

# Advanced Computer Graphics

## Lecture-01 Introduction

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# Course information (CI5326701)

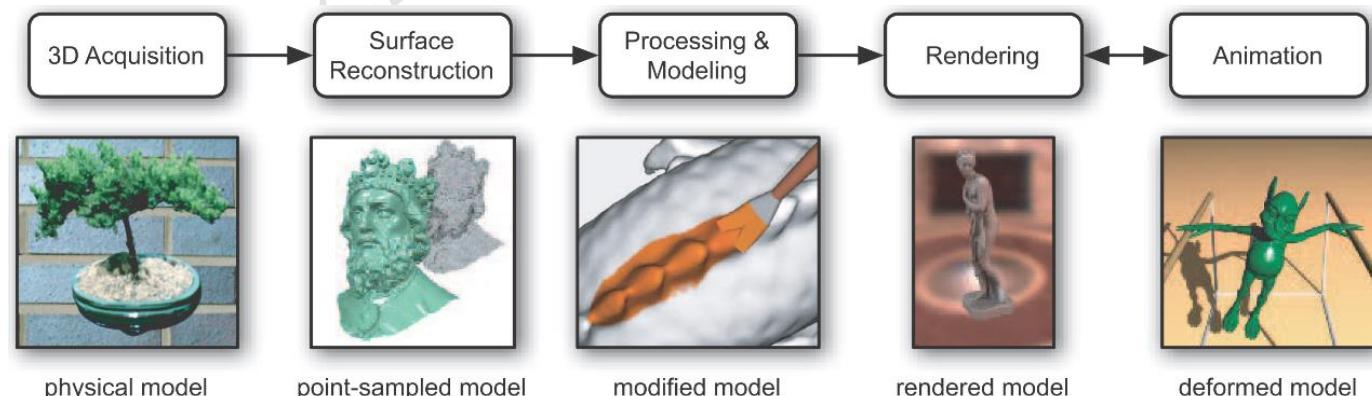
- Instructor : Tzung-Han Lin (林宗翰)
- E-mail: [thl@mail.ntust.edu.tw](mailto:thl@mail.ntust.edu.tw)
- web: <http://homepage.ntust.edu.tw/thl/>
- Office: IB1037 (Int. Bld. 10F)
- Phone: (02)27303717
- Course TA: NA
  
- Location : IB607
- Time : (Tue.) T6~8 PM3:30~6:20





# Course direction

- To serve the need of industry in so-called “3D”
- We will focus on
  - 3D transformation (matrix operation)
  - 3D file format I/O
  - 3D visualization pipeline
- 3D scanning and printing relevant industry, in part.





# Course overall outline

- Introduction and 3D Computer Graphics Review
- 3D Model Files Format
- Basic Math and Linear Algebra
- 2D and 3D Transformation
- 3D Projection and Viewing
- 3D, Depth and Stereoscopic Render
- Lighting and Shading Algorithm
- OpenGL (+Shading Language)



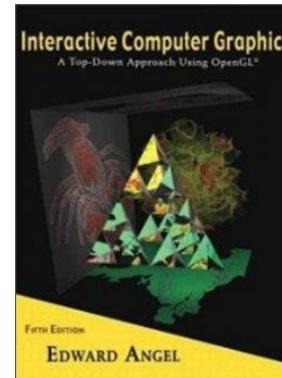
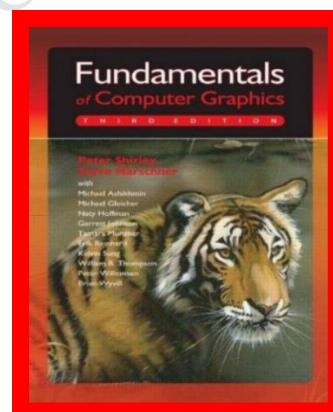
# Course agenda (tentative)

Week	Date	Content	Tentative Item
1	09/15	Introduction	
2	09/22	3D geometry	
3	09/29	fundamental linear algebra	homework#1
4	10/06	coordinate transformation	
5	10/13	introduction to 3D open graphics lib. (Open	homework#2
6	10/20	Camera model and 3D projection	
7	10/27	Camera model and 3D projection	Midtern project Assignment
8	11/03	graphics of 3D object	
9	11/10	Midterm Ex. Week	11/4~11/8 Midterm Exam Week
10	11/17	implementation in OpenGL-2	
11	11/24	3D object rendering	homework#3
12	12/01	3D object rendering	
13	12/08	lighting and shading model	homework#4
14	12/15	implementation in OpenGL-3	
15	12/22	lighting and shading model	Final project report Assignment
16	12/29	implementation in OpenGL-4	
17	01/05	implementation in OpenGL-5	
18	01/12	Final Ex. Week	1/6~1/10 Final Exam Week



# Reference and textbook

- Course Lectures (Major)
- Peter Shirley, “Fundamentals of Computer Graphics,” 3rd edition, A. K. Peters, ISBN: 9781568814698 (Primary Use)
- Edward Angel, “Interactive computer graphics a top-down approach using OpenGL,” (5th edition), Addison-Wesley, ISBN:9780321535863 (Supplemental Textbook)





# Course objective

- Learn fundamentals of 3D computer graphics
- Understand the algorithm of graphics
- 3D file format
- Know how to process 3D data
- Capability of 3D programming by OpenGL(based on python or C/C++)



# Course Level

- Lecture: Upper Intermediate
- Programming: Middle
- Homework: Middle
- Midterm & Final project: Upper Intermediate



# Learning objective

- Understand 3D coordinate and its transformation
- Read / modify 3D files by self-developed programs
- Solve problems in or by 3D geometry
- Correctly and precisely **determine the transformation** between 2D and 3D
- Write high performance 3D program, and develop basis of commercial software



# Pre-request skills

- Calculus or linear algebra: basic matrix operation
- Programming skill: python (or C/C++)
  - Python sample codes will be provided
  - Modify python code under given examples
- Rookie is acceptable and welcome.



# Grade evaluation (tentative)

- Participation, feedback(10%)
- Homework (40%)
  - 3~5 Assignments (normally 4 assignments)
- Midterm Project (25%)
- Final Project (25%)



# Grade qualify (NTUST policy)

- A+：達成學習目標，且表現優異
  - A：達成學習目標
  - A-：雖達成學習目標，但需再精進
  - B+：達成部分目標，且品質佳
  - B：達成部分目標
  - B-：雖達成部分目標，但需要精進
  - C+：達成最低目標
  - C：雖達成最低目標，但需精進
  - C-：達成最低目標，但有重大缺失
  - D：雖未達最低目標，但可再研修
  - E：未達最低目標，不核予成績
- Qualified (for Graduate)
- Qualified (for under Graduate)

等第制	百分制	GP									
A+	95	4.0	B+	78	3.3	C+	68	2.3	D	55	1.0
A	87	4.0	B	75	3.0	C	65	2.0	E	49	0.0
A-	82	3.7	B-	71	2.7	C-	61	1.7			



# Grade distribution in last five semesters



# Course performance evaluation

## ■ Good response list (last 5 years) from students

108(一)	CI5326701	高等電腦圖學 Advanced computer graphics	<ol style="list-style-type: none"><li>1. 老師上的很實用，觀念教的很紮實，</li><li>2. 老師教得好</li></ol>
107(一)	CI5326701	高等電腦圖學 Advanced computer graphics	<ol style="list-style-type: none"><li>1. 好課，有實務上的學習，可以學到很多</li><li>2. 這門課對沒有碰過圖學的人會有一點難，但是跟著老師的脚步學，會慢慢的覺得有趣</li><li>3. 老師講的很詳細</li><li>4. 了解圖學的背後的原理和程式撰寫</li><li>5. 老師用心講解</li><li>6. 老師很樂意為學生解答，助教也是，讓我從中學習許多。</li><li>7. 老師講話詳細</li></ol>



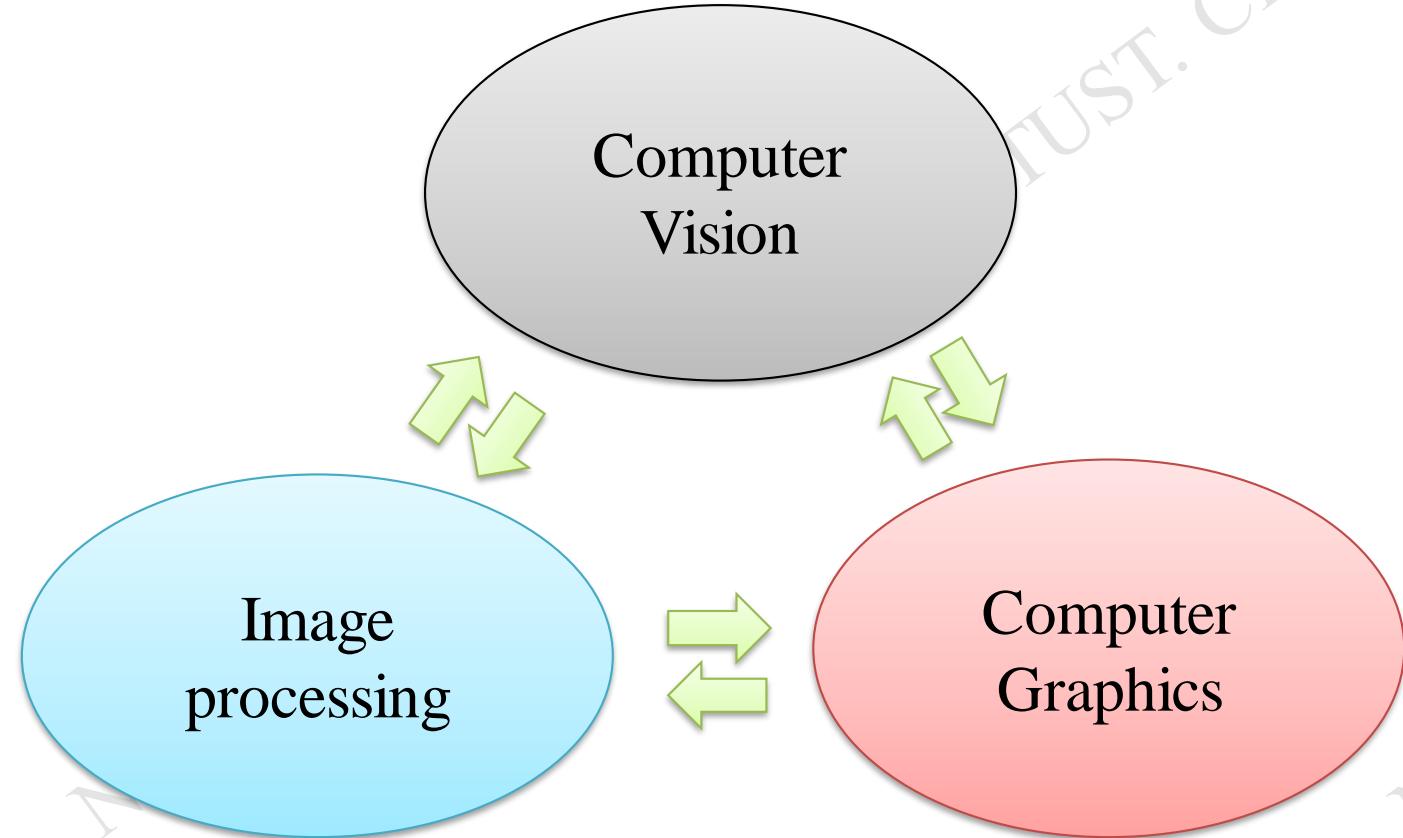
# Course performance evaluation

## ■ Good response list (last 5 years) from students

106(一)	CI5326701	高等電腦圖學 Advanced computer graphics	<ol style="list-style-type: none"><li>理論實作並進。</li><li>老師講解詳細。</li><li>老師和助教很有耐心。</li><li>教學詳細，有很多sample code供學生參考，老師與助教皆非常樂意為學生解惑，以一句話形容就是「付出多少，就能得到多少」。</li><li>老師和助教都很認真地回復並回答我的問題，讓我在這門課受益良多，學到很多相關知識和程式的寫法。</li><li>每每課堂第一節，總是會有上周重點整理。</li><li>老師也會提前放上講義，供參考及練習。</li><li>適度調整作業的收件日，及作業的技巧提示etc。</li><li>電腦圖學課程很難不沉悶，畢竟理論，實作各佔一半，若老師能有在課堂上更良好的互動，會更能夠消化及學習。</li><li>教師授課表達清楚、舉例很貼切，上課認真，並且盡力表達清楚，也很盡心幫同學解惑。</li></ol>
105(一)	CI5326701	高等電腦圖學 Advanced computer graphics	<ol style="list-style-type: none"><li>老師詳細講解，範例清楚</li><li>老師解說清楚</li><li>相當有趣，雖然矩陣真的不是有趣的東西</li><li>教材準備很詳細</li><li>老師很認真，有程式範例，讓學習效果更好很棒。</li><li>上課認真清楚易懂</li></ol>
104(一)	CI5326701	高等電腦圖學 Advanced computer graphics	<ol style="list-style-type: none"><li>了解圖學，知道3D資料概念</li><li>理論與實作並重</li><li>了解3D的概念以及在使用3D軟體時不會如此迷茫</li><li>老師會盡力講解每一部分</li><li>有一些sample code更容易進入狀況</li><li>製作動畫的概念與程式作業，讓自己對於3D更加的感興趣</li><li>首先謝謝老師及助教的指導，讓我無痛進入圖學的領域！專案的實作也讓我思考很多！雖然專案沒有標準答案，但希望可以給一些評語或建議大家可以擦出更多想法。</li></ol>



# Relation among other fields





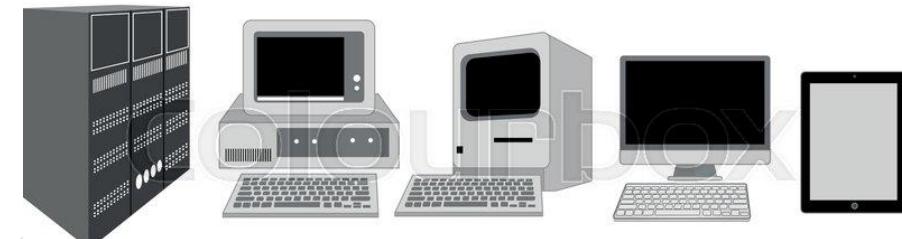
# An introduction & graphics evolution short history

- 1960 Age - Sutherland
  - E. SUTHERLAND, Sketchpad: A man-machine graphical communication system, Summer Joint Computer Conference, (1963).
- 1970 Age
  - Shading- Gouraud shading and Phong shading
  - Ray tracing
- 1980 Age
  - Binary space partitioning (BSP)
  - IBM Silicon Graphics (SGI) and VR (by NASA)
- 1990 Age
  - Silicon Graphics GL / OpenGL
  - Hardware acceleration (acceleration card, vectorization)
- 2000 Age
  - Parallel Computing
  - Mobile Computing



# An introduction & graphics evolution short history

## ■ Graphics interfaces

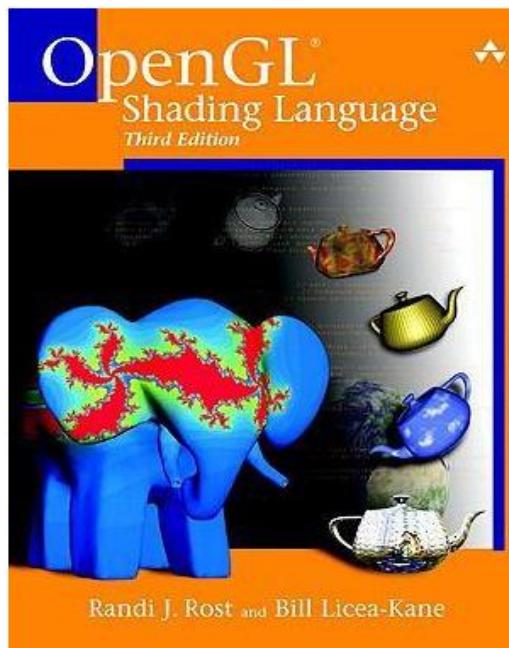




# An introduction & graphics evolution short history

## ■ In last decade...

Vectorize



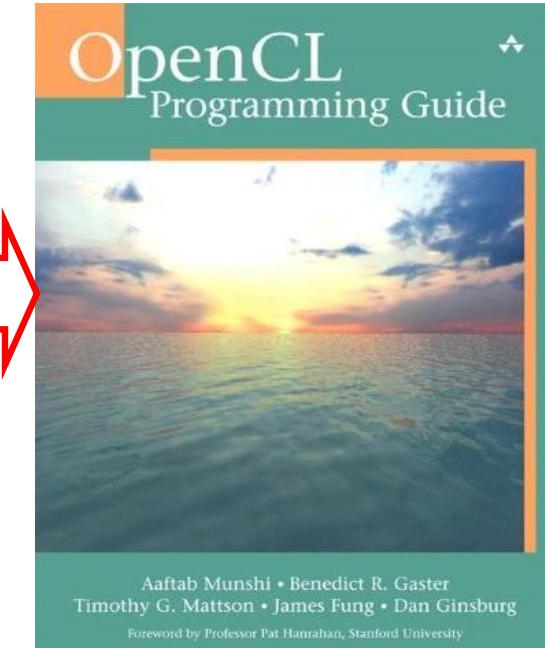
OpenGL Shading Language

Parallel



Faking reality 2007 GPU/Cuda

Shader (Parallel)



OpenCL



# What does Computer Graphics mean?

- “Computer graphics are visual representations of data displayed on a monitor made on a computer. Computer graphics can be a series of images (most often called video) or a single image.”
- “The term computer graphics includes almost everything on computers that is not text or sound”



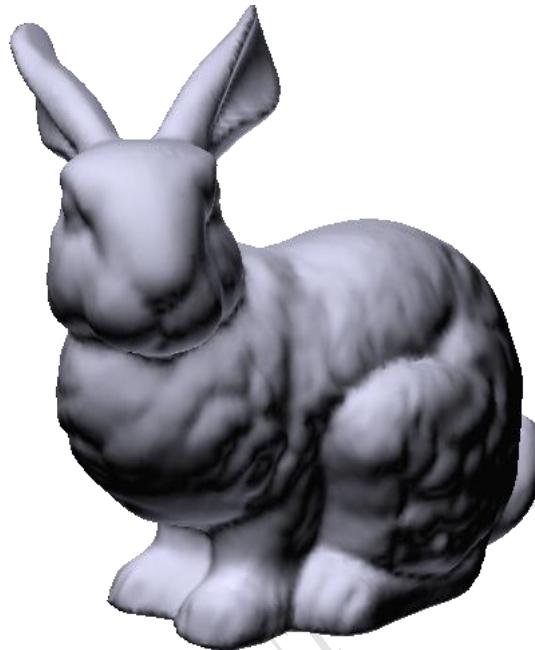
# What position is this lecture?

- Application
- Engine / Framework
  - Unity, Orge3D, ID Tech, Unreal, HeroEngine...
- Platform
  - Windows / Linux / Mac / Android ...
- System (Driver/Firmware)
- Render API
  - OpenGL, DirectX, html5
- Graphic Card
  - nvidia, AMD



# Computer graphics and visualization

- For general purpose



Gouraud Shading  
Traditional rendering method



Rendering(light reflection)  
Environmental Texture



Realistic rendering



# Computer graphics and visualization

- For medical information



Scientific application  
Medical use



Augmented reality / VR  
Superimpose images



Medical rendering  
Diagnose purpose



# Computer graphics and visualization

- For special effect



Computational photography  
(Embedded 3D information)



NPR/ART  
Non-photo realistic  
rendering



Voxel rendering



# Computer graphics and visualization

- For special effect
- Frame-buffer processing



Special effect (Avatar movie)  
Synthesized image

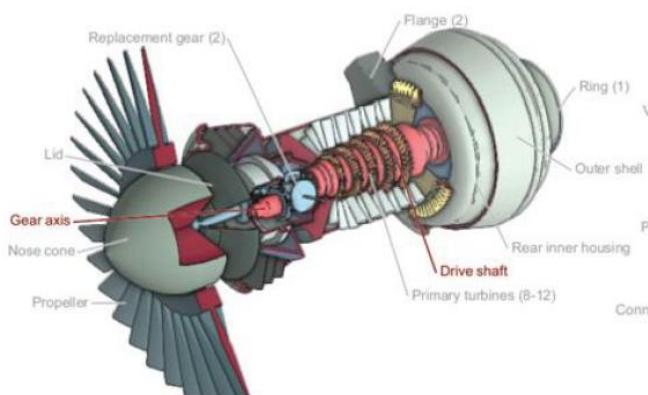


Shading effect  
(Game Street Fighter)

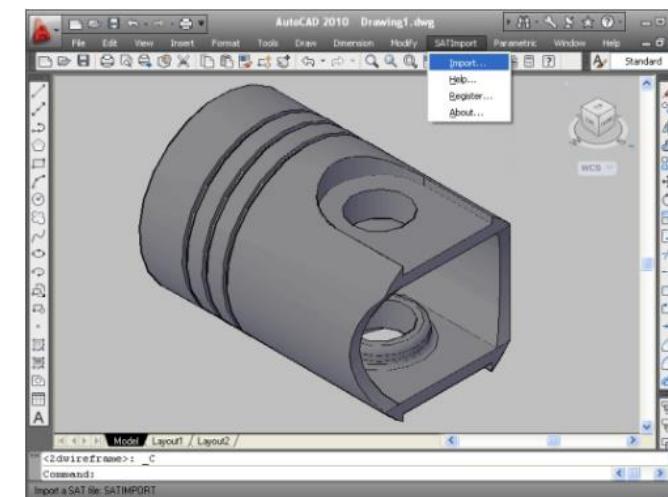


# Computer graphics and visualization

## ■ Enhanced contours and outlines



Design/illustration

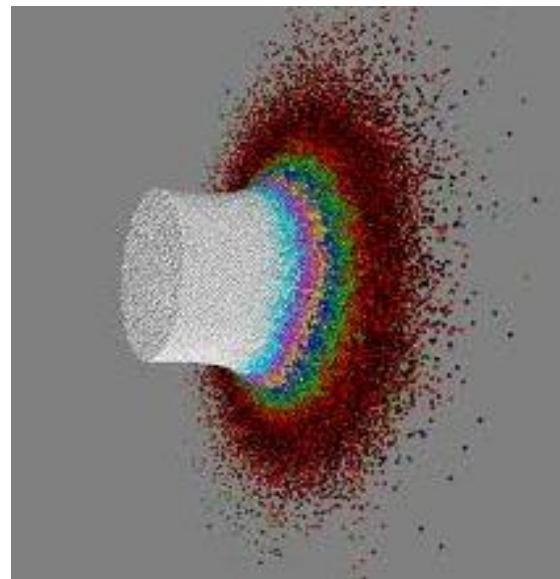


CAD / Autodesk AutoCAD  
(Emphasize contour)



# Computer graphics and visualization

- For high performance computing



Particle simulation / Pixel render

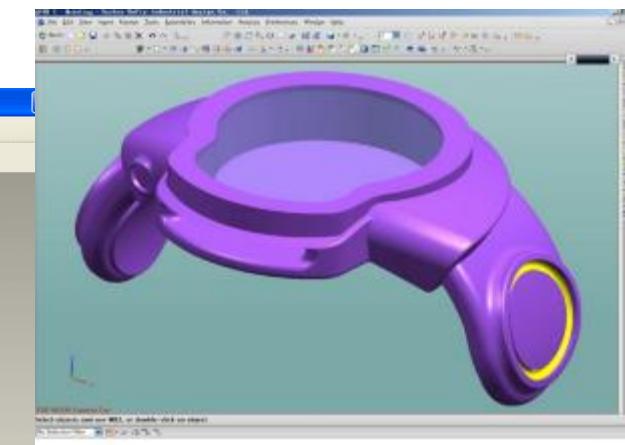
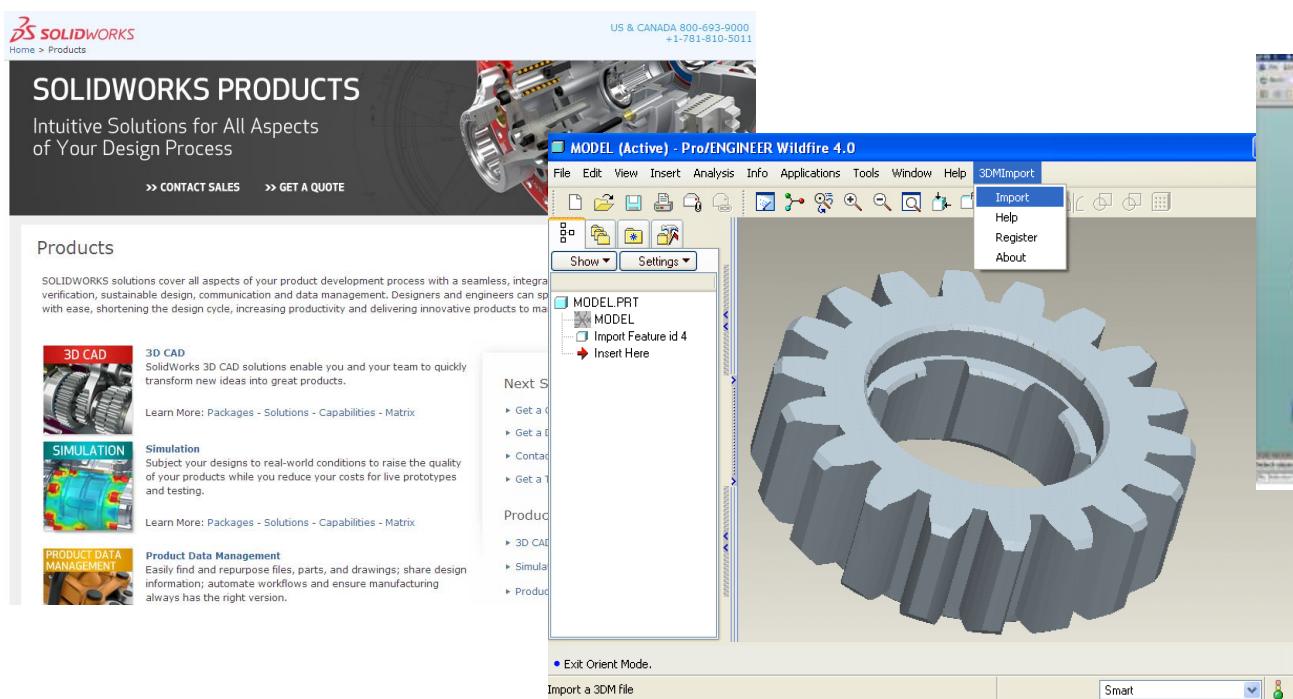


Ray tracing



# Current 3D software-1

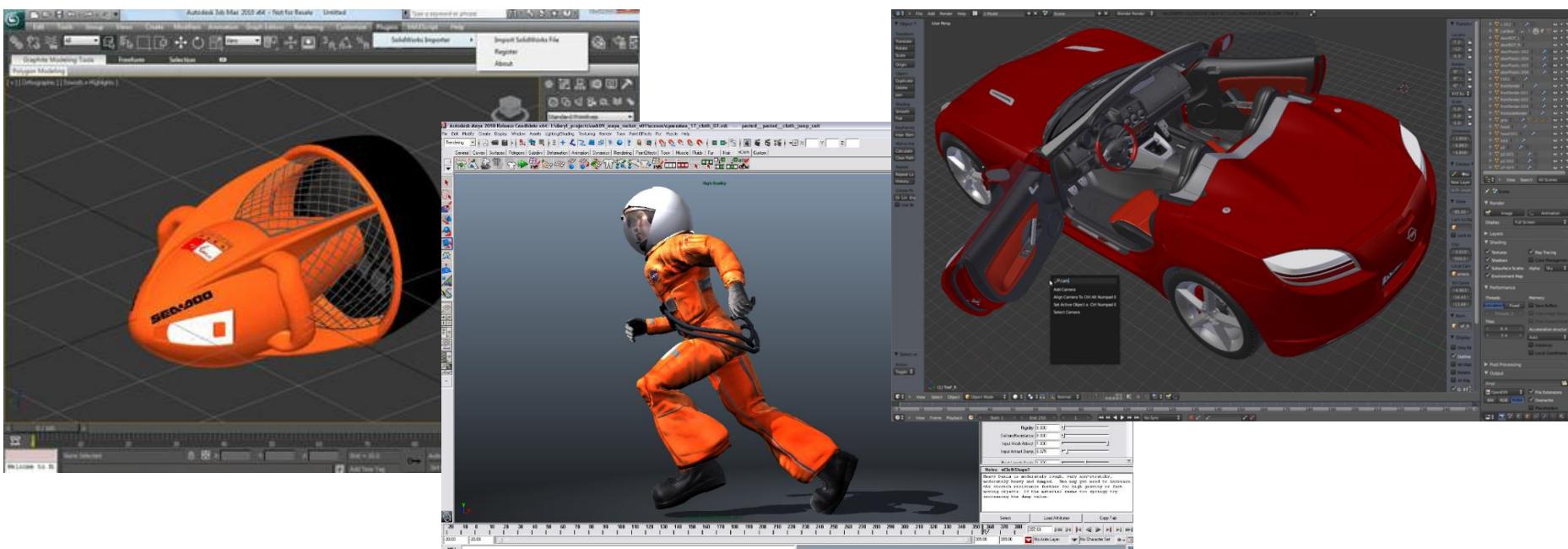
- CAD software: 3D visualization
- Data defined as “solid model” (B-rep)
- Pro-E, CATIA, Solidworks...





# Current 3D software-2

- Mesh software: 3D visualization
- Data defined as “polygon”
- 3DS Max, Maya, Blender...





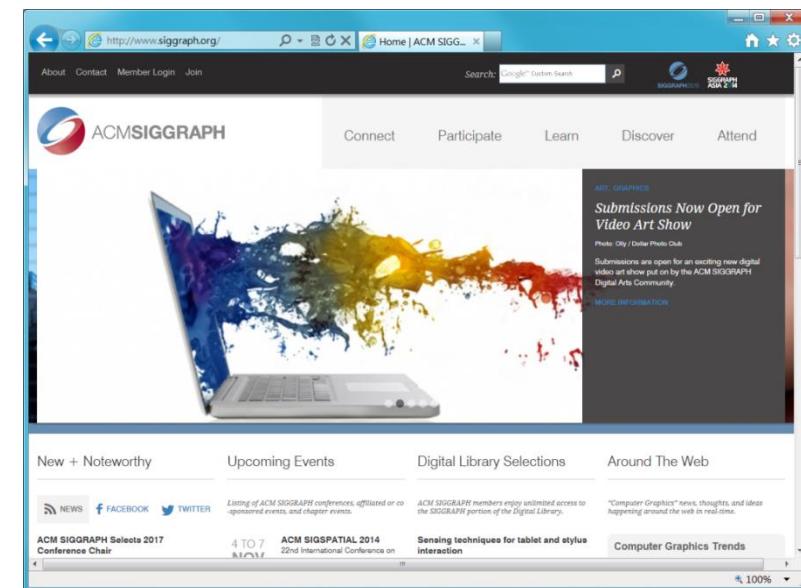
# What job I can apply for?

- Researcher related to 3D applications
- Development of 3D software
- Visualization or Rendering
- Game
- Special effects in film, advertisement industries
- 3D Printing industries
- 3D Scanning industries
- Others



# What event I can join in computer graphics

- Annual conference
- SIGGRAPH (Jul.~Aug.)
- SIGGRAPH ASIA (Nov.~Dec.)
- EUROGRAPH (Apr.~May.)





# Commercial portable product

- Computer graphics in portable devices (3D supported)



Sony PSP



Sony phone



Andriod



iphone



Nintendo DS



Nintendo 3DS

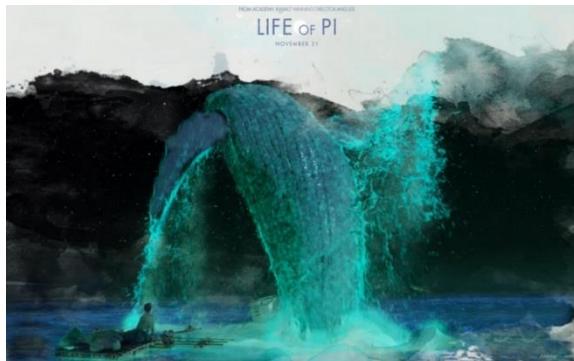


Tablet/ultrabook  
PanelPC



# Industry applications

## ■ Computer graphics in Movie and other fields



For reality



VR/AR



Facial tracking



Panorama / HDR



motion tracking



3D Printing



# Application summary

- Information visualization
- Cartoons
- Video Game
- Film special effects
- CAD/CAM
- Simulation
- Medical imaging



# All you learn in Computer Graphics is...

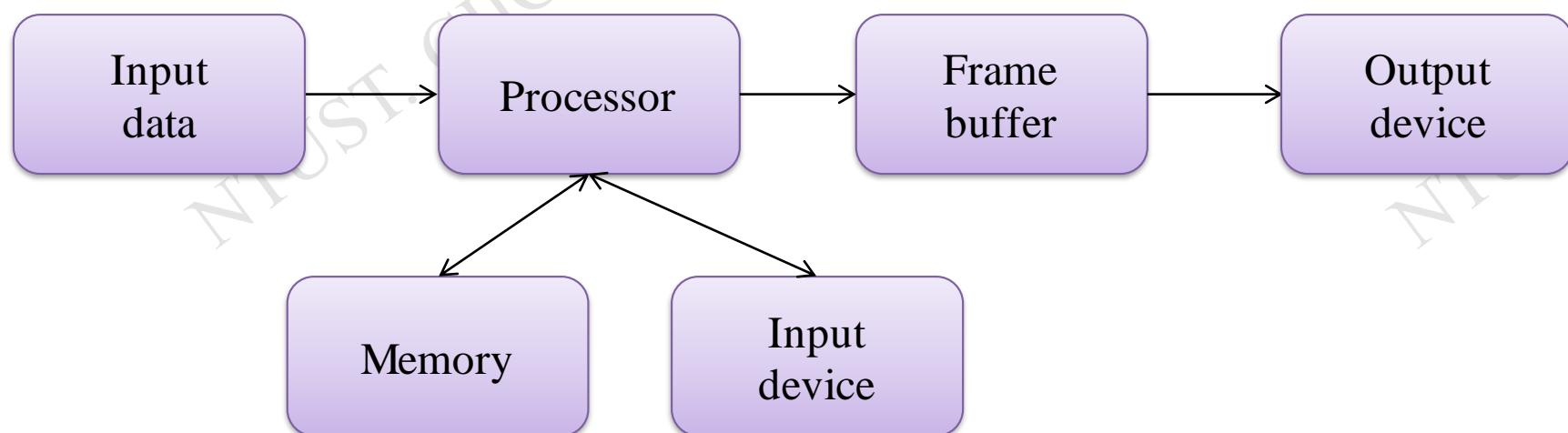


Pixar monster inc.



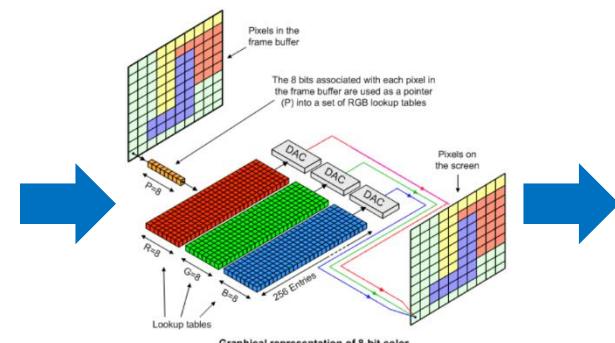
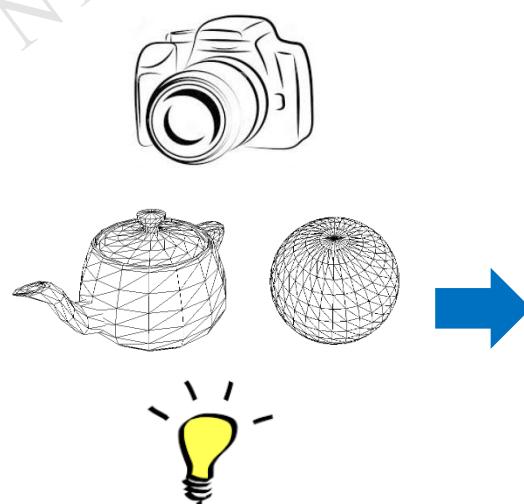
# Brief framework in computer graphics

- The major elements for a graphics system
- Input devices
- Processor\*, Memory and Input device
- Frame buffer\*
- Output device





# Rendering 3D scene



Display



# Input devices (in 3D console)



Mouse



Graphic Tablets



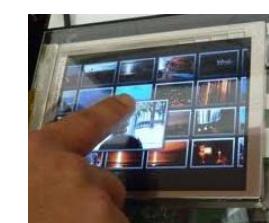
Infra ray

VR glove  
(Gesture control)

3D Mouse



joystick

Gyroscope /  
AccelerometerTouch panel  
(Gesture control)3D Input  
(Touch 3D Stylus)

Imaging



Depth sensor



Keyboard



# Output devices for 3D data



CRT

Flat panel  
(stereoscopic)HMD  
(Head mount display)

3D display



projector



LED



Flexible display



3D printer



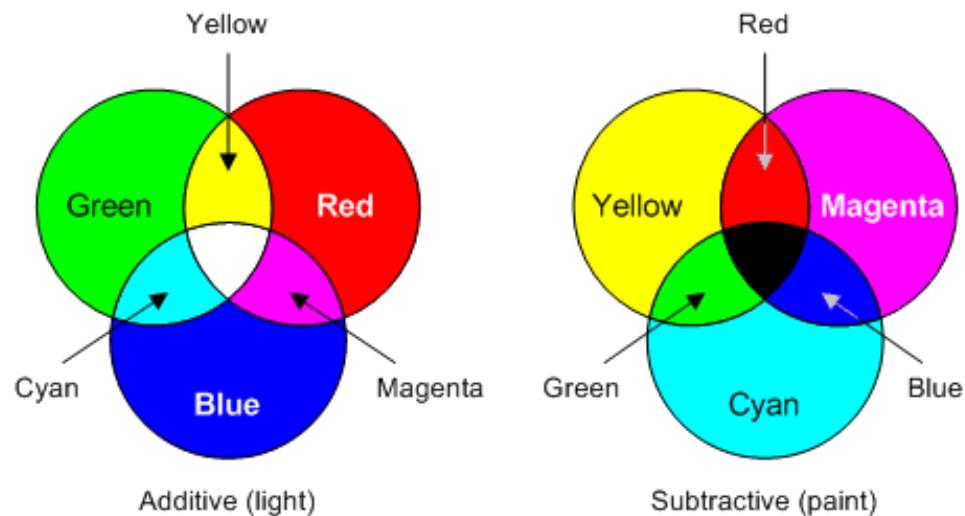
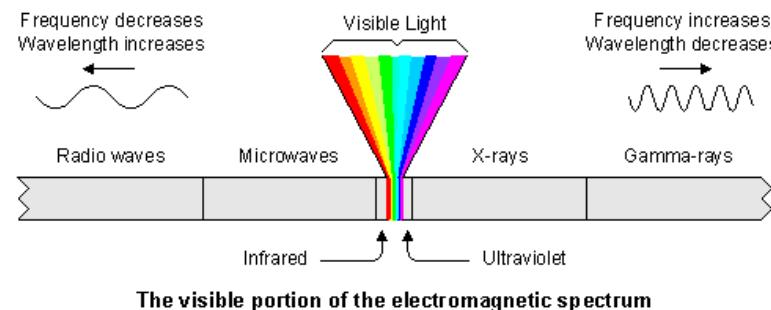
# Color and rendering

- Color or colour (see [spelling differences](#)) is the [visual perceptual property](#) corresponding in [humans](#) to the categories called red, blue, yellow, green and others. Color derives from the [spectrum of light](#)(distribution of [light](#) power versus [wavelength](#)) interacting in the eye with the spectral sensitivities of the [light receptors](#). Color categories and physical specifications of color are also associated with objects or materials based on their physical properties such as light absorption, reflection, or emission spectra. By defining a [color space](#), colors can be identified numerically by their coordinates.
- Because perception of color stems from the varying [spectral sensitivity](#) of different types of [cone cells](#) in the [retina](#) to different parts of the spectrum, colors may be defined and quantified by the degree to which they stimulate these cells. These physical or [physiological](#) quantifications of color, however, do not fully explain the [psychophysical](#) perception of color appearance.



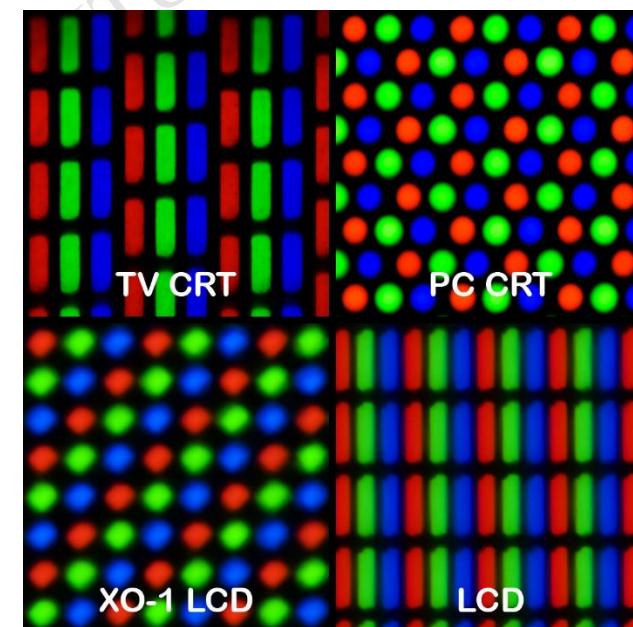
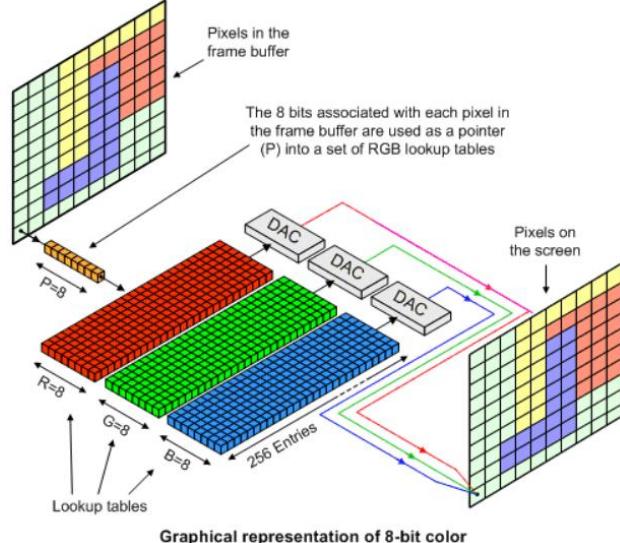
# Color formation

## ■ How color formed?



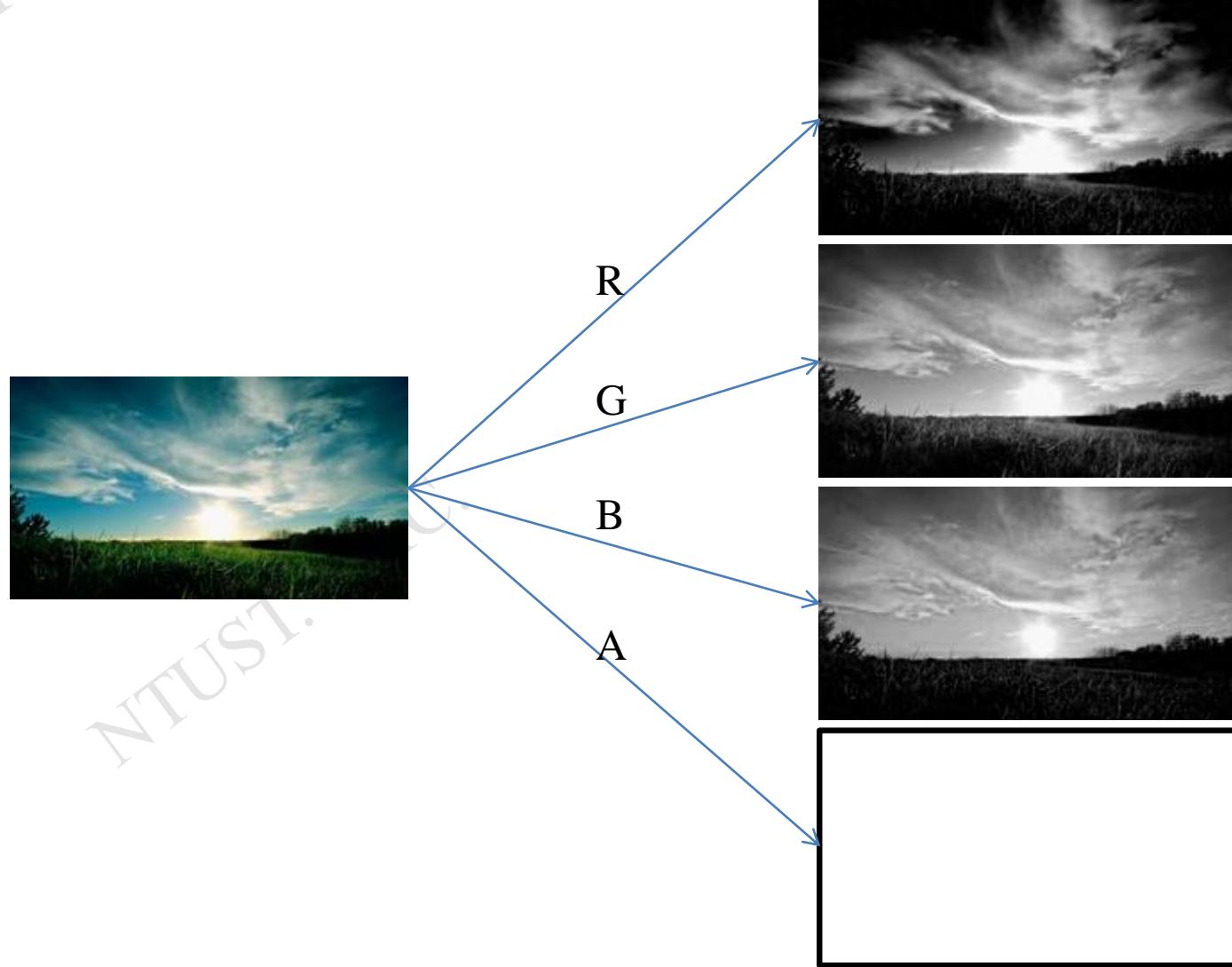


# How color shown on screen?





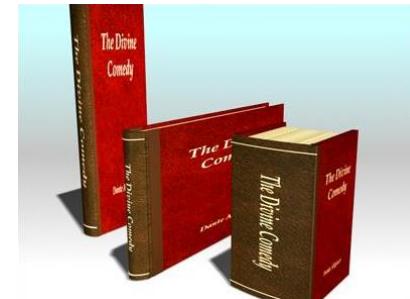
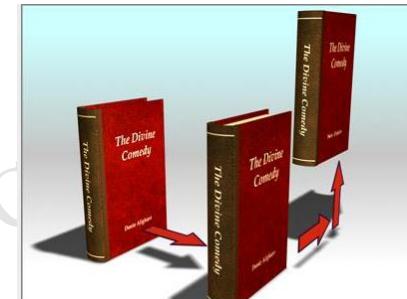
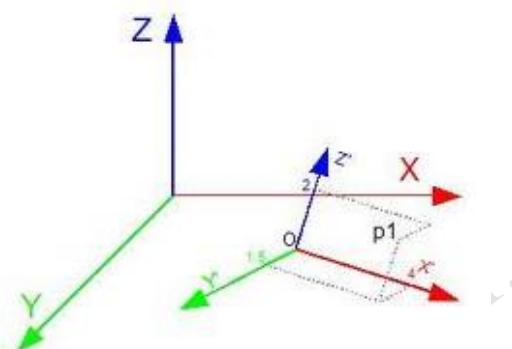
# What does 32bit color stand for?





# 3D transformation

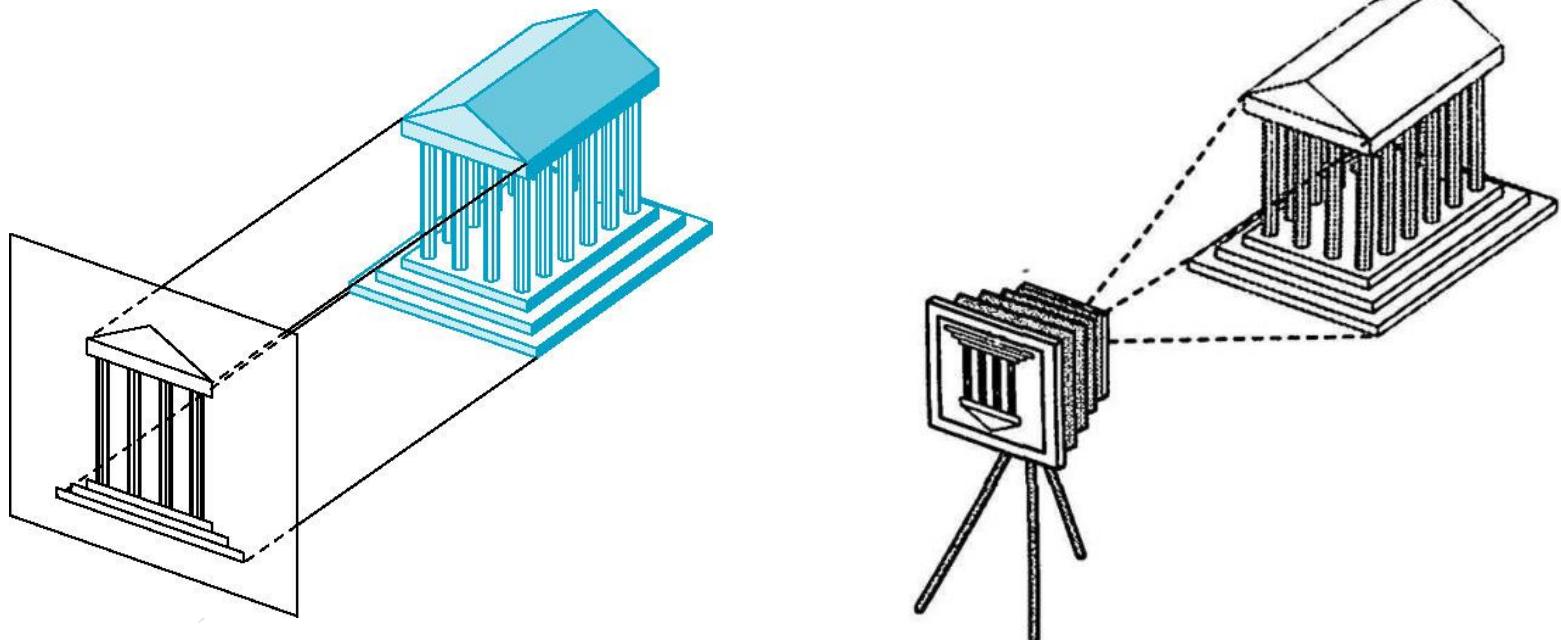
- Object transformation
- Coordinate transformation





# How to project 3D on 2D screen

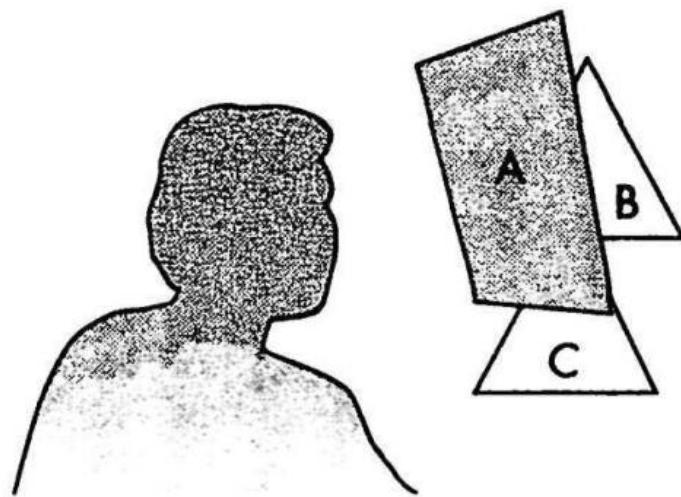
- Camera intrinsic parameter





# 3D space priority problem

- 3D space / hidden face removal (software algorithm)
- The priority in viewing direction...

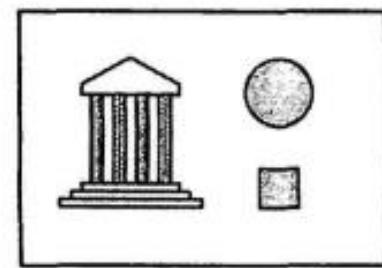


What you see is  
A + partial C without B

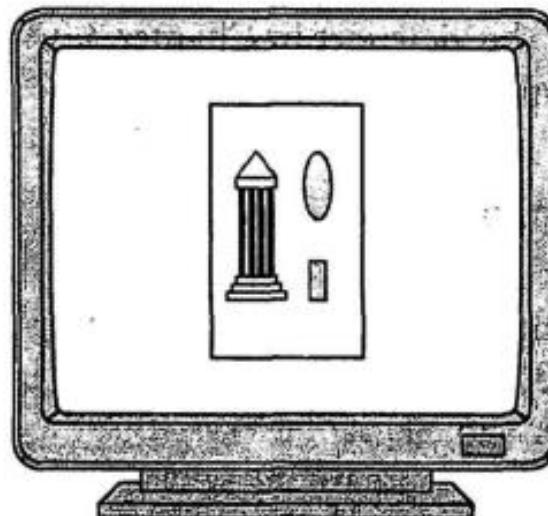


# Viewport control on screen

## ■ Aspect-ratio



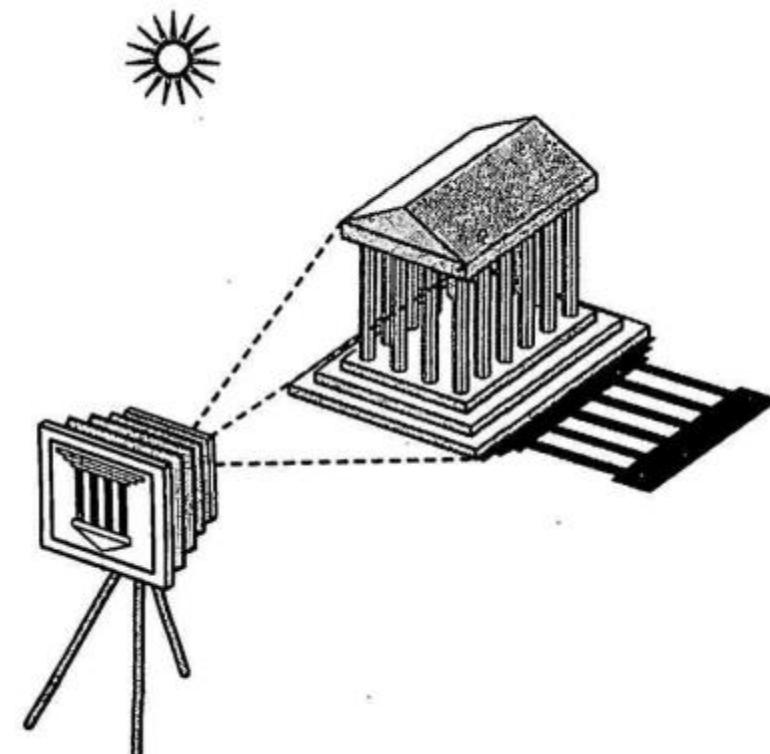
(a)



(b)



# Lighting, shading and shadow





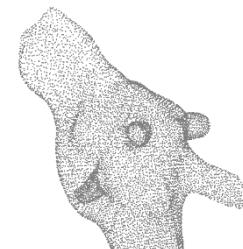
# Rendering algorithm

- Conjugate with “light”
- To determine how much the intensity of a pixel should be.

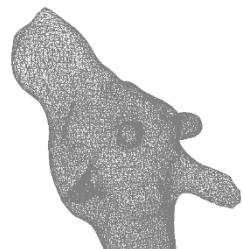




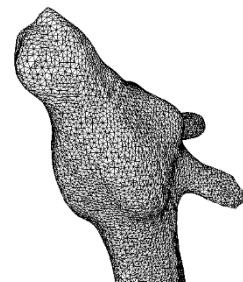
# How to perform shading



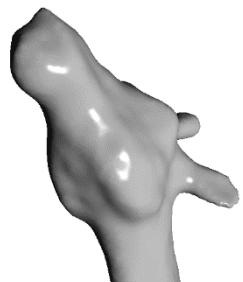
Point cloud



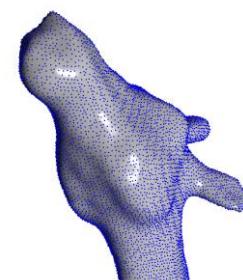
Wireframe



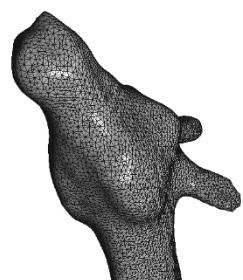
Hidden line removal



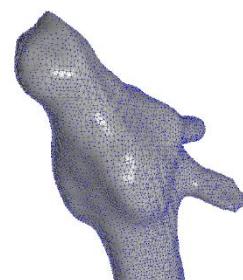
Phong shading



Point on surface  
(Phong shading)



Wireframe on surface  
(Phong shading)



Point & Wireframe  
on surface  
(Phong shading)

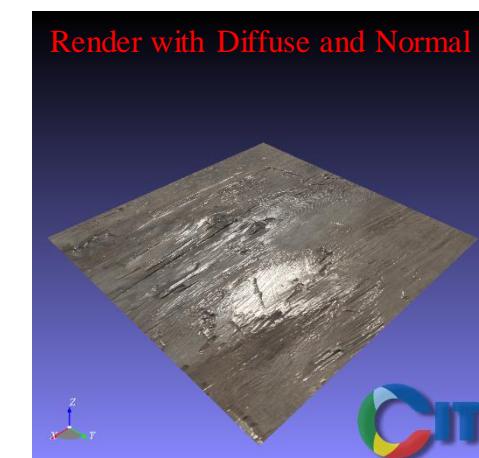
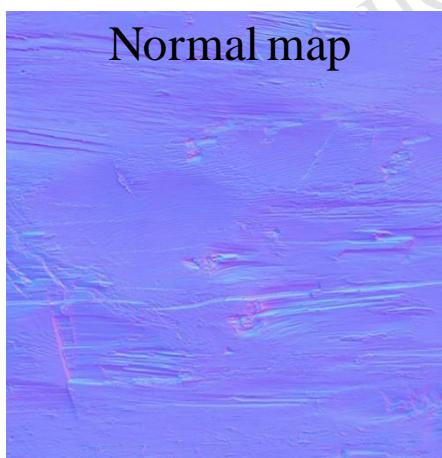
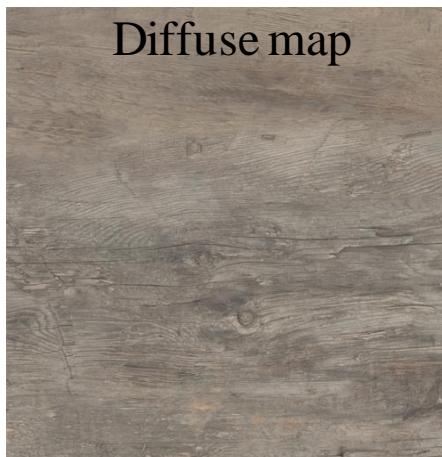


Phong shading  
(vertex color)



# How to perform shading

## ■ Shader





# Data format in this lecture

- Vector
  - Stored as high precision float.
  - Line/Wireframe/Control Points/Triangle/Polygon...
- Pixel
  - Stored or compress as integral (BYTE)
  - Ex. Bitmap, JPEG, TIF, PNG,...
- 3D file format
  - Standard: STL, 3DS, PLY, OBJ, VRML...
  - Individual: MAX...

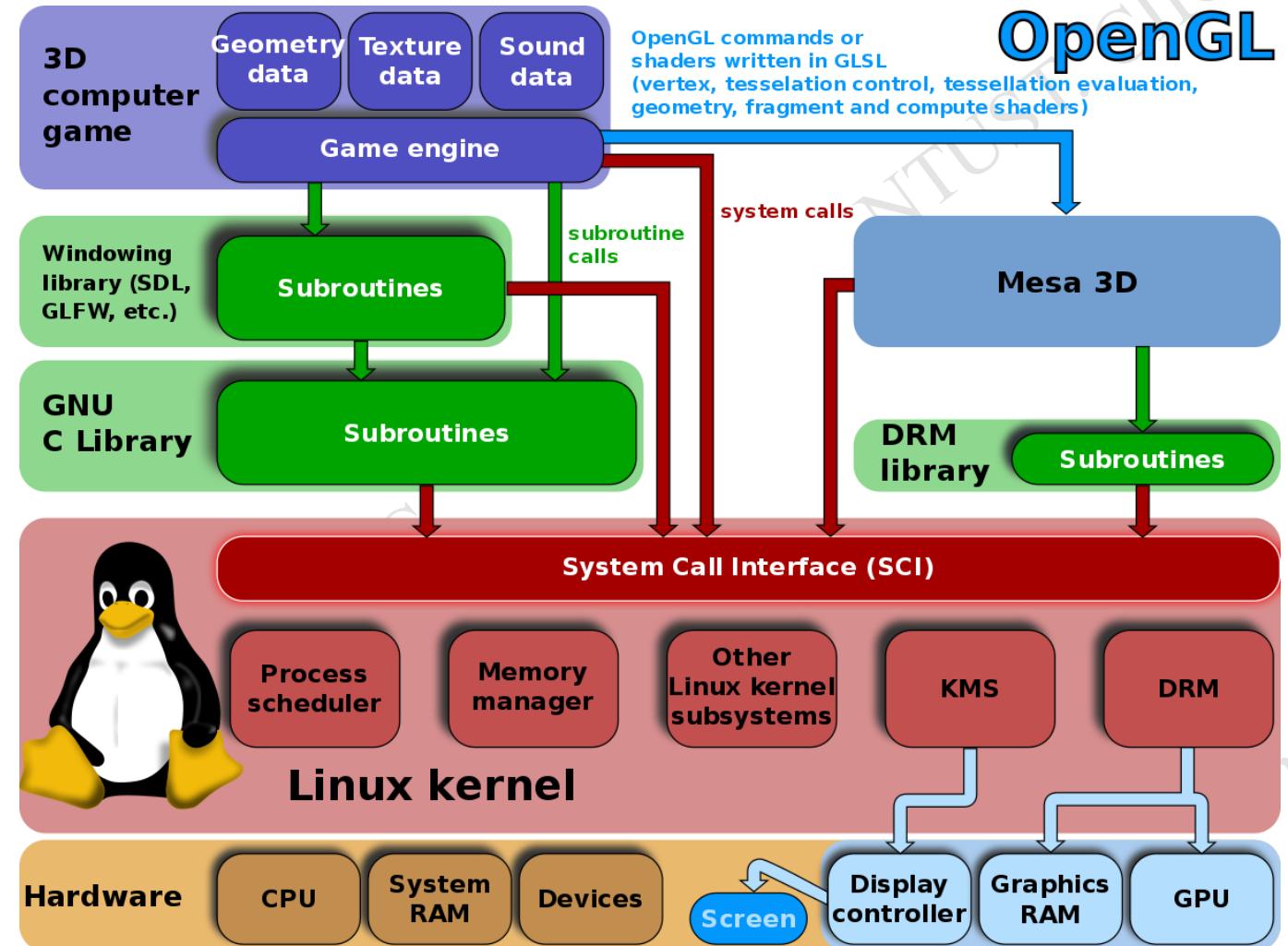


# Why we choose OpenGL?

- OpenGL was designed to be open and available on a wide range of systems. → FREE
- The OpenGL Architecture Review Board (ARB) consists of representatives from industry, universities, and private research groups.
- The OpenGL ARB gathers a wide range of feedback and modifies OpenGL according to industry needs.



# Why we choose OpenGL?





# OpenGL online resource

- Open Graphics Language
  - OpenGL
  - OpenGL ES
  - WebGL
- Vulkan (new standard)

The screenshot shows the OpenGL.org homepage. At the top, it features the OpenGL logo and the tagline "The Industry's Foundation for High Performance Graphics". Below this, there are links for Documentation, Coding Resources, Wiki, Forums, and About OpenGL. A banner for "OpenGL, OpenGL ES, and WebGL Community Experiences" is displayed, along with a CRC Press logo. The main content area includes several news articles:

- OpenGL Headline News**: An article about the release of OpenGL 4.5, categorized under Developers and Comments.
- OpenGraph Updated**: An article about the OpenGraph Library, categorized under Developers and Comments.
- Maxwell GM204 OpenGL Extensions**: An article about new OpenGL extensions supported by NVIDIA's Maxwell 2 generation of GPUs, categorized under Developers and Comments.
- Khronos Group releases OpenVX 1.0 specification for Computer Vision Acceleration**: An article about the release of the OpenVX 1.0 specification, categorized under Developers and Comments.

On the right side, there are sidebar links for Getting Started with OpenGL, Official OpenGL 4.5 feedback thread, OpenGL 4.5 Reference Card, OpenGL Reference Pages, OpenGL Conformance Products, OpenGL ES links, and WebGL links.



# Prepare your learning tool (ex. 3DS Max)

Search "Autodesk Student" or link this address

Sign up first(create account)

- Register as: I am a “Student”
- Fill in all slots
  
- Remember your email and password
- Download the latest version

The screenshot shows the Autodesk Create account form. The 'Education status' section is highlighted with a red box. It includes fields for Country (set to Taiwan), Birthdate (Month, Day, Year dropdowns), and two dropdown menus for Education status ('I am a' set to Student) and Type ('College/University'). Below this is the 'Account information' section with fields for First name, Last name, Autodesk ID (Username), Email, Confirm email, Password, and Confirm password. At the bottom is the 'Terms & conditions' section with a checkbox for receiving e-mail communications.



# Prepare your learning tool (ex. 3DS Max)

- To download 3DS Max Design or 3DS Max
  - Step-1 Sign In
  - Step-2 Find what version you need
  - Step-3 Write down your own serial number and product key
  - Step-4 Download ISO (or install online)
  - You are legal to use any Autodesk® software for research / education purpose for 3 years



## 3ds Max Design

3ds Max Design software provides a comprehensive 3D modeling, animation, and rendering solution used by architects, designers, civil engineers, and visualization specialists. Validate and sell designs before they are built, and get rapid iteration of designs, accurate daylight analysis, and high-impact visuals and animations.

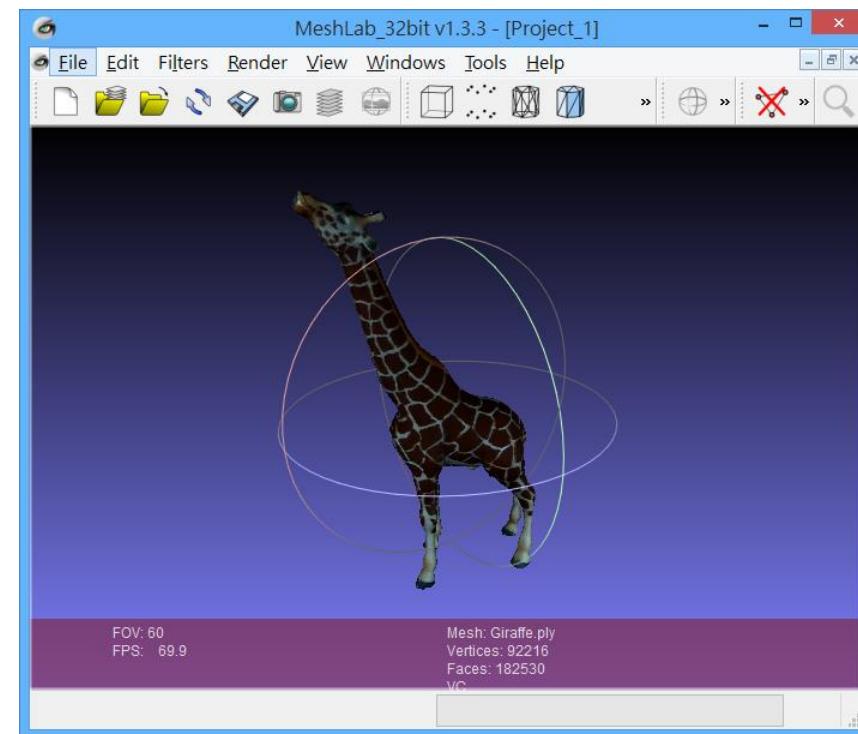
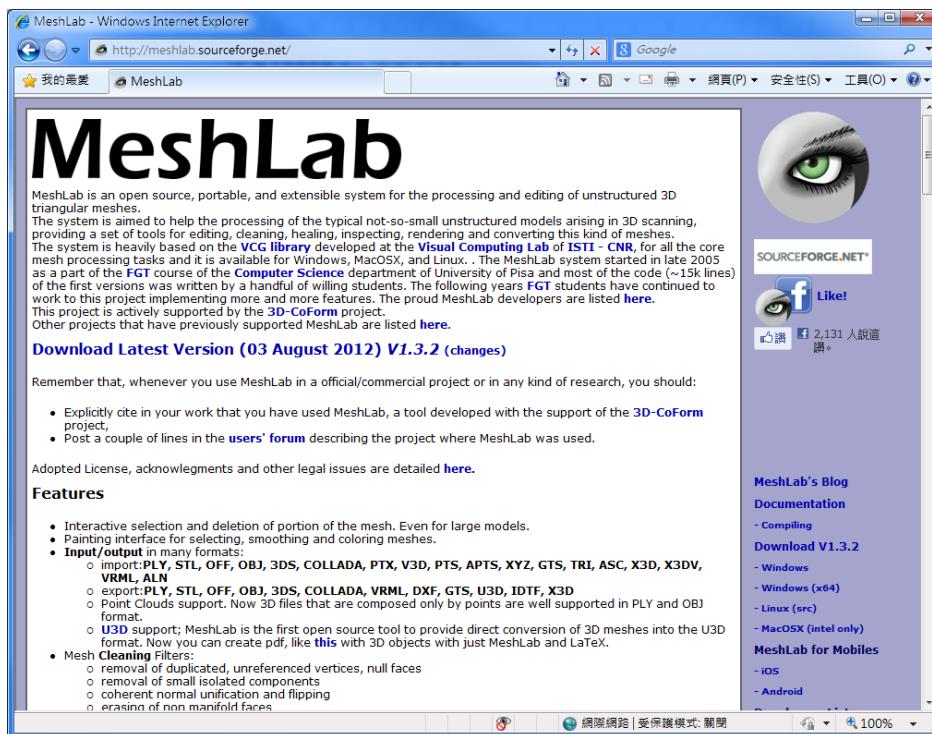
### System requirements

The screenshot shows the Autodesk 3ds Max Design 2015 download page. It includes sections for signing in, selecting the software version (3ds Max Design 2015), and reviewing the download. A red box highlights the 'Autodesk 3ds Max Design 2015 - WIN 64-bit' section, which displays the product key and a note about an email containing license information. The bottom of the page contains important license information and a 'BROWSER DOWNLOAD' button.



# Prepare your learning tool (ex. Meshlab)

- Free 3D software (from academic institute)
  - Recommend to install 64bit version (better performance)
  - Install 32bit as well (better capability and format support)





# Prepare for programming tools

- Programming skill
  - Either: C/C++ Compiler: Visual Studio 2019 (default, in example), Dev C++, etc.
  - Or Python
  - 64 bit environment is strongly recommended
- We will teach “python” version for practicing openGL in this semester
- First homework will be assigned around at 3rd week



# Overview - How to create 3D data

## ■ 34 Best 3D “Free STL Model” providers

Websites	Type	Free / Paid	Models	Visitors
<a href="#">Thingiverse</a>	Repository	Free	★★★★★	★★★★★
<a href="#">Grabcad</a>	Repository	Free	★★★★★	★★★
<a href="#">Sketchfab</a>	Repository	Free	★★	★★★
<a href="#">Autodesk 123d</a>	Repository	Free	★★★★	★★★
<a href="#">CGTrader</a>	Marketplace	Free, Paid	★★★	★★★
<a href="#">My Mini Factory</a>	Marketplace	Free	★★★	★★★
<a href="#">Yeggi</a>	Search Engine	Free, Paid	n/a	★★★
<a href="#">Pinshape</a>	Marketplace	Free, Paid	★★★	★★★
<a href="#">XYZprinting 3D Gallery</a>	Marketplace	Free, Paid	★★★	★★★
<a href="#">Dremel Idea Builder</a>	Repository	Free	★★	★★★
<a href="#">YouMagine</a>	Repository	Free	★★★	★★★
<a href="#">Yobi3D</a>	Search Engine	Free	n/a	★★
<a href="#">STL Finder</a>	Search Engine	Free, Paid	n/a	★★
<a href="#">3DExport</a>	Marketplace	Free, Paid	★★★	★★
<a href="#">Cults</a>	Marketplace	Free, Paid	★★	★★
<a href="#">Zortrax Library</a>	Repository	Free	★★	★★
<a href="#">New Matter</a>	Repository	Free	★★	★★
<a href="#">Rinkak</a>	Marketplace	Free, Paid	★★	★★



# Overview - How to create 3D data

Websites	Type	Free / Paid	Models	Visitors
<a href="#">3DShook</a>	Subscription Service	Free, Paid	★★	★★
<a href="#">Rascomras</a>	Repository	Free	★	★★
<a href="#">Threeding</a>	Marketplace	Free, Paid	★★	★★
<a href="#">Repables</a>	Repository	Free	★	★★
<a href="#">Libre3D</a>	Repository	Free	★	★
<a href="#">3Dagogo</a>	Marketplace	Free, Paid	★	★
<a href="#">Shapetizer</a>	Marketplace	Free, Paid	★	★
<a href="#">The Forge</a>	Repository	Free	★★	★
<a href="#">Redpah</a>	Marketplace	Free, Paid	★★	★
<a href="#">Trinpy</a>	Subscription Service	Free, Paid	★	★
<a href="#">Polar Cloud</a>	Repository	Free	★★	★★
<a href="#">3D Warehouse</a>	Repository	Free	★	★★★★★
<a href="#">STLHive</a>	Shop	Free, Paid	★	★
<a href="#">NASA</a>	Repository	Free	★	★★★★★
<a href="#">NIH 3D Print Exchange</a>	Repository	Free	★★★★★	★★★★★
<a href="#">Instructables</a>	Repository	Free	★★	★★★★★



# Overview - How to create 3D data

## ■ 22 Best 3D Modeling/3D CAD software Tools

Name	Level	OS	Price	Formats
<a href="#">123D Design</a>	Beginner	Windows, Mac and iOS	Free	123x, step, stl, x3d, vrml
<a href="#">3D Slash</a>	Beginner	Windows, Mac, Linux, Raspberry Pi or Browser	Free, 24€/year Premium	3dslash, obj, stl
<a href="#">3ds Max</a>	Professional	Windows	2.141,70 € / year, Educational licenses available	stl, 3ds, ai, abc, ase, asm, catproduct, catpart, dem, dwg, dxf, dwf, flt, iges, ipt, jt, nx, obj, prj, prt, rvt, sat, skp, sldprt, sldasm, stp, vrml, w3d xml
<a href="#">AutoCAD</a>	Professional	Windows and Mac	1400 €/year	dwg, dxf, pdf
<a href="#">Blender</a>	Professional	Windows, Mac and Linux	Free	3ds, dae, fbx, dxf, obj, x, lwo, svg, ply, stl, vrml, vrm197, x3d
<a href="#">CATIA</a>	Industrial	Windows	7.180 €; Educational licenses available	3dxml, catpart, igs, pdf, stp, stl, vrml
<a href="#">FreeCAD</a>	Intermediate	Windows, Mac and Linux	Free	step, iges, obj, stl, dxf, svg, dae, ifc, off, nastran, Fcstd
<a href="#">Fusion 360</a>	Industrial	Windows and Mac	499.80 €/year, Educational licenses available	catpart, dwg, dxf, f3d, igs, obj, pdf, sat, sldprt, stp
<a href="#">Inventor</a>	Industrial	Windows and Mac	€2,060/year	3dm, igs, ipt, nx, obj, prt, rvt, sldprt, stl, stp, x_b, xgl
<a href="#">Meshmixer</a>	Intermediate	Windows, Mac and Linux	Free	amf, mix, obj, off, stl
<a href="#">Moment of Inspiration (MoI)</a>	Intermediate	Windows and Mac	266 €	3ds, 3dm, dxf, fbx, igs, lwo, obj, skp, stl, stp and sat
<a href="#">Mudbox</a>	Professional	Windows and Mac	85 € /year	fbx, mud, obj



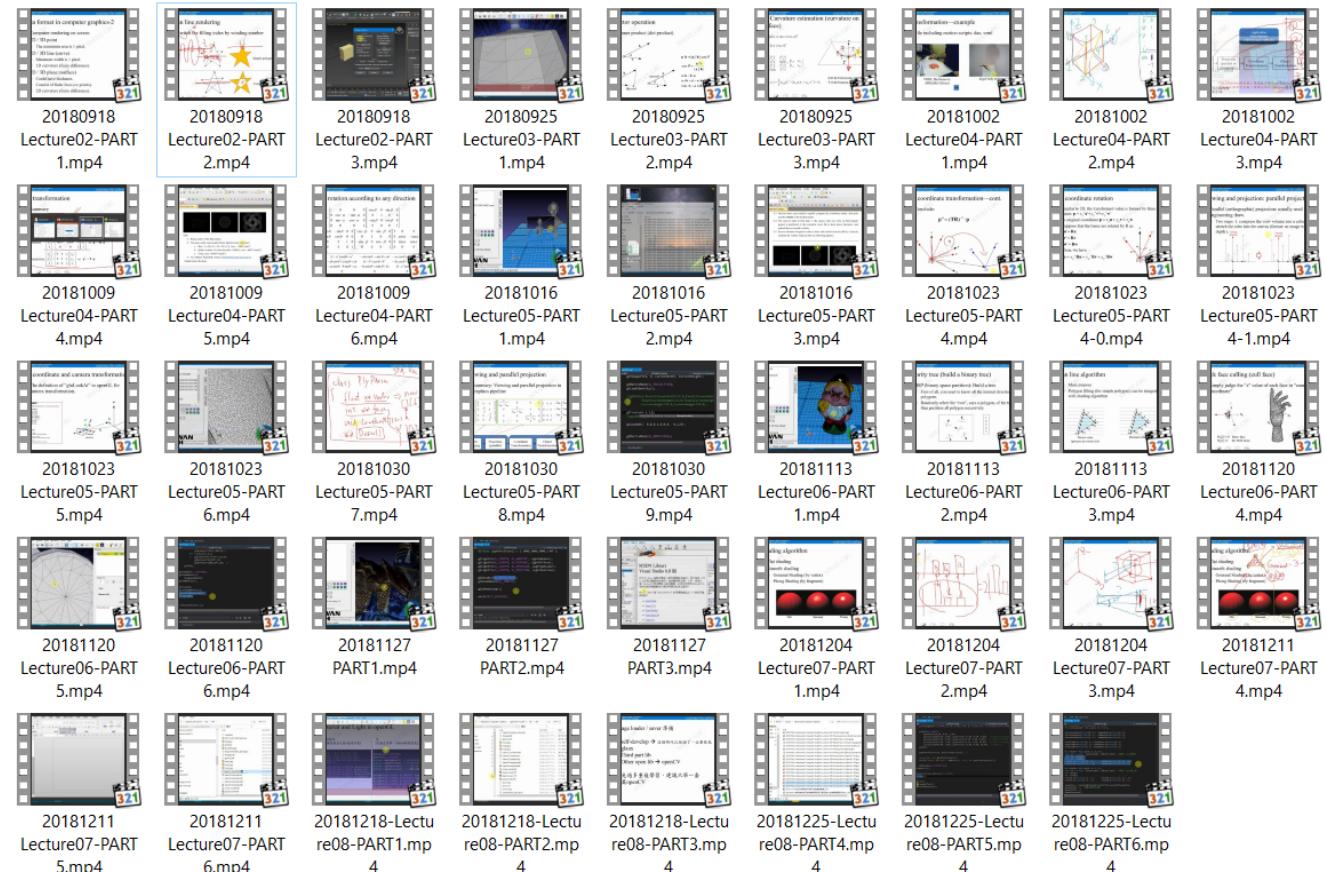
# Overview - How to create 3D data

Name	Level	OS	Price	Formats
<a href="#">Onshape</a>	Professional	Windows, Mac, Linux, iOS, Android	€ 2.400 / year, free and price reduced business version available	sat, step, igs, iges, sldprt, stl, 3dm, dae, dfx, dwg, dwt, pdf, x_t, x_b, xxm_txt, ssm_bin
<a href="#">OpenSCAD</a>	Intermediate	Windows, Mac and Linux	Free	dxf, off, stl
<a href="#">Photoshop CC</a>	Beginner	Windows and Mac	142 €/year	3ds, dae, kmz, obj, psd, stl, u3d
<a href="#">Rhino3D</a>	Professional	Windows and Mac	495€ Educational, 1695 € Commercial	3dm, 3ds, cd, dae, dgn, dwg, emf, fbx, gf, gdf, gts, igs, kmz, lwo, rws, obj, off, ply, pm, sat, scn, skp, slc, sldprt, stp, stl, x3dv, xaml, vda, vrml, x_t, x, xgl, zpr
<a href="#">SculptGL</a>	Beginner	Browser	Free	obj, ply, sgl, stl
<a href="#">Sculptris</a>	Intermediate	Windows and Mac	Free	obj, goz
<a href="#">SketchUp</a>	Intermediate	Windows and Mac	Free, 657€ Pro	dwg, dxf, 3ds, dae, dem, def, ifc, kmz, stl
<a href="#">Solidworks</a>	Industrial	Windows	9.950 €, Educational licenses available	3dxml, 3dm, 3ds, 3mf, amf, dwg, dxf, idf, ifc, obj, pdf, sldprt, stp, stl, vrml
<a href="#">TinkerCAD</a>	Beginner	Browser	Free	123dx, 3ds, c4d, mb, obj, svg, stl
<a href="#">ZBrush</a>	Professional	Windows and Mac	400€ Educational License, 720€ Single User License	dxf, goz, ma, obj, stl, vrml, x3d



# Chinese version video lectures (at 2018)

Chinese version & C/C++ programming example



[http://140.118.118.100/URL/20200914\\_2020\\_FALL-Advanced\\_Computer\\_Graphics.html](http://140.118.118.100/URL/20200914_2020_FALL-Advanced_Computer_Graphics.html)



色彩與照明科技研究所  
Graduate Institute of  
Color and Illumination Technology

