CS 433/433H, 533

Instructor: Kobus Barnard
TA: Joseph Schlecht

Plan for today
- What is graphics? Why study it?
- Syllabus issues
- Math warm up

Why graphics?

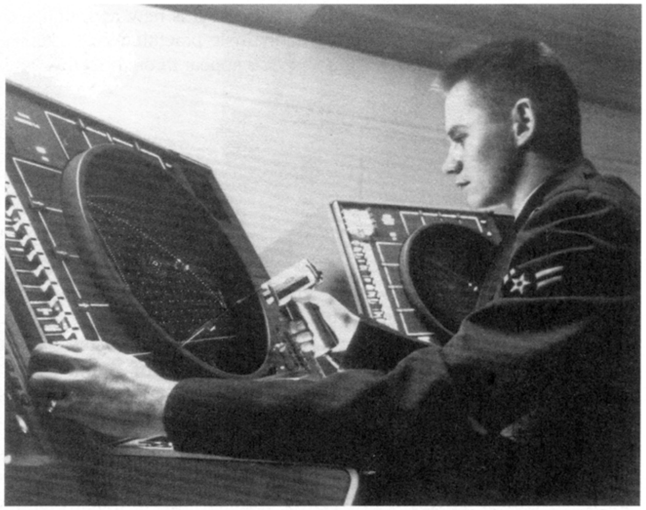
- Presenting an alternative world
- Visual interfaces
- Enhancing our view of the existing world (visualization)

Presenting an alternative world

- For training
  - Landing expensive aircraft
- For amusement
  - Games; movies
- For aesthetic pleasure
  - Computer art
- For understanding
  - Visualize data sets in an accessible way

Interaction

- Key to the games industry
- Key to most current user interfaces
- Idea dates back to '55, at least
- Sketchpad was the first interactive graphics system where user could manipulate what is displayed ('63 thesis, Ivan Sutherland)

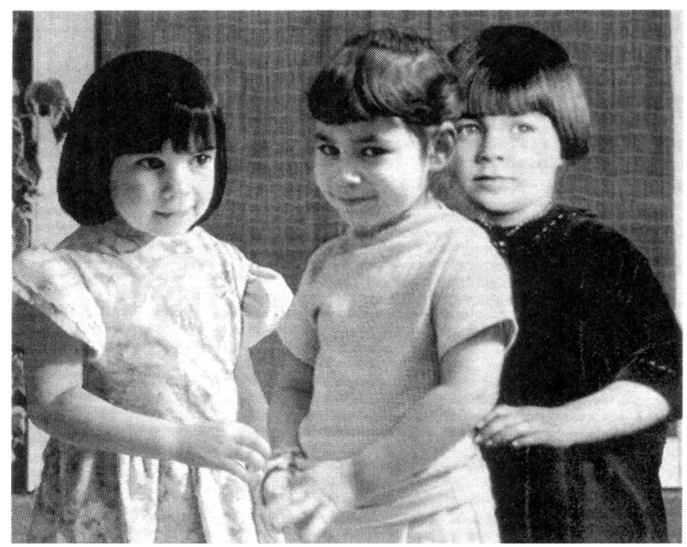


SAGE - aircraft target selection - 1958, from Spalter

Sketchpad, c 1955, from Spalter

Computer Art

- 2D graphics to create and manipulate images
  - Image editing and composition tools
  - Computer paint programs
  - User interfaces are improving - pressure sensitive tablets, etc.
- 3D virtual reality for new ways of expression



Me, My Mom and My Girl at Three, 1992, Michele Turre

You Wish, from Tree Fix, 1997, Michele Turre

Enhancing the existing world

- Mix models with the real world
  - Movies!
- Allow operation planning
  - Neurosurgery
  - Plastic surgery
- Add information to a surgeons view to improve operation
  - Neurosurgery

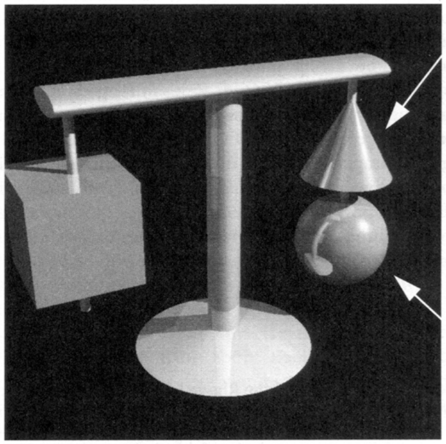
From Eric Grimson’s research group at MIT

What is graphics?

- Mathematical model of world --> images
- Main technical activities are **modeling the world** and **rendering**
- Modeling may either be in support of artists/actors who provide the content, and/or, physics based models to make things look real.

Rendering takes a model to a picture

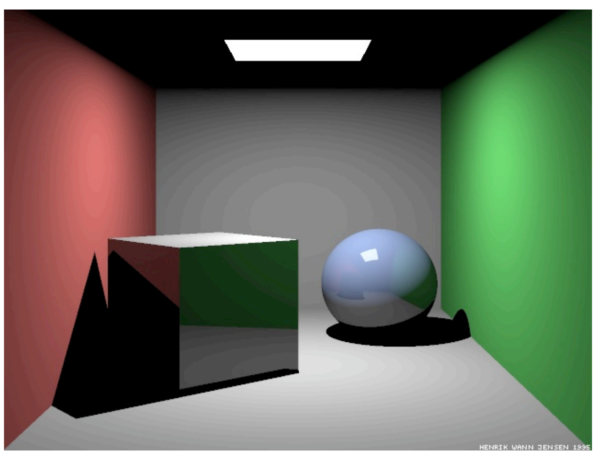
```
trans [
scale 1.03 1.03 1.03
translate -1.55 0.29 0
object cube [
diffuse 0.9 1 0.9
ambient 0.06 0.05 0.07
specular 0.9 0.9 0.9
reflect 0.38 0.38 0.38
shine 30
]
]
```



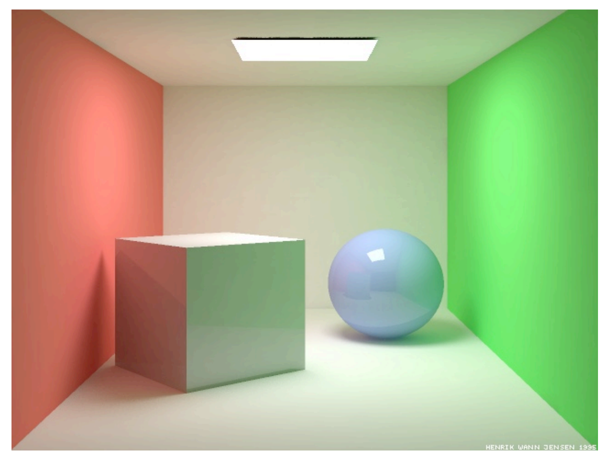
```
trans [
translate 1.55 0.74 0
scale 1.04 0.93 1.04
object cone [
diffuse 0.9 1 0.9
ambient 0.06 0.05 0.07
specular 0.9 0.9 0.9
reflect 0.47 0.47 0.47
shine 30
]
]
```

```
trans [
translate 1.55 -0.53 0
scale 1.1 1.1 1.1
object sphere [
diffuse 0.9 1 0.9
ambient 0.06 0.05 0.07
specular 0.9 0.9 0.9
reflect 0.42 0.42 0.42
shine 30
]
```

PCKTWTCH by Kevin Odhner, POVRay

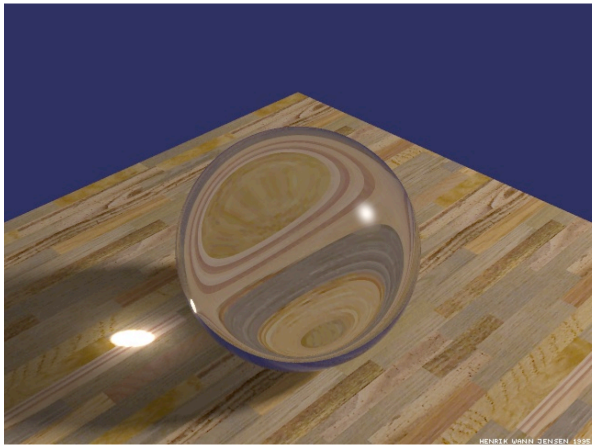


Ray-traced Cornell box, due to Henrik Jensen, http://www.gk.dtu.dk/~hwj



Radiosity Cornell box, due to Henrik Jensen, http://www.gk.dtu.dk/~hwj, rendered with ray tracer

Refraction caustic



Henrik Jensen, http://www.gk.dtu.dk/~hwj

Refraction caustics

Henrik Jensen, http://www.gk.dtu.dk/~hwj

Course Outline

(not exactly in order!)

- Intro (1 week)
  - OpenGL intro
  - Math review
- Rendering (6 weeks)
  - Proceeding from a geometrical model to an image Involves understanding
    - Displays
    - Geometry
    - Cameras
    - Visibility
    - Illumination
  - Technologies
    - the rendering pipeline
    - ray tracing
- Modeling (2 weeks)
  - Producing a geometrical, or other kind of model that can be rendered.
  - Involves understanding
    - Yet more geometry
    - A little calculus
- Misc (2 weeks)
  - colour
  - animation
  - advanced rendering
- Exam, review, guest, etc (2 week, equivalent)

Syllabus Issues

Other than passwords, everything that you need to know should be available at:

www.cs.arizona.edu/classes/433/fall06

Instructor (virtual)

Instructor: Kobus Barnard

Email: kobus @ cs

Web: kobus.ca (link to class under teaching)

Instructor (real)

Instructor: Kobus Barnard

Office: GS 730

Office Hours (**by electronic sign up**): kobus.ca/calendar
Tuesday and Thursday 9:30 to 10:00
Friday 11:00 to 12:00

Calendar access off campus	To make an appointment
login: me	login: public
pw: pw4cal	pw: meetkobus

Teaching Assistant

TA: Joseph Schlecht

Email: schlecht @ cs

Office Hours: MW 10:30 -- 11:30

Office Location: Gould Simpson 909A

Notes

Notes will be distributed in “chunks”.

Notes will have some missing “answers” identified by a “?” for you to think about and/or fill in as we go along.

After each lecture, the part that was actually covered that day will be put on line (with the “answers”).

Text

Hearn and Baker (optional)

What you need to know is in the notes. However the above text provides a different view with a relatively friendly style.

See on-line syllabus for additional recommended books.

Web Pages

Web page: www.cs.arizona.edu/classes/433/fall06

For remote access to restricted items (slides, assignments):
login: me
pw: graphics4fun

Grading, etc.

Assignments (70%)
Quizzes (10%) (Best 2 out of 3)
Final (20%)

Projects can be substituted for assignments (with permission).

Grad students will have **extra** assignment parts and will have to do more of the exam for the same grade.

Honors students need to do 4 out of 6 grad student parts (or project).

Grading, etc.

Assignments (70%)
Quizzes (10%) (Best 2 out of 3)
Final (20%)

Assignments need to be done individually (no teams).

Late policy (10% off per day until 5 days late, then 0)

We will check assignments for duplication

Platforms and Languages

Programs must be in C/C++ for linux.

If you develop on windows, you must check that your code compiles and runs on linux.

Computer Resources

Please do “Apply”--it is needed for CAT card access to graphics lab.

Graphics “lab” (Eight linux machines in GS 920)

I need your E-mail--check it on the list; if you are not on the list because your paperwork has not yet percolated through the system, add your name and E-mail at the bottom of the list.

What is this course really like?

The course targets **fundamentals**. It is not about any particular “API”. I will introduce OpenGL in the first week, but it is **not** an OpenGL course.

The assignments are relatively substantive.

Many of the concepts will be expressed mathematically.

Quick Math Review

We will discuss the underlying math further as it comes up. Today we “warm up” and give a flavour.

Math topics relevant to this course:

- Geometry, especially cartesian geometry
  - (equations for lines, planes, circles, etc)
- Linear Algebra
  - (Matrix representation of transformations)
- Calculus (minimal)
  - (Fit smooth curves through points; aliasing)

Quick Math Review

Usual 2D and 3D Euclidian geometry
(Will also use 4D vectors, no difference in linear algebra)

Cartesian coordinates--algebraic representation of points in 2D space (x,y), and 3D space (x,y,z)

Somewhat interchangeably, the point represents a **vector** from the origin to that point.

A vector is used to define either a direction in space, or a specific location relative to the origin.

Basic Vector Operations

Let $\mathbf{X} = (x_1, x_2, x_3) \quad and \quad \mathbf{Y} = (y_1, y_2, y_3)$

Sum $\mathbf{X}+\mathbf{Y} = (x_1+y_1,\ x_2+y_2,\ x_3+y_3)$

Difference $\mathbf{X}-\mathbf{Y} = (x_1-y_1,\ x_2-y_2,\ x_3-y_3)$

Scale $a\mathbf{X} = (x_1, x_2, x_3) = (ax_1, ax_2, ax_3)$

Magnitude $|\mathbf{X}| = \sqrt{x_1^2+x_2^2+x_3^2}$

Representations for lines and segments

Cartesian

Representations for lines and segments

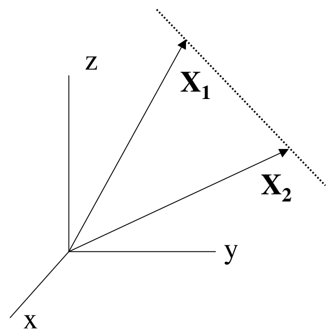
Cartesian

$$m = \frac{y_1-y_0}{x_1-x_0} = \frac{y-y_o}{x-x_o} \quad \Rightarrow \quad y = mx+b$$

Question--what is the analogous formula for 3D?

Representations for lines and segments

Vector representation



$$t\mathbf{X_1} + (1-t)\mathbf{X_2}$$

Works in any dimension

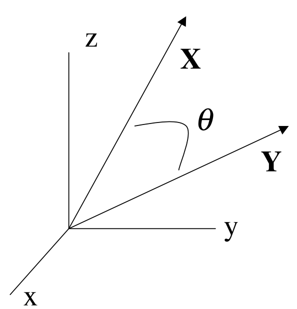
Simplifies representing *segments*

More Vector Operations

Dot Product (any number of dimensions)

More Vector Operations

Dot Product (any number of dimensions)

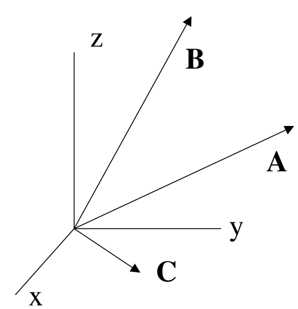


$$\mathbf{X} \bullet \mathbf{Y} = (x_1 y_1 + x_2 y_2 + x_3 y_3)$$
$$= |\mathbf{X}||\mathbf{Y}|\cos\theta$$

Orthogonal $\Leftrightarrow$ $\mathbf{X} \bullet \mathbf{Y} = 0$

More Vector Operations

Vector (cross) product (3D)



$\mathbf{C} = \mathbf{A} \times \mathbf{B}$

$\mathbf{C} \perp \mathbf{A}$ *and* $\mathbf{C} \perp \mathbf{B}$

Use Right Hand Rule

$|\mathbf{C}| = |\mathbf{A}||\mathbf{B}|\sin\theta$

$$\begin{pmatrix} \mathbf{C_x} \\ \mathbf{C_y} \\ \mathbf{C_z} \end{pmatrix} = \begin{pmatrix} \mathbf{A_y B_z} - \mathbf{A_z B_y} \\ \mathbf{A}_z \mathbf{B}_x - \mathbf{A}_x \mathbf{B}_z \\ \mathbf{A}_x \mathbf{B}_y - \mathbf{A}_y \mathbf{B}_x \end{pmatrix}$$

Representations for planes (1)

A plane passes through a point and has a given "direction"

Representations for planes (1)

A plane passes through a point and has a given "direction"

Direction of plane is given by its normal

$$(\mathbf{X}-\mathbf{X_0})\bullet\hat{\mathbf{n}}=\mathbf{0} \quad \Rightarrow \quad \mathbf{ax}+\mathbf{by}+\mathbf{cz}=\mathbf{k}$$

A half space is defined by $(\mathbf{X}-\mathbf{X_0})\bullet\hat{\mathbf{n}}\geq 0$

Representations for planes (2)

Three points determine a plane

We can make it the same as previous approach---how?

?

Representations for planes (3)

Direct vector representation (analog of parameterized form for line segments).

?

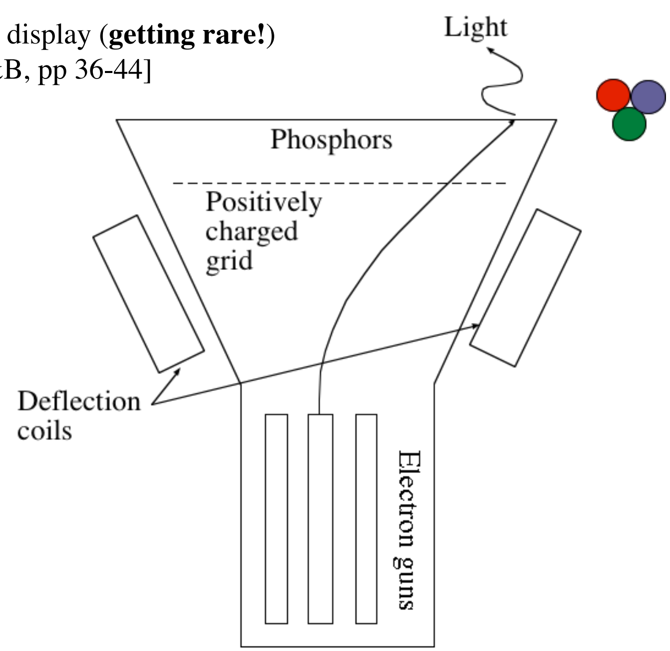
Typical Graphics Problems

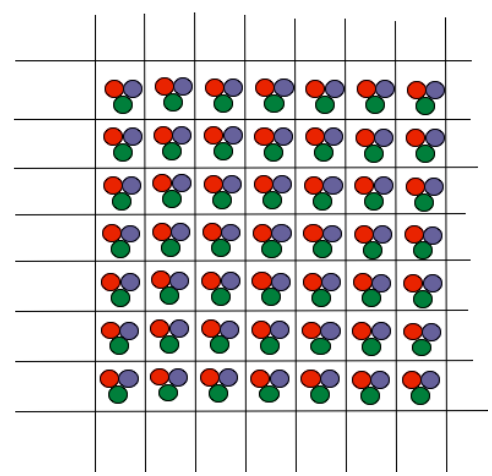
Which side of a plane is a point on?

Is a 3D point in a convex 2D polygon?

Dots, Software, and Lines

CRT display (**getting rare!**)
[H&B, pp 36-44]



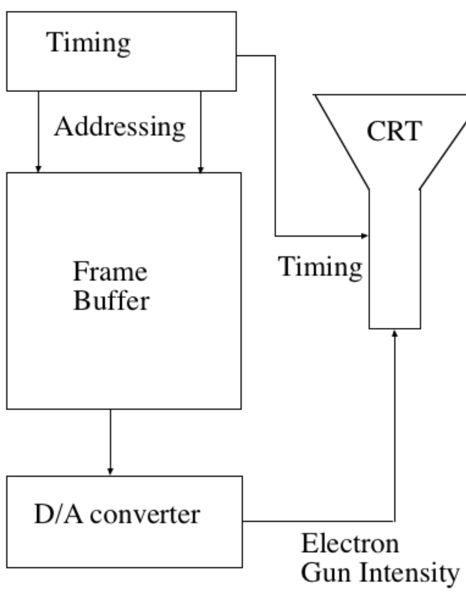


CRT Displays

- Phosphors glow when hit by electron beam.
- Color is adjusted via intensity of beam delivered to each of R,G, and B phosphor
- CRT display phosphors glow for limited time--need to be refreshed (typically about 75 times a second).
- Too much glow time would make animation hard.

CRT Displays

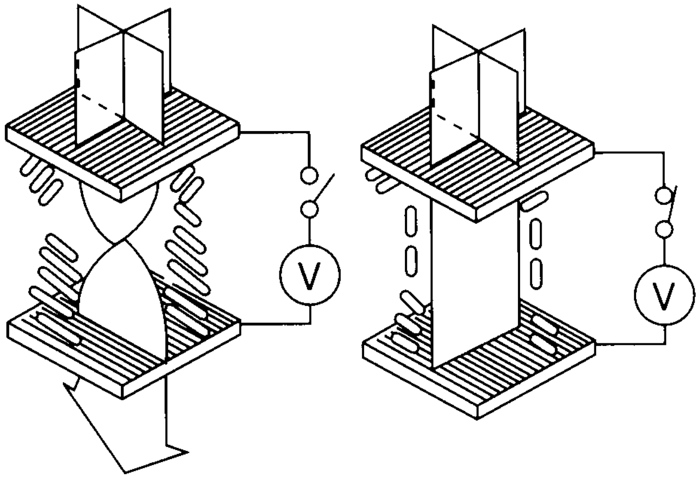
- Raster displays refresh by scanning from top to bottom in left right order.
- Timing is used to make screen elements correspond to memory elements.
- Memory elements called pixels
- Refresh method creates architectural and *programming* issues (e.g. double buffering), defines "real time" in animation.



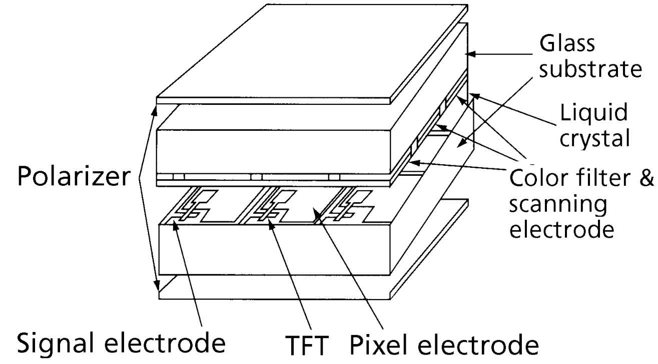
Flat Panel TFT* Displays

[H&B, pp 44-47]

*Thin film transistor



From http://www.atip.or.jp/fpd/src/tutorial



From http://www.atip.or.jp/fpd/src/tutorial

[H&B, pp 47-49]

3D displays

Use some scheme to control what each eye sees

Color, temporal + shutter glasses, polarization + glasses

OpenGL and GLUT

[H&B, §2,9, pp 73-80]

Demo and discussion of example program

http://www.cs.arizona.edu/classes/cs433/fall05/triangle.c

OpenGL and GLUT

- Layer between your program and lower levels (hardware, low level display issues)
- Provides primitives
  - points
  - lines
  - polygons
  - bitmaps, fonts
- Provides standard graphics facilities
  - We will learn how some of these work. Some assignments will therefore have some routines "out of bounds"
  - GLUT simplifies interactive program development with intuitive callbacks and additional facilities (menus, window management).

OpenGL and GLUT

- Initialization code from the example

```
/* initialize GLUT system */
glutInit(&argc, argv);

glutInitDisplayMode(GLUT_RGB | GLUT_DOUBLE);
glutInitWindowSize(400,500);          /* width=400pixels height=500pixels */
win = glutCreateWindow("Triangle");   /* create window */

/* From this point on the current window is win */

/* set background to black */
glClearColor((GLclampf)0.0,(GLclampf)0.0,(GLclampf)0.0,(GLclampf)0.0);
gluOrtho2D(0.0,400.0,0.0,500.0); /* how object is mapped to window */
```

OpenGL and GLUT

- Window display callback. You will likely also call this function. Window repainting on expose and resizing is done for you

```
/* set window's display callback */
glutDisplayFunc(display_CB);
```

```
static void display_CB(void)
{
    glClear(GL_COLOR_BUFFER_BIT);         /* clear the display */

    /* set current color */
    glColor3d(triangle_red, triangle_green, triangle_blue);

    /* draw filled triangle */
    glBegin(GL_POLYGON);

    /* specify each vertex of triangle */
    glVertex2i(200 + displacement_x, 125 - displacement_y);
    glVertex2i(100 + displacement_x, 375 - displacement_y);
    glVertex2i(300 + displacement_x, 375 - displacement_y);

    glEnd();           /* OpenGL draws the filled triangle */
    glFlush();         /* Complete any pending operations */

    glutSwapBuffers(); /* Make the drawing buffer the frame buffer
                          and vice versa */
}
```

OpenGL and GLUT

- User input is through callbacks, e.g.,

```
/* set window's key callback */
glutKeyboardFunc(key_CB);

/* set window's mouse callback */
glutMouseFunc(mouse_CB);

/* set window's mouse move with button pressed callback */
glutMotionFunc(mouse_move_CB);
```

```
static void key_CB(unsigned char key, int x, int y)
{
    if( key == 'q' ) exit(0);
}

/*  /\ /\ /\ /\ /\ /\ /\ /\ /\ /\ /\ /\ /\ /\ /\ /\ /\ /\ /\ /\   */

/* Function called on mouse click */
static void mouse_CB(int button, int state, int x, int y)
{
    /*
     *  Code which responses to the button, the state (press, release), and where
     *  the pointer was when the mouse event occured (x, y).
     *
     *  See example on-line for sample code.
    */
}

/*  /\ /\ /\ /\ /\ /\ /\ /\ /\ /\ /\ /\ /\ /\ /\ /\ /\ /\ /\ /\   */

/* Function called on mouse move while depressed. */
static void mouse_move_CB(int x, int y)
{
    /* See example on-line for sample code. */
}
```

OpenGL and GLUT

- GLUT makes pop-up menus easy. We will save development time by using (perhaps abusing) this facility.

```
/* Create a menu which is accessed by the right button. */
submenu = glutCreateMenu(select_triangle_color);
glutAddMenuEntry("Red", KJB_RED);
glutAddMenuEntry("Green", KJB_GREEN);
glutAddMenuEntry("Blue", KJB_BLUE);
glutAddMenuEntry("White", KJB_WHITE);
glutCreateMenu(add_object_CB);
glutAddMenuEntry("Triangle", KJB_TRIANGLE);
glutAddMenuEntry("Square", KJB_SQUARE);
glutAddSubMenu("Color", submenu);
glutAttachMenu(GLUT_RIGHT_BUTTON);
```

OpenGL and GLUT

- Ready for the user!

```
/* start processing events... */
glutMainLoop();
```

- For the rest of the code see
  http://www.cs.arizona.edu/classes/cs433/fall06/triangle.c

Displaying lines

- Assume for now:
  - lines have integer vertices
  - lines all lie within the displayable region of the frame buffer
- Other algorithms will take care of these issues.

Displaying lines

- Assume for now:
  - lines have integer vertices
  - lines all lie within the displayable region of the frame buffer
- Other algorithms will take care of these issues.
- Consider lines of the form y=m x + c, where 0<m<1
- Other cases follow by symmetry
- (Boundary cases, e.g. m=0,m=1 also work in what follows, but are often considered separately, because they can be done very quickly as special cases).

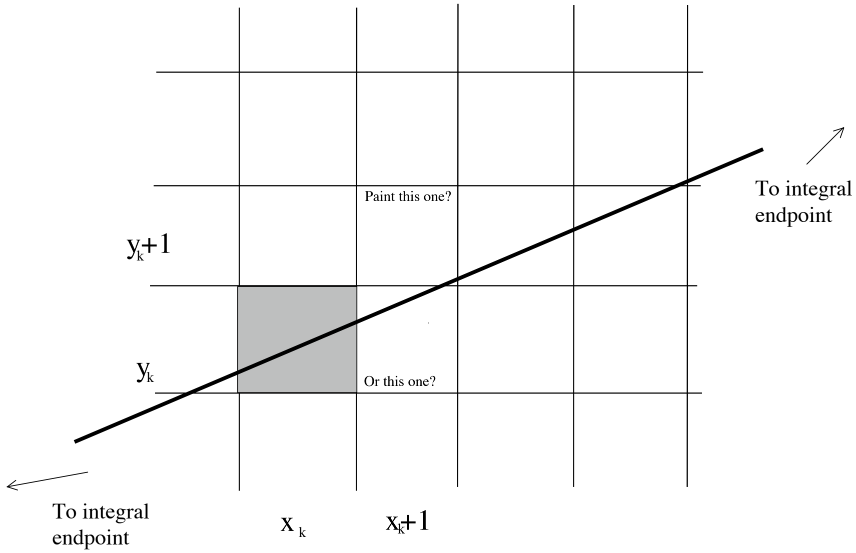
Displaying lines

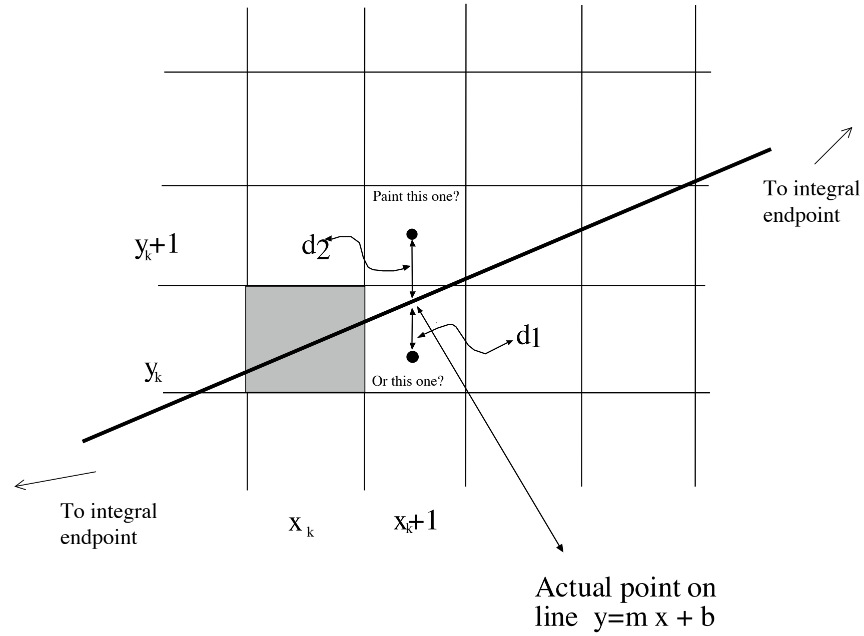
- Variety of naive (poor) algorithms:
  - step x, compute new y at each step by equation, rounding
  - step x, compute new y at each step by adding m to old y, rounding

Bresenham's algorithm

[H&B, pp 95-99]

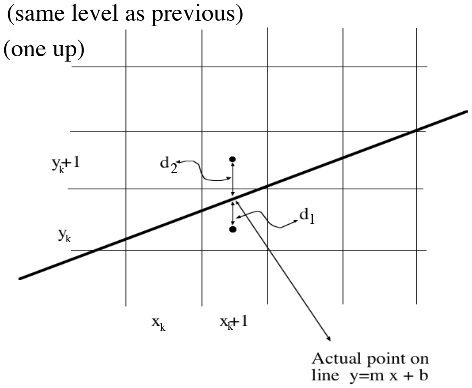
- Plot the pixel whose y-value is closest to the line
- Given (x_k, y_k), must **choose** from either (x_k+1, y_k+1) or (x_k+1, y_k)---recall we are working on case 0<m<1
- Idea: compute value that will determine this choice that is easy to update and cheap to compute (no floating point operations if endpoints are integral).





Bresenham's algorithm

- Determiner is $d_1 - d_2$
  - $d_1 - d_2 < 0$ => plot at y_k (same level as previous)
  - otherwise => plot at y_k+1 (one up)



(Current point is, (x_k, y_k) line goes through $(x_k + 1, y)$)

$$d_1 = y - y_k \quad and \quad d_2 = (y_k + 1) - y$$

So $$d_1 - d_2 = (y - y_k) - ((y_k + 1) - y)$$

Plugging in $y = m(x_k + 1) + b$

Gives:

$$d_1 - d_2 = 2m(x_k + 1) - 2y_k + 2b - 1$$

Avoiding Floating Point

From the previous slide

$$d_1 - d_2 = 2m(x_k + 1) - 2y_k + 2b - 1$$

Recall that,

$$m = (y_{end} - y_{start})/(x_{end} - x_{start}) = dy/dx$$

So, for integral endpoints we can avoid floating point if we scale by a factor of dx. Use determiner P_k.

$$\begin{aligned} p_k &= (d_1 - d_2)dx \\ &= (2m(x_k + 1) - 2y_k + 2b - 1)dx \\ &= 2(x_k + 1)dy - 2y_k(dx) + 2b(dx) - dx \\ &= 2(x_k)dy - 2y_k(dx) + \text{constant} \end{aligned}$$

Incremental Update

From previous slide

$$p_k = 2(x_k)dy - 2y_k(dx) + \text{constant}$$

Finally, express the next determiner in terms of the previous, and in terms of the decision on the next y.

$$\begin{aligned} p_{k+1} &= 2(x_k + 1)dy - 2y_{k+1}(dx) + \text{constant} \\ &= p_k + 2dy - 2(y_{k+1} - y_k) \end{aligned}$$

Either 1 or 0 depending on decision on y

Bresenham algorithm

- $p_{k+1} = p_k + 2\,dy - 2\,dx\,(y_{k+1} - y_k)$
- Exercise: check that $p_0 = 2\,dy - dx$
- Algorithm (for the case that 0<m<1):
  - x=x_start, y=y_start, p=2 dy - dx, **mark** (x, y)
  - until x=x_end
    - x=x+1
    - p>0 ? y=y+1, **mark** (x, y), p=p+2 dy - 2 dx
    - else y=y, **mark** (x, y), p=p+2 dy
- Some calculations can be done once and cached.

Issues

- End points may not be integral due to clipping (or other reasons)
- Brightness is a function of slope.
- Discretization problems “aliasing” (related to previous point).