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Computer Graphics and Computer Vision

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Graphics and Vision: A Unified View

- **This major field is about Computers and Images**
- **Computer Graphics (CG)**
  - **Computational models → images and videos**
  - **Forward mathematical problem**
  - **Synthesis**
- **Computer Vision (CV)**
  - **Images and videos → computational models**
  - **Inverse mathematical problem**
  - **Analysis**

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History of Computer Graphics and Computer Vision

- Two PhD thesis projects at MIT in the early 1960s
  - Ivan E. Sutherland, 1963
    - "Sketchpad, a man-machine graphical communication system"
  - Lawrence G. Roberts, 1963
    - "Machine perception of three-dimensional solids"
- CG and CV have developed as independent fields
- In recent years, CG and CV are synergizing
- Cross-fertilization with other fields:
  - Physics, biology, cognitive science, artificial intelligence, art, ….

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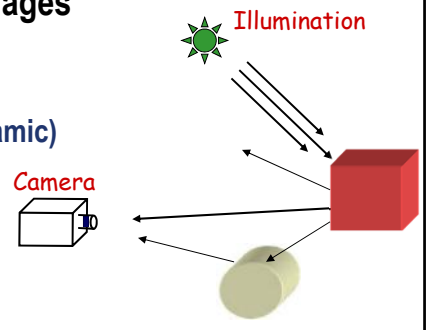
What is an Image / Video?

- Array of pixels (one or more numbers)
- A video is a time sequence of images
- How they are formed:
  - Objects in the world (static or dynamic)
  - Illumination (light sources)
  - Imaging device (eye, camera)



- We want to synthesize and analyze images and videos by computer

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Why? Images and movies are everywhere!

- Entertainment: Motion pictures & Games
- Virtual worlds (especially for movies and games)
- Industrial design
- Scientific and medical visualization
- Human-computer interaction
- Fine arts
- Etc.

- Robotics
- Automotive
- Visual Surveillance / Biometrics
- Industrial inspection
- Medical imaging
- Remote sensing
- Image and video retrieval
- Etc.

- For a deeper understanding of the physical world and living systems, including the human brain

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Computer Graphics

- **The art and science of creating imagery by computer**
- **Three main research themes**
  - **Modeling**
    - How do we model (mathematically represent) objects?
    - How do we construct models of specific objects?
  - **Animation**
    - How do we represent the motions of objects?
    - How do we give animators control of this motion?
  - **Rendering**
    - How do we simulate the real-world behavior of light?
    - How do we simulate the formation of images?

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Standard Display Devices

CRT
(Cathode Ray Tube)

Plasma

LCD
(Liquid Crystal Display)

OLED
(Organic Light-Emitting Diode)

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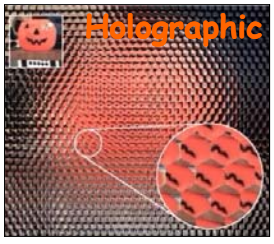
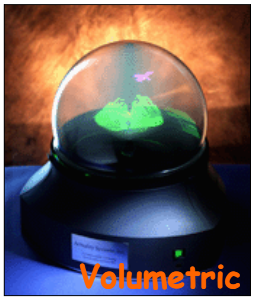
Exotic Display Devices

Head-Mounted





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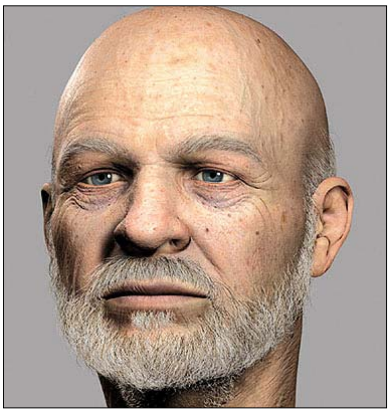
Movies

- To reality and beyond !



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Movies

- Special effects

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Movies

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Digital Compositing

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Digital Compositing

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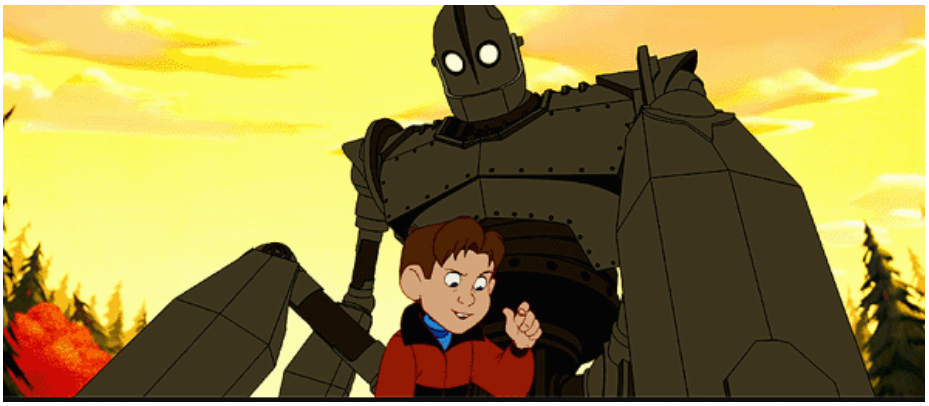
Digital Cartoons



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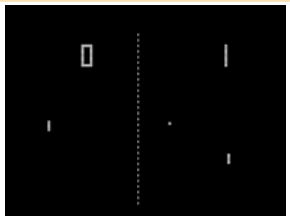
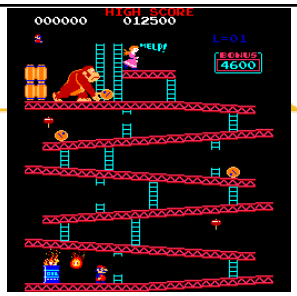
Games

- Focus on interactivity





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Games

- Artificial Life characters

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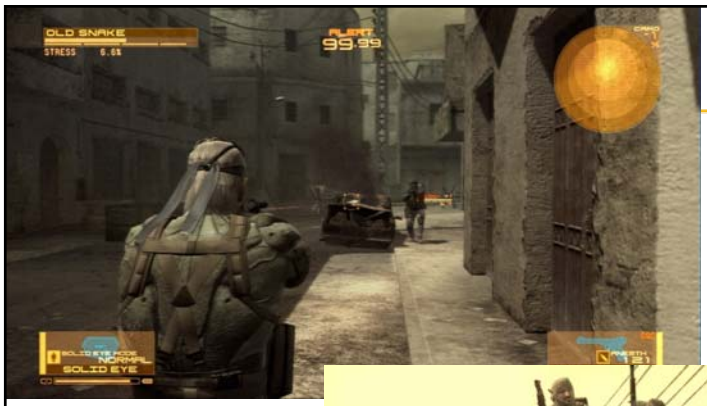
Metal Gear Solid 4

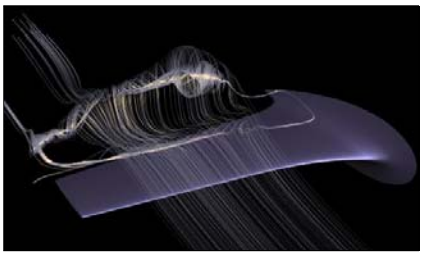


Computer-Aided Design

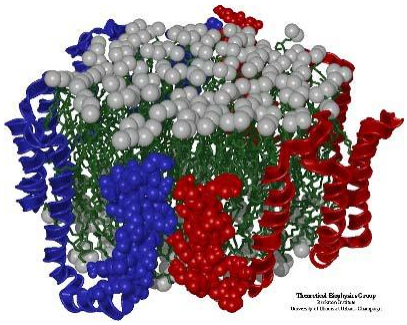
- Precision modeling
- Engineering visualization

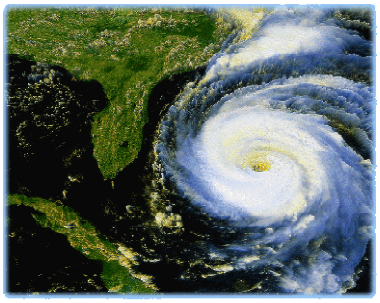
Computer-Aided Design

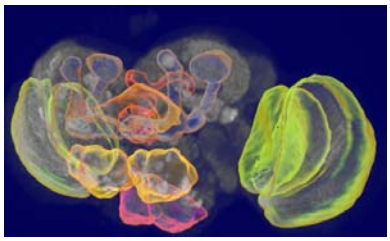
- It's not just about visualization
- Simulation is also useful

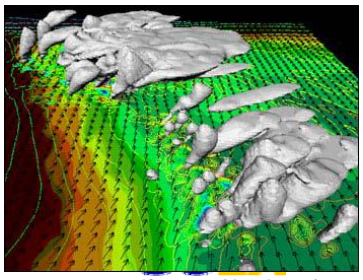


Visualization: Scientific









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Visualization: Architectural

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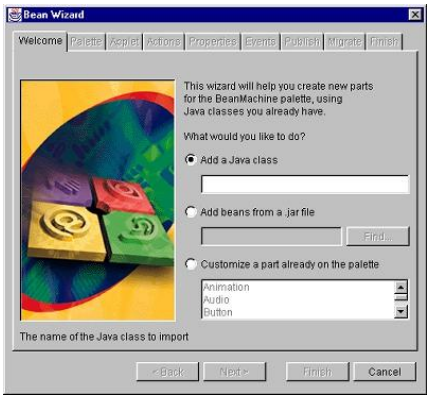
Graphical User Interfaces

WIMP GUIs



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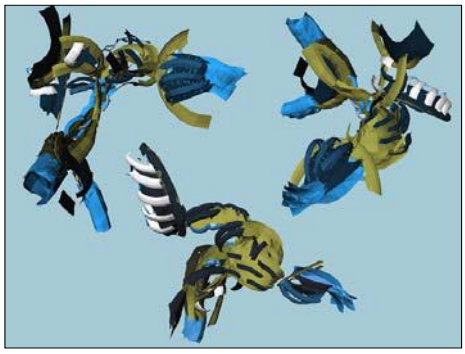
3D User Interfaces

Steven Schkolne



Sculpture Art

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Digital Art

The 2nd Highest-Grossing Movie of All Time, Titanic

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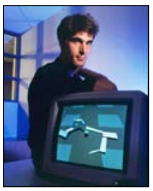
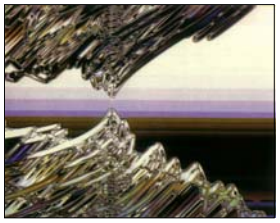
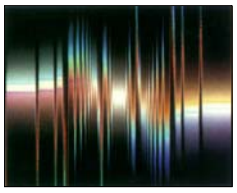
Digital Art

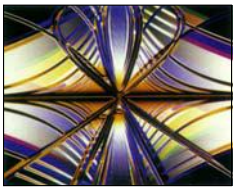
- Genetically evolved

Carl Sims









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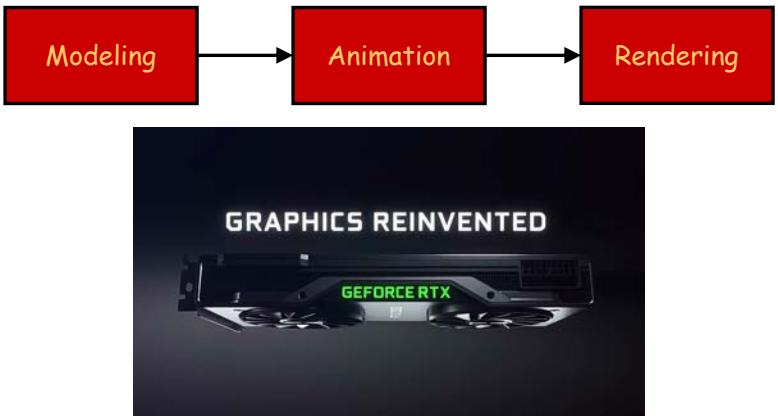
Elements of CG

- The graphics pipeline



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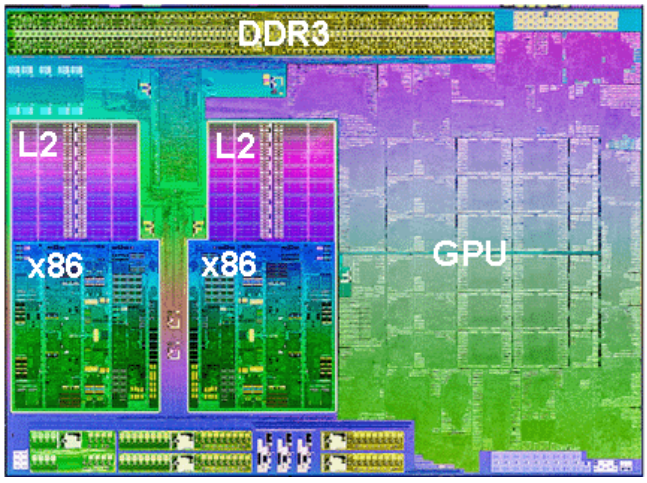
An Integrated GPU (AMD Trinity)



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Modeling

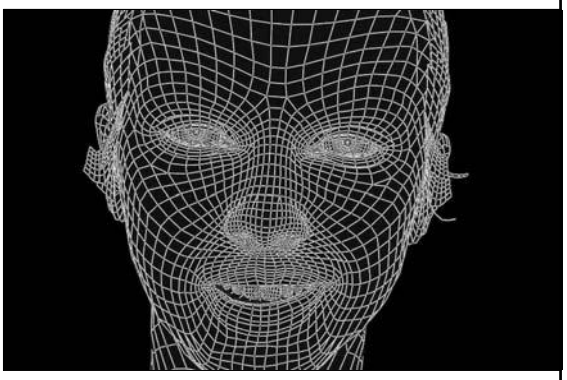
Primitives

- 3D points
- 3D lines and curves
- surfaces (BREPs): polygons, patches
- volumetric representations
- image-based representations

Attributes

- Color, texture maps
- Lighting properties

Geometric transformations



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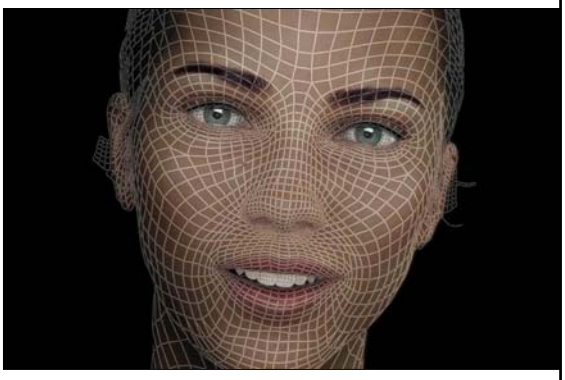
Rendering

Visibility

Simulating light propagation

- Reflection
- Asborption
- Scattering
- Emission
- Interference



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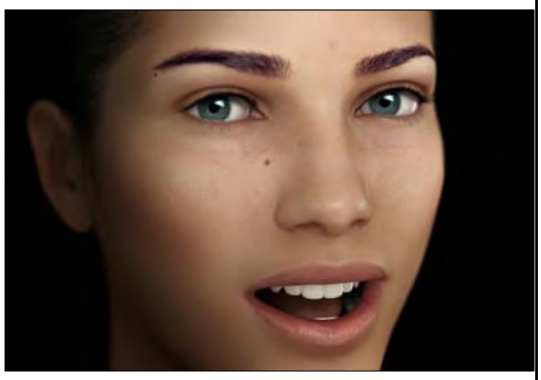
Animation

Keyframe animation

Motion capture

Procedural animation

- **Physics-based animation**
- **Behavioral animation**



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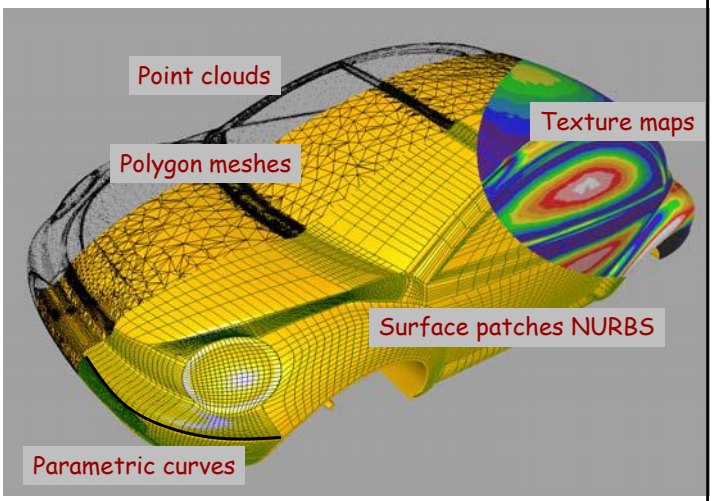
Modeling

◆**Representing objects geometrically on a computer**



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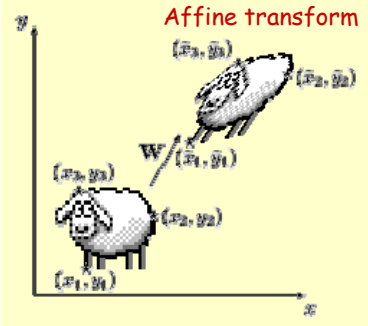
Modeling

- Altering geometric models



Ying, Kristjansson, Biermann, Zorin

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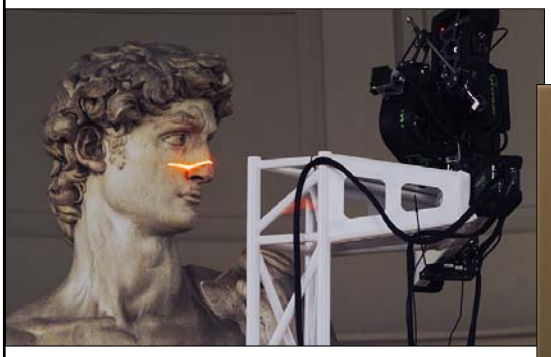
Scanning Shapes

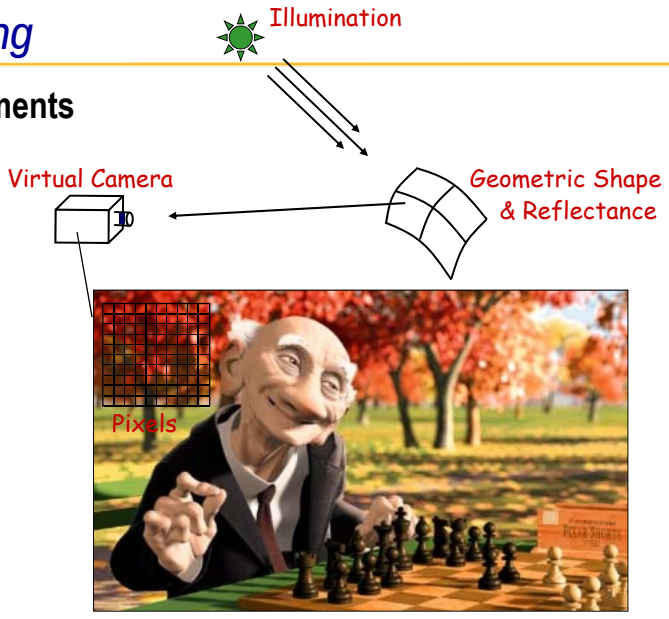


Digital Michaelangelo Project

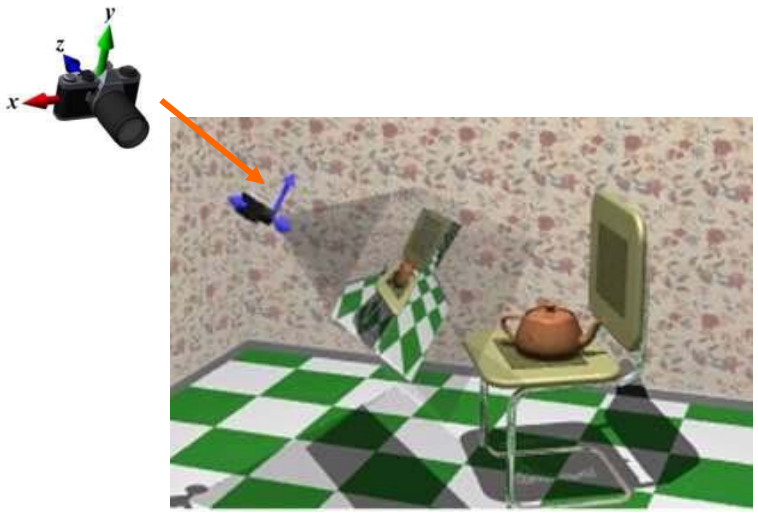
Plant Modeling

Rendering

- Key elements



Camera Model



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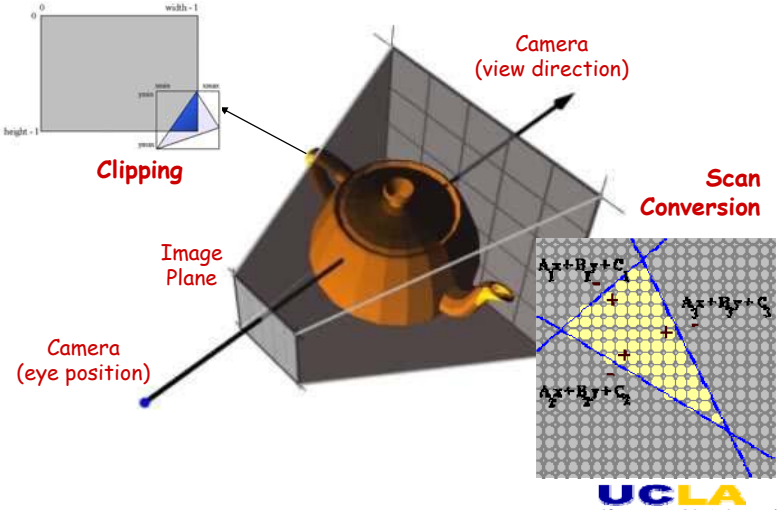
Rendering

- Draw visible surfaces onto display



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Reflectance Modeling

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Reflectance Modeling

Diana the Huntress

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Subsurface Scattering

- Translucency and varied levels of light penetration can be created using subsurface scattering effects (nVIDIA)

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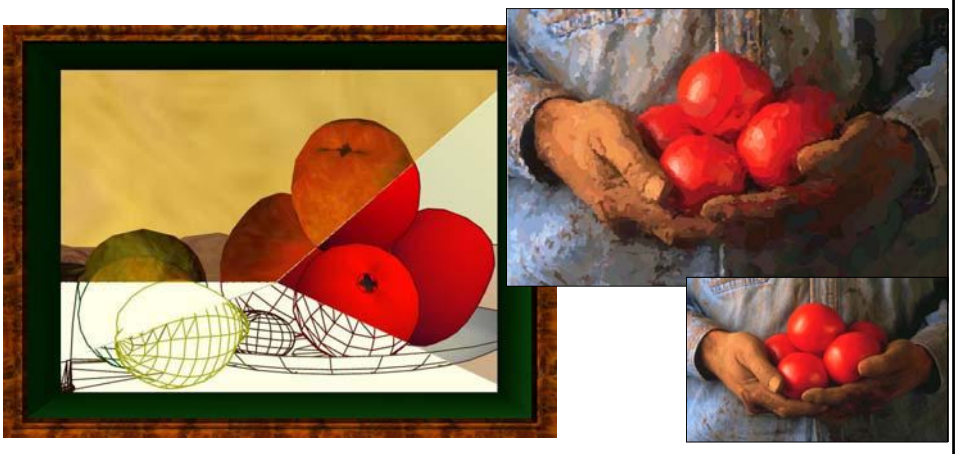
Rendering

- Non-photorealistic rendering



Aaron Hertzmann

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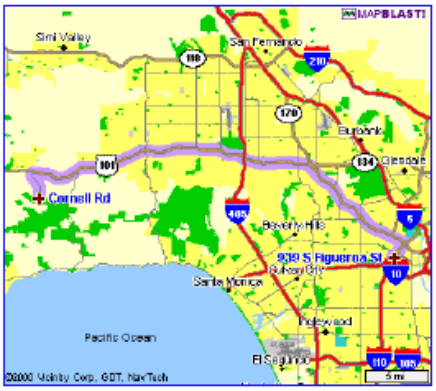
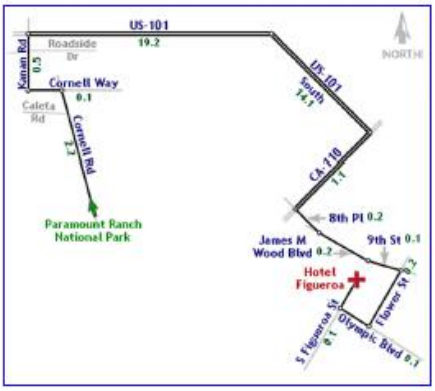
Rendering: Information





Agrawala and Stolte

Mapblast.com

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Animation

- **Keyframe animation**

Keyframing

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Animation

- Motion capture

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Animating Golem in LOTR

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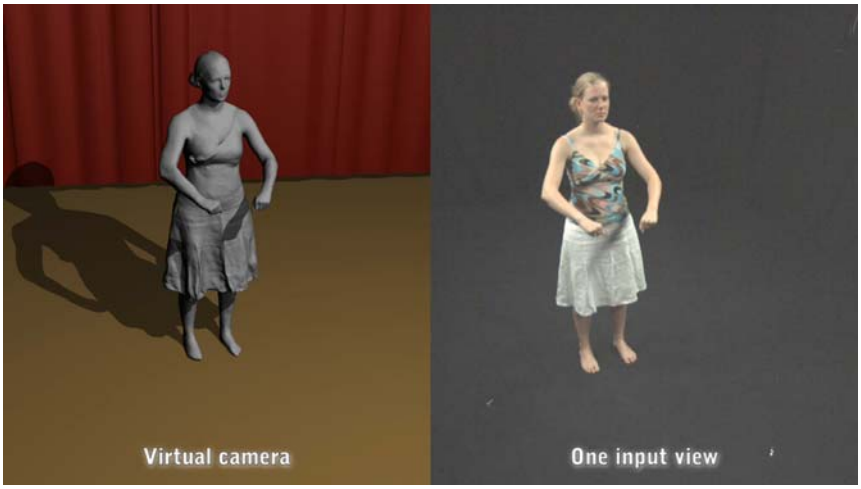
Markerless Motion Capture

- Max Plank Institute of Informatics, Germany



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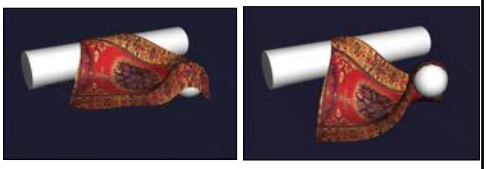
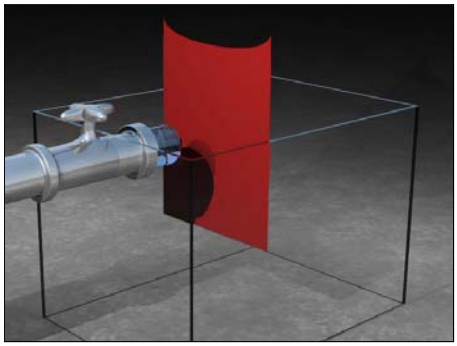
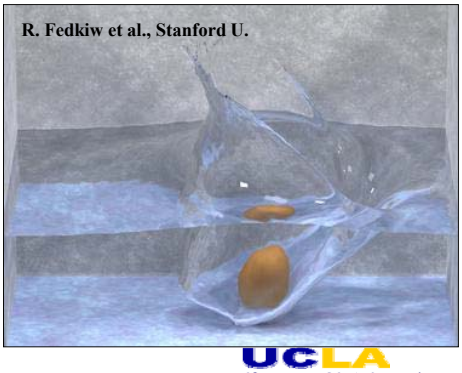
Animation

- Physical simulation







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"Atlanta in Motion"

- **J. Hodgins, et al., Georgia Tech**

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NBC - Los Angeles

- **The digital stuntman**

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Falling Sideways

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Falling Backward, Rolling Over, Rising, and Balancing in Gravity

- Help, I've fallen! … ***and I <u>can</u> get up!***

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Rising From a Supine Position

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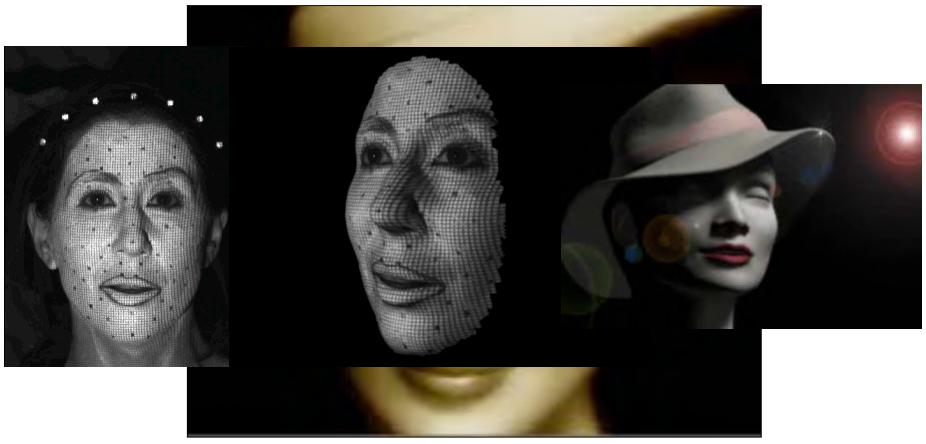
Virtual Celebrity

- Virtual Celebrity Productions, LLC



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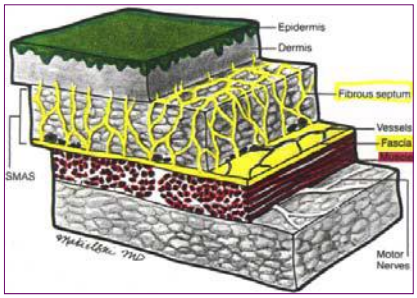
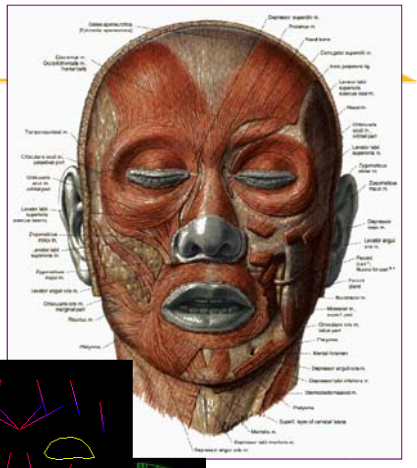
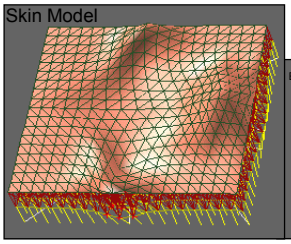
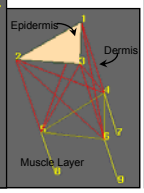
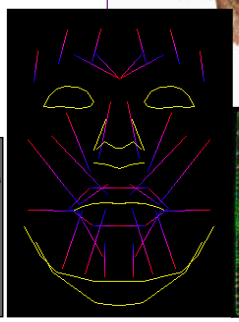
Facial Anatomy

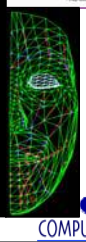












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Real-Time Facial Simulation

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Neck-Head-Face Animation

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Animation

- **Behavioral animation**

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Animation

- Example: “Geri’s Game” - Pixar

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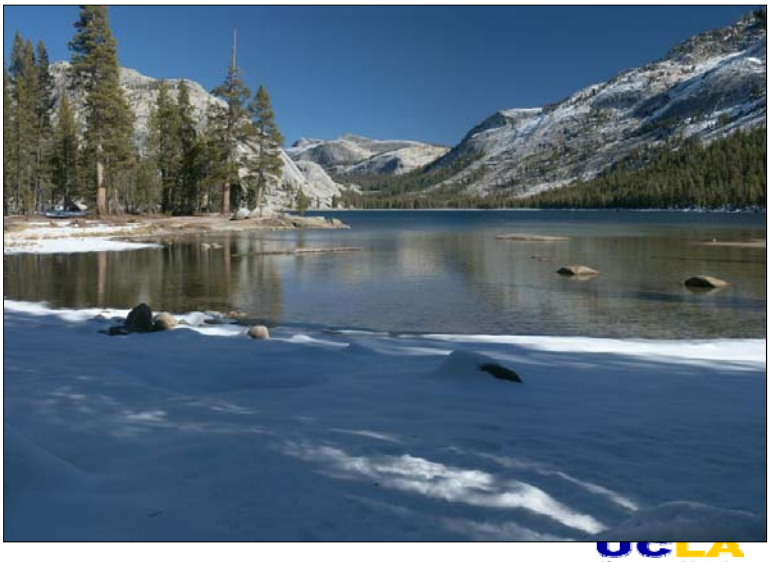
Reality is *Very* Complex



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Virtual Reality

- Artificial life and other natural phenomena

Discuss later…

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Many Open Research Problems

- How to model/render/animate a complex scene?

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Computer Vision

- **Related fields**
  - Image processing
  - Pattern recognition
  - Visual perception
- **Image understanding**
  - True IU seems to involve a great deal of human intelligence
  - Automated systems are still far from human performance
  - Some good solutions in constrained special cases
    - (e.g., inspection: IC manufacturing, circuit boards)

- **Inverse problems are generally tougher to solve**

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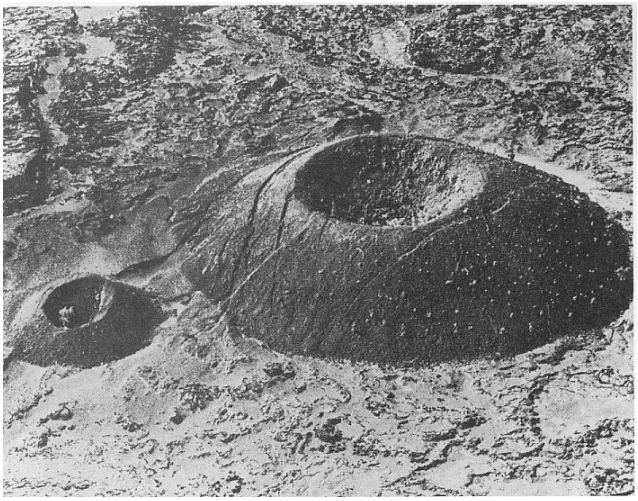
WHAT DO YOU SEE?



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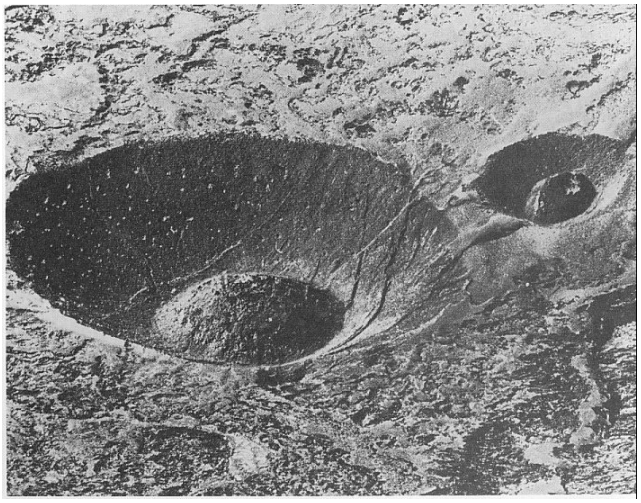
AND NOW?



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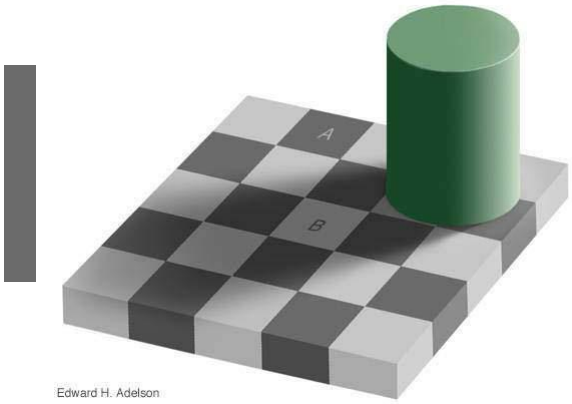
Are Squares A and B Different Shades of Gray?



Edward H. Adelson

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Vision Research Themes

- Edge and region extraction
- Image segmentation
- Visual reconstruction: From images to surfaces
- Shape from X
  - Contours
  - Shading
  - Stereo
  - Motion
- Object tracking
- Object recognition (including faces)
- Event and activity recognition

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Interactive Image Analysis Using Snakes

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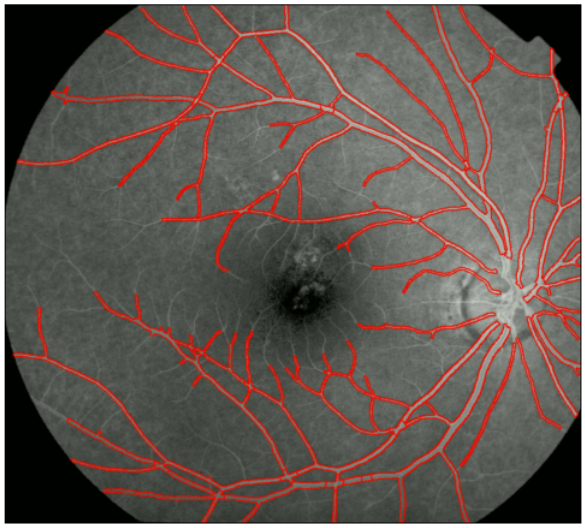
Retinal Angiogram Segmentation



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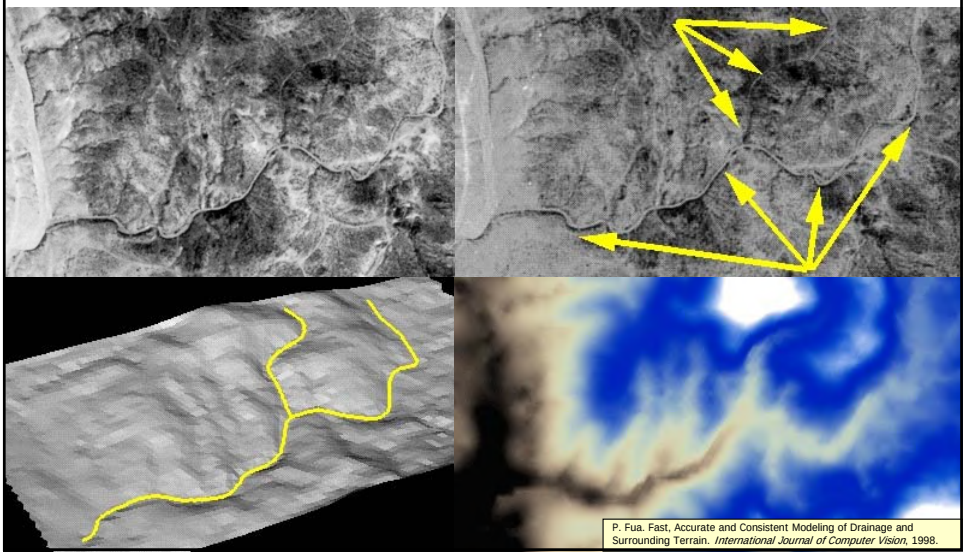
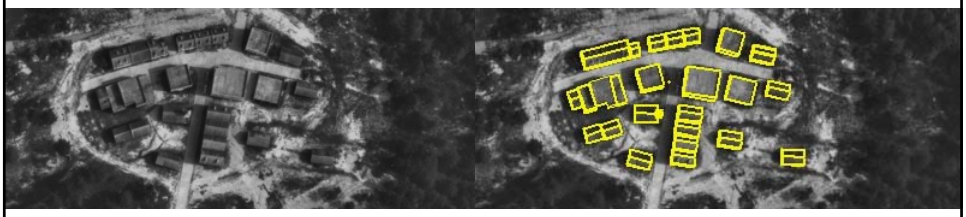
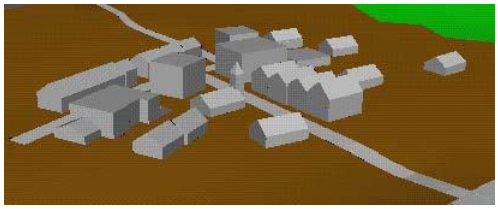
Cartographic Modeling: Rivers



P. Fua. Fast, Accurate and Consistent Modeling of Drainage and Surrounding Terrain. *International Journal of Computer Vision*, 1998.

Cartographic Modeling: Buildings and Roads





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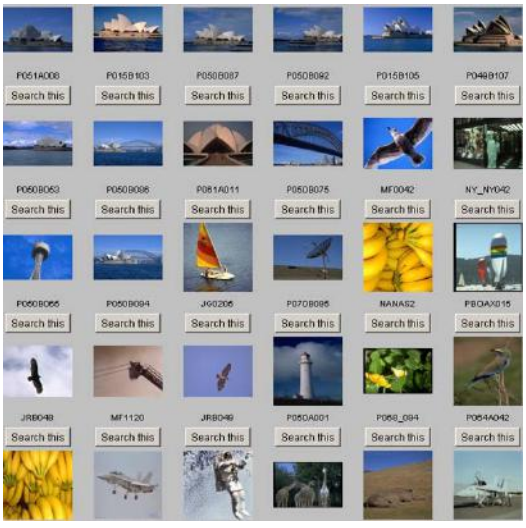
Automated Image Retreival



- **Find pictures of the Sydney opera house**
  - **in a large database**
  - **on the web**

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Space Robotics: Mars Rover

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Self-Driving Cars: Intelligent Transportation

- **Professor Stefano Soatto**

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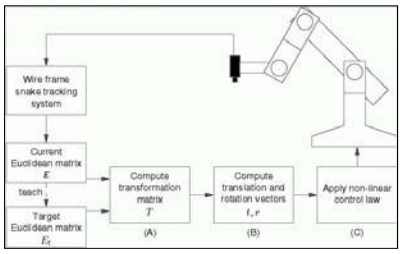
Visual Servoing



Tom Drummond, Univ. of Cambridge

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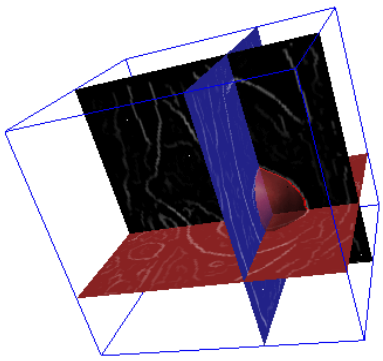
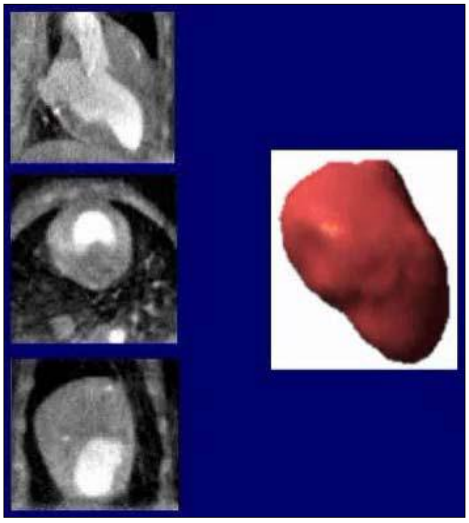
Model-Based Heart Motion Tracking





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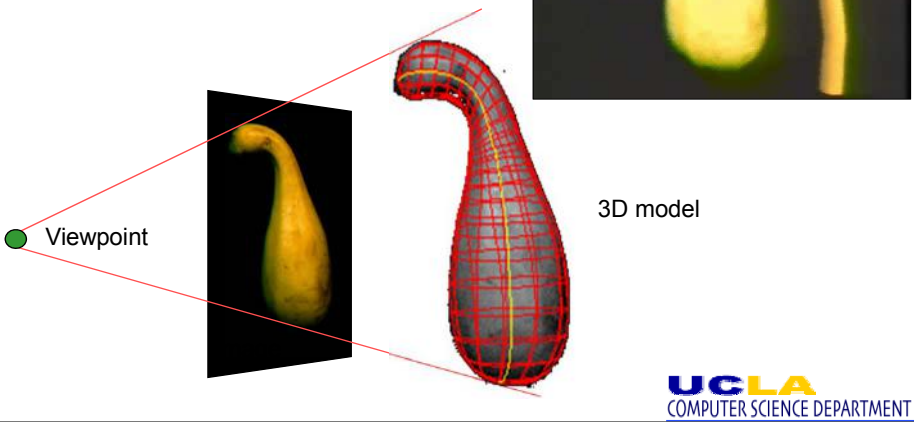
3D Reconstruction

- From image(s) to model(s)
  - Inverting 3D projection
  - Image-based modeling



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Performance-Based Animation

- [Pighin, Szeliski, Salezin, 1999]

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Performance-Based Animation

- [Pighin, Szeliski, Salezin, 1999]

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Performance-Based Animation

- [Pighin, Szeliski, Salezin, 1999]

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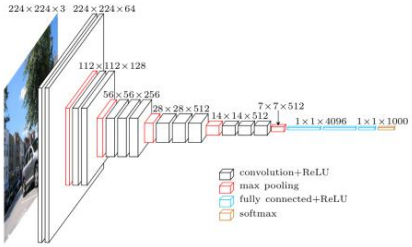
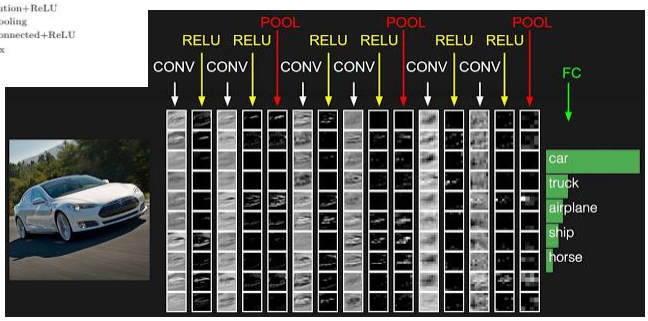
Deep Learning in Computer Vision

- **Convolutional Neural Nets (CNNs) are a "hot" topic**





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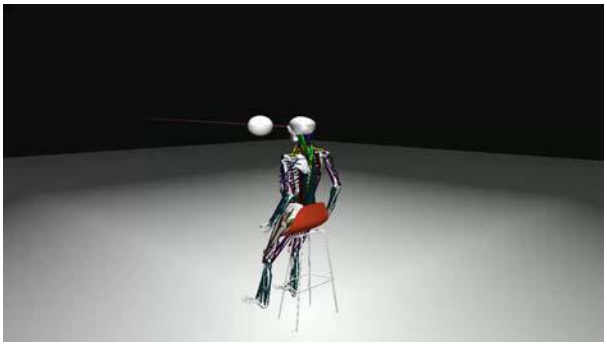
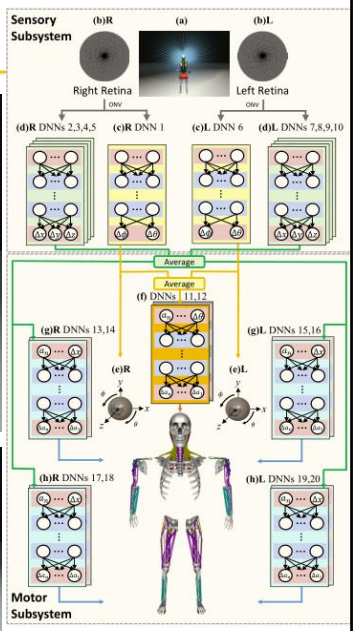
Virtual Biomimetic Robotics





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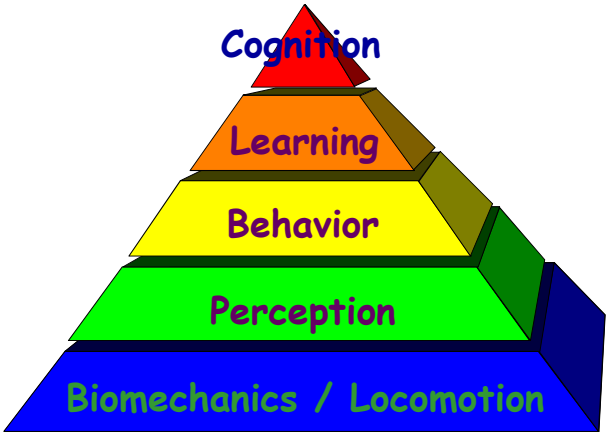
ALife Modeling Pyramid

- Computational model of animals and humans



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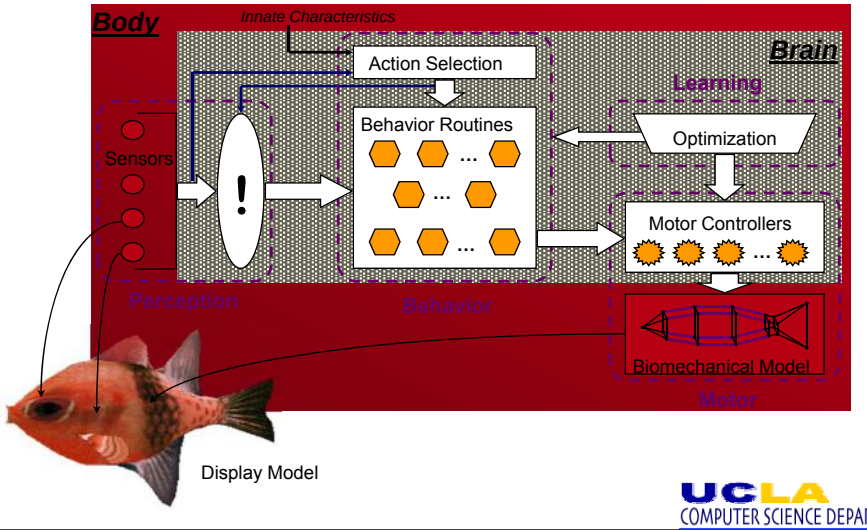
An Artificial Fish Model



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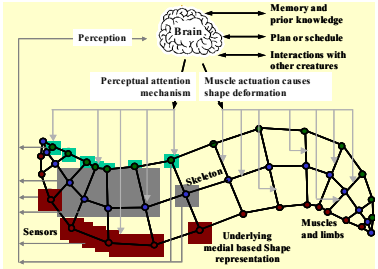
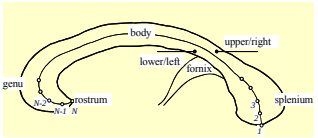
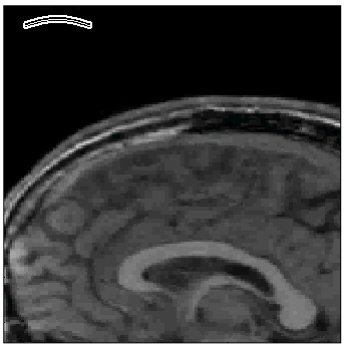
ALife for Vision

- **Deformable organisms for automated medical image segmentation**







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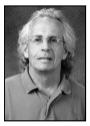
CS Faculty Conducting CG and CV Research

- Stanley Osher (CV - Mathematics)
- Stefano Soatto (CV - Computer Science)
- Demetri Terzopoulos (CG & CV - Computer Science)
- Song-Chun Zhu (CV - Statistics)

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Courses Offered

- CS 174A – Introduction to Computer Graphics
- CS 174B – Image-Based Modeling and Rendering
- CS 174C – Computer Animation

Plus several graduate courses in graphics and vision:

- Artificial Life for Computer Graphics and Vision
- Machine Perception
- Deformable Models for Computer Vision
- Humanoid Character Simulation
- Etc.

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Core Knowledge Needed to Specialize in Computer Graphics and Vision

- **Mathematics**
  - Especially geometry, linear algebra, applied math, numerical methods
- **Programming and software development**
  - Especially C/C++, OpenGL, Javascript
- **Creativity and an appreciation of Art + Science + Engineering**
- **Core computer graphics subjects**
  - Rendering – synthesizing images from mathematical representations
  - Modeling – geometry-based, physics-based, biology-based
  - Animation – kinematics, dynamics, motion control
  - Interactive techniques – human-computer interaction, GUIs, games, …

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Relevant Courses From Other Departments

- **Mathematics**
  - MS 33A – Linear Algebra and Applications
  - MS 142 – Analytic Mechanics
  - MS 149 – Mathematics of Computer Graphics
  - MS 153 – Numerical Methods for Partial Differential Equations
  - MS 157 – Software Techniques for Scientific Computations
  - MS 270A – Techniques of Scientific Computing
  - MS 272A – Foundations of Continuum Mechanics
  - MS 2xx – Graduate courses taught by Professor Joseph Teran
- **Design | Media Arts**
  - DMA 157 – Game Design

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Thank you!