

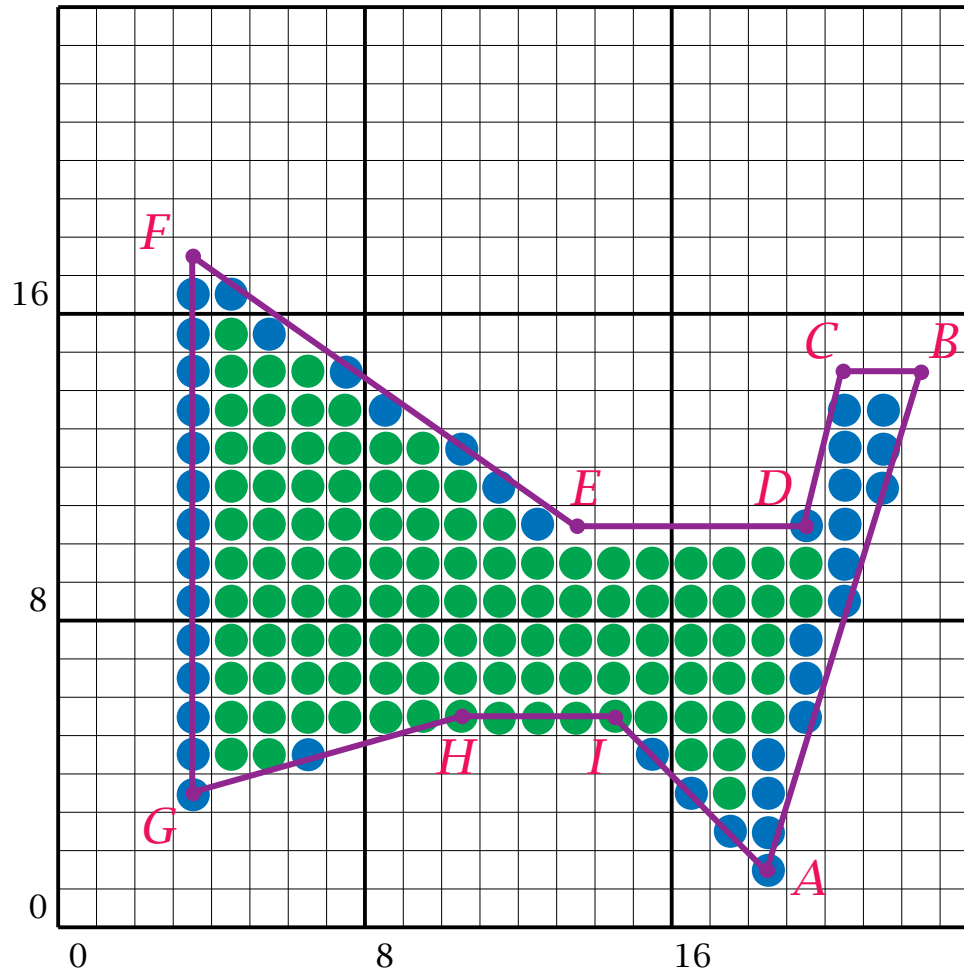
Scanline Fill Algorithm

- Terminology
- Generalities
- Scan-Line Polygon Fill Algorithm
- Boundary-Fill Algorithm
- Flood-Fill Algorithm

Interior Pixel Convention

- Pixels that lie in the interior of a polygon belong to that polygon, and can be filled.
- Pixels that lie on a **left** boundary or a **lower** boundary of a polygon belong to that polygon, and can be filled.
- Pixels that have centers that fall outside the polygon, are said to be **exterior** and should **not** be drawn.
- Pixels that lie on a **right** or an **upper** boundary do **not** belong to that polygon, and **should not** be drawn.

Example



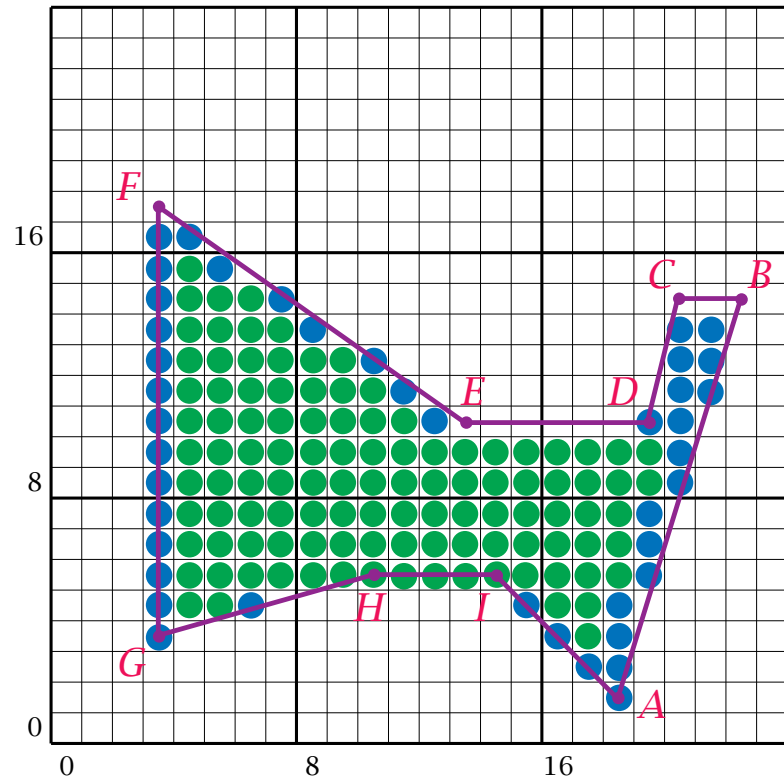
The scan extrema (blue) and interior (green) pixels that are obtained using our interior pixel convention for the given polygon (purple).

Basic Scan-Fill Algorithm (Foley et al., pp. 92–99)

1. For each non-horizontal edge of the polygon boundary identify the upper and lower endpoints, (x_l, y_l) and (x_u, y_u) , such that $y_u > y_l$, and construct a record for each that contains
 - y_u , the y -coordinate at the upper endpoint
 - $x = x_l$, the current x -intersection
 - $w = 1/m = (x_u - x_l)/(y_u - y_l)$, the reciprocal of the slope of the edge
2. Set the **AET** (the active edge table) to be empty.
3. Apply a bucket sort algorithm to sort the edges using the y_l as the primary key, and x_l as the secondary, and w as the tertiary. N.B., Each bucket contains a list. The set of buckets is called the **ET** (edge table):

Example – Buckets

23 ϕ
 \vdots
 11 ϕ
 10 $\{\mathcal{Y}_F, \mathcal{X}_E, w_{EF}\} \rightarrow \{\mathcal{Y}_C, \mathcal{X}_D, w_{DC}\}$
 9 ϕ
 \vdots
 4 ϕ
 3 $\{\mathcal{Y}_F, \mathcal{X}_G, w_{GF}\} \rightarrow \{\mathcal{Y}_H, \mathcal{X}_G, w_{GH}\}$
 2 ϕ
 1 $\{\mathcal{Y}_I, \mathcal{X}_A, w_{AI}\} \rightarrow \{\mathcal{Y}_B, \mathcal{X}_A, w_{AB}\}$
 0 ϕ

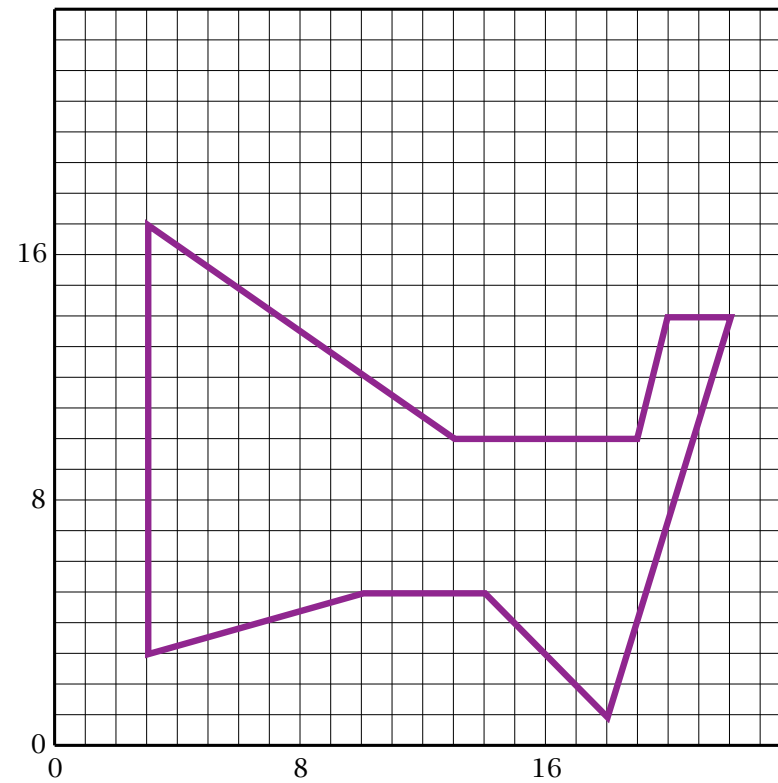


Basic Scan-Fill Algorithm (cont.)

4. Set y equal to the smallest index in the ET that has a non empty bucket.
5. Repeat until the ET and the AET are empty:
 - (a) Move any edges from bucket y in the ET to the AET.
 - (b) Remove any edges from the AET that have a y_u equal to y .
 - (c) Sort the AET according to x .
 - (d) Fill in the requisite pixels between the even and odd adjacent pairs of intersections in the AET: round up, $\lceil x \rceil$ the x -coordinate of “left” intersections, round down, $\lfloor x - 1 \rfloor$ that of the “right” intersections.
 - (e) Increment y by one.
 - (f) Update $x \leftarrow x + w$ for every nonvertical edge in the AET.

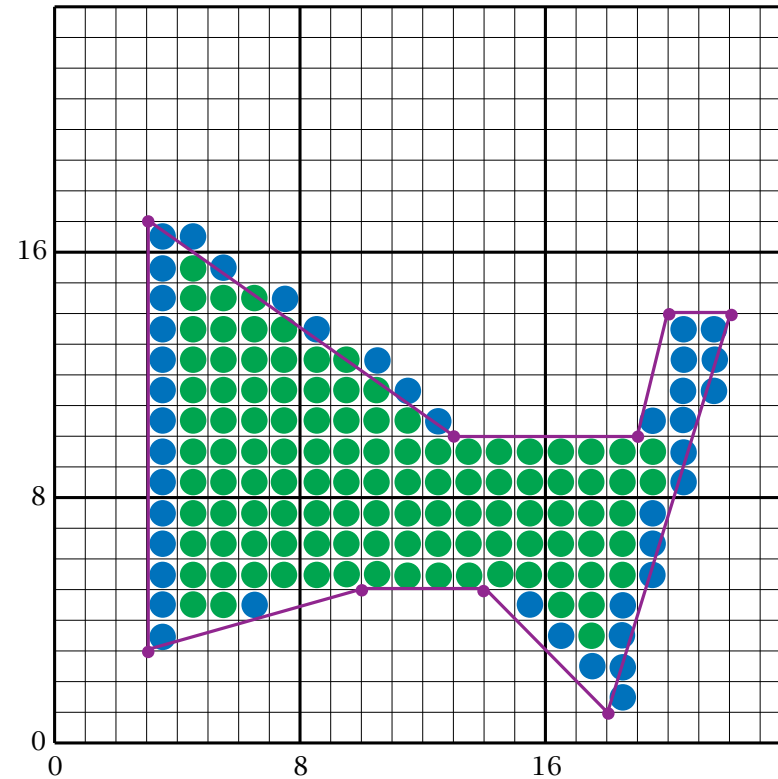
Screen Grid Coordinates

See page 114 of Hearn and Baker.



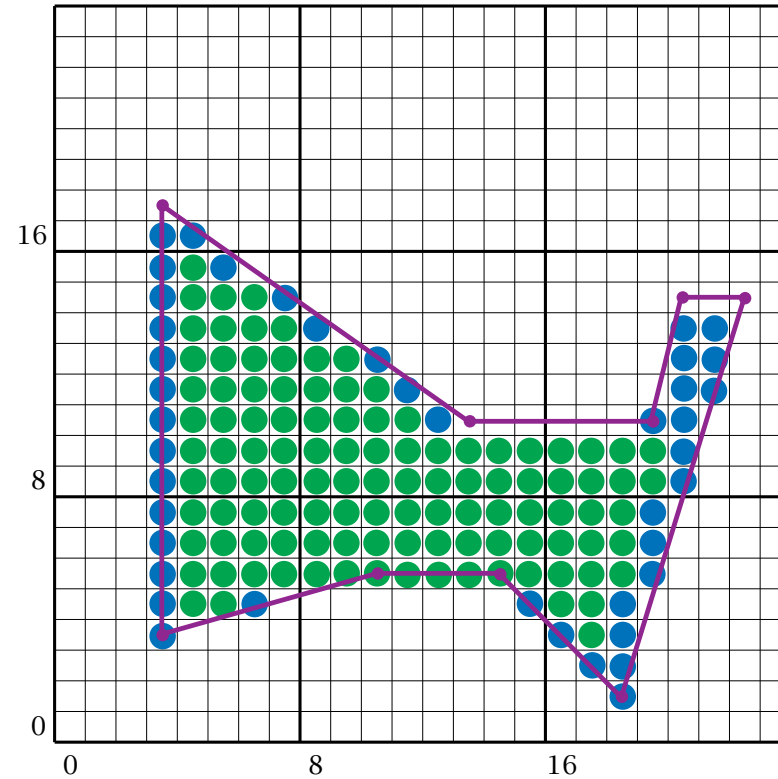
Integer coordinates correspond to the grid intersections: rounding can now be implemented via truncation.

Screen Grid Coordinates



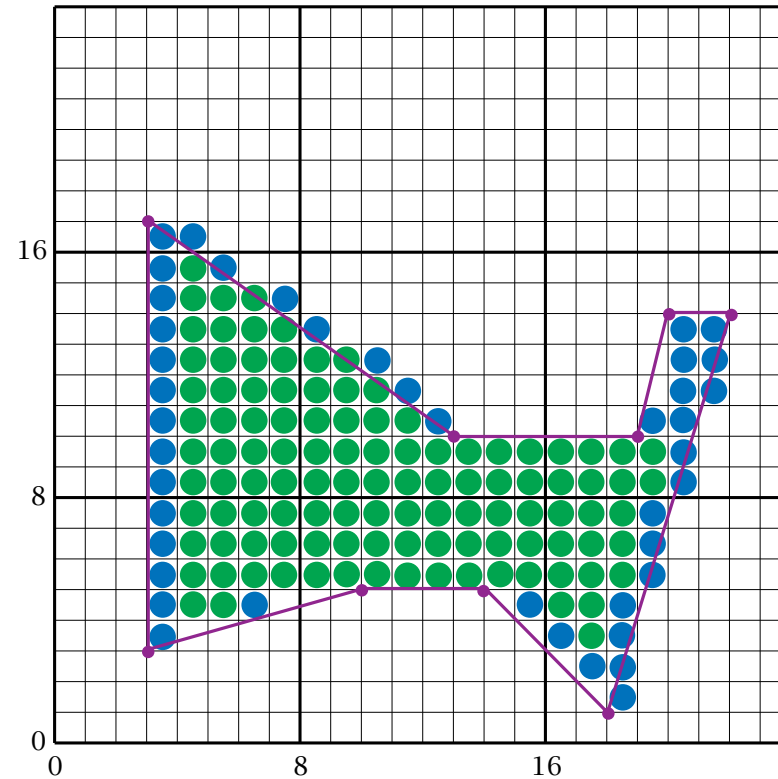
Integer coordinates correspond to the **grid intersections**: rounding can now be implemented via truncation. (See page 114 of Hearn and Baker.)

Pixel Center Coordinates



Integer coordinates correspond to the **pixel centers**.

Screen Grid Coordinates



Integer coordinates correspond to the **grid intersections**: rounding can now be implemented via truncation. (See page 114 of Hearn and Baker.)

Scan-Fill Algorithm — The Code

The edge data structure

```
typedef struct tEdge {  
    int yUpper;  
    float xIntersect, dxPerScan;  
    struct tEdge * next;  
} Edge;
```

```
typedef struct tdcPt {  
    int x;  
    int y;  
} dcPt;
```

Scan-Fill Algorithm — The Code (cont.)

```
void scanFill (int cnt, dcPt * pts) {  
    Edge * edges[WINDOW_HEIGHT], * active;  
    int i, scan;  
  
    for (i=0; i<WINDOW_HEIGHT; i++) {  
        edges[i] = (Edge *) malloc (sizeof (Edge));  
        edges[i]->next = NULL;  
    }  
    buildEdgeList (cnt, pts, edges);  
    active = (Edge *) malloc (sizeof (Edge));  
    active->next = NULL;
```

```
for (scan=0; scan<WINDOW_HEIGHT; scan++) {  
    buildActiveList (scan, active, edges);  
    if (active->next) {  
        fillScan (scan, active);  
        updateActiveList (scan, active);  
        resortActiveList (active);  
    }  
}  
/* Free edge records that have been malloc'ed ... */  
}
```

Scan-Fill Algorithm — The Code (cont.)

```
void scanFill (int cnt, dcPt * pts) {  
    Edge * edges[WINDOW_HEIGHT], * active;  
    int i, scan;  
  
    for (i=0; i<WINDOW_HEIGHT; i++) {  
        edges[i] = (Edge *) malloc (sizeof (Edge));  
        edges[i]->next = NULL;  
    }  
    buildEdgeList (cnt, pts, edges);  
    active = (Edge *) malloc (sizeof (Edge));  
    active->next = NULL;
```

```
for (scan=0; scan<WINDOW_HEIGHT; scan++) {  
    buildActiveList (scan, active, edges);  
    if (active->next) {  
        fillScan (scan, active);  
        updateActiveList (scan, active);  
        resortActiveList (active);  
    }  
}  
/* Free edge records that have been malloc'ed ... */  
}
```

Scan-Fill Algorithm — The Code (cont.)

```
void buildEdgeList (int cnt, dcPt * pts, Edge * edges[]) {
    Edge * edge;
    dcPt v1, v2;
    int i, yPrev = pts[cnt - 2].y;

    v1.x = pts[cnt-1].x; v1.y = pts[cnt-1].y;
    for (i=0; i<cnt; i++) {
        v2 = pts[i];
        if (v1.y != v2.y) {                                /* nonhorizontal line */
            edge = (Edge *) malloc (sizeof (Edge));
            if (v1.y < v2.y)                                /* up-going edge      */
                makeEdgeRec (v1, v2, yNext (i, cnt, pts), edge, edges);
            else                                             /* down-going edge    */
                makeEdgeRec (v2, v1, yPrev, edge, edges);
        }
    }
```



```

        yPrev = v1.y;
        v1 = v2;
    }
}
/* For an index, return y-coordinate of next nonhorizontal line */
int yNext (int k, int cnt, dcPt * pts) {
    int j;
    if ((k+1) > (cnt-1))
        j = 0;
    else
        j = k + 1;
    while (pts[k].y == pts[j].y)
        if ((j+1) > (cnt-1))
            j = 0;
        else
            j++;
    return (pts[j].y);
}

```

Scan-Fill Algorithm — The Code (cont.)

```
void buildEdgeList (int cnt, dcPt * pts, Edge * edges[]) {
    Edge * edge;
    dcPt v1, v2;
    int i, yPrev = pts[cnt - 2].y;

    v1.x = pts[cnt-1].x; v1.y = pts[cnt-1].y;
    for (i=0; i<cnt; i++) {
        v2 = pts[i];
        if (v1.y != v2.y) {                                /* nonhorizontal line */
            edge = (Edge *) malloc (sizeof (Edge));
            if (v1.y < v2.y)                                /* up-going edge      */
                makeEdgeRec (v1, v2, yNext (i, cnt, pts), edge, edges);
            else                                             /* down-going edge    */
                makeEdgeRec (v2, v1, yPrev, edge, edges);
        }
    }
```

Scan-Fill Algorithm — The Code (cont.)

```
/* Store lower-y coordinate and inverse slope for each edge. Adjust
   and store upper-y coordinate for edges that are the lower member
   of a monotonically increasing or decreasing pair of edges */
void makeEdgeRec
    (dcPt lower, dcPt upper, int yComp, Edge * edge, Edge * edges[])
{
    edge->dxPerScan =
        (float) (upper.x - lower.x) / (upper.y - lower.y);
    edge->xIntersect = lower.x;
    if (upper.y < yComp)
        edge->yUpper = upper.y - 1;
    else
        edge->yUpper = upper.y;
    insertEdge (edges[lower.y], edge);
}
```

Scan-Fill Algorithm — The Code (cont.)

```
/* Inserts edge into list in order of increasing xIntersect field. */
void insertEdge (Edge * list, Edge * edge) {
    Edge * p, * q = list;

    p = q->next;
    while (p != NULL) {
        if (edge->xIntersect < p->xIntersect)
            p = NULL;
        else {
            q = p;
            p = p->next;
        }
    }
    edge->next = q->next;
    q->next = edge;
}
```

Scan-Fill Algorithm — The Code (cont.)

```
void scanFill (int cnt, dcPt * pts) {  
    Edge * edges[WINDOW_HEIGHT], * active;  
    int i, scan;  
  
    for (i=0; i<WINDOW_HEIGHT; i++) {  
        edges[i] = (Edge *) malloc (sizeof (Edge));  
        edges[i]->next = NULL;  
    }  
    buildEdgeList (cnt, pts, edges);  
    active = (Edge *) malloc (sizeof (Edge));  
    active->next = NULL;
```

```
for (scan=0; scan<WINDOW_HEIGHT; scan++) {  
    buildActiveList (scan, active, edges);  
    if (active->next) {  
        fillScan (scan, active);  
        updateActiveList (scan, active);  
        resortActiveList (active);  
    }  
}  
/* Free edge records that have been malloc'ed ... */  
}
```

Scan-Fill Algorithm — The Code (cont.)

```
void buildActiveList (int scan, Edge * active, Edge * edges[])
{
    Edge * p, * q;

    p = edges[scan]->next;
    while (p) {
        q = p->next;
        insertEdge (active, p);
        p = q;
    }
}
```

Scan-Fill Algorithm — The Code (cont.)

```
void scanFill (int cnt, dcPt * pts) {  
    Edge * edges[WINDOW_HEIGHT], * active;  
    int i, scan;  
  
    for (i=0; i<WINDOW_HEIGHT; i++) {  
        edges[i] = (Edge *) malloc (sizeof (Edge));  
        edges[i]->next = NULL;  
    }  
    buildEdgeList (cnt, pts, edges);  
    active = (Edge *) malloc (sizeof (Edge));  
    active->next = NULL;
```



```
for (scan=0; scan<WINDOW_HEIGHT; scan++) {  
    buildActiveList (scan, active, edges);  
    if (active->next) {  
        fillScan (scan, active);  
        updateActiveList (scan, active);  
        resortActiveList (active);  
    }  
}  
/* Free edge records that have been malloc'ed ... */  
}
```

Scan-Fill Algorithm — The Code (cont.)

```
void fillScan (int scan, Edge * active) {  
    Edge * p1, * p2;  
    int i;  
  
    p1 = active->next;  
    while (p1) {  
        p2 = p1->next;  
        for (i=p1->xIntersect; i<p2->xIntersect; i++)  
            setPixel ((int) i, scan);  
        p1 = p2->next;  
    }  
}
```

Scan-Fill Algorithm — The Code (cont.)

```
void scanFill (int cnt, dcPt * pts) {  
    Edge * edges[WINDOW_HEIGHT], * active;  
    int i, scan;  
  
    for (i=0; i<WINDOW_HEIGHT; i++) {  
        edges[i] = (Edge *) malloc (sizeof (Edge));  
        edges[i]->next = NULL;  
    }  
    buildEdgeList (cnt, pts, edges);  
    active = (Edge *) malloc (sizeof (Edge));  
    active->next = NULL;
```

```
for (scan=0; scan<WINDOW_HEIGHT; scan++) {  
    buildActiveList (scan, active, edges);  
    if (active->next) {  
        fillScan (scan, active);  
        updateActiveList (scan, active);  
        resortActiveList (active);  
    }  
}  
/* Free edge records that have been malloc'ed ... */  
}
```

Scan-Fill Algorithm — The Code (cont.)

```
/* Delete completed edges. Update 'xIntersect' field for others */
void updateActiveList (int scan, Edge * active) {
    Edge * q = active, * p = active->next;

    while (p)
        if (scan >= p->yUpper) {
            p = p->next;
            deleteAfter (q);
        } else {
            p->xIntersect = p->xIntersect + p->dxPerScan;
            q = p;
            p = p->next;
        }
}
```

```
void deleteAfter (Edge * q) {  
    Edge * p = q->next;  
  
    q->next = p->next;  
    free (p);  
}
```

Scan-Fill Algorithm — The Code (cont.)

```
void scanFill (int cnt, dcPt * pts) {  
    Edge * edges[WINDOW_HEIGHT], * active;  
    int i, scan;  
  
    for (i=0; i<WINDOW_HEIGHT; i++) {  
        edges[i] = (Edge *) malloc (sizeof (Edge));  
        edges[i]->next = NULL;  
    }  
    buildEdgeList (cnt, pts, edges);  
    active = (Edge *) malloc (sizeof (Edge));  
    active->next = NULL;
```

```
for (scan=0; scan<WINDOW_HEIGHT; scan++) {  
    buildActiveList (scan, active, edges);  
    if (active->next) {  
        fillScan (scan, active);  
        updateActiveList (scan, active);  
        resortActiveList (active);  
    }  
}  
/* Free edge records that have been malloc'ed ... */  
}
```


Scan-Fill Algorithm — The Code (cont.)

```
void resortActiveList (Edge * active) {  
    Edge * q, * p = active->next;  
  
    active->next = NULL;  
    while (p) {  
        q = p->next;  
        insertEdge (active, p);  
        p = q;  
    }  
}
```

Remarks

- The intersection update can be implemented more efficiently using integer arithmetic. If $m > 1$, for example:

```
int x = xMin;
int numerator    = xMax - yMin;
int denominator = yMax - yMin;
int counter = denominator;
...
/* When updating the edge intersections */
counter += numerator;
if (counter > denominator) {
    x++;
    counter -= denominator;
}
...
```

Remarks (cont.)

- The fill can be a periodic pattern using either

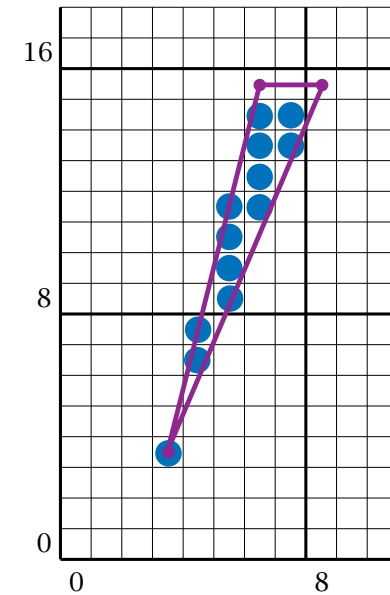
```
if (pattern[x % M][y % N])  
    setPixel(x, y);
```

or if setPixel takes a value for a third argument:

```
setPixel(x, y, pattern[x % M][y % N]);
```

Problems

- What happens if a vertex is shared by more than one polygon, e.g. three triangles?
- What happens if the polygon intersects itself?
- What happens for a “sliver”?



A sliver

Attributes

1. dashed lines
2. line thickness
 - (a) parallel lines
 - (b) vertical or horizontal spans
 - (c) rectangular pens
 - (d) scan-line fill
3. antialiasing

Line Endcaps



Butt Cap



Round Cap



Projecting
Square Cap

Line Joins

