Raster Graphics

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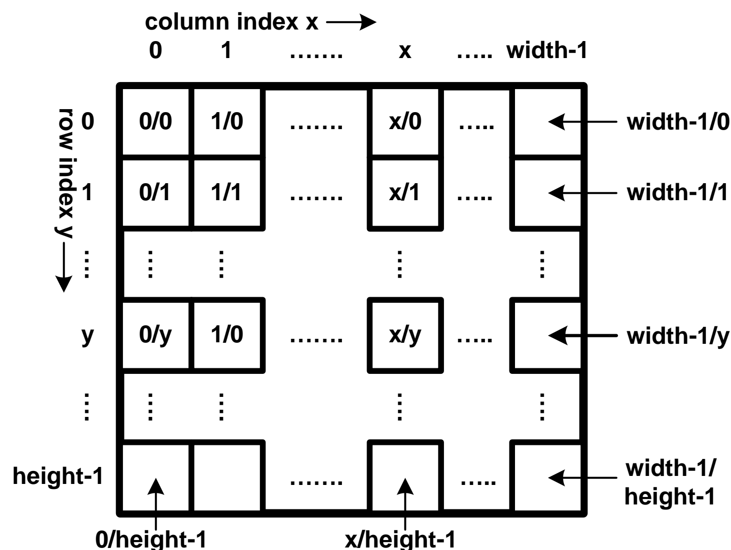
Why Raster Graphics ?

Until approx. 1980 computer graphics was only and exclusively vector graphics. The computer community was inspired of the aesthetics of the fast line movements of the vector displays, which were much more elegant than the thick horizontal TV lines and it appeared absurdly that TV could ever replace the elegant vector pictures of the computers.
One did not feel as lack that the vector displays could not fill surfaces and that there was just one color.
On the other hand TV receivers were cheap and popular, vector displays however expensive and exotic.
Therefore the computer industry had to use TV to conquer a mass-market. It had to connect a linearly addressed digital machine (the computer) with a surface covering, matrix oriented, analog CRT = TV.
This was the birth of an important computer extension, the graphic board, consisting of:
1) fast RAM to store the raster matrix (=digital image memory)
2) fast address generator for the matrix synchronously to the analog H- and V-Sync signals (=video controller)
3) fast digital-to-analog converter (=DAC), which has to convert the matrix figures
into analog brightness + color signals
The first raster graphics looked deterring: Mickey Mouse was composed of flickering and clumsy pixels and had roughly jagged ears. The fusion of computer and TV was first a failure. It became clear that useful raster graphics need much better technology than TV i.e. approx. double resolution of space and time.
Under this pressure two new (at first pretty expensive) products emerged:
the computer monitor and the graphics board.
Nowadays raster graphics rules the desk top although it has neither thin lines nor curves, which have to be simulated by stairs. It carries enormous redundancy and it's very difficult to write pure raster graphics programs.
This is the reason why vector graphics will never die. We desperately need them as back ground data behind all artificial raster graphics (not behind pure photos and videos).

The Raster Matrix

is a rectangular arrangement of integers (types `Byte`, `UInt16`, `UInt32` oder `Color`)
in `width` columns and `height` rows.

```
column index: x, with 0 <= x < width
row    index: y, with 0 <= y < height.
```



Example: `Homunculus` = bright person on dark background
no. of columns = `width = 9`,
no. of rows = `height = 10`

```
0 0 0 9 9 9 0 0 0
0 0 0 9 3 9 0 0 0      [4,1] = mouth
0 0 0 9 9 9 0 0 0
0 0 0 0 9 0 0 0 0      [4,3] = neck
3 4 5 9 9 9 5 4 3      [0,4] and [8,4] = hands
0 0 0 9 8 9 0 0 0      [4,5] = navel
0 0 0 9 9 9 0 0 0
0 0 0 6 0 6 0 0 0
0 0 0 5 0 5 0 0 0
0 0 0 5 0 5 0 0 0      [3,9] and [5,9] = feet
```

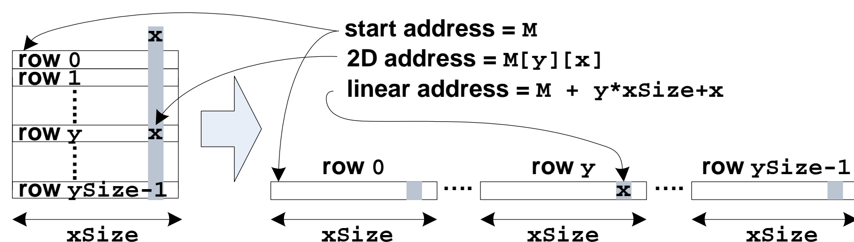
Examples of the definition of a raster matrix `M` with 32-Bit color pixels = ARGB-pixel:

```
C++  as array : int M[height][width];
Java as array : int[][] M = new int[height][width];
C#   as array : Color[,] M = new Color[height, width];
C#   as bitmap: Bitmap M = new Bitmap( width, height, PixelFormat.Format32bppArgb );
```

Confusing, but important: All computer languages require to write first the `y`-coordinate **in front of** the `x`-coordinate in 2D raster arrays. Reason: In computers there are no such things as a matrix.
Computers just have a linearly addressed memory space and map any matrix into this space.
When you want to map the first line (`y = 0`) first, then you have to write `y` first.
Otherwise the computer maps differently: It stores the fist column first, which is contrary to any intuition.
Consequence: If you want to blacken the mouth of the Homunculus, then write:

```
C++  as array : Homunculus[1][4] = 0;
Java as array : Homunculus[1][4] = 0;
C#   as array : Homunculus[1,4] = Color.Black;
C#   as bitmap: Homunculus.SetPixel( 4, 1, Color.Black );
```

Linear addressing:
A matrix is a pure language construct, because computers know only a linear address schema. Imagine the `[y][x]`-matrix as a chest of drawers. Inside the main memory the drawers are put on the floor side by side.



In main memory: At first row `0`, then row `1` etc. until row `height-1`. If you want a pixel `M[y][x]` from inside, the computer has to find the linear address `M + y * width + x`.
You pay the comfortable access `M[y][x]` with 2 additions and a multiplication.

Consequence: With millions of pixels the matrix addressing is slow.
Better: Use pointers for fast operations on images.
Example: Slow code to clear a matrix `M[height][width]`:

```
for ( y=0; y < height; y++ )
  for ( x=0; x < width; x++ )
    M[y][x] = 0;
```

Example: Fast code to clear a matrix `M[height][width]`:

```
int* pointer = M;
for ( i=0; i < width*height; i++ ) *pointer++ = 0;
```

Example: Very fast code to clear a matrix `M[height][width]`:

```
for ( int* pointer = M; pointer < M + width*height; ) *pointer++ = 0;
```

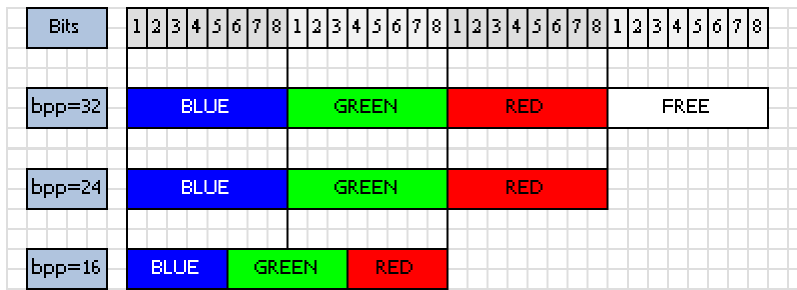
Pixel

= acronym for "Picture Element" denominates an element of the raster matrix.
A matrix accommodates just one type of pixel, but many types = pixel formats exist.
Samples:

1bppIndexed	1 bit per pixel with indexed color. Requires a LUT with 2 colors in it. For binary images.
4bppIndexed	4 bits per pixel, indexed. Requires a LUT with 3x16 palette entries.
8bppIndexed	8 bits per pixel, indexed. Requires a LUT with 3x256 palette entries.
16bppGrayScale	16 bits per pixel. The color information specifies 65536 shades of gray.
16bppRgb555	16 bits per pixel; 5 bits each are used for the red, green, and blue components. The remaining bit is not used.
24bppRgb	24 bits per pixel; 8 bits each are used for the red, green, and blue components.
32bppArgb	32 bits per pixel; 8 bits each are used for the alpha, red, green, and blue components.
32bppRgb	32 bits per pixel; 8 bits each are used for the red, green, and blue components. The remaining 8 bits are not used.
64bppArgb	64 bits per pixel; 16 bits each are used for the alpha, red, green, and blue components.

False Color Image = generic term for the first 3 formats 1bppIndexed, 4bppIndexed und 8bppIndexed.
Gray Value Image = 16bppGrayScale.
True Color Image = generic term for all other formats.

Usual pixel formats are:
1bppIndexed → for binary images and b/w-printers, being quite space saving.
32bppRgb → for color photos, because 32bpp fits to the 32-bit memory and 32-bit addressing of PCs.



3 Memory Layouts of a Pixel:

32bppRgb,

24bppRgb und

16bppRgb555

Imge by Thomas Schedl

Comparison Vector ↔ Raster Graphics

Main differences

	Vector Graphics	**Raster Graphics**
main data structure	Polygon: `PointF[] p = new PointF[n];`	Matrix: `Bitmap bmp = new Bitmap( width, height, PixelFormat.Format32bppRgb );`
other data structures	rectangle, ellipse, Bézier curve, spline, mesh	RLC, Crack Code, MPEG
file formats	WMF, PostScript, XAML, PDF, Flash, X	BMP, GIF, JPEG, MPEG, PNG, TIFF, AVI
memory consumption	minimal: `n*sizeof(PointF)`	enormous: `width*height*sizeof(Color)`
capability to draw lines	very good	with CRTs horizontal only , with flat panels horizontal and vertical, but never oblique
capability to fill areas	hatching only	good, but with jagged borders
capability to writing	too lean, but good for scalable outlinings = one font for all sizes = TrueType	good, but with jagged borders, needs a font for every size
capability to pictures of the real world	null, outlines only	good = TV
capability to produce colors	CRTs almost ever monochrome, maximal 2 colors possible	good: almost ever RGB
produced by	always a human being	almost always a machine: a) real world digital images (camera, scanner) b) rendered from vector graphics (graphic board)
mathematics	all laws of analytic geometry apply	new digital geometry necessary
flickering, refresh	flickers only when polygons have too many vertices	independent from picture content
ability to drawings	CAD, Comics	texts, images
volatile output	RA-CRT = vector display	line-CRT, flat panel display = raster display
durable output	plotter	printer

Comparison of the operations scroll, zoom, rot

scroll, zoom, rot of polygon `p0` → `p1`	**scroll, zoom, rot of bitmap `bmp0` → `bmp1`**
all `x, y` are floats	all `x, y` are integers
steplessly	only integer steps
always highly precise	nearly always with rounding errors
forward transformation from `p0` to `p1`: transform each vertex from `p0` to `p1`	back transformation from `bmp1` to `bmp0`: replace each `bmp1`-pixel by a pixel from `bmp0`
there is no image border	big problem: losses by clipping
completly reversible	operations hardly ever reversible
operations are cascadeable	operations must always start from the original `bmp0`
`p0` can be overwritten by `p1`	normally `bmp0` must be preserved, do not overwrite by `bmp1` !

Code comparison of scroll (translations: float dx, float dy)

Vector-Scroll of Polygon `p0` → `p1`	Raster-Scroll of Bitmap `bmp0` → `bmp1`

`for all vertices 0 <= i < n`
`{ p1[i].x = p0[i].x + dx;`
`  p1[i].y = p0[i].y + dy;`
`}`
	`int idx = Convert.ToInt32( dx );`
	`int idy = Convert.ToInt32( dy );`
	`for ( int y1=0; y1 < bmp1.Height; y1++ )`
	`{ int y0 = y1 - idy;`
	`  if ( y0 < 0 || y0 >= bmp0.Height ) continue; //outside`
	`  for ( int x1=0; x1 < bmp1.Width; x1++ )`
	`  { int x0 = x1 - idx;`
	`    if ( x0 < 0 || x0 >= bmp0.Width ) continue; //outside`
	`    Color color = bmp0.GetPixel( x0, y0 );`
	`    bmp1.SetPixel( x1, y1, color );`
	`  }`
	`}`

Code comparison of Zoom (scalings: float zoomx, float zoomy)
Center of zoom = origin of the coordinates

Vector-Zoom of Polygon `p0` → `p1`	Raster-Zoom von Bitmap `bmp0` → `bmp1`

`//center (0/0)`
`for all vertices 0 <= i < n`
`{ p1[i].x = p0[i].x * zoomx;`
`  p1[i].y = p0[i].y * zoomy;`
`}`
	`for ( int y1=0; y1 < bmp1.Height; y1++ )`
	`{ int y0 = Convert.ToInt32( y1 / zoomy );`
	`  if ( y0 < 0 || y0 >= bmp0.Height ) continue; //outside`
	`  for ( int x1=0; x1 < bmp1.Width; x1++ )`
	`  { int x0 = Convert.ToInt32( x1 / zoomx );`
	`    if ( x0 < 0 || x0 >= bmp0.Width ) continue; //outside`
	`    Color color = bmp0.GetPixel( x0, y0 );`
	`    bmp1.SetPixel( x1, y1, color );`
	`  }`
	`}`

Code comparison of Rotation (by α degrees clockwise around the origin)

By α-Rotation of Polygon `p0` → `p1`	By α-Rotation of Bitmap `bmp0` → `bmp1`

`//center of rotation (0/0)`
`double arcus  = alpha * 2 * Math.PI / 360;`
`float sinus   = (float)Math.Sin( arcus );`
`float cosinus = (float)Math.Cos( arcus );`
`for all vertices 0 <= i < n`
`{ p1[i].x = p0[i].x * cosinus`
`         - p0[i].y * sinus;`
`  p1[i].y = p0[i].x * sinus`
`         + p0[i].y * cosinus;`
`}`
	`double arcus  = alpha * 2 * Math.PI / 360;`
	`float sinus   = (float)Math.Sin( arcus );`
	`float cosinus = (float)Math.Cos( arcus );`
	`for ( int y1=0; y1 < bmp1.Height; y1++ )`
	`{ float y1_sinus   = y1 * sinus;`
	`  float y1_cosinus = y1 * cosinus;`
	`  for ( int x1=0; x1 < bmp1.Width; x1++ )`
	`  { int x0 = Convert.ToInt32( x1 * cosinus + y1_sinus );`
	`    if ( x0 < 0 || x0 >= bmp0.Width ) continue;`
	`    int y0 = Convert.ToInt32( -x1 * sinus + y1_cosinus );`
	`    if ( y0 < 0 || y0 >= bmp0.Height ) continue;`
	`    Color color = bmp0.GetPixel( x0, y0 );`
	`    bmp1.SetPixel( x1, y1, color );`
	`  }`
	`}`

Annotation to raster rotation:
The `Graphics`-class of .NET contains an elegant variant of the method `DrawImage(...)`. It accepts a parameter of three verices `p[0]`, `p[1]` and `p[2]` which define a parallelogram. `DrawImage(...)` scales, rotates and shears the raster image to fit the corners of the image to the corners of the parallelogram. You just have to rotate the polygon `PointF[] p = new PointF[3];`, feed the rotated triangle into `DrawImage(myBitmap, p)` and the complete raster rotation follows automatically.
See: **http://msdn.microsoft.com/library/...**. You find such a rotation animation where the vertices of the triangle slide along the window borders here: **../../C_IPCis/C1_Bitmap/CIPCisBitmap_e.htm#a9**.