Computer Graphics Fundamentals

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- What is CG Fundamentals
  - Looking at how Images (and Animations) are actually produced in the Computer
  - Gaining an in depth understanding of the processes the tools we use apply to create animations and images.
- What does this Involve?
  - Some Maths (nothing too complex)
  - Some Science (Physics)
- Why Do I need to know this?
  - To help you use the tools better (and know some of the limitations)
  - To help you communicate with the technical people who write the tools and give us common language for expressing ideas

Why do I need Maths

- So you know why things get slower the more buttons you press
- So you know why things don't look quite right when you combine a number of Render passes
- So you can figure out how to get your characters facing in the right direction
  - and get them to go the correct way when you place them on a path
- So when you start scripting you can express your ideas in a way the computer understands
- And countless other reasons which will come apparent as the course progresses

And what about Physics?

- Physics isn't just about gravity (although that is important)
- Physics is also used to describe how light interacts with object
  - This is exactly how (but much simplified) Computer Rendering works
- So once we learn the basics we can understand what the different shading models actually do
  - and thus create the images we really want to see

Basic Curriculum

- Basic Maths
  - Trigonometry (lines, triangles, circles)
- 3D Maths
  - Vectors, Matrices, Affine Transforms
- How Animation Systems work
  - The Computer Image, The Animation Pipeline (how XSI, Maya, Houdini, Shake etc really work)
  - Some Basic Computer Principles, How the computer Actually works
- Rendering
  - How a renderer actually produces and image, Lighting Models, Shading Models.
- And a whole lot more besides.

Lecture Program

- The computer Image
- Numbers, number manipulation, functions and basic algebra
- Trigonometry, Lines, Circles Pythagorus
- Vectors, Matrices and Affine Transforms
- Viewing Systems, Perspective and CG Images
- The Virtual Camera
- The Mathematics of Compositing
- Image Representation, Culling, Clipping
- Image Generation, Rendering Ray-tracing Scanline rendering

Pixels

"A pixel (a portmanteau of picture element) is one of the many tiny dots that make up the representation of a picture in a computer's memory.
Each such information element is not really a dot, nor a square, but an abstract sample.
With care, pixels in an image can be reproduced at any size without the appearance of visible dots or squares; but in many contexts, they are reproduced as dots or squares and can be visibly distinct when not fine enough.
The intensity of each pixel is variable; in color systems, each pixel has typically three or four dimensions of variability such and Red, Green and Blue, or Cyan, Magenta, Yellow and Black." [1]

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Pixels

- The more pixels used to represent an image, the closer the results can resemble the original.
  - This is usually called the resolution.
- Pixels are usually expressed as a single number
  - 3 Mega-Pixel digital camera (which has a nominal 3 million Pixels)
- or as a pair of numbers
  - 640 x 480 which represent width (640) by Height 480. with a total number of pixel = 640x480 = 307,200 pixels

Resolution

- Image resolution describes the detail an image holds.
- The term is most often used in relation to digital images, but is also used to describe how grainy a "film-based" image is.
- Higher resolution means more image detail.
- For digital raster-images, the convention is to describe the image resolution with the set of two positive integer-numbers, where the first number is the number of pixel-columns (width) and the second is the number of pixel-rows (height).
- The second most popular convention is to describe the total number of pixels in the image (typically given as number of mega-pixels), which can be calculated by multiplying pixel-columns with pixel-rows.

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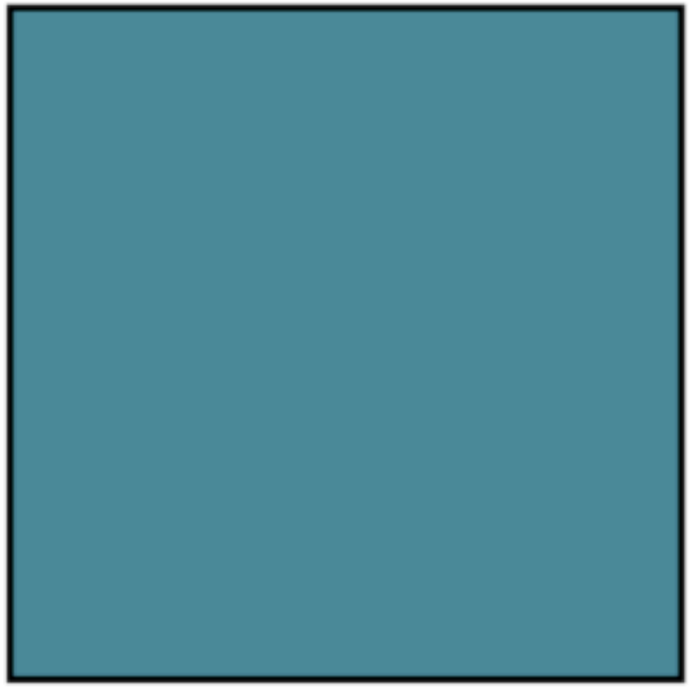
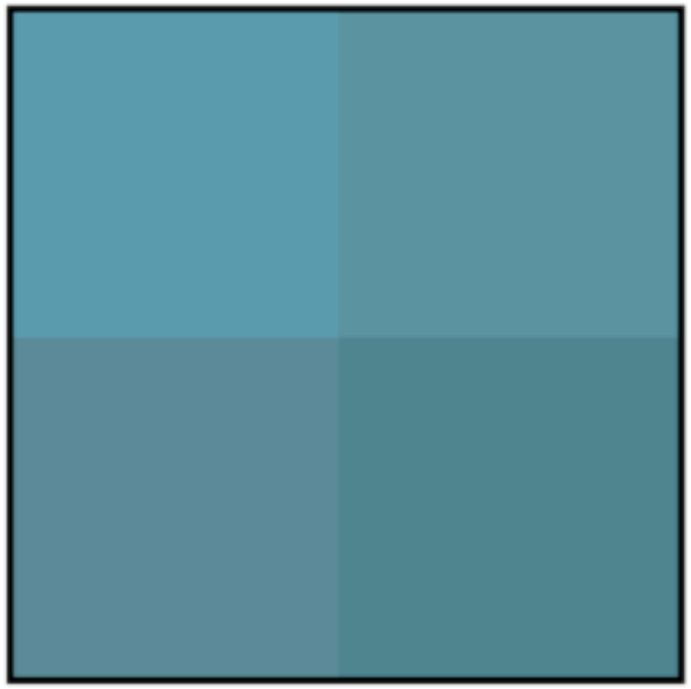
Resolution

1 x 1



Resolution

2 x 2



Resolution

5 x 5

Resolution

10 x 10

10

Resolution

20 x 20

Resolution

50 x 50

Resolution

100 x 100

Pixel Depth [2]

- Pixel Depth refers to the number of colours possible on screen.
- Another way of looking at this is to determine how many different bits are used to make up an individual pixel (pixel depth).

Pixel Depth

8 Bit Graphics

128	64	32	16	8	4	2	1
0	0	0	1	0	0	0	1

$2^8 = 256$ *Colours*

Pixel Depth

16 Bit Graphics

$$\underbrace{0\,0\,0\,1\,0\,0\,0\,1}\;\underbrace{0\,0\,0\,1\,0\,0\,0\,1}$$

$$2^{16} = 65536$$ *Colours*

Pixel Depth

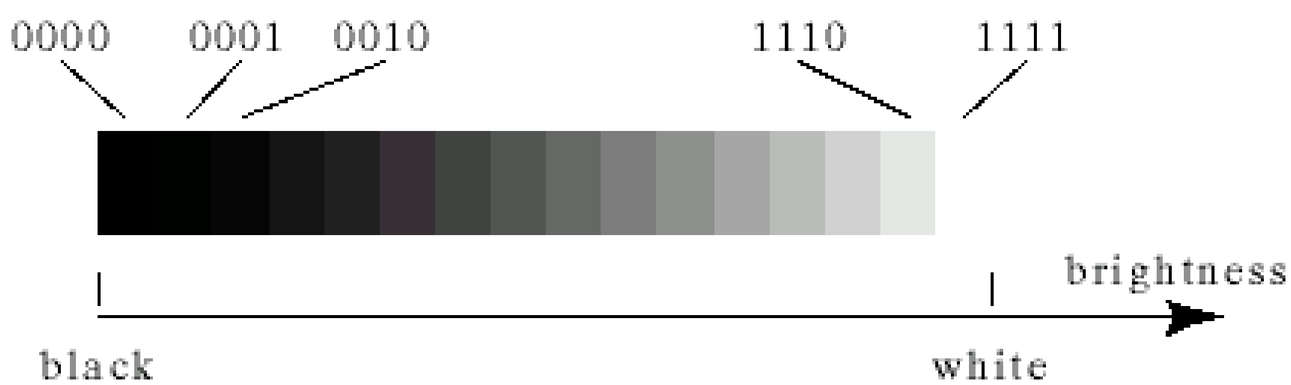
24 Bit Graphics

$$\underbrace{0\,0\,0\,1\,0\,0\,0\,1}\;\underbrace{0\,0\,0\,1\,0\,0\,0\,1}\;\underbrace{0\,0\,0\,1\,0\,0\,0\,1}$$

$$2^{24} = 16.77$$ *Million Colours*

Pixel Depth

- Most grey scale images are referred to by pixel depth with the most common shown below
  - Two bits per pixel produces 4 grey levels
  - Four bits per pixel produces 16 grey levels
  - Eight bits per pixel produces 256 grey levels



Raster Images [3,4]

- A raster Image (commonly called a Bitmap, pixmap etc)
- Is a data structure for storing computer images (usually in a rectangular grid) composing of a number of pixels
- A bitmap corresponds bit-for-bit with an image displayed on a screen, generally in the same format used for storage in the display's video memory, or maybe as a device-independent bitmap.
- Bitmap is technically characterized by the width and height of the image in pixels and by the number of bits per pixel (a colour depth, which determines the number of colors it can represent).

Raster Images

- The following raster image is made up of many cells in different shades of grey.

- Zooming in on these show

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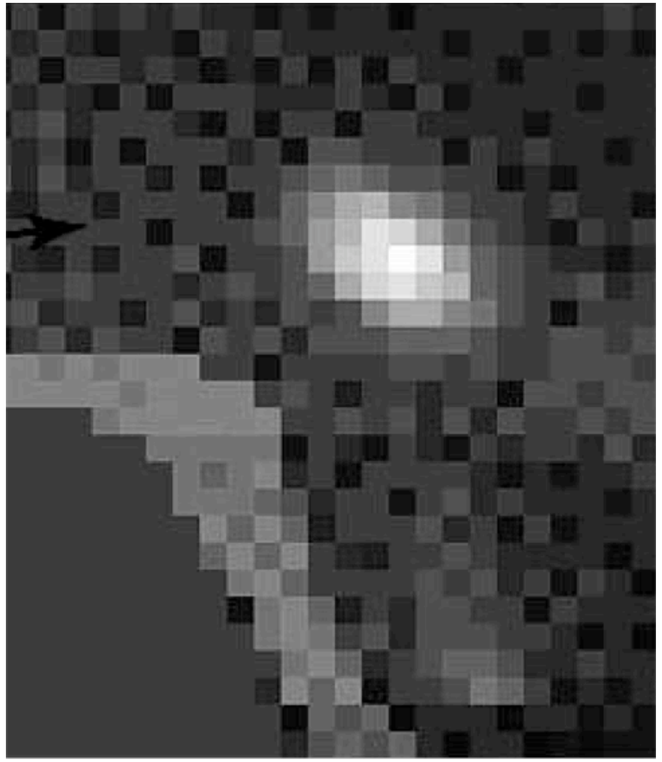
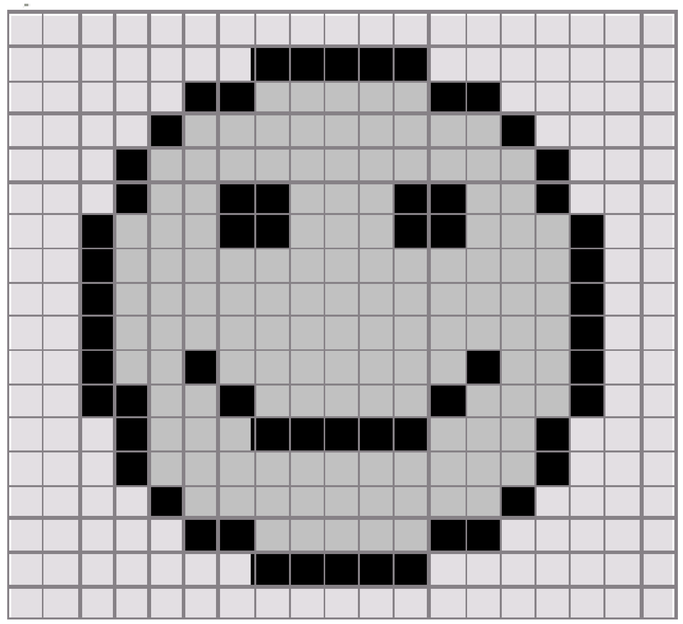


Raster Images



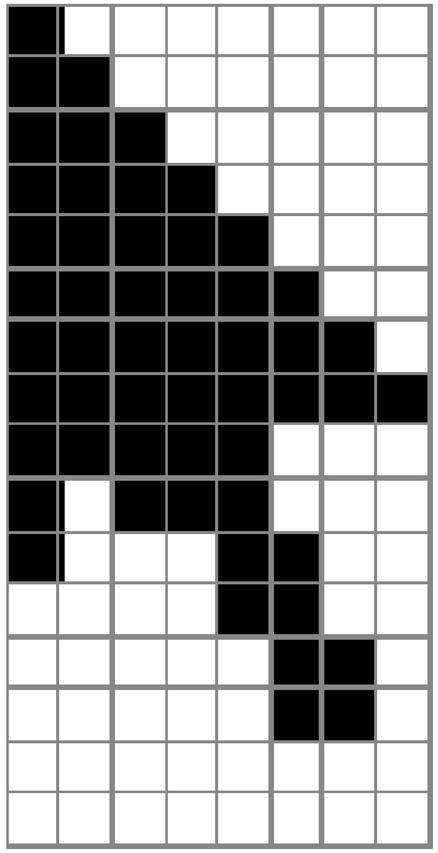
2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	7
2	2	2	2	2	7	7	1
2	2	2	2	7	1	1	1
2	2	2	7	1	1	1	1
2	2	2	7	1	1	7	7

- The example above shows a simple 3 level bitmap image.
- Each level of grey is encoded with the values 1,2 and 7
- The second image shows how this is stored for the upper left 6 by 8 section of the image

Representation of grey and Colour

- The simplest format for a raster image is the bi-level format as shown apposite

- This is usually referred to as a one-bit-per-pixel image.



1	0	0	0	0	0	0	0
1	1	0	0	0	0	0	0
1	1	1	0	0	0	0	0
1	1	1	1	0	0	0	0
1	1	1	1	1	0	0	0
1	1	1	1	1	1	0	0
1	1	1	1	1	1	1	0
1	1	1	1	1	1	1	1
1	1	1	1	1	0	0	0
1	0	1	1	1	0	0	0
1	0	0	0	1	1	0	0
0	0	0	0	1	1	0	0
0	0	0	0	0	1	1	0
0	0	0	0	0	1	1	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

Colour Raster Images

- Colour images are usually represented by an ordered triple
- This is used to represent the red green and blue intensity of the pixel
- The number of bits used to represent each pixel is called the colour depth.
- In its simplest form we can use the following table

Colour value	Displayed
[0,0,0]	Black
[0,0,1]	Blue
[0,1,0]	Green
[0,1,1]	Cyan
[1,0,0]	Red
[1,0,1]	Magenta
[1,1,0]	Yellow
[1,1,1]	White

Colour

- Although the previous example is good for simple colour often images need more detail
- True colour images have a pixel depth of 24 bits. This allows for finer control of the colour
- However images become very big at this level.
- Another alternative is to use a colour look up table in the image.
- This is also known as a palette, and is usually stored as part of the image format

32 Bit Colour

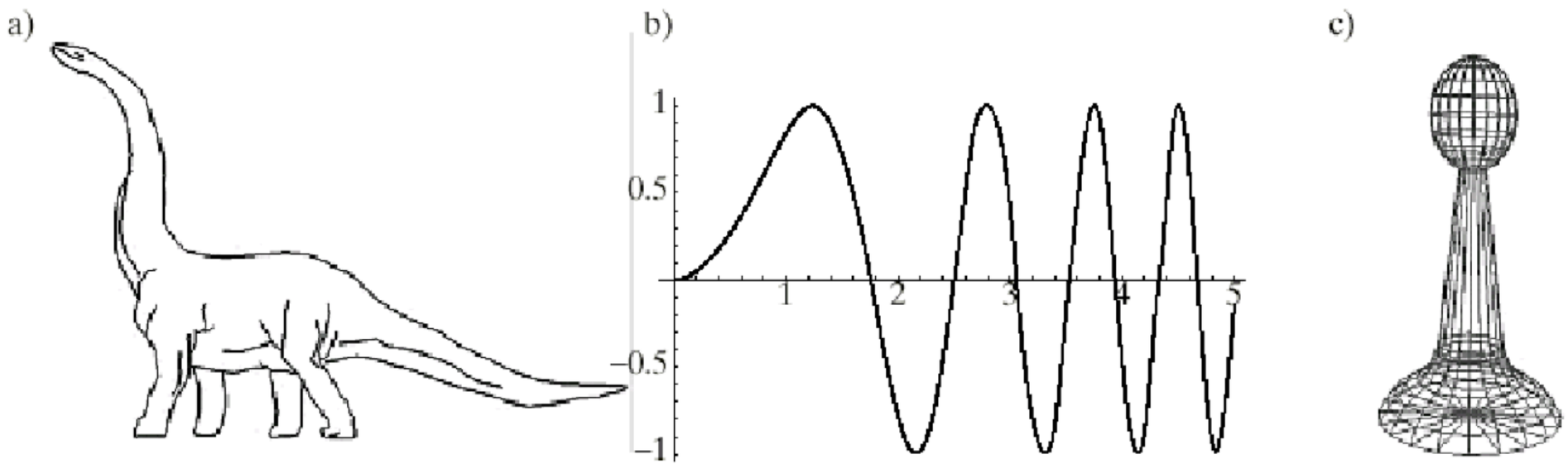
- A common misconception is that 32-bit colour produces 4,294,967,296 distinct colours.
- In reality, 32-bit colour actually refers to 24-bit colour (True colour) with an additional 8 bits
- These extra bits are used to represent an alpha channel.

Representing Images in the Computer

- Computer images are usually composed of the following output primitives
  - polylines
  - text
  - filled regions
  - raster images

Polyline

- A polyline is a sequence of connected straight lines
- The polyline may appear smooth but as shown below this is not the case



Polyline

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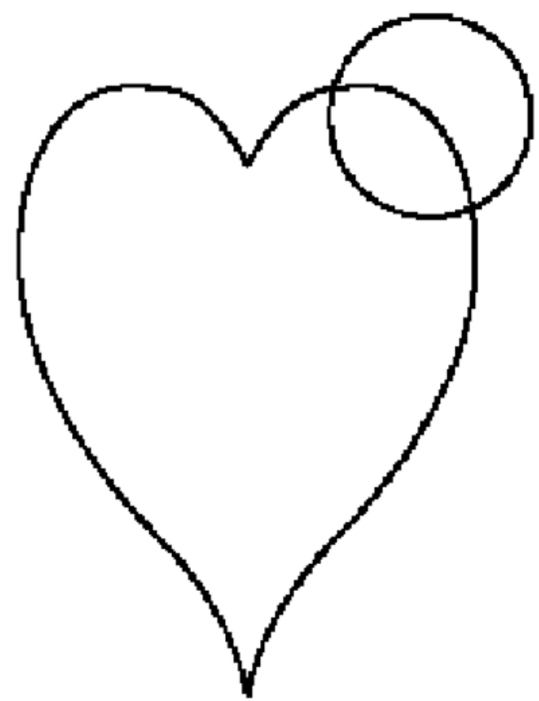

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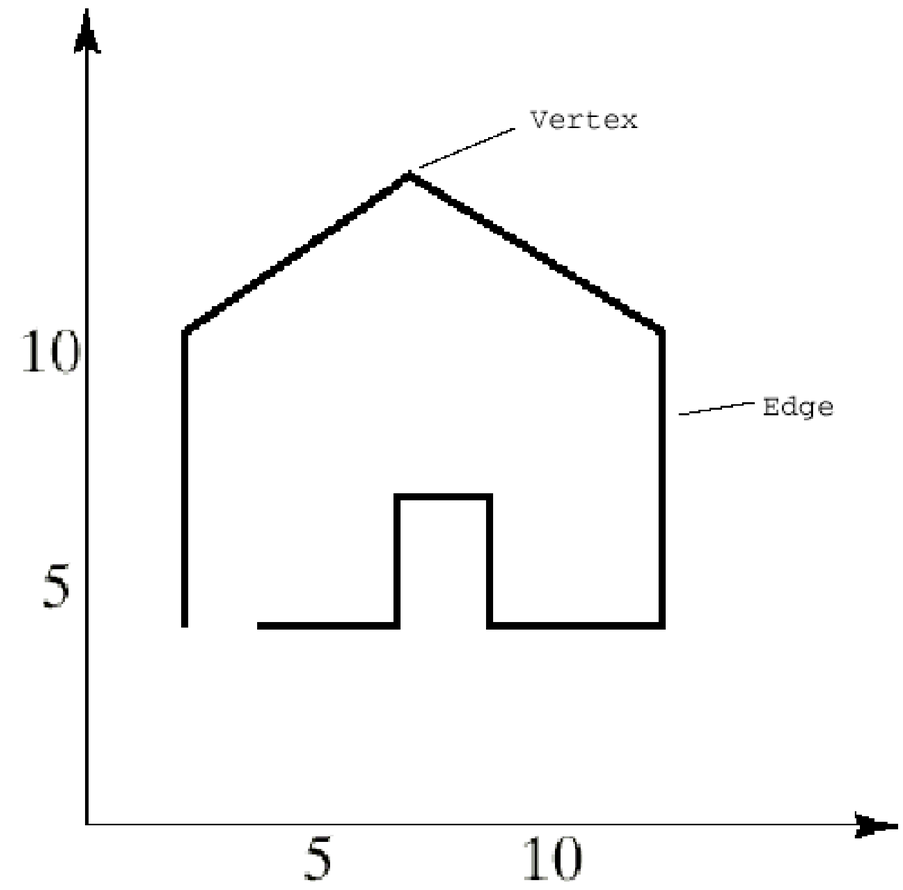
Drawing polylines

- The simplest polyline is a straight line segment represented by a start point and an end point :- $(x_1, y_1)(x_2, y_2)$
- When there are several lines in a polyline, each one is called an **edge** and two adjacent lines meet at a **vertex** (more on these in another lecture)



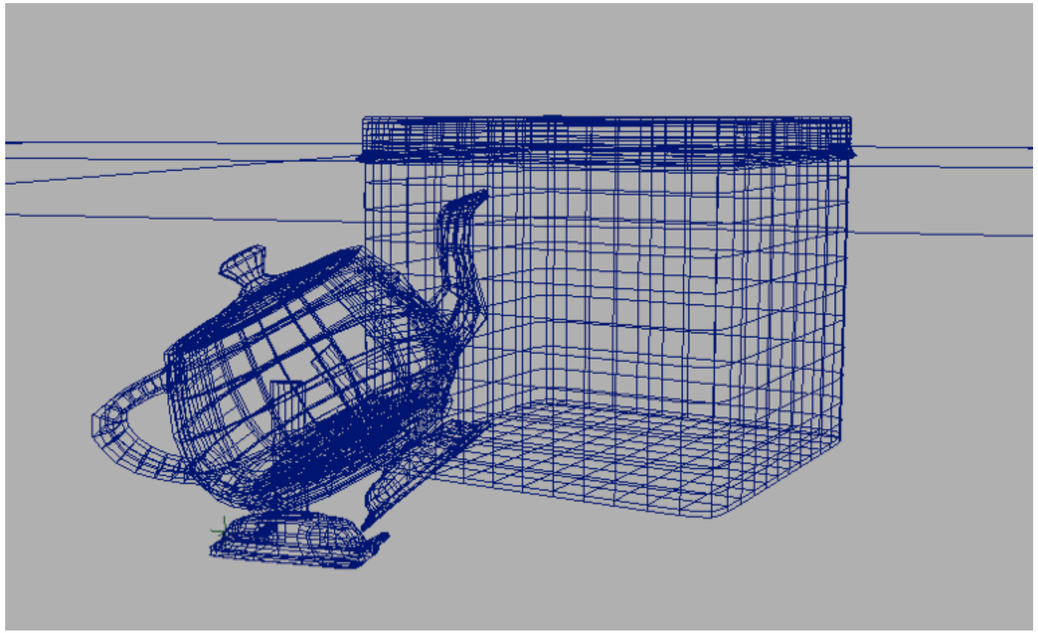
(2,4),(2,11),(6,14),(12,11),(12,4) .....

Polygons

- Mathematically a Polygon is described as a closed plane figure with n sides. [6]
- In computer graphics the term polygon has taken on a slightly altered meaning, more related to the way the shape is stored and manipulated within the computer. [7]
- Typically in CG we use Triangles and Quads as our basic polygon primitives

Polygons

- We can now assign colours, textures and surfaces to the polygons
- Then render them to produce the final image.



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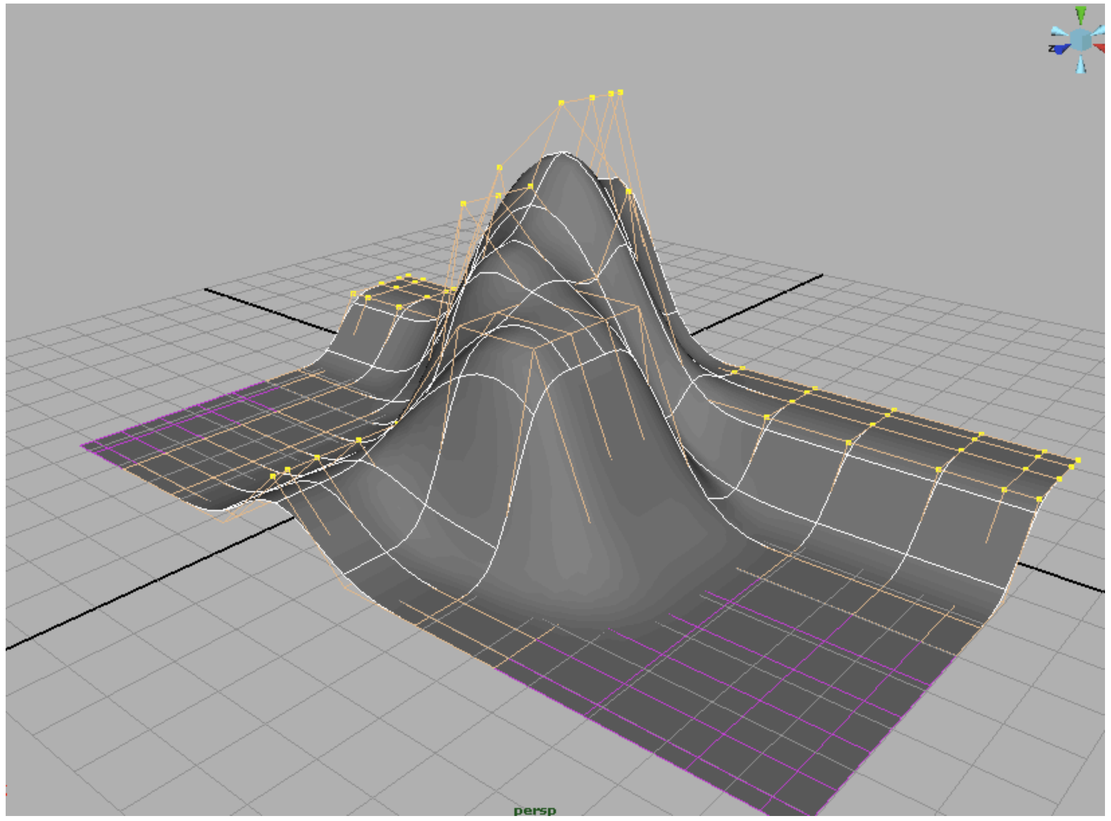
NURBS

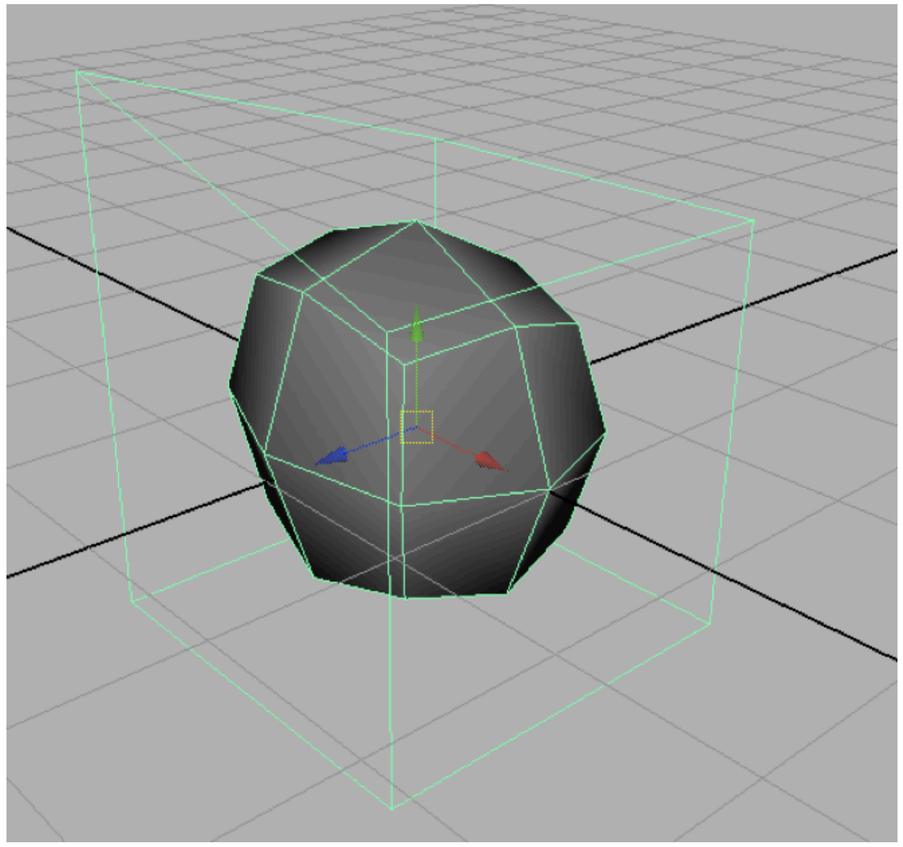
- non-uniform, rational B-spline (NURBS) is a mathematical model commonly used in computer graphics for generating and representing curves and surfaces

- The control points determine the shape of the curve.



Subdivision Surfaces

- A subdivision surface is a method of representing a smooth surface via the specification of a coarser polygon mesh.
- A Refinement Scheme is then applied to this mesh.
- This process takes that mesh and subdivides it, creating new vertices and new faces.



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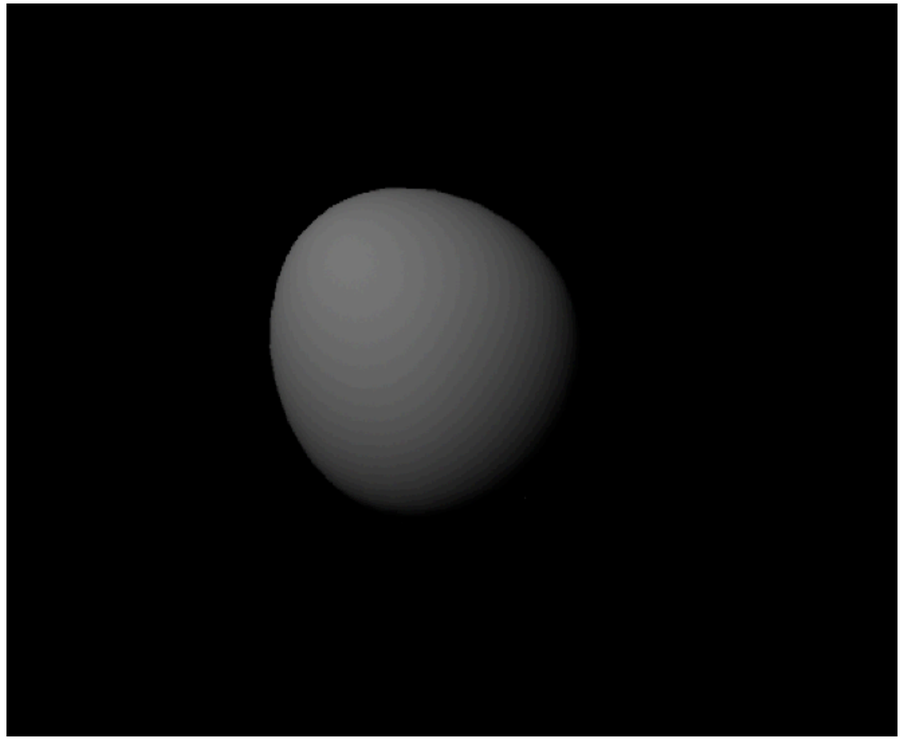

References

- [1] http://en.wikipedia.org/wiki/Pixel
- [2] http://www.usu.edu/sanderso/multinet/depth.html
- [3] http://en.wikipedia.org/wiki/Raster_graphics
- [4] Computer Graphics With OpenGL F.S. Hill Jr Prentice Hall
- [5] The Computer Image Watt & Policarpo Addison Wesley
- [6] http://mathworld.wolfram.com/Polygon.html
- [7] http://en.wikipedia.org/wiki/Polygon

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