EE 4702
3D Graphics Modeling

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Lectures:	Mon/Wed/Fri 1:40pm – 2:30pm 149 EE Building
Office Hours:	Mon/Wed 2:30pm – 5pm 313 Electrical Engineering Building

Course Synopsis

- What is it about?
  - An advanced computer graphics course
  - Concepts, theory, algorithms, techniques, programming in Graphics and Geometric Computing
    - To understand, represent, render, analyze, and manipulate 3D shapes
- Topics:
  - Basic Computer Graphics pipeline
  - Geometry for 3D Computer Graphics
  - 3D Geometric Modeling
  - Basic OpenGL programming, 3D Graphics
  - Geometric Processing
  - Applications of visual and geometric computing

Workload

- A fun course, and you will learn a lot
- reading and programming work
  - 4 homework
  - 1 course project
  - 1 mid-term presentation, 1 final presentation for the course project
  - No exam
- Start early on your homework and projects
  - Come and discuss your course project; start early
- Grading is generous

Grading

- Attendance (10%)
- Course Project (45%)
  - Midterm Presentation (13%)
  - Final Presentation + Demo (12%)
  - Final codes + 1-Page Report (20%),
- Homework (45%)
  - Homework 1 (10%)
  - Homework 2 (10%)
  - Homework 3 (12%)
  - Homework 4 (13%)

Prerequisites

- basic linear algebra, calculus
- self-learning:
  - c/c++ and OpenGL
  - paper reading (for the course project)
- presentation
  - Midterm presentation: algorithm of the course project
  - Final presentation: you implementation of the course project + demo
- programming
  - starter codes will be provided in C++ (for programming homework)

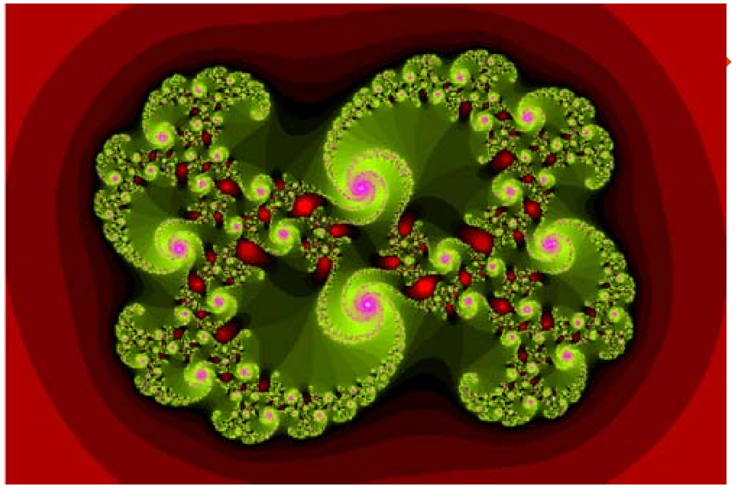
What is Computer Graphics?

The creation of, manipulation of, analysis of, and interaction with pictorial representations of objects and data using computers.

-- Dictionary of Computing

- A picture is worth a thousand words.

  - Chinese Proverb



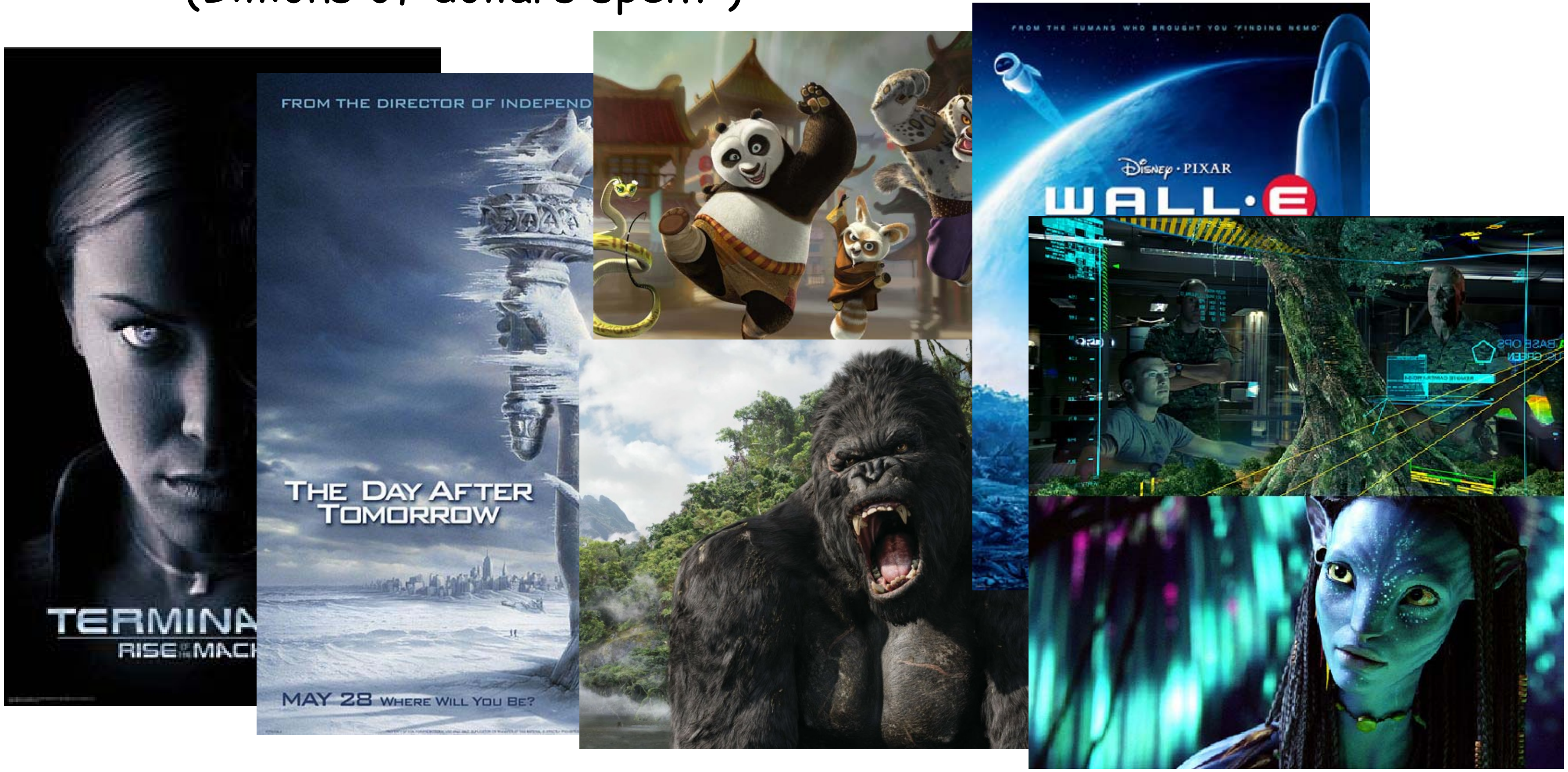
It looks like a swirl. There are smaller swirls at the edges. It has different shades of red at the outside, and is mostly green at the inside. The smaller swirls have purple highlights. The green has also different shades. Each small swirl is composed of even smaller ones. The swirls go clockwise. Inside the object, there are also red highlights. Those have different shades of red also. The green shades vary in a fan, while the purple ones are more uni-color. The green shades get darker towards the outside of the fan …

Why Computer Graphics?

1) To Digitize the world → CAD/CAGD/CAM → save the cost
2) Dominant form of computer output → visualization → help see scientific phenomenon better
3) To study/measure images or shapes → Geometric modeling and processing, vision → help understand/analyze the geometries around us
4) And many more…

Movies

- If you can imagine it, it can be done with Computer Graphics!
- CG has been changing Special Effects in the Movie Industry (Billions of dollars spent)


TERMINA
RISE MACH
FROM THE DIRECTOR OF INDEPEND
THE DAY AFTER TOMORROW
MAY 28 WHERE WILL YOU BE?
FROM THE HUMANS WHO BROUGHT YOU 'FINDING NEMO'
Disney · PIXAR
WALL·E

Video Games

- Important driving force
- Focus on interactivity
- Try to avoid heavy computation and use various CG tricks

Quake IV

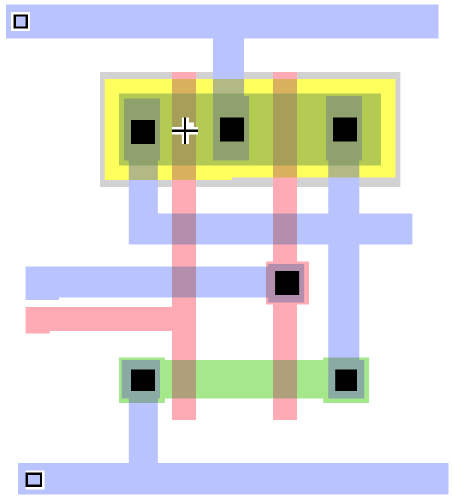
Age of Empire II

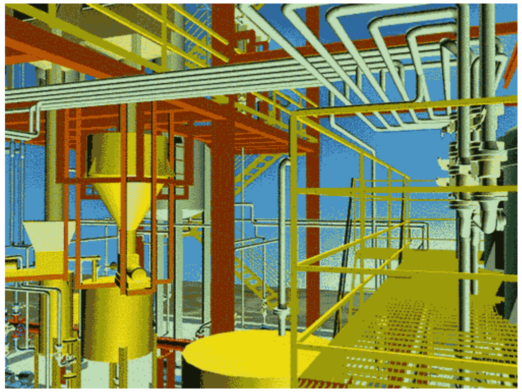
Starcraft II

Computer Aided Design

Significant impact on the design process:

- Mechanical, electronic design (entirely on computer environments)
- Architectural and product design (migrate to computer environments)

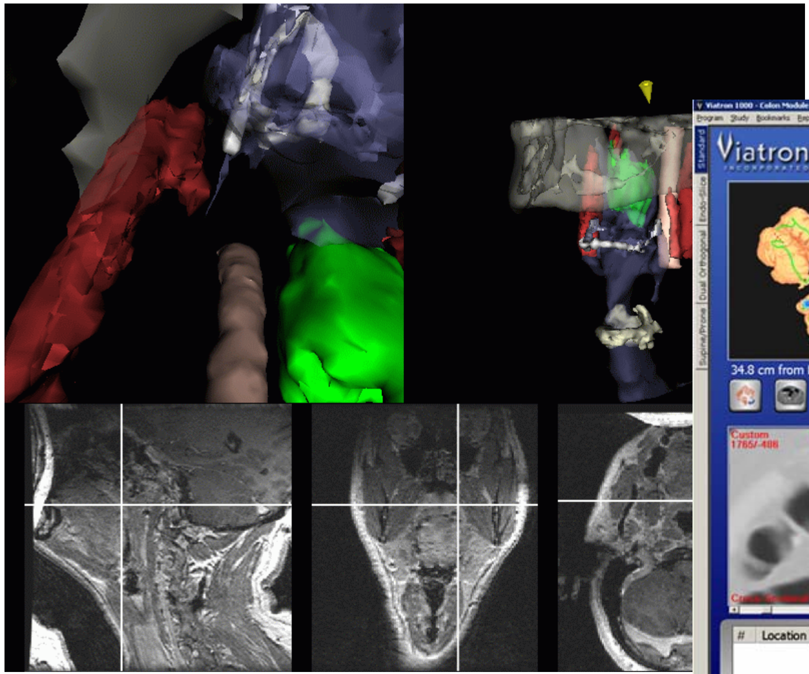


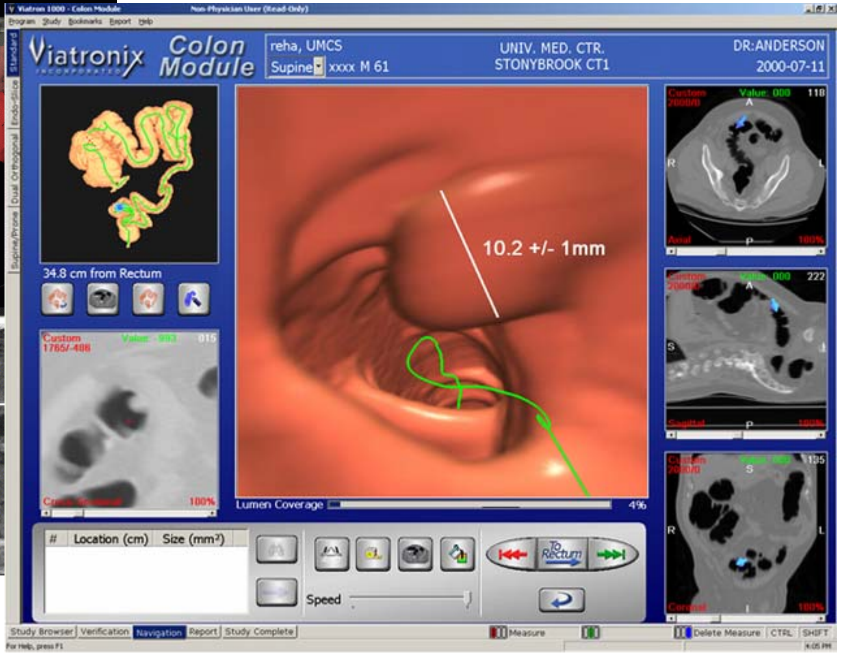


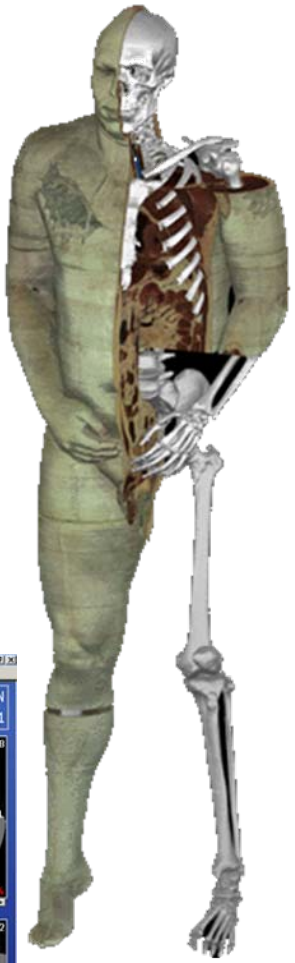
- Interactive design/visualization → assist modeling
- Simulating their behavior in the virtual environment

Medical Applications

- Aid in clinical analysis/diagnosis
- Virtual medical training and educations

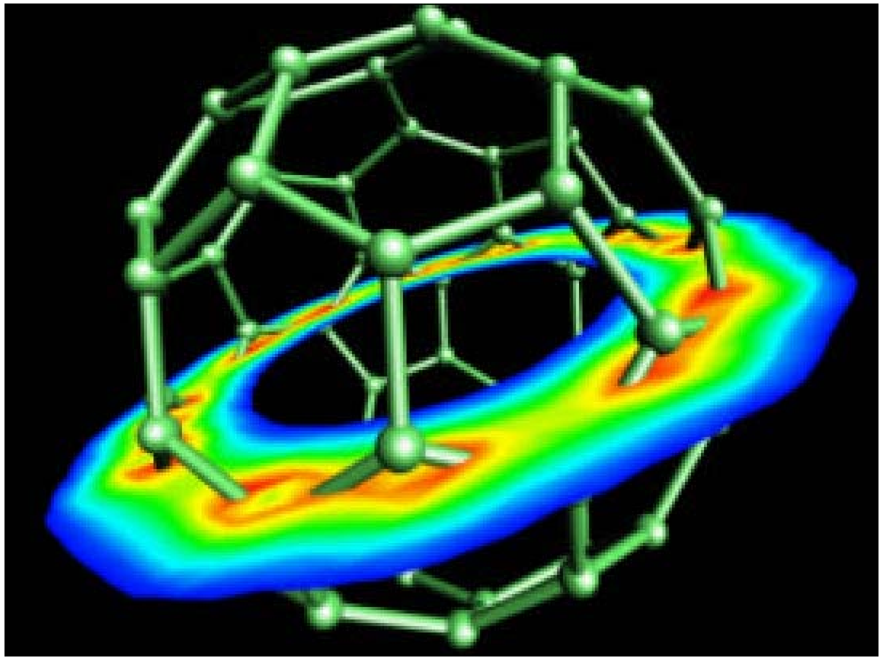






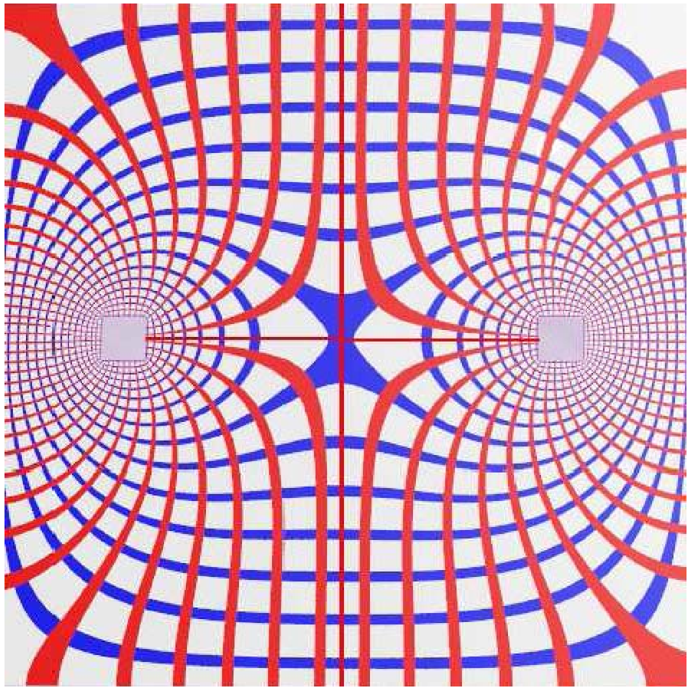
Scientific Visualization

- Scientific data representation
- Picture vs. stream of numbers
- CG Techniques: contour plots, color coding, constant value surface rendering, custom shapes

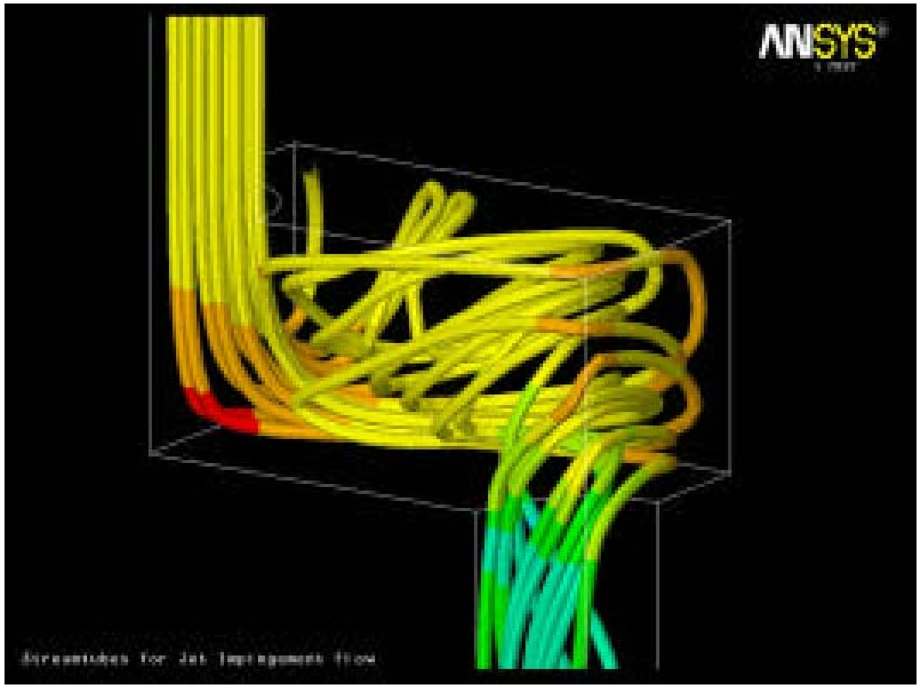

Display of a 2D slice through the total electron density of C-60; Created by Cary Sandvig of SGI

Scientific Simulation

Electromagnetic potential field

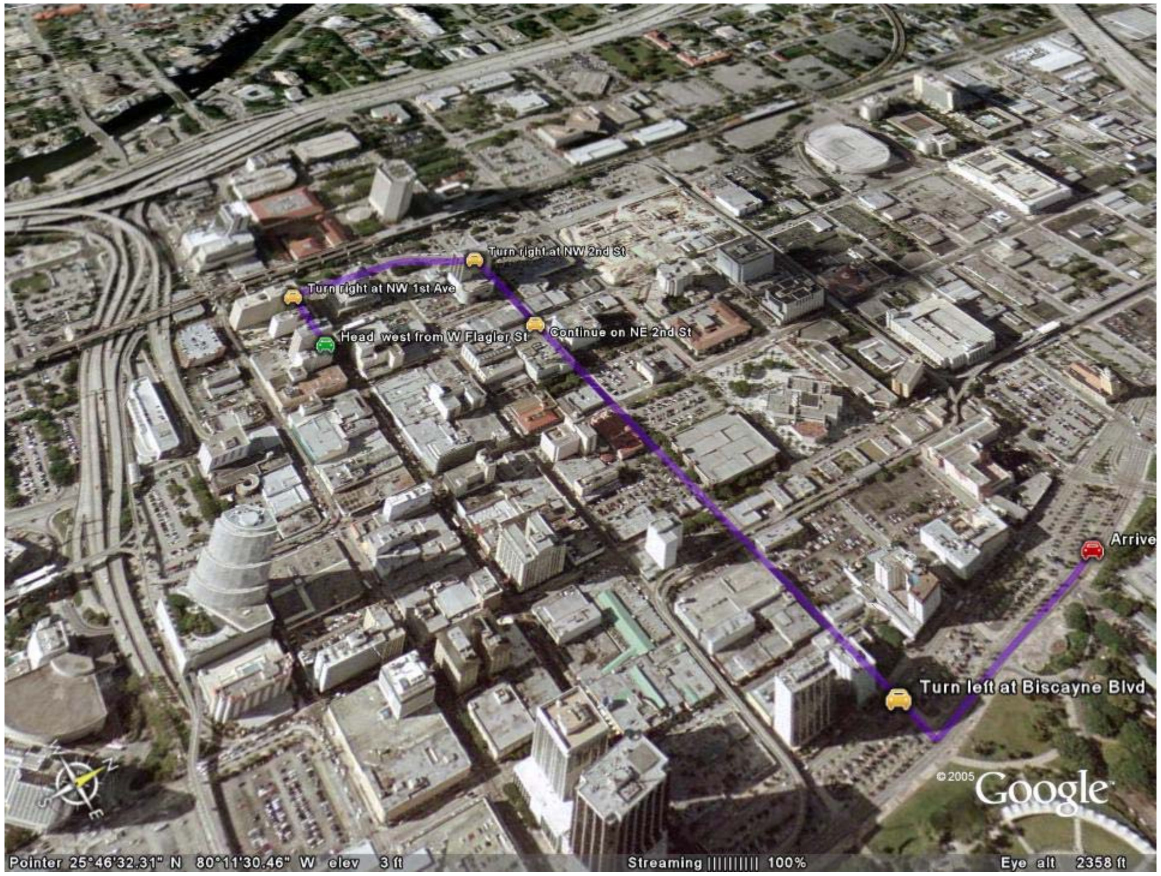


Computational Fluid Dynamics (CFD)



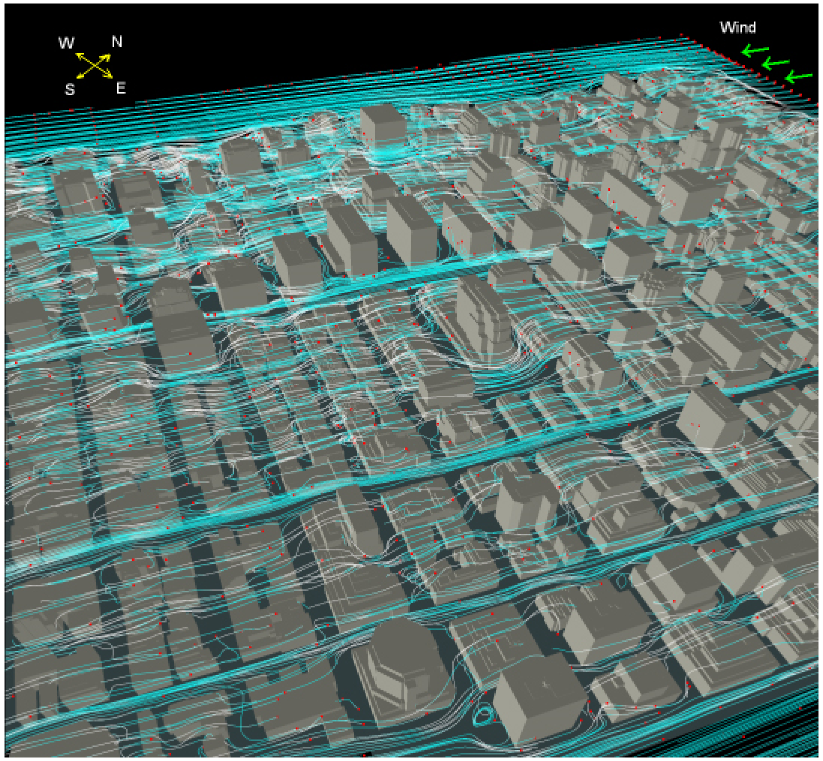
Courtesy of Mark Toscinski and Paul Tallon

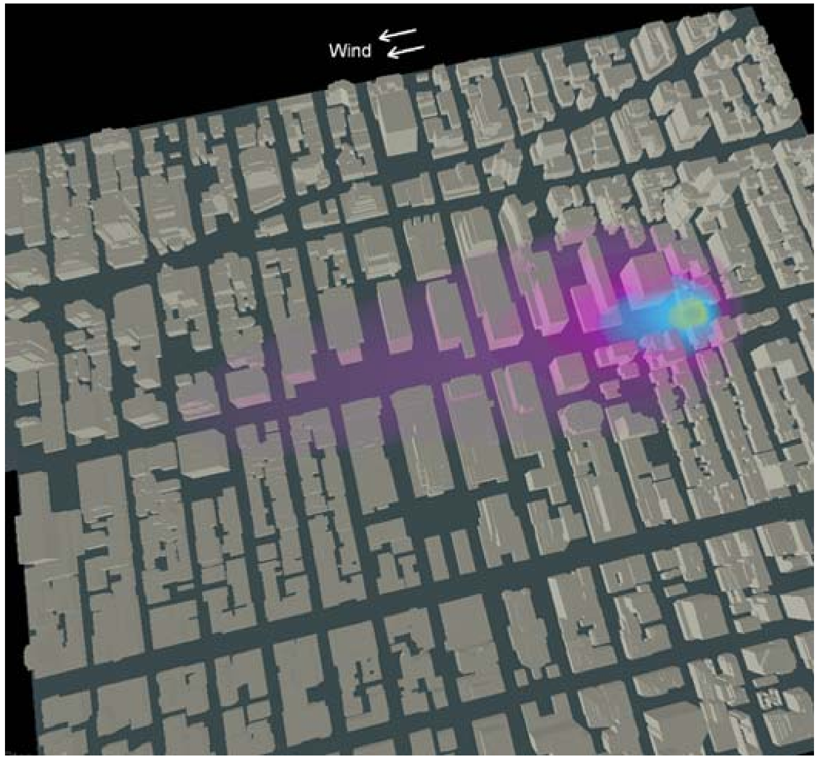
Navigation, Urban Security…


Turn right at NW 2nd St
Turn right at NW 1st Ave
Head west from W Flagler St
Continue on NE 2nd St
Arrive
Turn left at Biscayne Blvd
© 2005 Google
Pointer 25°46'32.31" N 80°11'30.46" W elev 3 ft
Streaming |||||||||| 100%
Eye alt 2358 ft

Google Earth

Navigation, Urban Security…

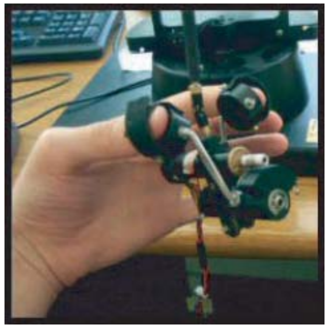


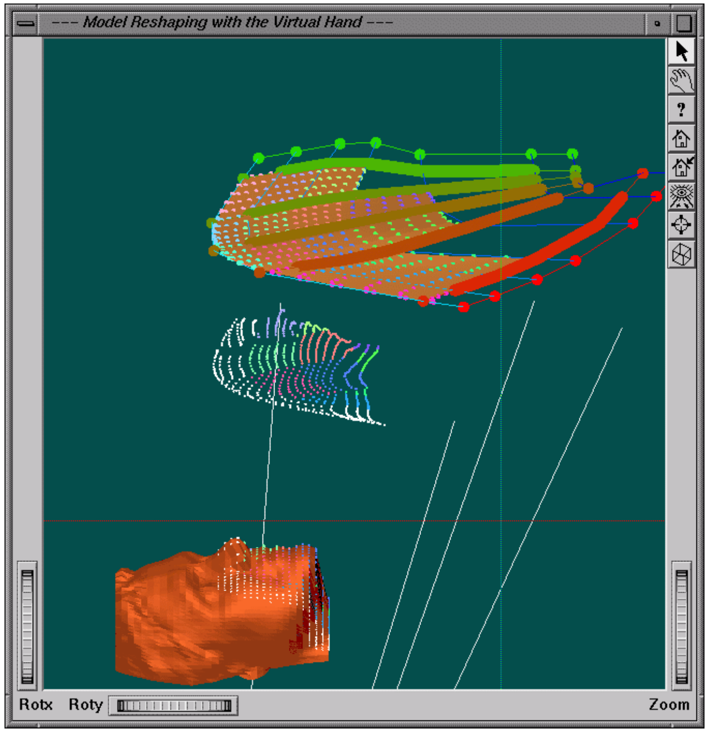


simulate/visualize/predict the propagation of airborne contaminants in virtual Manhattan

Virtual Reality

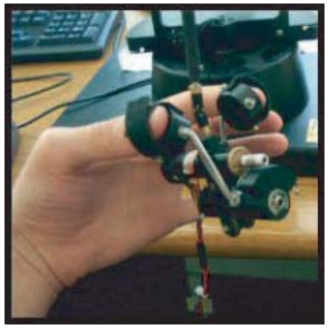
- CAVE, Interactive modeling

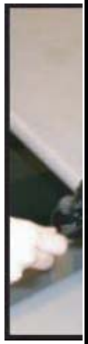


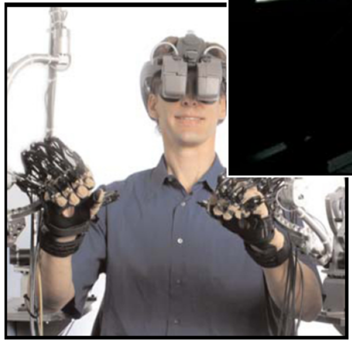


Virtual Reality

- CAVE, Interactive modeling
- Virtual walkthroughs (training pilots, surgeons…)

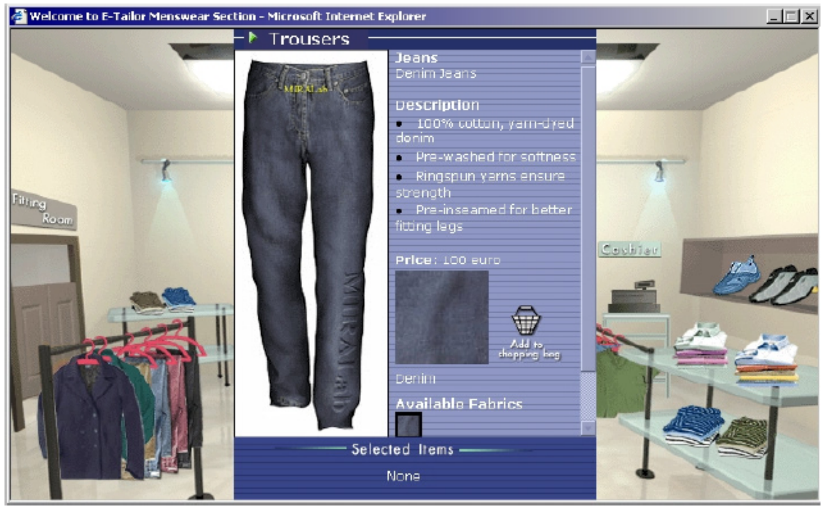






Textile/Cosmetics Industry

- Fashion design
- Real-time cloth animation
- Web-based virtual try-on applications


Welcome to E-Tailor Menswear Section - Microsoft Internet Explorer

Trousers

Jeans
Denim Jeans

Description
- 100% cotton, yarn-dyed denim
- Pre-washed for softness
- Ringspun yarns ensure strength
- Pre-inseamed for better fitting legs

Price: 100 euro

Denim

Available Fabrics

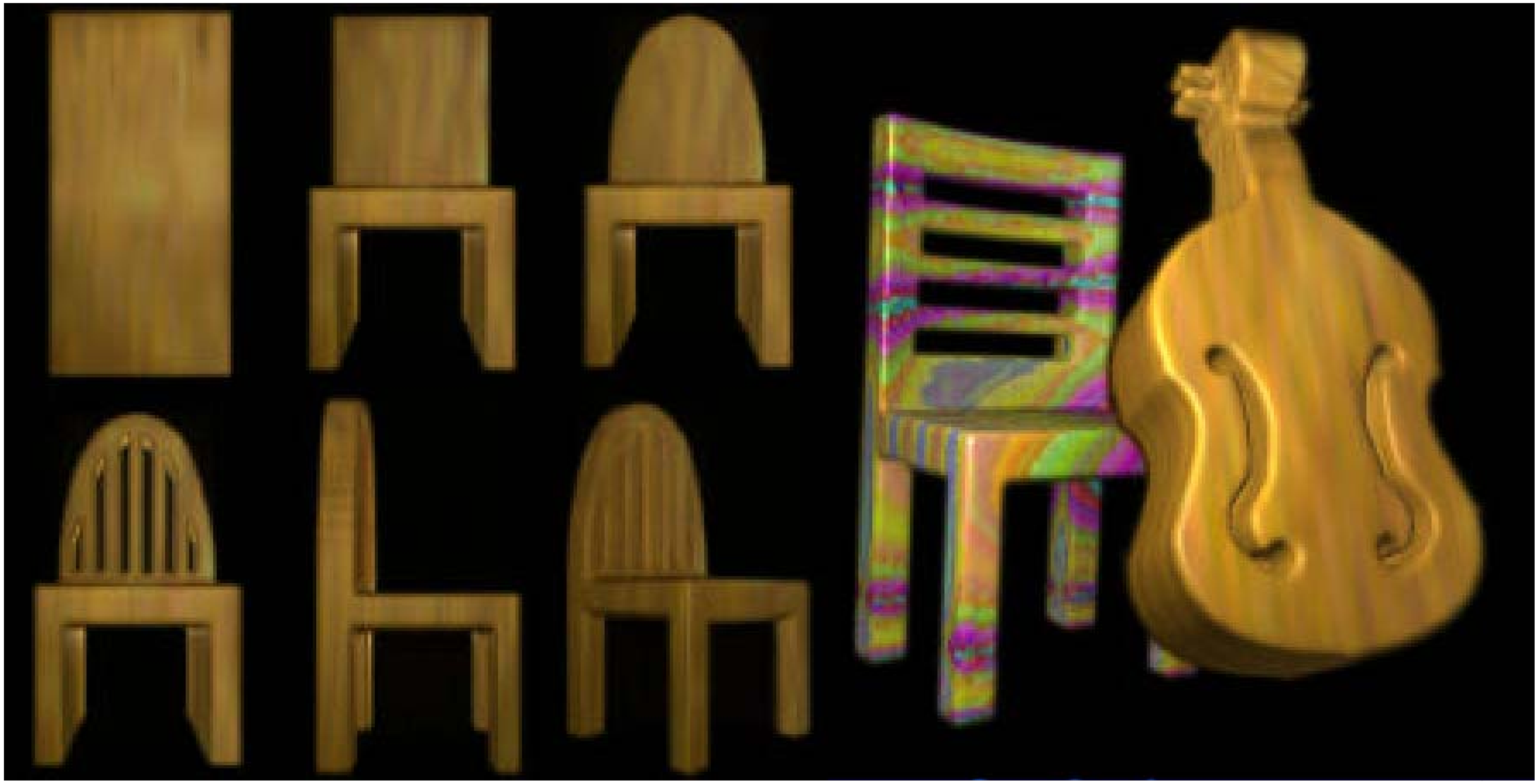
Selected Items
None

Computer Art

- Digital Painting

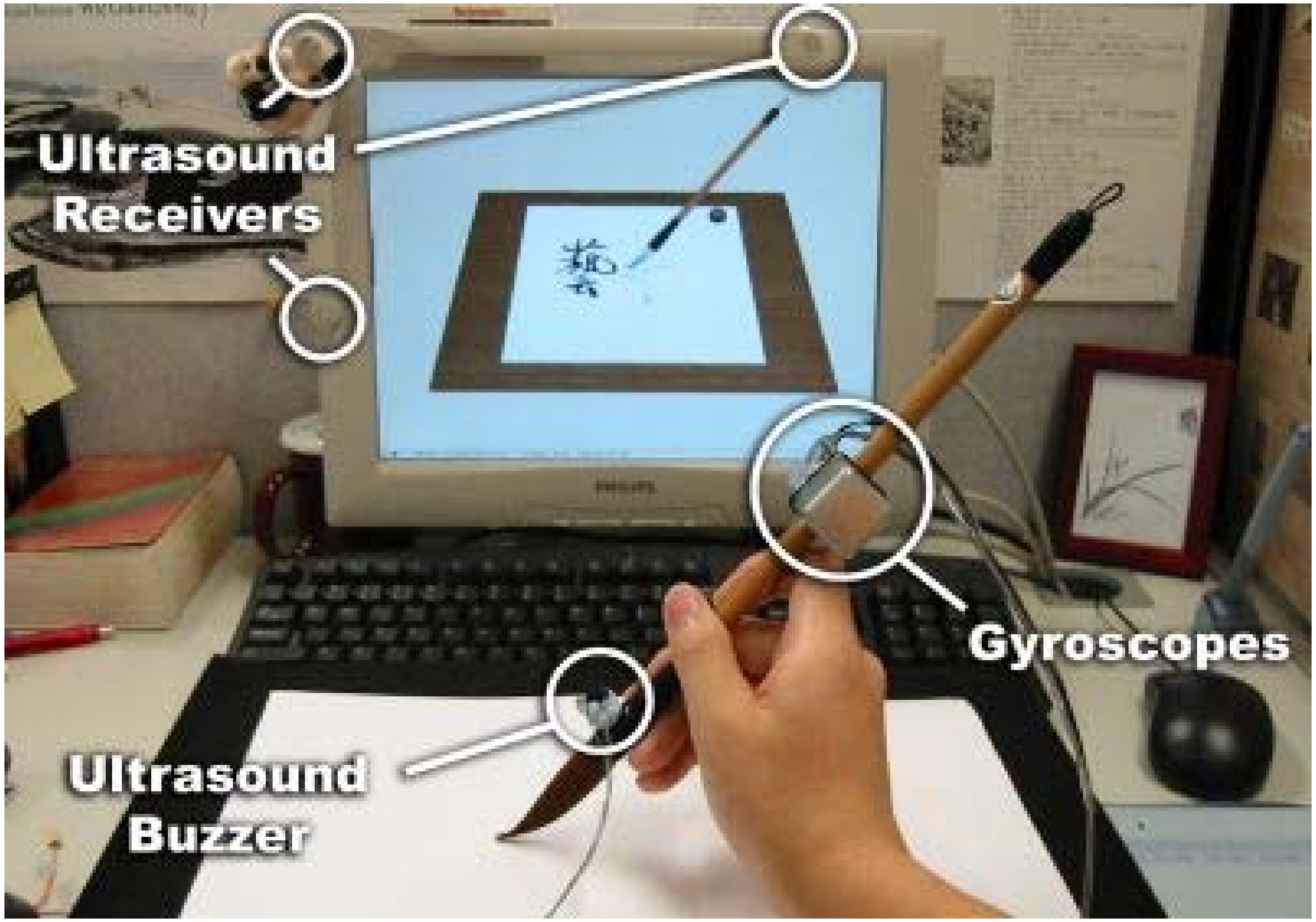
Computer Art

- Digital Painting, Digital Sculpting



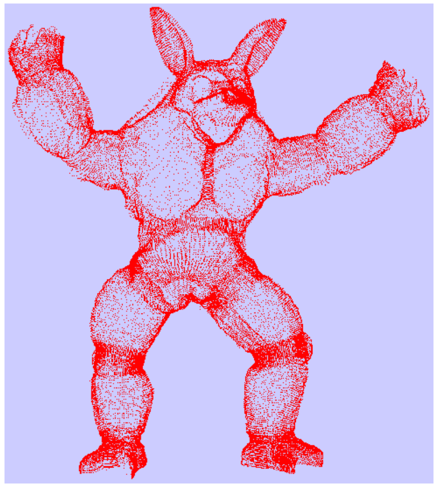
Computer Art

- Digital Painting, Digital Sculpting, Digital Calligraphy



And more …

3D Graphics Pipeline



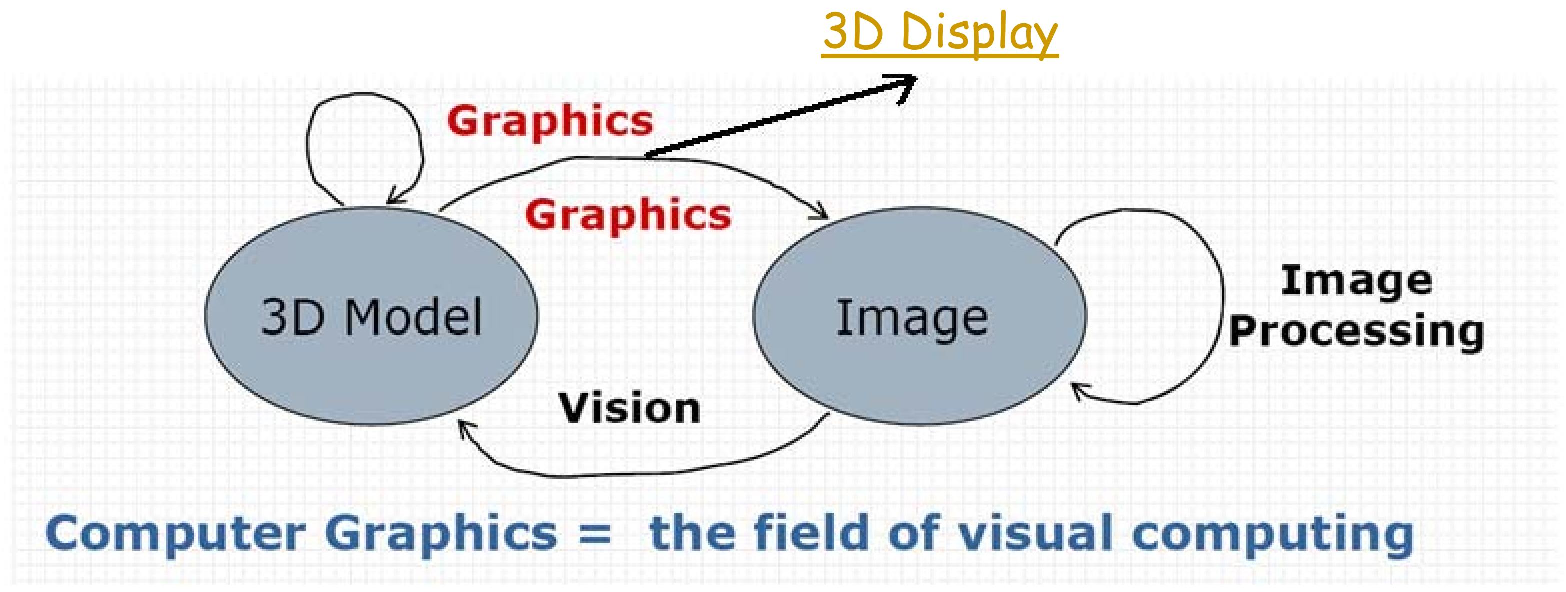
$$\begin{tikzcd}\boxed{\text{3D Model Acquisition}} \arrow[r] & \boxed{\text{Geometric Modeling and Processing}} \arrow[r] & \boxed{\text{Animation, Rendering, Visualization}}\end{tikzcd}$$

Range images,
Point clouds

Digital geom. processing
Multi-resolution modeling
…

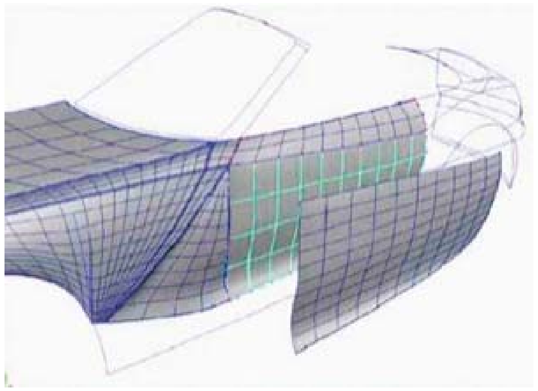
Ray tracing
Texture synthesis
Appearance modeling
Physics-based simulation
…

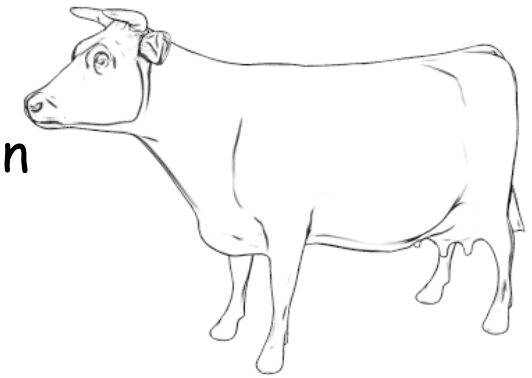
Geometry Shapes & Images

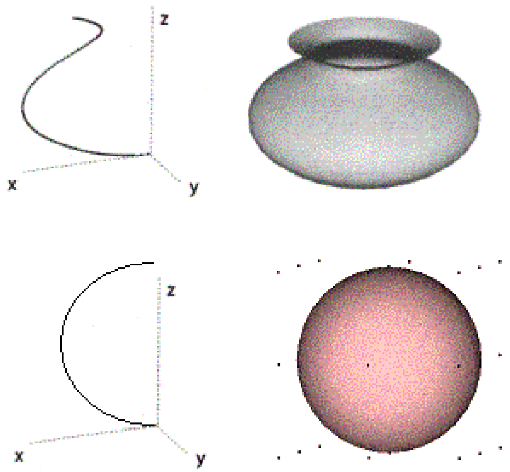


Creating 3D Digital Models

- Manual strategy
  - interactive manual modeling
  - sketch-based modeling
- Laser ranger, or camera
- Mathematical description
- Sweeping



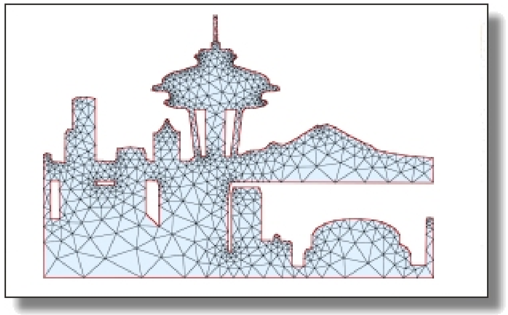




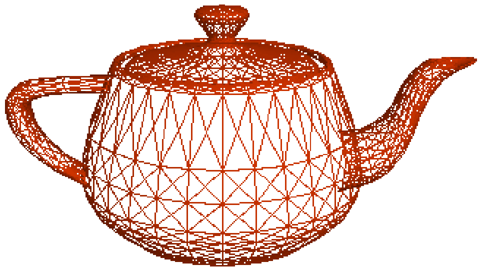
$$S(u,v) = \sum_{i=0}^{8} \sum_{j=0}^{m} R_{i,2;j,q}(u,v) P_{i,j}$$

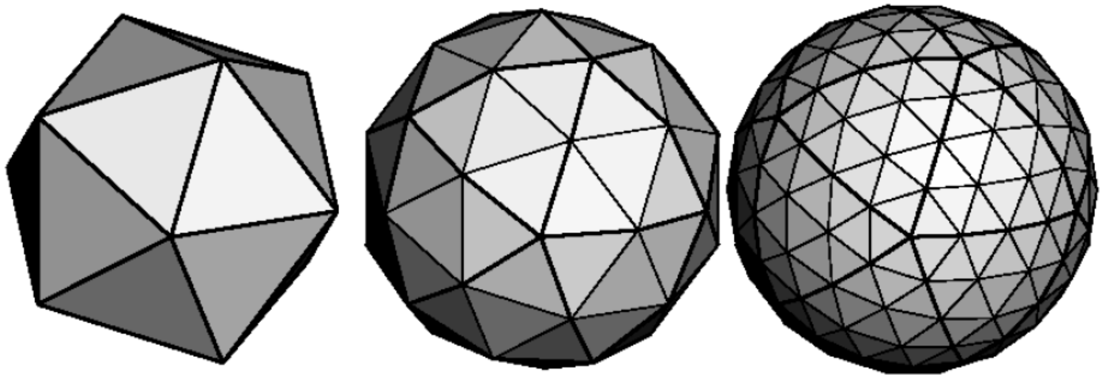
Triangular Mesh

- Surface shapes can be triangulated



Polygonal approximation of surfaces:



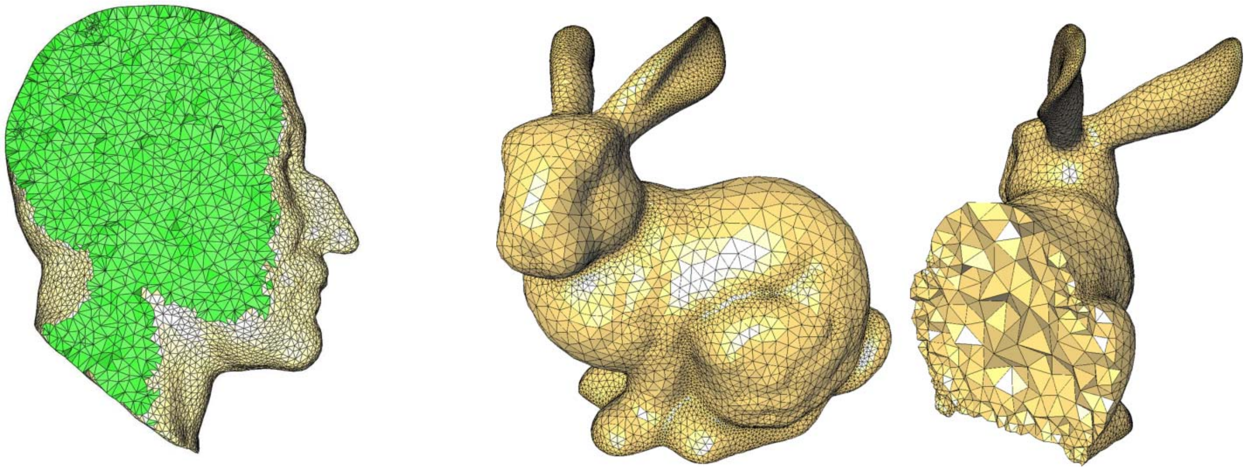


Any 2D shape or 3D surface (2-manifold) can be approximated with locally linear polygons. To improve (visual or numerical approximation quality), we only need to increase the number of edges

Tetrahedral Mesh

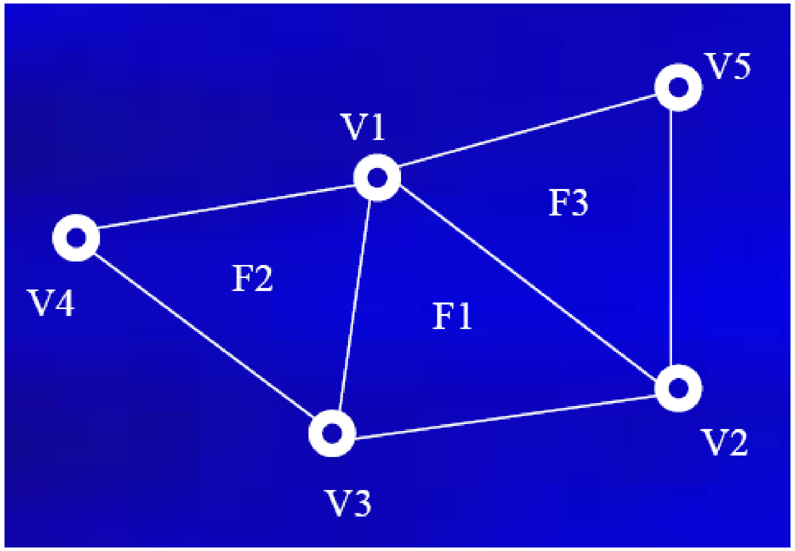
- Solid shapes can be tetrahedralized

Polyhedra approximation of solid geometric data



Any 3D volumetric data (3-manifold) can be approximated with locally linear polyhedra. To improve (visual or numerical approximation quality), we only need to increase the number of edges

How to Represent Triangular Meshes?

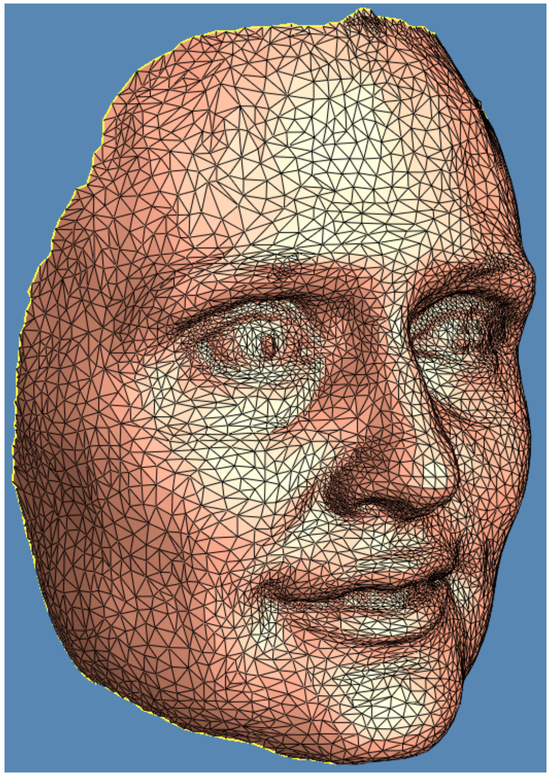


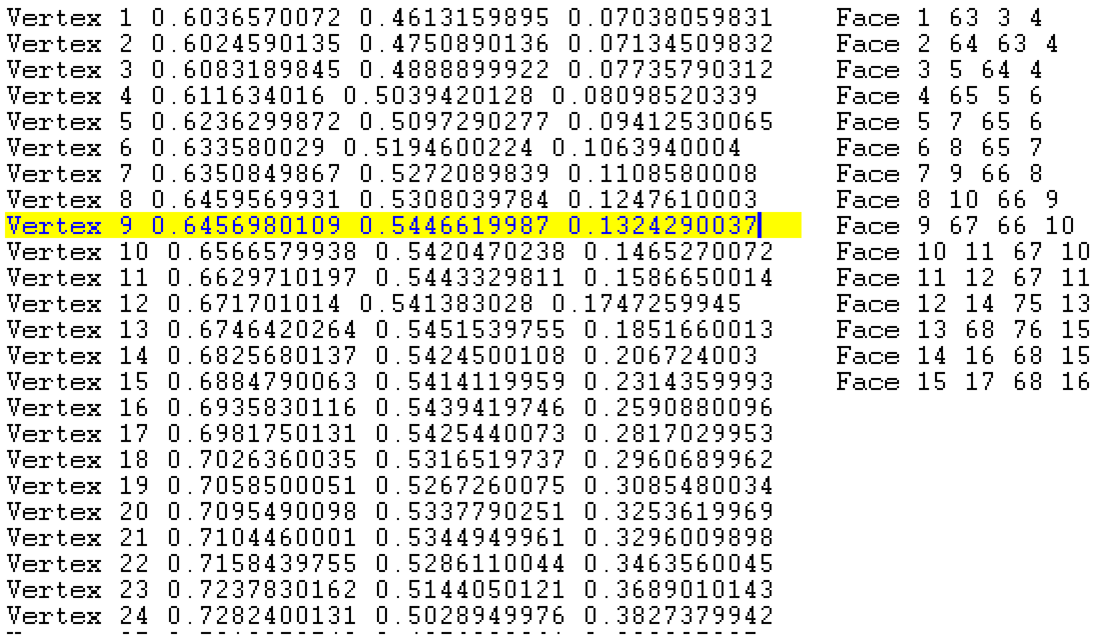
Vertex table	
V1	(x1,y1,z1)
V2	(x2,y2,z2)
V3	(x3,y3,z3)
V4	(x4,y4,z4)
V5	(x5,y5,z5)

Face table	
F1	V1,V3,V2
F2	V1,V4,V3
F3	V5,V1,V2

How to Represent Triangular Meshes?

Example: a female face mesh with 10k triangles

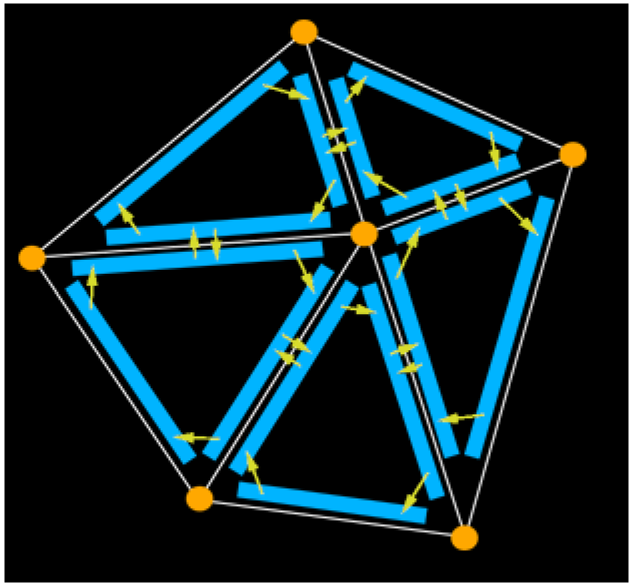




```
Vertex 1 0.6036570072 0.4613159895 0.07038059831      Face 1 63 3 4
Vertex 2 0.6024590135 0.4750890136 0.07134509832      Face 2 64 63 4
Vertex 3 0.6083189845 0.4888899922 0.07735790312      Face 3 5 64 4
Vertex 4 0.611634016 0.5039420128 0.08098520339       Face 4 65 5 6
Vertex 5 0.6236299872 0.5097290277 0.09412530065      Face 5 7 65 6
Vertex 6 0.633580029 0.5194600224 0.1063940004        Face 6 8 65 7
Vertex 7 0.6350849867 0.5272089839 0.1108580008       Face 7 9 66 8
Vertex 8 0.6459569931 0.5308039784 0.1247610003       Face 8 10 66 9
Vertex 9 0.6456980109 0.5446619987 0.1324290037       Face 9 67 66 10
Vertex 10 0.6566579938 0.5420470238 0.1465270072      Face 10 11 67 10
Vertex 11 0.6629710197 0.5443329811 0.1586650014      Face 11 12 67 11
Vertex 12 0.671701014 0.541383028 0.1747259945        Face 12 14 75 13
Vertex 13 0.6746420264 0.5451539755 0.1851660013      Face 13 68 76 15
Vertex 14 0.6825680137 0.5424500108 0.206724003       Face 14 16 68 15
Vertex 15 0.6884790063 0.5414119959 0.2314359993      Face 15 17 68 16
Vertex 16 0.6935830116 0.5439419746 0.2590880096
Vertex 17 0.6981750131 0.5425440073 0.2817029953
Vertex 18 0.7026360035 0.5316519737 0.2960689962
Vertex 19 0.7058500051 0.5267260075 0.3085480034
Vertex 20 0.7095490098 0.5337790251 0.3253619969
Vertex 21 0.7104460001 0.5344949961 0.3296009898
Vertex 22 0.7158439755 0.5286110044 0.3463560045
Vertex 23 0.7237830162 0.5144050121 0.3689010143
Vertex 24 0.7282400131 0.5028949976 0.3827379942
```

How to Represent Triangular Meshes?

A common data structure for geometric processing:
Half-Edge structure

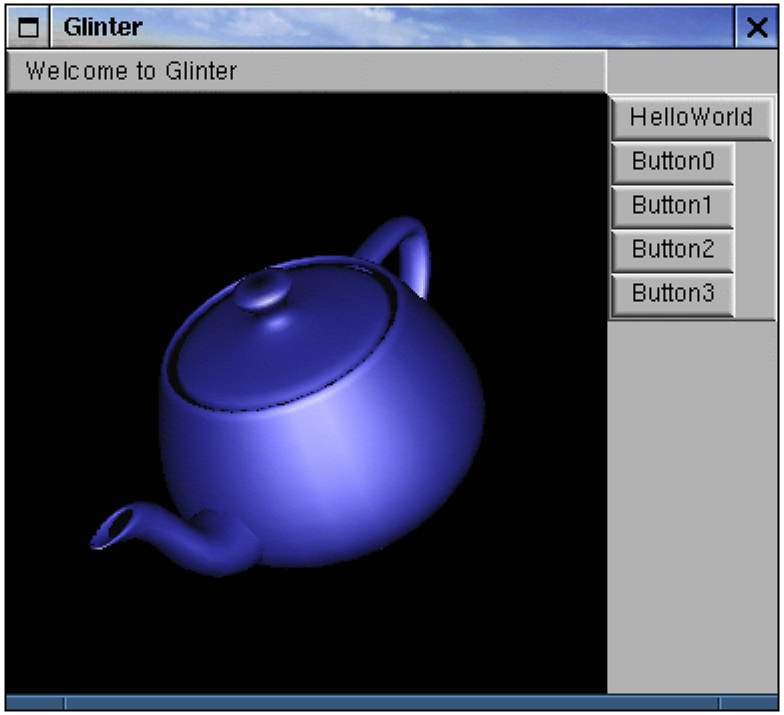


- ❑Concepts and algorithm will be discussed shortly
- ❑Full implementation will be provided
- ❑Get familiar with it (will be our starting point in future projects)

How to Render Triangular Meshes?

From next class, we'll start to learn:

How to use OpenGL for rendering triangular meshes?



Representation of 3D Objects

- Polygonal Representation
  - Triangle mesh
  - Quadrilateral mesh
- Constructive Solid Geometry (CSG) Representation
- Space Subdivision Technique
- Implicit Function Representation
- Spline Function
- Other Methods
  - GC (Generalized Cones, Generalized Cylinders)
  - Skeleton Representation
  - Spatial Decomposition (Spherical harmonics, Zernike…)
  - Overlapping Spheres

Representation of 3D Objects

- Polygonal Representation
  - Triangle mesh

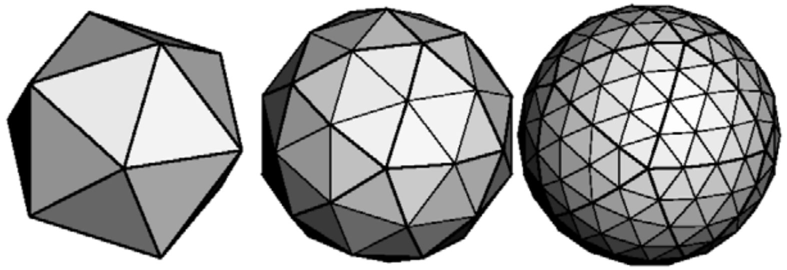
How do we choose a representation?

- ❑the nature of the object
- ❑the particular geometric processing we want to apply
- ❑the application

  - Skeleton Representation
  - Spatial Decomposition (Spherical harmonics, Zernike…)
  - Overlapping Spheres

Polygonal Mesh

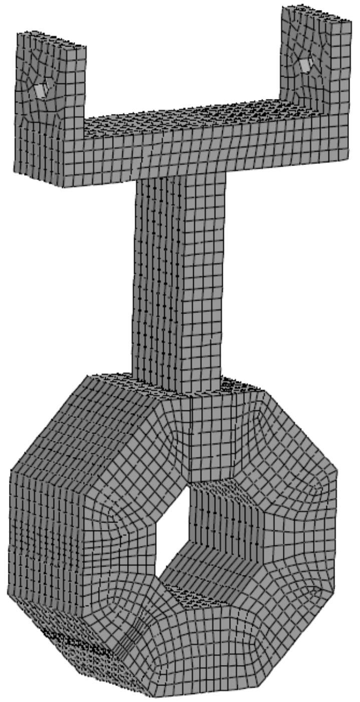
- Objects ← a net/mesh of planar polygonal facets
  - can represent an object to an accuracy that we choose

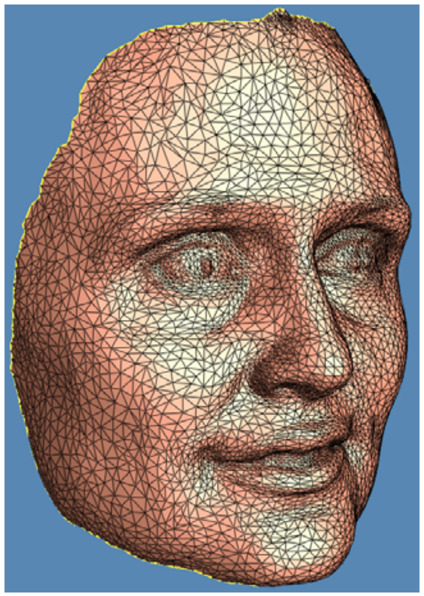


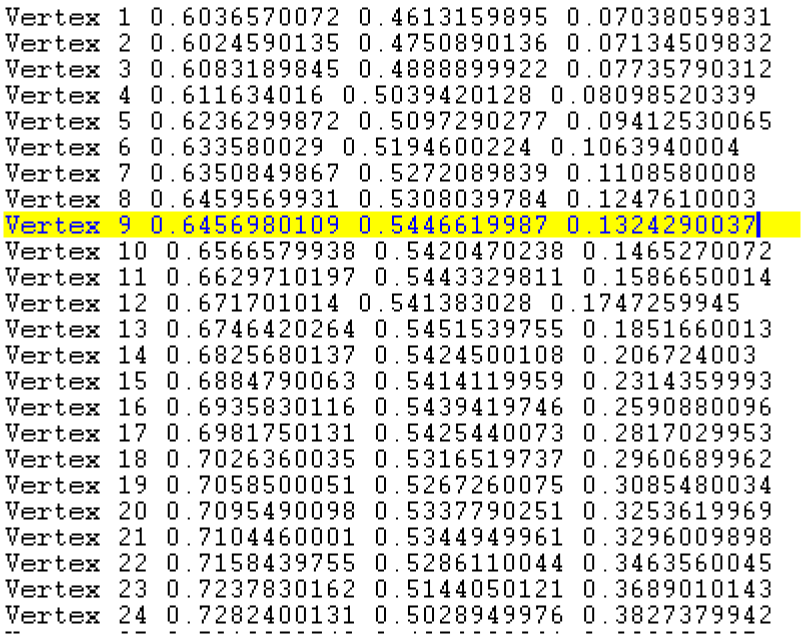
- Pro: A ubiquitous representation in Computer Graphics
  - Easy to generate and process
  - With effective algorithm for rendering (machine-oriented rep.)
  - Other rep. (CSG, splines, voxels…) → mesh before rendering)
- Con: accuracy
  - Faceted rep. VS curved surfaces : usually arbitrary
  - Constructing methods matter : mesh quality
  - …

Polygonal Mesh

- Quad-Mesh
- Triangle Mesh
- A Mesh = {Vertex Positions,
  Connectivity,
  Additional Attributes}







```
Vertex 1 0.6036570072 0.4613159895 0.07038059831
Vertex 2 0.6024590135 0.4750890136 0.07134509832
Vertex 3 0.6083189845 0.4888899922 0.07735790312
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Vertex 23 0.7237830162 0.5144050121 0.3689010143
Vertex 24 0.7282400131 0.5028949976 0.3827379942
```
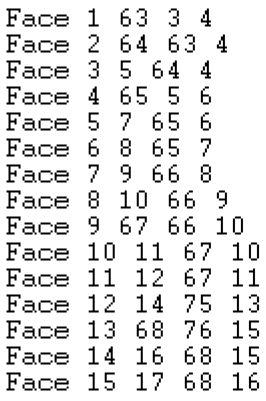
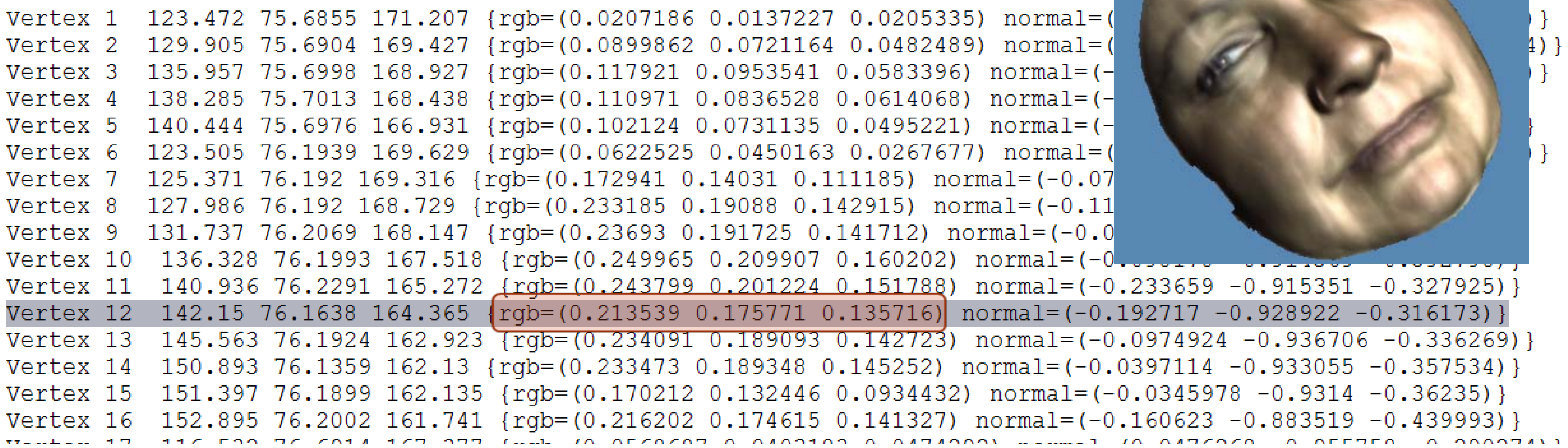



```
Face 1 63 3 4
Face 2 64 63 4
Face 3 5 64 4
Face 4 65 5 6
Face 5 7 65 6
Face 6 8 65 7
Face 7 9 66 8
Face 8 10 66 9
Face 9 67 66 10
Face 10 11 67 10
Face 11 12 67 11
Face 12 14 75 13
Face 13 68 76 15
Face 14 16 68 15
Face 15 17 68 16
```

Polygonal Mesh

- Quad-Mesh
- Triangle Mesh
- A Mesh = {Vertex Positions,
  Connectivity,
  Additional Attributes}

Vertex Normal, Edge length, face area, any scalar/vector fields…



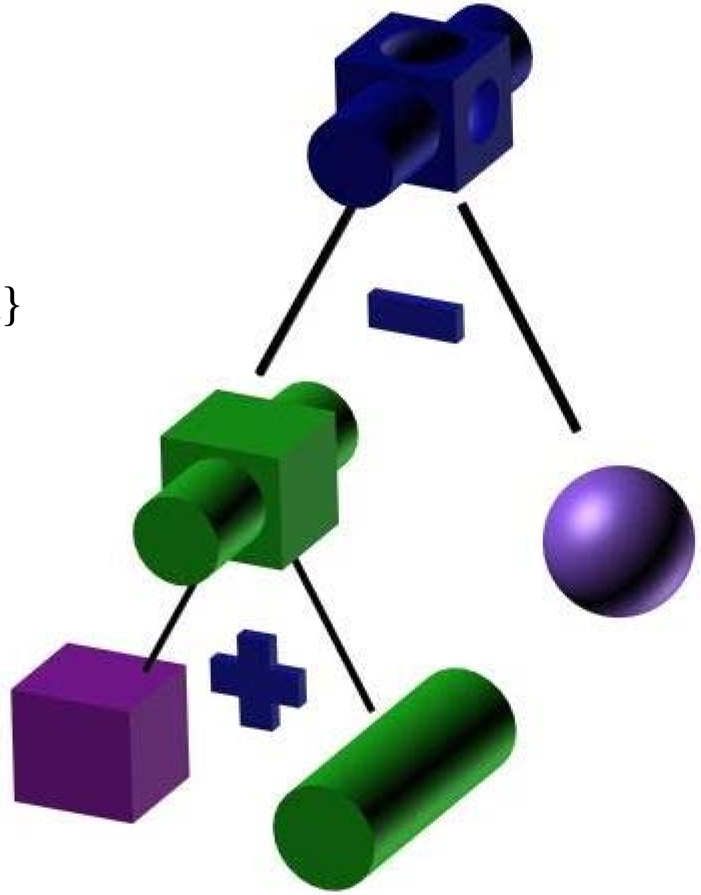
```
Vertex 1  123.472 75.6855 171.207 {rgb=(0.0207186 0.0137227 0.0205335) normal=(                    )}
Vertex 2  129.905 75.6904 169.427 {rgb=(0.0899862 0.0721164 0.0482489) normal=(                    4)}
Vertex 3  135.957 75.6998 168.927 {rgb=(0.117921 0.0953541 0.0583396) normal=(-                    )}
Vertex 4  138.285 75.7013 168.438 {rgb=(0.110971 0.0836528 0.0614068) normal=(-
Vertex 5  140.444 75.6976 166.931 {rgb=(0.102124 0.0731135 0.0495221) normal=(-                    }
Vertex 6  123.505 76.1939 169.629 {rgb=(0.0622525 0.0450163 0.0267677) normal=(                    )}
Vertex 7  125.371 76.192 169.316 {rgb=(0.172941 0.14031 0.111185) normal=(-0.07
Vertex 8  127.986 76.192 168.729 {rgb=(0.233185 0.19088 0.142915) normal=(-0.11
Vertex 9  131.737 76.2069 168.147 {rgb=(0.23693 0.191725 0.141712) normal=(-0.0
Vertex 10  136.328 76.1993 167.518 {rgb=(0.249965 0.209907 0.160202) normal=(-0
Vertex 11  140.936 76.2291 165.272 {rgb=(0.243799 0.201224 0.151788) normal=(-0.233659 -0.915351 -0.327925)}
Vertex 12  142.15 76.1638 164.365 {rgb=(0.213539 0.175771 0.135716) normal=(-0.192717 -0.928922 -0.316173)}
Vertex 13  145.563 76.1924 162.923 {rgb=(0.234091 0.189093 0.142723) normal=(-0.0974924 -0.936706 -0.336269)}
Vertex 14  150.893 76.1359 162.13 {rgb=(0.233473 0.189348 0.145252) normal=(-0.0397114 -0.933055 -0.357534)}
Vertex 15  151.397 76.1899 162.135 {rgb=(0.170212 0.132446 0.0934432) normal=(-0.0345978 -0.9314 -0.36235)}
Vertex 16  152.895 76.2002 161.741 {rgb=(0.216202 0.174615 0.141327) normal=(-0.160623 -0.883519 -0.439993)}
```

CSG Representation

- Polygonal Mesh → machine-oriented representation
- CSG → user-oriented representation
  - store the "logic of the shape"
- A CSG modeling system
  = {building blocks, Boolean operations}

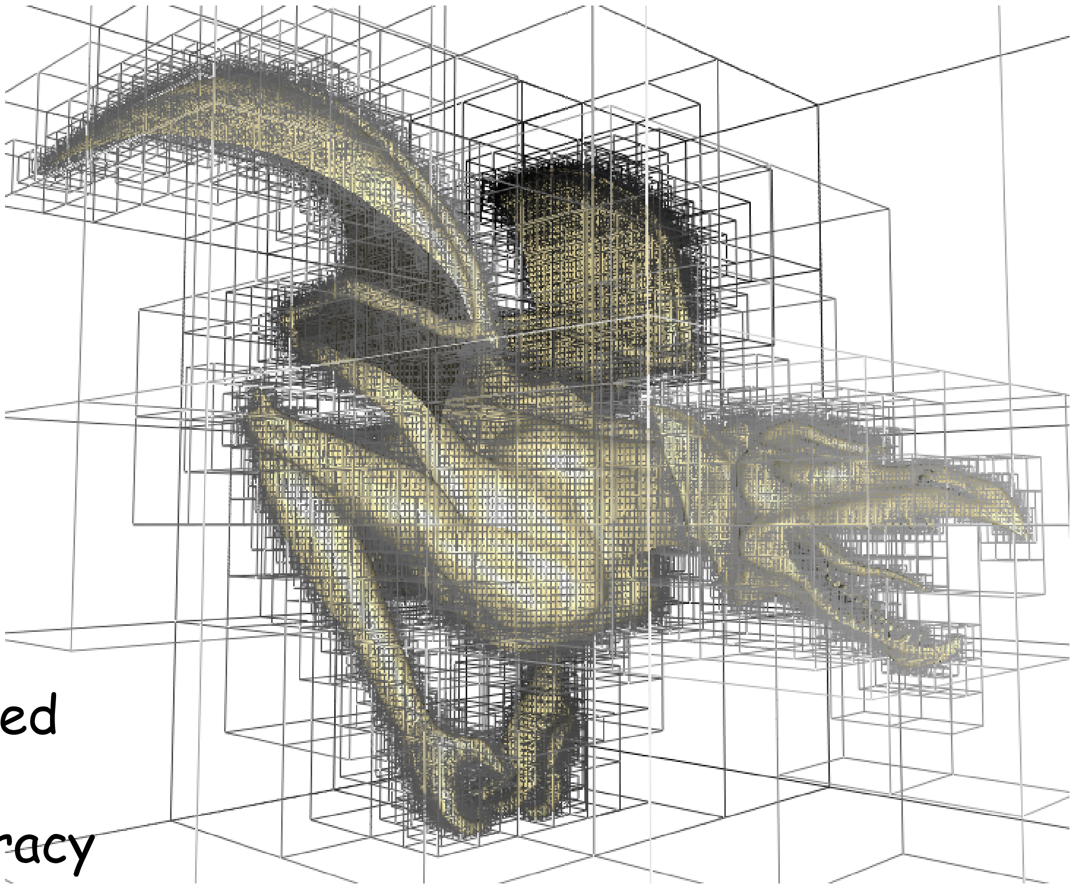
{union, subtract, intersect}

Widely used in 3DMax, Maya… as their modeling scheme:
❑Support user-intervention
❑Good for simple shapes



Space Subdivision Representation

- Not explicitly represents the geometric object
- But consider the space the object occupy



an octree rep.

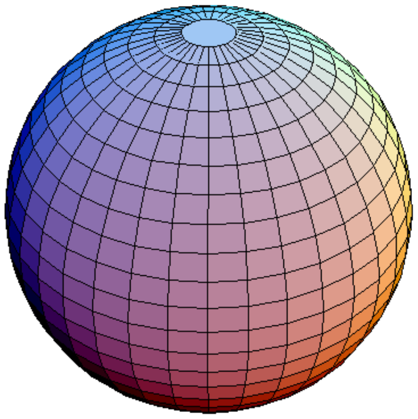
= a hierarchical tree built by sequential subdivision of occupied cells

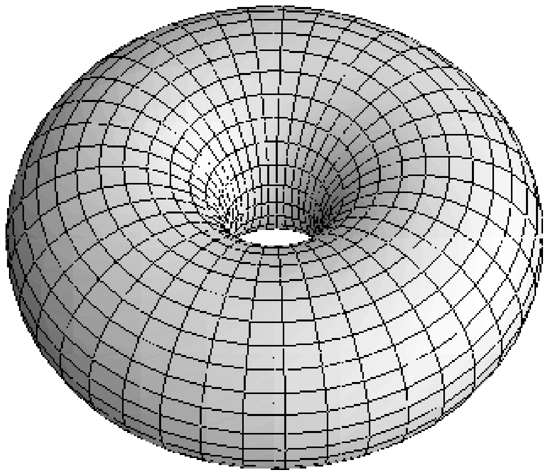
- Widely used for complicated scenes that need faster processing and lower accuracy

e.g. Collision detection in realtime simulation or animation

Implicit Representation

- Usually Compact
- Good for modeling shapes with closed-form expression
- Good for processing with topological changes
  - Simulation
  - Reconstruction (Hole-filling)
  - …

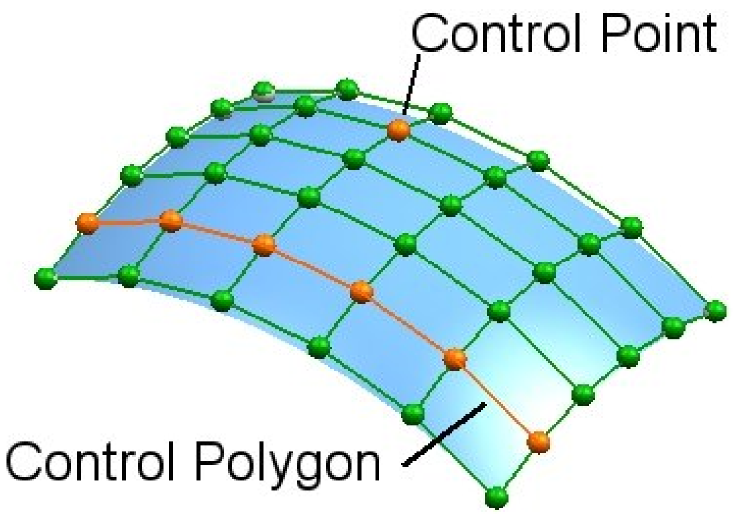


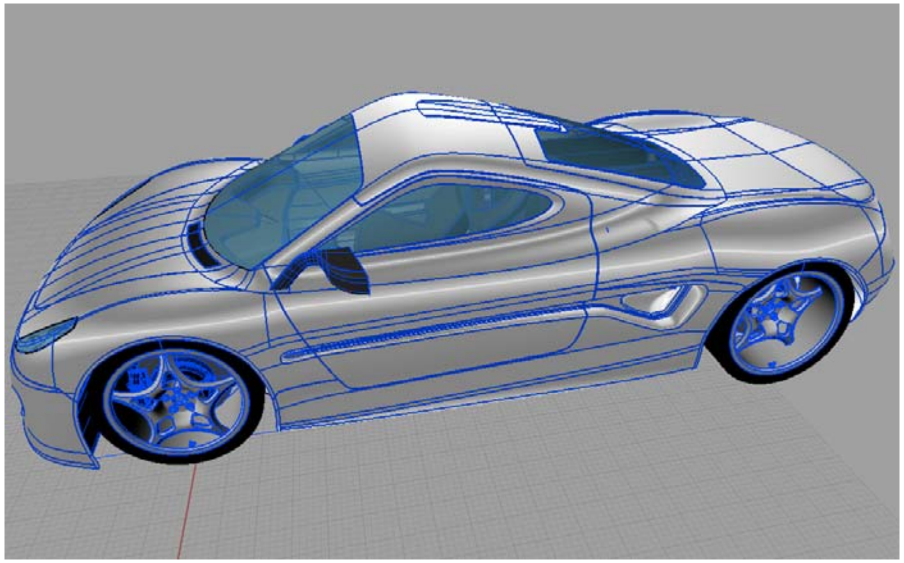


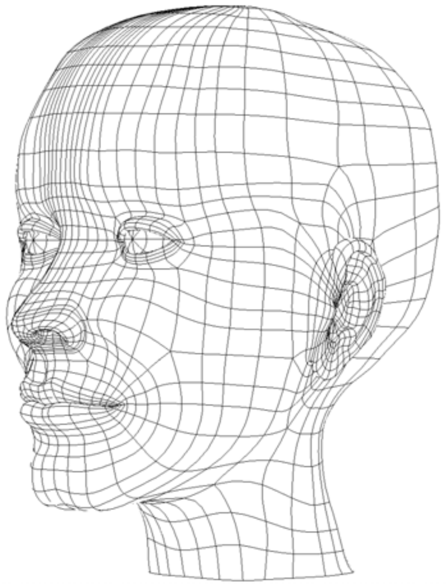
Spline

- Exact analytical rep.
- Support interactive shape editing
- Compact rep.

- Major modeling techniques in CAD







Resources

Reference books (not required) :

1. OpenGL Programming Guide (the Red Book)
   http://www.glprogramming.com/red/
2. 3D Computer Graphics
   by Alan Watt. Addison-Wesley.
3. Computer Graphics: Principles and Practice
   by James Foley, Andries van Dam, Steven Feiner, John Hughes. Addison-Wesley.

To do research in CG:

What math is important for Computer Graphics? (by Greg Turk)

Welcome to drop by my office for discussion, or check my webpage: www.ece.lsu.edu/xinli