Schedule

- **12:00 – 12:15 Introduction**
  - *Prof. Nadia Magnenat-Thalmann*
- **12:15 – 13:05 Anatomical modelling from medical data**
  - *Prof. Nadia Magnenat-Thalmann and Jérôme Schmid*
- **13:05 – 13:30 Physically-based simulation of biological tissues (Part 1)**
  - *Dr. Hervé Delingette*
- **15:00 – 15:25 Physically-based simulation of biological tissues (Part 2)**
  - *Dr. Hervé Delingette*
- **15:25 – 16:15 Medical visualisation and applications**
  - *Dr. Marco Agus and J.A. Iglesias Guitián*
- **16:15 – 16:30 Conclusion and discussion**

Medical visualization and applications

Dr. Marco Agus and J.A. Iglesias Guitián – ***CRS4, Visual Computing group, Italy***

Section Overview

Introduction:

- Medical data rendering: applications and related problems

Visualization in radiology: past, present and future

- 3D radiology workstations: state of the art
- 3D analysis with guided interaction: virtual endoscopy, measurements and pre-operative planning
- Medical visualization on future displays
- Development of a medical volume visualization tool based on a Light Field display

Volumetric data rendering techniques:

- Volume rendering, non-photorealistic rendering, introduction of timing constraints, GPU accelerated methods, large model visualization
- Advanced rendering on the light field display

Medical visualization and applications

Introduction

Medical data rendering

Different and evolving modalities:

- X-Ray, CT, US, PET

Different spaces

- 2D, 2D+T, 3D, 3D+T, Multi-modal

Visualization modes

- Photorealistic-non photorealistic, color-coded information

Lots of emerging applications:

- Diagnosis, intervention planning, surgical simulation, display of offline simulation results
- Virtual Humans, physical studies

Necessity of specialized, application-driven visualization algorithms

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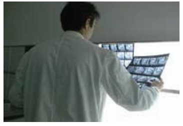
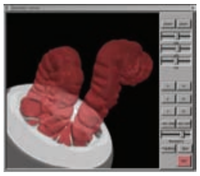
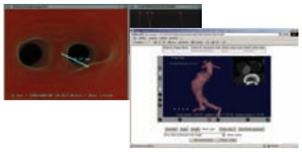
New visualization paradigms

- From 2D to 3D (+)

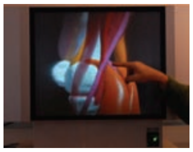




- Navigation, measurement in 3D



- New interaction modes with advanced displays



Applications

Display of data provided by modern diagnostic modalities in a way easy to be interpreted by radiologists and physicians (3D radiology workstation)

Anatomy (functional) teaching tools

Surgical/interventional planning with 3D measurement tools

Image guided surgery, augmented reality

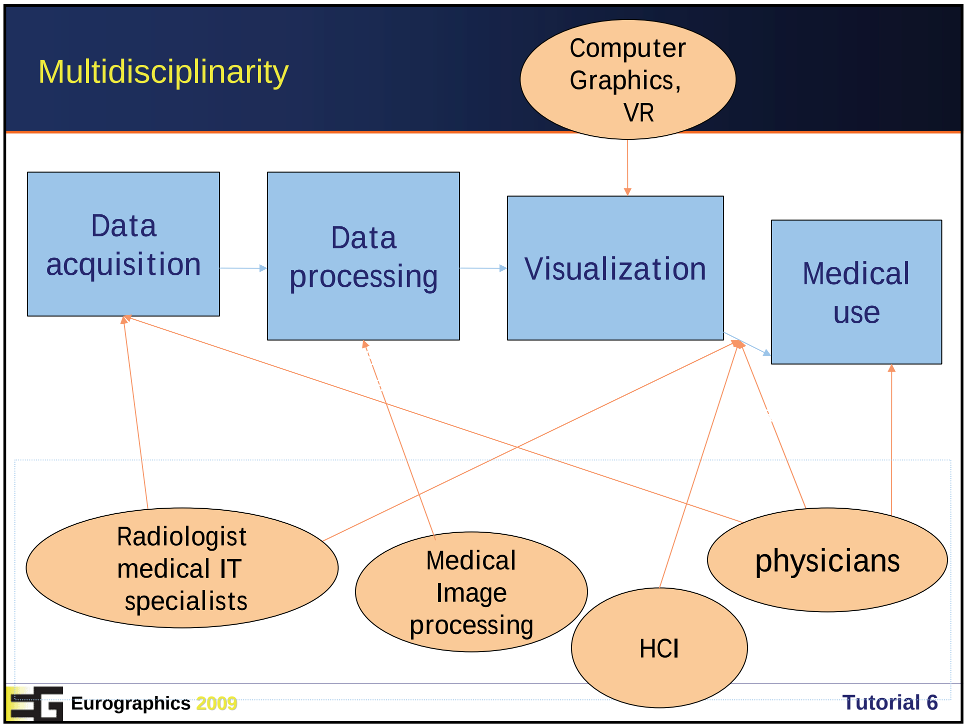
Visualization modules of surgical simulators

Visualization modules for human body simulation

Related problems

- Efficient visualization of shape, motion and additional information
- Interactivity: time constraints, large data sets
- Enhancement of relevant information
- Pre processing of data: segmentation, reconstruction, classification, multiple source data fusion
- Display technology: how to represent effectively volumes with depth cues
- User interfaces, navigation. Development of user friendly 3D measurement tools
- Accuracy and validation (removal of artefacts, clinical validation)

Multidisciplinarity


Computer Graphics, VR

Data acquisition

Data processing

Visualization

Medical use

Radiologist medical IT specialists

Medical Image processing

HCI

physicians

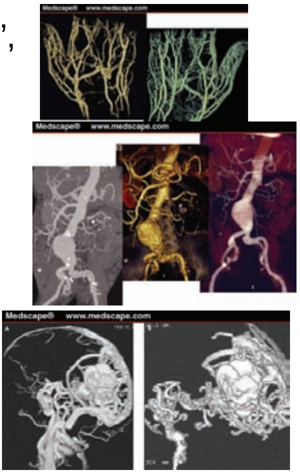
Medical visualization and applications

Visualization in radiology

Dr. Marco Agus – *CRS4, Visual computing group, Italy*

Visualization in Radiology

- Increased diffusion of “3D workstations”, (Barco, Philips, GE, Viatronix, etc.)
  - Integration with PACS
  - Standard 3D visualization modes (Image reformations, MIP, Ray Casting, surface rendering)
  - Support for different modalities
  - Basic segmentation tools
  - Specific modules available for particular applications (i.e. Virtual endoscopy, heart, vascular)

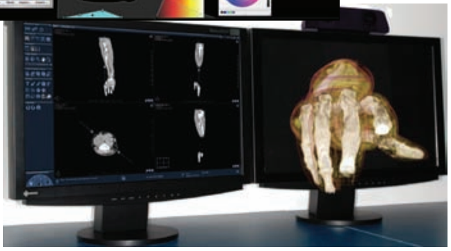


Images from
www.medscape.com

Radiology Workstations

- Lots of solutions, often expensive (even if no expensive software is usually required)
- Powerful open source alternatives like Osirix (Rosset and Ratib, UniGE, 2006)
- Use of spatial displays interaction modes is the next step to increase acceptance and medical use of 3D rendering

Osirix



SpatialView Workstation

Radiology workstations: what is still missing

- 3D Quantitative analyses still limited (compared with the large amount of 3D data) Stereo depth cues usually missing. No motion parallax.
- General inspection of virtual worlds on 2D screens requires navigation tools. Metaphors used to navigate in 3D scenes with standard input devices are often not immediate for the radiologist.
- Support for very large datasets may be a problem for standard accelerated volume rendering techniques
- 3D visualization often used only for well defined simulation procedures, where the user interface is simplified, i.e. Virtual endoscopy, preoperative assisted measurements, video/image guided surgery

Interaction problems

- Representation of 3D scenes on standard 2D monitors limits possible applications
- Navigation is unnatural
  - No 3D analogue of WIMP interfaces emerged in HCI research
  - Immersive displays could reduce the problem
  - Problems: tracking, devices, etc.
- Exception: guided or simulated procedures. i.e.:
  - Virtual endoscopy
  - Video/image guided surgery
  - Augmented reality in operating rooms

Virtual Endoscopy (see Bartz 2005)

- Simulates the clinical procedure of inserting a catheter with a camera (and other devices) inside a tubular structure Based on:
  - 3D segmentation
  - Centerline path planning
  - Surface or Volume rendering
  - 3D navigation interfaces

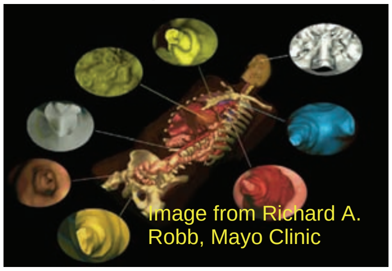


Image from Richard A. Robb, Mayo Clinic

- One of the 3D visualizazion applications widely used for diagnosis

Clinical applications

- Virtual Colonoscopy
- Blood vessel analysis (virtual angioscopy),
- Virtual bronchoscopy
- Planning of endonasal interventions.
- 3D interaction problem reduced by simulating the real endoscopic procedures!

Advantages/limits of the real procedure

+ Better resolution
+ Real texture information
+ Possibility of interacting with tissues and directly perform the actual intervention if necessary

− Changes may happen between the image acquisition and the intervention
− Can be painful and uncomfortable
− Limited exploration

Advantages/limits of virtual procedure

+ Non-invasivity
+ Lower cost
+ Complete control of lighting and orientation
+ Absence of access limitations.
+ Additional information can be superimposed (i.e. color coding)

− Depends on classification/segmentation
− Limited resolution
− No actual interaction

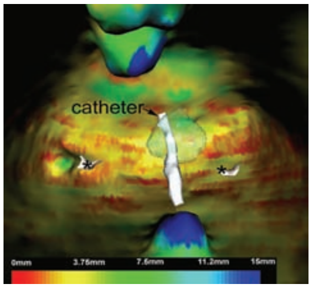


Image from Nain et al. MIT

Additional rendering /analysis tools

Example: virtual colonoscopy (CT)

- Special transfer functions
- Colon flattening (Halier et al. 2000)
- Automatic polyp detection (Summers et al. 2001)

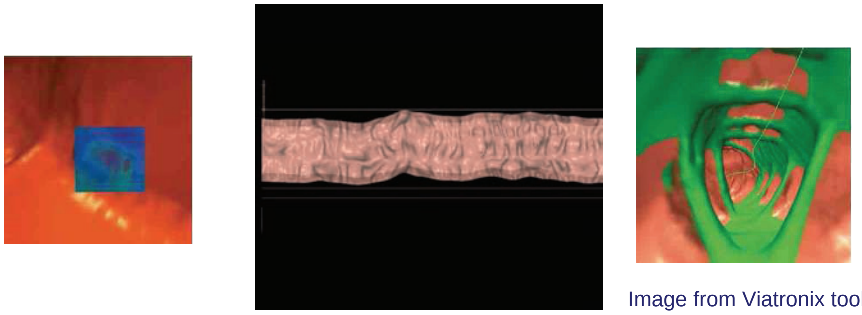


Image from Viatronix tools

Rendering (Surface vs Volume)

- Both Suface and Voume rendering applied
- Interactivity problems for past Volume rendering approaches due to HW limitations
- Clinical superiority of Volume Rendering over Surface Rendering for diagnostic purposes demonstrated
- Nonphotorealistic rendering improves the efficacy of Virtual Colonoscopy (Kaufman et al, '05)

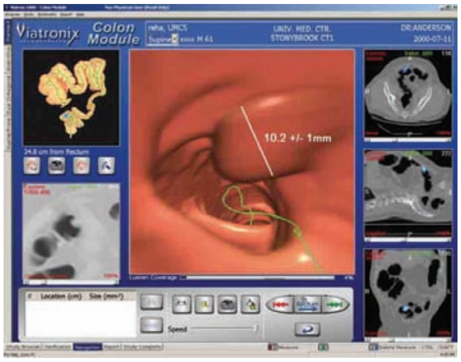
Navigation

- CRS4 System (1998): physically based virtual camera control:
  - input from 6 DOF device used to generate forces and torques applied to a virtual camera
  - Viscous friction force field proportional to volume opacity used to avoid penetration in opaque areas.
  - Camera confined in the interior of the cavity
  - Wall detection: accumulated-opacity algorithm

Navigation

Other typical approach:

- centerline constraint for camera path and free or constrained camera orientation
- (semi) Automatic curve skeleton extraction, pruning, representation is fundamental

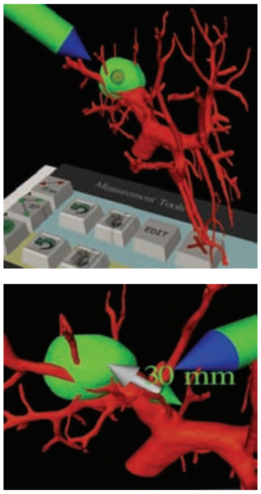


Diagnostic/simulated endoscopy

- Note: Diagnostic Virtual Endoscopy do not require photorealistic rendering
- Endoscopy simulators may require a different kind of rendering, without diagnostic information but close to the real procedure view
- Image based rendering proposed as solution
  - Texture mapping
  - Generation of arbitrary views from several images (view morphing, lumigraphs)

3D measurements

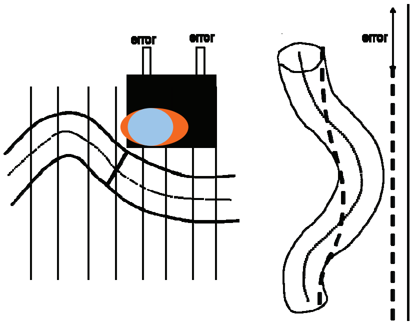
- Clinical validation of reconstruction and measurement procedures required
- Interaction with 3D scenes not simple
- Two kind of applications
  - Basic 3D measurement tools (volumes, distances, angles)
  - Specific interaction modes for each diagnostic/interventional procedure
- User dependent segmentation is often required
- Changes in radiologist and surgeon workflows are required



From Reitinger et al (2006) , TU Graz

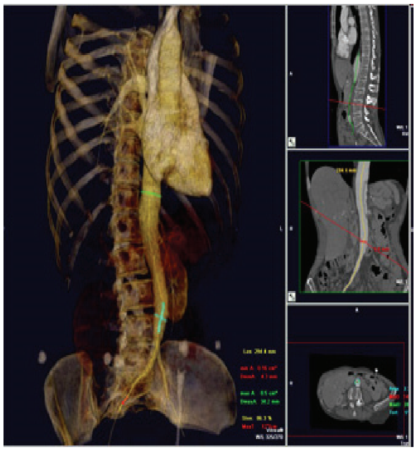
Example: 3D vascular measurement

- Use of 2D projection for vessel measurements introduces large errors (e.g. Tillich et al. 2001)
- 3D analysis improves accuracy
- Segmentation is required. Often interactive
- 3D centerline path automatic or semiautomatic extraction is required



Notes on vascular visualization/analysis

- Vessel analysis is a very specific field and involves specialized procedures.
- Commercial SW available and widely used
- Review on Visualization of vascular structure in (Oeltze and Preim, 2005, IEEE TMI)
- Graph representations, simplified structures, different requirements for different applications
- Specific illustrative vessel rendering developed (es. coding shape and topology without color in Ritter et al. 2006)

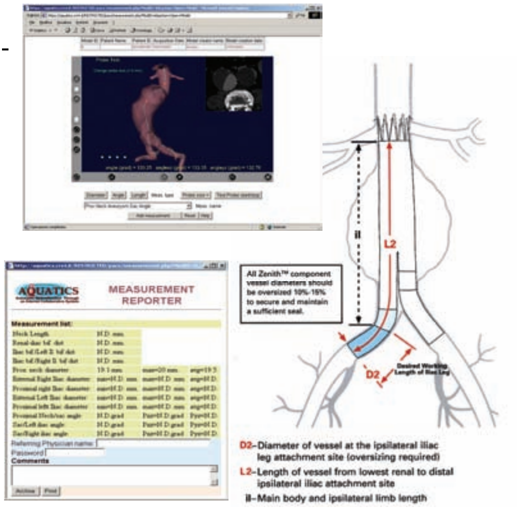


Vessel Measurement SW by Vital Images

http://www.vitalimages.com/Solutions/Radiology/Vessel_Measurement.aspx

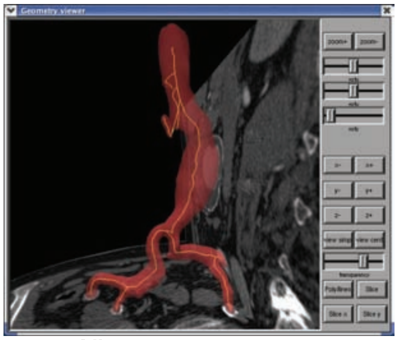
Example Pre-Operative measurements with Web3D

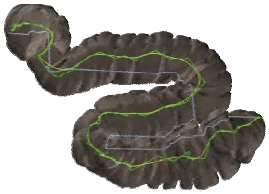
- AQUATICS Project (IST 1999-20226 EUTIST-M):
  - Quantitative analysis of Abdominal Aortic
  - Aneurysm
  - Endovascular procedure planning
  - Web 3D visualization/Interaction



Vascular reconstruction/visualization

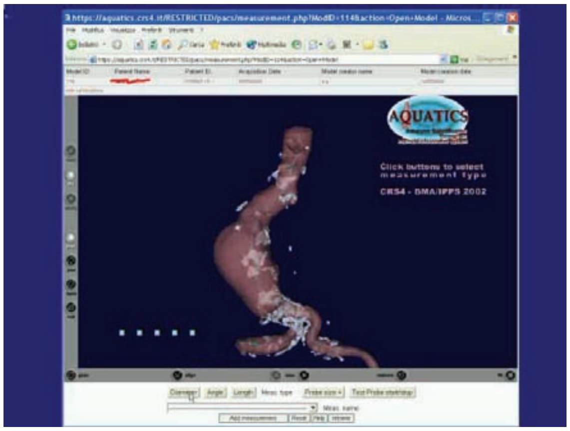
- Segmentation previously discussed (deformable models)
- Curve skeleton extraction:
  - Several methods (Cornea et al. 2007, IEEE TVCG)
  - Voxel coding technique (Zhou & Toga '99) customized with ad hoc regularization
  - Same methods applied in Virtual Colonoscopy





2D User interface for measurement

- Simple Web based tool
- Guided procedures for navigation
- Simple selection of centerline ponts



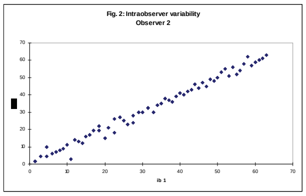
https://aquatics.crs4.it/RESTRICTED/pacs/measurement.php?ModID=114&action=Open+Model - Micros...

Click buttons to select measurement type

CRS4 - DMA/IPFS 2002

Validation

- Measurements on phantom (U. Innsbruck)
  - 8 models, scanned at different protocols (1-5 mm)
  - Models measured independently by three different (remote) operators
  - 8 models reconstructed independently by two operators
- Patient data
  - 5 models reconstructed twice
  - 40 models created and measured independently in the three locations
- Good results
  - low intraobserver variability (p<0.0001)
  - significant correlation between observers (p<0.0001)



Unconstrained 3D volume analysis

Limitations of 3D workstations

- Visualization on flat screens do not provide depth cues
- Necessity of moving the object
- Difficult collaborative work

Solution: use of advanced 3D displays

- Stereo/Autostereoscopic monitors
- Immersive VR environments
- Spatial displays

3D Immersive display

- Allow immediate understanding of 3D morphology
- Allow natural interaction with 3D scenes (with special devices or Computer Vision tools)
- Stereoscopic view
  - Different images on each eye (polarized glasses or synchronized shuttering, eye mounted displays)
  - Depth perception
  - Tracking/scene update for motion parallax

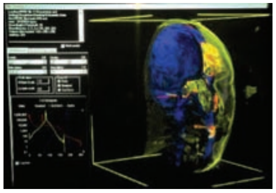
Stereo system from Barco.com

Advanced technology

- Autostereoscopic monitors
  - Couples of images viewed by different eyes on screen (lenticular glasses or filters)
  - One or more user positions
  - Several manufacturers/sizes
- Real 3D images on 3D support
  - Actuality Systems Display
  - LightSpace DepthCube
- “Virtual 3D” images: Continuous parallax through multiple beams
  - HoloVizio displays by Holografika


Autostereoscopic monitor


Actuality Systems Display (image from Rush U.)


LightSpace Depth Cube

Clinical use of stereo

- Barco CAVE (Computer Automatic Virtual Environment) VR system installed at Erasmus Medical Center in Rotterdam.
- Polarization based stereo, head tracking, 3D joystick tracked
- Diagnostic study in 3d Echo, presented at CARS 2007
- 3D analysis with VR revealed ventricular defects not viewed in the 2D analysis
- Same diagnostic time than using a 2D workstation, but quicker system use learning
- Problem: huge system, cost, single view


Bol Raap G,et al. Virtual reality 3D echocardiography in the assessment of tricuspid valve function after surgical closure of ventricular septal defect Cardiovascular Ultrasound, 5:8 2007

Clinical use of physical 3D displays

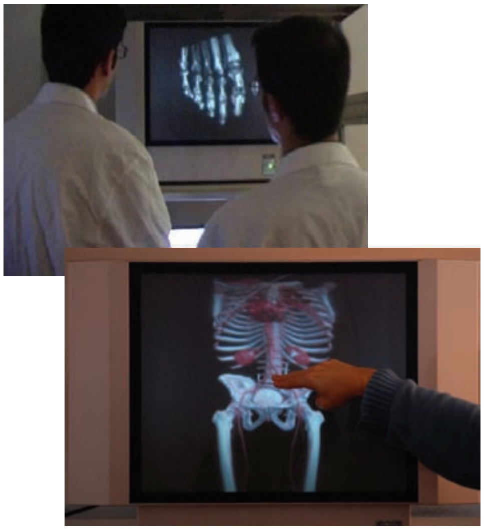
- Actuality Systems Perspecta:
  - synthesize light fields by projecting light beams on a reflective medium moved in space
  - clinical tests performed on radiation therapy planning
  - Limits:
    - Limited datasets size
    - Limited visualization volume

Radiation therapy planning using a volumetric 3-D display: PerspectaRAD Proc. SPIE, Vol. 6803, 680312 (2008)

Medical visualization on spatial light field displays

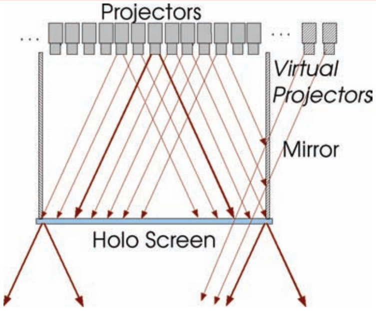
Holografika – CRS4:

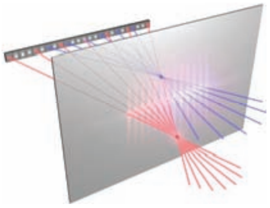
- Display volumes on a 26`` light field display
- Stereo and motion parallax cues in a large user area
- Support for illustrative volume rendering
- Support for large datasets
- Limits: only horizontal parallax



HoloVizio Display by Holografika

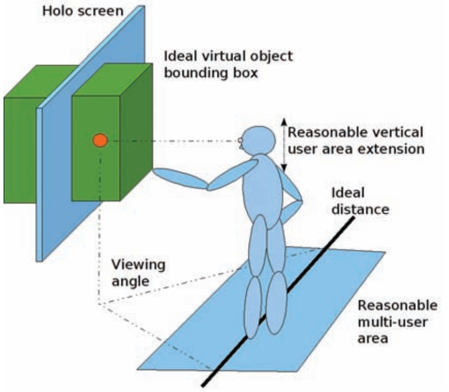
- Multiple beams technology
- No glasses needed
- Viewers can walk around the screen in a wide fov (50-70)
- Motion parallax
- Unlimited number of viewers seeing different details
- Objects can appear behind or even in front of the screen like on holograms
- No positioning or head tracking applied





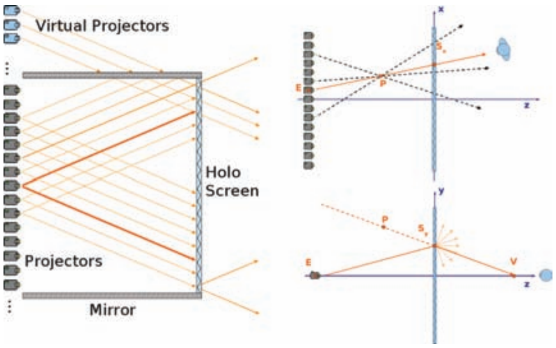
Design of the visualization system

- Rendering solutions described later
- Ideally, we must simulate the light field generated by the real object
- Problem: multiple views are generated only horizontally
- Distorted views perceived by users displaced from the ideal position
- Approximated geometrical model (MCOP)



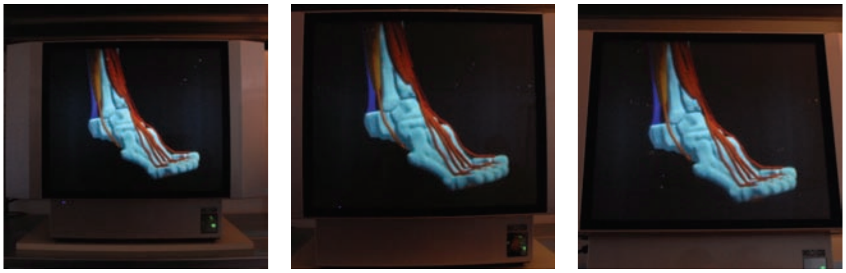
Display concept

- Each projector emits light beams toward a subset of the points of the holographic screen.
- Horizontally, the screen maintains separation between views.
- Vertically, the screen scatters widely: projected image can be viewed from essentially any height,



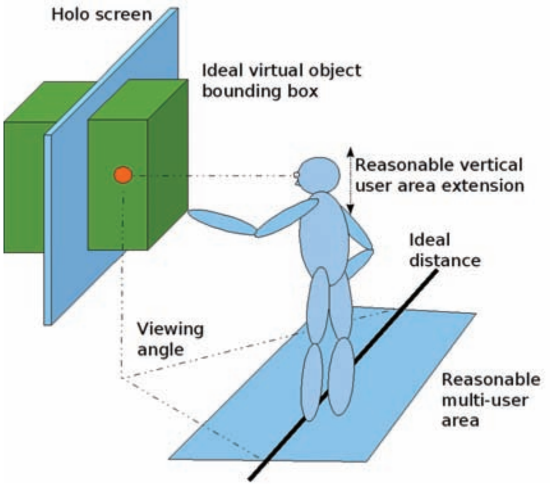
Projective errors

- Moving away from the ideal position in the MCOP models, the virtual object appear rotated
- Main problem: collaborative users may see corresponding points in different position

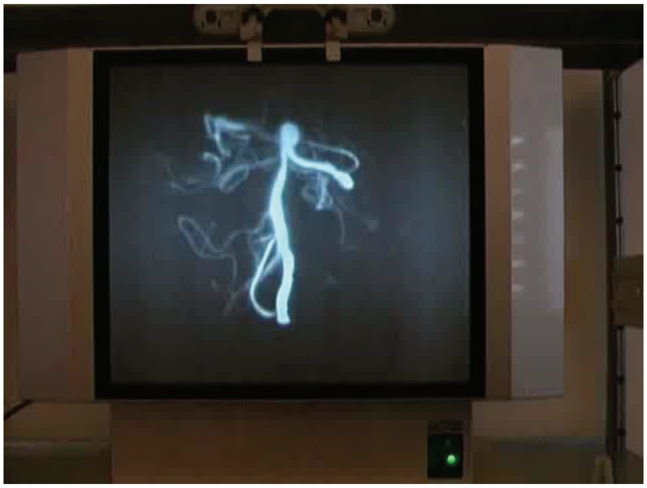


Collaborative workspace

For an object bounding box of 20x30 cm, and an optimal distance from the screen of 1m, the collaborative area where pointing errors are less than 1 cm is about 60x70x70 cm



Display in use



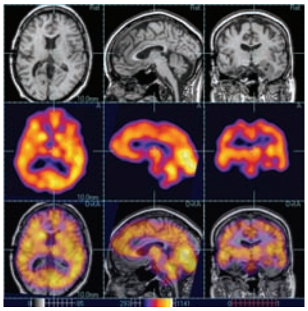
Medical visualization and applications

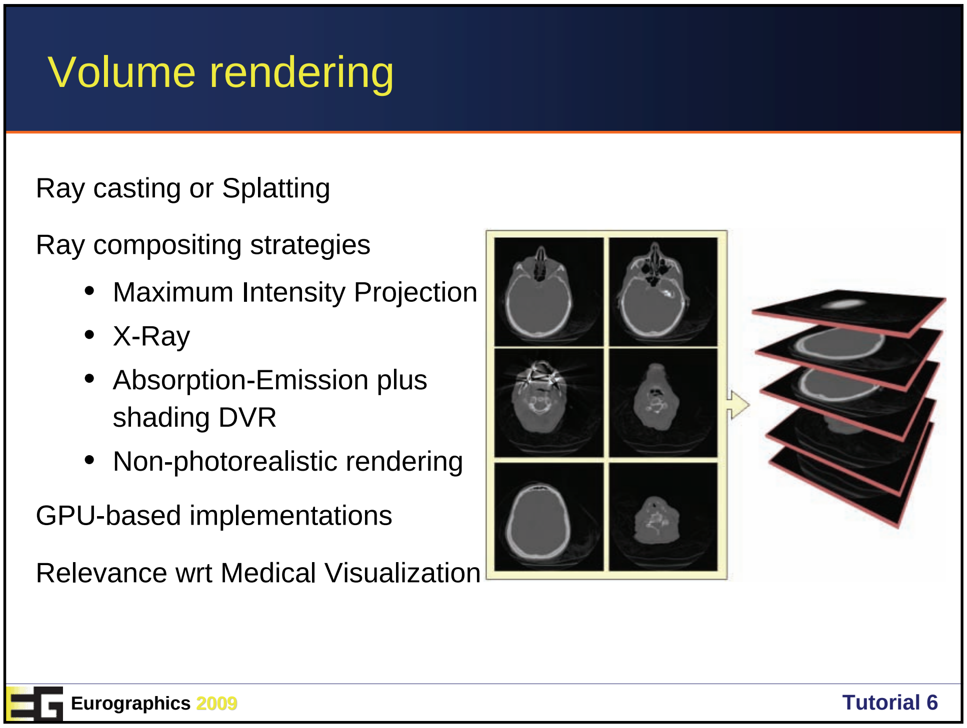
Volumetric data rendering techniques

J.A. Iglesias Guitián – ***CRS4, Visual computing group, Italy***

Medical volume data

- Scalar(Tensor) field coming from medical scanner devices
    - Computed Tomography (CT)
    - Magnetic Resonance (MRI)
    - Positron Emission Tomography (PET)
- Typical 3D array of scalars
    - 8 to 16 bits per volume element (voxel)
    - 256^3 or 512^3 typical size
    - 32 MB to 512 MB dataset size





Volume rendering

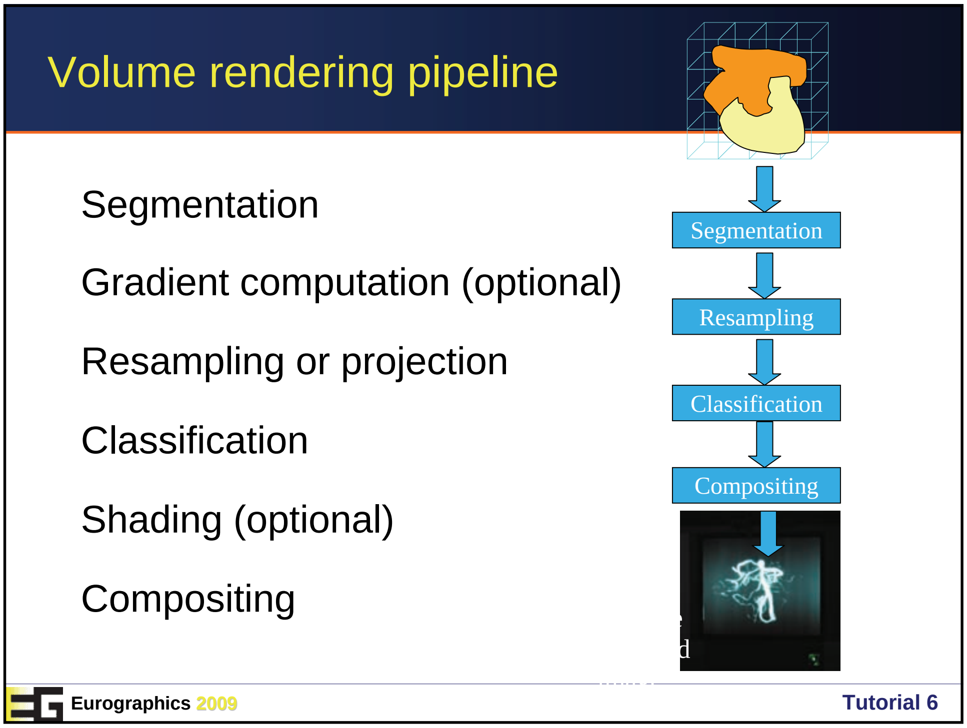
Ray casting or Splatting

Ray compositing strategies

- Maximum Intensity Projection
- X-Ray
- Absorption-Emission plus shading DVR
- Non-photorealistic rendering

GPU-based implementations

Relevance wrt Medical Visualization



Volume rendering pipeline

Segmentation

Gradient computation (optional)

Resampling or projection

Classification

Shading (optional)

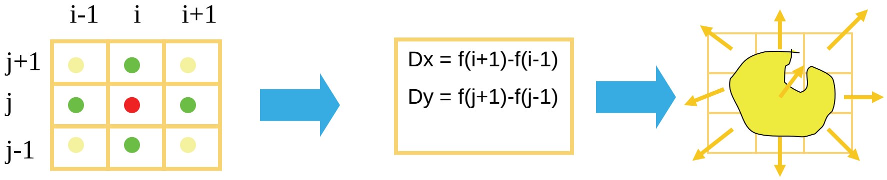
Compositing

Segmentation

- Volume preprocessing task
- Labelling or marking voxels according to type by assigning material
- Medical volumes: air, skin, bone, muscle, fat, nerve, blood, contrast liquid, tumour, etc
- Segmentation procedures ranging from fully manual to fully automated
- Problems:
  - Noise
  - Overlapping intensity ranges

Gradient computation

- Optional preprocessing task, normally performed on the scalar field, before classification
- Highlighting density change for
  - Illumination model
  - Boundary detection
  - Multi-dimensional transfer function
- Various numerical methods:
  - Forward, backward, or central differences
  - Smooth filtering (e.g. Sobel)



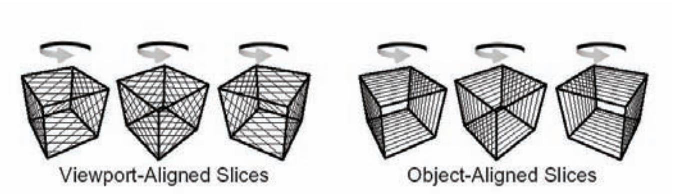
Dx = f(i+1)-f(i-1)

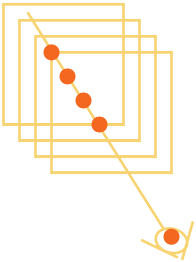
Dy = f(j+1)-f(j-1)

Resampling

- Various techniques to project volume data to screen
- Object order or object based techniques
  - Project each non-void voxel to screen (splat)
  - Blend and filter projections
  - Aliasing artifacts
- Image order or image based techniques
  - Ray casting approach
  - Pixel color is obtained as integral of volume rendering equation along ray casted from eye through screen
  - Various optical models and approximation techniques

From UCSD

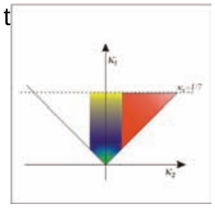


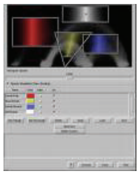


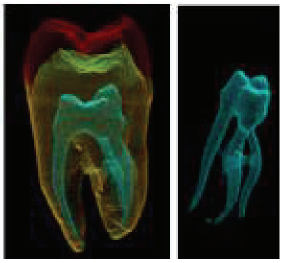
Classification

From Univ.Utah

- Transfer function mapping voxel data t RGBA colors
- Mono-dimensional transfer functions:
  - A = f(I)
  - RGB = f(I)
- Multi-dimensional transfer function
  - Gradient modulus and curvature radius can be considered to highlight boundaries between materials
- Complex and time-consuming task (not particularly appreciated by physicians)







Shading

- Various illumination models:

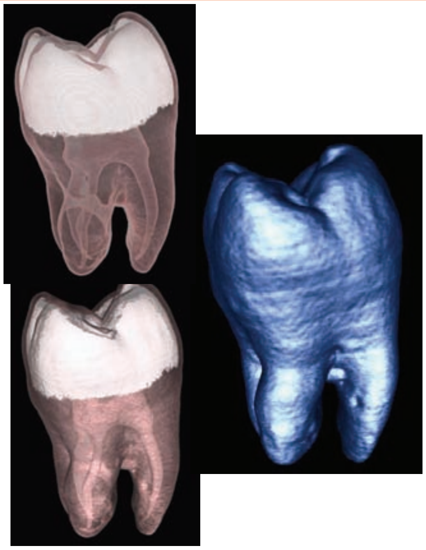
$$C = C_s(k_a + k_d(\nabla \cdot \hat{l} + k_s(\nabla \cdot \hat{h})^n)$$

  - Lambertian surfaces, employing ambient and diffuse
  - Phong shading with specular highlights
- Gradients are used as surface normals

Compositing

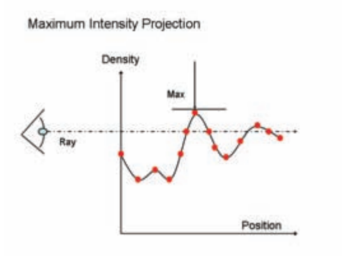
Courtesy of Univ. Stuttgart

- Compose data from volume samples along ray
- Various strategies to accumulate sample contributions:
  - Iso-surface(First hit strategy)
  - MIP
  - X-Ray
  - Direct Volume Rendering
  - NPR (illustration techniques)



Maximum Intensity Projection (MIP)

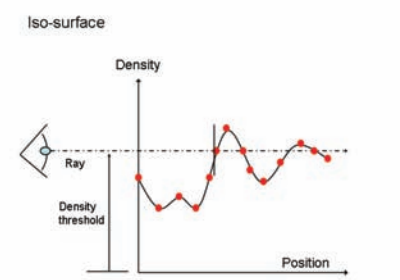
- The maximum intensity value for each ray
- Best suited for angiography datasets
- Depth oblivious



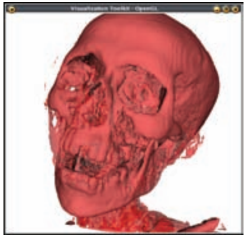

From MicroPhotonics Inc.


From CRS4

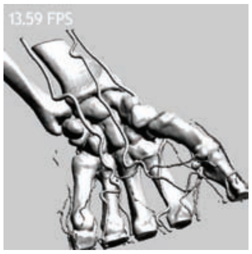
Iso Surface (first hit)



Courtesy of Univ. Utah

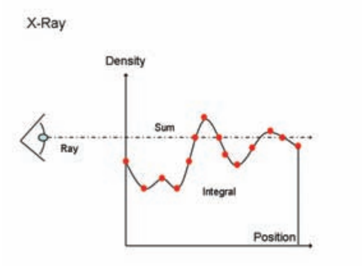


- First sample in the ray above a given density threshold
- Surface-like appearance
- Well suited for boundary discrimination



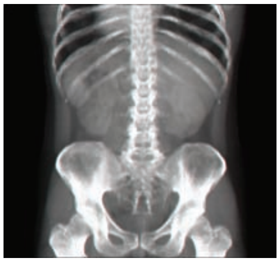
Courtesy of VrVIS

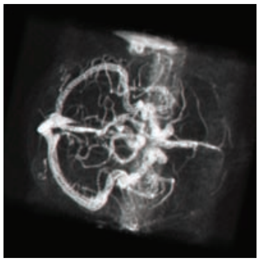
X-Ray simulation



From Univ. Budapest

- Sum of sample intensities
- Depth oblivious
- Most employed for medical visualization





Direct Volume Rendering

Accumulation of optical properties plus illumination

Approximation of volume rendering integral:

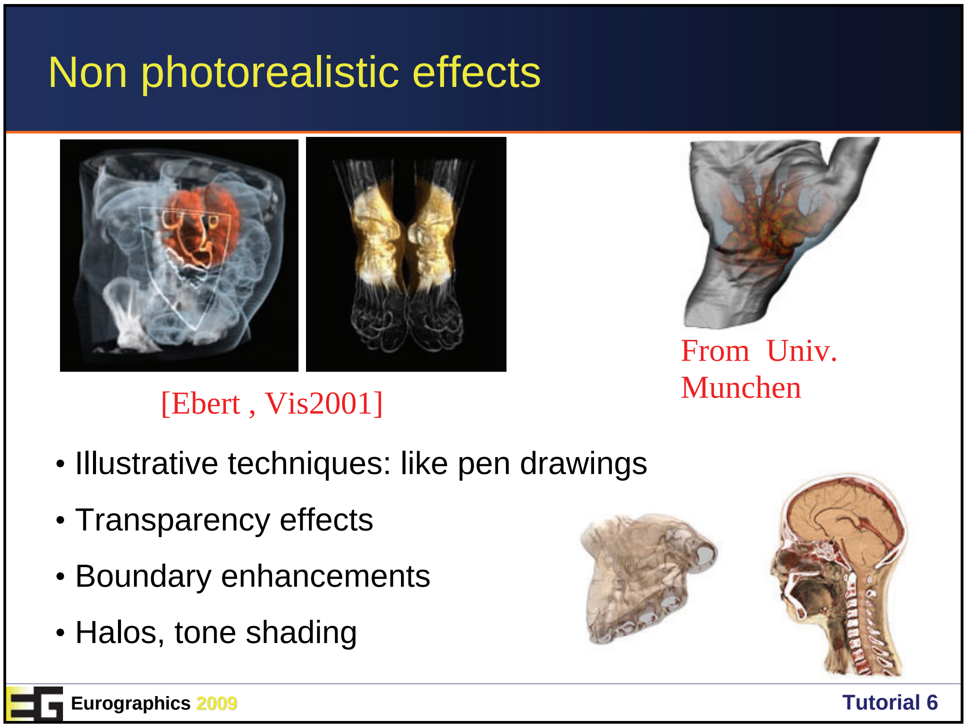
$$C = \int_o^\infty c(t) e^{-\int_0^t k(\tau) d\tau} dt$$

$$C = \sum_{i=0}^{n} C_i \prod_{j=0}^{i-1} (1 - \alpha_j)$$

Front-to-back composition:

$$\begin{aligned} C_i &= (1 - \alpha_s) C_{i-1} + C_s \\ \alpha_i &= (1 - \alpha_s) \alpha_{i-1} + \alpha_s \end{aligned}$$

From VrVIS

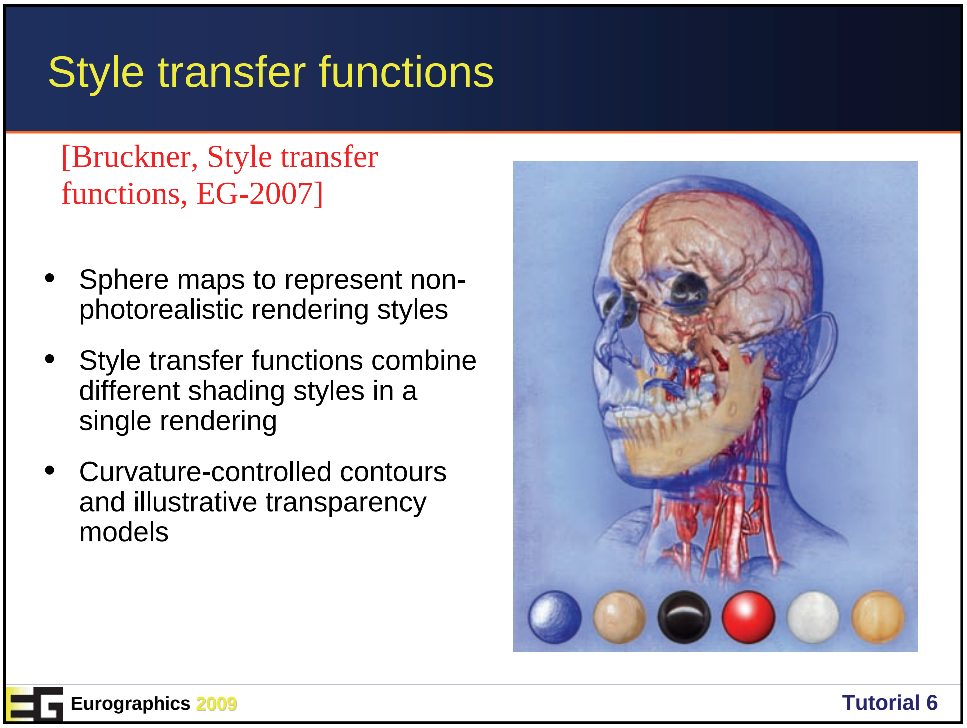


Non photorealistic effects

[Ebert , Vis2001]

From Univ. Munchen

- Illustrative techniques: like pen drawings
- Transparency effects
- Boundary enhancements
- Halos, tone shading



Style transfer functions

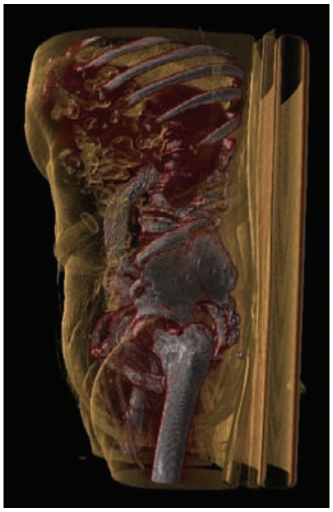
[Bruckner, Style transfer functions, EG-2007]

- Sphere maps to represent non-photorealistic rendering styles
- Style transfer functions combine different shading styles in a single rendering
- Curvature-controlled contours and illustrative transparency models

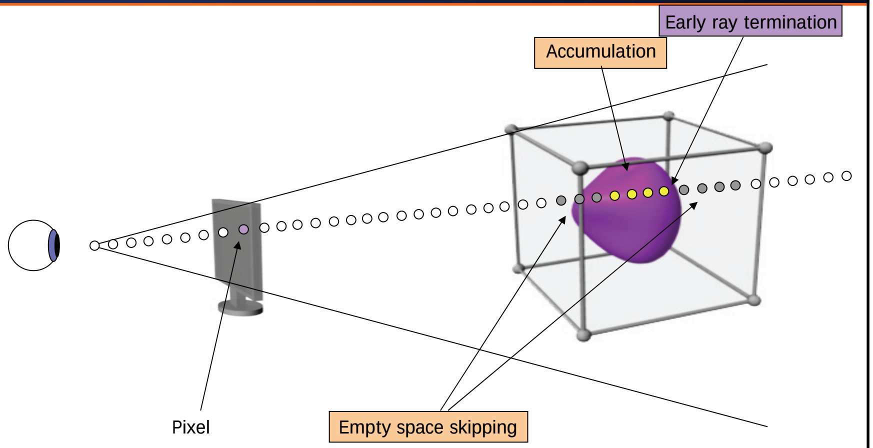
GPU accelerating techniques

Methods for speeding-up volume ray casting methods

- Volume data stored in a single 3D texture
- GPU fragment programs for compositing along rays
- [Hadwiger & al, AMI-ARCS 2006]
- [Kruger & Westermann, IEEE-Vis 2003]



Volume Rendering problem

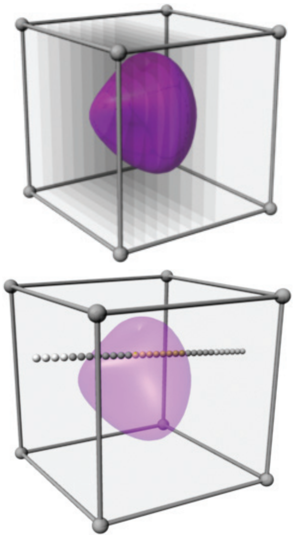


Order independent

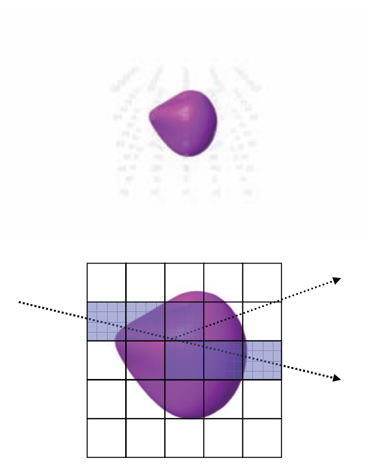
Order dependent

Moderately sized volumes

- Current high quality solutions are based on GPU fragment programs implementing …
  - Slice-based methods
  - Ray casting techniques
- ☹ The full volume must fit on GPU memory



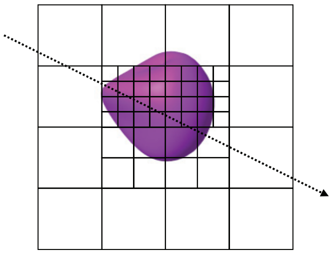
Large volumes: independent blocks



- Subdivide the original volume into independent blocks:
  - select blocks
  - separately render blocks
  - composition of results
- ☺ Scalable
  - potentially support unlimited size datasets
- ☹ Rendering synchronization and communications overhead

Single-pass ray traversal

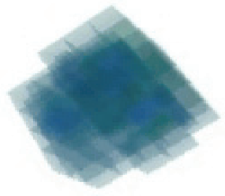
- Flat multi-resolution blocking
  - … constructs a fixed grid of blocks and varies the resolution of each block to achieve adaptability
  - ☹ only 2-level adaptability …
    - … introduce a compromise between 1st and 2nd level to reach the full volume resolution
    - … is not fully adaptive



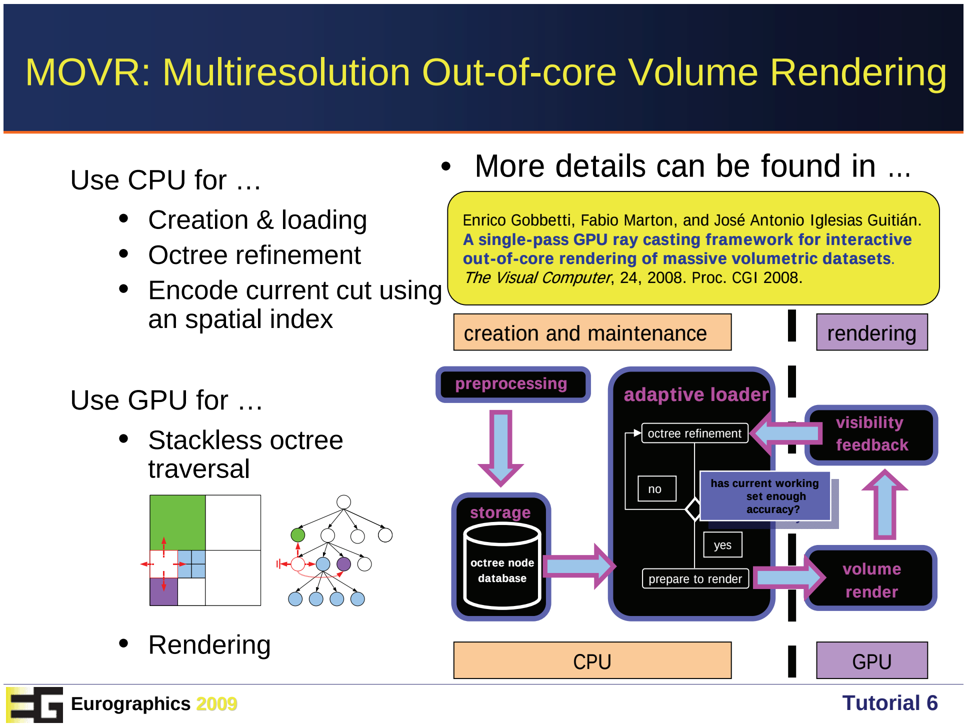
Flat multi-resolution blocking

Single-pass ray traversal

- We propose to use a full multi-resolution octree structure traversed on the GPU, which …
  - ☺ is scalable and fully adaptive
  - ☺ increase performance and reduce overhead
  - ☺ produces simple code (single-pass)



Multi-resolution volumetric octree



MOVR: Multiresolution Out-of-core Volume Rendering

Use CPU for …

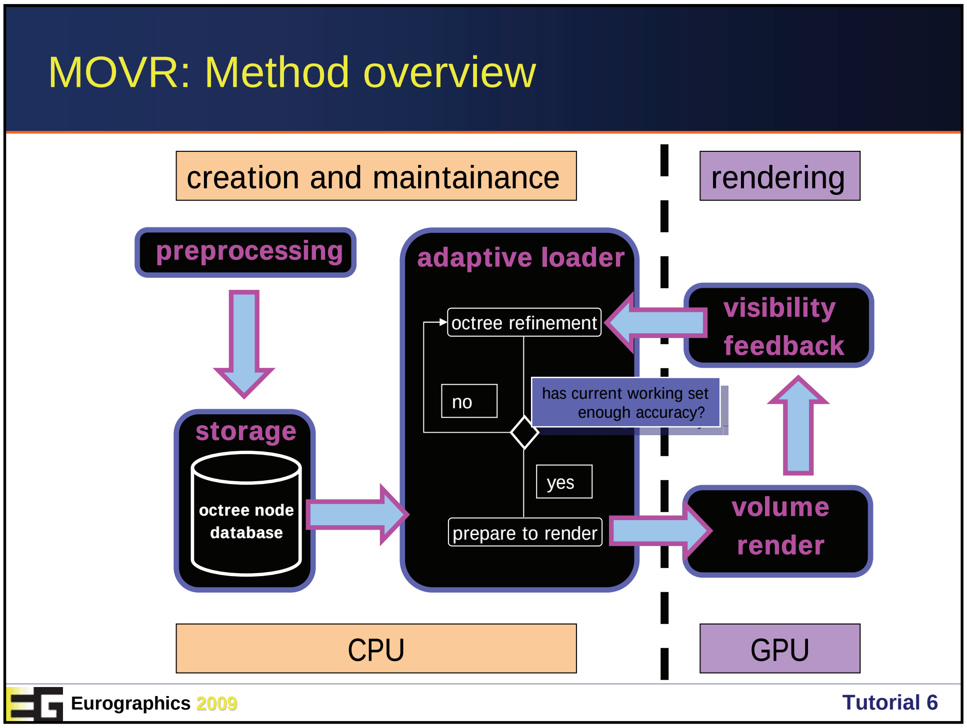
- Creation & loading
- Octree refinement
- Encode current cut using an spatial index

Use GPU for …

- Stackless octree traversal
- Rendering

- More details can be found in ...

Enrico Gobbetti, Fabio Marton, and José Antonio Iglesias Guitián. **A single-pass GPU ray casting framework for interactive out-of-core rendering of massive volumetric datasets**. *The Visual Computer*, 24, 2008. Proc. CGI 2008.



MOVR: Method overview

Integration with 3d light-field displays

- The key feature characterizing 3D displays is **direction-selective light emission**
- Resolving the spatial arrangement of **complex 3D structures** is a difficult task
- In medical data CT's and MRI's often contains **overlapping structures**, leading to cluttered images difficult to understand
- Improving **volumetric understanding** by employing more depth cues than the conventional 2D monitor

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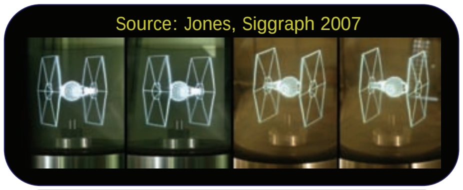
Related work

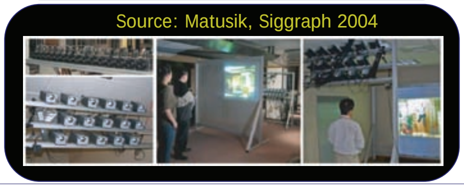
- Volumetric approaches
  - light beams projected on refractive/reflective media positioned or moved in space
- Pure holographic approaches
  - holographic patterns reconstructing the light wavefront originating from the displayed object
- Multi-view approaches
  - based on an optical mask or a lenticular lens array

Source: Favalora, 2007-2008

Source: Jones, Siggraph 2007

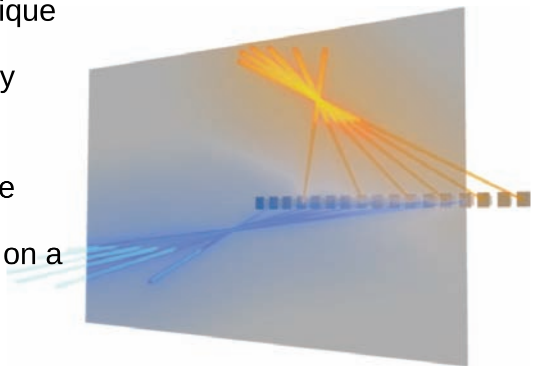


Source: Matusik, Siggraph 2004



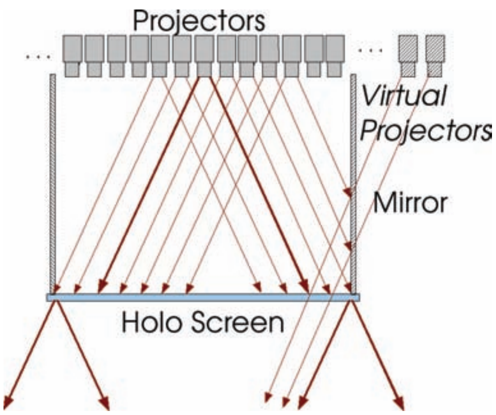
Display overview (1/3)

- Our Holografika display prototype employs multi-view technology combined with light shaping capabilities of a holographically recorded screen
- A general MCOP technique for a class of horizontal parallax light field display
- A hardware and software prototype system with interactive performance on a single PC configuration

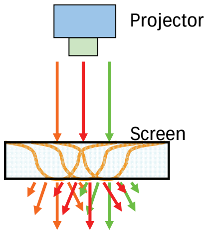


Display overview (2/3)

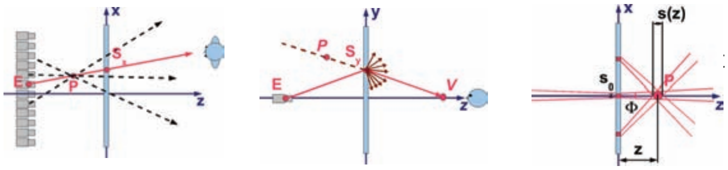
- specially arranged projector array and a holographic screen
- each projector emits light beams toward a subset of the points of the holographic screen
- side mirrors increase the available light beams count



Display overview (3/3)



- selective light transmission in the horizontal parallax, vertically, the screen scatters widely.
- homogeneous light distribution and continuous 3D view



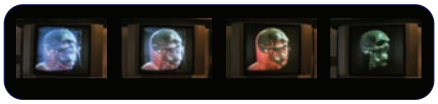
field

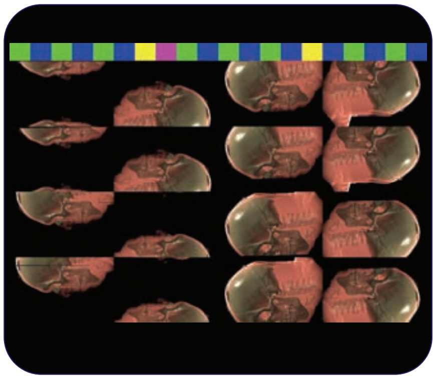
- More details in ...

M. Agus, E. Gobbetti, J.A. Iglesias Guitián, F. Marton, and G. Pintore.
GPU Accelerated Direct Volume Rendering on an Interactive Light Field Display.
Computer Graphics Forum, 27(3), 2008. Proc. Eurographics 2008.

Prototype system setup

- Display system manufactured and built by Holografika
  - 7.4M beams / frame
  - 96 fast 320x240 LCD displays
  - FPGA input processing units decoding DVI stream
  - 2D pixel size 1.25 mm, angular accuracy 0.8°
- Athlon64 3300 + Linux PC with a NVIDIA 8800GTX graphics board
- C++, OpenGL, Cg shaders implementing volume ray casting with different composition techniques



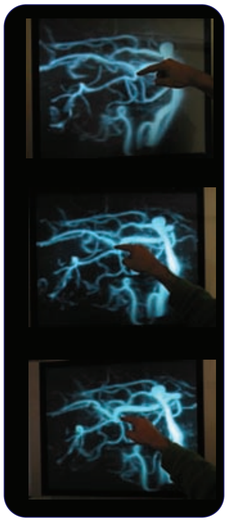


GPU cluster system setup

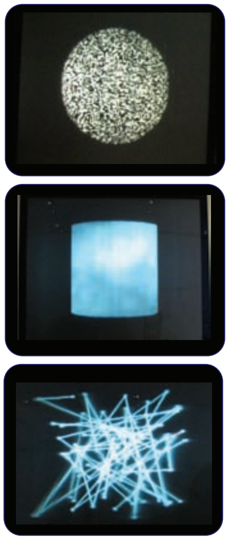
- Display system manufactured and built by Holografika
  - GPU cluster with 18 nodes
  - Resolution: 800x600x72 projectors
  - 33M beams / frame
- Nodes are PC Athlon64 3300 + Linux with 2 NVIDIA 8800GTS
- Each graphic board has 2 graphics outputs, so we need to control a total of 72 projectors.

Evaluation

- The main goal of tests performed in the evaluation process is …
  - … to elucidate if light field displays could provide visual information not available with traditional volume rendering systems
- The main focus will be set on psychophysical tests.



Evaluation tests



- Stereopsis evaluation
  - **Random dot spiral ramp** test
  - **Rotating direction** of a Perlin noise cylinder
- Spatial understanding evaluation
  - **Path tracing** performance evaluation

Enhanced 3D Understanding

- Users rapidly recover all depth cues to instantaneously recognize complex structures
  - Very useful for analysis of angiography datasets

- More details about the evaluation tests can be found in …

M. Agus, A. Giachetti, E. Gobbetti, J. A. Iglesias Guitián, J. Nilsson, G. Pintore and G. Zanetti.
Implementation and evaluation of an interactive volume visualization system on a lightfield display.
Visual Computer – Special Issue 3D Physiological Human, to appear 2009.