Simulation and Virtual Reality

for Education and Medical Applications

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Contents

1. Simulation of Fluids

- Objective
  - Liquid behavior: water waves, wakes behind boats
  - Dust behavior: dust behind moving vehicles
  - Distortion: water drop on glasses
  - Lens and depth of field: nonplanar projection, fog effects
- Applications
  - Integrated synthetic virtual environment
  - Education, training, visualization, and entertainment
    - Project originally funded by US Army STRICOM
    - SAIC, STRICOM, Disney, Dreamworks requested the methods

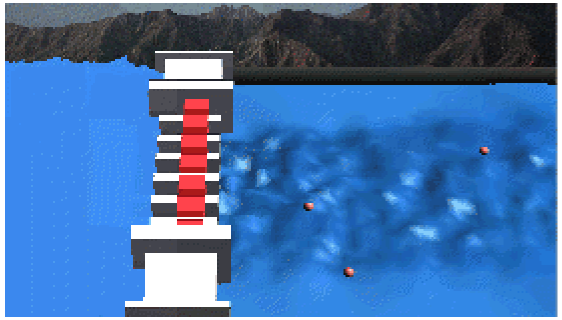
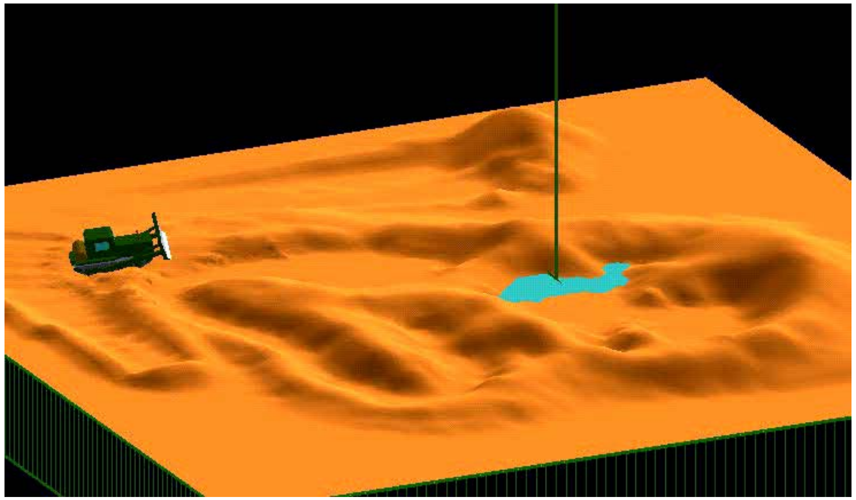
1.1 Liquid behavior

- Physically-based real-time simulation 2D Navier-Stokes Equations in 120x80 grids
  – raise to 3D according to the pressure p(x,y)
  – method later justified by Bernoulli equation
  – many new modeled behaviors in graphics: objects interacting with the fluid, wakes, etc.

Snapshots: water behavior

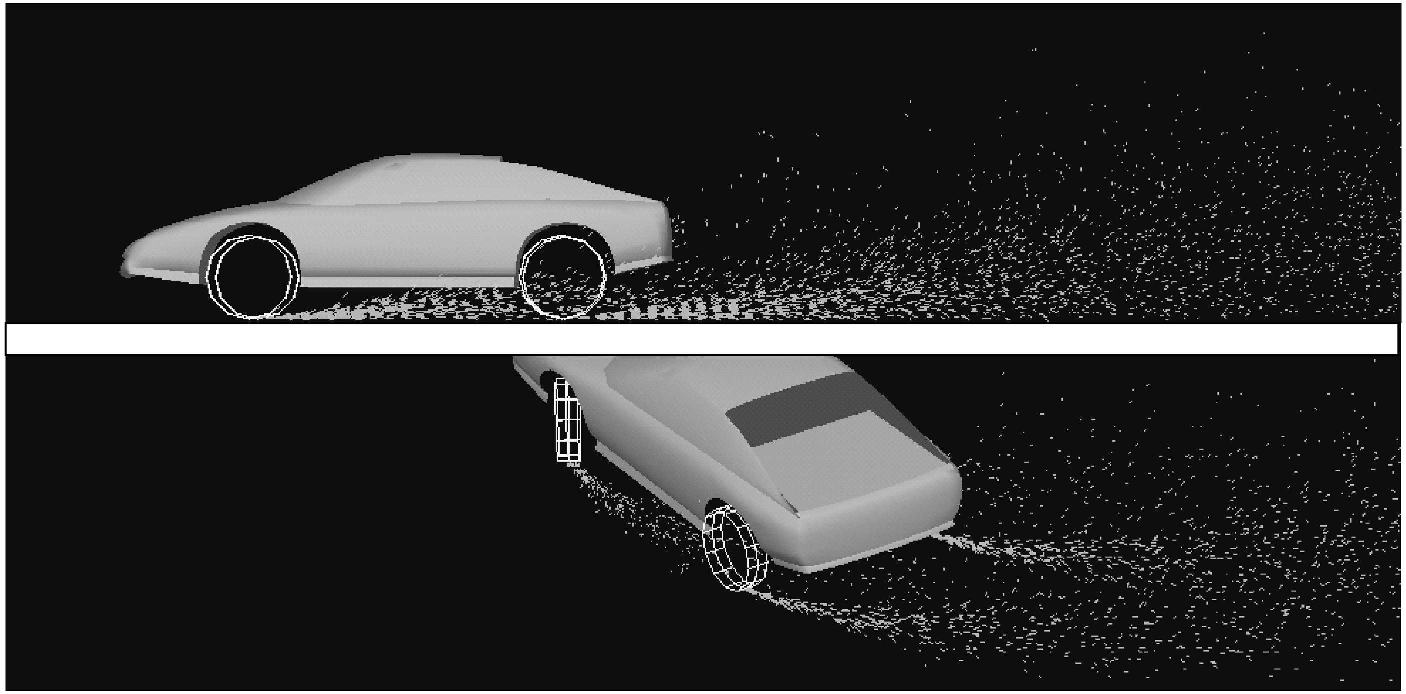
- Wake, turbulence, & environment



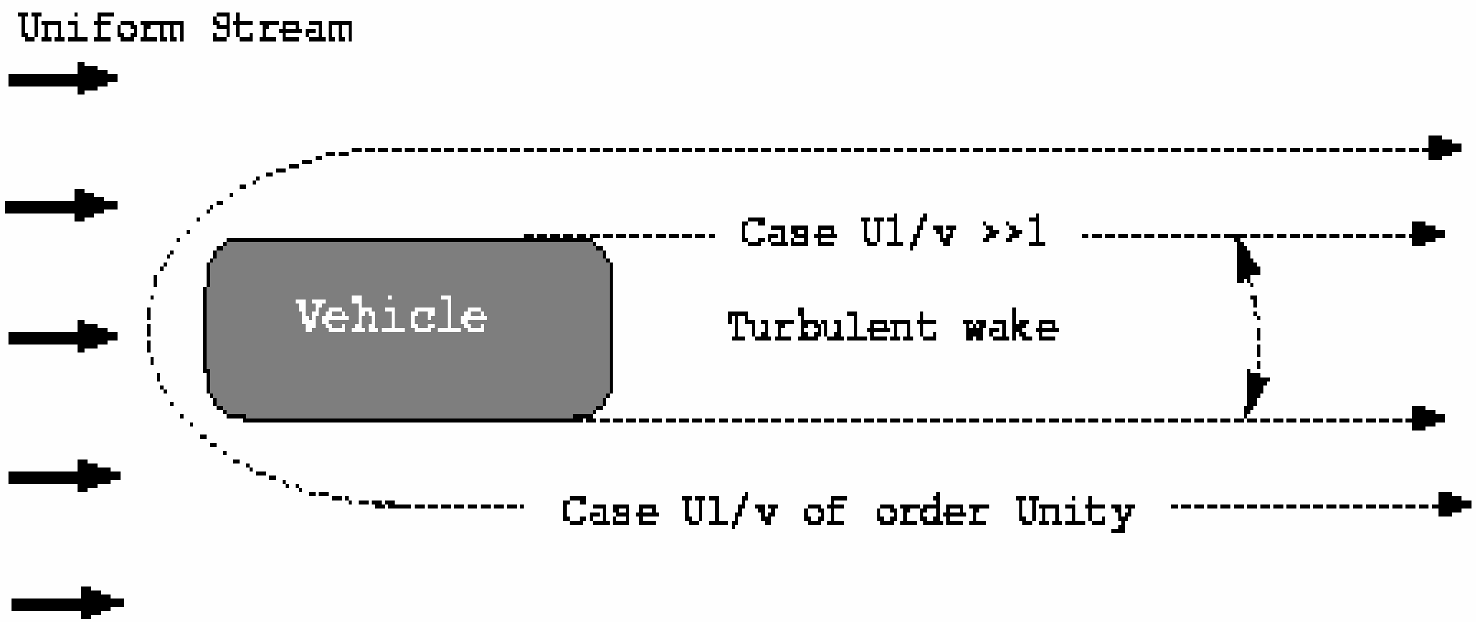
1.2 Dust behavior

- Fluid behavior behind a moving vehicle
- Dust particle generation and dynamics



Turbulent fluid behavior

- $Re > 10^5$: full turbulent in the wake area

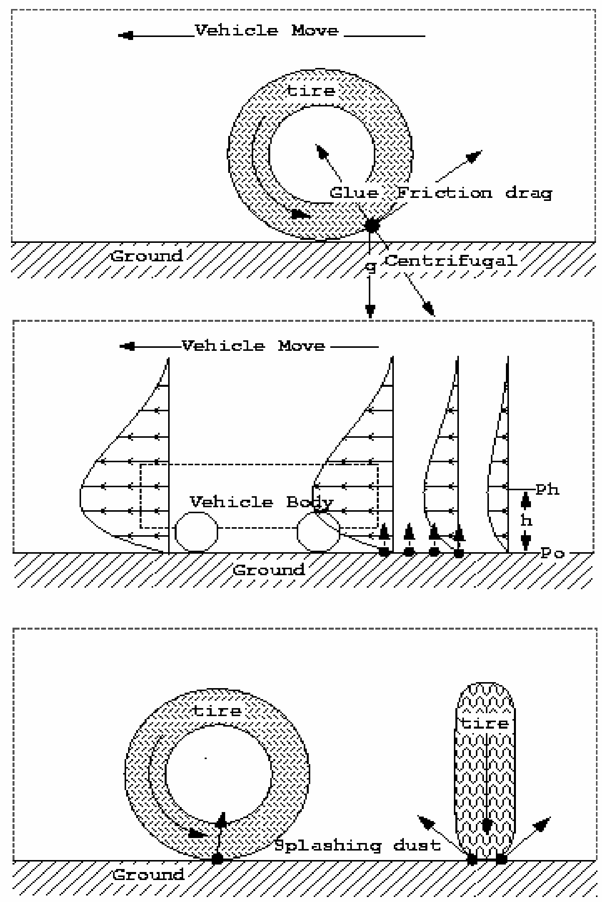


Fluid simulation method

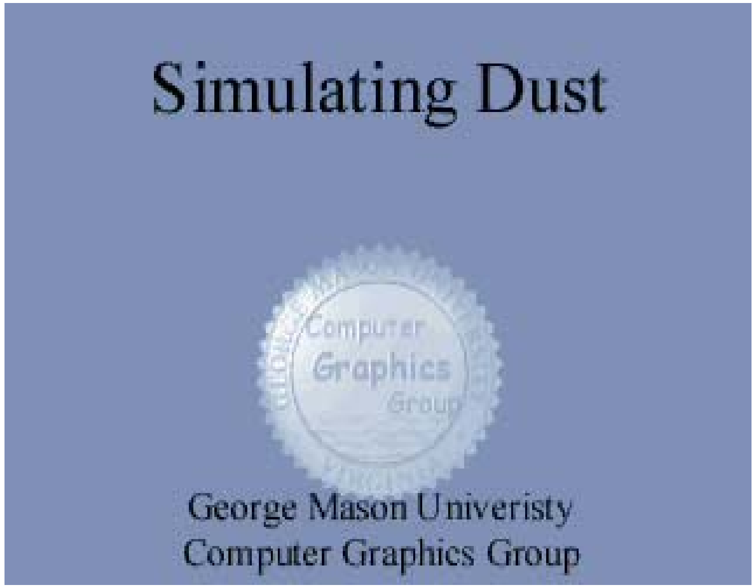
- At low Re region, use 3D finite difference to calculate the Navier-Stokes equations.
  - Numerical scheme:
    - Successive-Over-Relaxation (SOR) for Poisson Pressure Equation
    - Alternating-Direction Implicit (ADI) for momentum equations

Dust generation

- Centrifugal, gravity, tire and air drag
- Pressure gradient under & behind car
- Tire splashing
- Many parameters related to vehicle, particle, and environment



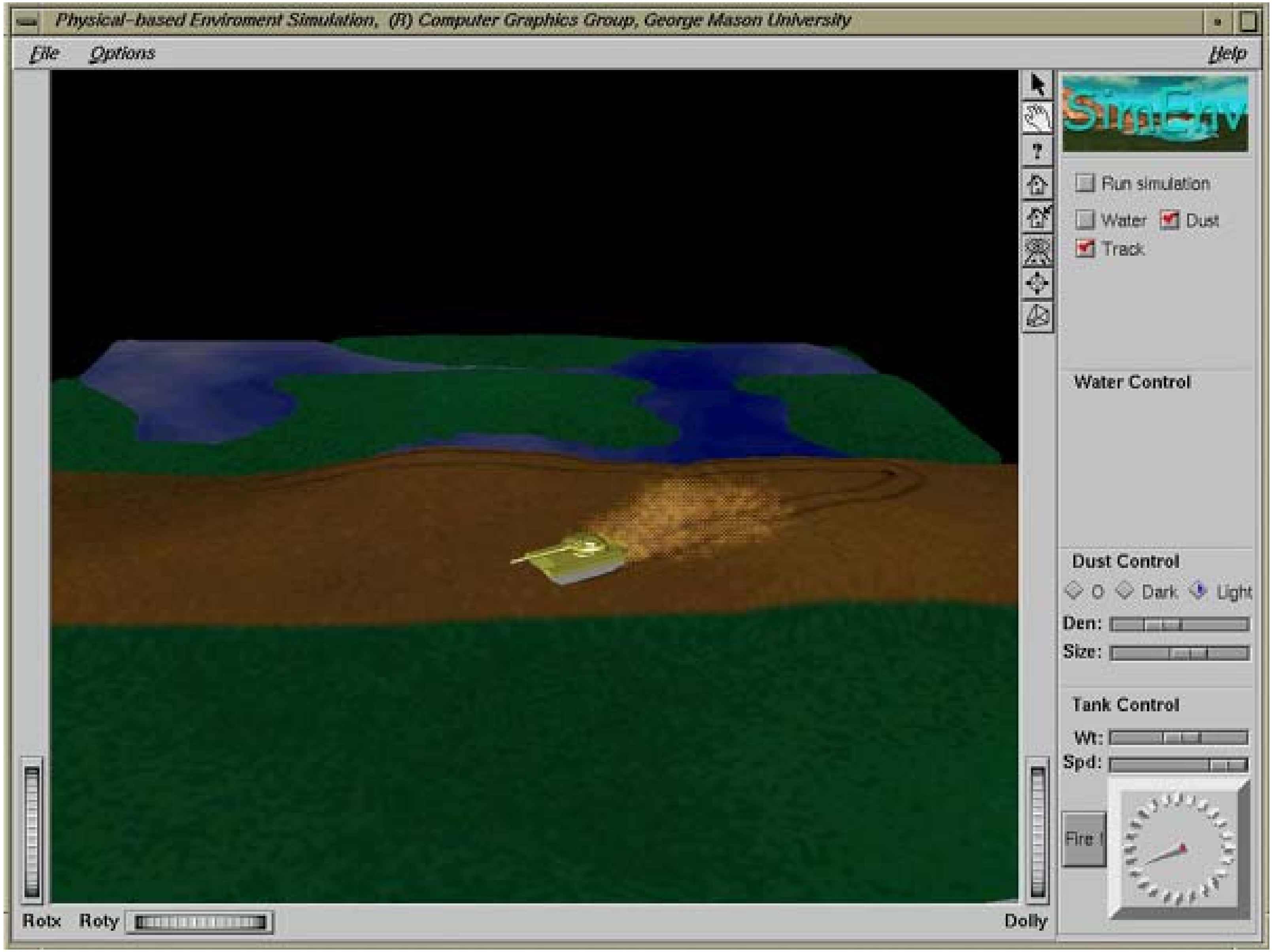
Animation & simulation: dust behavior



Real-time rendering

- Pre-calculate fluid dynamics
  - laminar velocity volume moving & turning
- Simplify dust dynamics: 3 stages
  - turbulence, momentum, and drift
- OpenGL advanced rendering
  - texture mapping, blending and transparency

Real-time fluid simulation



1.3 Distortion: water drop

- Submarine periscope
  - water flows on the periscope when raised form underwater
  - Distorted view of the world

Real-time simulation of water droplets on glass windows

- In order to be in real-time
  - manipulate the framebuffer after rendering
  - ignore physics behavior

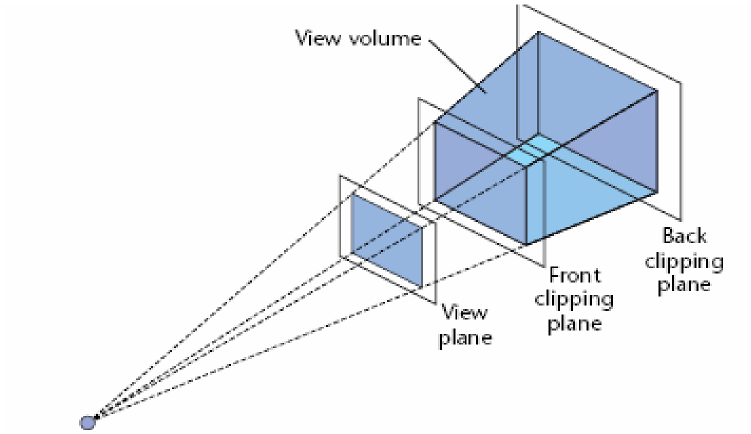
1.4 Lens and depth-of-field

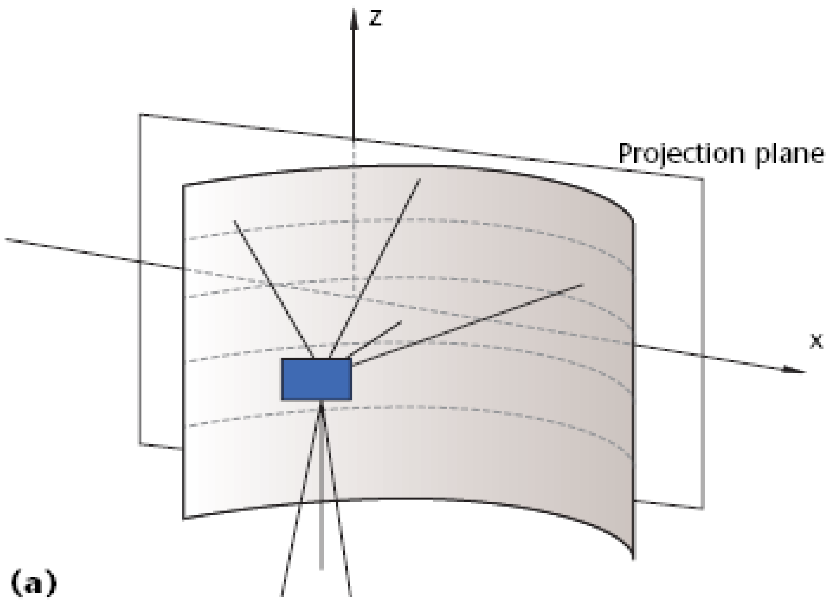
- Lens
  - Lens distortion for special effects
  - What would be the physically-correct scene from the periscope?

- Depth of Field
  - Graphics is better than camera
  - Lens has focal point that relates to the depth

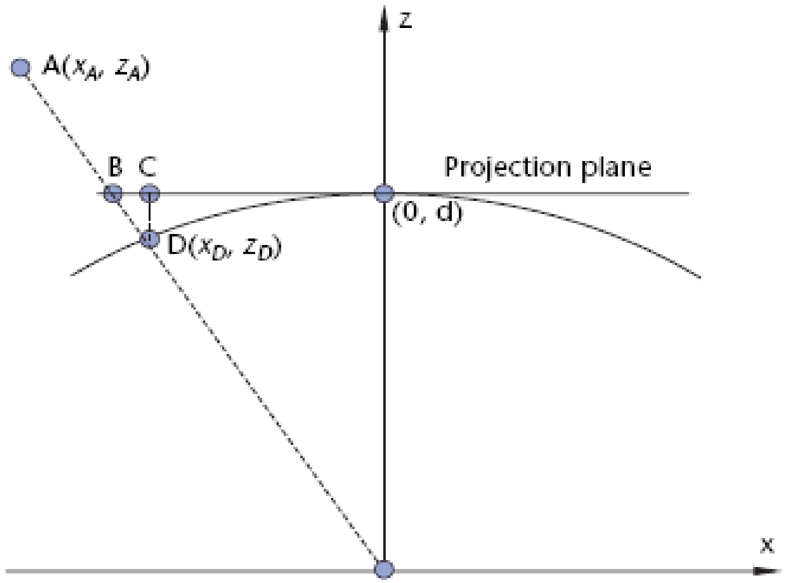
Lens distortion: nonplanar projection

- Different from traditional graphics projection





(a)

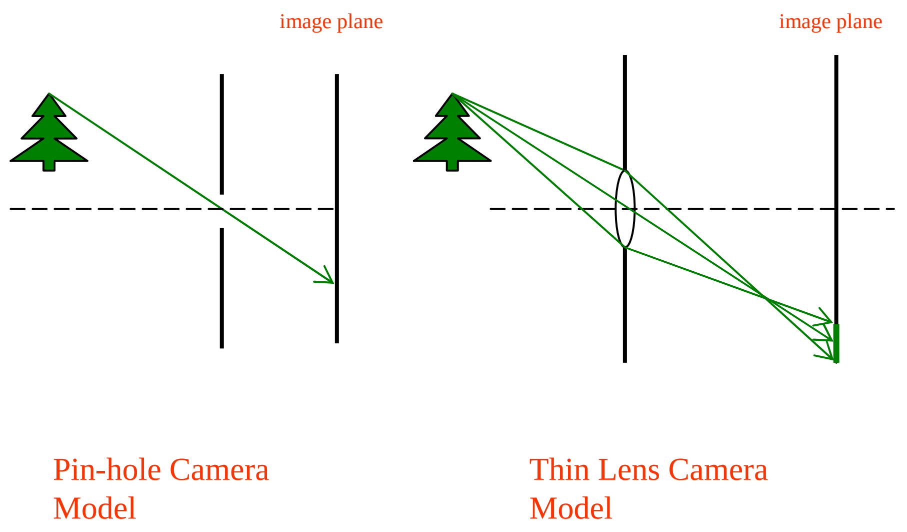


(b)

Effects of distortion

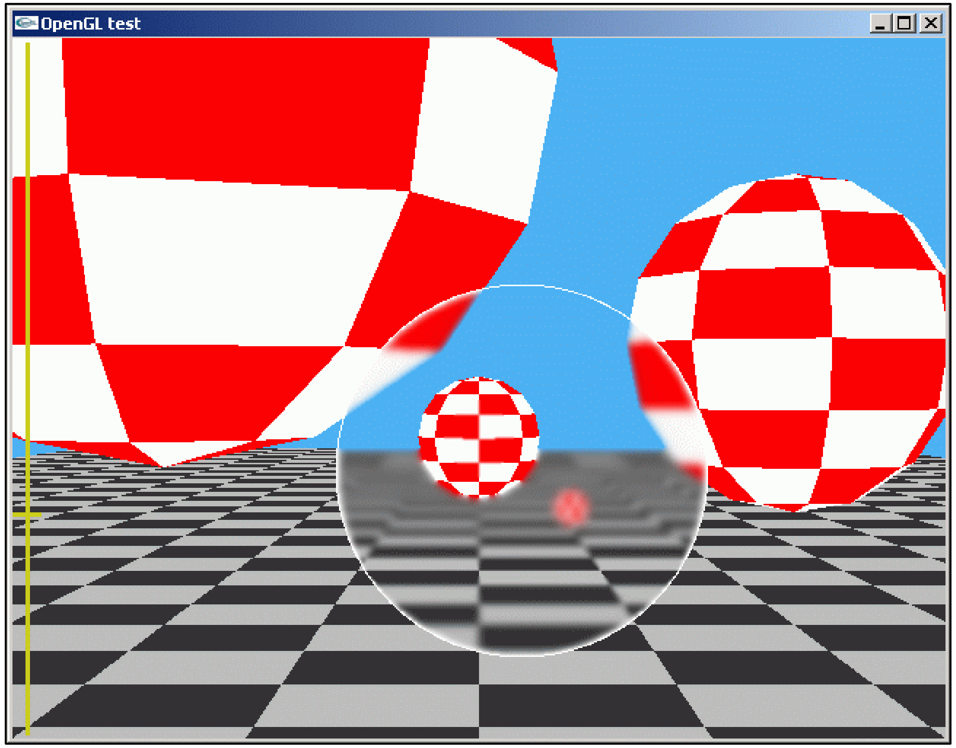
Depth-of-field

- Graphics use pin-hole camera; water-drop adds a lens layer



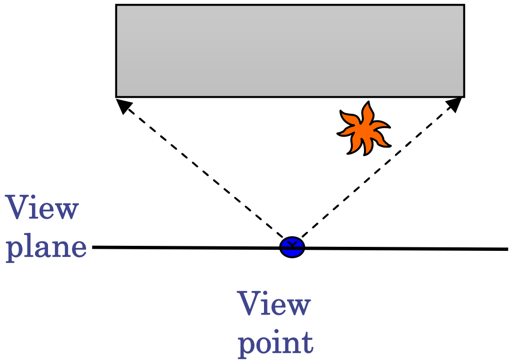
Lens and depth-of-field

- Only things in focus will be sharp … z-buffer value in hardware calculation

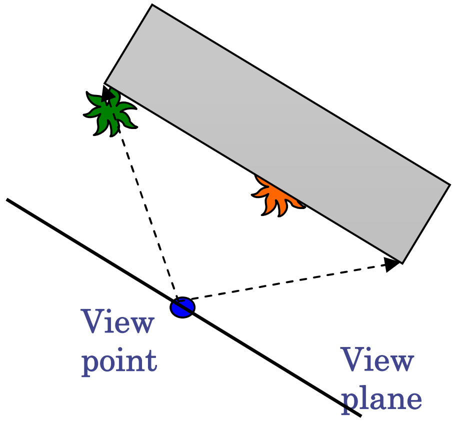


Undesirable fog artifacts

Background is not fogged



Initial observer's
orientation

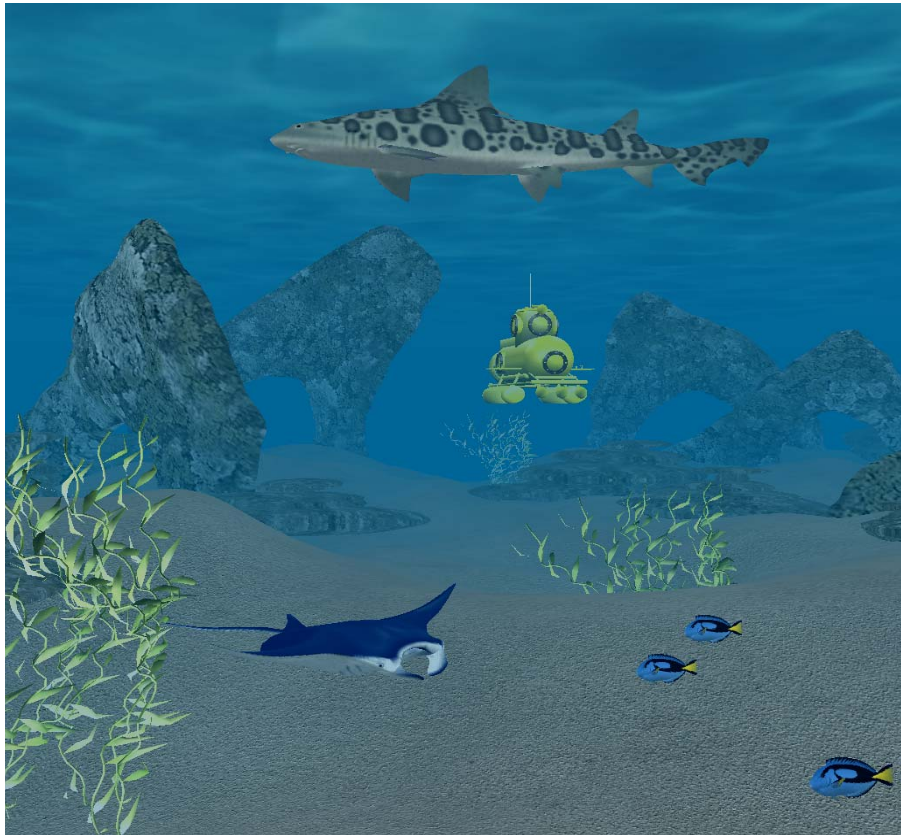


After observer's
rotation

Post-processing

calculate from z-buffer value and viewpoint with custom fog functions

Layered fog



Linear attenuation

Summary: selected publications

- T. Zhou and **J.X. Chen**, “Fog Effects Using Post Processing,” in submission.
- T. Zhou, **J.X. Chen**, and M. Pullen, “Generating Accurate Depth Effects in OpenGL,” *Computer Graphics Forum*, to appear.
- S. Liu, X. Jin, C.C.L. Wang, and **J.X. Chen**, “Water-Wave Animation on Mesh Surfaces,” *IEEE Computing in Science and Engineering*, vol. 8, no.5, Sept. 2006, pp. 81-87.
- Y. Yang, **J.X. Chen**, and M. Beheshti, “Nonlinear Perspective Projections and Magic Lenses: 3D View Deformation,” *IEEE Computer Graphics and Applications*, vol. 25, no. 1, Jan. 2005, pp. 76-84.
- **J.X. Chen**, Y. Yang, and X. Wang, “Physics-based Modeling and Real-time Simulation,” *IEEE Computing in Science and Engineering*, vol. 3, no. 3, May/June 2001, pp. 98-102. .
- **J.X. Chen**, X. Fu, and E.J. Wegman, “Real-Time Simulation of Dust Behaviors Generated by a Fast Traveling Vehicle,” *ACM Transactions on Modeling and Computer Simulation*, vol. 9, no. 2, April 1999, pp. 81-104.
- **J.X. Chen** and X. Fu, “Integrating Physics-Based Computing and Visualization: Modeling Dust Behavior,” *IEEE Computing in Science and Engineering*, vol. 1, no. 1, Jan. 1999, pp. 12-16.
- **J.X. Chen**, N.V. Lobo, C.E. Hughes and J.M. Moshell, “Real-time Fluid Simulation in a Networked Virtual Environment,” *IEEE Computer Graphics and Applications*, vol. 17, no. 3, 1997, pp. 52-61.
- **J.X. Chen**, “Physically-based Modeling and Real-time Simulation of Fluids in a Networked Virtual Environment,” *The Link Foundation Fellowship in Advanced Simulation and Training*, PUBLISHER - Institute for Simulation and Training, Orlando, Florida, June 1995.
- **J.X. Chen**, and N. V. Lobo, “Toward Interactive-Rate Simulation of Fluids with Moving Obstacles Using Navier-Stokes Equations,” *CVGIP: Graphical Models and Image Processing*, vol. 57, no. 2, 1995, pp. 107-116.

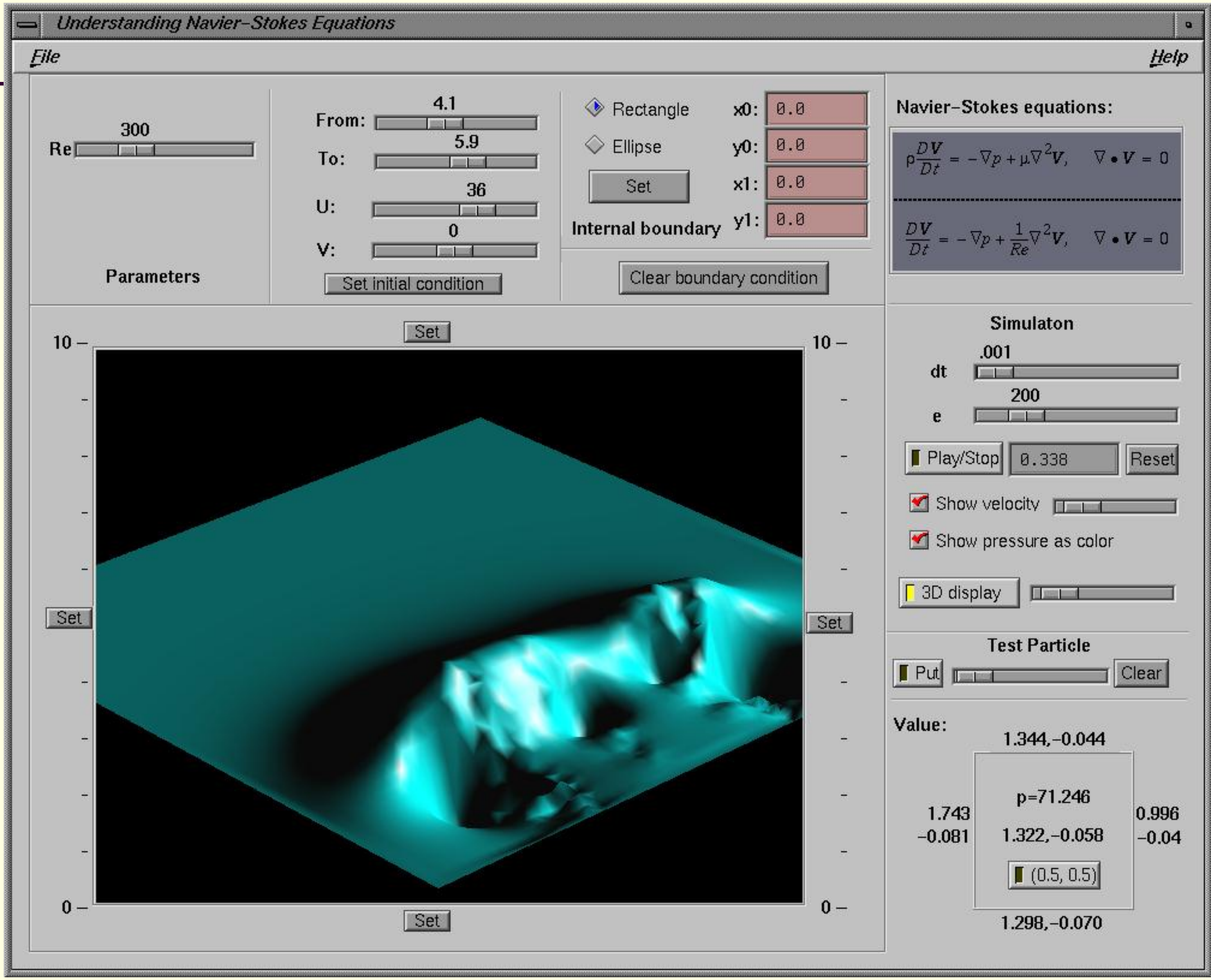
2. Edutainment: Learning through Playing

- Objective
  - Implementation and integration of
    - Physics/math behavior with abstract equations
    - Virtual environment in 3D sound and haptic devices
    - PC-based VR platform
    - Networked virtual environments
- Applications
  - Learning abstract scientific concepts
    - Computational Steering: Navier-Stokes' equations
    - ScienceSpace: Maxwell' equations, Newton's laws
    - DEVISE - Designing Environments for Virtual Immersive Science Education
  - Learning in networked virtual environments
    - MUVEES – multi-user virtual environments exploration system

2.1 Computational steering

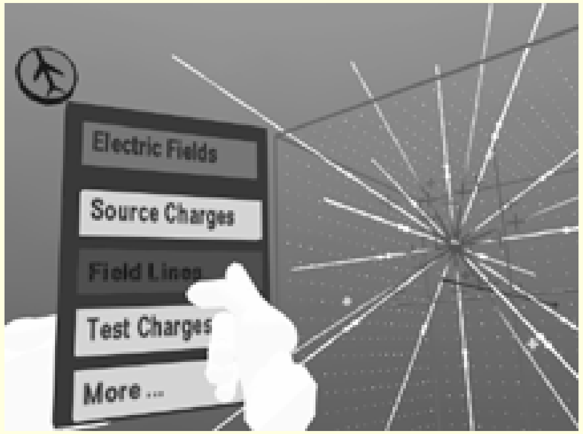
- Learn 2D and 3D Navier-Stokes equations
- Interactive control of the parameters in the equation
- Immersive application let the student ‘feel’ the fluid

Learning Fluid Concepts



2.2 Project ScienceSpace:

Using Immersive Virtual Worlds in Real World Classrooms



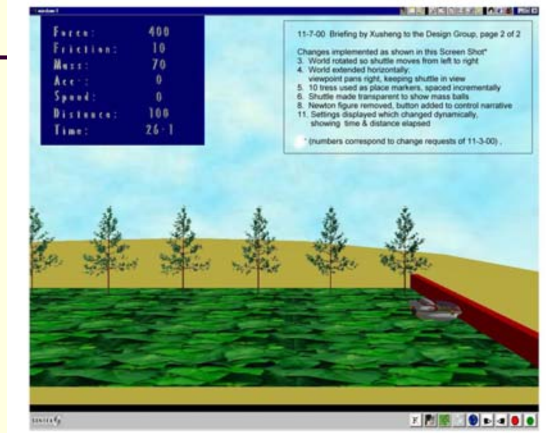
2.3 Project DEVISE:

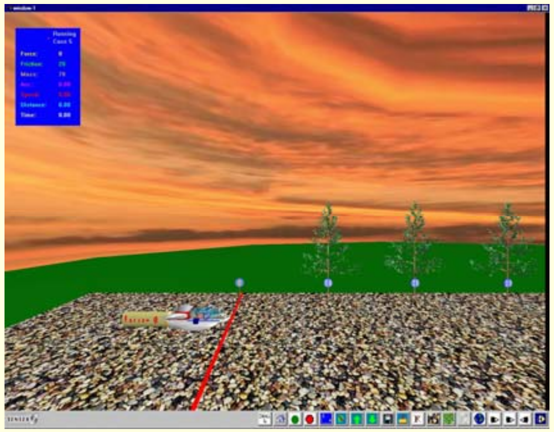
Designing Environments for Virtual Immersive Science Education

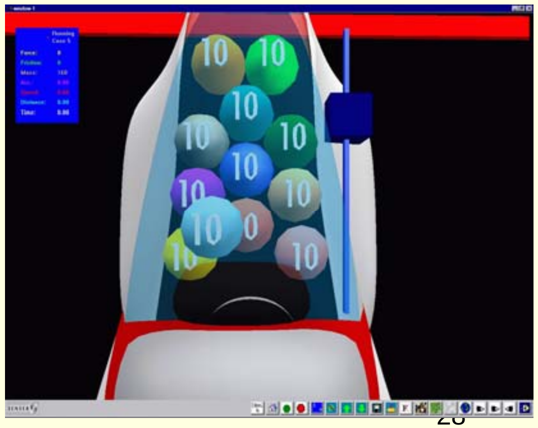
- Low-end PC Platform
- Physics Real-time Simulation
- Visual and Auditory Immersion
- Dynamic Reconfigurable HCI for Learners with a Disability

Analyzed the Prototype for:

- Science content
- Usability of interface
- Appeal to our teenaged audience
- Appropriate strategies for students with learning disabilities



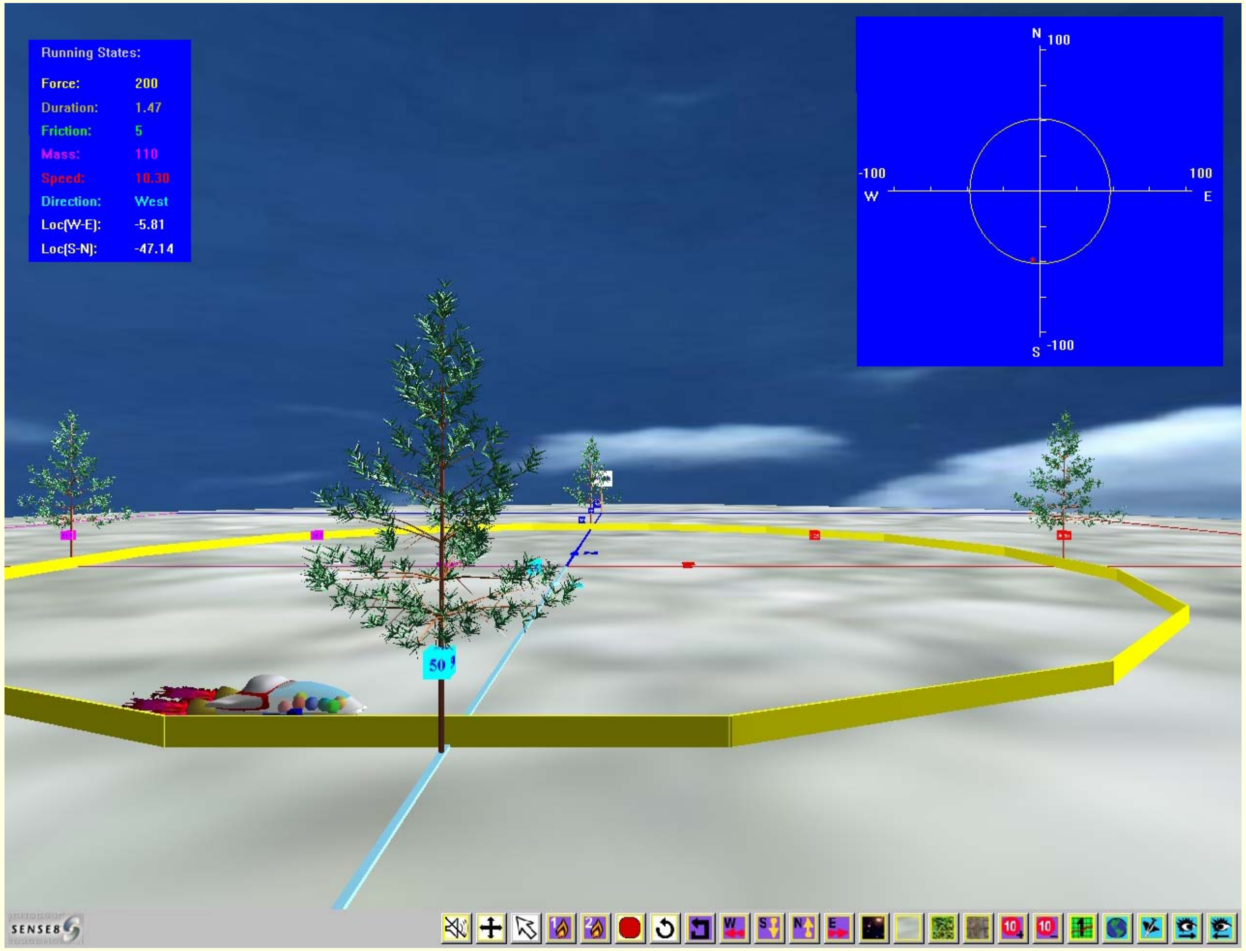




Example: Demo Circular Motion

Students explore and manipulate variables to discover how a shuttle's motion is affected by:

- horizontal circular motion
- an impulse force
- friction
- mass

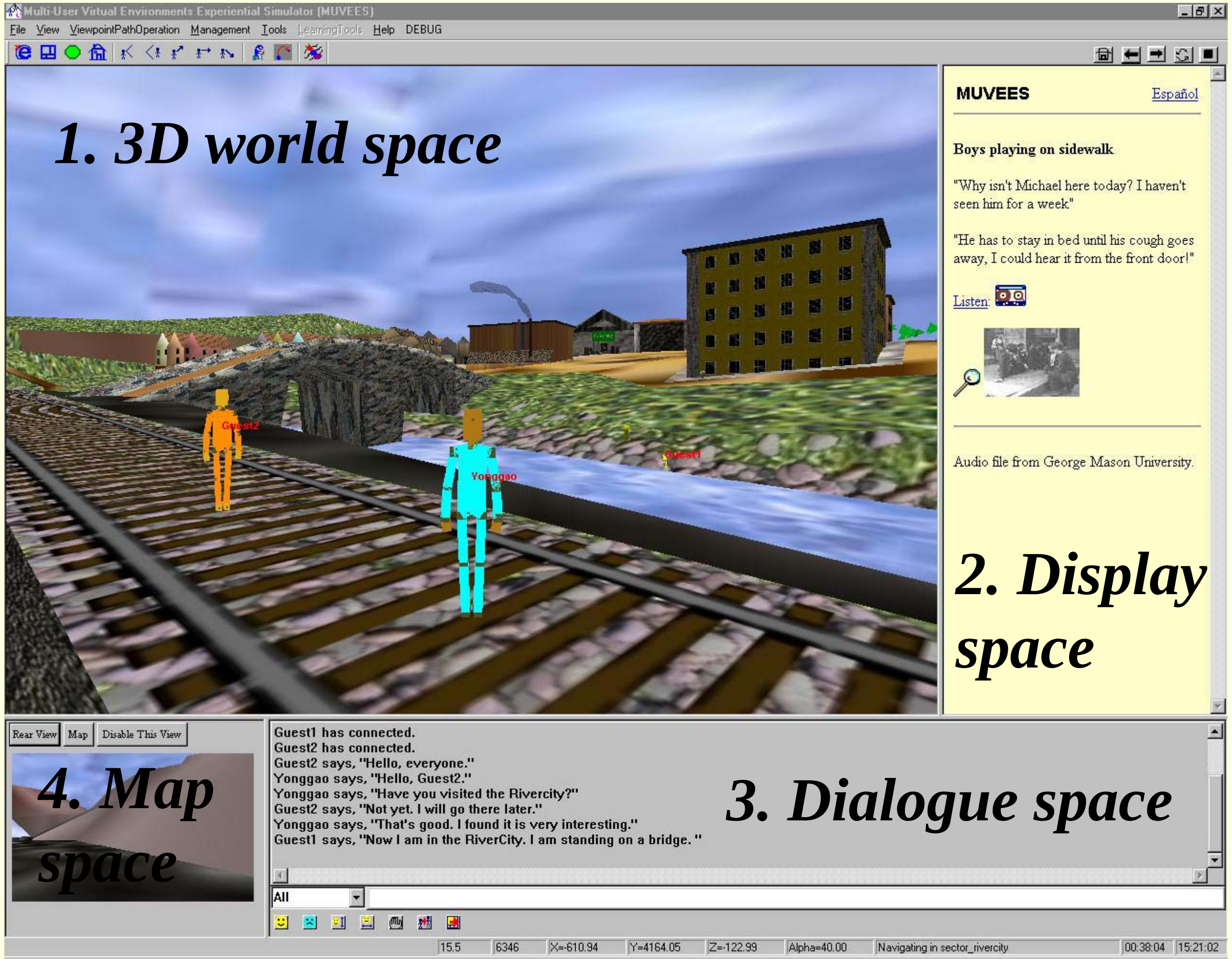


2.4 PROJECT MUVEES:

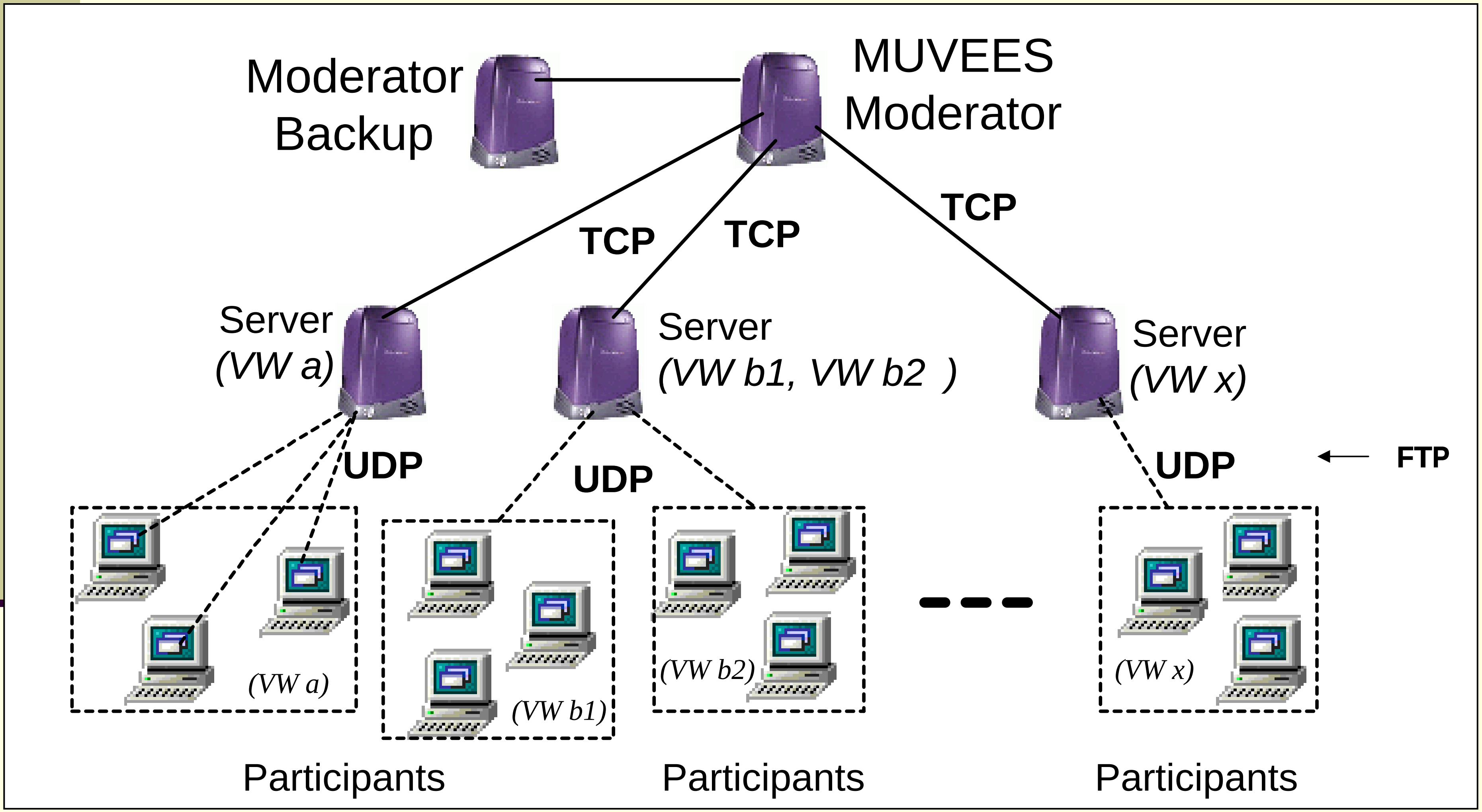
Multi-User Virtual Environments Exploration System

- Networked multimedia environments
- Multi-user avatars simultaneously navigating VR worlds
- Distance users communicating among groups
- Computer-generated agents joining intelligent discussions
- Collaborative learning activities of various types, and
- Users' behavior analysis and documentation

MUVEES Interface



MUVEES Architecture

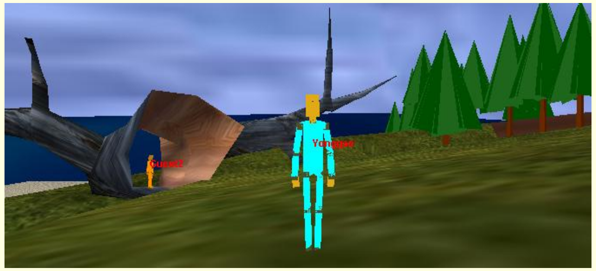


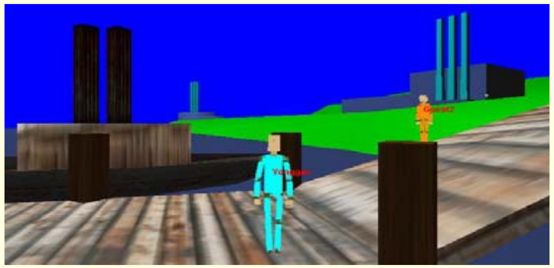
MUVEES Functions

Divided into six categories:

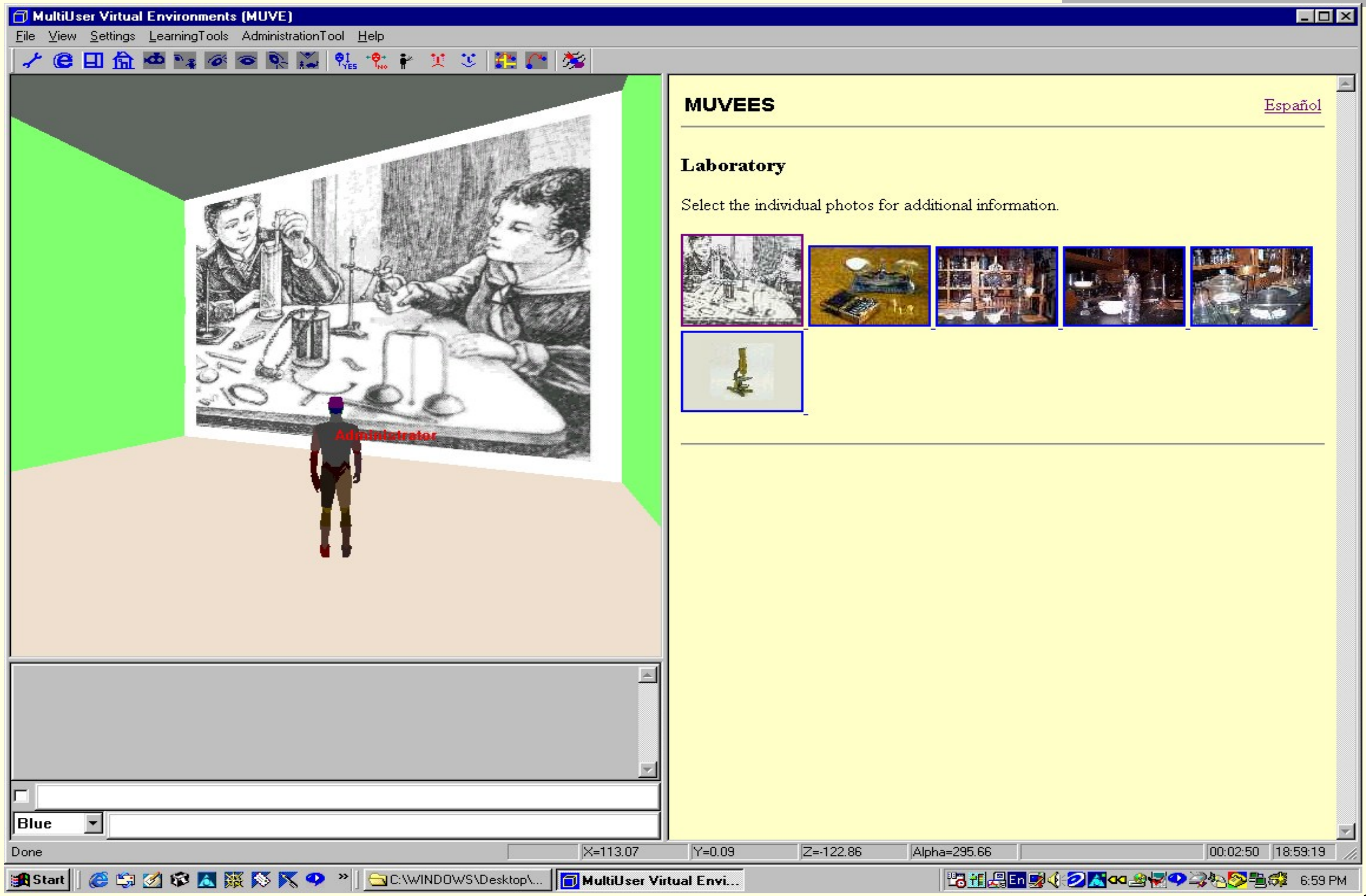
- Navigation
- Education
- 3D Object Construction
- Administration
- Graphics
- Others

MUVEES Snapshots

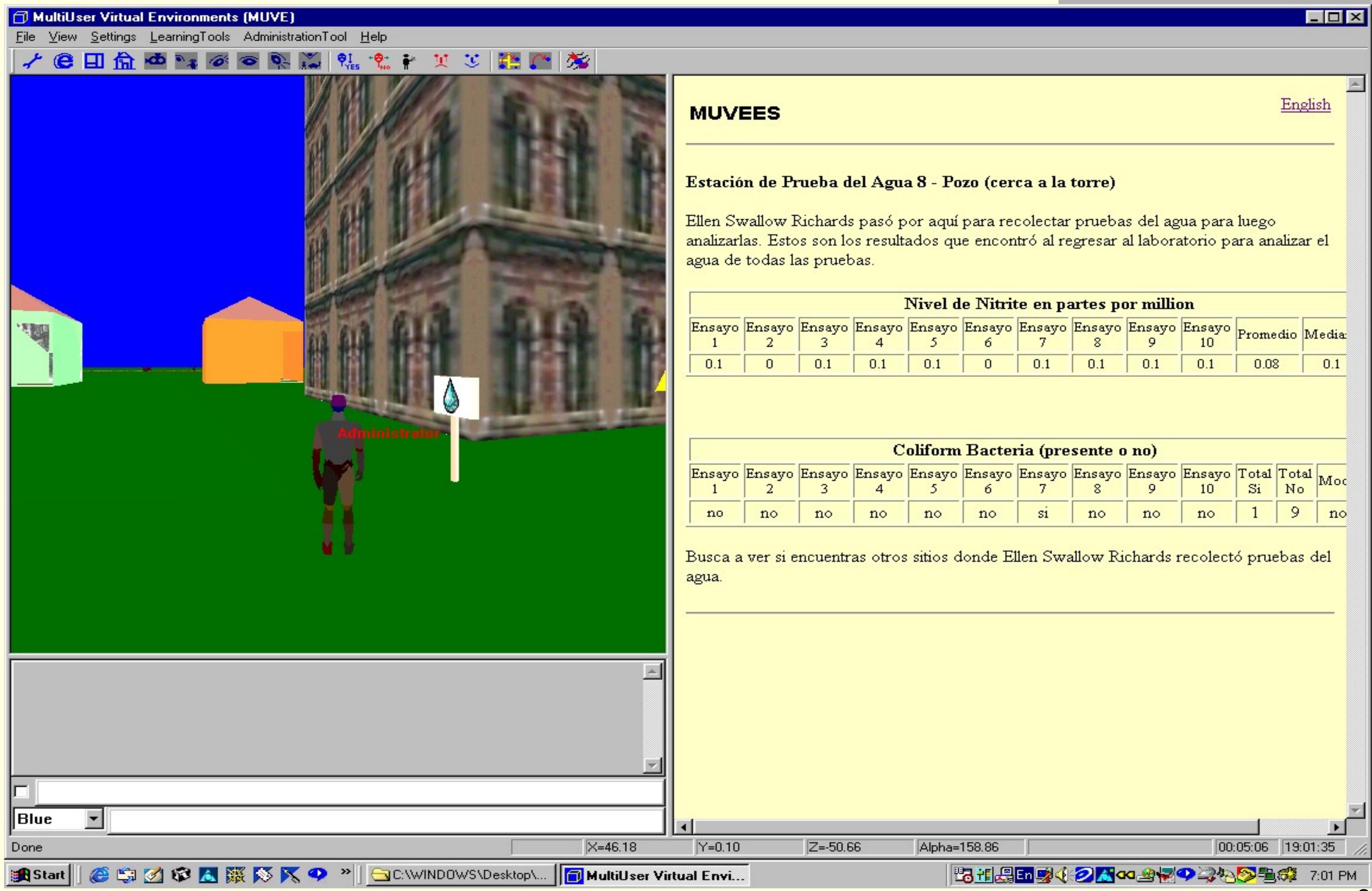




Entering the Chemistry Lab



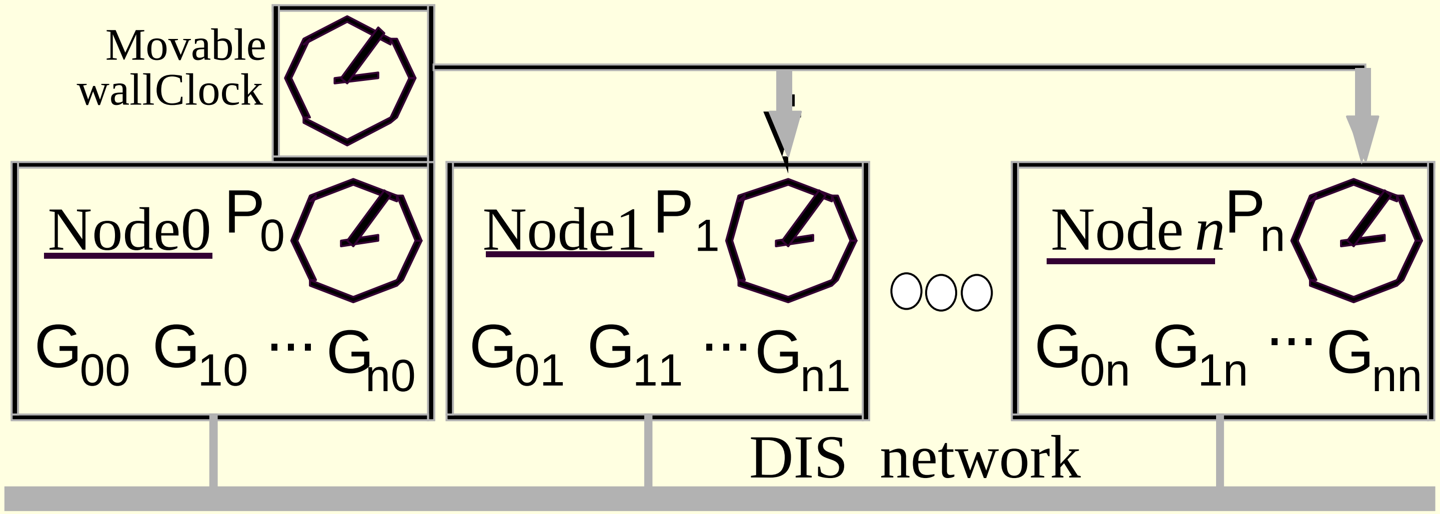
Testing the Water Quality



2.5 Synchronization in Networked Virtual Environment (NVE)

- Physical behavior & effects generated locally (vehicles, water, dust, etc.)
- Uniform time scale & variable time-slicing: lastTime; currentTime
- Player and ghost synchronization

Synchronization Mechanism

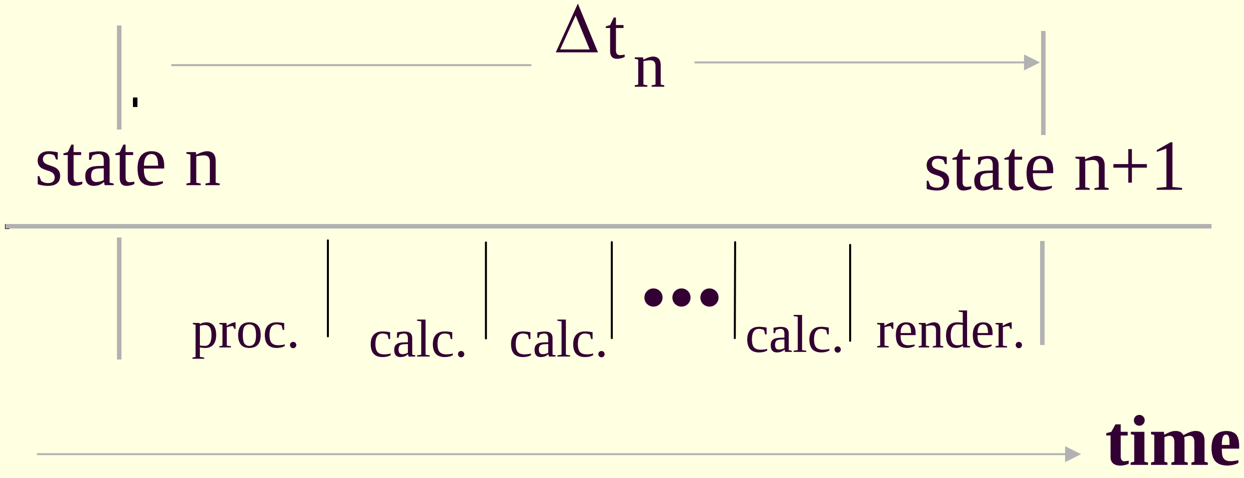


P_i = Object i (on node i)

G_{ij} = Ghost of Object i on node j

Time differential for physically-based models

- Assume Δt satisfies numerical stability.
- Δt_n can be divided into a number of Δt's
- physical phenomena can be simulated $\lfloor \Delta t_n / \Delta t \rfloor$ times



Collaborative learning in NVE

- learners in the networked simulations see other learners' actions and study the corresponding results
  - discussing experiences of manipulating various parameters
  - mastering the theories behind the simulation by playing motivational, interactive games together.
- instructors can demonstrate abstract concepts by correlations between the natural phenomena and the abstract variables.
- All participants can manipulate parameters and variables.

Summary: selected publications

- **J.X. Chen**, "Learning Abstract Concepts through Interactive Playing," *Computers & Graphics*, vol. 30, no.1, 2006, pp. 10-19.
- Z. Xu, Y. Yan, and **J.X. Chen**, "OpenGL Programming in Java," *IEEE Computing in Science and Engineering*, vol. 7, no. 1, Jan. 2005, pp. 51-55.
- F.T. Alotaiby, **J.X. Chen**, H. Wechsler, E.J. Wegman, and D. Sprague, "Adaptive Web-based Learning System," *12th IEEE International Conference and Workshop on the Engineering of Computer Based Systems (ECBS'05),* April 2005, pp. 423 - 430.
- F.T. Alotaiby, **J.X. Chen**, E.J. Wegman, H. Wechsler, and D. Sprague, "Teacher-Driven: Web-based Learning System," *ACM SIGITE'04,* Oct. 2004, pp. 284-288.(32%)
- **J.X. Chen**, Y. Yang, and R.B. Loftin, "MUVEES: a PC-based Multi-User Virtual Environment for Learning," *Proc. IEEE Virtual Reality (VR'03)*, IEEE Computer Society Press, New York, April 2003, pp. 163-170. (28%)
- **J.X. Chen**, C. J. Dede, X. Fu, and Y. Yang, "Distributed Interactive Learning Environment," *3rd IEEE International Workshop on Distributed Interactive Simulation and Real Time Applications (DiS-RT'99)*, Oct. 1999, pp. 49-56. (57%)
- M.C. Salzman, C. J. Dede, R.B. Loftin, and **J.X. Chen**, "Understanding How Immersive VR Learning Environments Support Learning through Modeling," *PRESENCE*: The Journal of Teleoperators and Virtual Environments, vol. 8, no. 3, June 1999, pp. 293-316.
- **J.X. Chen**, D. Rine, and H.D. Simon, "Advancing Interactive Visualization and Computational Steering," *IEEE Computational Science and Engineering,* vol. 3, no. 4, 1996, pp. 13-17.
- **J.X. Chen**, J.M. Moshell, C. E. Hughes, B. Blau, and X. Li, "Distributed Virtual Environment Real-Time Simulation Network," *Advances in Modeling and Analysis B*, AMSE periodicals, vol. 31, no. 1, 1994, pp. 1-7.

3. Modeling and visualization for knee surgery assistance

- Objective
  - Implementation and integration of
    - 3D patient-specific model construction
    - 3D knee motion
    - Contact area calculation
    - Contact force and pressure distribution
    - Real-time surgery simulation
- Applications
  - Patient diagnostics
  - Problem and surgery procedure explanation
  - Specific surgery planning
  - Virtual surgery simulation for training

3.1 3D patient model construction

- Marching cube algorithm
- Interpolation between contours
- Model-based reconstruction
- Our approach

3D knee model construction

- Also called knee reconstruction
- Find corresponding points between the MRI boundary pixels and the references model
- Deform the reference model to patient bone model

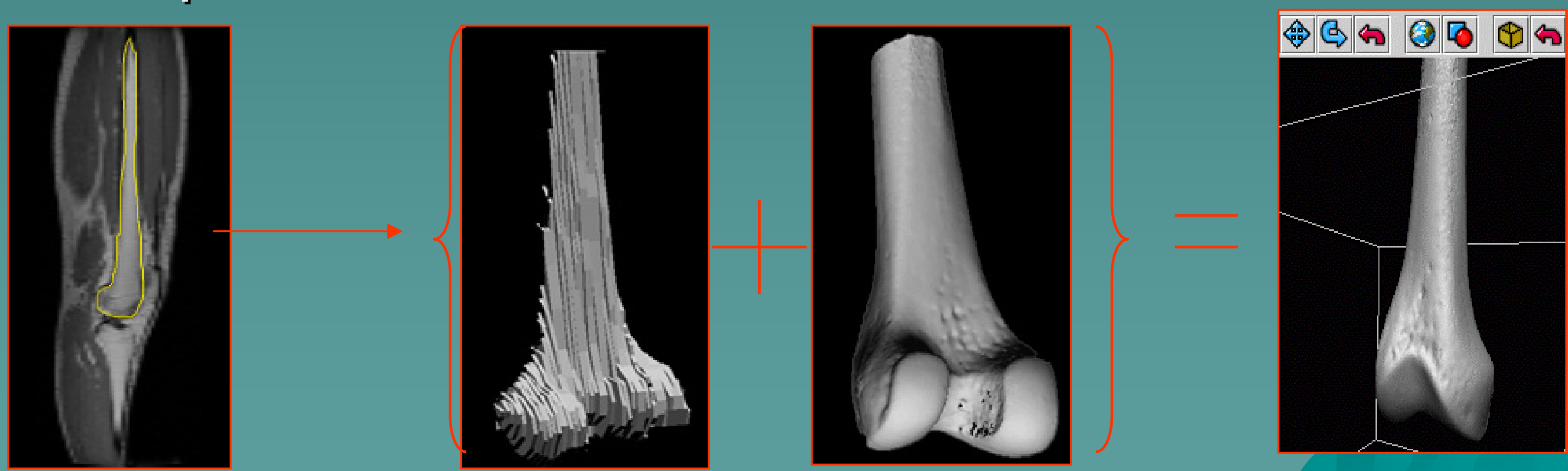


Image segmentation

- ***'Snake' algorithm*:**
  - Cut 3D reference model where the MR images are taken.
  - Use the intersections as initial 2D deformable model.
  - Use 2D 'snake' algorithm to segment MR images.

Reference model

Image segmentation

- Snake must be close to boundary
- Use previous contour for next slice

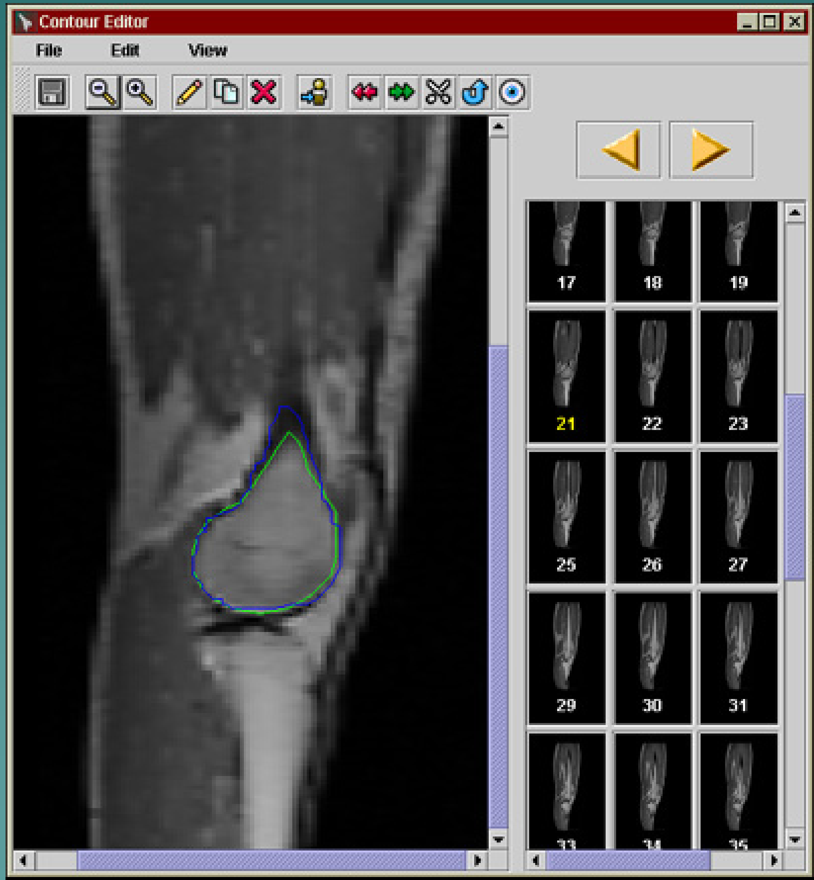
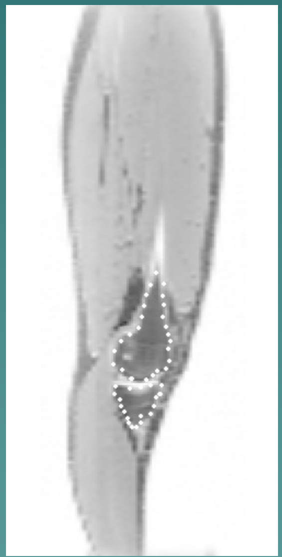
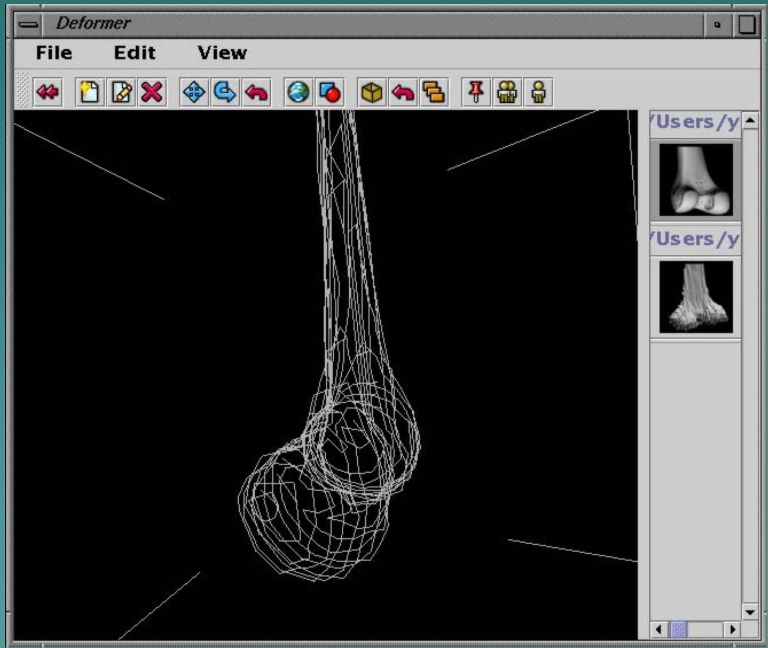


Image segmentation – cont.

Initial "snake" position



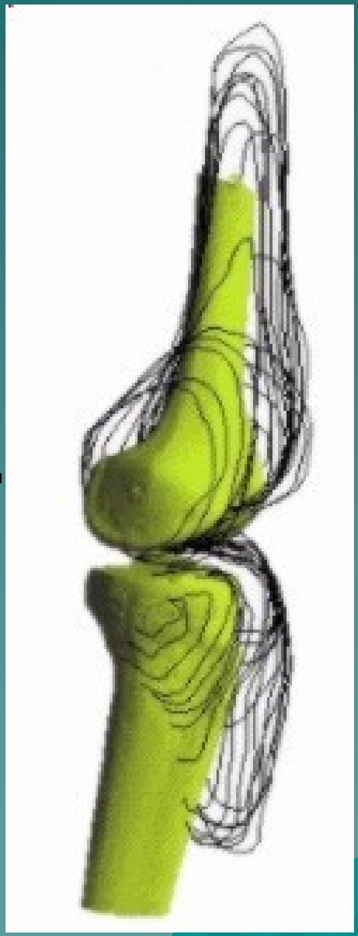
After segmentation



Contour model

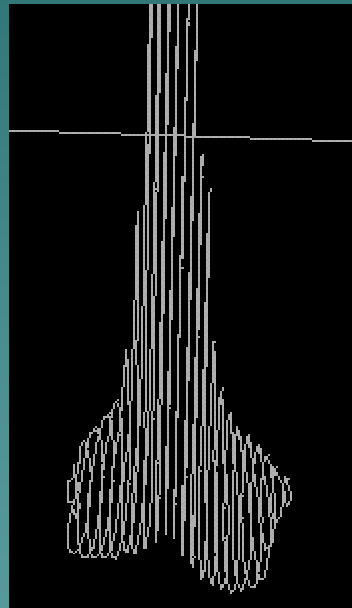
Align Reference Model with Contour Model

- Roughly align reference model with knee contours using affine transformations.

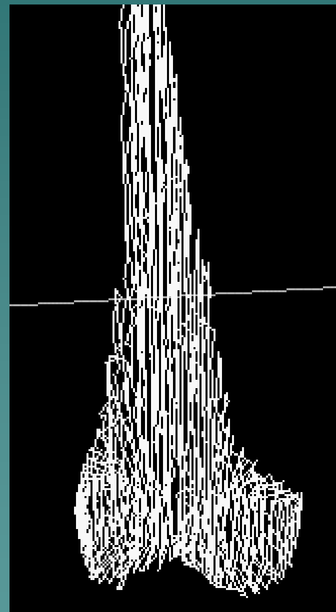


Establish correspondence

- Project the reference model and contour model respectively onto an intermediate object.
- Points projected to the same location of the intermediate object are paired as corresponding points.



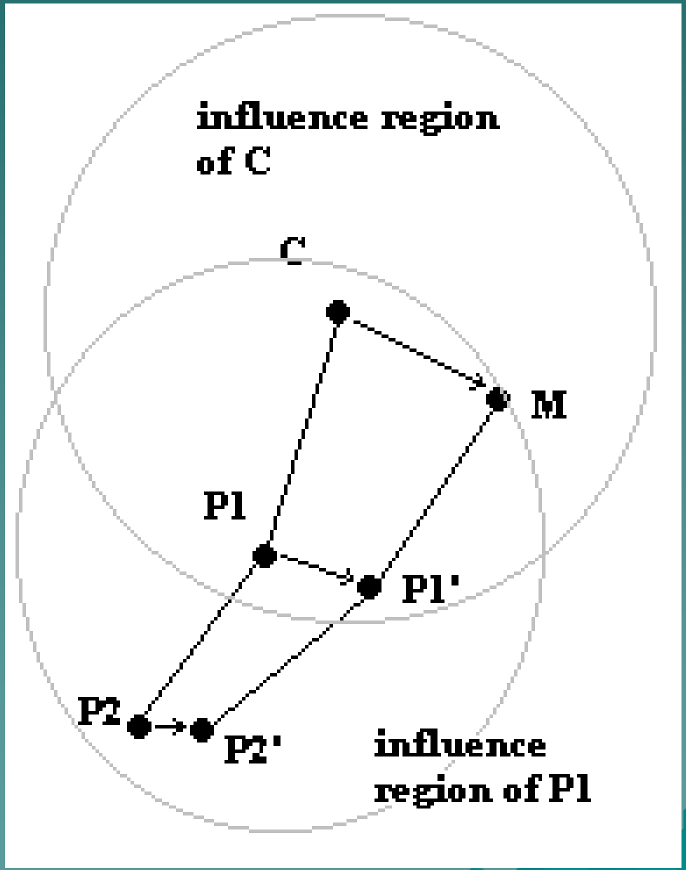
MRI Model



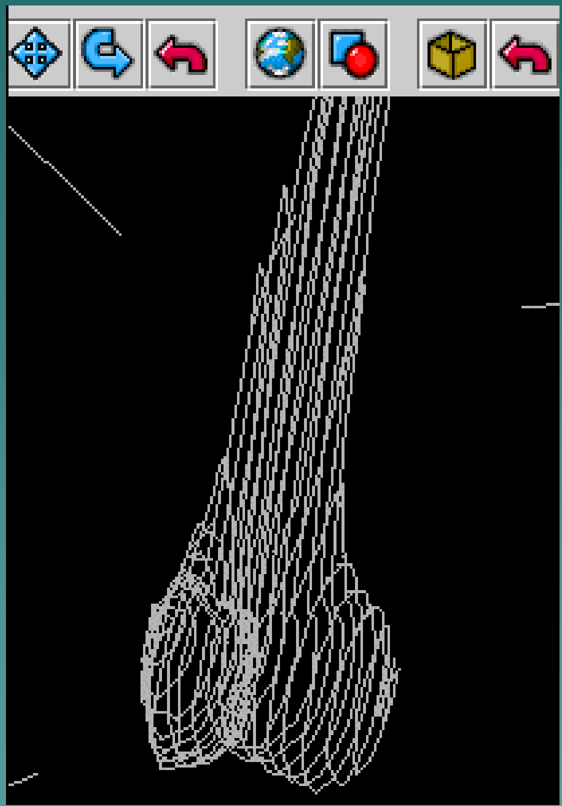
Feature curves on reference model

Model deformation

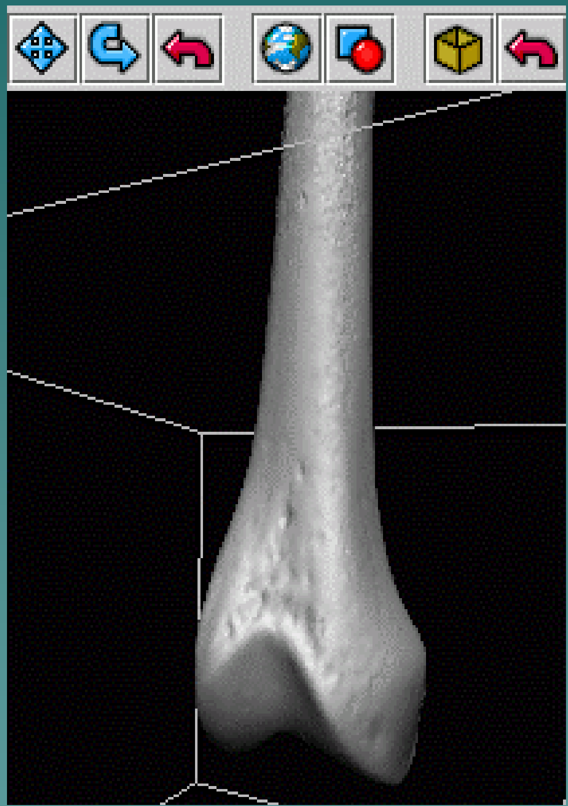
- Define feature points and their influence regions.
- The ***influence region*** includes all the points that are within certain surface distance from the feature point.



3D Reconstruction Result

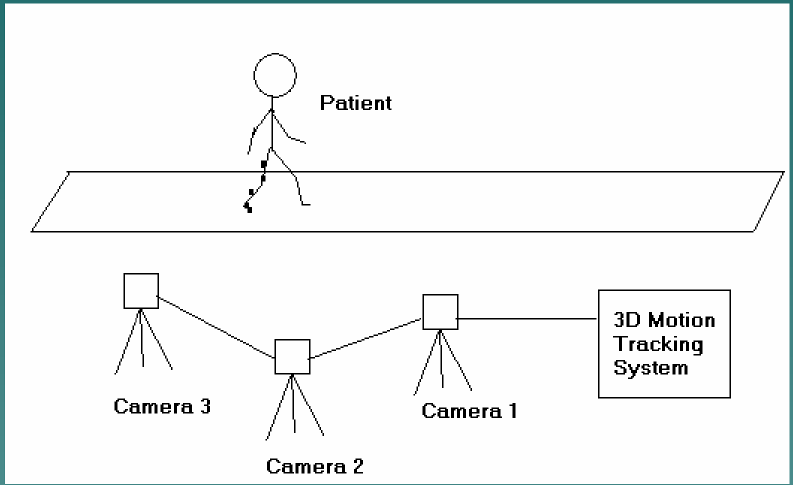


Contour model

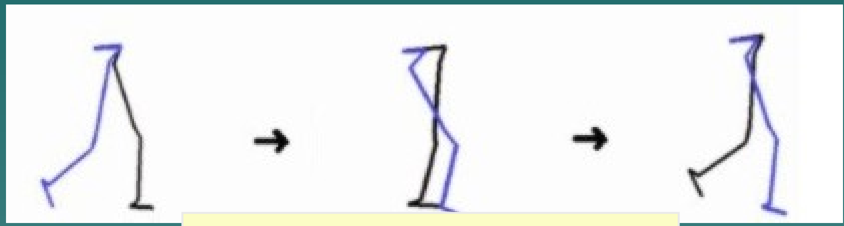


Result model

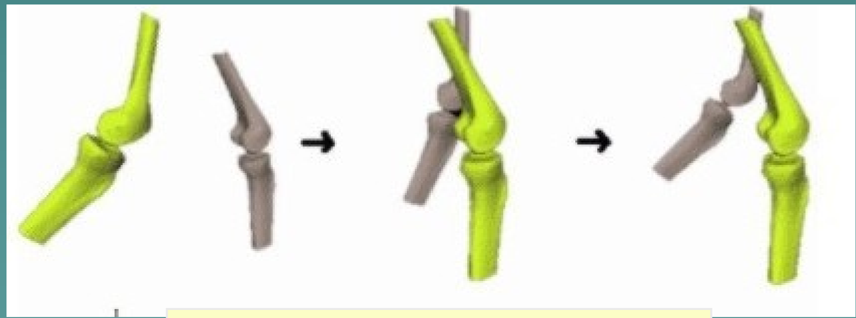
3.2 Visualization of knee motion



Collect data from patient through a motion capture system.



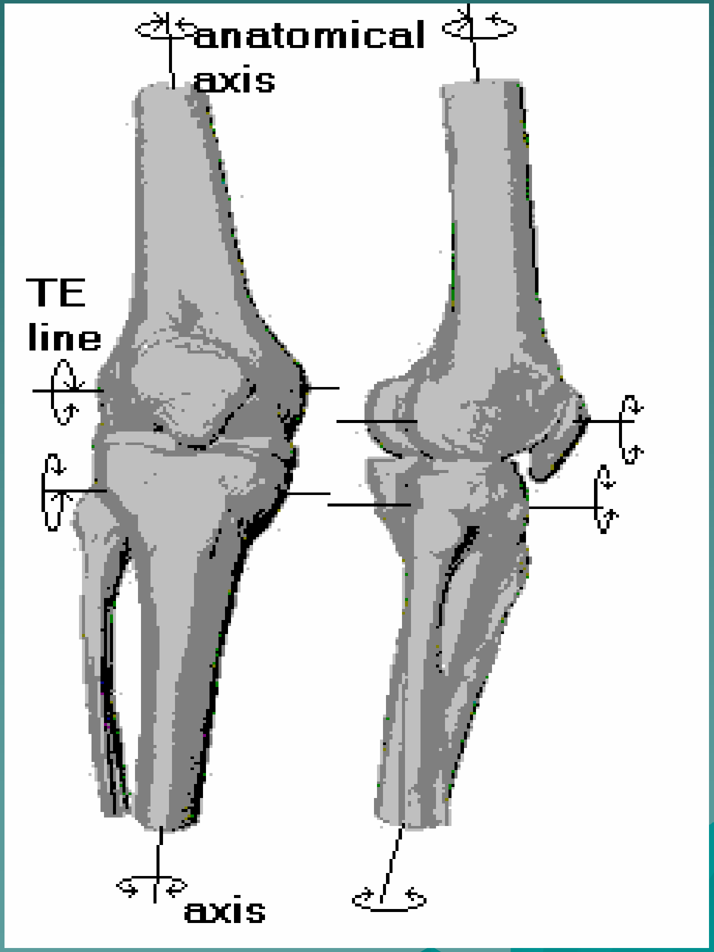
Knee motion visualization with stick model.



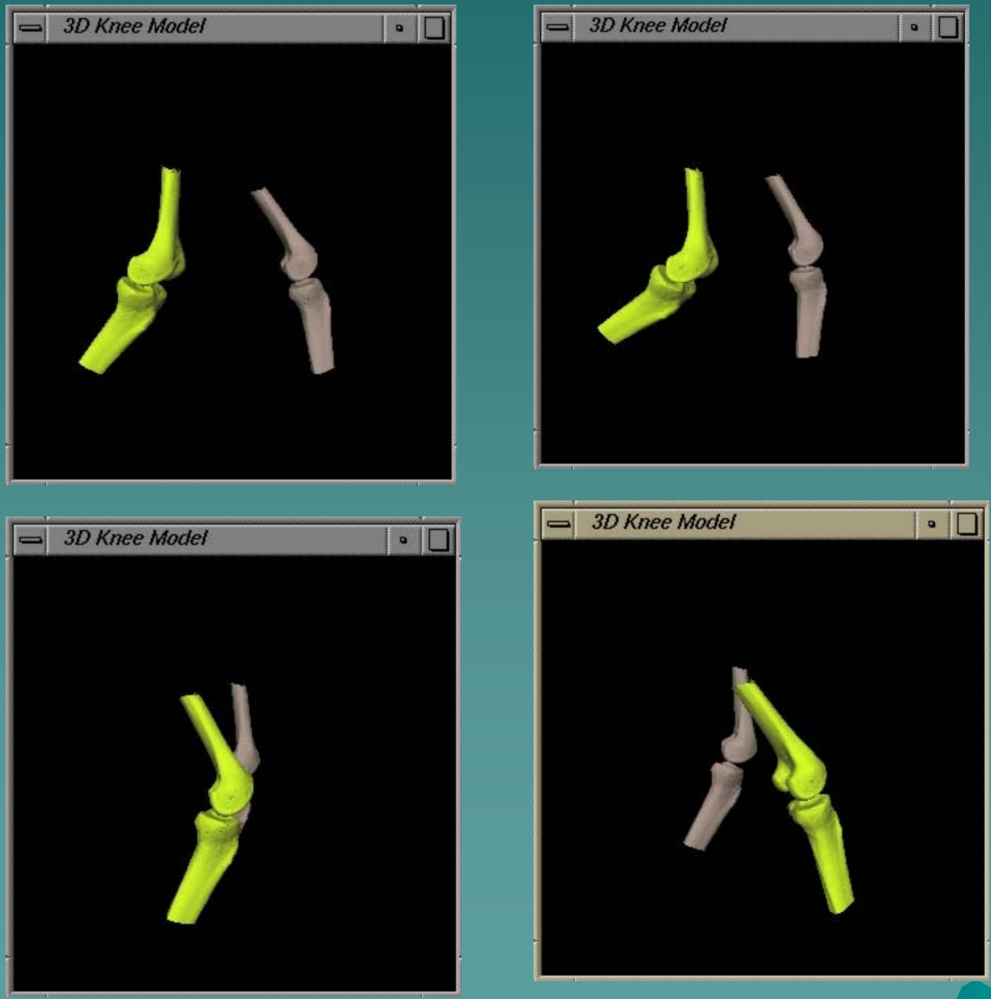
Knee motion visualization with patient-specific 3D model

Knee Motion Simulation

- ***Motion definition:***
  - three rotations
  - two kinds of translations, vertical translations are ignored.
- ***Definition of knee rotation axes.***



Motion Simulation Result

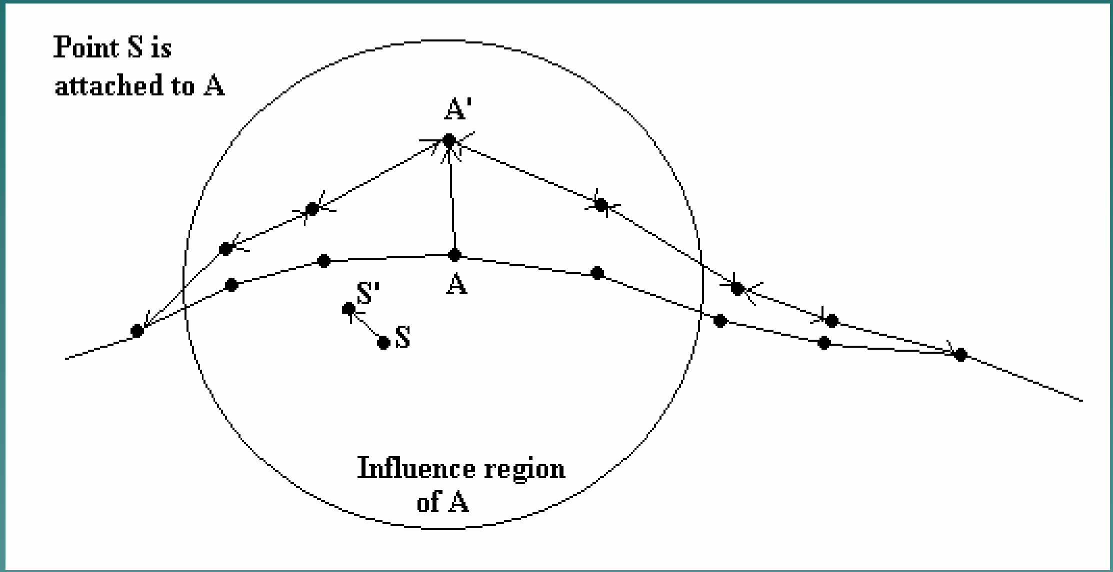


3.3 Contact Area Calculation

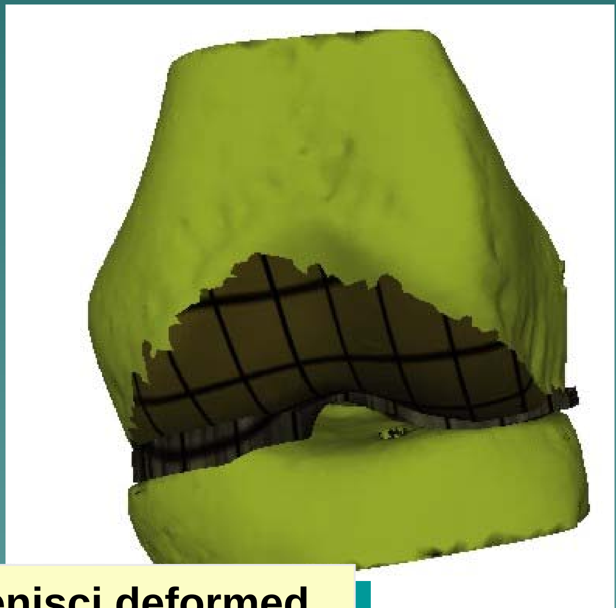
- ***Purpose***: Detect and measure the contact area between femur and menisci.
- Simulate the deformation of menisci.
- Use collision detection to identify and measure the contact area.

A New Deformation Technique

- Each object is bundled with a number of feature wires.
- Each point on a wire has its own influence region on the 3D model.



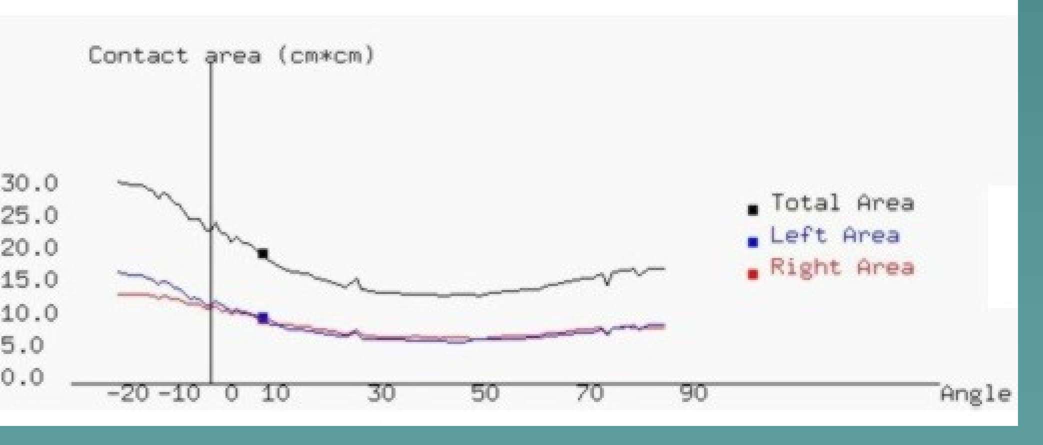
- The deformation of feature curves are physically-based.
- When a point on a feature wire is moved, all the points in its influence region will move accordingly.



Menisci deformed

Menisci not deformed

Contact Area Display



3.4 Contact Force Calculation and Visualization

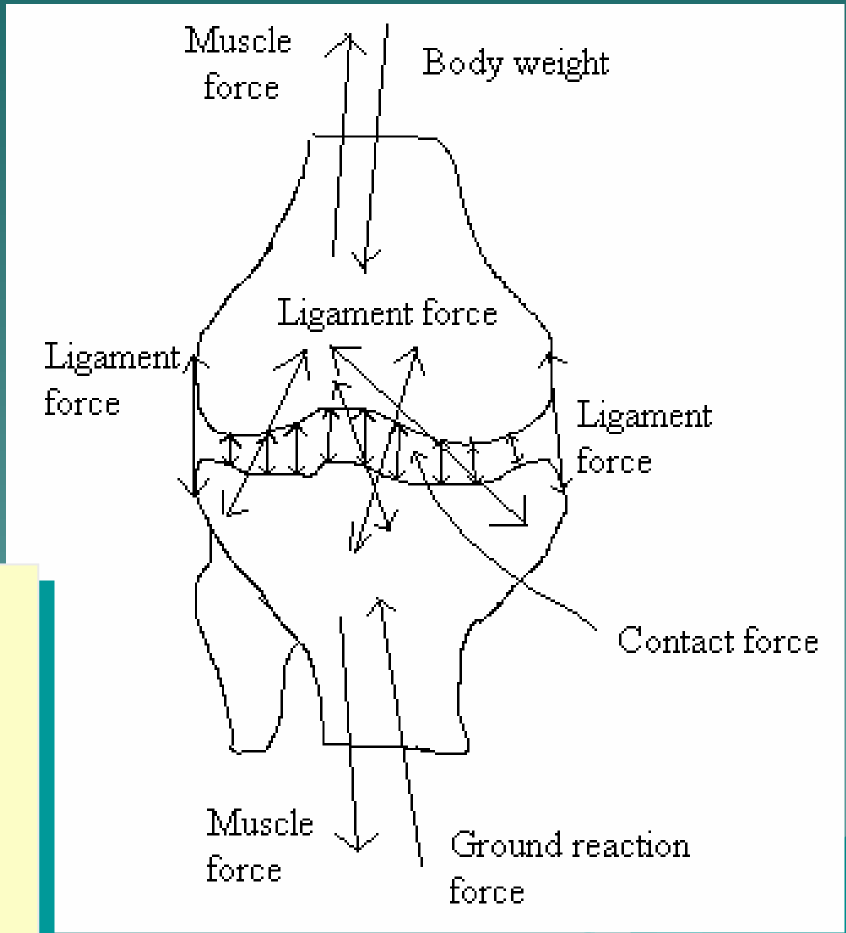
- Establish a biomechanical knee model.
- Solve the biomechanical knee model and obtain the contact forces between femur and tibia.
- Knee contact force visualization.

Calculate contact pts & stress

– Equilibrium laws

$$F_e + F_c + \sum F_l^{\,j} = 0$$

$$M_e + M_c + \sum_j M_l^{\,j} = 0$$



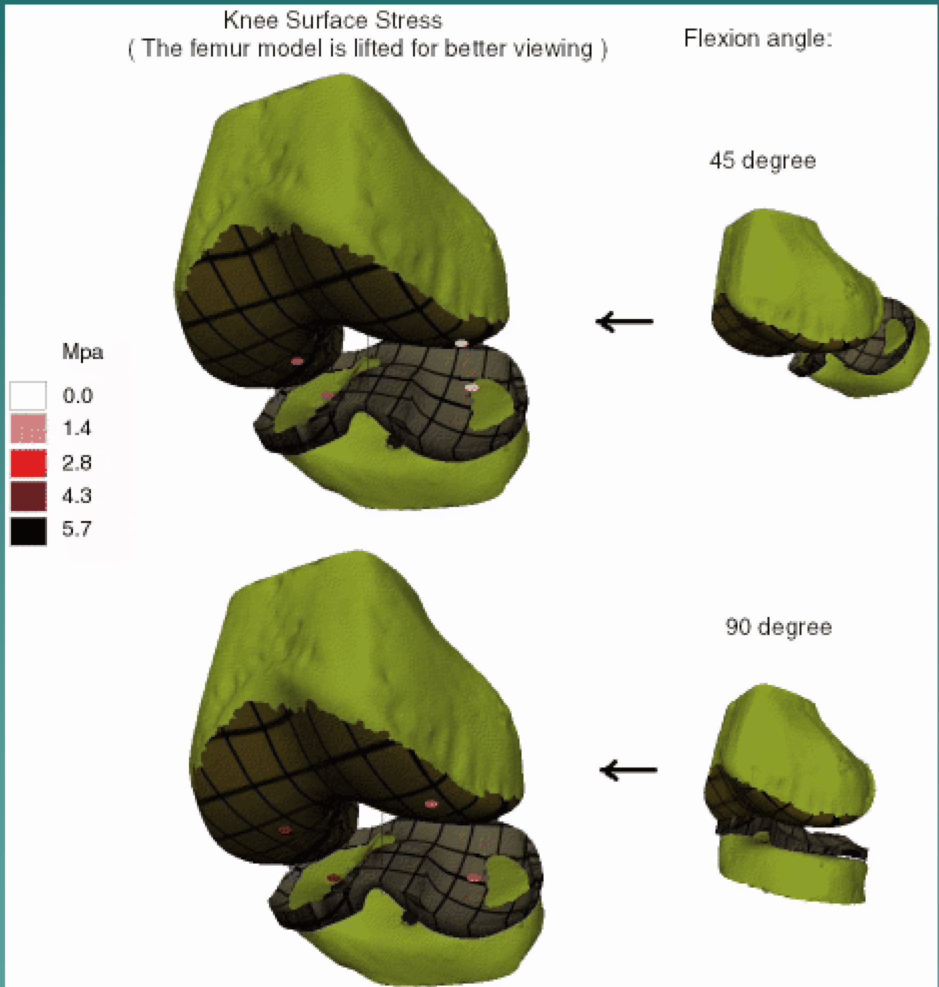
Fe: external forces, including body weight, ground reaction force, and muscle forces.

Fc: contact forces; *Fl:* ligament forces. There are 7 ligaments on the knee joint.

Me: external moments; *Mc*: contact moments.

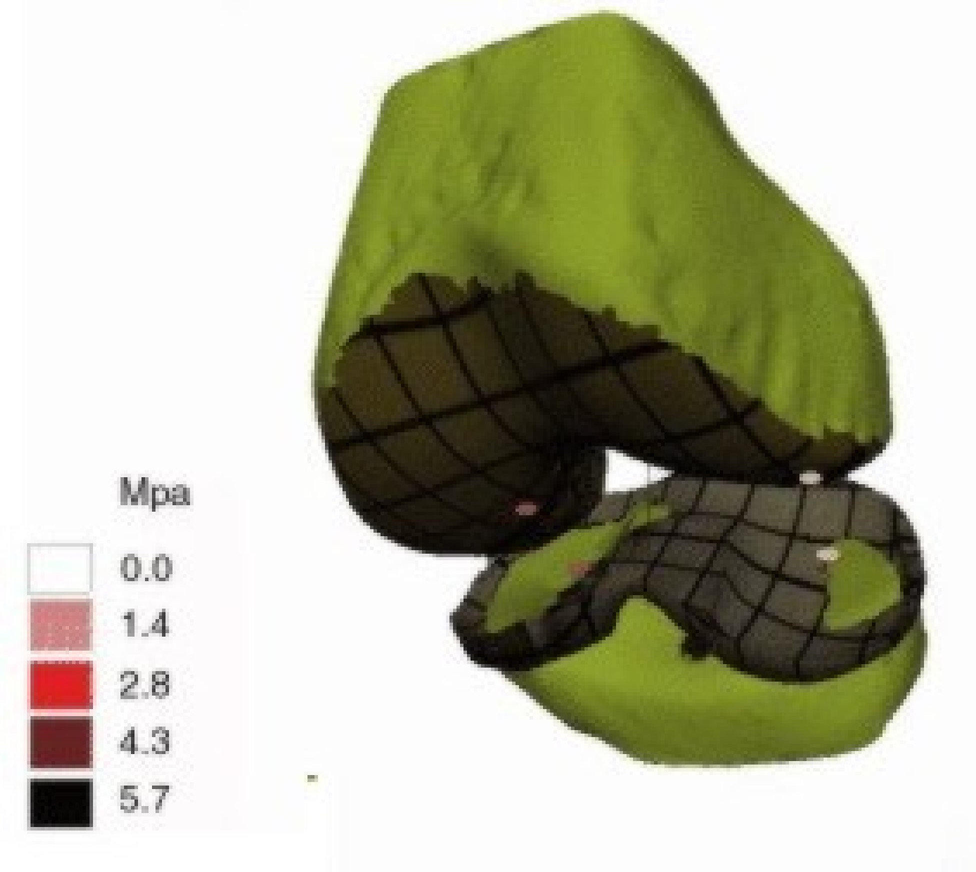
Ml: ligament momunts.

Visualizing Knee Contact Force



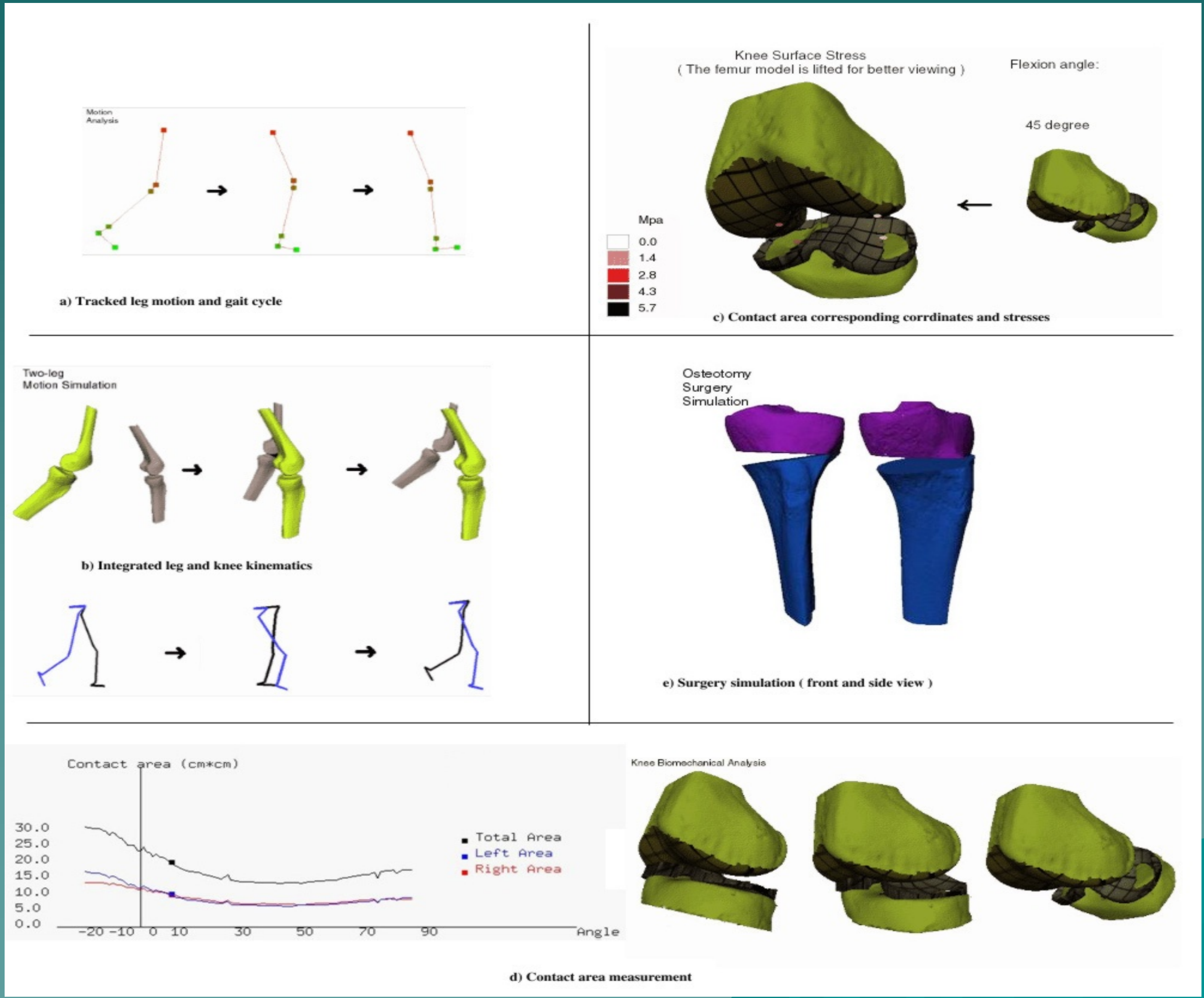
The colored circles on the knee surface show the contact forces.

Visualization of contact stress



The colored circles on the knee surface show the contact stress.

3.5 Surgery assistance



Summary: selected publications

- Y. Zhu and **J.X. Chen**, “Simulation and Visualization of Knee Joint Contact using Deformable Model”, *4th IEEE International Conference on Computer and Information Technology (CIT 2004)*, ISBN 0-7695-2216-5/04, IEEE Computer Society Press, Sept. 2004, pp. 708-715. (26%)
- **J.X. Chen**, H. Wechsler, J.M. Pullen, Y. Zhu, E.B. MacMahon, “Knee Surgery Assistance: Patient Model Construction, Motion Simulation, and Biomechanical Visualization,” *IEEE Transactions on Biomedical Engineering*, vol. 48, no. 9, Sept. 2001, pp. 1042-1052.
- Y. Zhu, **J.X. Chen**, and X. Fu, “A Virtual Reality System for Knee Diagnosis and Surgery Simulation,” *IEEE Virtual Reality’99*, March 1999, pp. 84-85. (21%)
- Y. Zhu, **J.X. Chen**, S. Xiao, and E.B. MacMahon, “3D Knee Modeling and Biomechanical Simulation,” *IEEE* Computing in Science and Engineering, vol. 1, no. 4, July 1999, pp. 82-87.

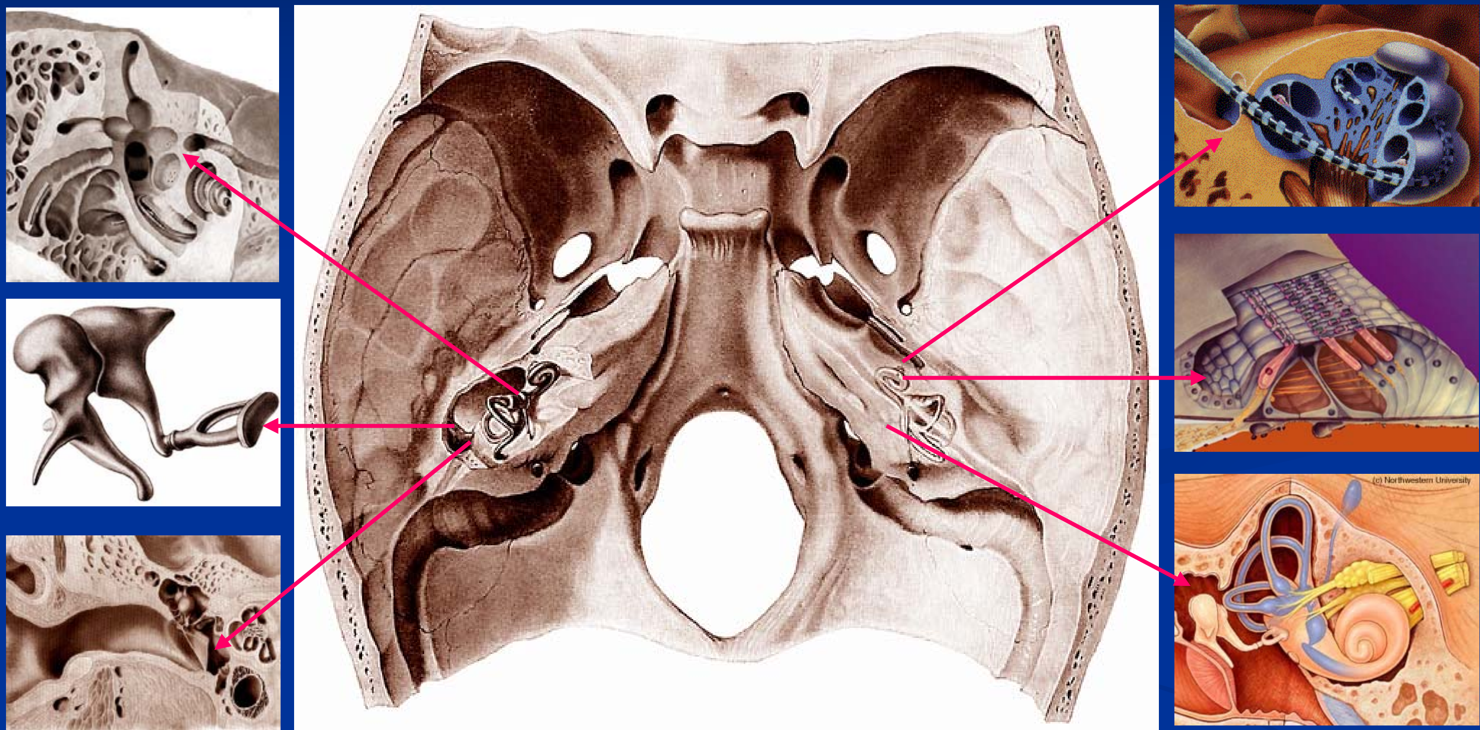
4. Temporal Bone Visualization & Virtual Ear Surgery

In collaboration with Peidong Dai, Tianyu Zhang, Zhenmin Wang, etc. at

Eye and Ear Nose Throat Hospital of Fudan University, Shanghai, China

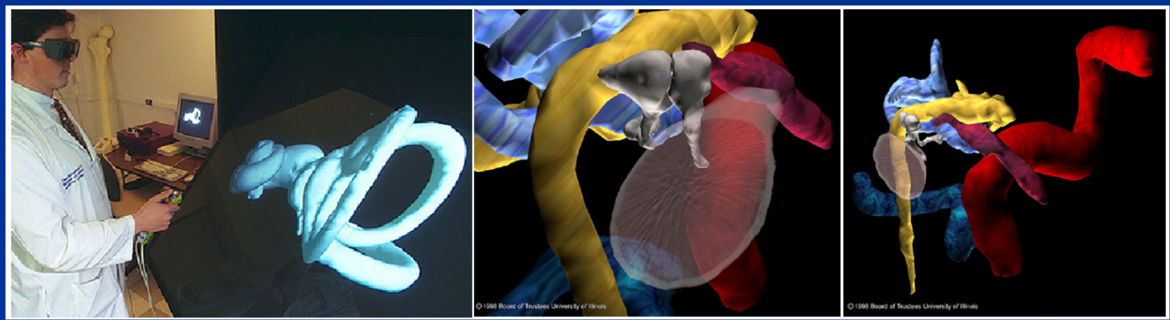
Introduction

- Objective
  - Construct detailed temporal bone model
  - Build up a virtual ear surgery system
- Applications
  - Surgery training
  - Surgery study
  - Hearing system modeling, simulation, and understanding



Lateral skullbase, especially its temporal bone, is one of the most complicated area in human body.

Three-dimensional reconstruction of temporal bone

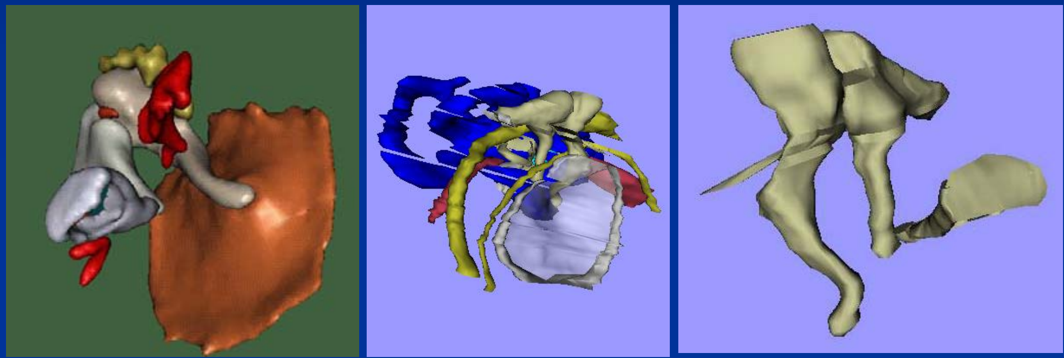


ImmersaDesk system for temporal bone visualization

Univ. of Illinois Chicago, School of Biomedical and Health Information Sciences, 1999.

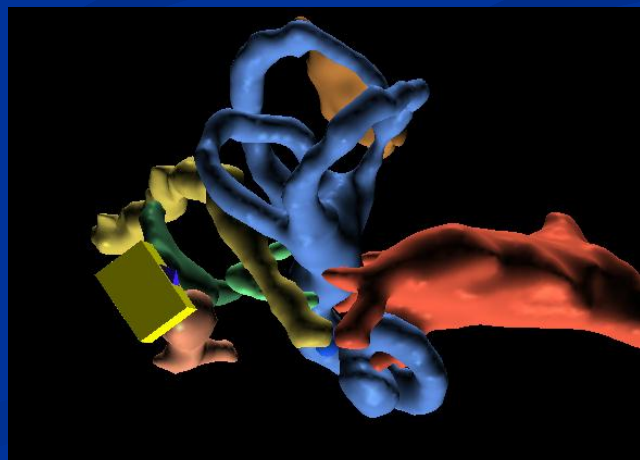
1,2. Labyrinth, auditory ossicles, and CNⅦ 3. Posterior tympanum

Dai Pu, et al. ENT department, 301 Hospital of PLA, Beijing, 1998.



René G. van Wijhe
McGill University
Biomedical Engineering
Montreal, Quebec,1997

Ron Kikinis, et al.
Surgical Planning Laboratory
Department of Radiology
Harvard Medical School, 2000



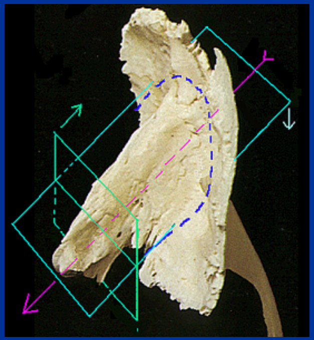
Our Research

- 3D morphological analysis of the lateral skullbase
- Visualization of the temporal bone
- Computer assisted design of approaches for ear surgery
- Virtual reality for ear microsurgery
- Virtual reality for sound conducting process through ear

Methods

Making serial sections of temporal bone specimen

- Specimen disposing
- Undecalcified bone embedded in MMA
- Serial 50μm sections
- HE staining



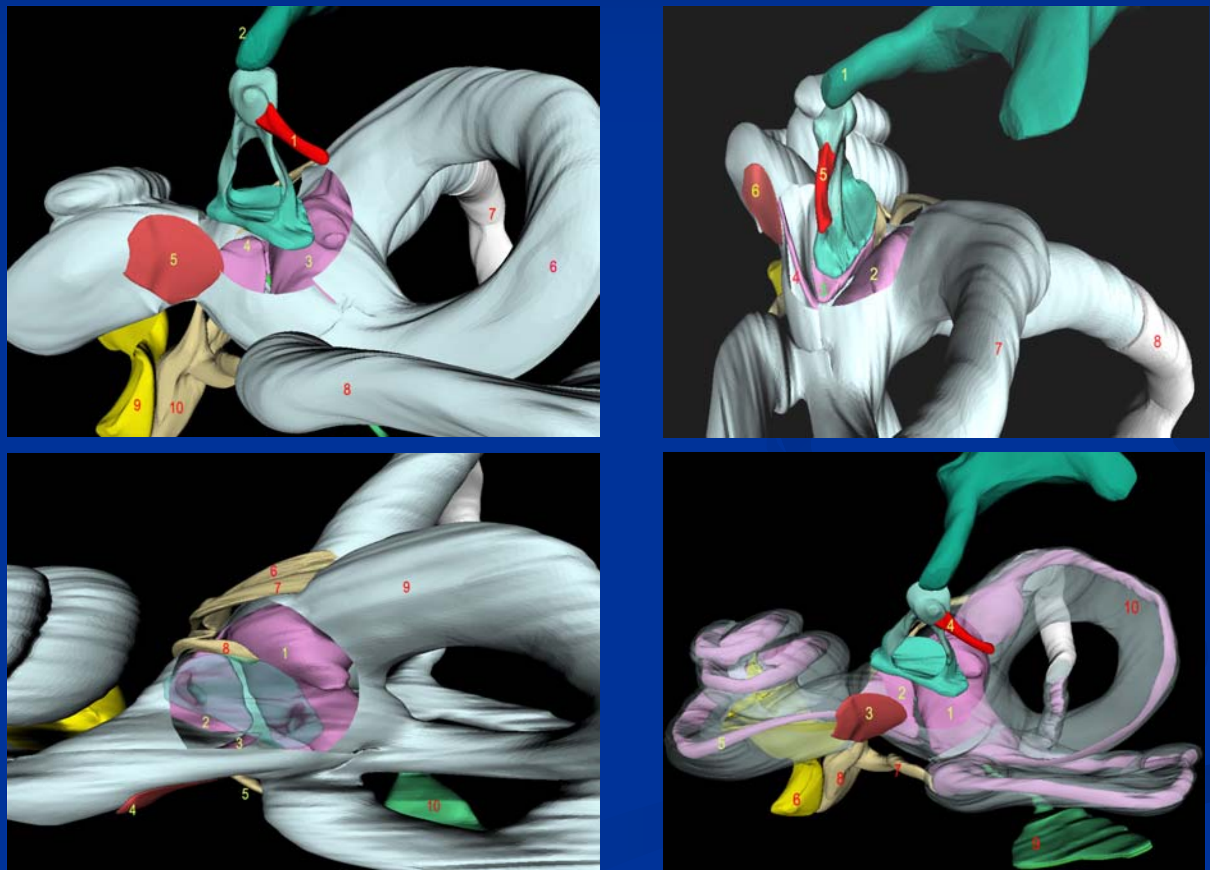
- **Section imaging**
- **Image processing**
- **Image alignment**
- **Image registration**
- **Contour extracting**
- **3D reconstruction**
- VR X6000A Virtual Lab

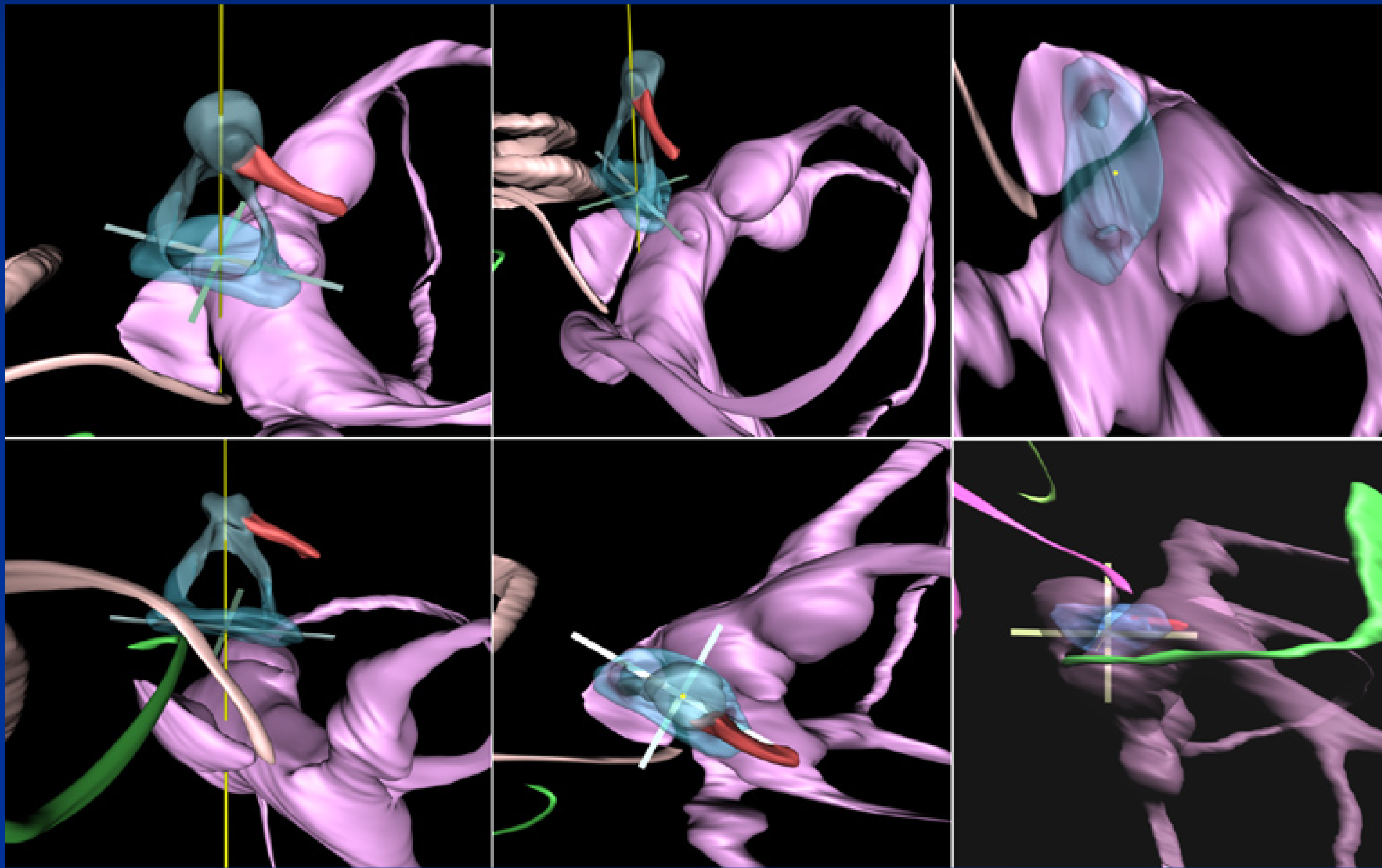
Computer processing flowchart diagram

Roaming virtual temporal bone with 3D glasses and stereo projection system

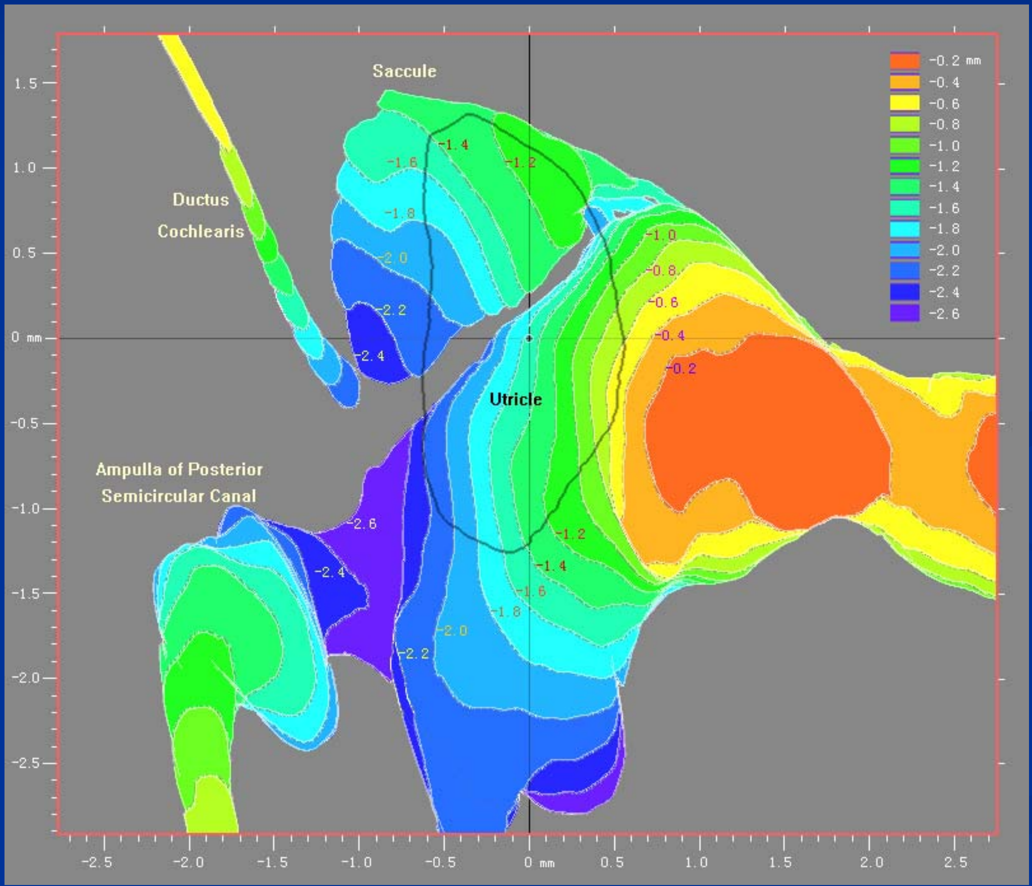
Performing virtual operation with Spaceball and 3D glasses

Utricle, saccule, and footplate in relation to stapedotomy

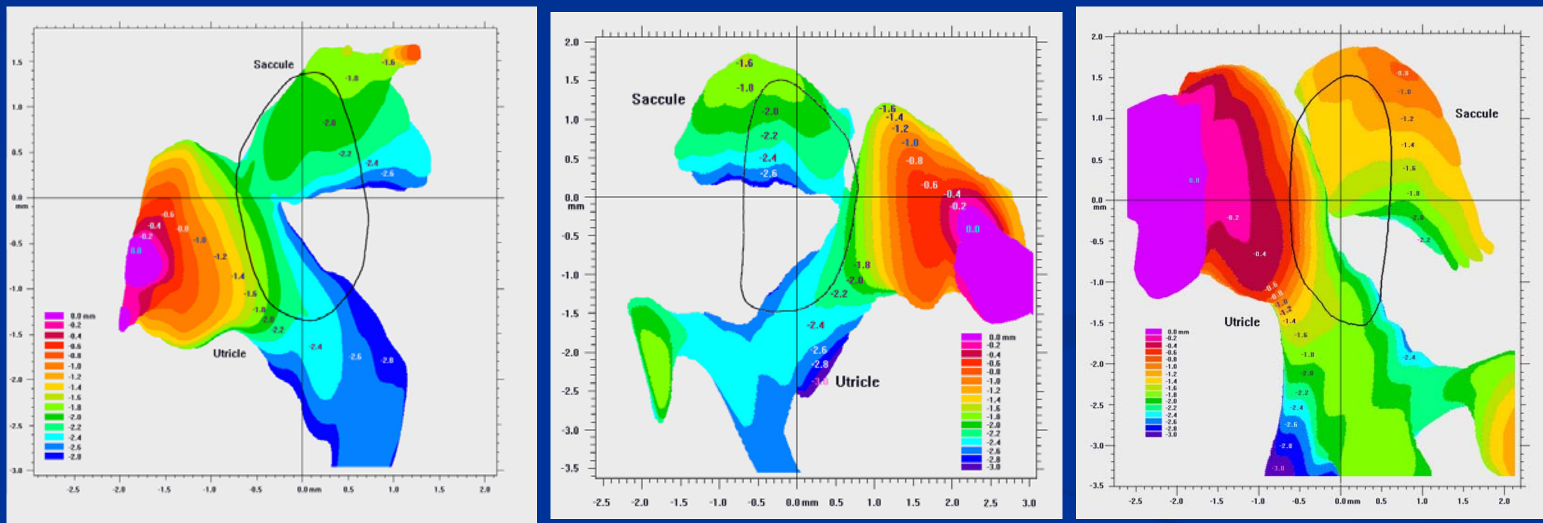




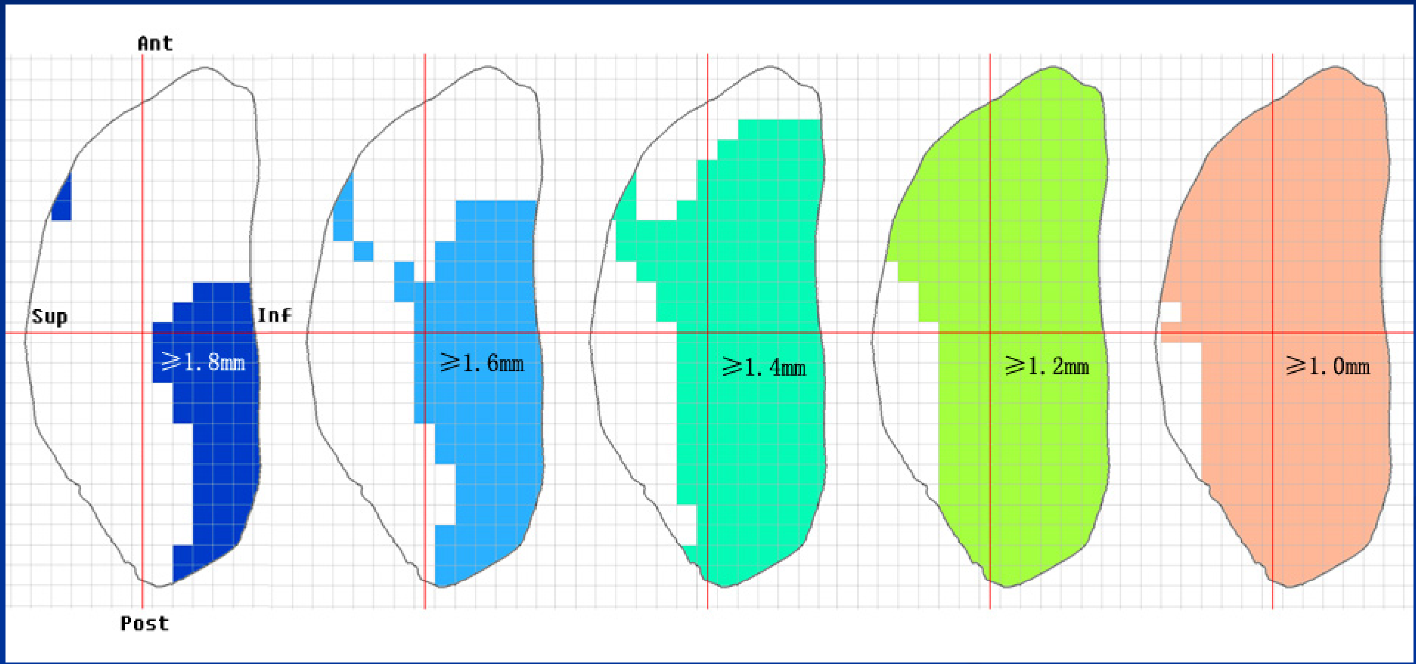
The contour map of *utricle* and *saccule*



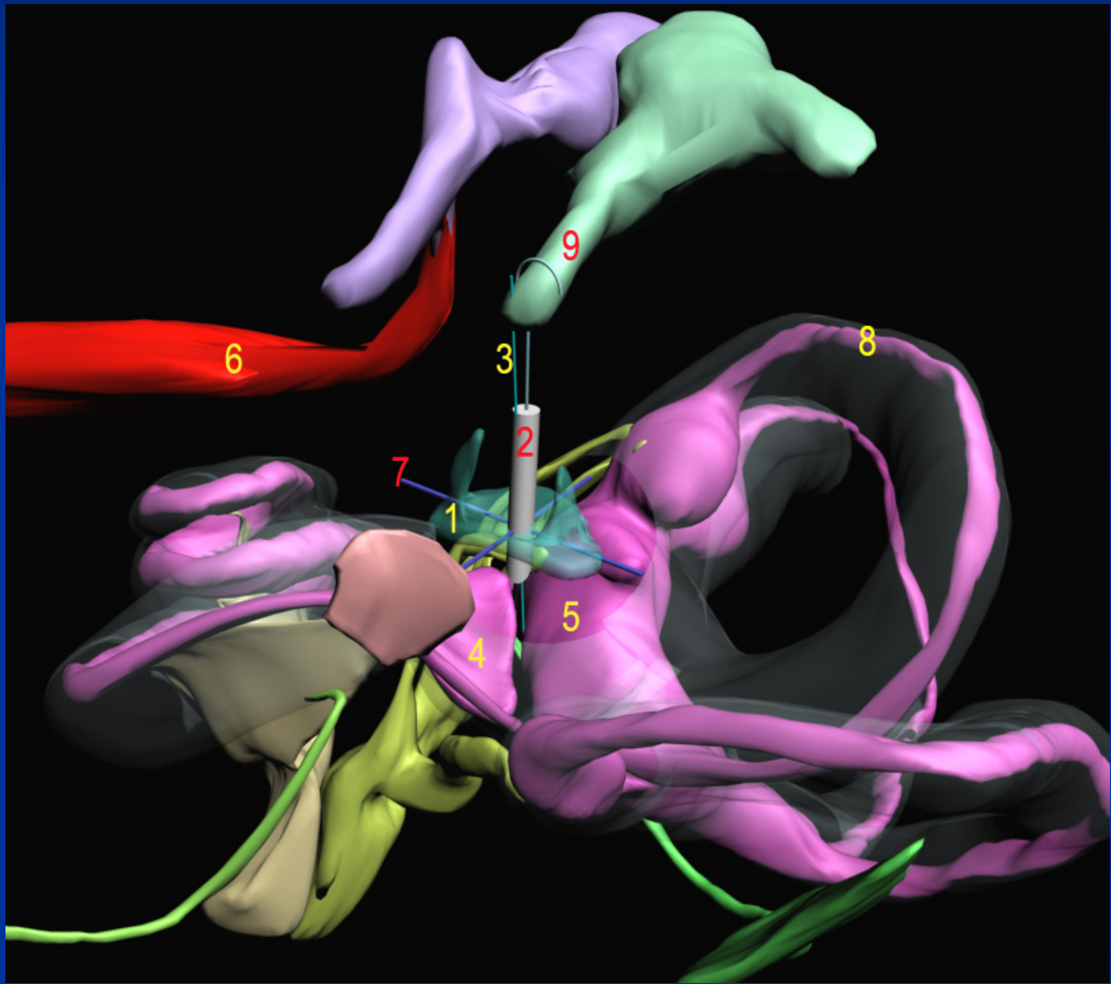
From the lateral surface of the footplate (assumed horizontal plane or "sea level") to "seabed", the different sections of the utricle, saccule, and cochlear duct with different elevations were marked with different colors, and all these sections were superposed to form the contour map. The contour interval is 0.2mm. The black oval contour at the center of the figure represented the footplate.



The other 3 contour maps of *utricles* and *saccules*

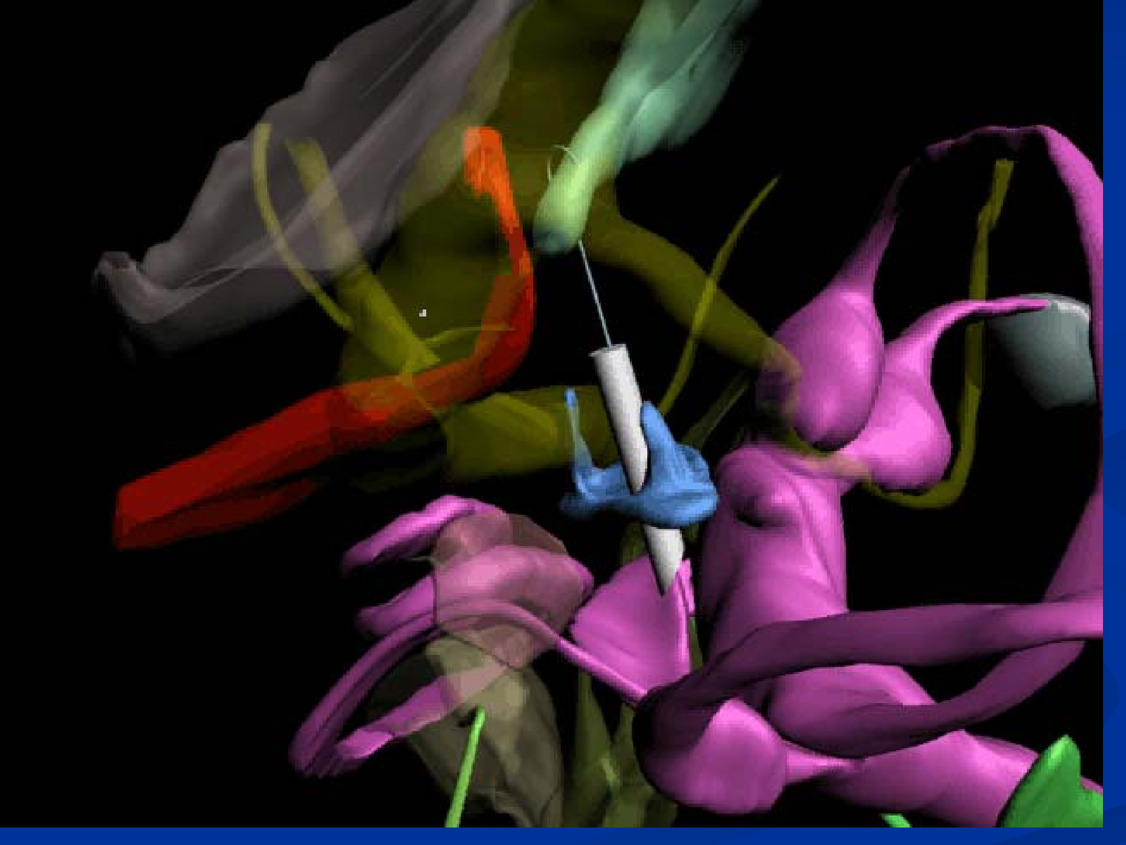


The diagrammatic sketch showing the different areas in which the shortest vertical distances between the footplate and utricle or saccule are no less than 1.8, 1.6, 1.4, 1.2, and 1.0 mm, respectively, among 4 specimens.



Designs for the depth and orientation of the small plug column stapedotomy

1-footplate
2-small column
3-Z axis
4-saccule
5-utricle
6-tensor tympani
7-X and Y axes
8-lateral semicircular canal
9-long process of incus



Summary: selected publications

- T. Zhang, P. Dai, **J.X. Chen**, L. Xie, Z. Wang, K. Wang, "The Contour Map of the Vestibular Apparatus Based on Three-Dimensional Reconstruction of the Temporal Bone," *Computing in Science and Engineering*, (to appear).
- P. Dai, T. Zhang, **J.X. Chen**, Z. Wang, and K. Wang, "Virtual Laboratory for Temporal Bone Microanatomy," *Computing in Science and Engineering*, vol. 7, no.2, March 2005, pp. 75-79.

5. Virtual Human Anatomy and Surgery System

Yanling Liu and Jim X. Chen
Department of Computer Science
George Mason University

Ling Yang
Sichuan Continuing Education College of Medical Sciences

Spring 2006

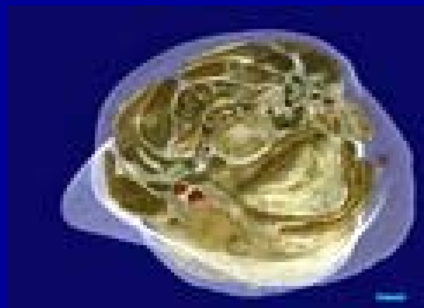
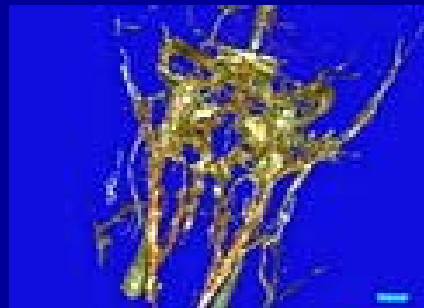
Introduction

- Objective
  - Construct detailed virtual human body
    - Natural color
    - Graphics objects for different components
  - Allow separating and labeling different components through haptic devices (virtual anatomy)
- Applications
  - Cadavers are in short supply in medical schools worldwide. Our solution: virtual human anatomy for learning
  - General medical and surgical training

Virtual Human Anatomy and Surgery System (VHASS)

- VHASS uses cryosection images – natural-color images generated by slicing a frozen cadaver – to reconstruct the human body.



VHASS functionalities so far

- Reconstruct natural-appearance volume model for each human part
- Allow grouping and labeling human parts
- Provide real-time interaction and browsing
- Generates arbitrary orientated natural color human cross section in real-time
- Integrate haptic device for drilling operation simulation

Dissection via Cryosection

- At Sichuan Continuing Education College of Medical Sciences in China
  - Prof. Lin Yang teach her students the anatomic structure using cryosection images.
  - students found pixels belonging to the same body part and filled these pixels with a designated color.
- Two sets of the same images: the natural color images and the colored images.

Data preparation and acquisition (1)

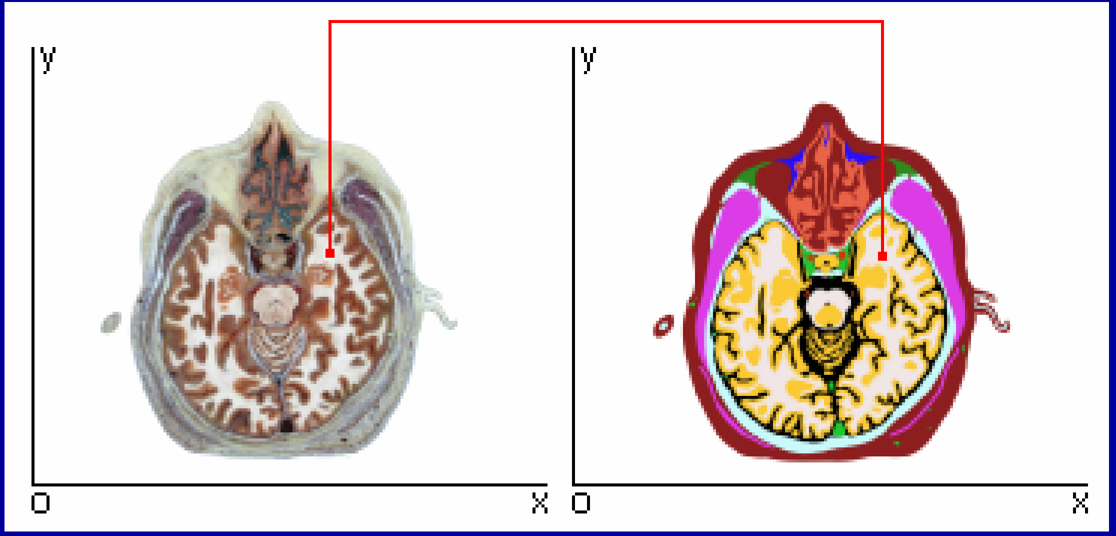
- 2100 scanned cryo-section images
  - 3072 x 2048 pixel resolution
  - 18M bytes for each uncompressed image
  - Four different thickness:
    - 0.1mm
    - 0.2mm
    - 0.5mm
    - 1.0mm
- 2100 colored images

Data preparation and acquisition (2)

Data preparation and acquisition (3)

Data preparation and acquisition (4)

- Pixels of one certain human part were extracted and converted as voxels.
- Volume data will be used later for rendering.



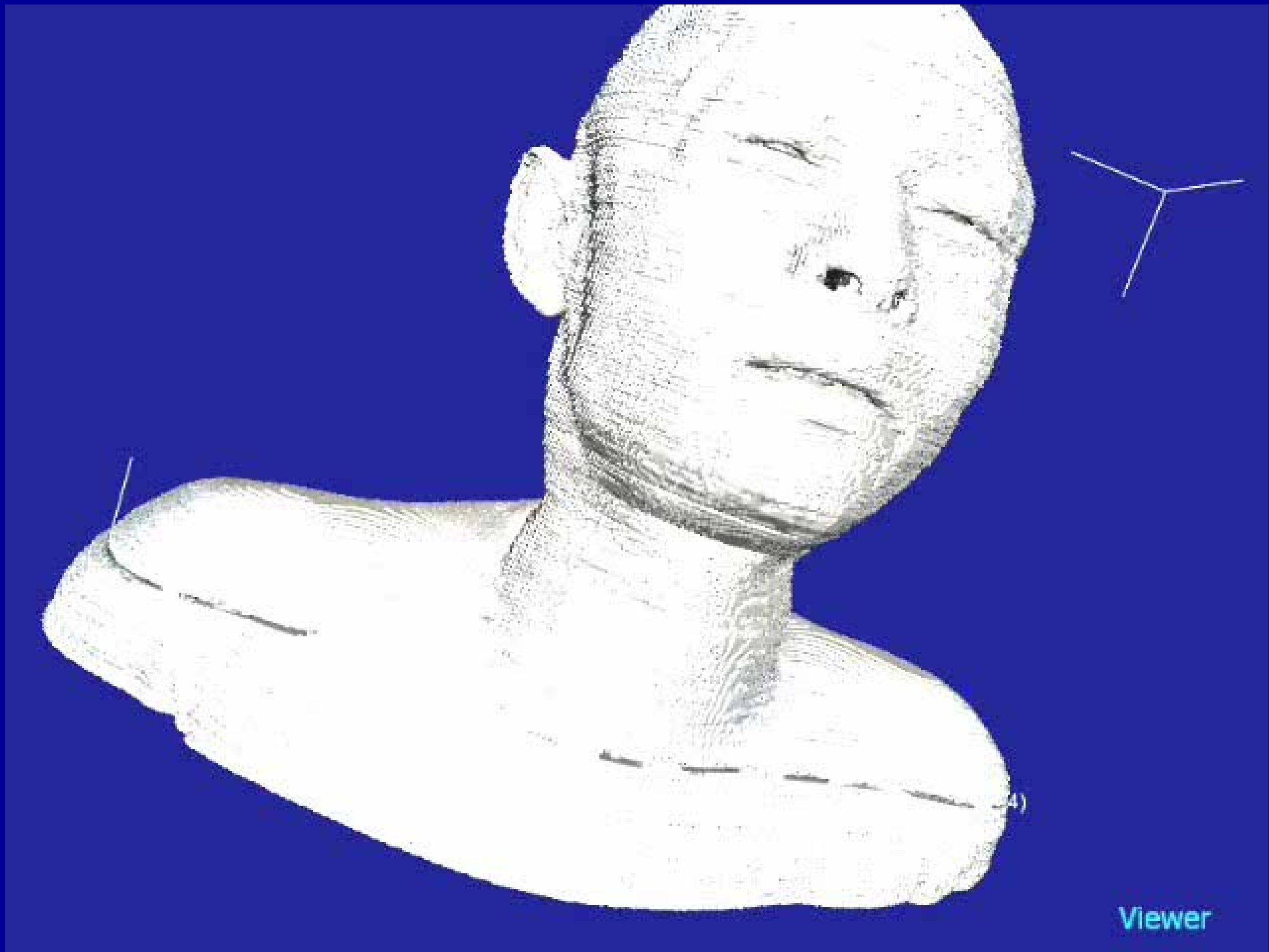
Some technical Details

- Totally we have 2011 original cryosection images and 2011 colored images.
- Both sets have a 3,072 x 2,048 pixel resolution, and each uncompressed image uses roughly 18Mbytes of storage space.
- Different from the Virtual Human Project, four different thicknesses are applied to reduce loss of details: 0.1mm, 0.2mm, 0.5mm and 1.0mm.

Rendering details

- Use OpenSceneGraph to handle renderings of volume models for human parts.
- Integrate GLSL (OpenGL Shading Language) for pixel shading support.
- This movie shows rendering effect of brain cortex, cerebellar cortex and eyeball.

High quality real-time virtual human rendering



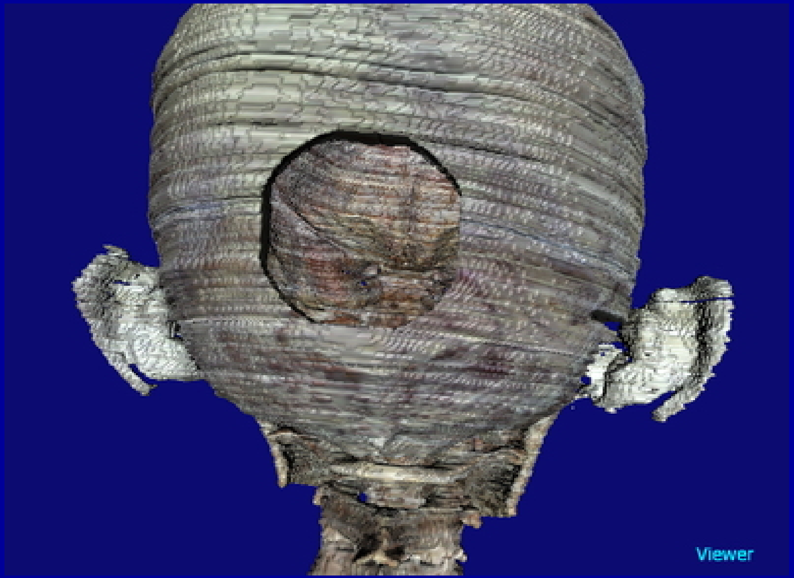
Real-time human part scanner (1)

- CT and MRI cannot generate natural color cross section of human body.
- Also they can not produce human body cross sections with an arbitrary orientation.

Real-time human part scanner (2)

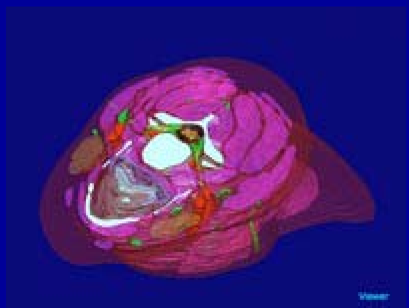
Virtual Drilling

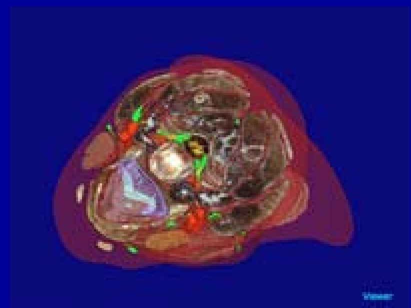
- drilling operation of a diamond burr on the back of skull.
- Drilling of a round hole produced by a large diamond burr.



Virtual human anatomy for learning (1)

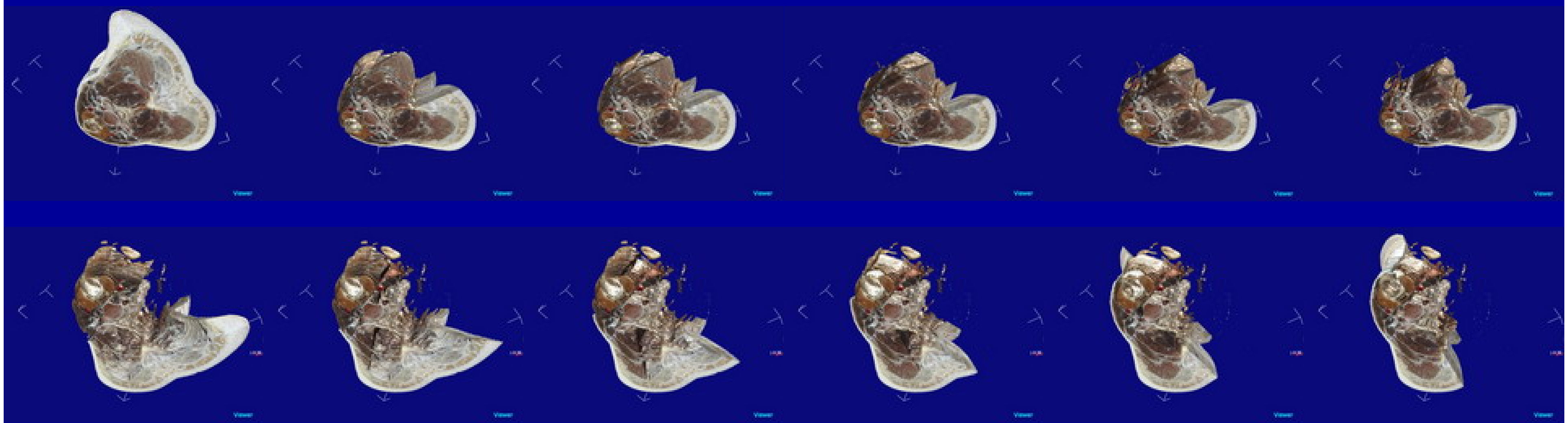
- Human parts browser
  - Each part has label and description
  - Material attributes changeable
  - Switch between natural rendering or colored rendering





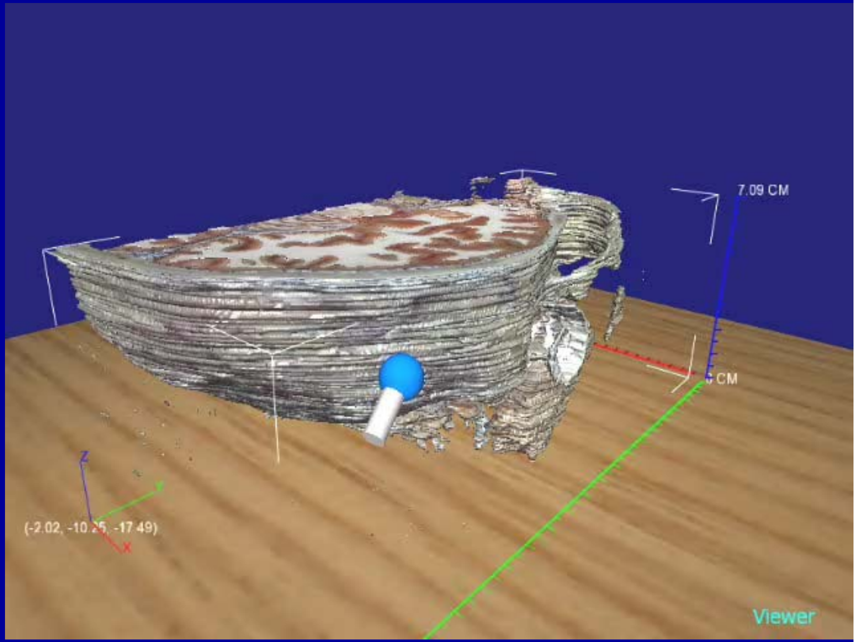
Virtual human anatomy learning (2)

- Human body scanner
  - Generates continuous natural appearance human body cross-sections at real-time
  - Scan multiple parts at same time

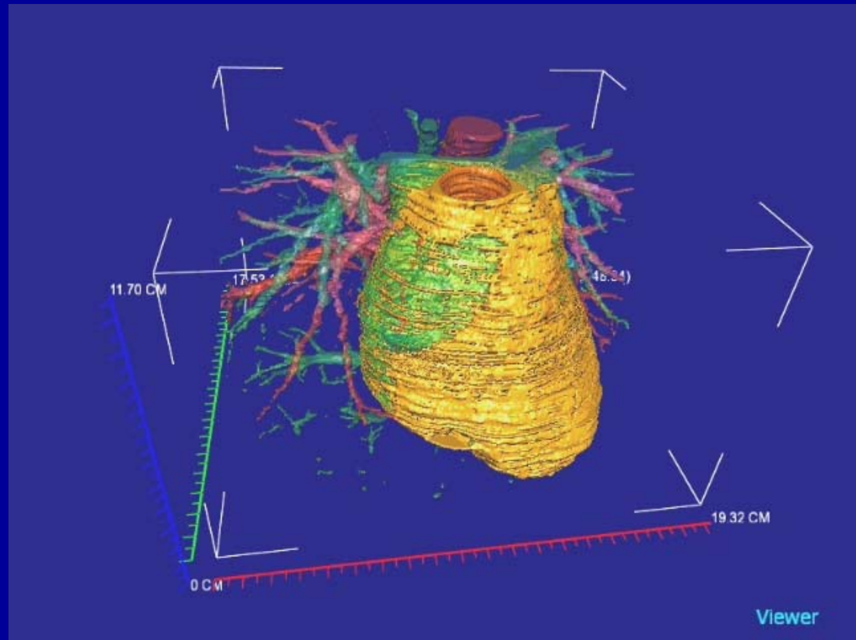


Virtual human anatomy learning (3)

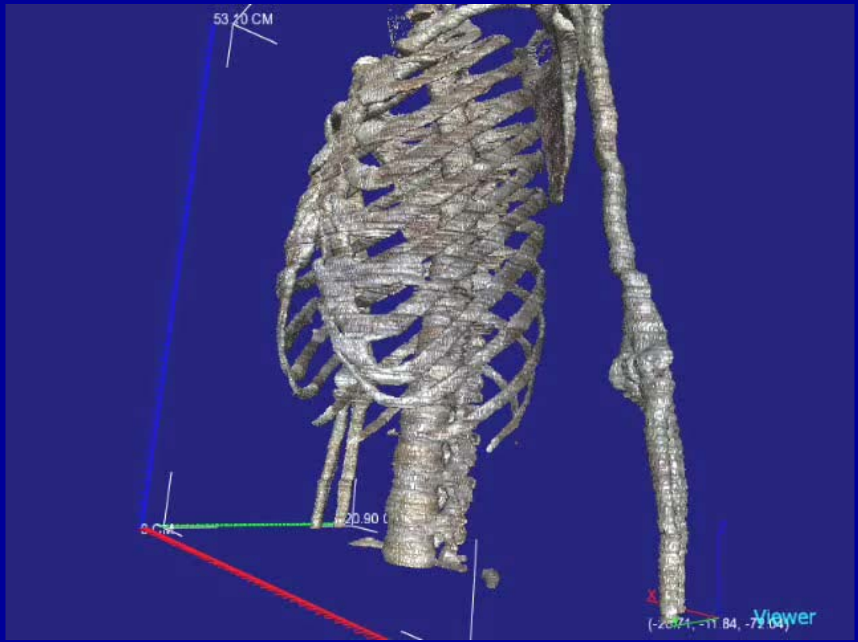
- Virtual anatomy/surgery tool
  - Haptics device
  - Virtual diamond burr
  - Virtual knife



Results …



More results …



We just set a foot on it. It’s an on-going project …

Summary: selected publications

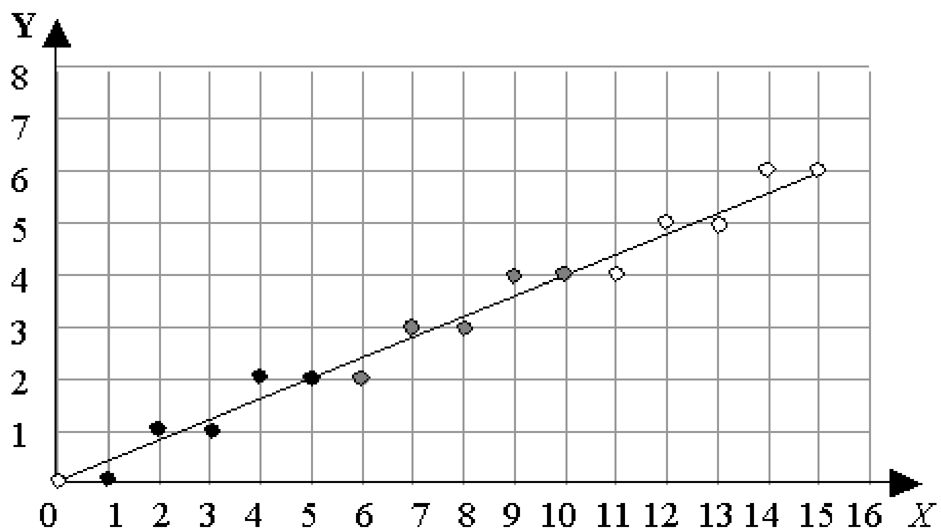
- Y. Liu, J.X. Chen, L. Yang, “High Quality Realistic Virtual Human Anatomy,” *IEEE Computing in Science and Engineering*, (to appear).
- L. Yang, J.X. Chen, and Y. Liu, “Virtual Human Anatomy,” *IEEE Computing in Science and Engineering*, vol. 7, no.5, Sept. 2005, pp. 71-73.

6. A New Graphics Pipeline for Atomic Primitives

- Objective
  - Improve line scan-conversion
  - Improve triangle scan-conversion
  - Design a new graphics pipeline for atomic primitives
- Applications
  - Graphics library will be faster

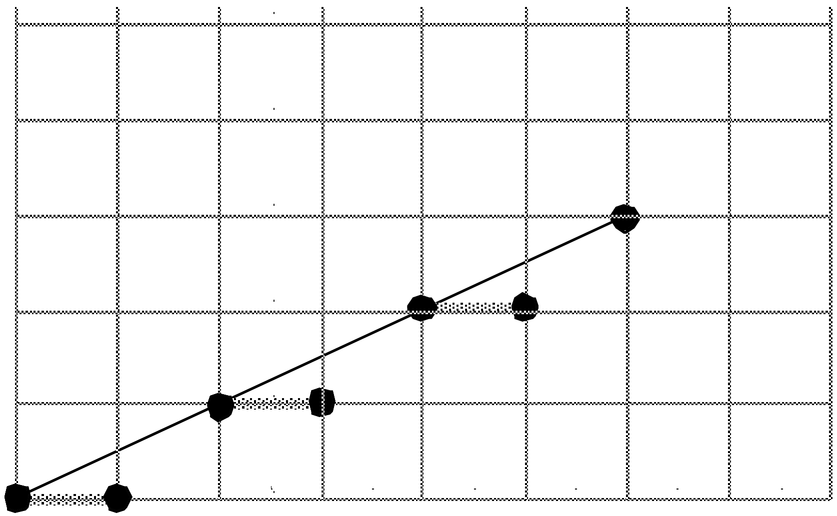
The multi-segment method

- **A line in a raster plane may include several identical segments.**
  - After only calculating the first segment, we can directly copy the pixel intensities and positions to the successive segments.



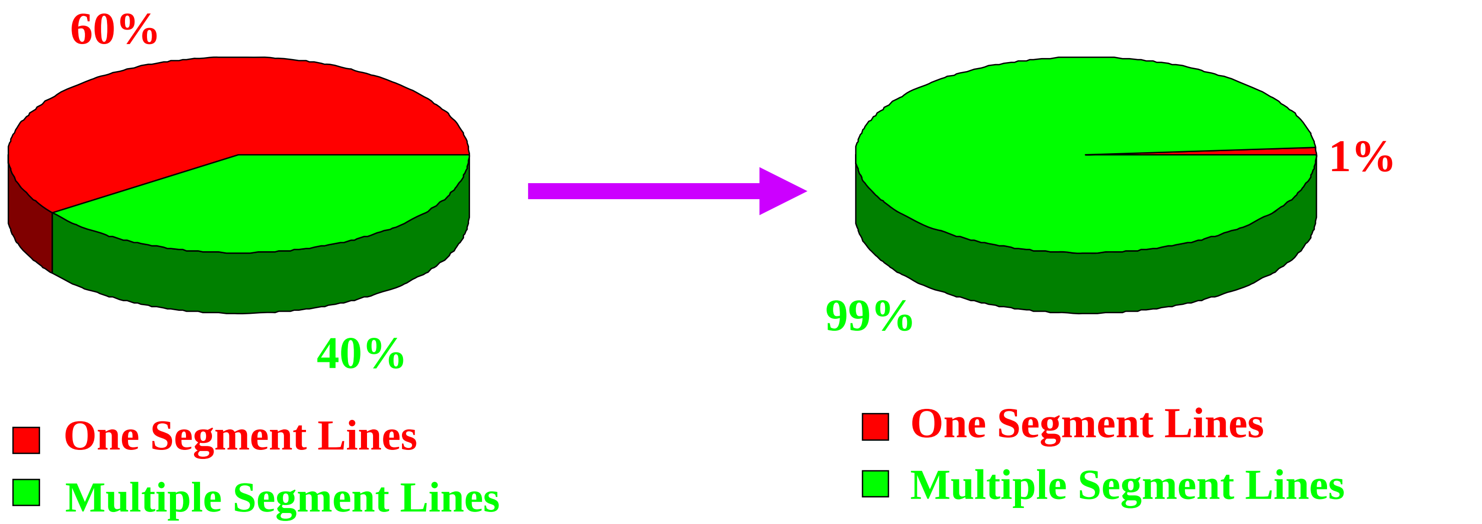
Multi-segment scan-conversion

- One segment line is more than 60%
- Speed up at 2.75 times
- Compressible efficiency at: 1.37

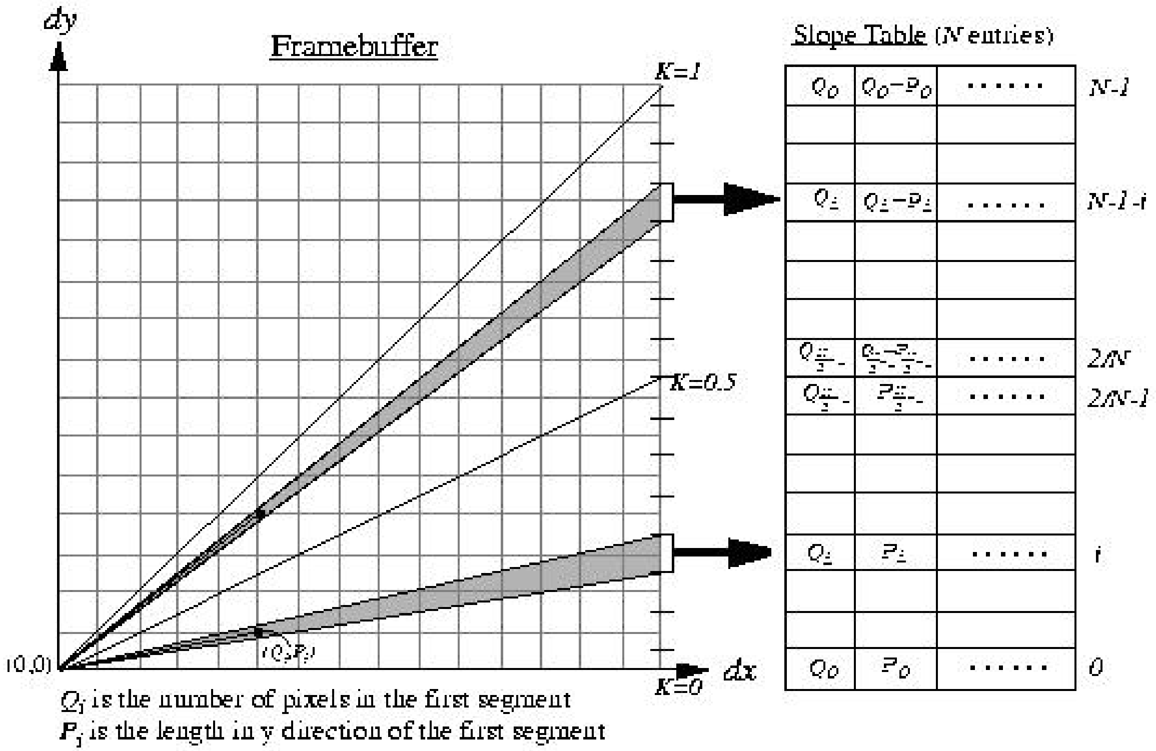


The multiple segment lines

- Unfortunately, the percentage of the multiple segment lines in a raster plane is less than 40%.
- However, with the Slope Table method, the percentage of the multiple segment lines can be increased to 99%.



The Slope Table method

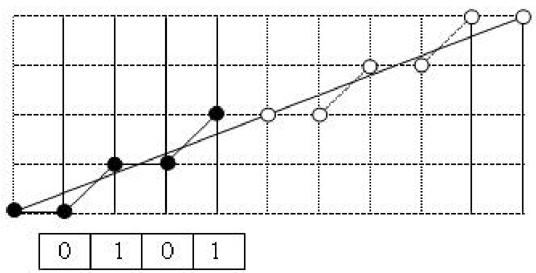


Approximate line scan-conversion

- Multisegment line is more than 99.8%
  - (statistics from randomly generated lines)
- N element ROM memory for an NxN display
- Possible errors generated
- Compressible efficiency: 13.83
  - (statistics from randomly generated lines)

Pixel pattern

- Pixel pattern of a line is the pixels chosen for forming the line in a raster plane
- Drawing a line **with its pixel pattern** can speed up the line scan-conversion process

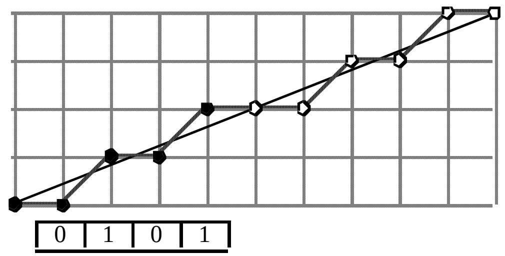


Q=5, P=2, the length of the pixel pattern is 4

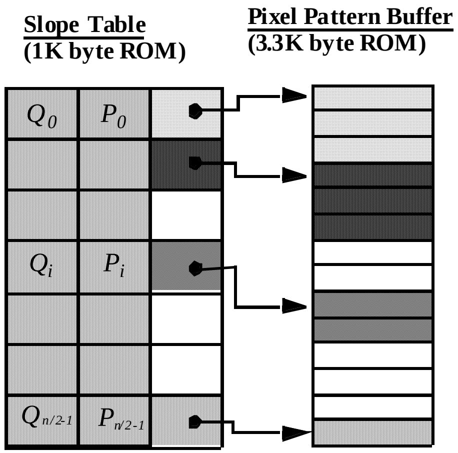
Storage property

- Without the Slope Table method
  - To save the pixel patterns of all 524,799 lines in a 1024×1024 raster plane
  - This requires at least **24M byte** memory
- With the Slope Table method
  - Only needs to save the pixel patterns of 1024 GRLs
  - That is 52,343 bits and only needs about **8K byte** memory

Data structure



Q=5, P=2, the length of the pixel pattern=4



Reality

- most lines (87%) in a drawing are fewer than 17 pixels
- an equi-likely line length distribution is inappropriate
- an axial line likely is worthwhile for hardware or software APIs since many (50%) of lines are uni-directional,
- line drawing set-up speed and pixel rasterization loop speed
- only a quarter (22%) of applications employ line drawing.

Reality - Statistics

- With our new statistical results from real applications,
  - The percentage of multiple segment lines only increases from 36.26% to 38.20% (instead of to 99%).
  - The compressible efficiency changes from 1.621 to 2.256 (instead of from 1.370 to 13.830)
- Nevertheless, the new methods are still practical

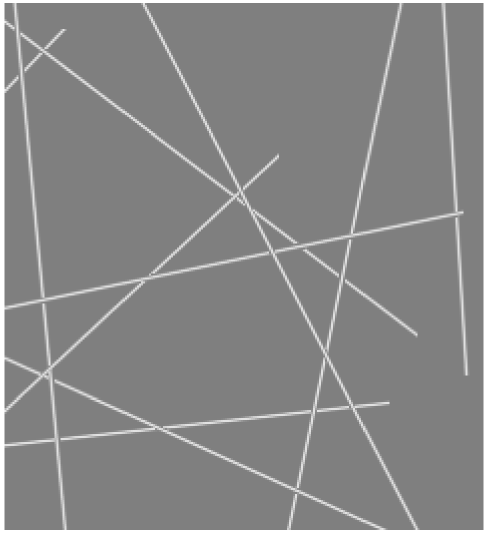
Line pixel fill rate of Technical Specifications of the Onyx2 Graphics Hardware

- **Onyx2 GRAPHICS / Onyx2 Reality**
  - Pixel fill 224M to 448M
  - Antialiased 3.7M
  - **Speed Comp 61 to 121**
- **Onyx2 Reality Monster**
  - Pixel fill 5.3 gigapixels/sec
  - Antialiased 60M pixels/sec
  - **Speed Comp 88 times slower**

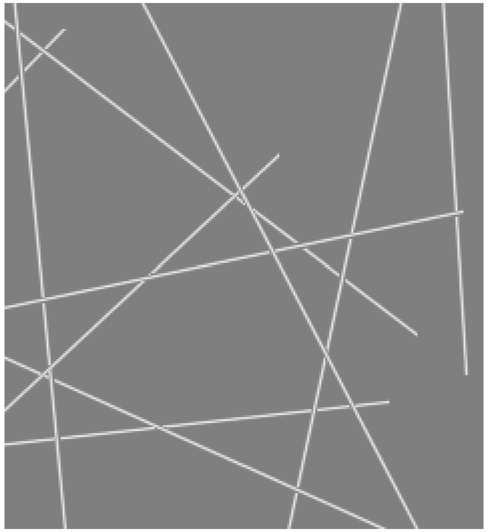
Hardware for antialiasing

- Save the distance to center of the line
- Given a filter, save the alpha value for the corresponding pixels
- For texture mapping, color will blend with current pixel value

Snapshots of line antialiasing



Antialiasing with
Gupta-Sproull's algorithms



Antialiasing with
the Slope Table method
(about **eight times** faster
than the left)

Triangle statistics

All edges

# of pixels	# of edges	percent
0 < # ≤17	3879974	91.410%
17 < # ≤33	182028	4.288%
33 < # ≤65	93756	2.209%
65 < # ≤129	49709	1.171%
129 < # ≤257	30157	0.710%
257 < # ≤385	6465	0.152%
385 < # ≤513	2390	0.056%
513 < #	95	0.002%
Total	4244574	100.00%

Longest edges

# of pixels	# of triangles	percent
0 < # ≤17	1255201	88.716%
17 < # ≤33	80829	5.713%
33 < # ≤65	39540	2.795%
65 < # ≤129	20747	1.466%
129 < # ≤257	14183	1.002%
257 < # ≤385	3221	0.228%
385 < # ≤513	1074	0.076%
513 < #	63	0.004%
Total	1414858	100.00%

Graphics Pipeline

- Viewing; Clipping
- Primitive model scan-conversion
  - Lighting, texture mapping
    - per polygon, vertex normals; per pixel
  - Hidden-surface removal
    - Per polygon, collision detection; Per pixel, z value
  - Anti-aliasing
    - Per edge/line; distance to the center of the line, per pixel

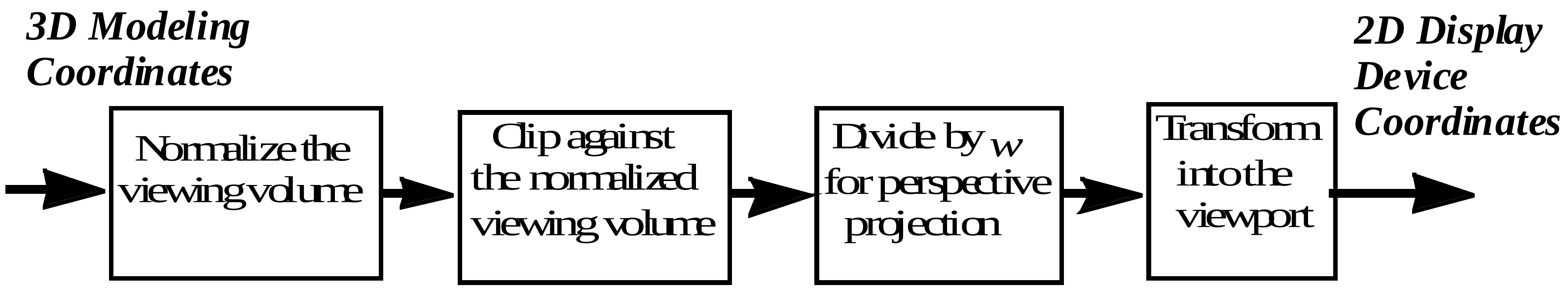


Image-based polygon scan-conversion

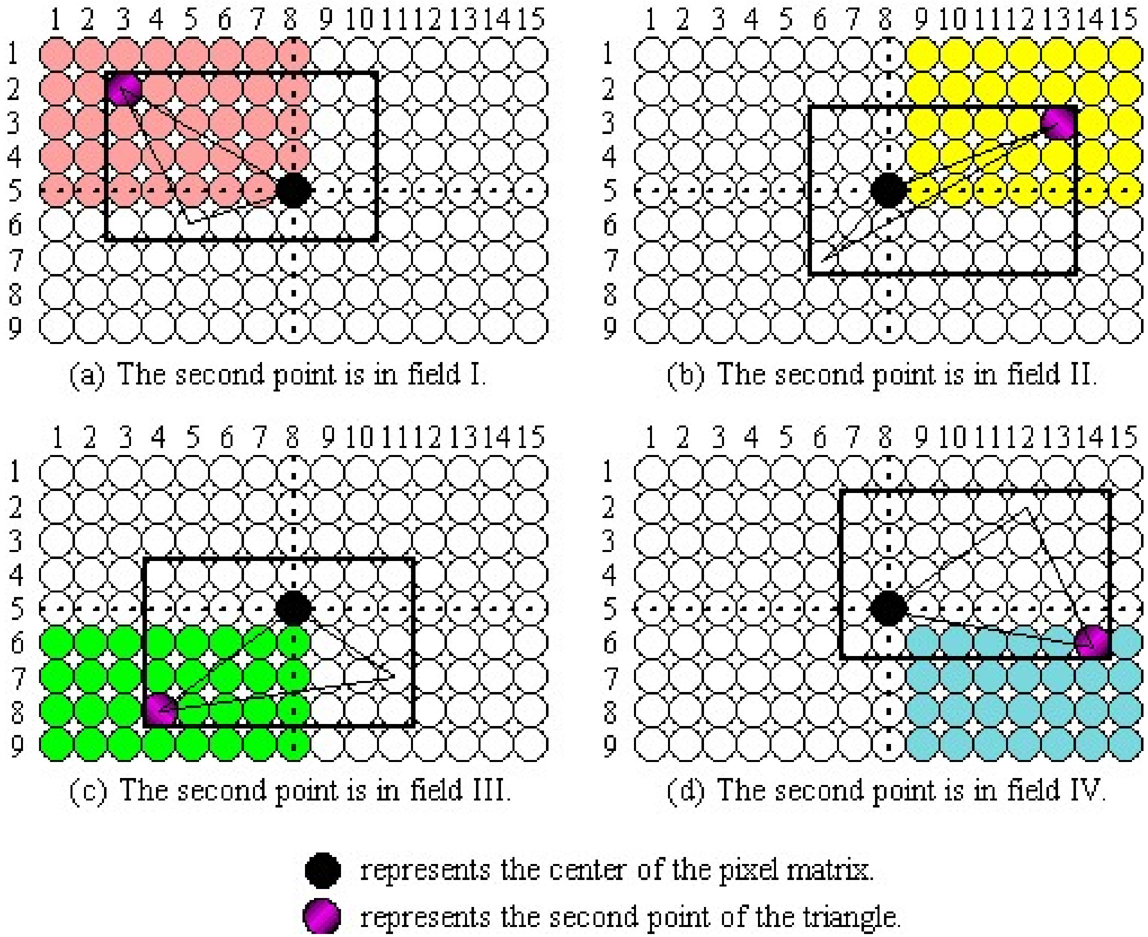
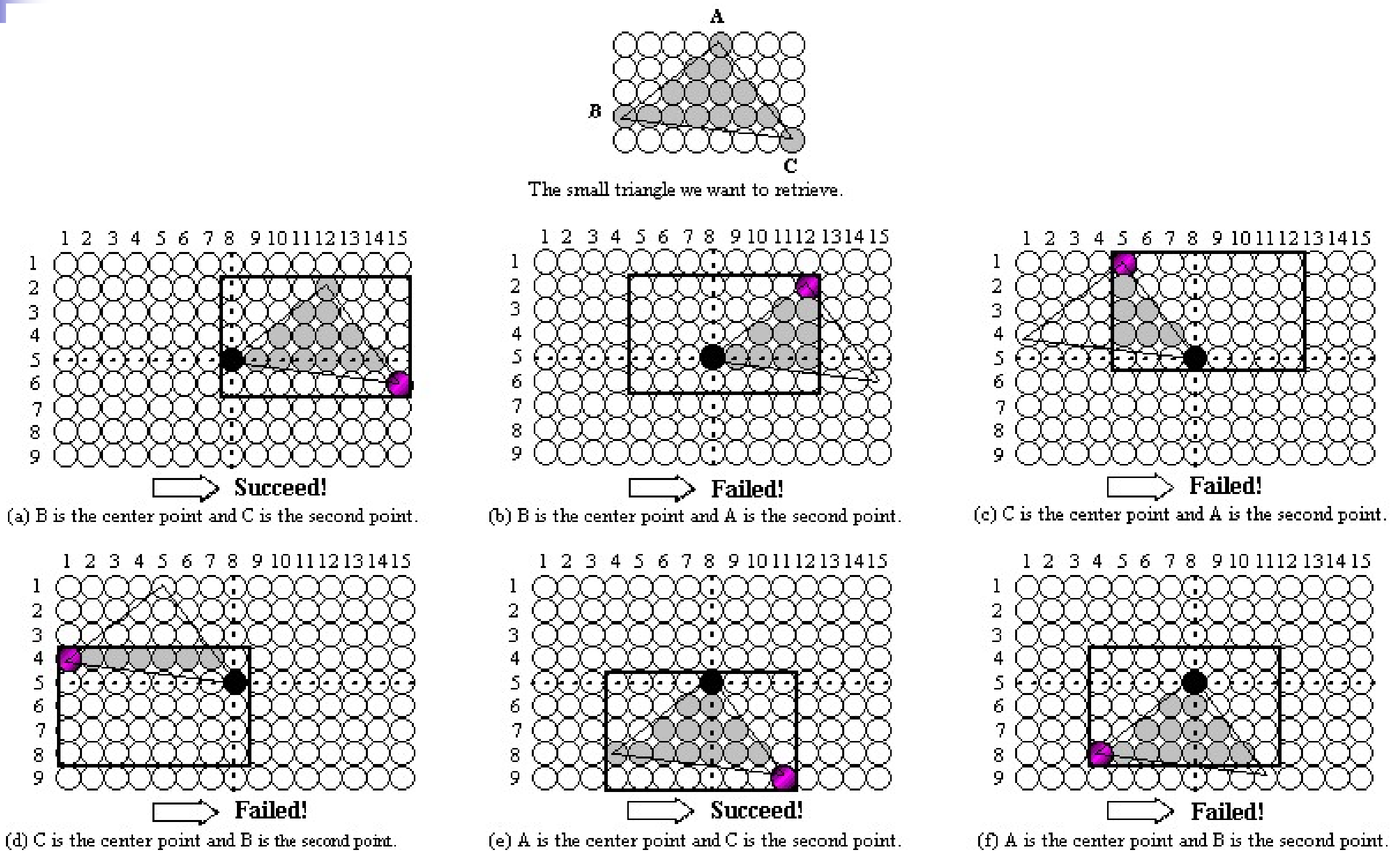


Image-based polygon scan-conversion



The small triangle we want to retrieve.

(a) B is the center point and C is the second point.

(b) B is the center point and A is the second point.

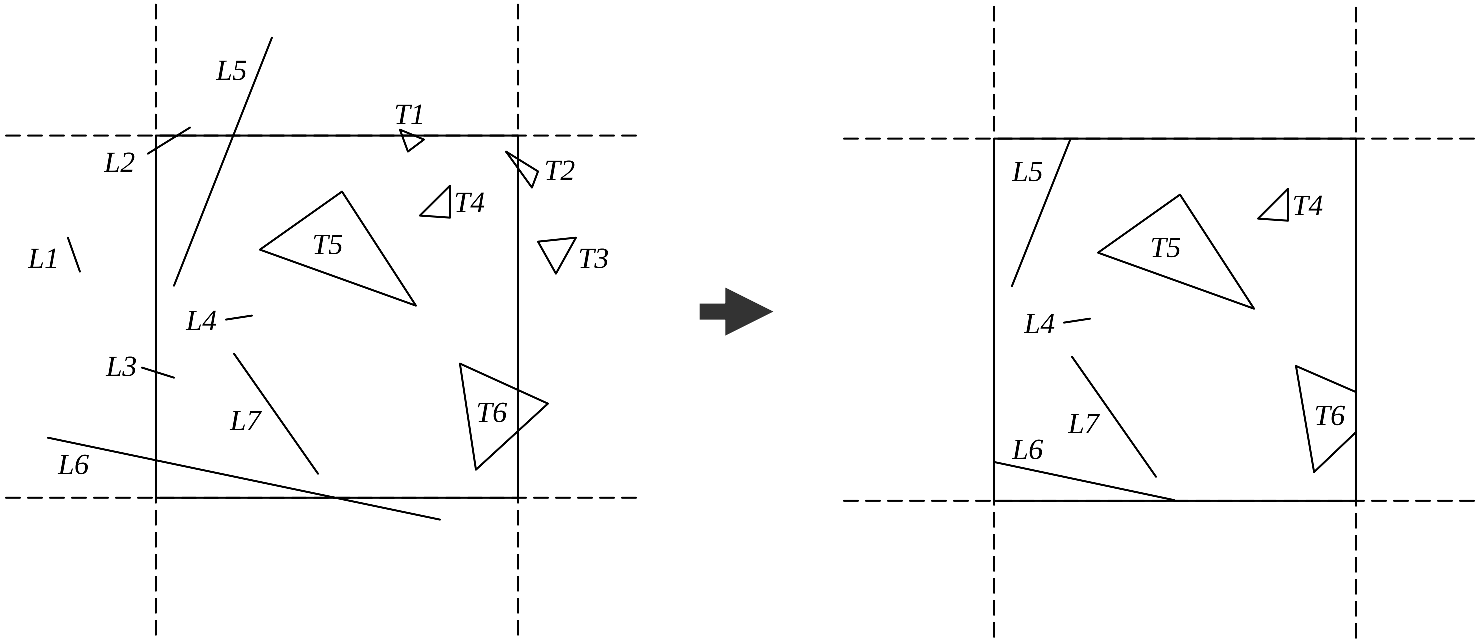
(c) C is the center point and A is the second point.

(d) C is the center point and B is the second point.

(e) A is the center point and C is the second point.

(f) A is the center point and B is the second point.

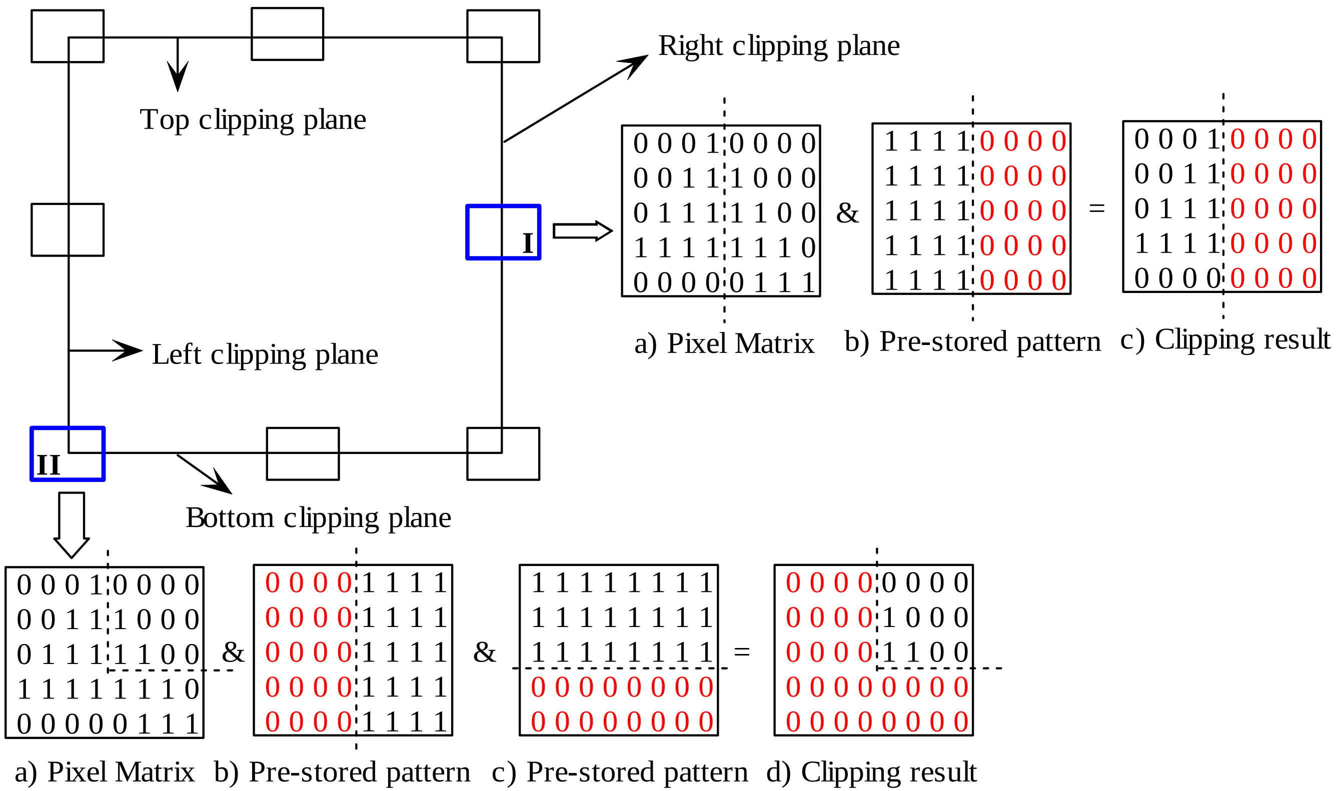
Line and polygon clipping



before clipping

after clipping

Line and polygon clipping



Summary: selected publications

- **J.X. Chen**, H. Wechsler, and J. Cui, "Image-Based Fast Small Triangle Rasterization," *16th International Conference on Artificial Reality and Telexistence*, Nov. 2006.
- **J.X. Chen**, "New Graphics Pipeline Approach Speeds Up Atomic Primitives Rendering," *IEEE Computing in Science and Engineering*, vol. 5, no. 3, May 2003, pp. 86-91.
- **J.X. Chen**, X. Wang and J. E. Bersenham, "The Analysis and Statistics of Line Distribution," *IEEE Computer Graphics & Application*, Vol. 22, No. 6, November/ December 2002, pp. 100-107.
- **J.X. Chen** and X. Wang, "Approximate Line Scan-Conversion and Antialiasing," *Computer Graphics Forum*, Vol. 18, No. 1, 1999, pp. 69-78.
- **J.X. Chen**, "Multiple Segment Line Scan-Conversion," *Computer Graphics Forum*, vol. 16, no. 5, 1997, pp. 257-268.
- **J.X. Chen**, "An Improvement on Line Scan-Conversion," *SIGGRAPH'97 Visual Proceeding*, Aug. 1997.

Conclusion

- Survey of Research Projects in the Computer Graphics Lab at GMU
- Future Work in Edutainment, Simulation for Training, and Virtual Reality for Medical Applications
  - Collaborating with faculty at GMU, local and international units
  - Searching for funding to extend our research

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- Ear: Peidong Dai, Tianyu Zhang
- Human Anatomy: Yanling Liu, Ling Yang
- Atomic Graphics: Jian Cui, Xusheng Wang, Harry Wechsler

THANKS!!!

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