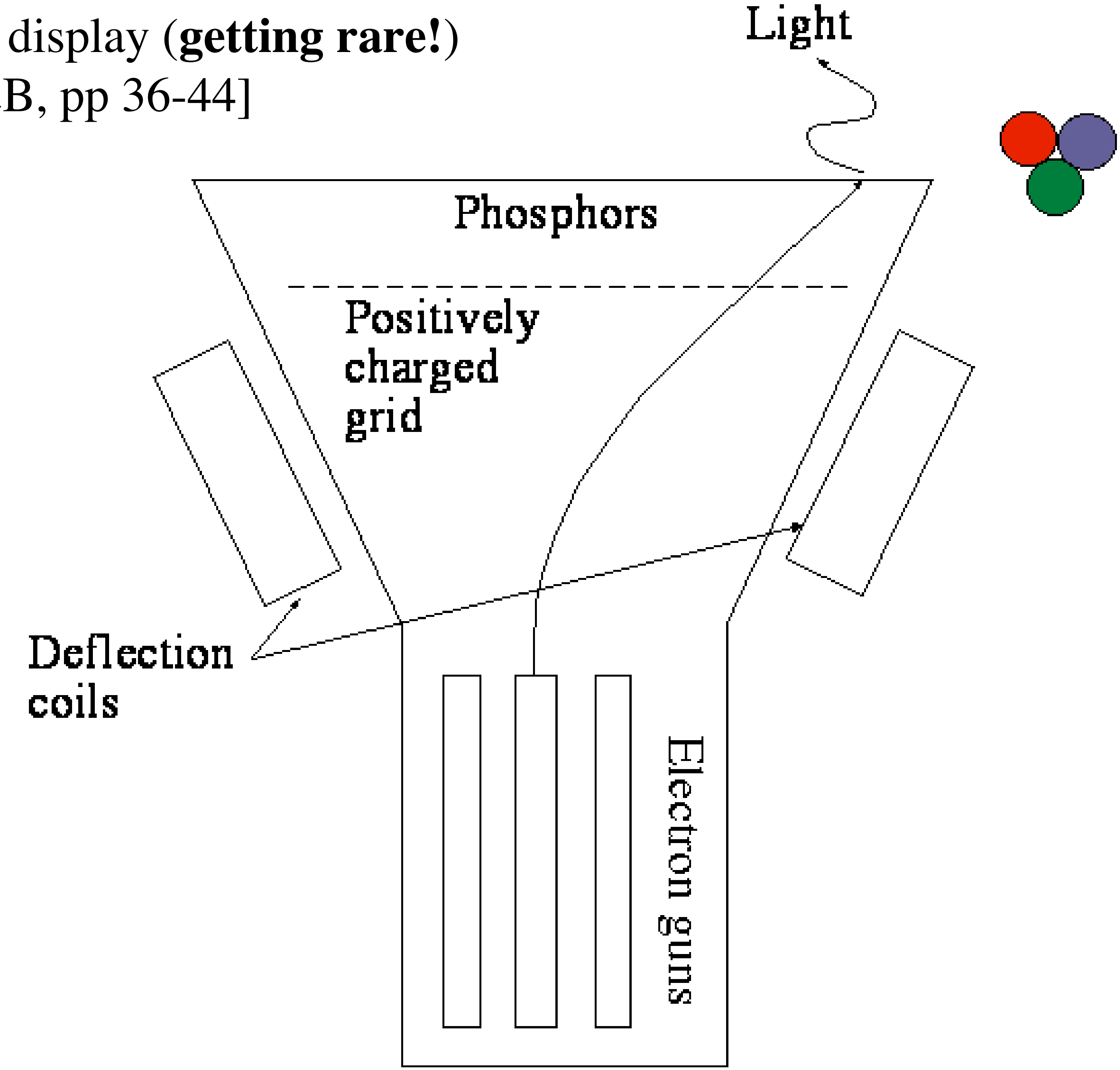
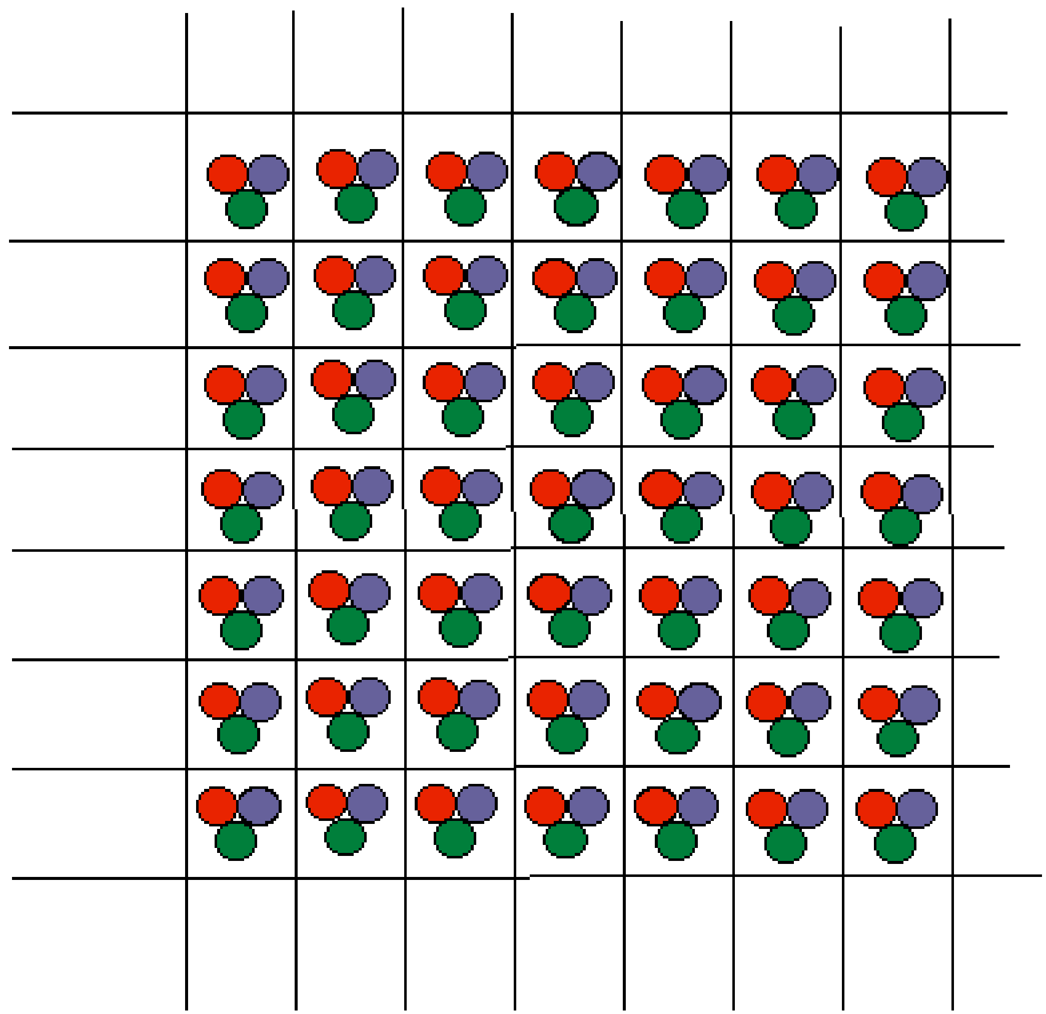
TA (Amy Platt) office hours

M and W, 1-2

GS 929b

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



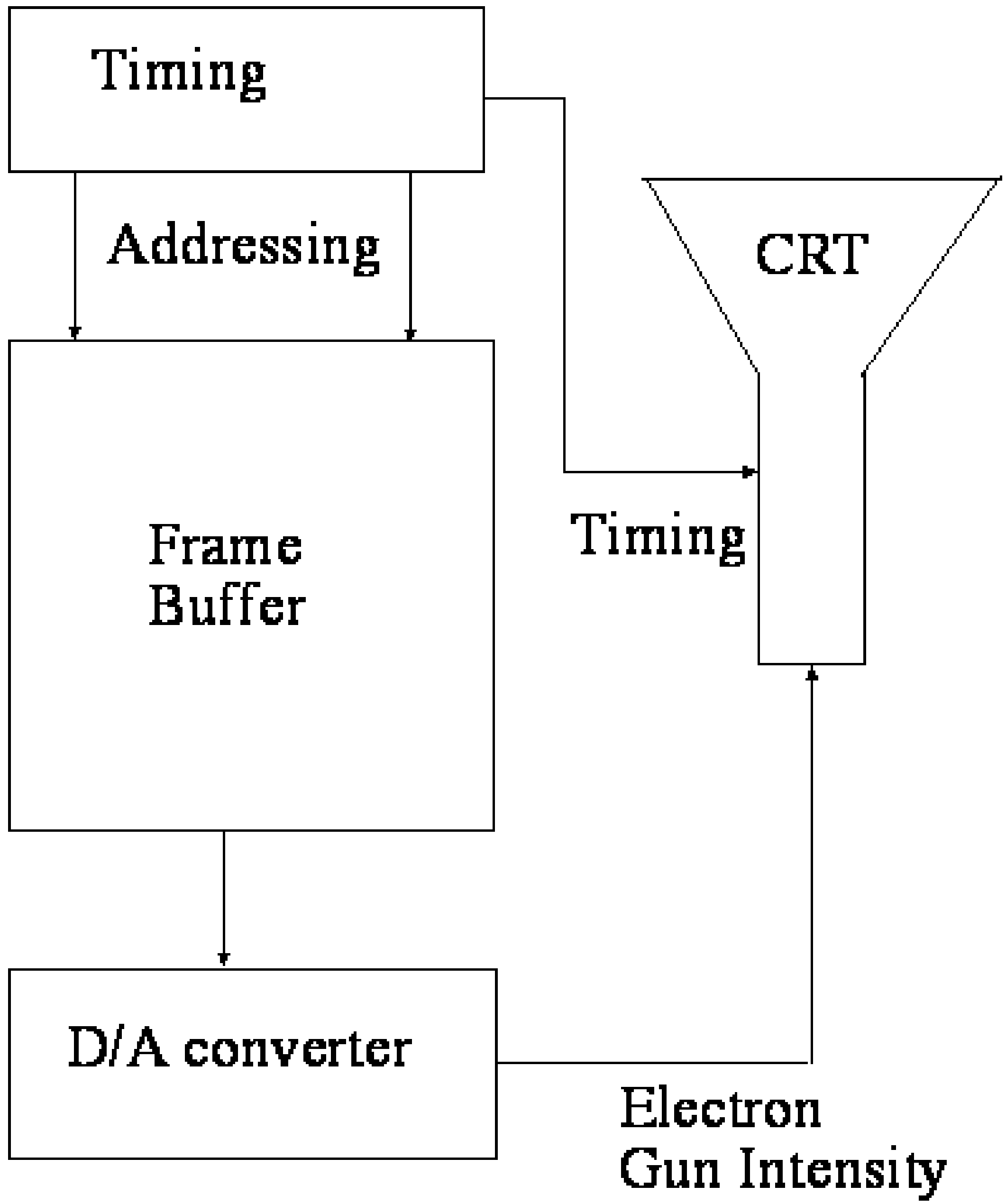


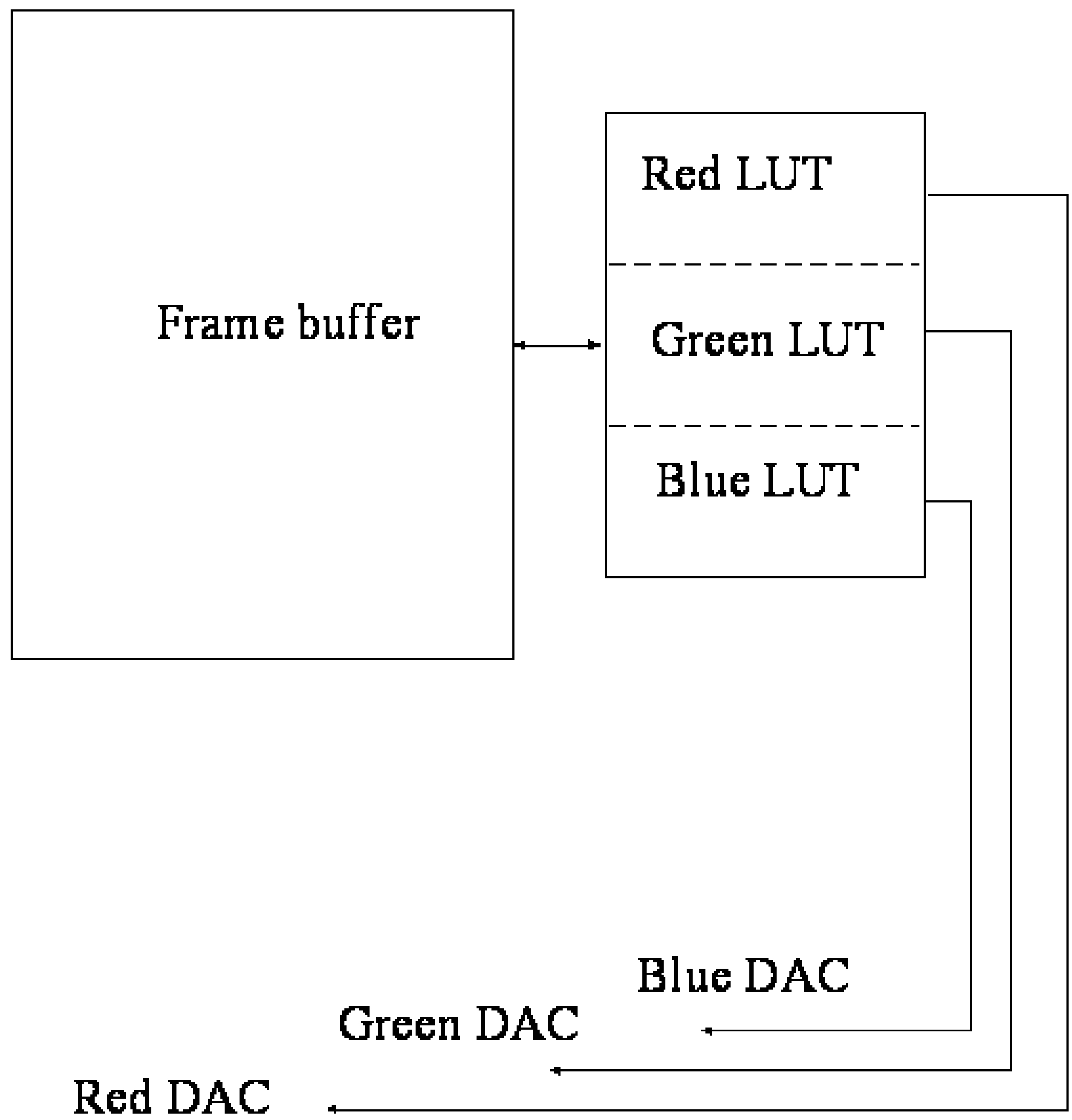
CRT Displays

- 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
- Raster displays refresh by scanning from top to bottom in left right order.
- Timing is used to make screen elements correspond to memory elements.

CRT Displays

- Typical refresh rate is 75 per second
- May have many phosphor dots corresponding to one memory element (old stuff), but more usually one per phosphor trio.
- Memory elements called pixels
- Refresh method creates architectural and *programming* issues (e.g. double buffering), defines “real time” in animation.

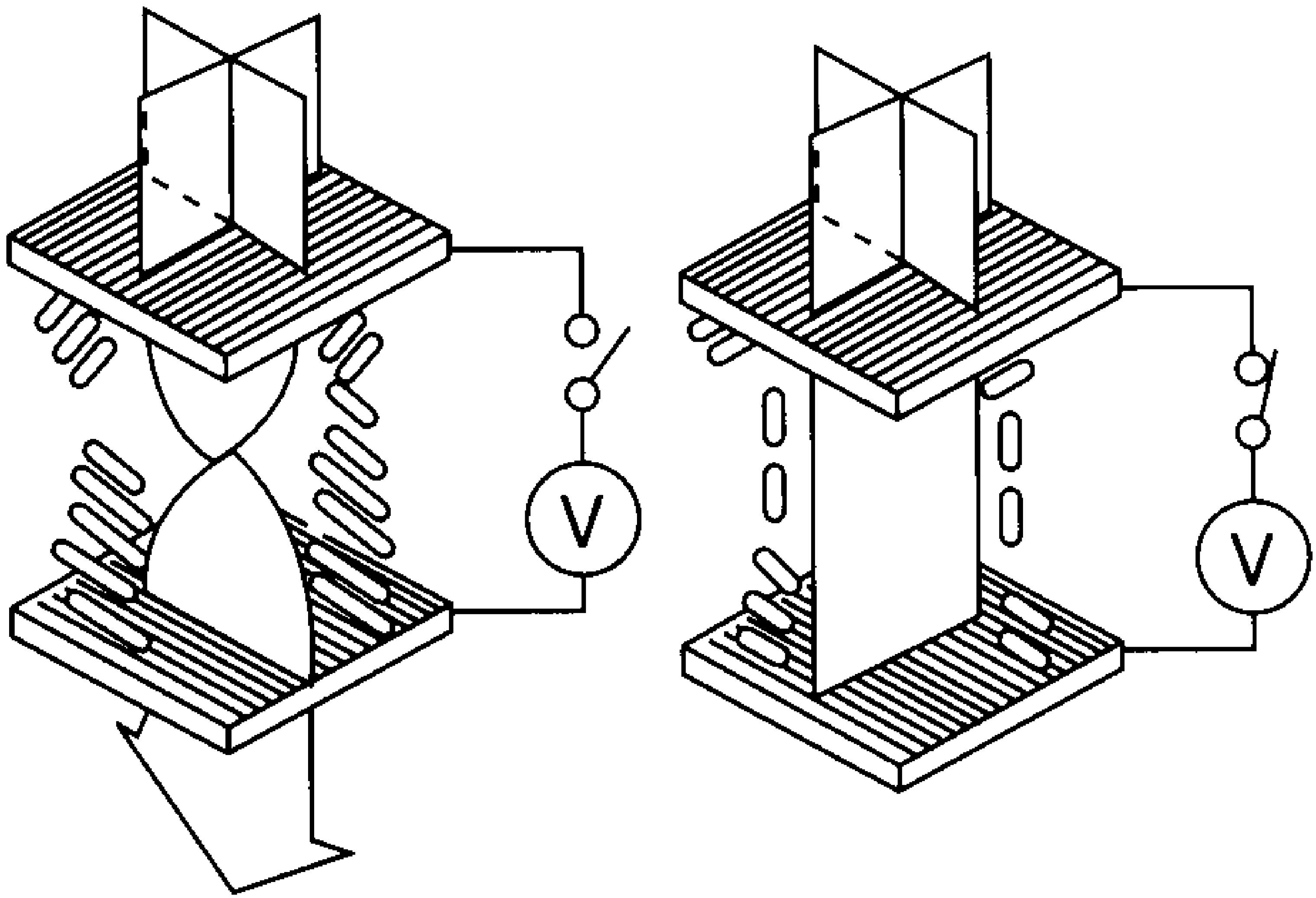

Timing
Addressing
CRT
Frame
Buffer
Timing
D/A converter
Electron
Gun Intensity


Frame buffer
Red LUT
Green LUT
Blue LUT
Blue DAC
Green DAC
Red DAC

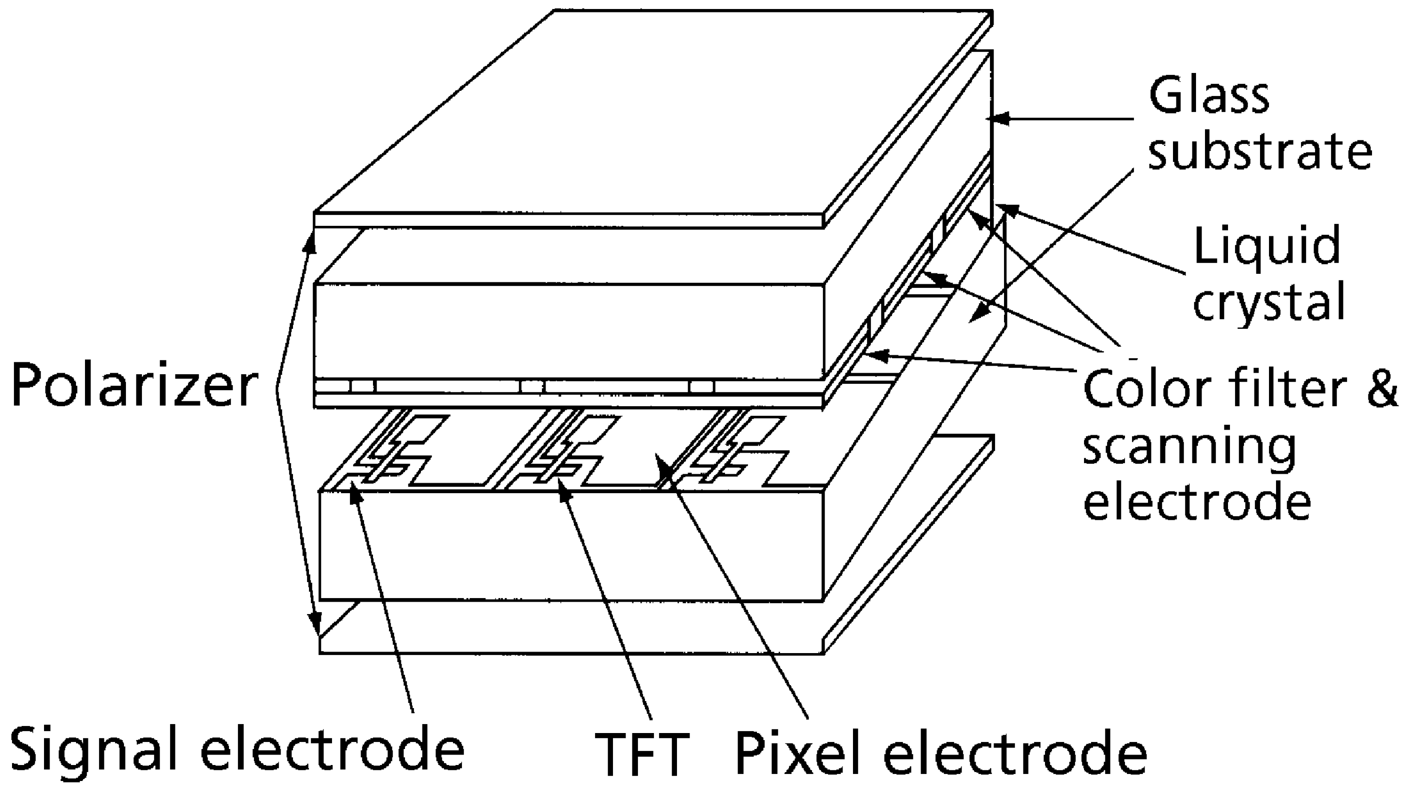
Flat Panel TFT* Displays

[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/fall05/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).

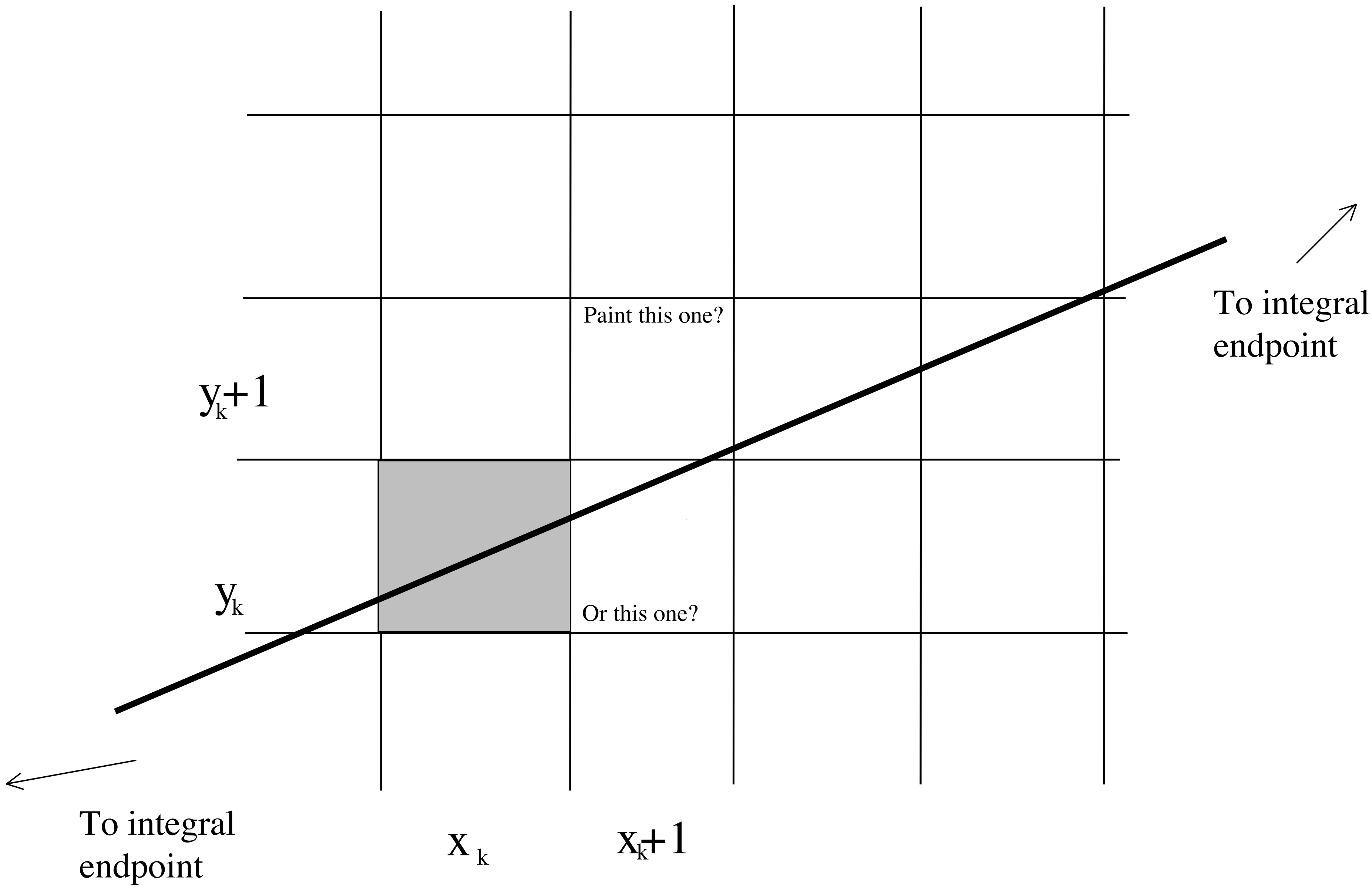
Displaying lines

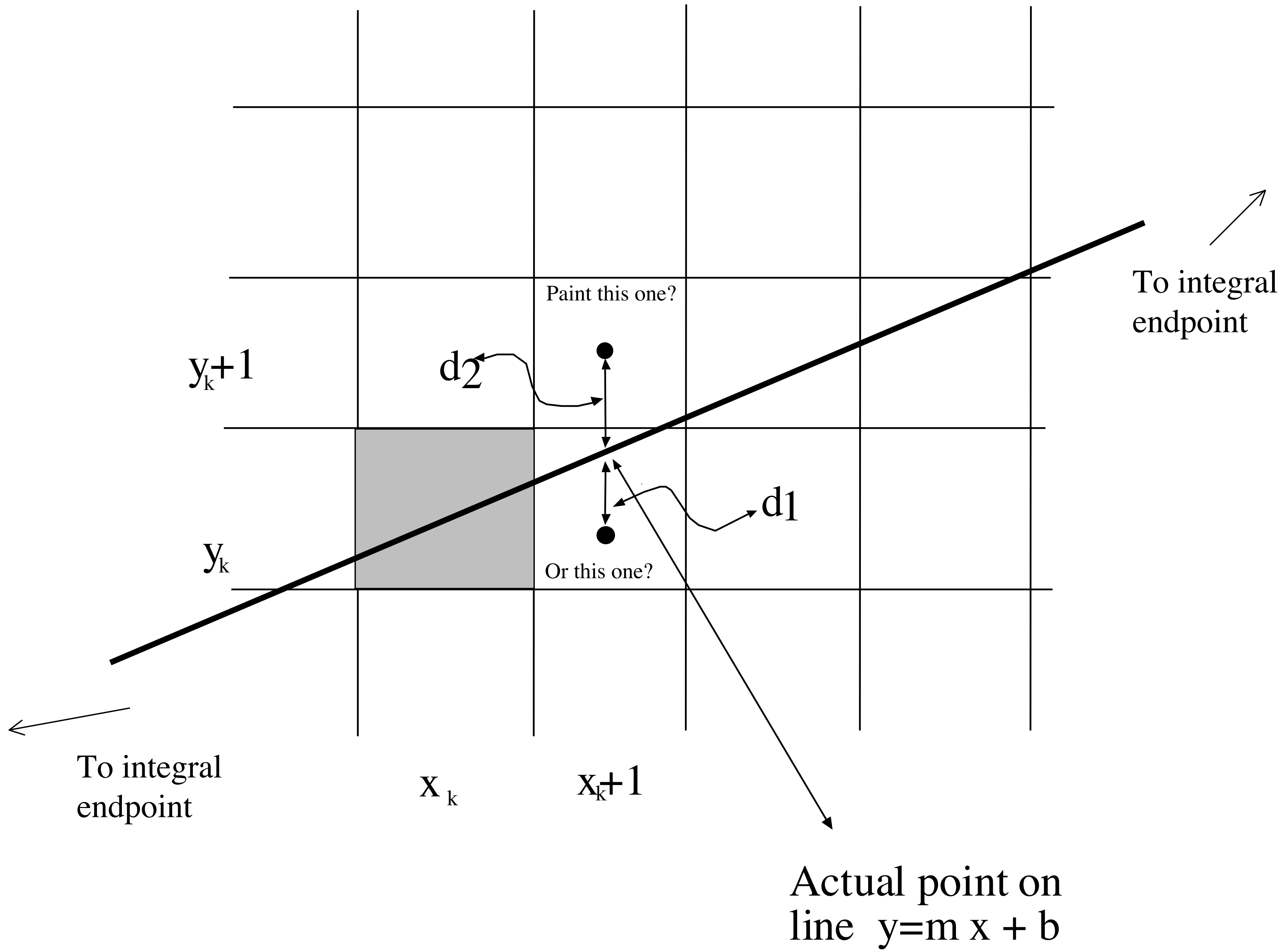
- Variety of naive (poor) algorithms:
  - step x, compute new y at each step by equation, rounding
  - step x, compute new y at each step by adding m to old y, rounding

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).


Paint this one?
y_k+1
y_k
Or this one?
To integral endpoint
To integral endpoint
x_k
x_k+1



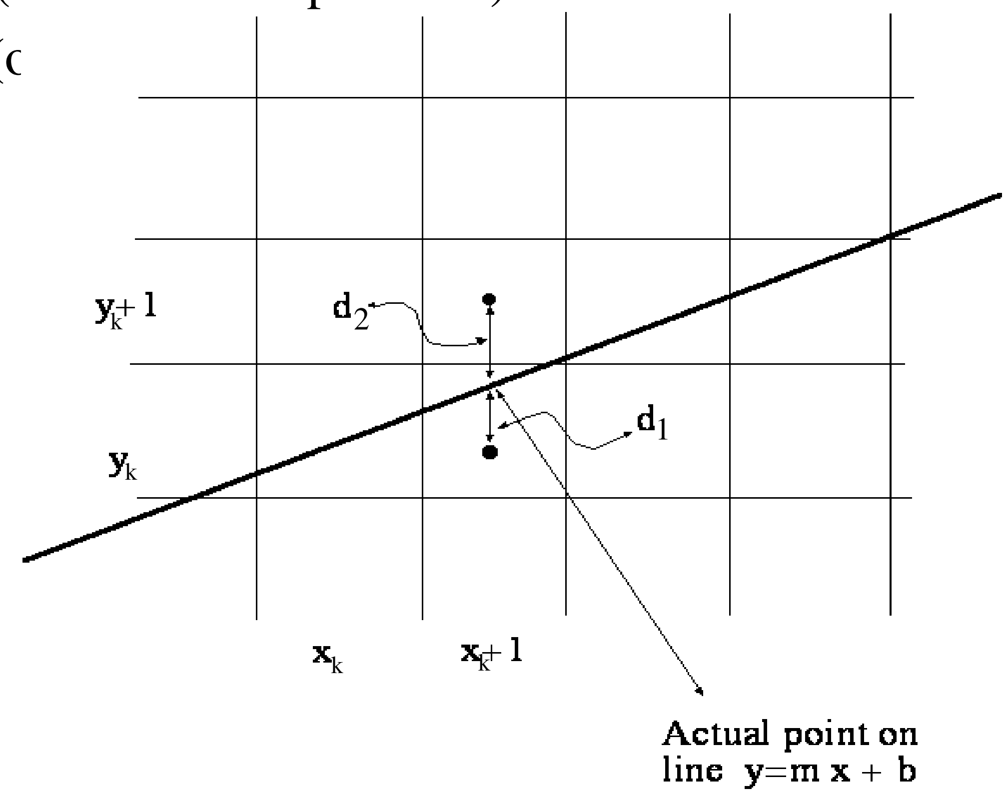
Paint this one?
y_k+1
d2
d1
y_k
Or this one?
To integral endpoint
To integral endpoint
x $_k$
x_k+1
Actual point on line y=m x + b

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 (c



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

$$d_1 = y - y_k \qquad \textit{and} \qquad d_2 = (y_k + 1) - y$$

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

$$\mathrm{d}_1 - \mathrm{d}_2 = 2m(x_k + 1) - 2y_k + 2b - 1$$

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.

$$\begin{aligned} p_k &= (\mathrm{d}_1 - \mathrm{d}_2)dx \\ &= (2m(x_k + 1) - 2y_k + 2b - 1)dx \\ &= 2(x_k + 1)dy - 2y_k(dx) + 2b(dx) - dx \\ &= 2(x_k)dy - 2y_k(dx) + \text{constant} \end{aligned}$$

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

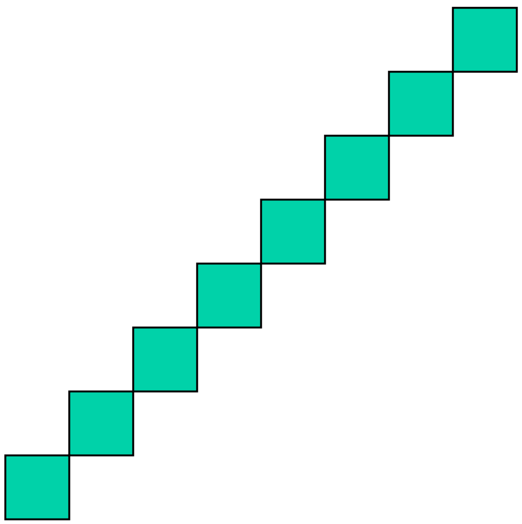
Bresenham algorithm

- $p_{k+1} = p_k + 2\,dy - 2\,dx\,(y_{k+1} - y_k)$
- 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.

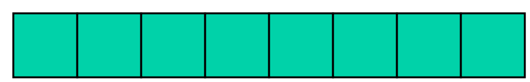
Issues

- 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).

Line drawing--simple line (Bresenham) brightness issues



8 pixels per 8*sqrt(2) length



8 pixels for 8 length
(Brighter)

Line drawing--discretization artifacts (often called aliasing)