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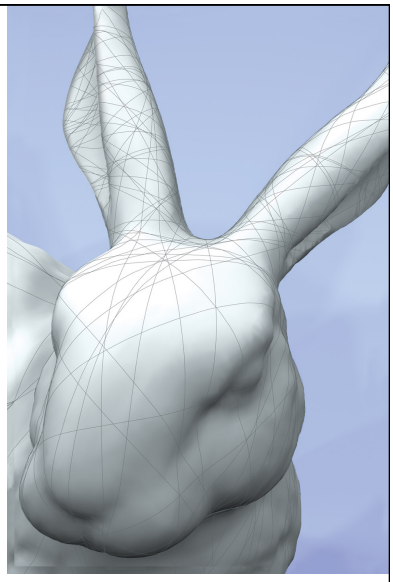
COMP27112

Computer Graphics and Image Processing



1: Introduction to the course

1

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About the course

Toby Howard
(course leader)

toby.howard@manchester.ac.uk

Tim Morris

tim.morris@manchester.ac.uk

Lectures: Monday 14:00, Thursday 14:00

in Kilburn 1.1 podcasted

2

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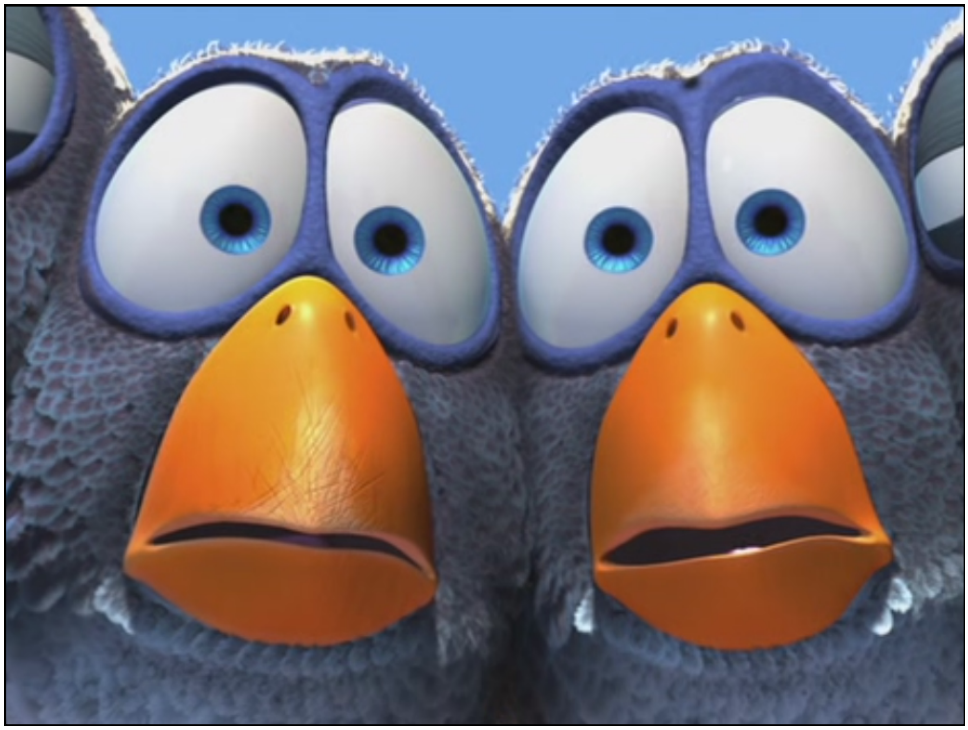
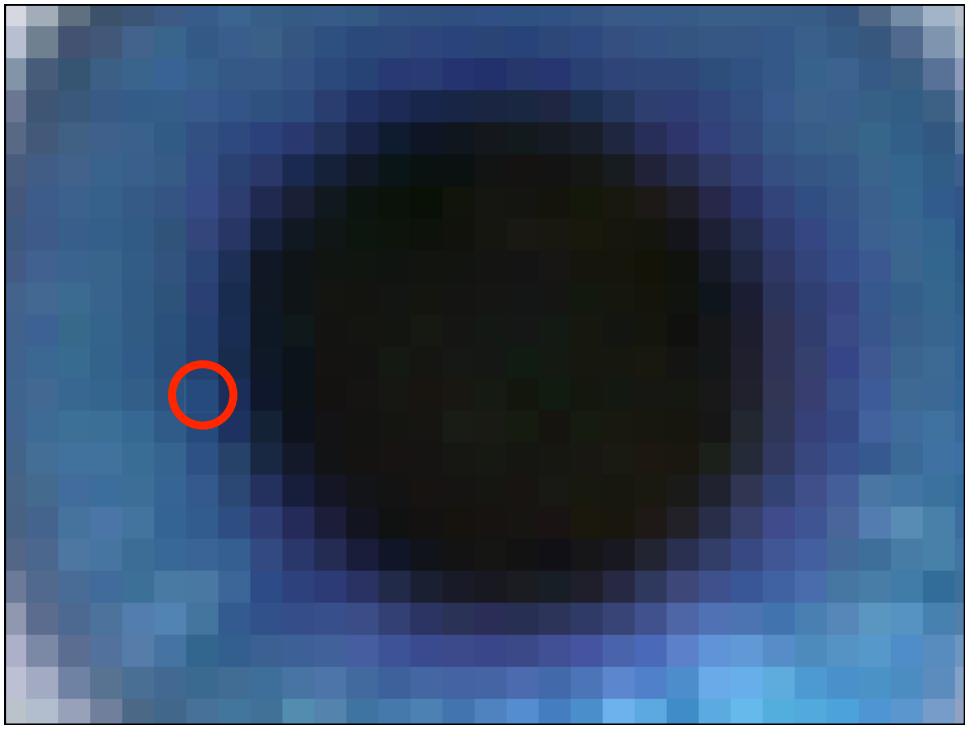
Aims and objectives

- **Aims**
  - to introduce the **theory and practice** of interactive 3D computer graphics, and image processing
- **Objectives**

  To understand:
  - the principles of interactive computer graphics (OpenGL)
  - the mathematics of 3D transformations and viewing
  - the principles of the rendering pipeline
  - the principles of image processing

3





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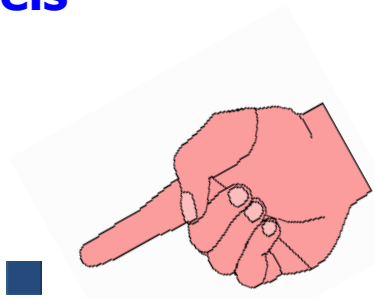
Pixels



- On an 23” screen at 1280 x 1024 …
- … a pixel is about 0.2mm, or 0.01”

6

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Pixels in a 90 minute movie

- a movie frame is 4K x 4K pixels
- 24 frames/sec
- movie is 90 min

- Total: about 1,000,000,000,000 pixels
- 10^{12} pixels

7

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Course activities

- Lectures & demonstrations
- Labs (4 exercises) in **Week A**
  - TAs, attendance, submit by deadline (no extensions)
- Coursework (5 x 1-hour exercises) in **Week B**
  - Personal study time, no TAs, submit by deadline (no extensions)
- 2-hour online exam: 20 MCQs + essay-type Qs

8

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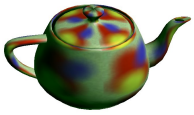
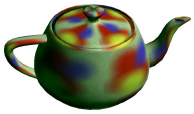
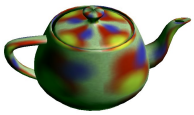
Assessment structure



Labs: 20%



Coursework: 5%



Exam: 75%

9

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Labs

- one lab every 2 weeks
- begin week of 13 February (Week 3A)

- 4 different lab exercises
  - we give you skeleton **C** code
  - deliverables are marked
  - code is **`submitted`**

- labs use **Linux**, **C, OpenGL**

10

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Lab schedule (Week A)

Lab G: Thu 0900-1100 in LF31

Lab H: Tue 1100-1300 in G23

Lab I: Fri 1100-1300 in LF31

Full timetable on course Blackboard page

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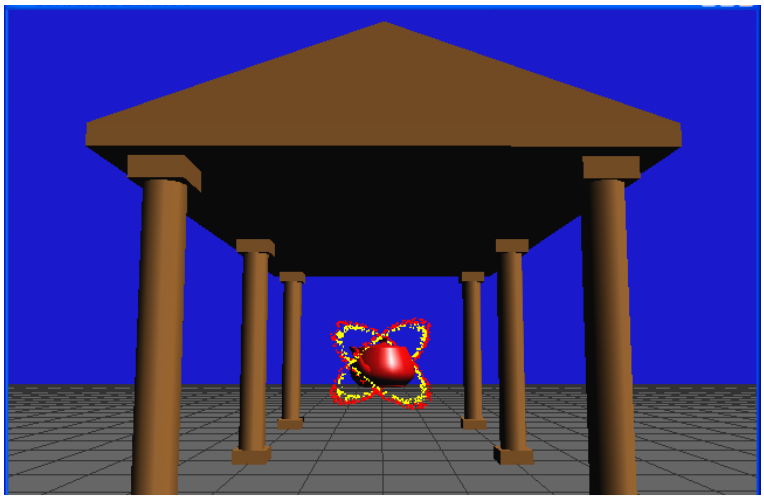
Lab 1 (1 session)



- 3D graphics: transformations and viewing

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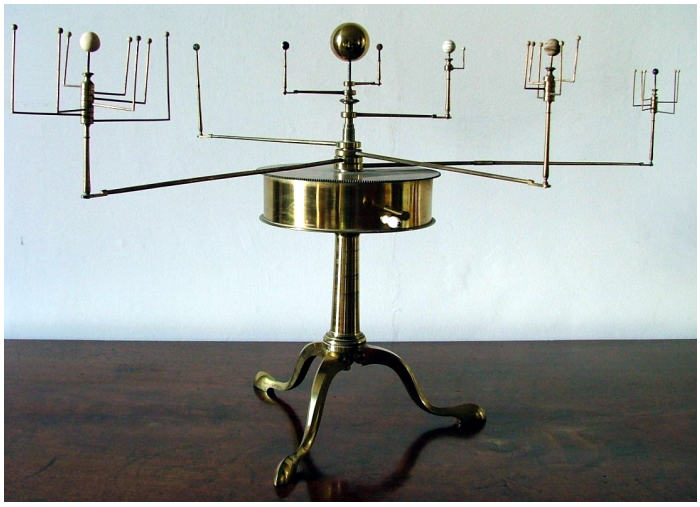
Lab2: build an orrery



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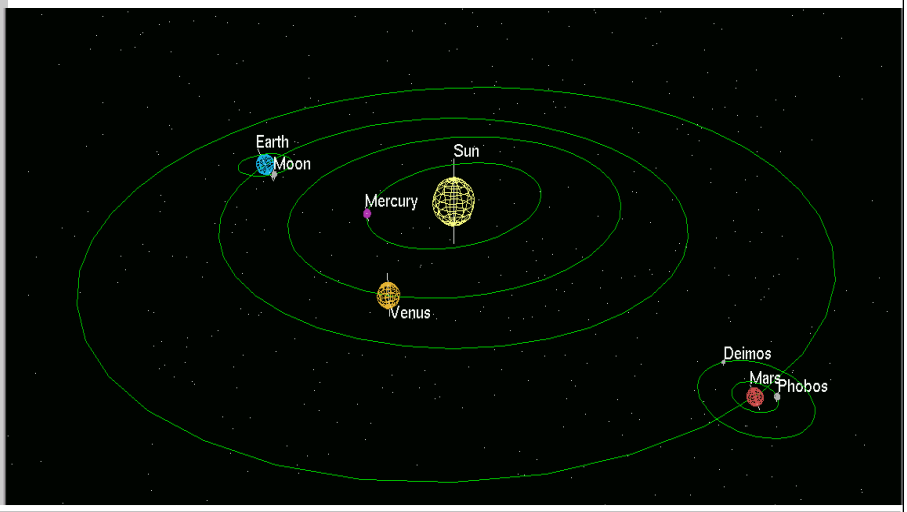
Lab 2 (2 sessions)



- Animated graphics with hierarchical transformations

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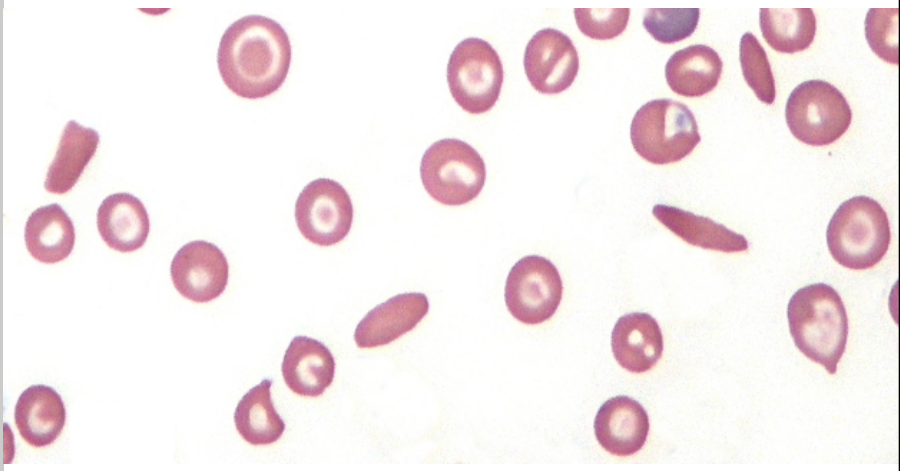
Lab 3 (1 session)



- Pixel processing

15

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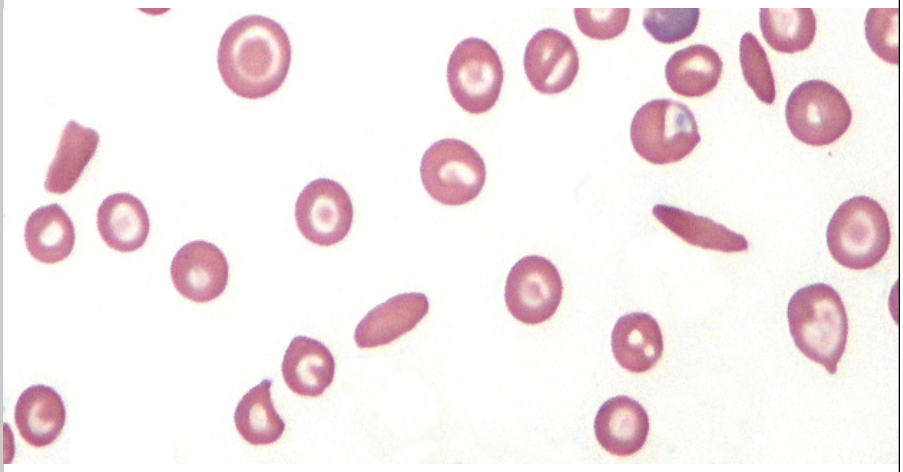
Lab 4 (1 session)



- Connected component labelling

16

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Coursework

- Coursework Assignments due every 2 weeks (alternating with labs)
- Begin week of 6 February (Week 2B)
- 5 different Assignments
- hands-on experiments, small bit of coding

- `submit` results, marks for all 5 Assignments **add up to one Lab exercise**

17

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Coursework (week B)

	Recommended start-time (but up to you)	Submission Deadline 17:00 (no extensions)
1	Mon 6 Feb	Fri 17 Feb
2	Mon 20 Feb	Fri 3 Mar
3	Mon 6 Mar	Fri 17 Mar
4	Mon 20 Mar	Fri 31 Mar
5	Mon 24 Apr	Fri 5 May

18

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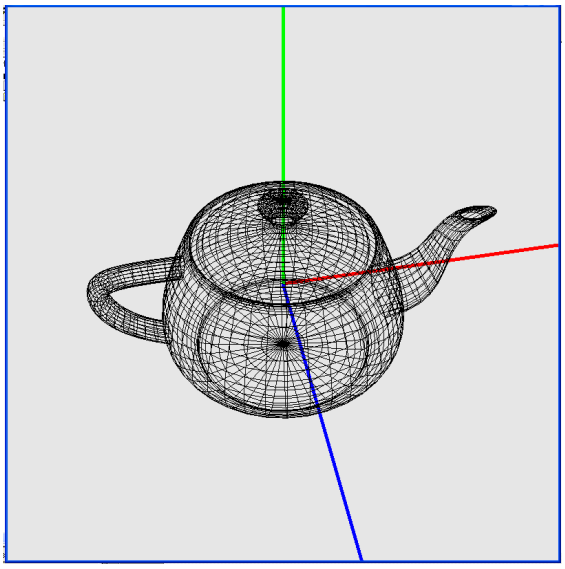
Coursework 1

- Intro to OpenGL



19

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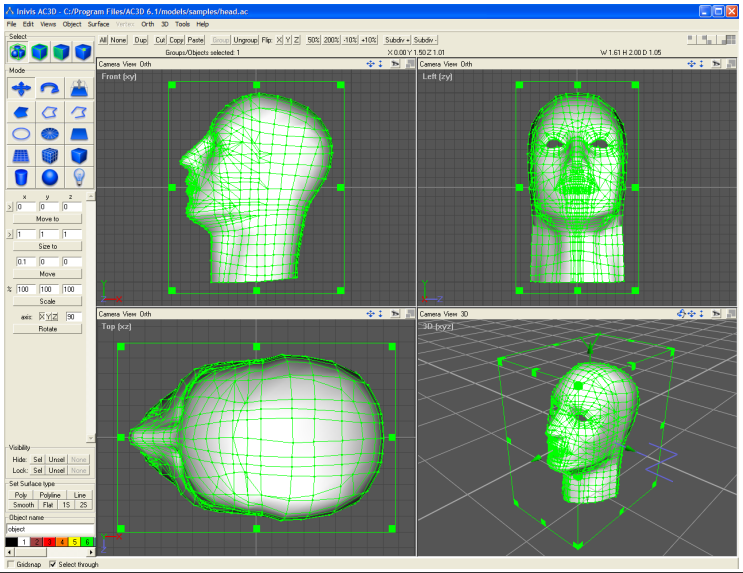
Coursework 2

- 3D modelling



20

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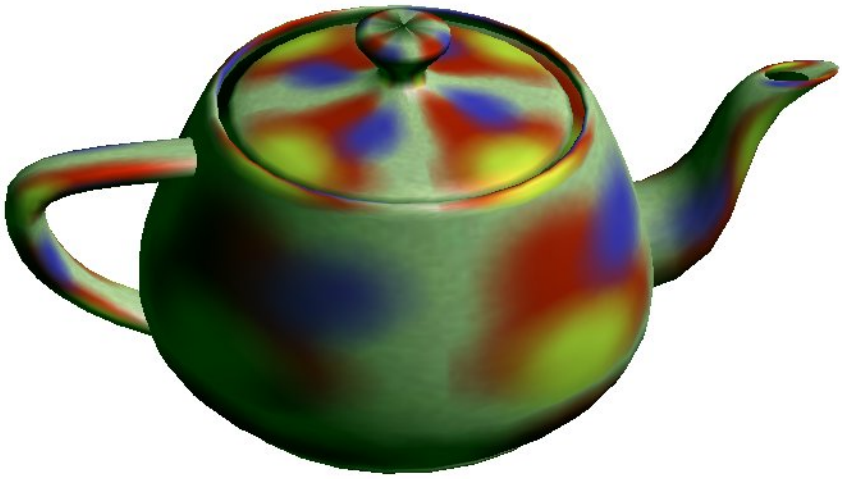
Coursework 3

- Lighting and texture



21

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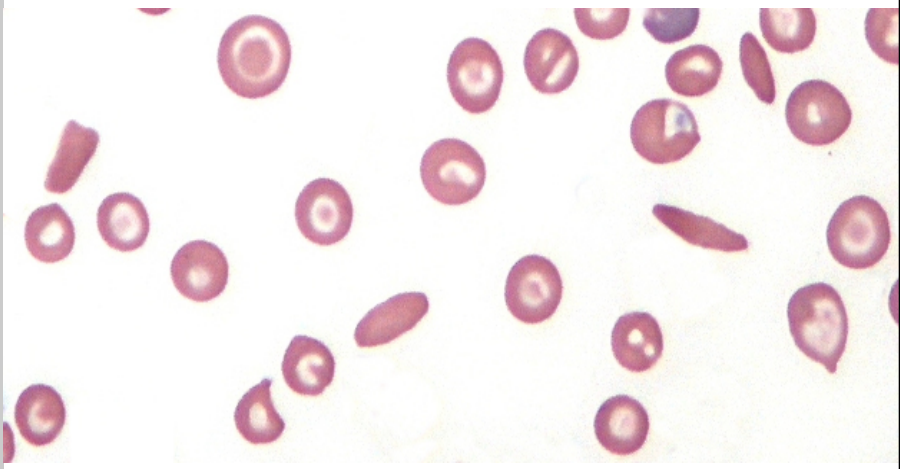
Coursework 4

- Read/modify/save images



22

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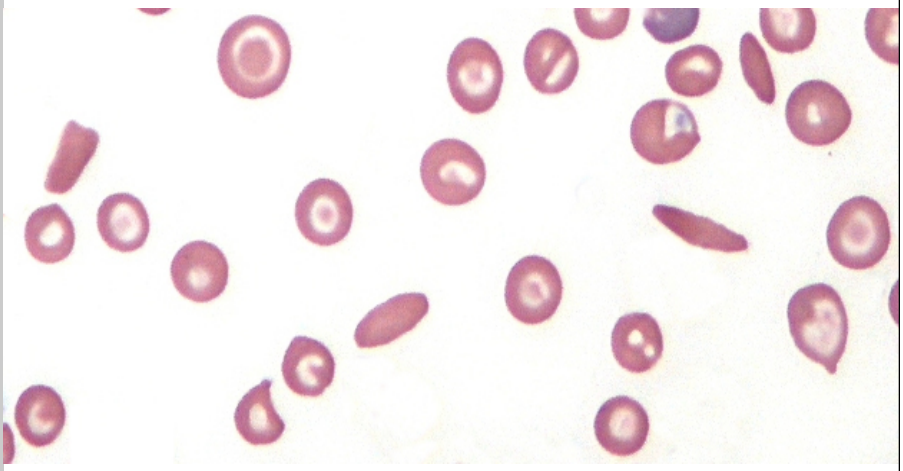
Coursework 5

- Region-based processing



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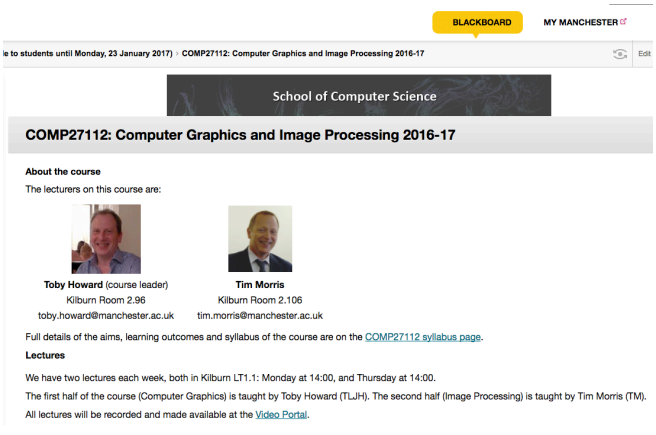
Essential resources



Blackboard

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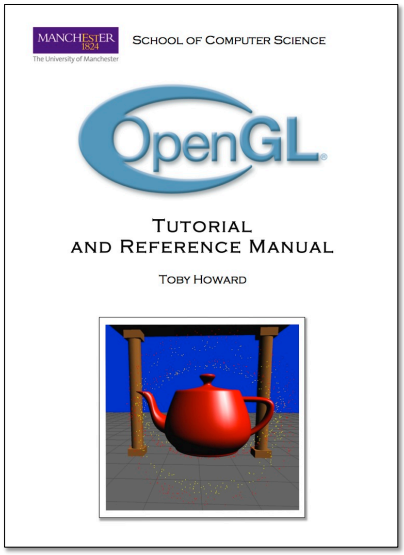
Essential doc: OpenGL



- **OpenGL tutorial and reference manual**
- Collect from the Student Resource Centre after this lecture

25

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Essential documentation

OpenGL support

This page offers some support for using OpenGL in the School of Computer Science at The University of Manchester (so contains some site-specific information). The page is maintained by Toby Howard. Please let me know if you have any comments or suggestions about what would be useful here.

Running OpenGL on various platforms

- **GNU/Linux:**
  - If you have just one source file, use **/opt/common/bin/cogl** on the School network. This is a Perl script designed for the School's Linux configuration.
  - Also for one source file, Karl Sutt has kindly contributed a more portable shell-script version of cogl called ucogl.
  - For more complicated projects, use a Makefile. Here's one to get you started.
- **Mac:** First install Xcode (free from here). Then, compile using:

```
gcc -o teapot teapot.c -framework OPENGL -framework GLUT
```

Note: on the Mac your GLUT include needs to be: #include <GLUT/glut.h>. It's good

http://studentnet.cs.manchester.ac.uk/ugt/COMP27112/OpenGL/

- **Windows:** Here are instructions for Visual Studio and Visual C++. Also, this project zip may be

26

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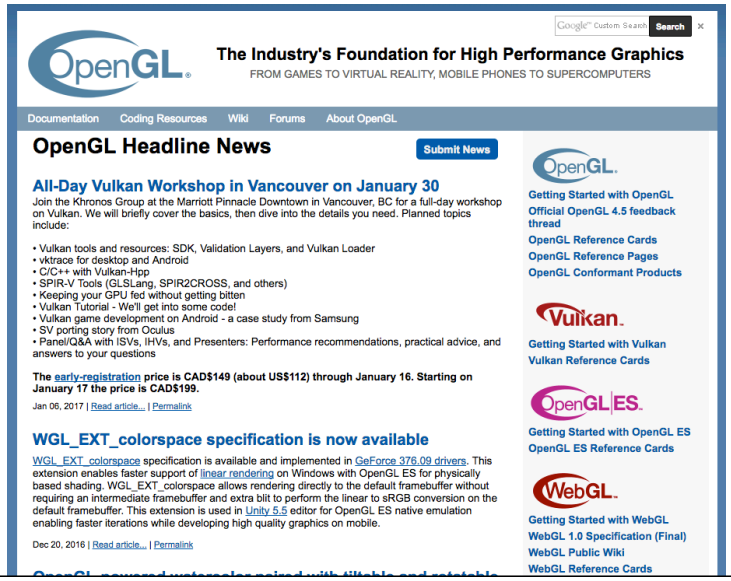
Essential doc: OpenGL home



27

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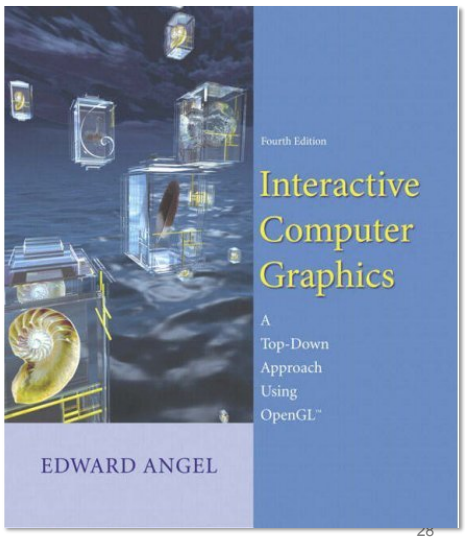
Course books (not essential)

Interactive Computer Graphics: A top-down approach with OpenGL

Edward Angel

Addison-Wesley
ISBN 0-201-38597-7



28

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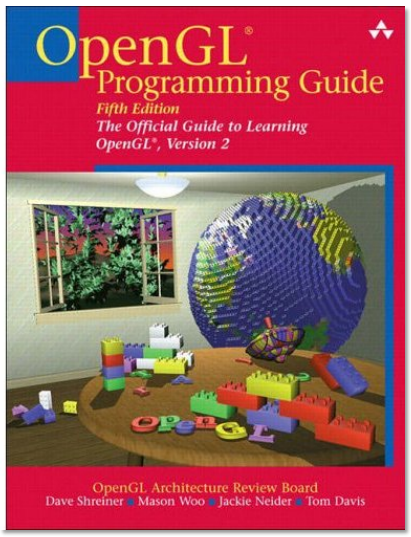
Course books (not essential)

OpenGL Programming Guide (5th-8th Editions)

Mason Woo, Jackie Neider, Tom Davis et al

Addison-Wesley
ISBN 0321481003



29

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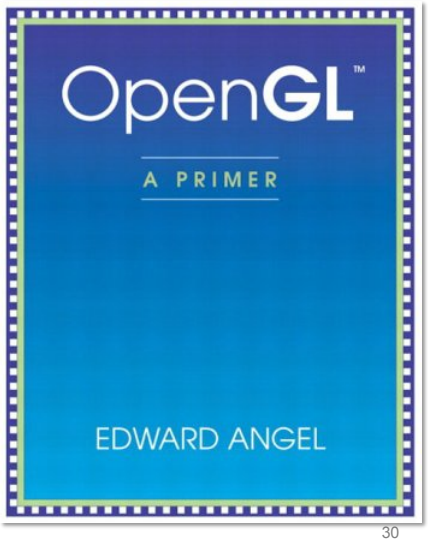
Course books (not essential)

OpenGL: A Primer

Edward Angel

Addison-Wesley
ISBN 0201741865



30

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Context

Why are computer graphics and image processing important?

31

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Computer graphics applications

32

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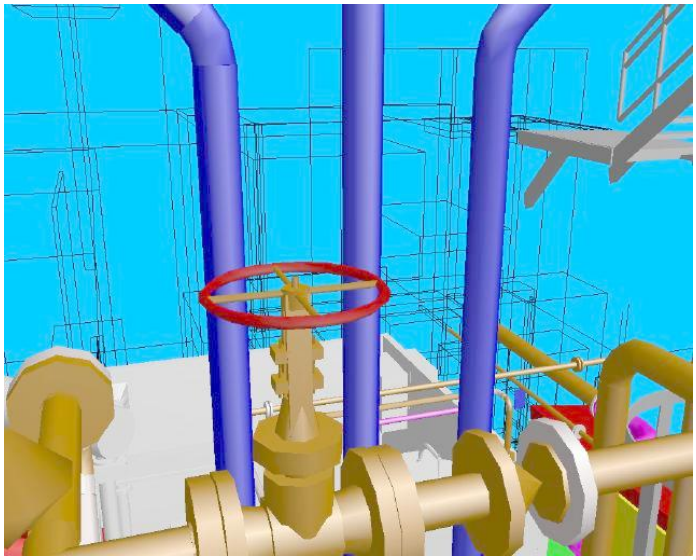
Engineering



33

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Visualization

34

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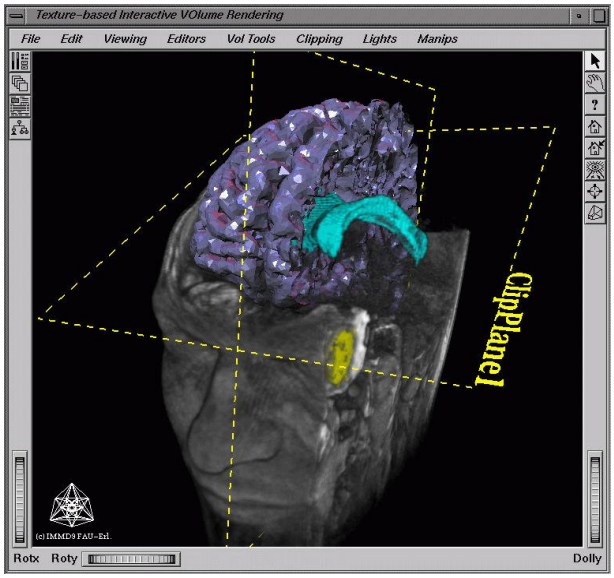
Visualization



35

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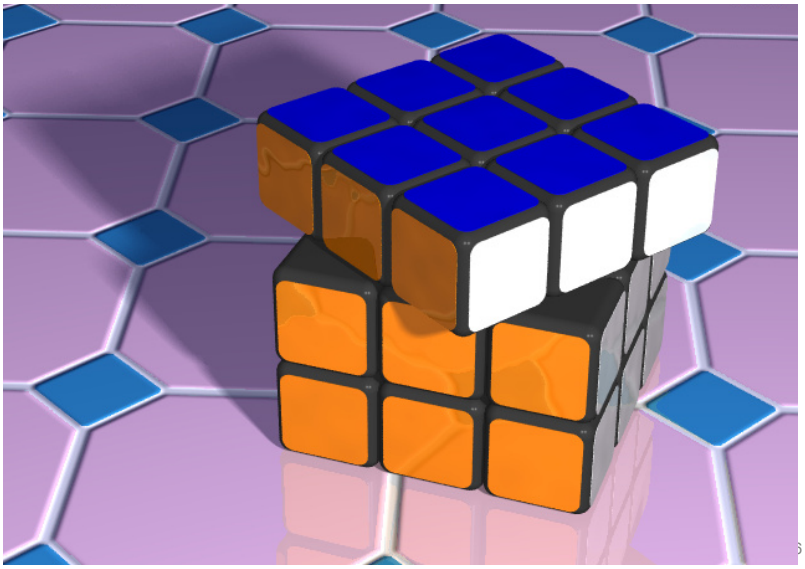
Simulation



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VR guy

Interactive virtual environments

$800

HTC Vive

$700

PlayStation VR

$600

Oculus Rift

$100

Google Daydream

$70

Samsung Gear

$15

Google Cardboard

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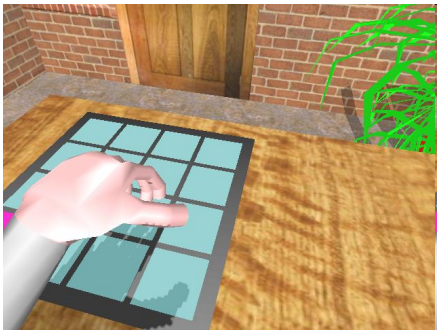
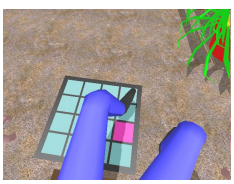
Virtual Environments for Therapy





38

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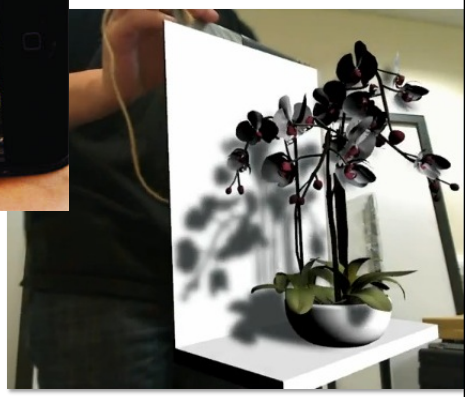
Augmented reality



39

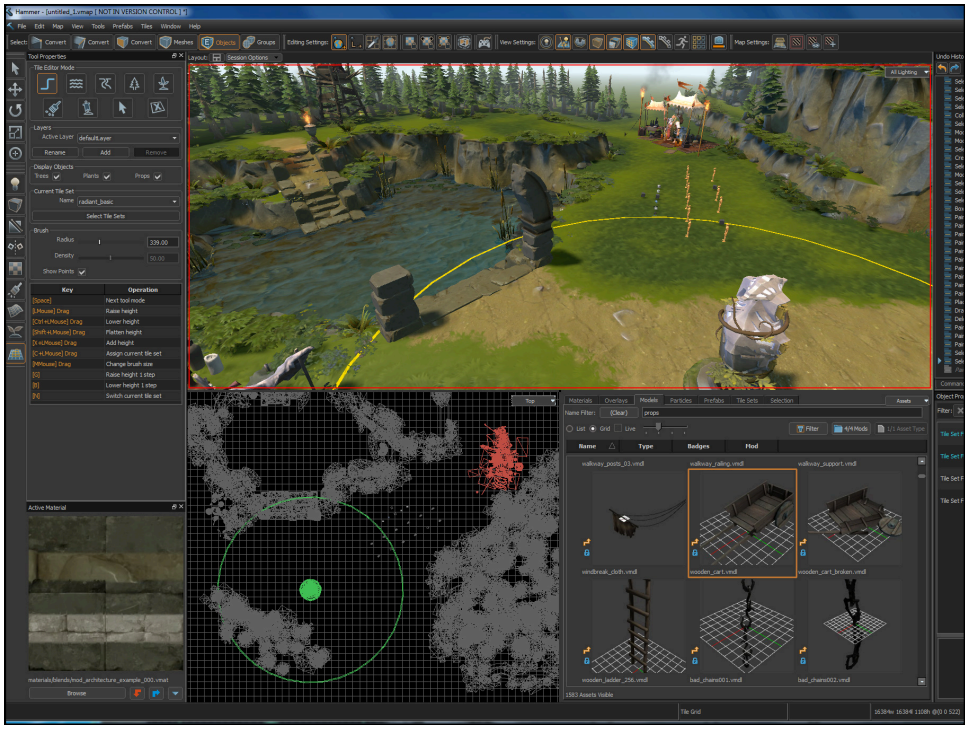


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Image processing applications

42

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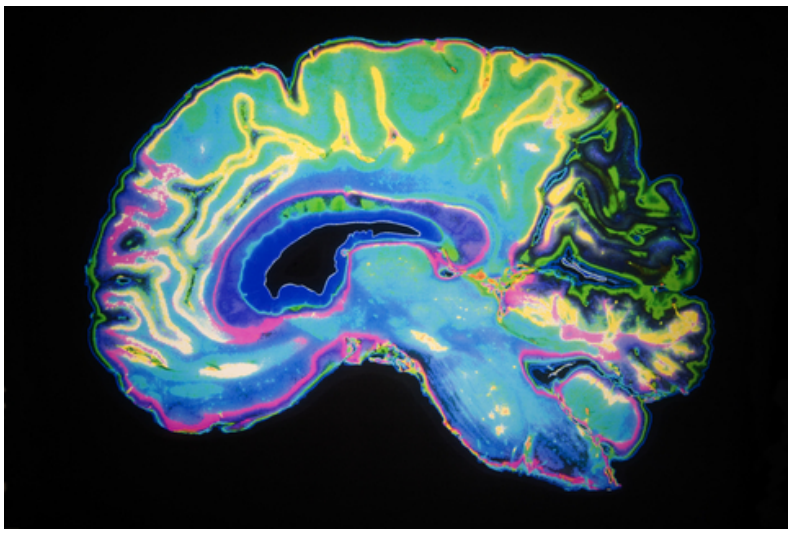
Medical



43

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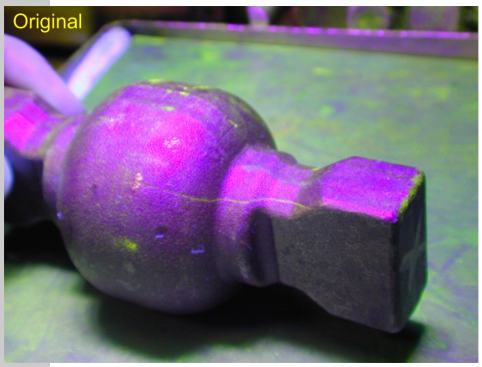
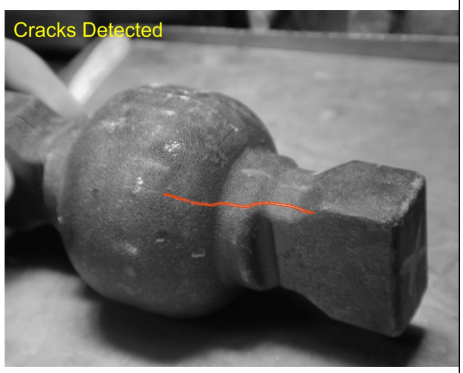
Engineering





44

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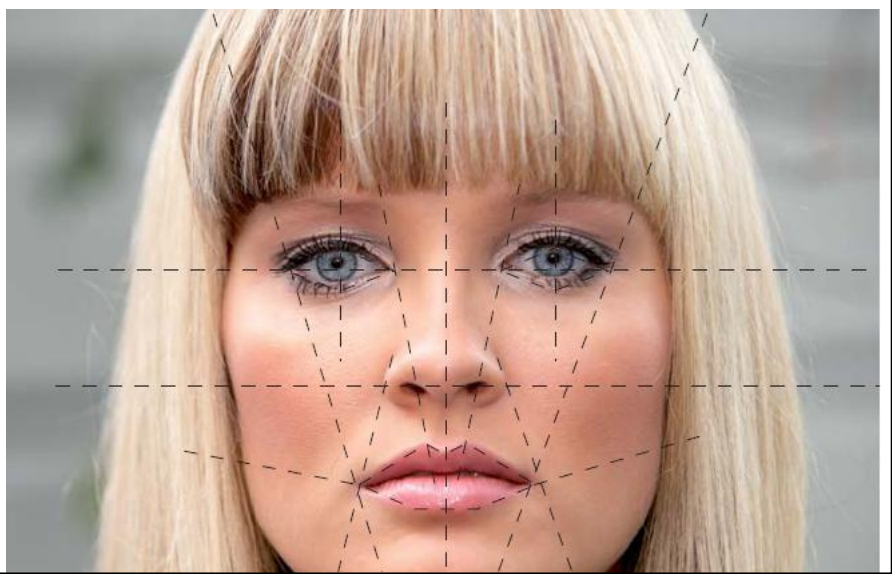
Face recognition



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Photography/video/media

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COMP27112 syllabus

- The course is in two parts

1. Interactive Computer Graphics (Toby) – **"synthetic"**

2. Image Processing (Tim) – **"analytic"**
   - image transformations
   - filters, convolution, finding edges
   - noise reduction, smoothing

47

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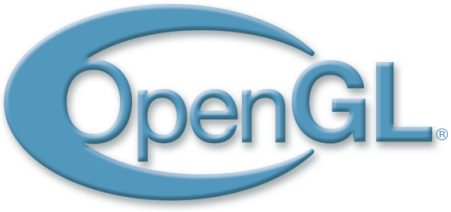
OpenGL

- History
- Basic concepts
- Program structure
- Demos



48

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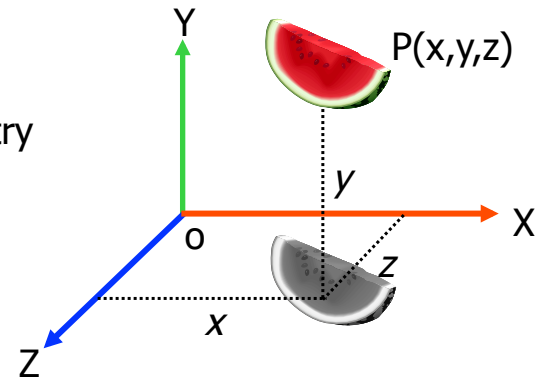
3D coordinate systems

- 3D geometry
- 3D trigonometry
- Homogeneous matrices



49

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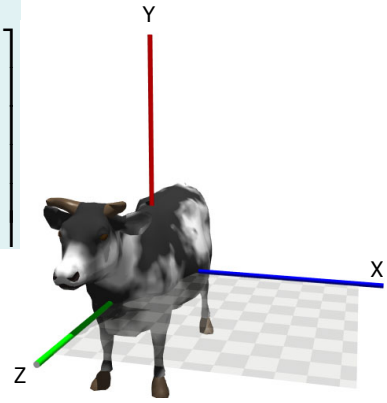
A scaling matrix

$$P' = T \cdot P$$

$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} S_x & 0 & 0 & 0 \\ 0 & S_y & 0 & 0 \\ 0 & 0 & S_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$



50

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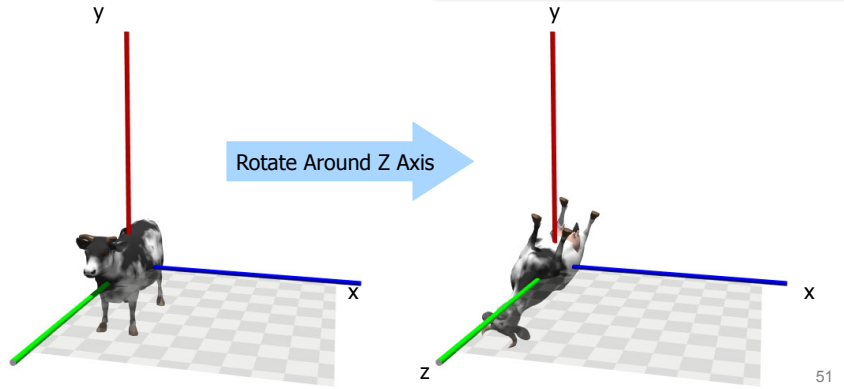
Rotation

Fundamental rotations are applied about the 3 major axes, e.g. a rotation angle θ about the Z axis

$$x' = x \,.\, \cos\theta \; - y \,.\, \sin\theta$$

$$y' = x \,.\, \sin\theta \; + y \,.\, \cos\theta$$

$$z' = z$$



51

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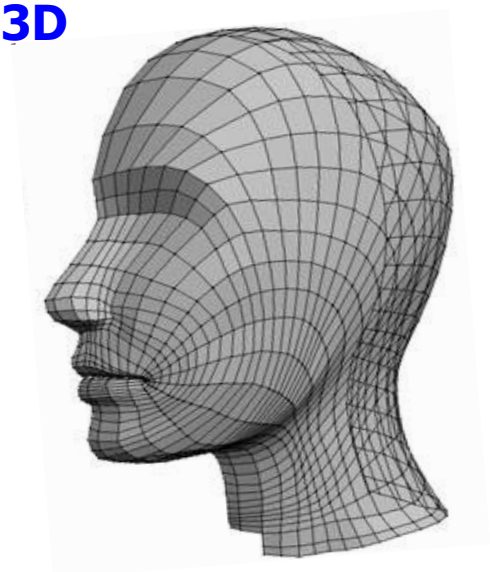
Modelling in 3D

- Representing geometry
- Polygons, meshes, surfaces
- Managing complexity
- Model formats



52

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Polygon meshes

53

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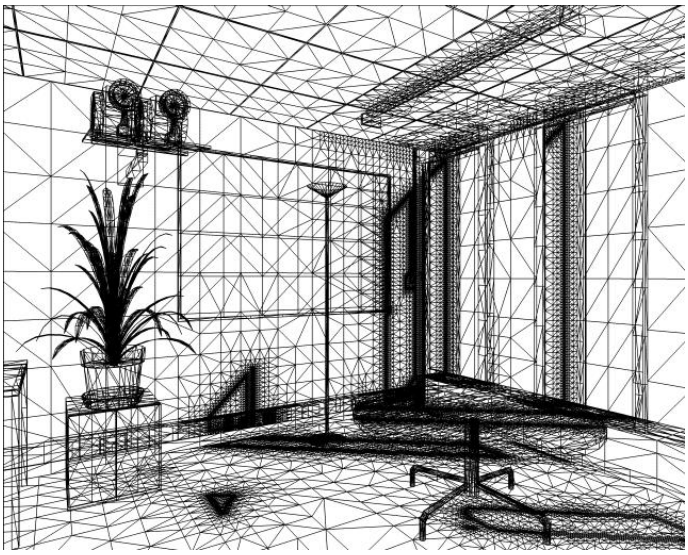
Polygon meshes



54

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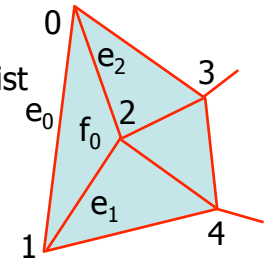
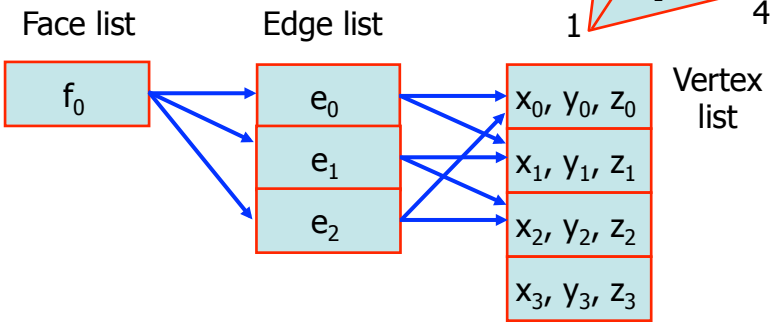
Mesh data structure

- **vertex list**
- **edge list**, indexing into the **vertex** list
- **face list**, indexing into the **edge** list





55

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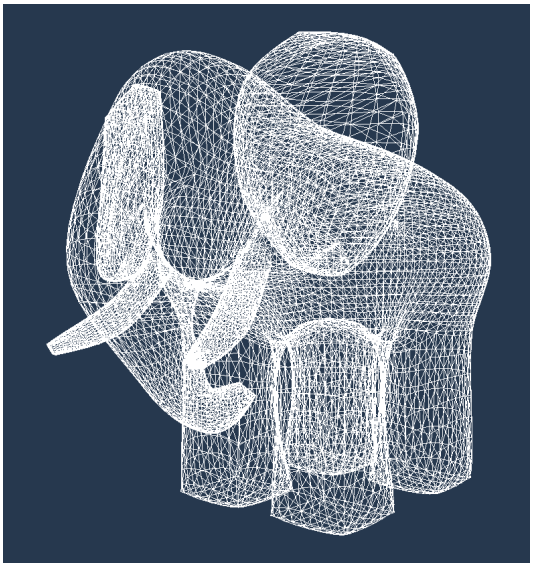
Hidden-surface removal



56

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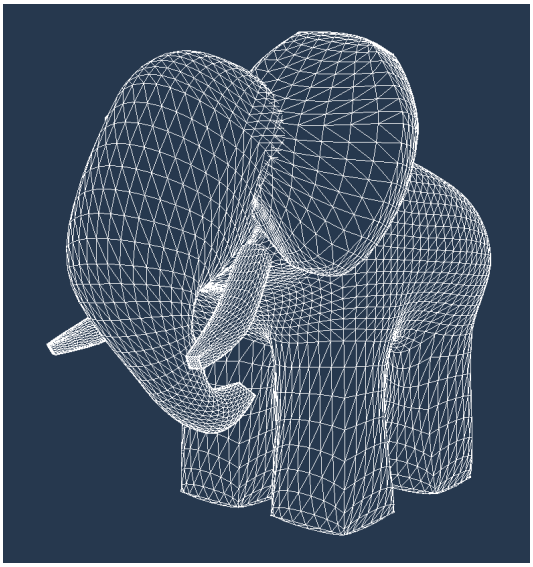
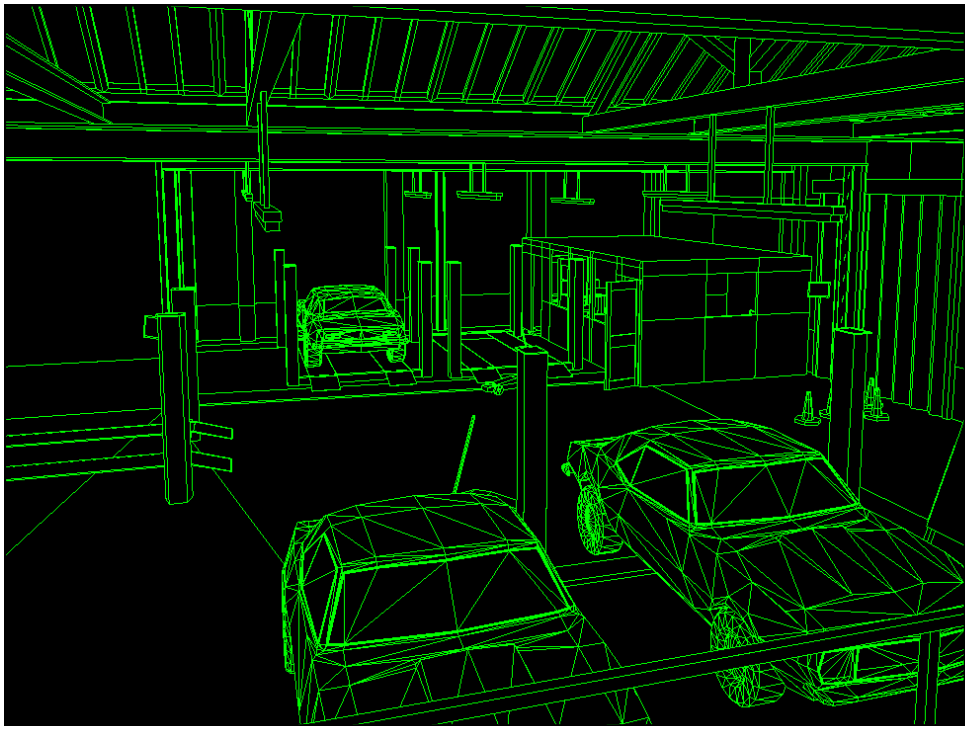
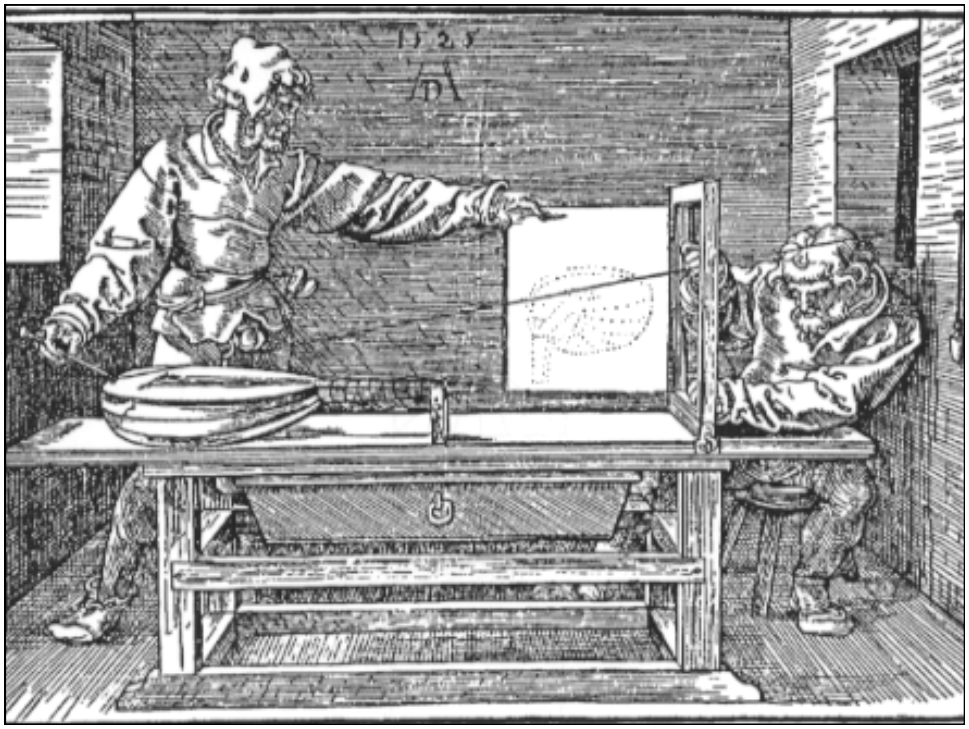
Hidden-surface removal



57





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The 3D Viewing Pipeline

3D vertex

$$\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

1 Modelling transformation **M** → 2 Viewing transformation **V** → 3 Projection transformation **P** →

Note: In OpenGL, **M** and **V** are combined into a single "modelview" matrix (see later)

→ 4 Clip to view volume → 5 Perspective division → 6 Viewport transformation → 2D pixel px,py

In this lecture we'll cover steps 1 and 2, and look at steps 3 to 6 in the next lecture.

60

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The Camera Analogy

Step 1: Set up your tripod and point your camera at the scene

61

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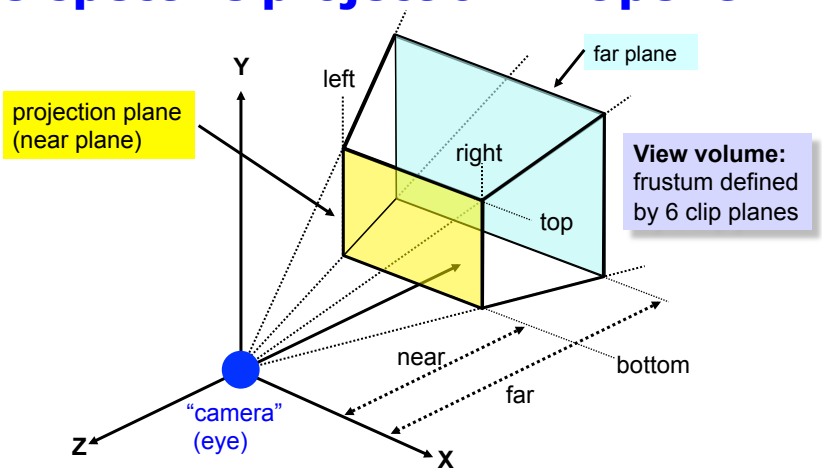
Perspective projection in OpenGL




```
glFrustum (GLdouble left,   GLdouble right,
           GLdouble bottom, GLdouble top,
           GLdouble near,   GLdouble far);
```

OpenGL

62

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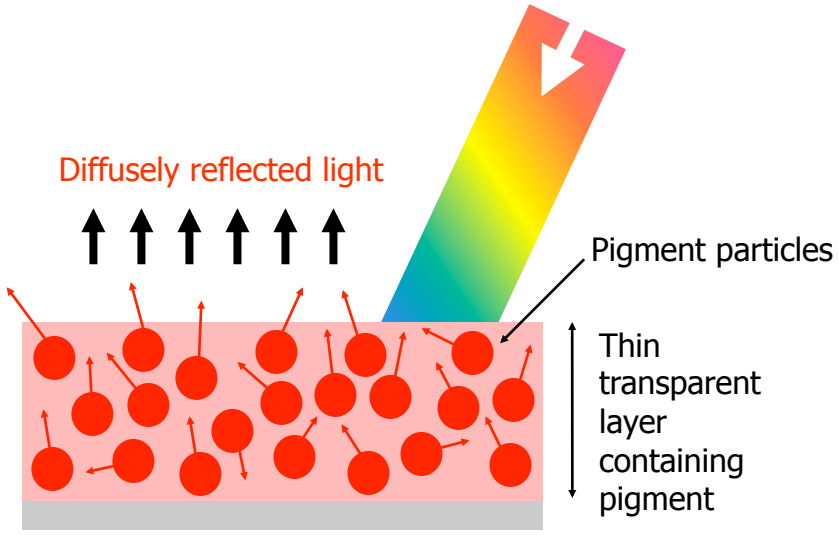
Diffuse light/surface interaction



63

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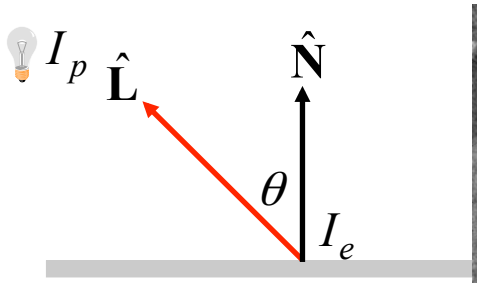
Diffuse reflection: Lambert's Law



- Light source of intensity I_p
- Effective intensity received is I_e
- Lambert's Law: $I_e = I_p \cos\theta$
  - Johann Heinrich Lambert (1728-1777)

64

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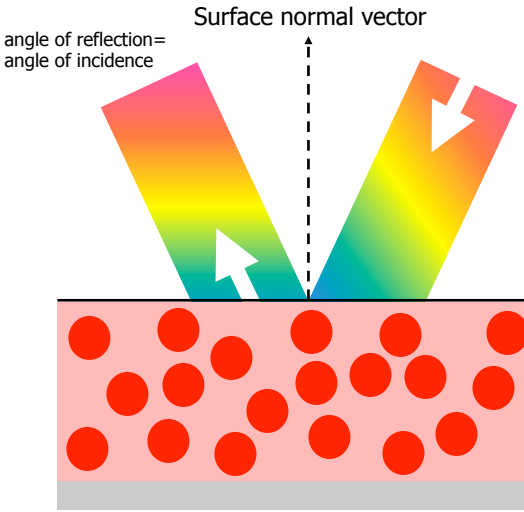
Specular light/surface interaction



When reflection occurs at the air/surface interface, light is **specularly** reflected, with no change of colour

The pigment particles are not involved in the reflection

65

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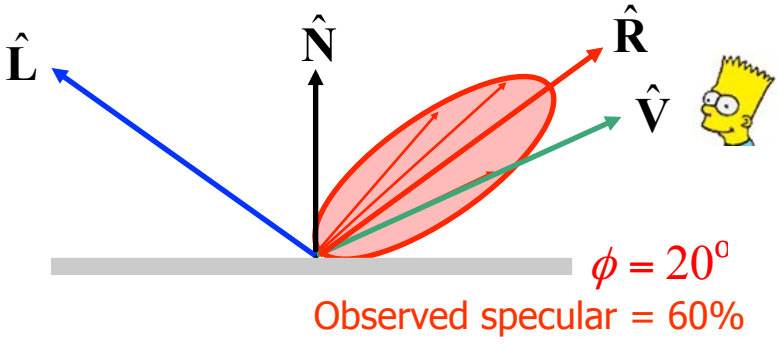
Modelling specular reflection



Observed specular = 60%

- As $\hat{\mathbf{V}}$ diverges from $\hat{\mathbf{R}}$ by angle ϕ, viewer sees less specular reflection

66

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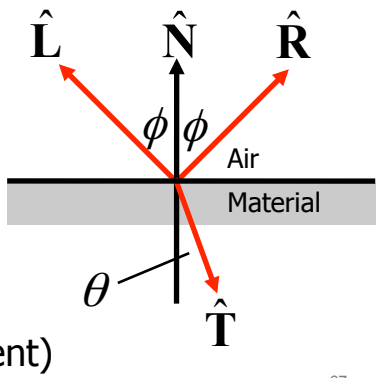
Incident angle and wavelength

- This complex variation is expressed by the Fresnel equation (Augustin-Jean Fresnel, 1788-1827)

$$F = \frac{1}{2}\left[\frac{\sin^2(\phi-\theta)}{\sin^2(\phi+\theta)} + \frac{\tan^2(\phi-\theta)}{\tan^2(\phi+\theta)}\right]$$



- F is the fraction of light reflected
- $\sin\theta = \sin\phi / \mu$
- μ is the refractive index of the material (λ dependent)

67

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Shading and interpolation

68

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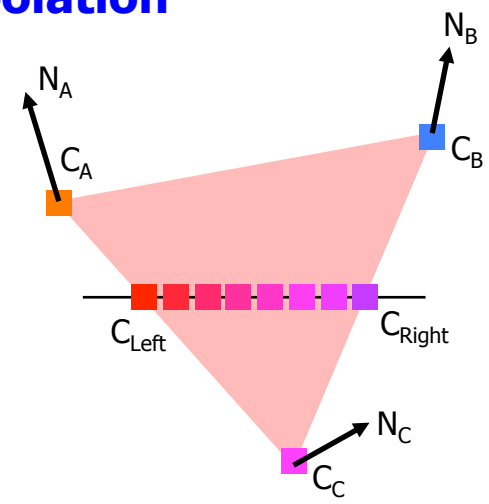
Gouraud interpolation

- compute average vertex normals at A, B and C
- compute pixel colours $\mathbf{C_A}$, $\mathbf{C_B}$, $\mathbf{C_C}$
- for each scanline {
  - average colour $\mathbf{C_{Left}}$ from $\mathbf{C_A}$ and $\mathbf{C_C}$
  - average colour $\mathbf{C_{Right}}$ from $\mathbf{C_B}$ and $\mathbf{C_C}$
  - average between $\mathbf{C_{Left}}$ and $\mathbf{C_{Right}}$ along the scanline

  }



69

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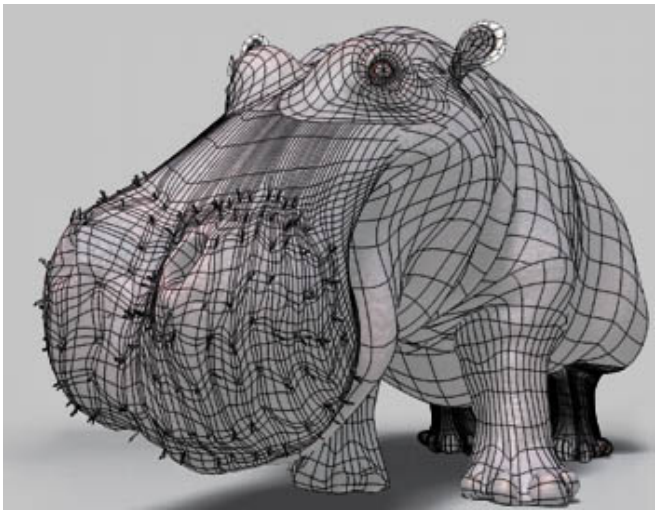
Texture mapping



Jeremy Birn

70

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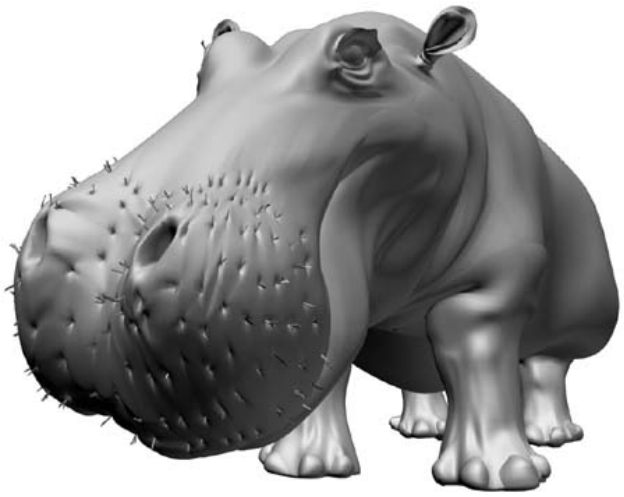
Texture mapping



Jeremy Birn

71

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Texture mapping

Jeremy Birn

72

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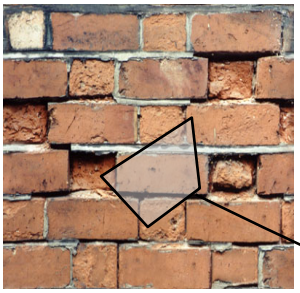
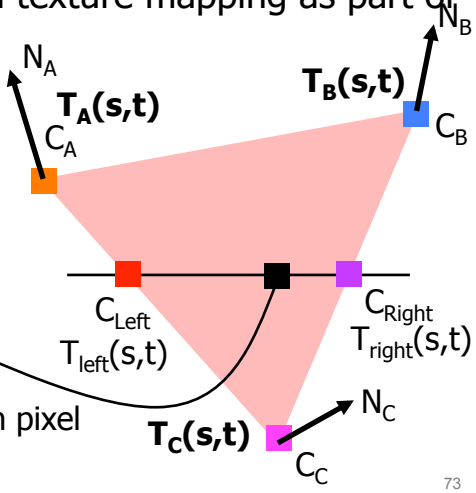
Performing texture mapping

- We want to peform texture mapping as part of rasterisation





Sampling the texture at each pixel

73

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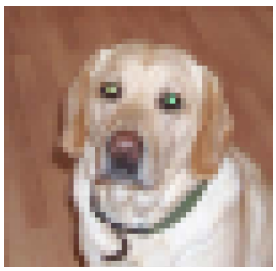
Texture filtering: comparison

Unfiltered texture (1 to 1 pixel correspondence)



Simple filter

Bilinear interpolation filter

74

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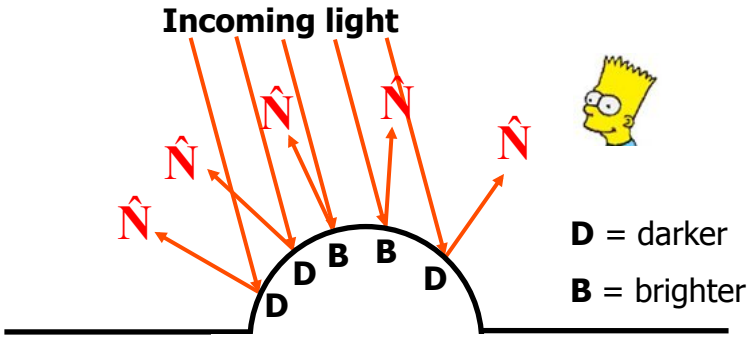
Bump mapping



- Why bumpy surfaces look bumpy
  - The **surface normals** change across the bumps, so the top of the bumps appear brighter than the sides

75

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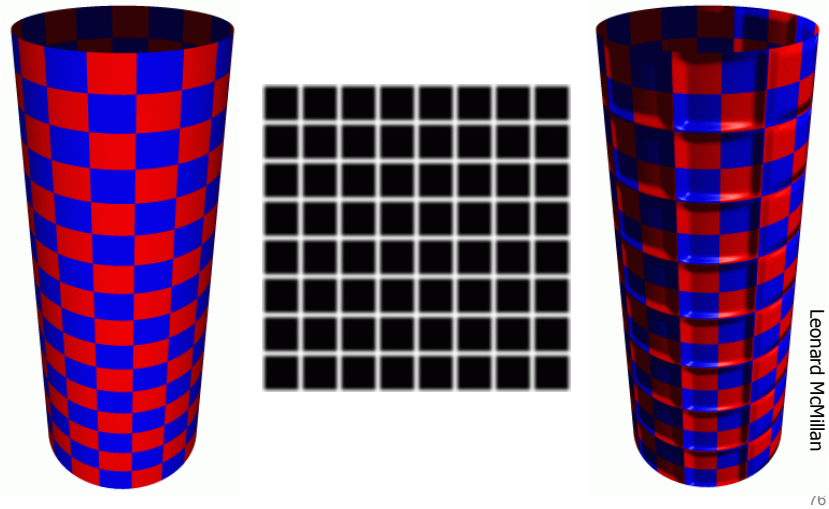
Bump mapping example



Leonard McMillan

76

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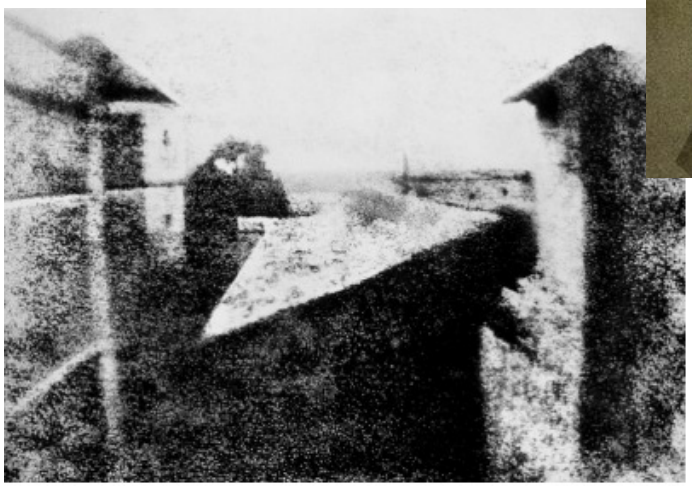
Image processing



Joseph Nicéphore Niépce, 1826 (bitumen on pewter)

77

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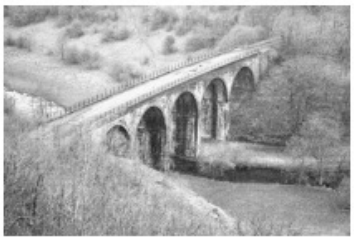
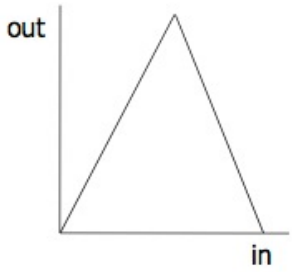
Point processing





78

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Region processing

79

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Image sharpening - before

80

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Image sharpening - after

81

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Image smoothing - before

82

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Image smoothing - after

83

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Edge detection - before

84

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Edge detection - after

85

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Region detection - before

86

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Region detection - after

87

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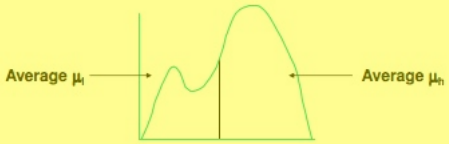
FAQ: how much Maths is there?

$$I_R = k_{aR} I_{aR} + \frac{I_{pR}}{d'}\left[k_{dR}(\hat{\mathbf{N}}\cdot\hat{\mathbf{L}}) + k_s(\hat{\mathbf{R}}\cdot\hat{\mathbf{V}})^n\right]$$

Find a threshold θ such that



$$\theta = \frac{\mu_l + \mu_h}{2} \Rightarrow T = \theta$$

(Start at θ = 0 and work upwards.)

$$M_{\alpha\beta} = \sum_{image} (x-\bar{x})^{\alpha}(y-\bar{y})^{\beta} f(x,y)$$

$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} S_x & 0 & 0 & 0 \\ 0 & S_y & 0 & 0 \\ 0 & 0 & S_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

88

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What to do next

1. Read the course webpage
2. Collect your OpenGL manual from SSO
3. Go through the Tutorial
4. Start Coursework 1