel size
  - Jagged lines (staircase effect)
  - Moire patterns, scintillation, "creep" in animations
- ✍ Raster scan is the principal “now” technology for graphics displays!

Tektronix Direct View Storage Tube

- ✍ 1st "inexpensive" graphics display device
- ✍ Extension of vector scan technique
- ✍ Two electron guns
  - writing gun
  - flood gun

- ✍ Writing gun beam knocks electrons out
  leaves + charges behind (constitute image)
- ✍ Flood gun supplies continuous source of unfocused electrons
  - migrate toward the + charges on grid
  - pass through grid and strike screen phosphors
    --> lighted dots
  - electrons continue to hit + charges
  - continuous light (Up to an hour)

Erasure of DVST image

1. Plus charge applied to entire grid
   - Attracts electrons to entire grid
   - Entire screen flashes (Image gone)
2. Minus charge applied to entire grid
   - Provides electrons that can be knocked out by writing gun
   - Ready to draw next image with writing gun

Advantages to DVST

- No refresh needed
  - unlimited image complexity possible
- High resolution
- Crisp lines
- Low cost
  - no fast refresh circuitry needed

Disadvantages to DVST

- No selective erase
  - whole image or nothing
- No animation
- Low light output
  - poor contrast
  - must use in subdued light
- No color
- No area fill

Interlaced Displays

- All even then all odd screen lines scanned
- Typically 1/60 second each
  - Same image presented twice in 1/30 second
  - Image changed at 1/2 non-interlaced frequency
    - less demands on image generation system
    - can be less expensive
    - 30 Hz is borderline for flicker
    - lower quality image (seeing half the image at a time)

Color Display Hardware (raster)

- Each pixel composed of 3 phosphors
  - glow red, green, and blue
- 3 electron guns shoot their beams through a shadow mask
  - so beams hit the sensitive phosphors
- Intensity of 3 beams determines how bright each phosphor glows
- Human eye detects an additive color mix
  - e.g., max red, green, & blue perceived as white

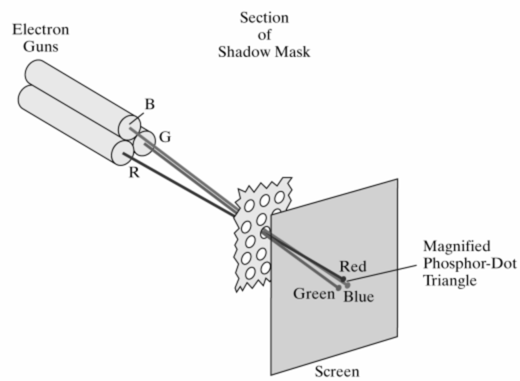


Figure 2-10

Operation of a delta-delta, shadow-mask CRT. Three electron guns, aligned with the triangular color-dot patterns on the screen, are directed to each dot triangle by a shadow mask.

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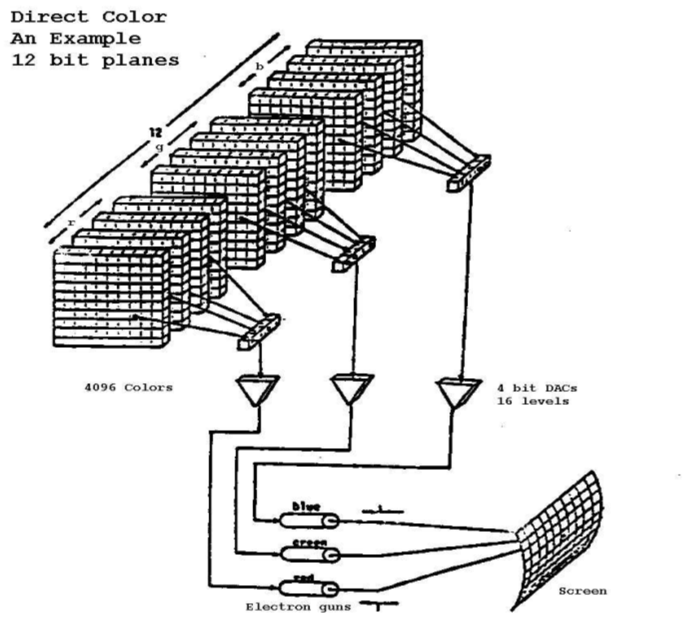
Direct color systems

- Frame buffer divided into bit planes
- A bit plane contributes one bit to the color of each pixel on the screen
- If resolution of the screen is W x H pixels:
  – a bit plane is a W x H x 1 bit memory
- Bit planes can be organized into 3 sets
  – Each called a color channel: (R, G, B)
  – Bit planes of a color channel provide the intensity values fed to that channel's electron gun
- A system with N bit planes per color channel:
  – 2^N red, 2^N green, & 2^N blue shades
  – 2^3N different colors displayable simultaneously

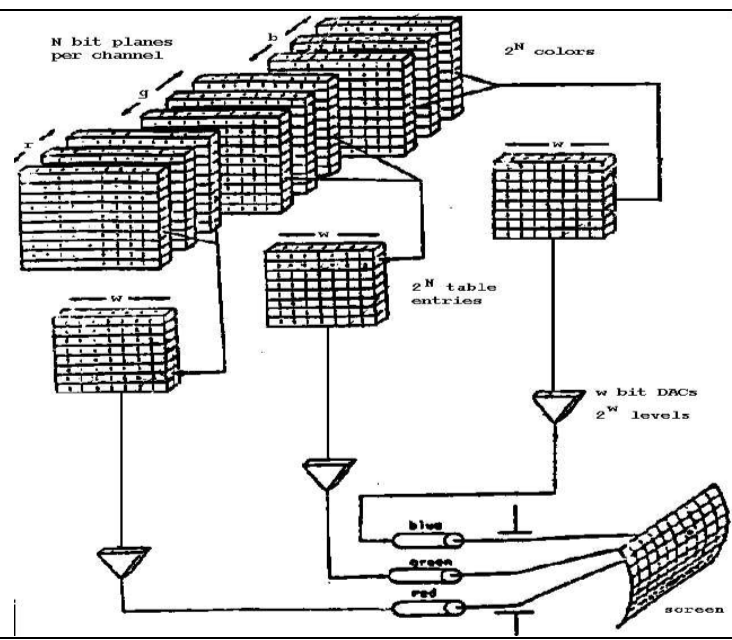


True Color & High Color Systems

- True color: direct color system with:
  N=8
    so 2^24 = 16,777,216 different colors possible for each pixel on screen
  More colors than discernable by human eye
- High color: direct color system with:
    Nr=5, Ng=6, Nb=5
    2^16 = 65, 536 different colors possible

Indirect Color Systems

- Values stored in bit planes are <u>indices</u> into one or more color lookup tables (CLUTs)
  - CLUT stores R, G, B intensity values
  - # of bit planes determines # of colors displayable simultaneously on screen
  - width of CLUTs determines # of possible colors.



Indirect Color Systems, continued

- If system has N bit planes per color channel
- And each set of bit planes indexes a CLUT of width w,
  - Then number of entries in each CLUT = 2^N
  - We say there are 2^{3N} colors displayable chosen from a total of 2^{3w} possible colors
  - Each set of 2^{3N} colors often called a palette
  - CLUTs often called palette registers

Advantages to Indirect Color

- Wide CLUTs (large w) ==>huge number of possible colors
- Modest # of bitplanes (small N) ==> VRAM not excessive in size
- Also, number CLUT entries is modest
  - So we get lots of possible colors with relatively little memory expense
- Fast animation for certain effects
  - just change contents of CLUTS

Down Side to Indirect Color

- Ultimately number of colors on screen is limited by number of bit planes (N)
  - Even if large number of possible colors (large CLUT w), only a small fraction of them are usable at one time
  - So graphics applications must set up CLUTs with values corresponding to most frequently occurring colors in scene
    - Different scenes might require different combinations of colors in the CLUTs
- Can be slower: 2nd memory access

Color Graphics on a PC

- Graphics capabilities depend on display adapter (video card) in the system
- Historical development:
  - CGA (Color Graphics Adapter)
  - EGA (Enhanced Graphics Adapter)
  - VGA (Video Graphics Array)
  - Many different types of SVGA cards
  - Each display adapter can function in many different text and graphics modes
  - Backwards compatibility

SVGA Adapters

- Many manufacturers
- Each designed differently
  - Each programmed differently at the pixel level
  - No compatibility
  - Most compliant with VESA standards
    - so VESA SVGA modes can be programmed with relative ease
    - often at the expense of performance

Setting the PC Graphics Mode of Operation

- Easiest way: use the BIOS VGA Services
  - via video interrupt 0x10
  - set AH register to 0 (set mode)
  - set AL to desired mode
  - make call to INT 0x10
- INT 0x10 can be used for many other graphics/video functions
  - usually very slow

VGA Graphics Modes

- Support all CGA and EGA modes
- 640 X 480 X 16 colors
- 320 X 200 X 256 colors (mode 13h)
- Also other modes

VGA Mode 13h--A Simple Example of Indirect Color

- One byte of VRAM controls one pixel
  - Row major ordered
- VRAM starts at address 0xa000:0000
- To set pixel at (x,y) to a given color:
  - Set a segment register (ES) to start of video RAM
  - Compute pixel offset = 320 * y + x
  - Load offset into a pointer register
  - Set pixel by loading location with a color (byte), e.g., *MOV ES:[SI], color*

VGA Mode 13h, continued

- Indirect color control thru 256 X 18 CLUT
- Color written to VRAM is a byte-size index into this CLUT
- Table entries: 6 bits red, 6 green, 6 blue
  (0=no intensity, 63=maximum intensity)
- To change an entry in the VGA CLUT
  - use the video interrupt (10h):
    - AH=10h, AL=10h, BX=CLUT position (0-255)
    - DH, CH, CL = R, G, B intensity: (0-63 each)

VESA SVGA BIOS Extension (VBE)

- Using high resolution, high color SVGA display modes in a standard way
- Documentation available at:
  - http://www.vesa.org/public/VBE/vbe3.pdf
    - entire document with example program in Adobe pdf format

Graphics under Microsoft Windows

- Windows GDI does not permit direct access to Display Adapter
- Must use GDI calls to do graphics
  - SLOW!
- Or Special Libraries giving some access to frame buffer
  - OpenGL
  - DirectX

Color Under Windows

- Direct or Indirect
- Direct Modes:
  - 16 bit “high color”
  - 24 bit “true color”
    - R, G, B: 8 bits each
    - 2^{24} different colors
  - Use RGB() macro to get a COLORREF
    - If used in low color modes, result is color dithering

Windows Indirect Color Modes

- 256 entry CLUT (8 bits)
- 16 entry CLUT (4 bits)
- CLUTS called palettes
- Controlled by Windows “Palette Manager”
  - A part of the GDI
- Using a color in the CLUT:
  - PALETTEINDEX(i) instead of RGB()
- We’ll look at the 256-color palette

The System Palette

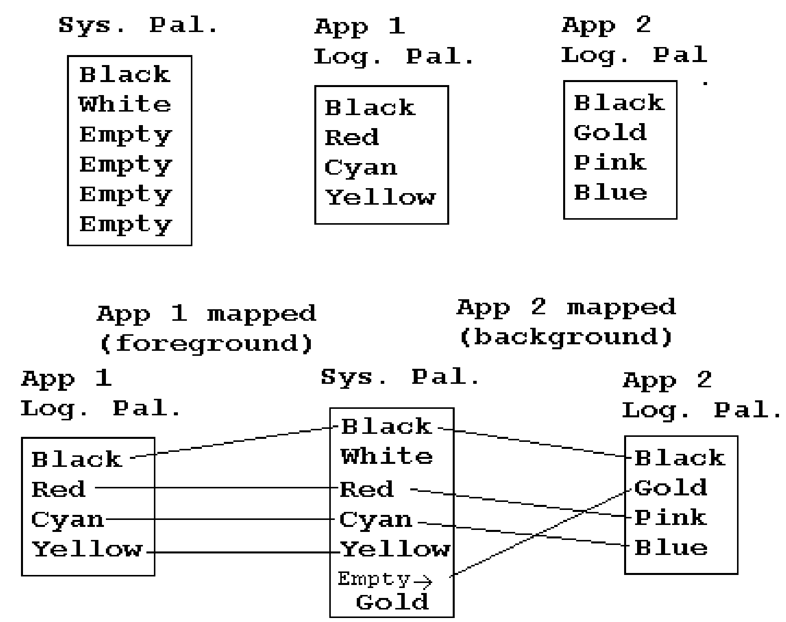
- Maintained by Palette Manager
- Sort of like the physical CLUT
- Entries contain 8 bits per color channel
- 20 “static” colors initially defined
- Contents determine colors displayed
- Used by all applications
  - Shared between all windows
- Arbitrary changing it could mess up color of other windows

Changing the Palette

- Create a “logical palette”
  - Use CPalette::CreatePalette()
  - Set up with desired colors
- Select into a Device Context
- “Realize” it
  - i.e., map it to the system palette
  - done by calling CDC::RealizePalette()

Color Mapping with RealizePalette()

- Causes Palette Manager to compare colors in logical palette with system palette
  - exact match==>
    - log. palette entry mapped to phys. palette entry
  - no exact match==>
    - if available free entry, copy and map
    - if not, map to closest existing entry
- Active foreground application mapped first
- So background window colors can change



Details in Changing System Palette

1. Set up a logical palette structure:

Windows LOGPALETTE structure:

```
WORD palVersion;          // 0x300
WORD palNumEntries;   // # colors to change
PALETTEENTRY palPalEntry[1] //new colors
```

- you may want to define & use your own logical palette struct for more colors

PALETTEENTRY structure:

```
BYTE     peRed;      // new color's red intensity
BYTE     peGreen;  // green intensity
BYTE     peBlue      // blue intensity
BYTE     peFlags;    // usually 0
```

2. Create the palette:

CPalette::CreatePalette(LPLOGPALETTE pLP);

– Member function of **CPalette**
– Takes ptr to desired logical palette structure
– Should be typecast
– Returns nonzero if successful

3. Select it into the DC:

CDC::SelectPalette(pLP,FALSE);

– pLP is a pointer to the logical palette structure created above

4. Map current logical palette to system palette:

CDC::RealizePalette();

Indirect Color in OpenGL

- First tell system you're using indexed color
  - wgl: set PIXELFORMATDESCRIPTOR's iPixelType field to PFD_TYPE_COLORINDEX instead of PFD_TYPE_RGBA
  - GLUT: glutInitDisplayMode(GLUT_SINGLE,CLUT_INDEXED);
    - May not work on some systems
- Set entries in window's CLUT
  - Wgl: Use logical palette structure as described above
  - GLUT: use glutSetColor(int color_index, r, g, b) to set an entry in the CLUT
- Selecting a color
  - Glndexi(index_value instead of glColor3f(r,g,b);