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COMP27112

Computer Graphics and Image Processing

1: Introduction to the course

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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

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Aims and objectives

- **Aims**

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

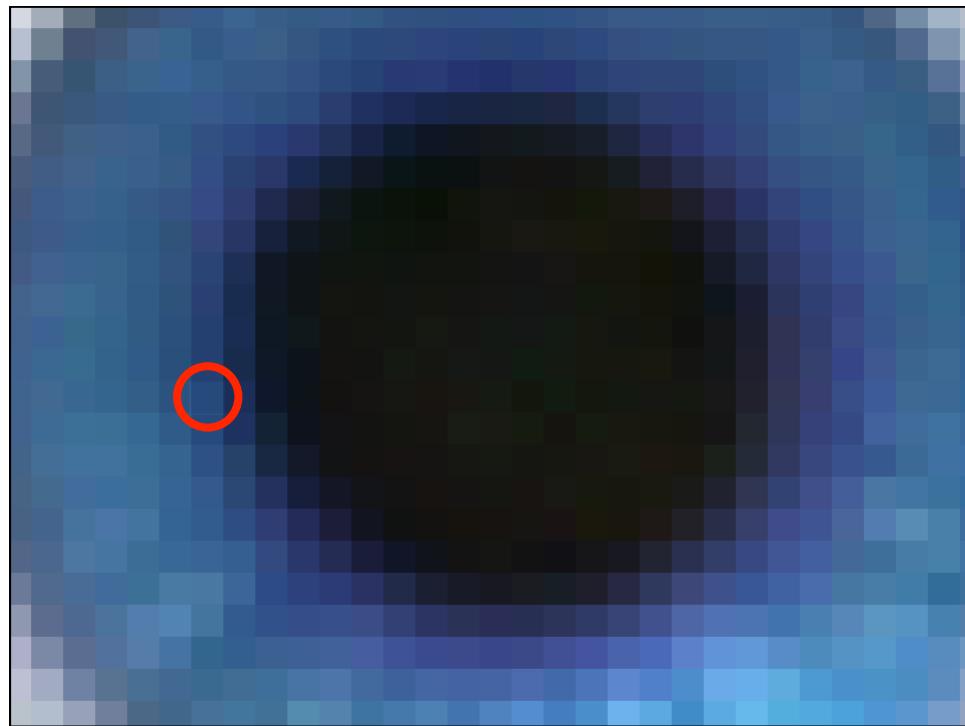
- **Objectives**

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

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Pixels

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

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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

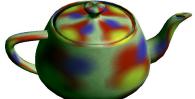
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Course activities

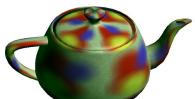
- Lectures & demonstrations
- Labs (4 exercises) in **Week A**
 - TAs, attendance, submit by deadline (no extensions)
- Coursework (5 x 1-hour exercises) in **Week B**
 - Personal study time, no TAs, submit by deadline (no extensions)
- 2-hour online exam: 20 MCQs + essay-type Qs

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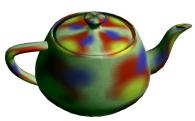
Assessment structure



Labs: 20%



Coursework: 5%



Exam: 75%

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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**

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Lab schedule (Week A)

Lab G: Thu 0900-1100 in LF31

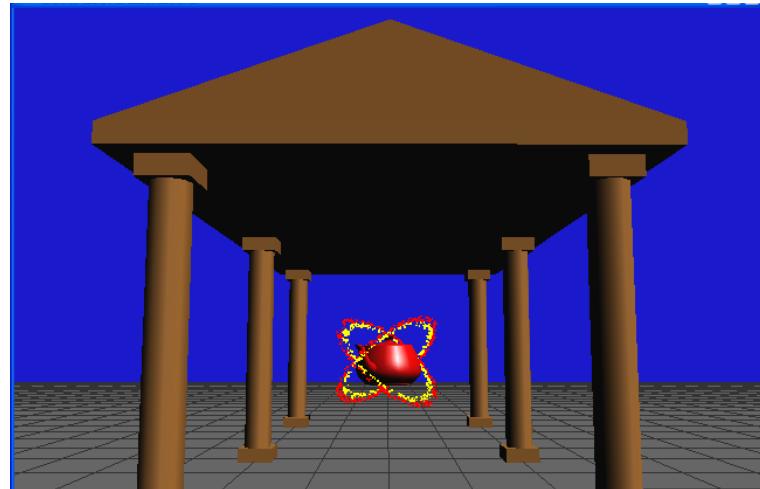
Lab H: Tue 1100-1300 in G23

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

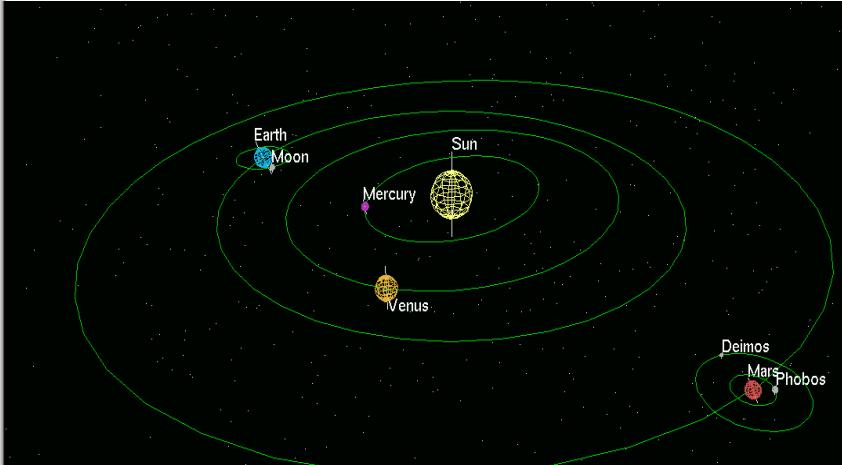
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Lab2: build an orrery



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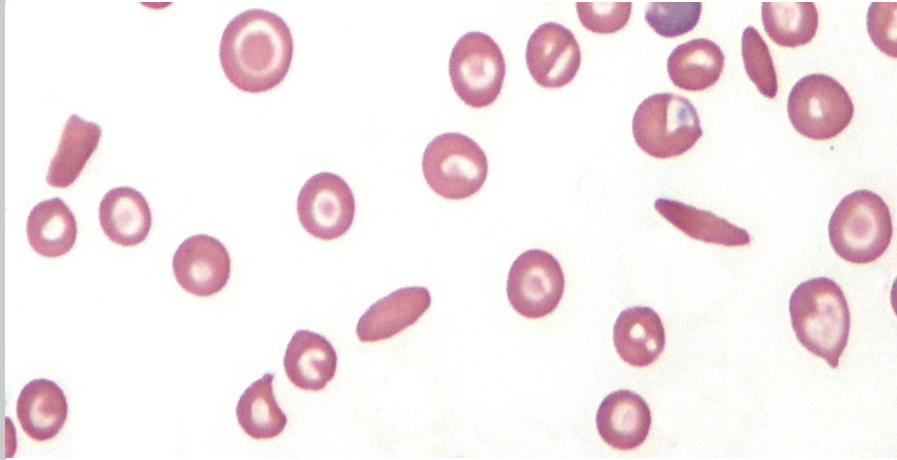
Lab 2 (2 sessions)



- Animated graphics with hierarchical transformations

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Lab 3 (1 session)



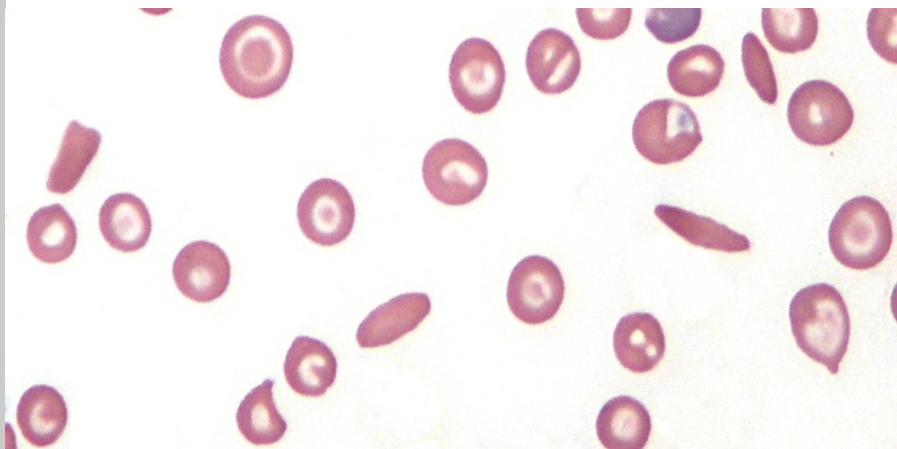
A microscopic image showing several red blood cells against a white background. The cells are roughly circular with a darker center. Some are oriented vertically, while others are more horizontal.

- Pixel processing

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Lab 4 (1 session)



A microscopic image showing several red blood cells against a white background. The cells are roughly circular with a darker center. Some are oriented vertically, while others are more horizontal.

- Connected component labelling

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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**

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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

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Coursework 1

- Intro to OpenGL

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Coursework 2

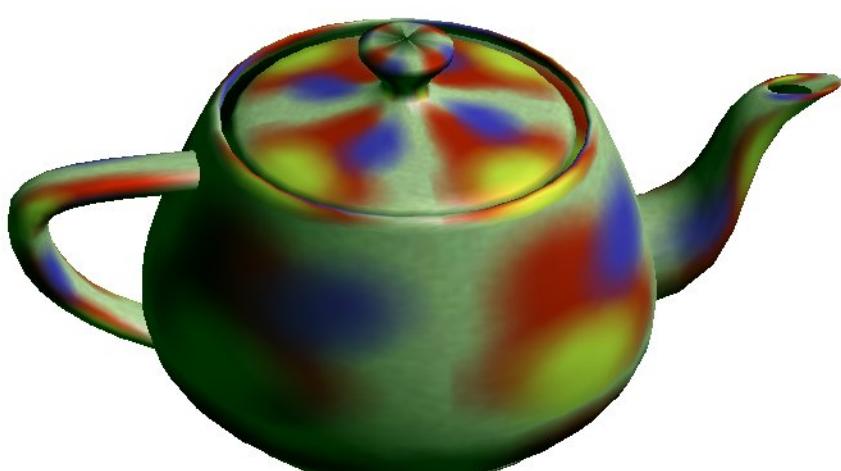
- 3D modelling

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Coursework 3

- Lighting and texture

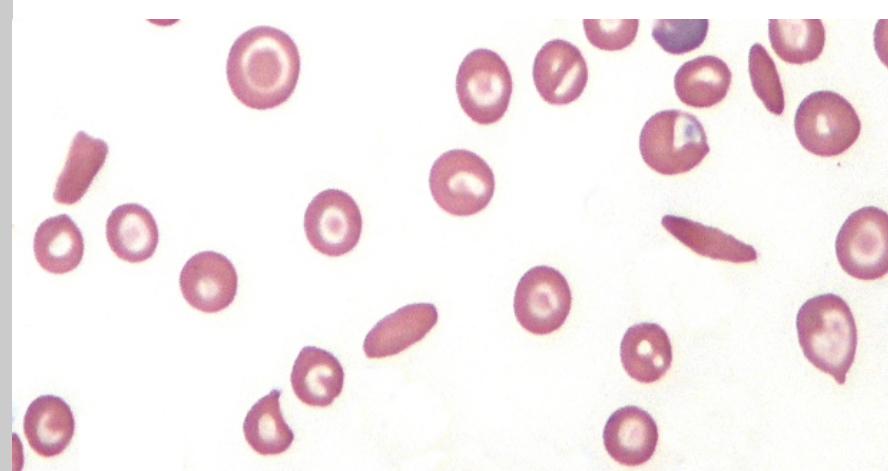


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Coursework 4

- Read/modify/save images

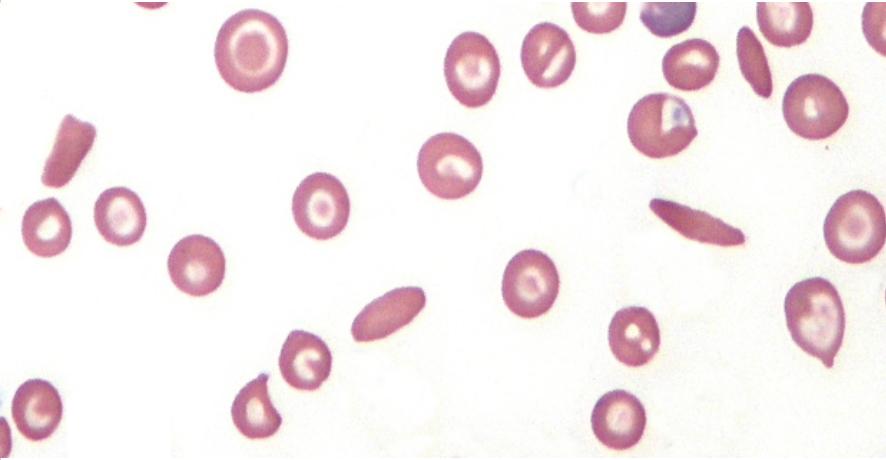


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Coursework 5

- Region-based processing



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Essential resources

[View course details](#)

[Blackboard](#) [My Manchester](#) [Edit](#)

Open to students until Monday, 23 January 2017 : COMP27112: Computer Graphics and Image Processing 2016-17

School of Computer Science

COMP27112: Computer Graphics and Image Processing 2016-17

About the course
The lecturers on this course are:

	
Toby Howard (course leader) Kilburn Room 2.96 toby.howard@manchester.ac.uk	Tim Morris Kilburn Room 2.106 tim.morris@manchester.ac.uk

Full details of the aims, learning outcomes and syllabus of the course are on the [COMP27112 syllabus page](#).

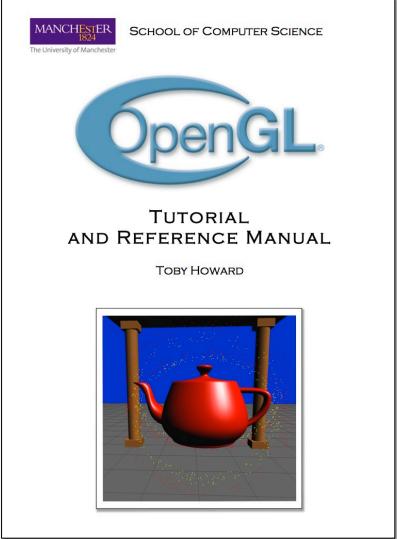
Lectures
We have two lectures each week, both in Kilburn LT1.1: Monday at 14:00, and Thursday at 14:00.
The first half of the course (Computer Graphics) is taught by Toby Howard (TLJH). The second half (Image Processing) is taught by Tim Morris (TM).
All lectures will be recorded and made available at the [Video Portal](#).

Blackboard

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Essential doc: OpenGL



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

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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 C++ include needs to be: `#include <cmath>`. 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

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Essential doc: OpenGL home

The OpenGL website homepage features a banner at the top with the text "The Industry's Foundation for High Performance Graphics" and "FROM GAMES TO VIRTUAL REALITY, MOBILE PHONES TO SUPERCOMPUTERS". Below the banner, there is a navigation bar with links to Documentation, Coding Resources, Wiki, Forums, and About OpenGL. A "Submit News" button is also present. The main content area includes a section for "OpenGL Headline News" with an article about an All-Day Vulkan Workshop in Vancouver. There are also sections for "WGL_EXT_colorspace specification is now available" and "OpenGL ES" and "WebGL" resources.

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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

The book cover for "Interactive Computer Graphics" by Edward Angel, 4th Edition, features a blue background with a central illustration of various 3D objects like cubes and a nautilus shell. The title "Interactive Computer Graphics" is at the top, followed by "A Top-Down Approach Using OpenGL™" and the author's name "EDWARD ANGEL" at the bottom.

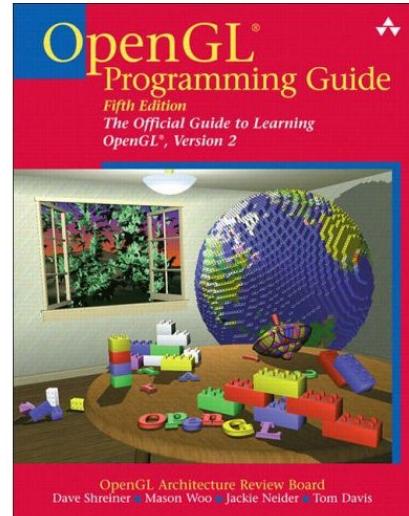
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Course books (not essential)

OpenGL Programming Guide (5th-8th Editions)

Mason Woo, Jackie Nieder, Tom Davis et al

Addison-Wesley
ISBN 0321481003



OpenGL Programming Guide
Fifth Edition
The Official Guide to Learning OpenGL®, Version 2

OpenGL Architecture Review Board
Dave Shreiner • Mason Woo • Jackie Nieder • Tom Davis

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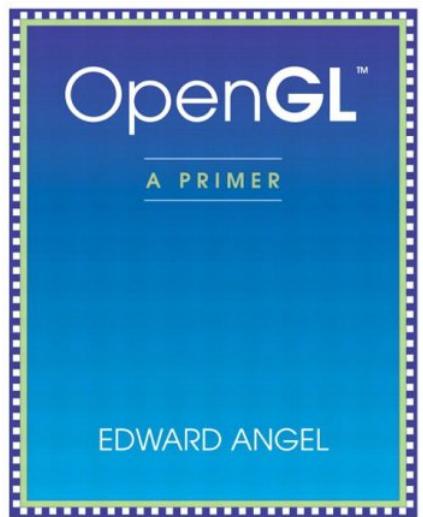
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Course books (not essential)

OpenGL: A Primer

Edward Angel

Addison-Wesley
ISBN 0201741865



OpenGL™
A PRIMER
EDWARD ANGEL

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Context

**Why are computer graphics and
image processing important?**

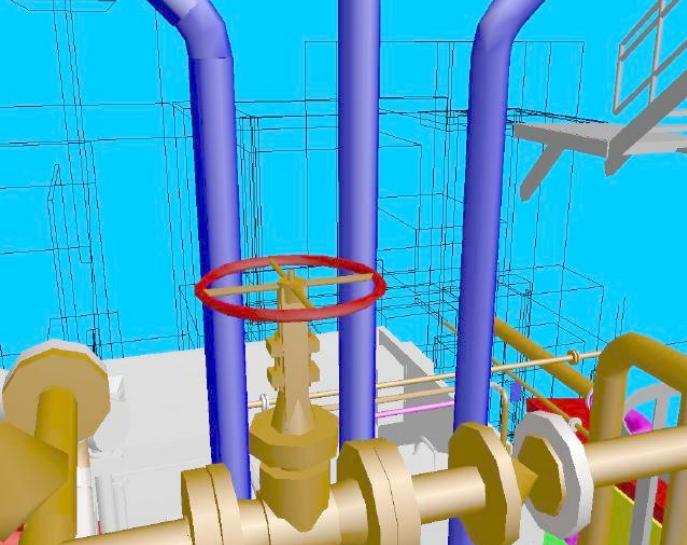
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Computer graphics applications

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Engineering



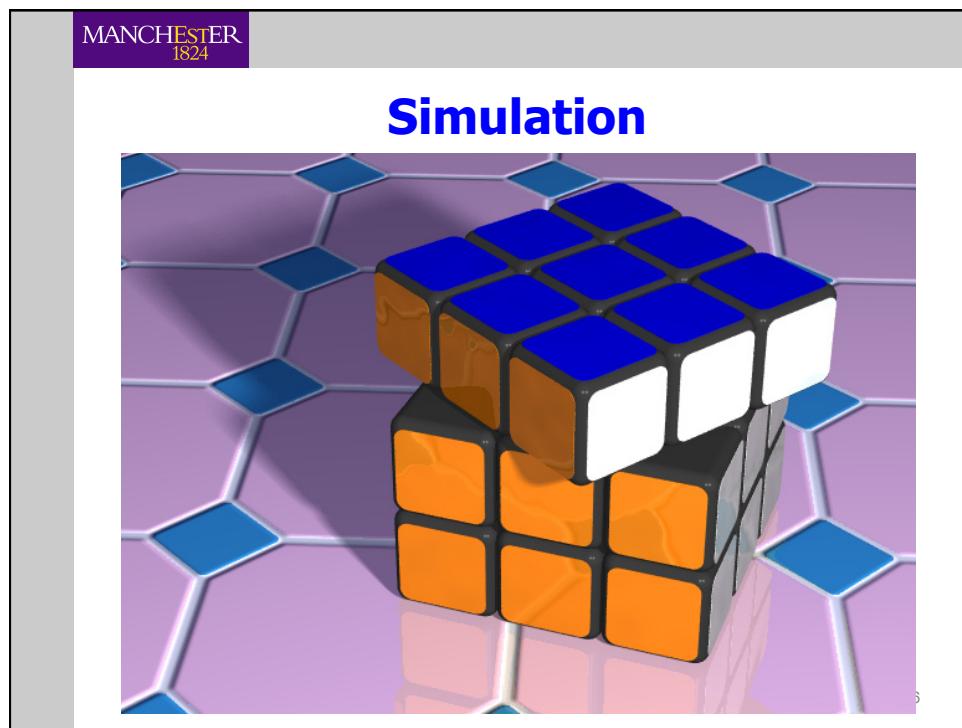
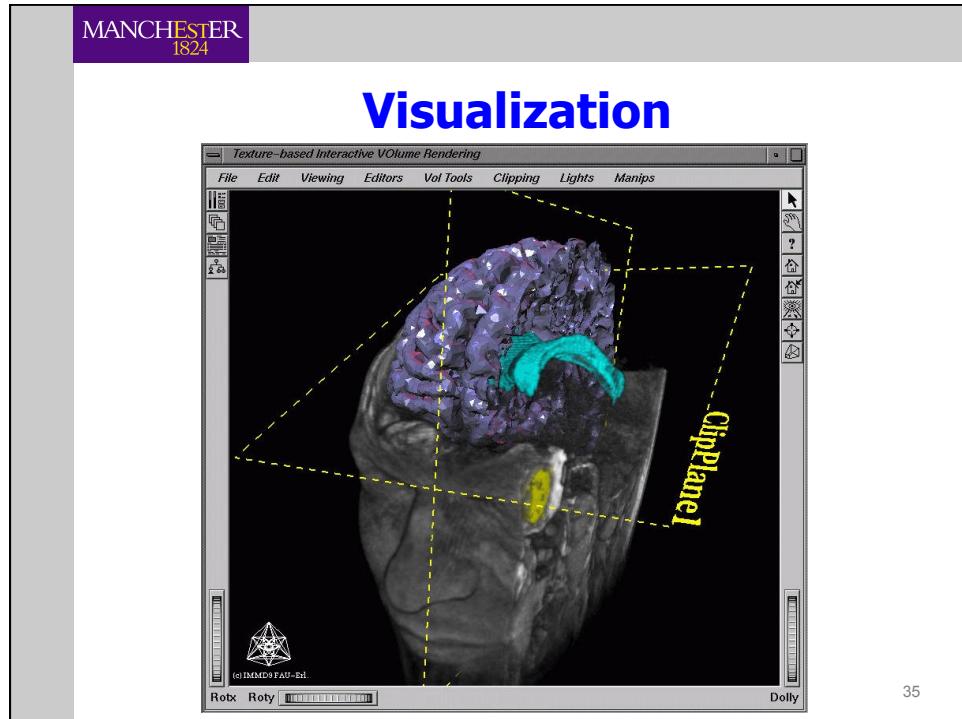
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Visualization



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VR guy

Interactive virtual environments

VR Headset	Price
HTC Vive	\$800
PlayStation VR	\$700
Oculus Rift	\$600
Google Daydream	\$100
Samsung Gear	\$70
Google Cardboard	\$15

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Virtual Environments for Therapy

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Augmented reality

Kings Place, N1 9GU

Network Rail
The Observer

THE RESTAURANT
Go to website
See menu
See reviews

Taxi - AVAILABLE

Jazz here from 7pm today

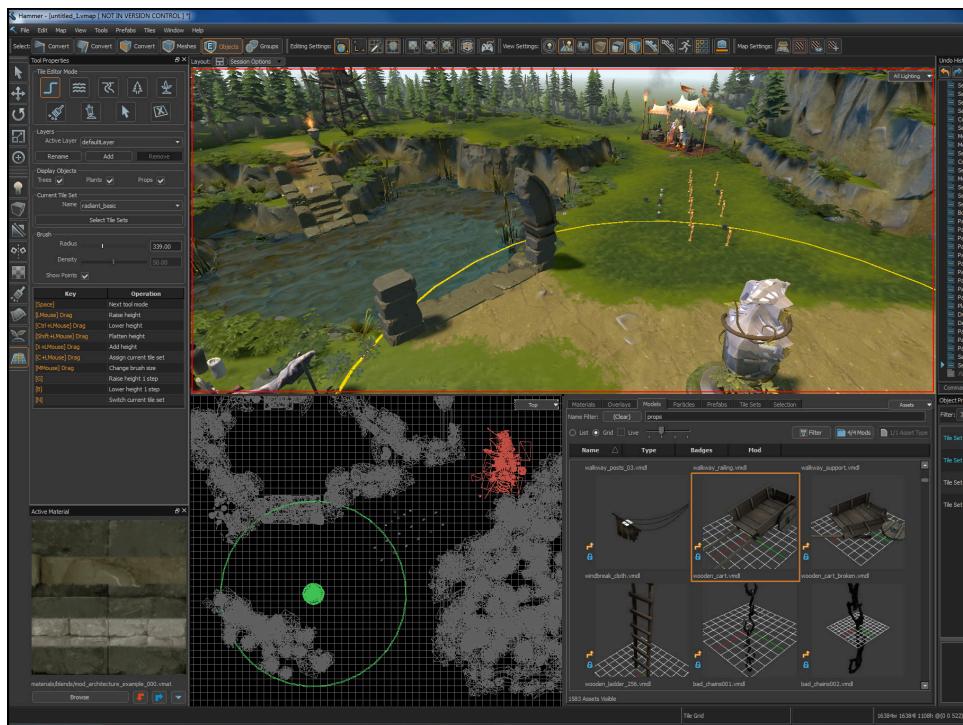
Board table King's Cross 300m

expand page?

more...

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Image processing applications

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Medical

A 3D rendering of a human brain in a lateral view, colored with a gradient from blue to yellow. The colors represent data such as cortical thickness or functional activity across the brain's surface. The word "Medical" is displayed in large blue letters above the image.

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Engineering

Two side-by-side images of a mechanical component, likely a metal casting. The left image is labeled "Original" and shows the part in a vibrant purple and pink color scheme. The right image is labeled "Cracks Detected" and shows the same part in grayscale, with a prominent red line highlighting a specific crack in the lower right section. The word "Engineering" is displayed in large blue letters above the images.

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Face recognition



A close-up photograph of a woman with blonde hair and blue eyes. A grid of dashed lines is overlaid on her face, starting from her forehead, through her eyes, nose, and mouth, down to her chin, used for facial recognition analysis.

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Photography/video/media



A photograph of a city skyline at sunset or sunrise, featuring several tall buildings reflected in a body of water in the foreground. The sky is a warm orange and yellow color.

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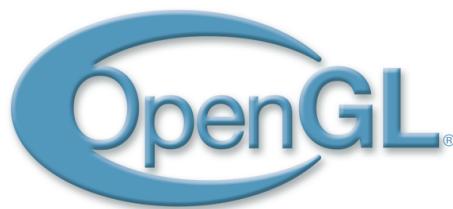
COMP27112 syllabus

- 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

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OpenGL

- History
- Basic concepts
- Program structure
- Demos

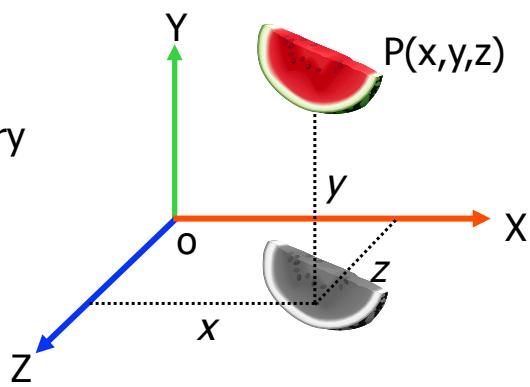


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3D coordinate systems

- 3D geometry
- 3D trigonometry
- Homogeneous matrices

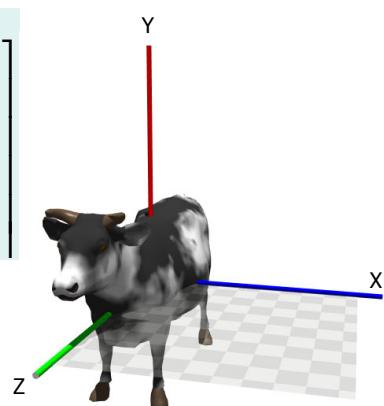


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A scaling matrix

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



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Rotation

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

$$x' = x \cdot \cos\theta - y \cdot \sin\theta$$

$$y' = x \cdot \sin\theta + y \cdot \cos\theta$$

$$z' = z$$

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Modelling in 3D

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

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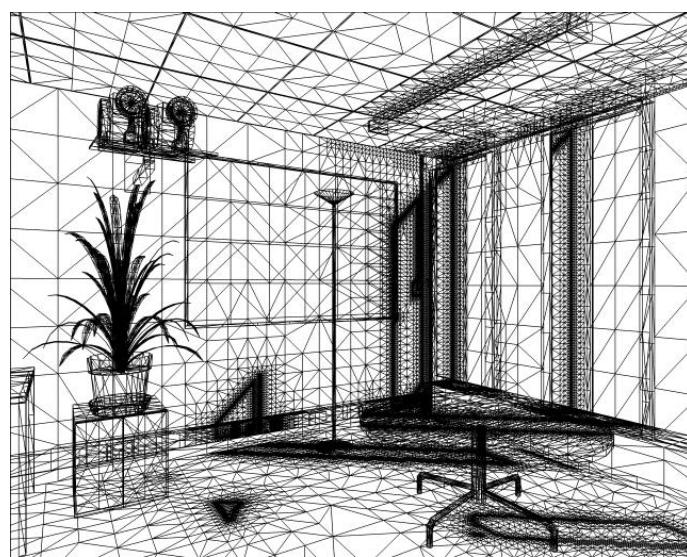
Polygon meshes



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Polygon meshes



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Mesh data structure

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

Face list	Edge list	Vertex list
f_0	e_0 e_1 e_2	x_0, y_0, z_0 x_1, y_1, z_1 x_2, y_2, z_2 x_3, y_3, z_3

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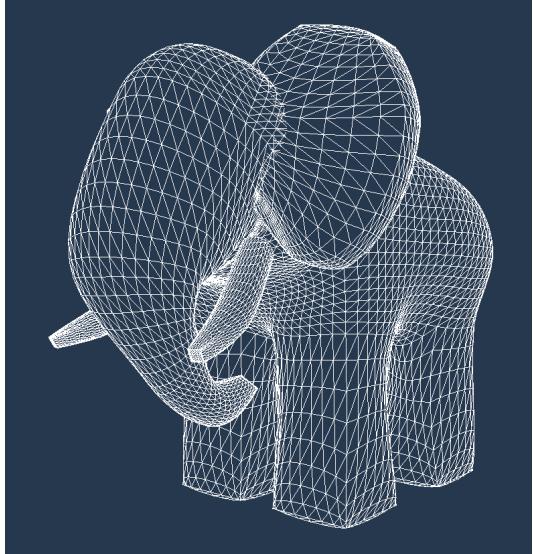
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Hidden-surface removal

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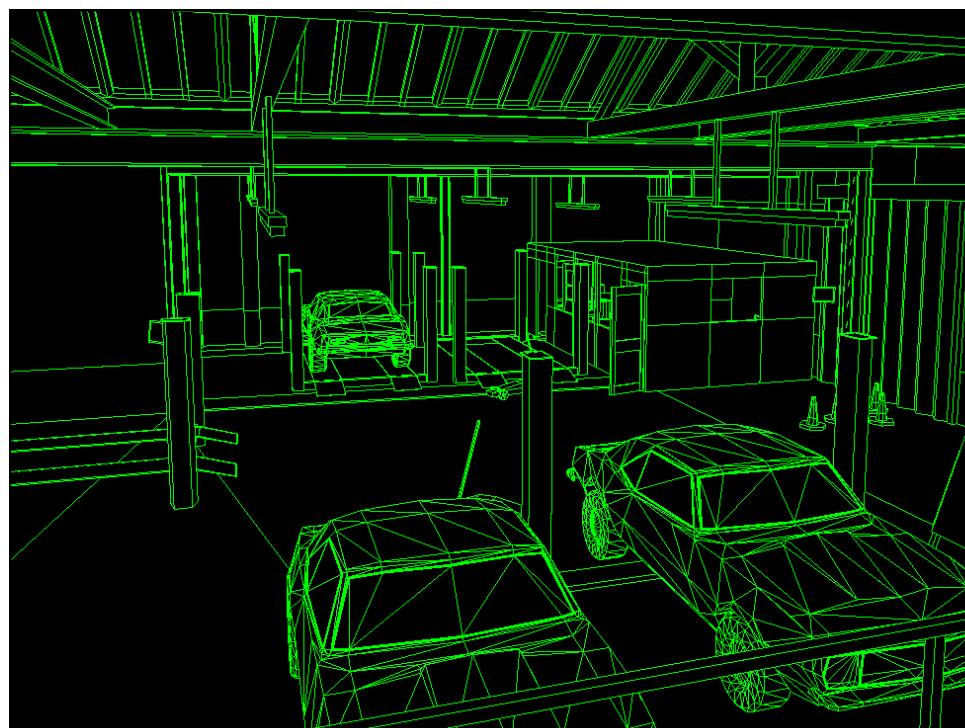
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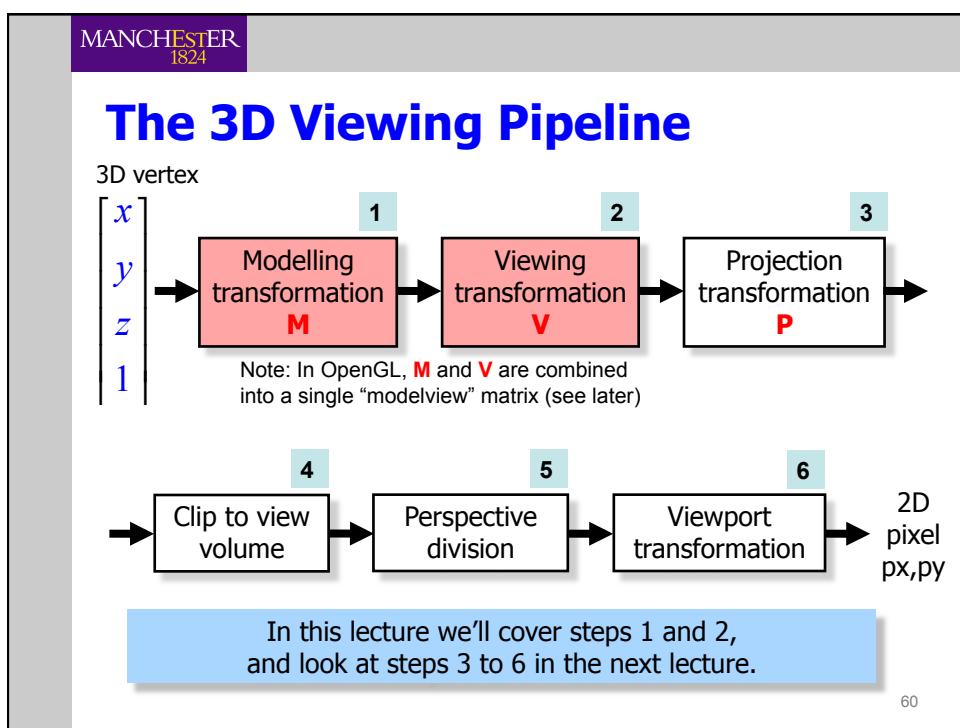
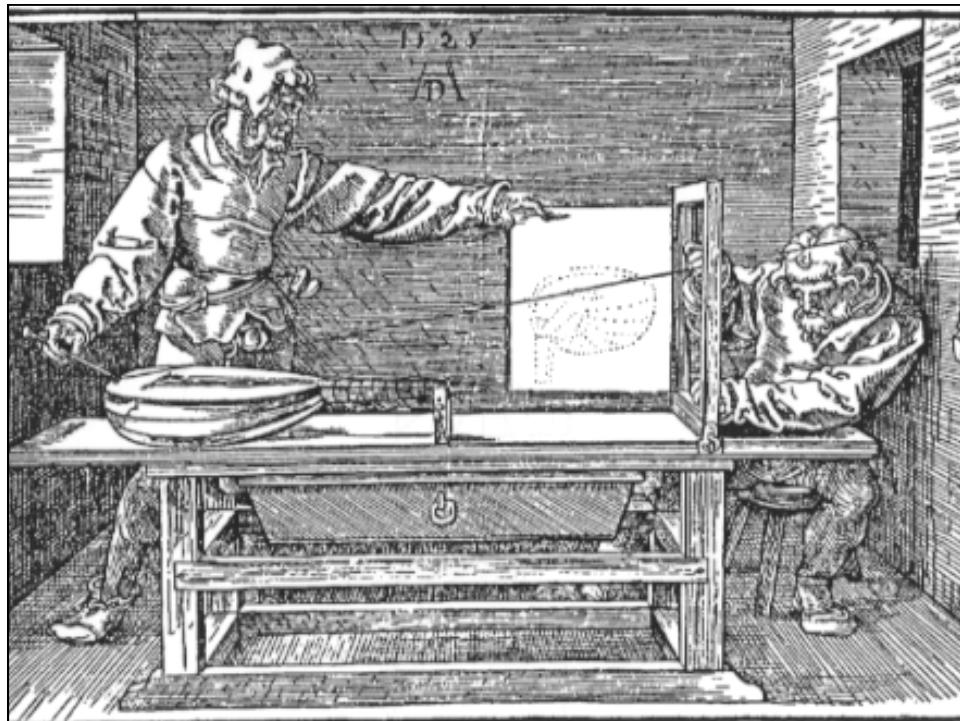
Hidden-surface removal



A wireframe model of a hand holding a small, irregularly shaped object, possibly a nut or bolt. The hand is shown from a three-quarter perspective, gripping the object. The background is dark blue.

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The Camera Analogy

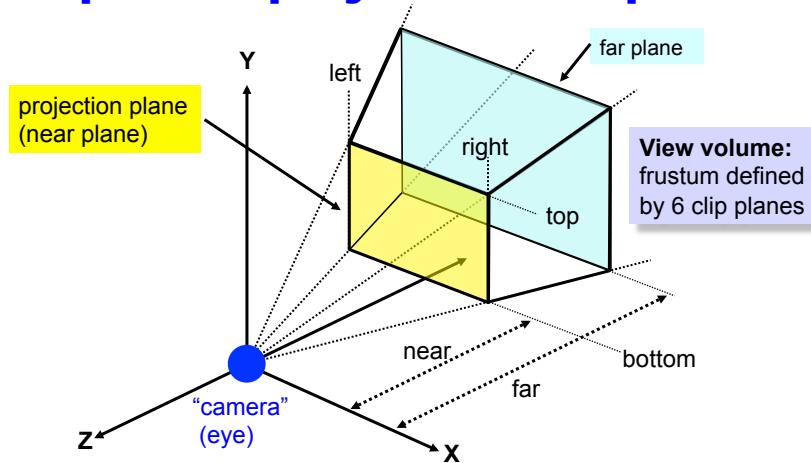


Step 1: Set up your tripod and point your camera at the scene

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Perspective projection in OpenGL



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

OpenGL

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Diffuse light/surface interaction

Diffusely reflected light

Pigment particles

Thin transparent layer containing pigment

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Diffuse reflection: Lambert's Law

I_p \hat{L}

\hat{N}

θ

I_e

- 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)

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Specular light/surface interaction

angle of reflection = angle of incidence

Surface normal vector

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

air/surface interface

The pigment particles are not involved in the reflection

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Modelling specular reflection

\hat{L}

\hat{N}

\hat{R}

\hat{V}

$\phi = 20^\circ$

Observed specular = 60%

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

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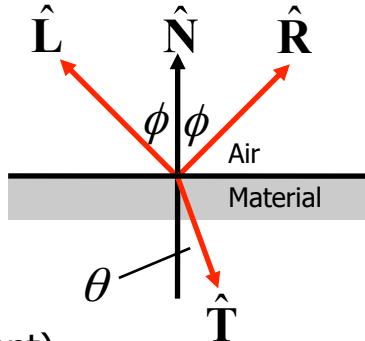
Incident angle and wavelength

- 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)



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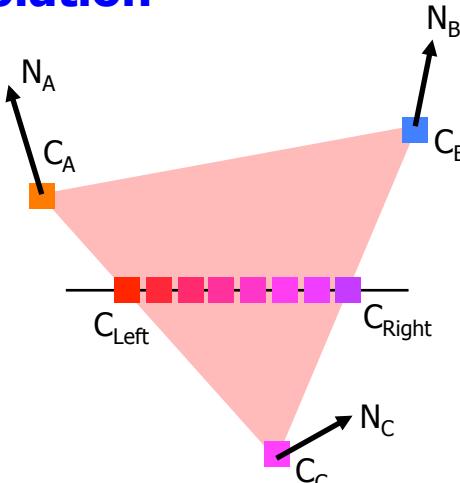
Shading and interpolation



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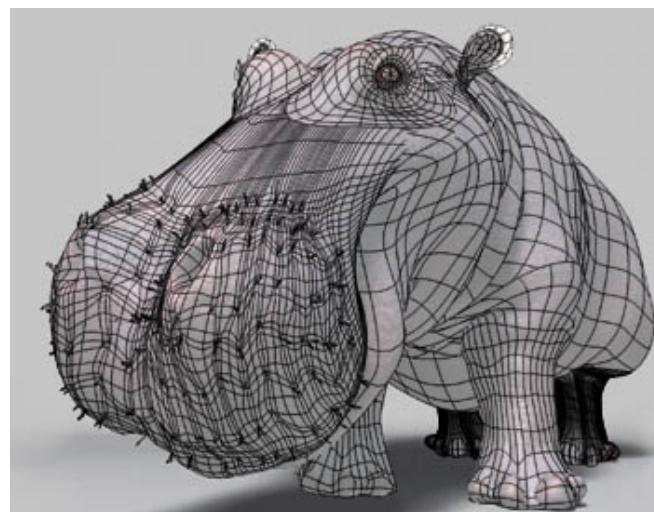
Gouraud interpolation

- 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 $\mathbf{C}_{\text{Right}}$ from \mathbf{C}_B and \mathbf{C}_C
 - average between \mathbf{C}_{Left} and $\mathbf{C}_{\text{Right}}$ along the scanline
- }



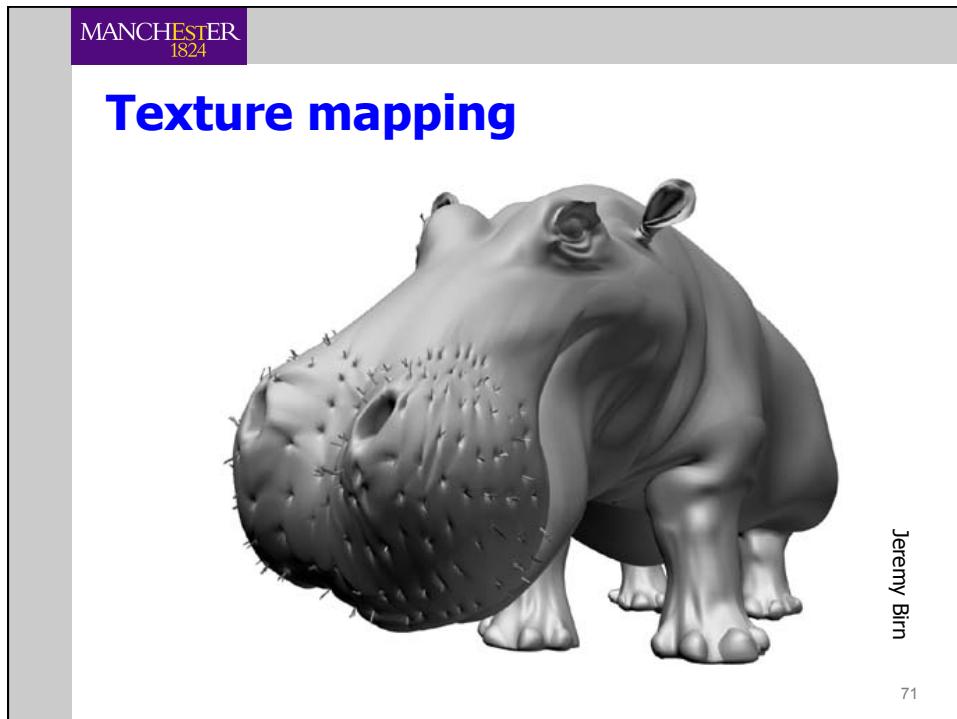
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Texture mapping



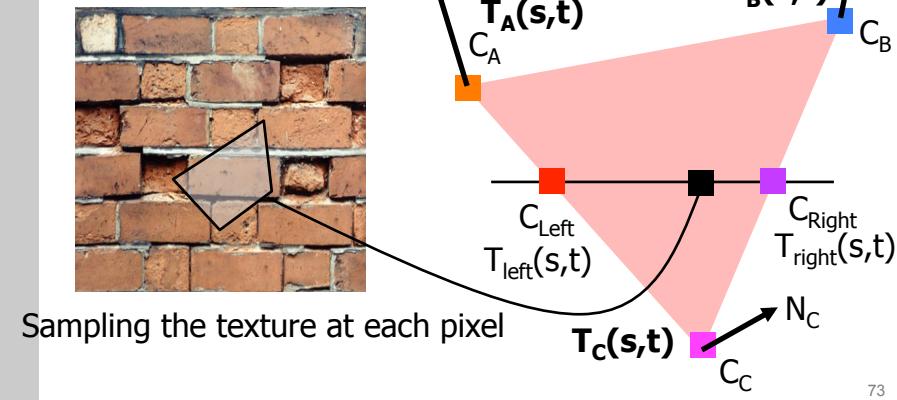
Jeremy Birn

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Performing texture mapping

- We want to perform texture mapping as part of rasterisation



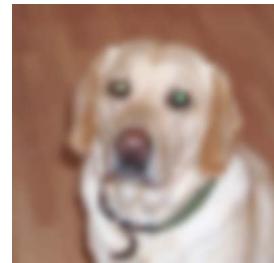
Texture filtering: comparison



Unfiltered texture
(1 to 1 pixel
correspondence)



Simple filter



Bilinear
interpolation filter

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Bump mapping

Incoming light

\hat{N}

\hat{N}

\hat{N}

\hat{N}

\hat{N}

\hat{N}

D D B B D D

D = darker

B = brighter

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

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Bump mapping example

Leonard McMillan

/b

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Image processing

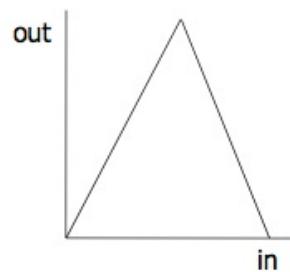
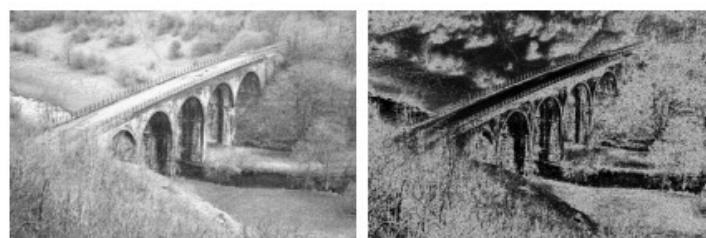


Joseph Nicéphore Niépce, 1826 (bitumen on pewter)

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Point processing



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Region processing



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Image sharpening - before



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Image sharpening - after



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Image smoothing - before



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Image smoothing - after



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Edge detection - before



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Edge detection - after



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Region detection - before



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Region detection - after

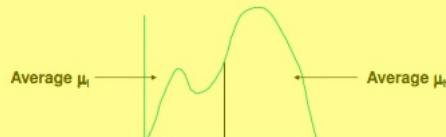


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FAQ: how much Maths is there?

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

Find a threshold θ such that

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

(Start at $\theta = 0$ and work upwards.)

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

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

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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