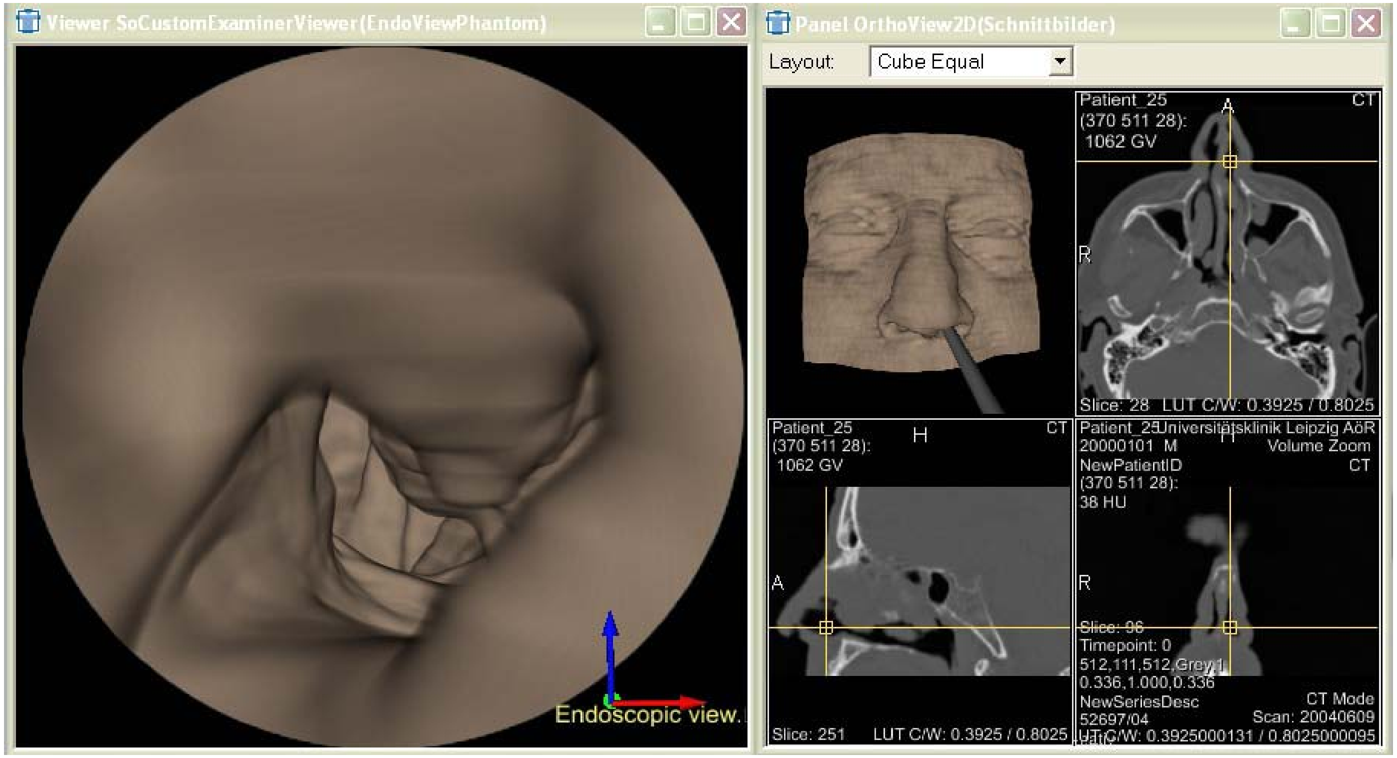
Tutorial Syllabus

Surface Visualization - Marching Cubes and its improvements - Smoothing of surface visualizations	(30 min.)
Direct Volume Visualization - Ray casting and texture-based approaches - Projection methods	(30 min.)
3D Vessel Visualization	(30 min.)
Virtual Endoscopy	(30 min.)
Augmented Reality and Intraoperative Visualization	(20 min.)
Medical Training and Surgical Planning	(20 min.)

Virtual Endoscopy



Outline

- Introduction and Motivation
- Rendering Techniques
- Navigation and Interaction Concepts
- Application Areas
  - Virtual Colonoscopy (Diagnosis)
  - Virtual Bronchoscopy (Diagnosis)
  - Virtual Endoscopy for Sinus Surgery (Intervention Planning and Training)
  - Virtual Endoscopy for Minimally-Invasive Surgery of the Pituitary Gland (Intervention Planning)
- Commercial Systems
- Conclusion

Introduction

- Virtual Endoscopy is based on high-resolution medical image data (often CT) and is a viewing and exploration mode derived from optical endoscopy.
- In optical endoscopy a thin (flexible or stiff) fiber optic is moved to the target area.
- Virtual endoscopy: Virtual camera is moved along air- or fluid filled structures.
- Optical properties of endoscopes are mapped to the virtual camera.

- Endoscopy is used as diagnostic tool and can be combined with interventions, e.g., removal of polyps or taking biopsies.
- Virtual endoscopy is limited to applications without interventions.
- Requirements for virtual endoscopy:
  - Sufficient accuracy
  - Identifiable (segmentable) structures of interest
  - Interactivity (high frame rate)
    - ➢ **Large amounts of data and interactivity – these aspects are difficult to achieve at the same time. Special emphasis is needed!**

Major applications for virtual endoscopy

- Diagnosis: virtual bronchoscopy
- Diagnosis: vascular diseases, such as aneurysms
- Screening for colon cancer prevention (or early detection)
- Treatment planning with respect to endoscopic procedures, such as Functional Endoscopic Sinus Surgery
- Training for endoscopic interventions. Due to the limited visual access there is a high demand for training these procedures.

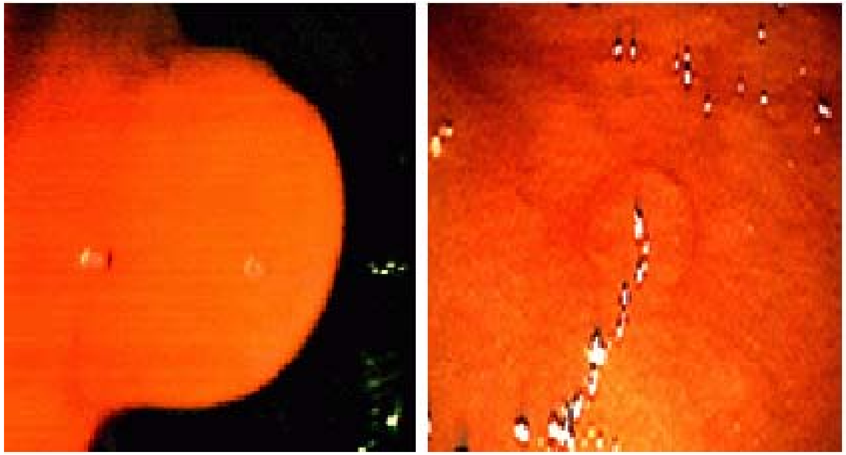
- Instruments for optical endoscopy:

Brochoscope,
Coloscope

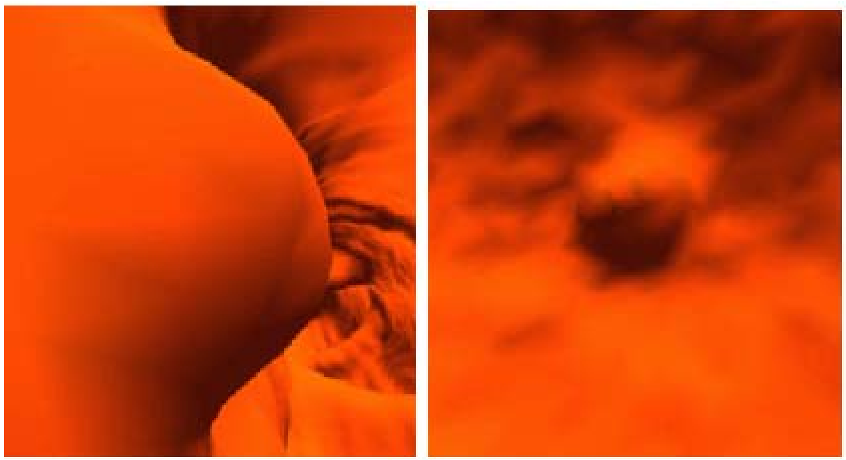
Light source,
Video processor

Sources: above – http://www.olympus.de/endo
below – http://www.info-endoskopie.de

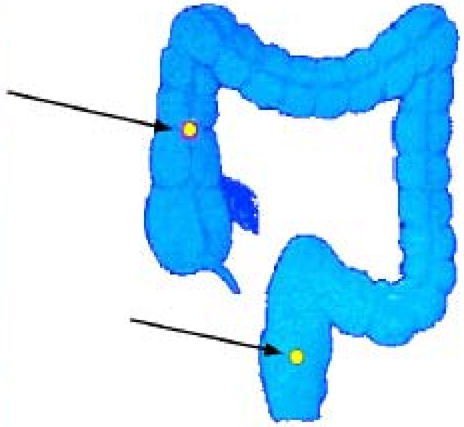
Nooses,
Forceps



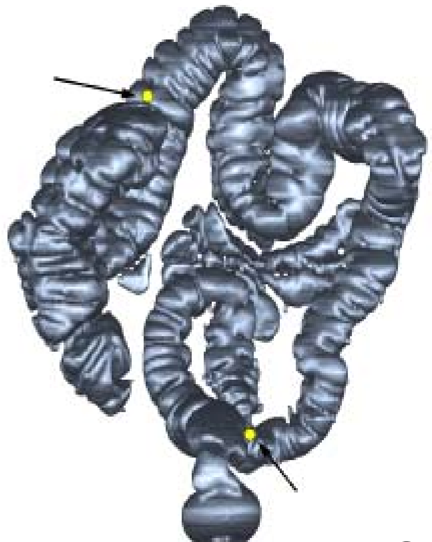
Optical Endoscopy



Virtual Endoscopy



8 mm polyp



4 mm polyp

Image Courtesy Dirk Bartz, Univ. of Leipzig

Motivation

- In contrast to optical endoscopy, virtual endoscopy allows
  - to „look behind the walls“
  - to reduce risks and costs associated with optical endoscopy
- However, virtual endoscopy
  - cannot be combined with interventions
  - does not provide realistic colour and texture information and
  - does not allow physical contact
  - is of limited value if the structure of interest has changed since acquisition, e.g. „brain shift“

Concept

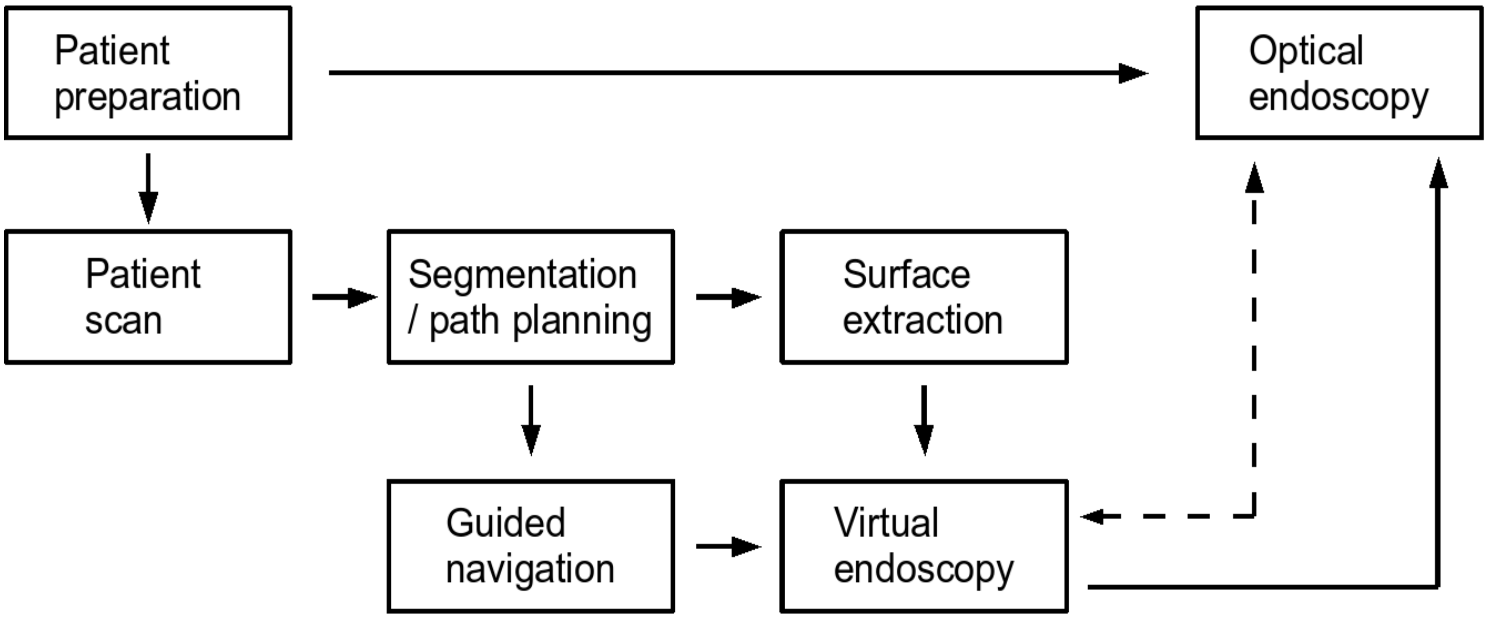
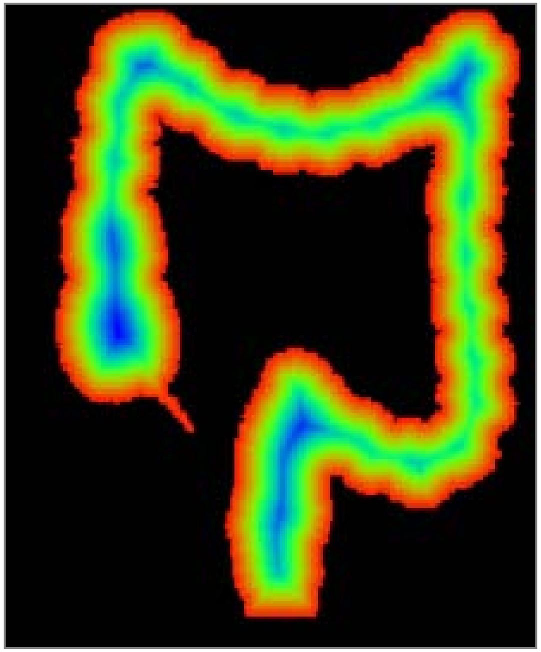


Image Courtesy Dirk Bartz,
Univ. of Leipzig

Segmentation/Path Planning

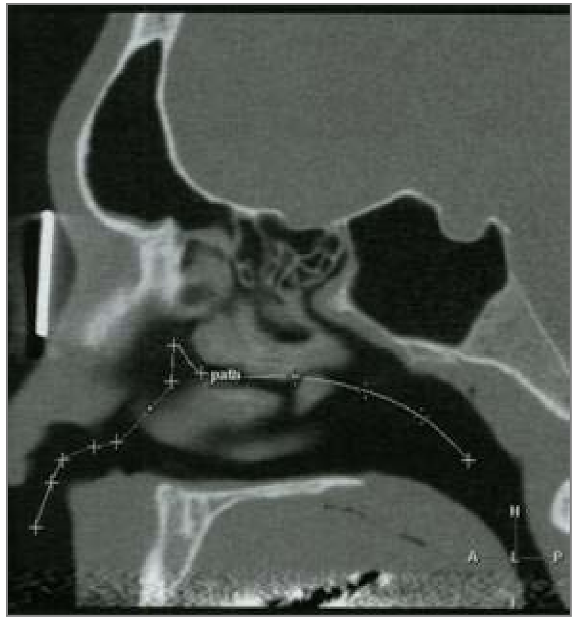
- Accuracy and value of virtual endoscopy depends on segmentation quality.
- Reliable, fast and automatic segmentation in general is very difficult.
- Good results are achieved in case of air-filled structures in CT, such as the colon.
- Path planning often based on the skeleton and/or the distance field of the target structure.

Segmentation/Path Planning



The distance field in the colon may be used for path computation and supporting guided navigation.

(From: Hong et al. 1997)



Interactive path specification based on coronal slices.

Surface visualization and Direct Volume Rendering

- Surface visualization requires pre-processing (segmentation).
- Segmentation result is converted to a polygonal mesh, post-processed (smoothing) and efficiently rendered using graphics hardware.
- Perspective rendering is preferred
- Acceleration Techniques:
  - Occlusion culling (restrict rendering to the small visible portion)
  - Empty-Space-Leaping

Image Courtesy Dirk Bartz

Typical artifacts of surface models generated by means of Marching Cubes for virtual endoscopy.

Occlusion Culling:

Specific possibilities of endoscopic views:

- Endoscopic views have very limited visibility
- Removal of occluded geometry (occlusion culling)
- Frequently achieves culling of 90%

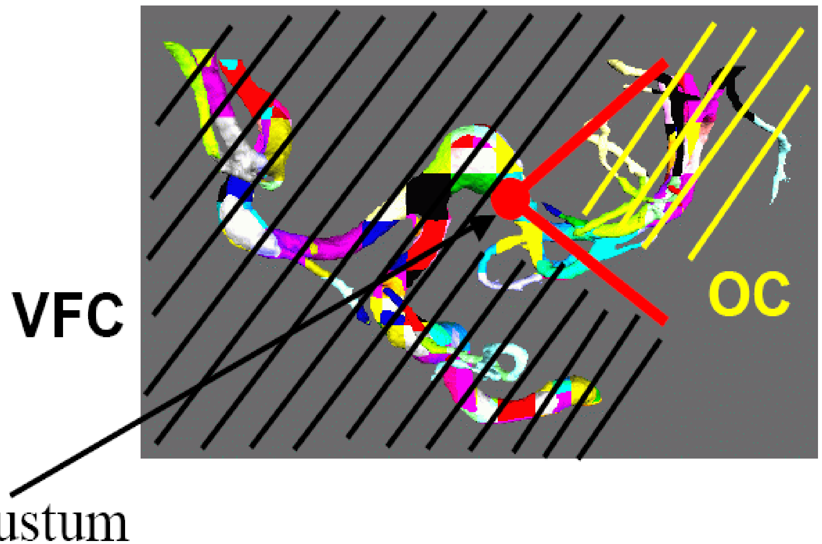
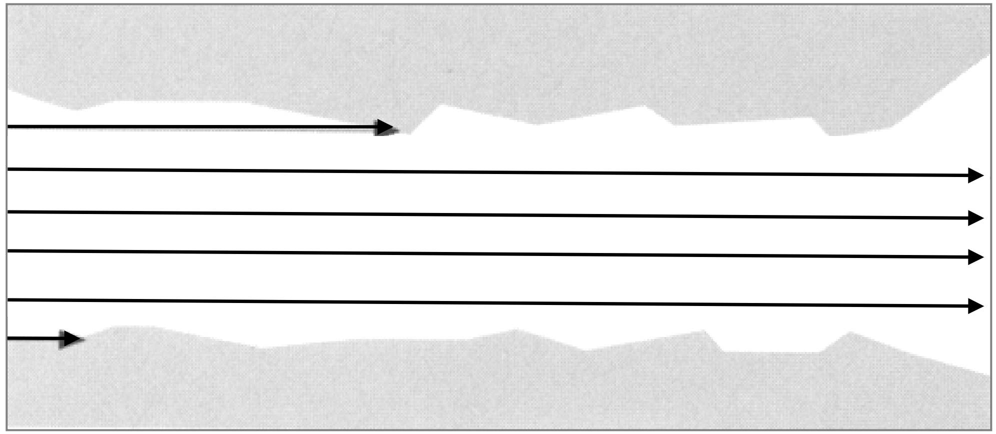
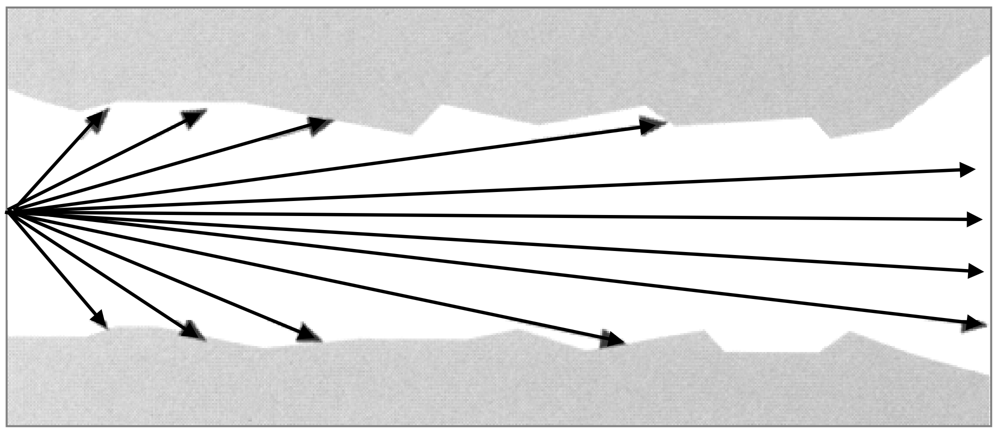


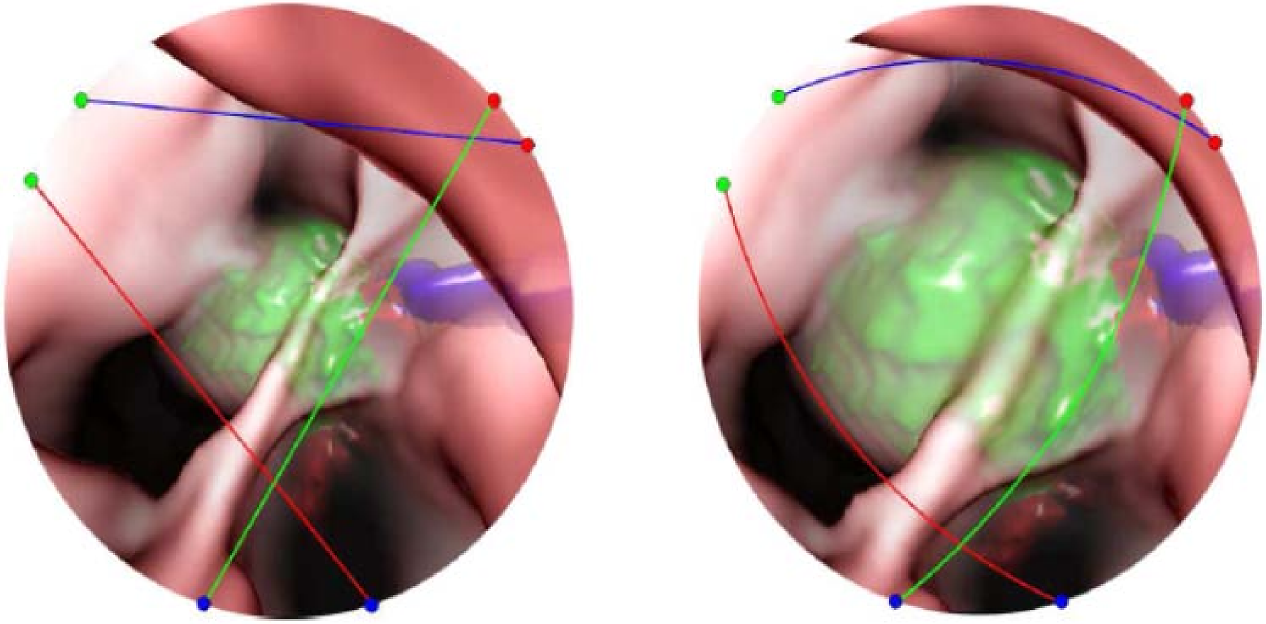
Image Courtesy Dirk Bartz

Parallel versus Perspective Rendering:

- More structures are visible with perspective rendering.
- Although parallel rendering is faster, perspective rendering is preferred.







Images are courtesy of André Neubauer, VR Vis Vienna

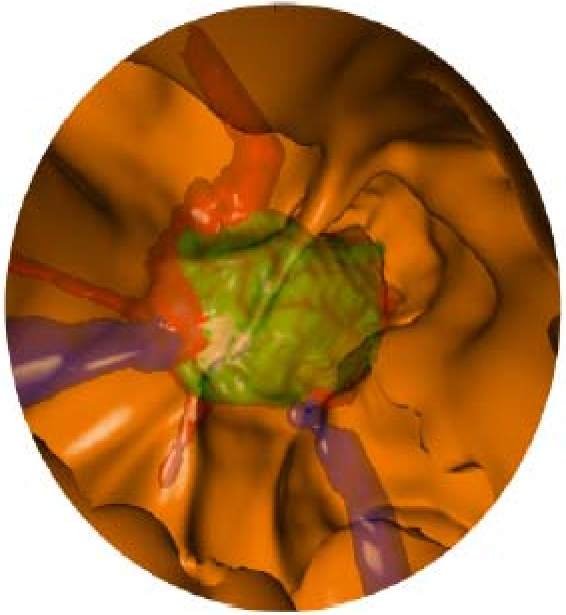
For intervention planning and training, it is essential to simulate the distorted view of virtual endoscopy.

To provide a sufficient overview, lenses at the tip of endoscopes use large opening angles (30°, 70°).

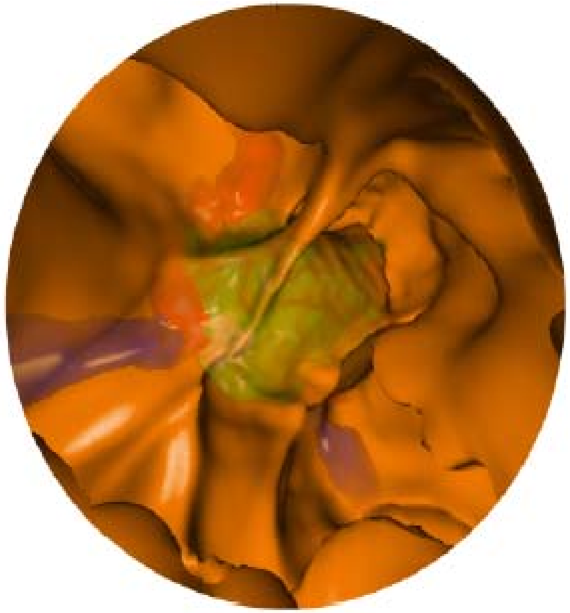
View from the sphenoid sinus to the pituitary gland

„Look behind the wall“

Provide additional information compared to optical endoscopy



constant blending parameter

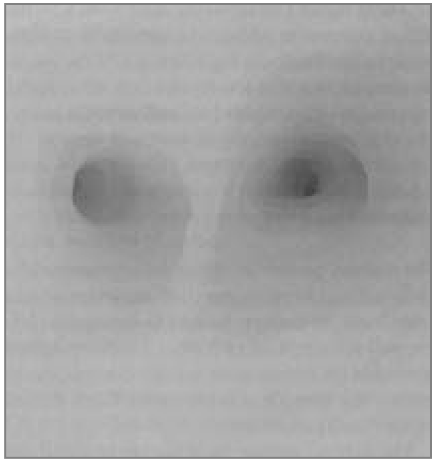


Modified blending considering the distance between fore- and background

Blended fore- and background images for first-hit ray casting. Images are courtesy of André Neubauer, VRVis Wien.

Illumination

ambient



diffuse

diffuse
+
low specular

diffuse
+
high specular

Source: Virtual Endoscopy and Related 3D Techniques, Springer 2001

Direct volume rendering

- Trilinear interpolation (better than linear interpolation, used in Marching Cubes)
- Special variant of ray-casting, first hit raycasting (Neubauer, 2004), where a predefined number of surfaces along each ray are located.

Rendering Techniques: Illumination

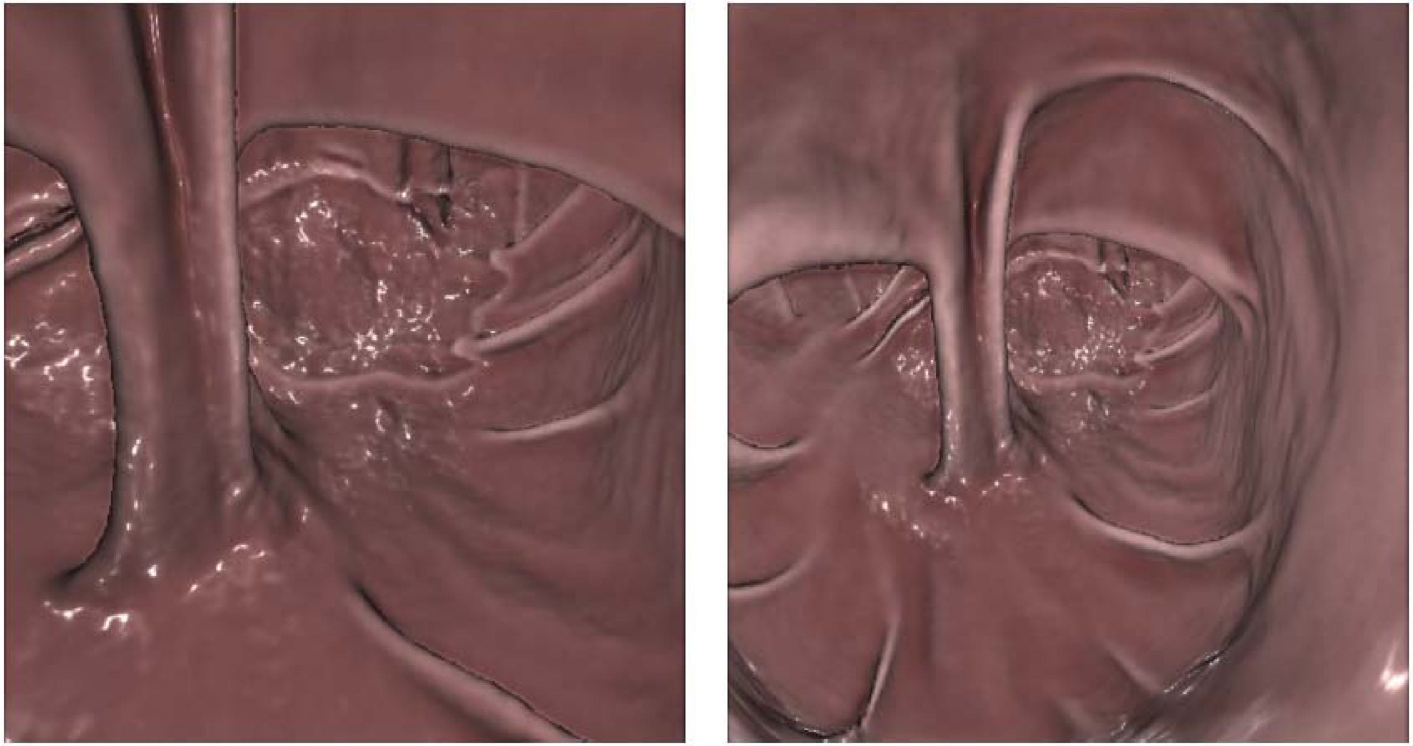
- Illumination
  - Ambient
  - + Diffuse
  - + Specular
- Additional effects
  - Diffuse
  - + Ambient occlusion
  - + Specular
  - + Texture
  - + Shadows

Virtual Endoscopy and Related 3D Techniques, Springer Verlag 2001

Source: Virtual Colonoscopy for Fecal Tagging CT-data, C. Ruß 2010

Virtual Endoscopy: Projection

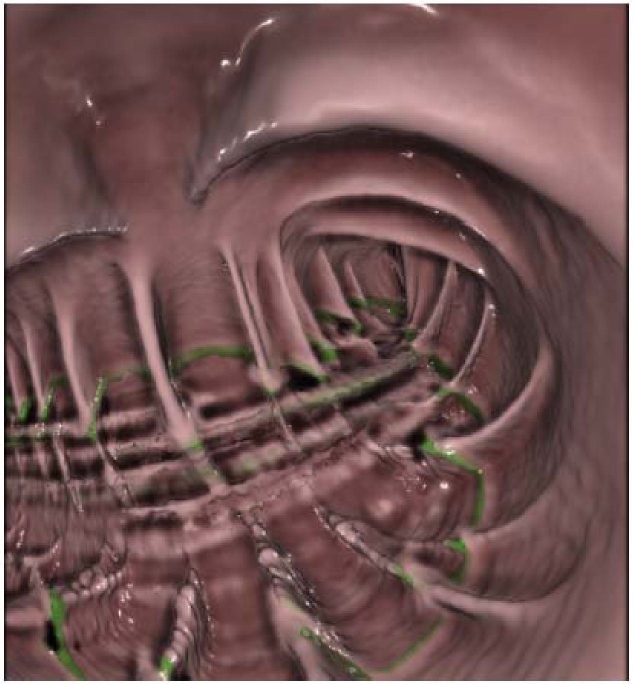
- Simulation of fisheye lenses for a wide field of view
  - 90° and 180° fisheye

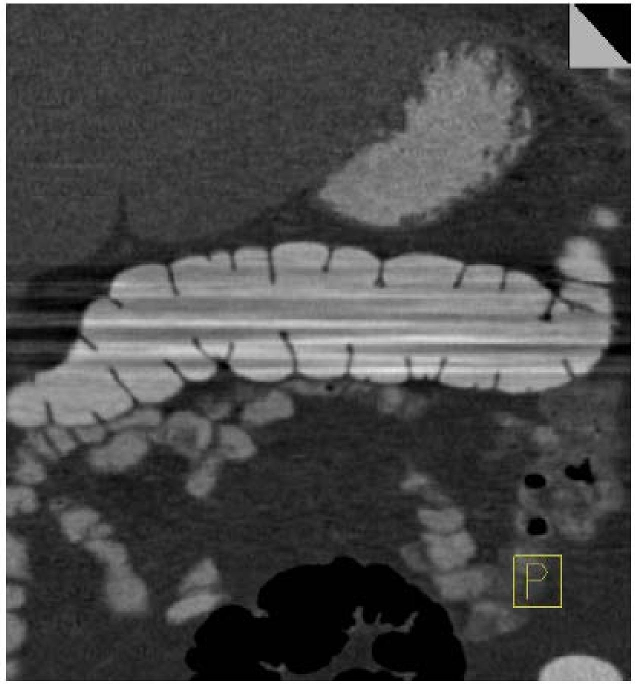


Source: Virtual Colonoscopy for Fecal Tagging CT-data, C. Ruß 2010

Virtual Endoscopy: Artifacts

- Artifacts in CT data





Source: Virtual Colonoscopy for Fecal Tagging CT-data, C. Ruß 2010

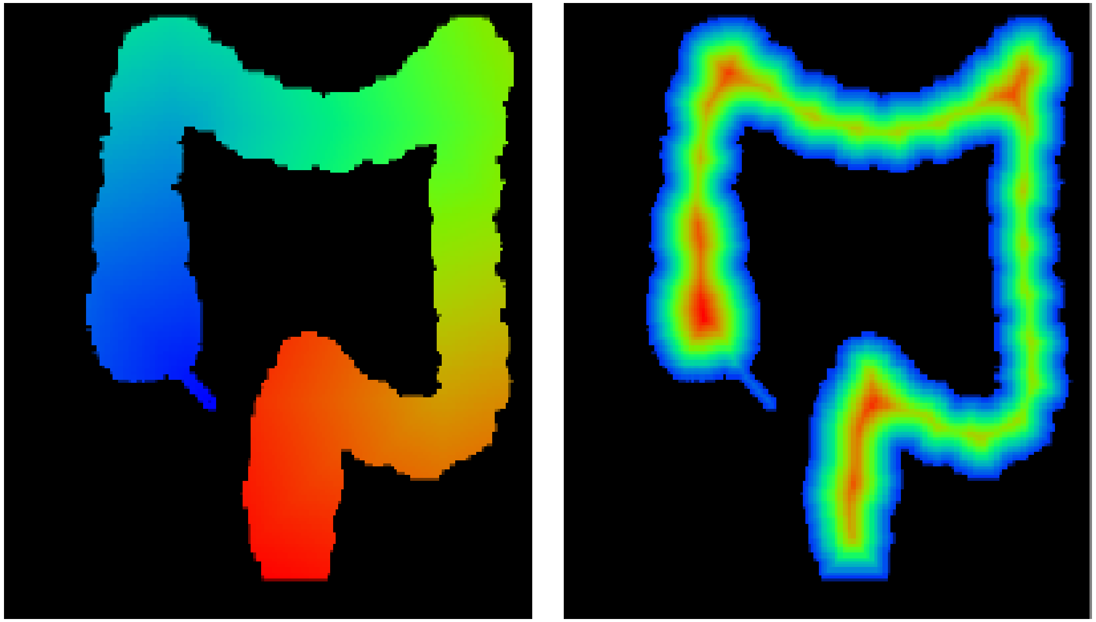
Navigation Models - Paradigms

- Planned Navigation (“Autopilot“)
  - Specification of a camera path
  - Camera is more or less fixed to that path
  - VCR-like interaction
  - Costly refinement
  - Some observations: only 70% of all polyps are visible in a typical flight through the colon. 95 % are visible if the flight is also shown in the reverse direction.

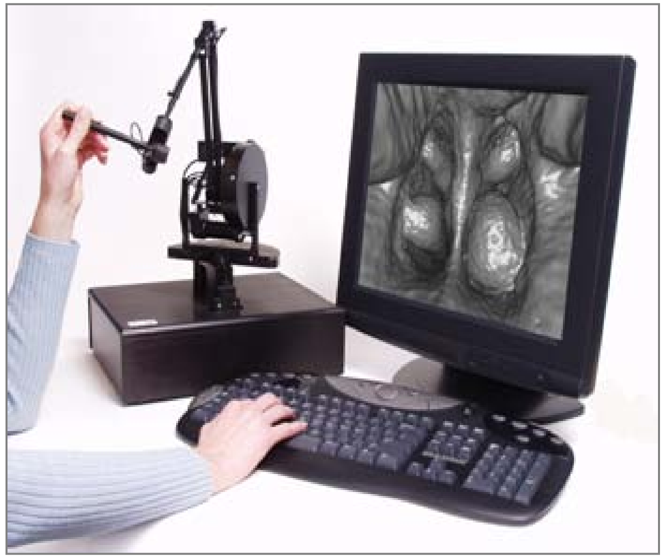
- Manual/free Navigation
  - Often difficult to control
  - Requires heavy 3D interaction

Guided Navigation:

- Combines flexibility and guidance
- Interactive and intuitive
- Camera dives through scene like submarine
- Current and thrust through distance fields and kinematic rules
- Principles have been invented in the Vivendi-System (Bartz, 2003)



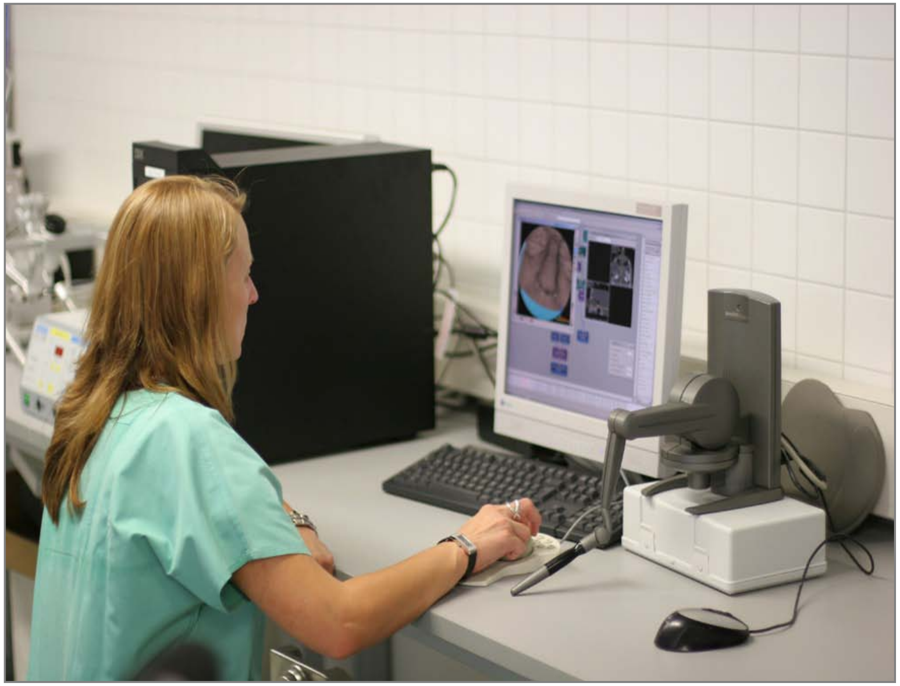
Distance to the target and distance to the vessel wall are employed for guided navigation (Hong, 1997). Images courtesy of Shigeru Muraki, AIST Japan



- Besides „traditional“ input devices, graphics tablets, force feedback devices as well as tactile input may be employed.
- Sources: http://www.wacom.com

  http://www.sensable.com

- Comparison of different input devices



(From: [Krüger, 2007])

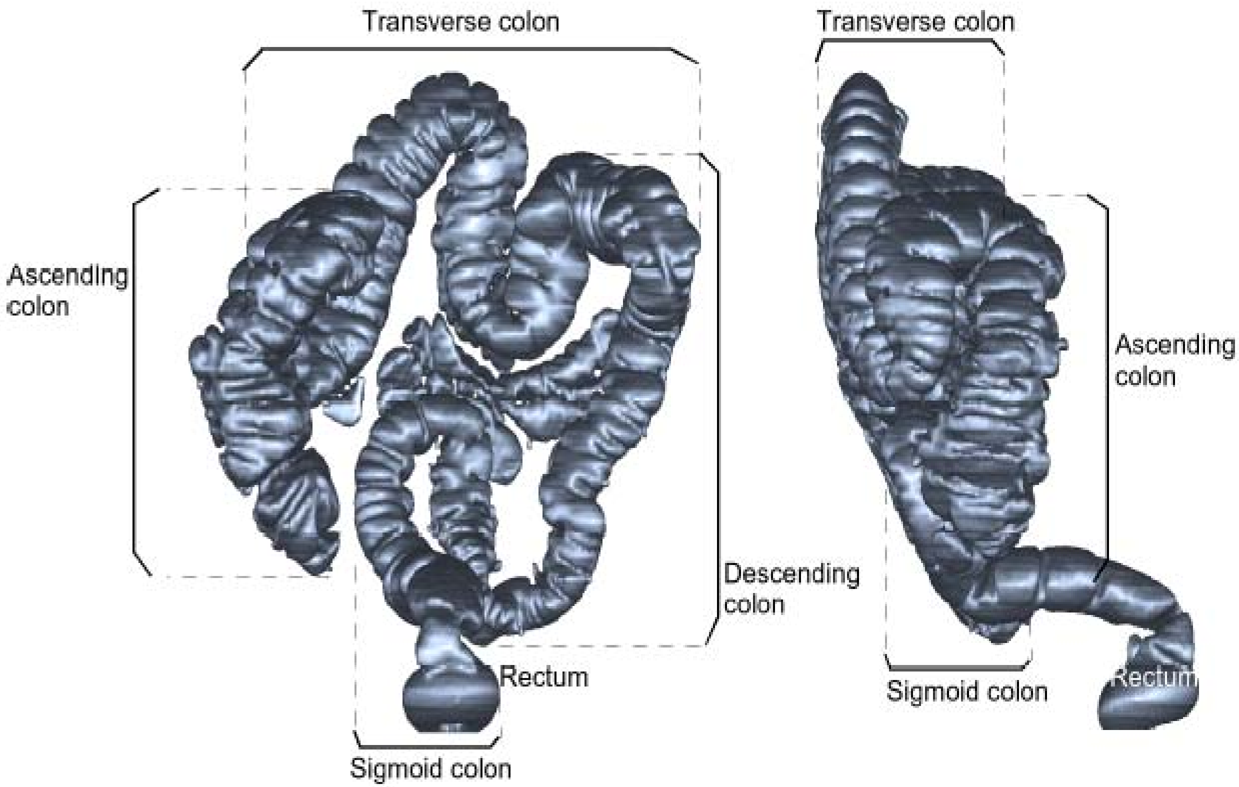
- Input devices
  - SpaceMouse
  - PHANToM without force feedback
  - PHANToM with force feedback
- Subjective Evaluation
  - Ease of learning, ease of use, spatial orientation
  - Satisfaction and level of fatigue
- PHANToM with force feedback yielded best results

Applications: Virtual Colonoscopy

- Cancer of the colon is a leading cause of death → prevention and early detection is crucial.
- Optical endoscopy is an effective diagnostic procedure to inspect the colon wall for pathologies.
- However, it is expensive (sedation of the patient) and suffers from low patient acceptance. → Virtual Endoscopy

- Major goals:
  - Reliable identification of polyps > 5 mm
  - Low rate of false positives (e.g., residual fluid or remaining stool)
  - Efficient processing of data for mass screening application of a whole age group

Applications: Virtual Colonoscopy



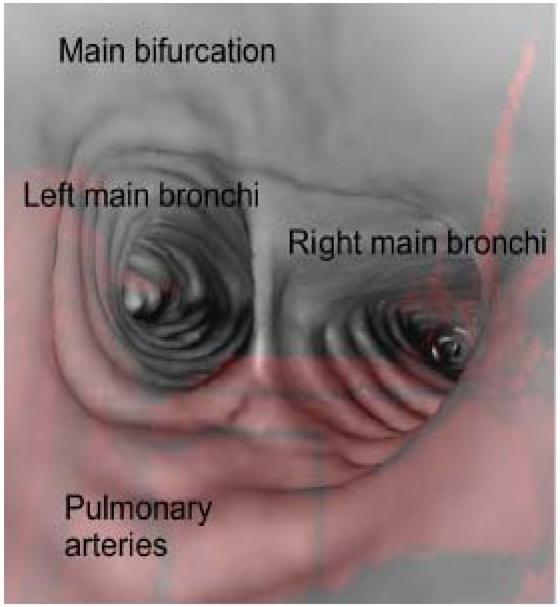
Coronal (left) and sagittal (right) view of the colon.

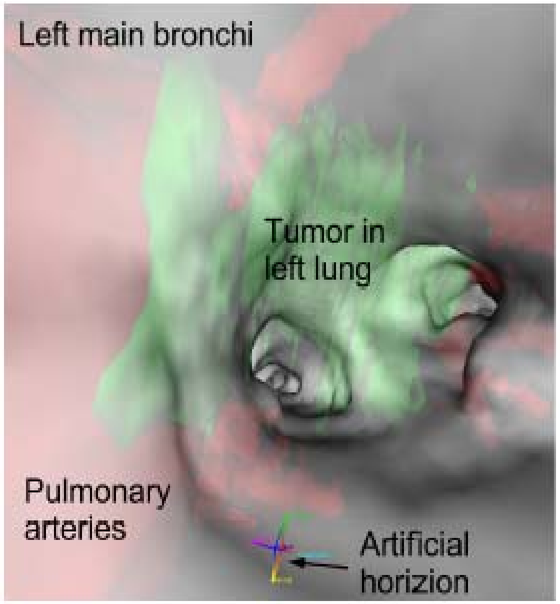
Results:

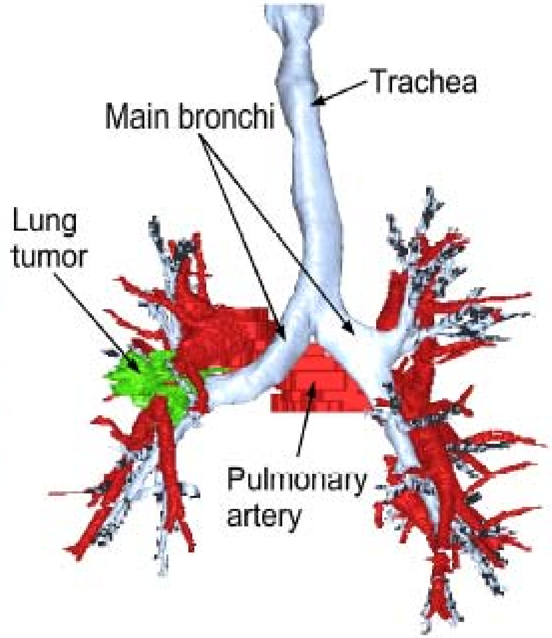
- The diagnostic performance (sensitivity, specificity) depends on many factors.
- Similar results to optical endoscopy are feasible (high quality data, experienced radiologists).
- It is essential that every part of the colon was inspected. Visibility maps indicate which regions have not been visited.

Applications: Virtual Bronchoscopy

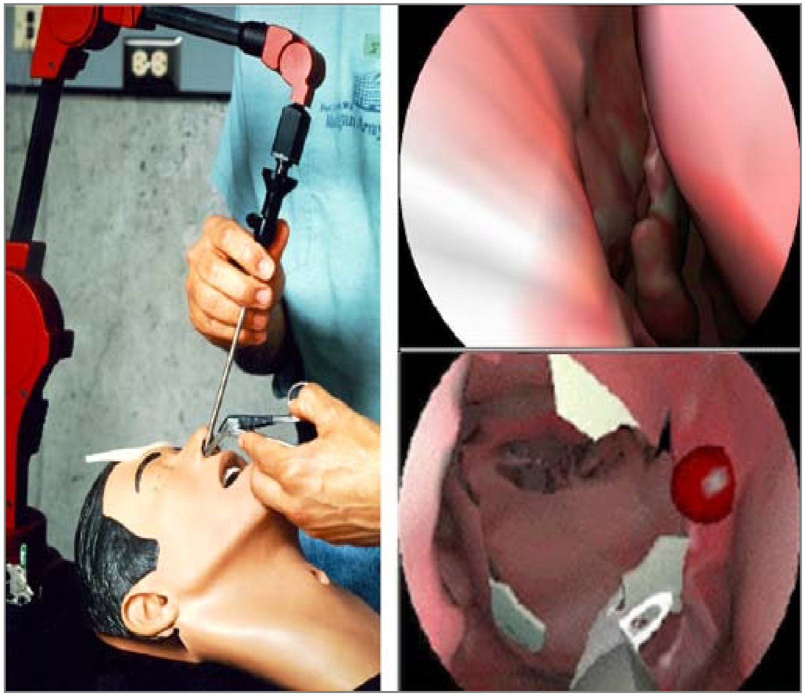
- Diagnostic and therapy planning related to diseases of the tracheo-bronchial system, e.g., lung cancer, emphysema, …
- Based on high resolution CT data (300 slices, 512x512)
- Target structures: Airways, blood vessels, tumors
- Segmentation of all structures requires a complex pipeline [Bartz, 2003]. In particular, reliable identification of the 5th and 6th generation of inner airways is difficult to accomplish.







Virtual bronchoscopy for surgery planning. Blended visualization of objects is crucial. (From: Bartz et al., 2003)



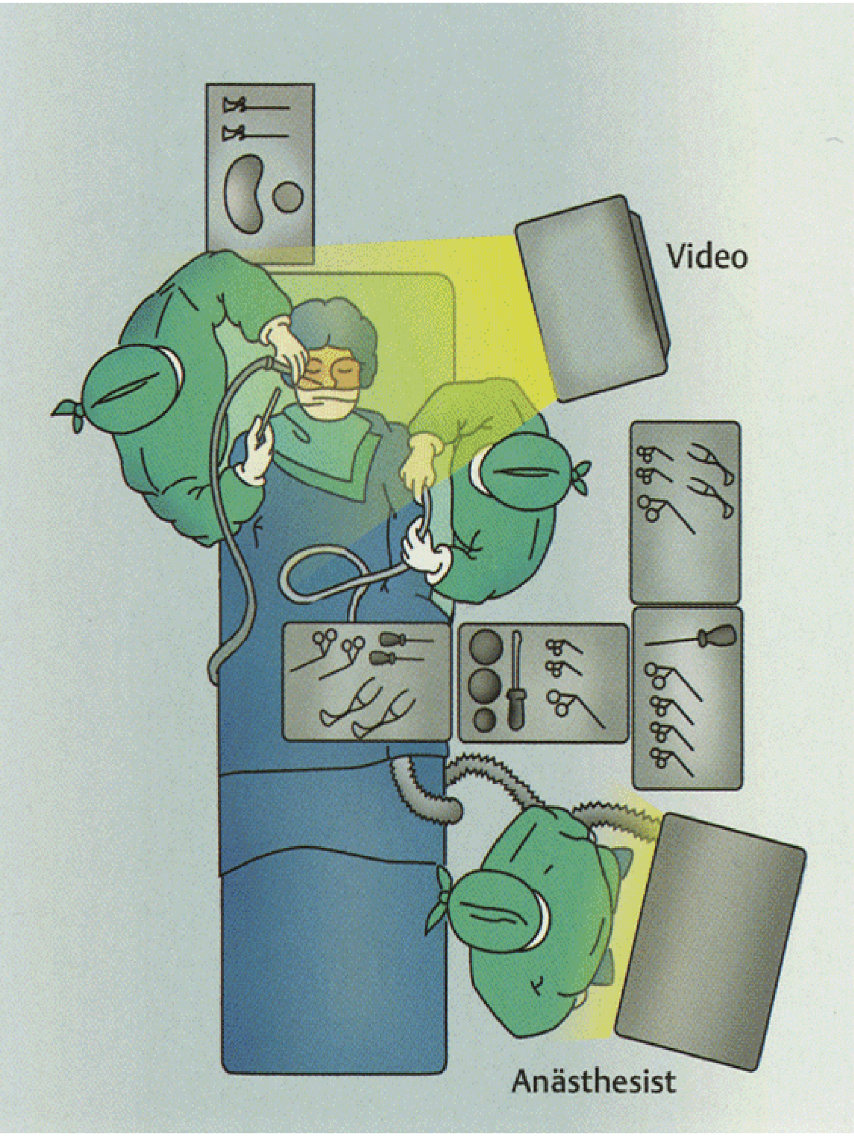
Endoscopic Sinus Surgery Simulator
[Weghorst, 1997]

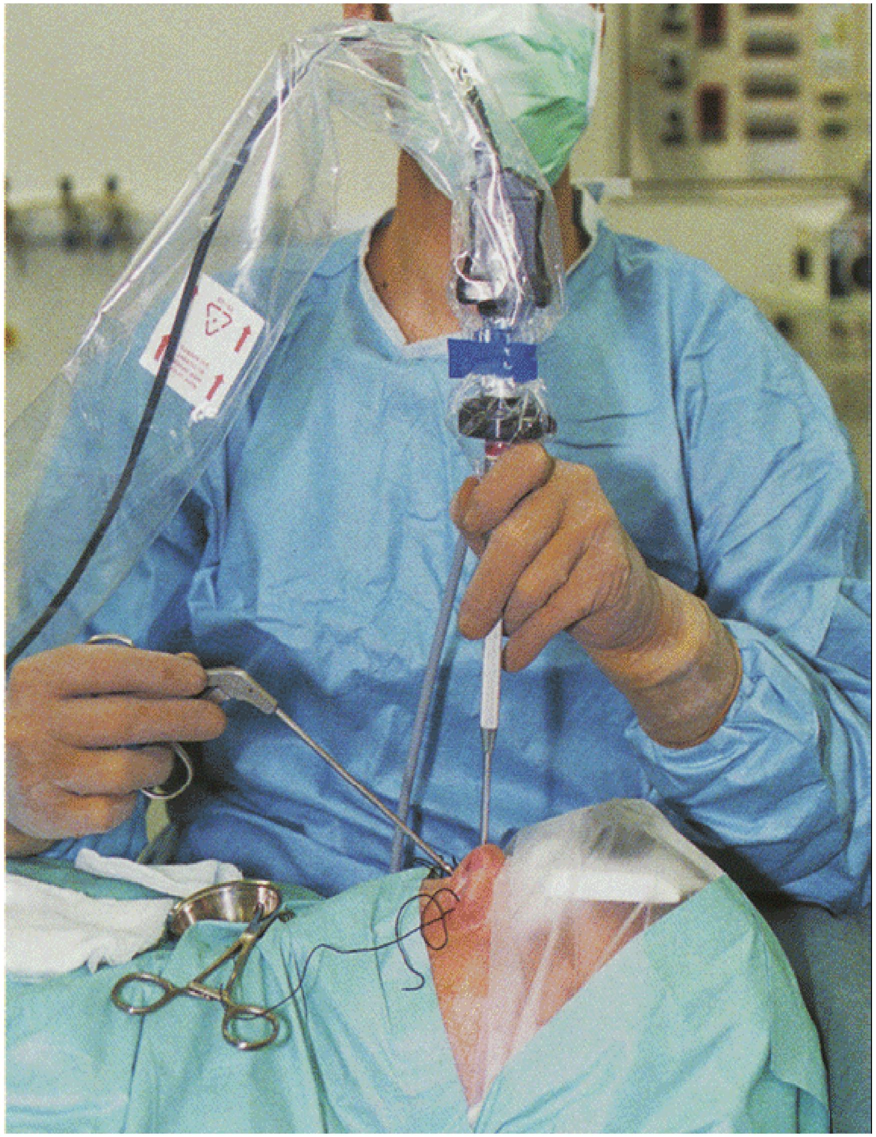
- Teaching anatomy of patients from interior viewpoints.
- Simulating endoscopic interventions, e.g. sinus surgery.
- Challenging application area since instrument-tissue interaction as well as soft tissue deformation must be simulated.

Major goals:

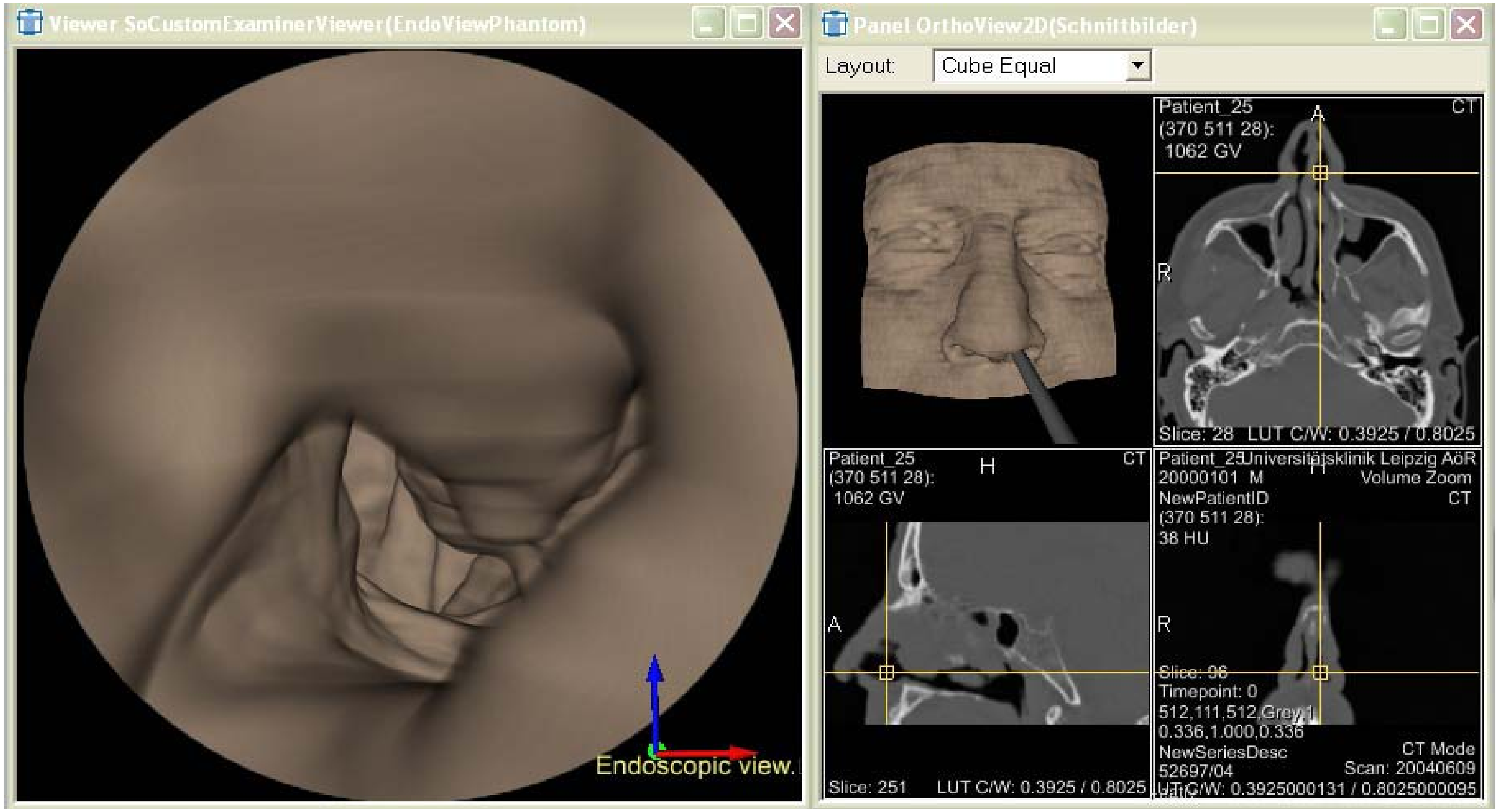
- 3D visualization of relevant structures
- Evaluation of spatial relations, e.g. with respect to risk structures, such as the optical nerve
- Measurement (e.g. to evaluate whether certain structures may be reached)
- Access planning
- Documentation of treatment planning

Real Endoscopy: Typical Approach

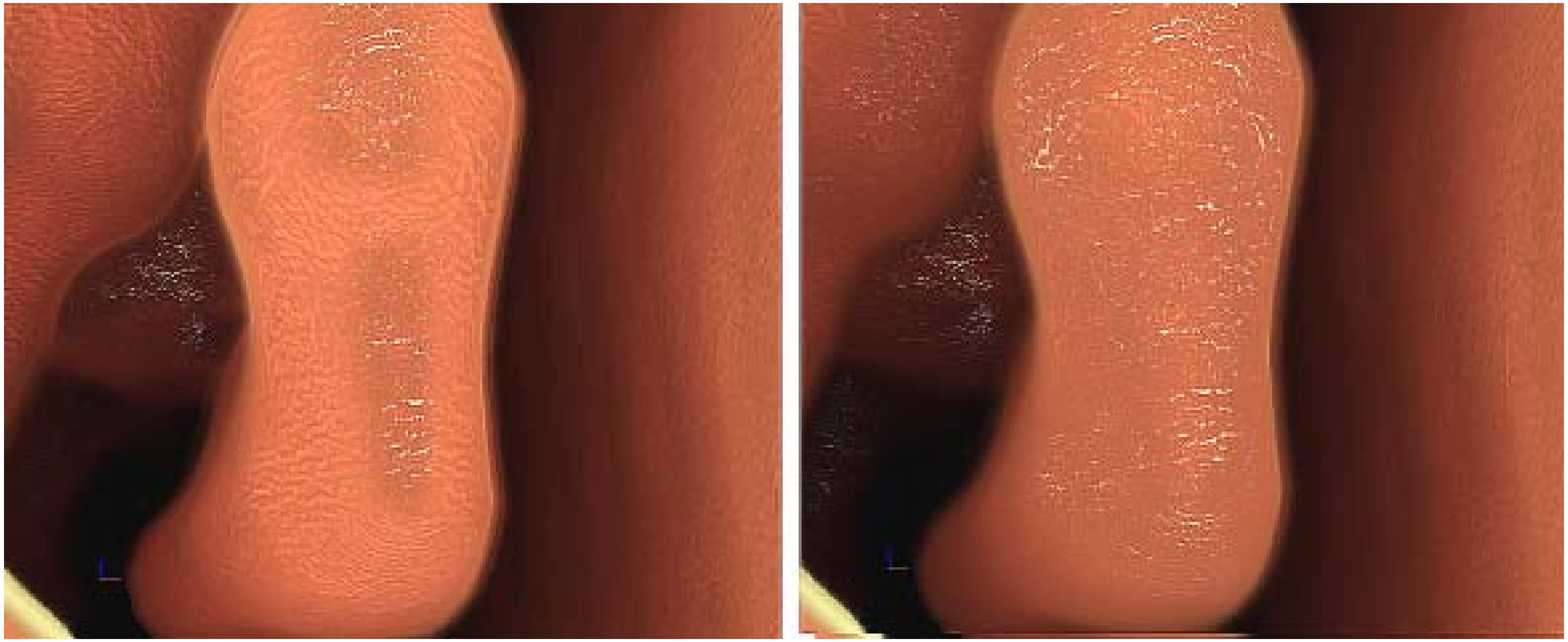




Chirurgie der Nasennebenhöhlen und der vorderen Schädelbasis. Thieme Verlag, 2005

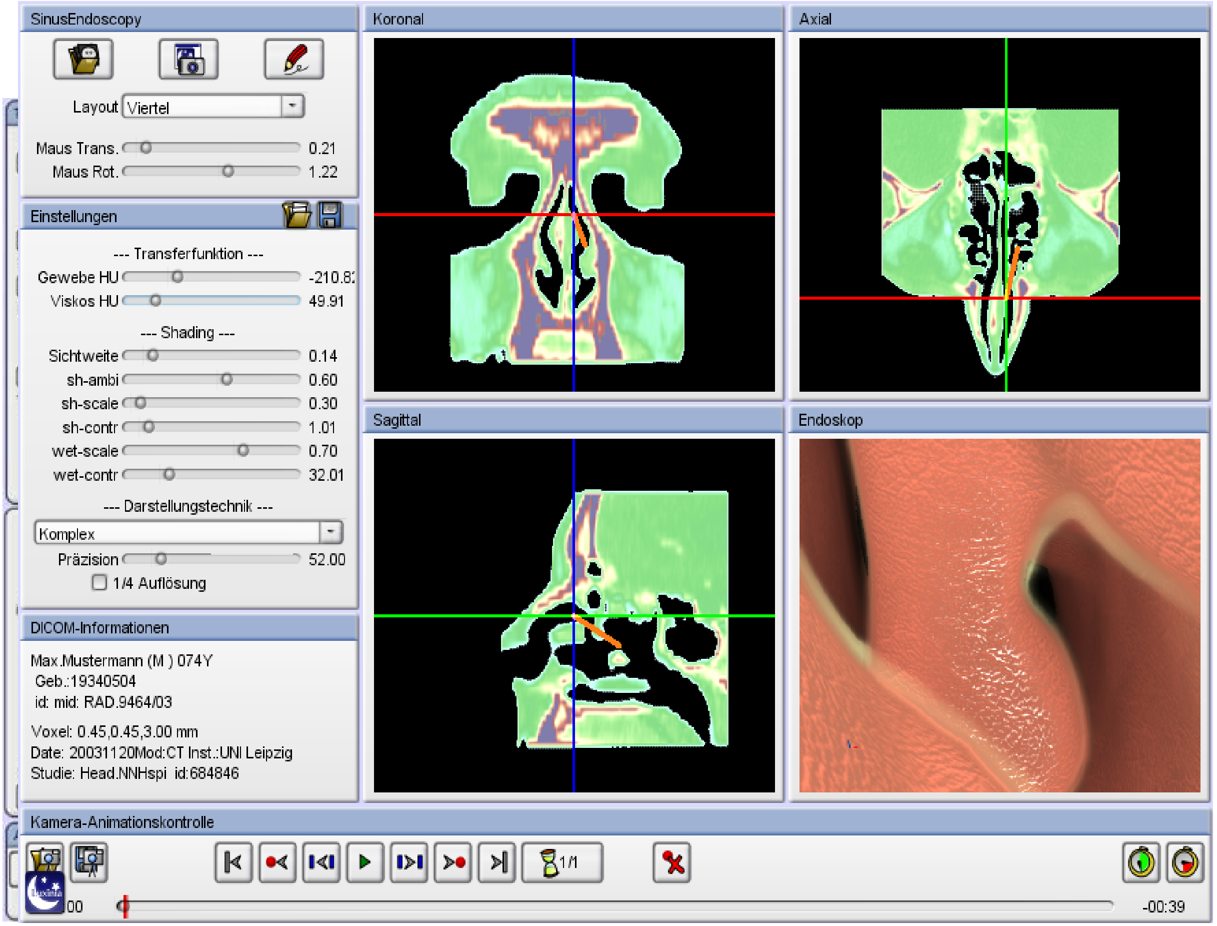


Endoscopic Sinus Surgery Planning System (From: [Krüger, 2007])
Segmentation and path planning is easy as long as cavities are filled with air. The more extended pathologic swellings are, the more difficult is the segmentation.

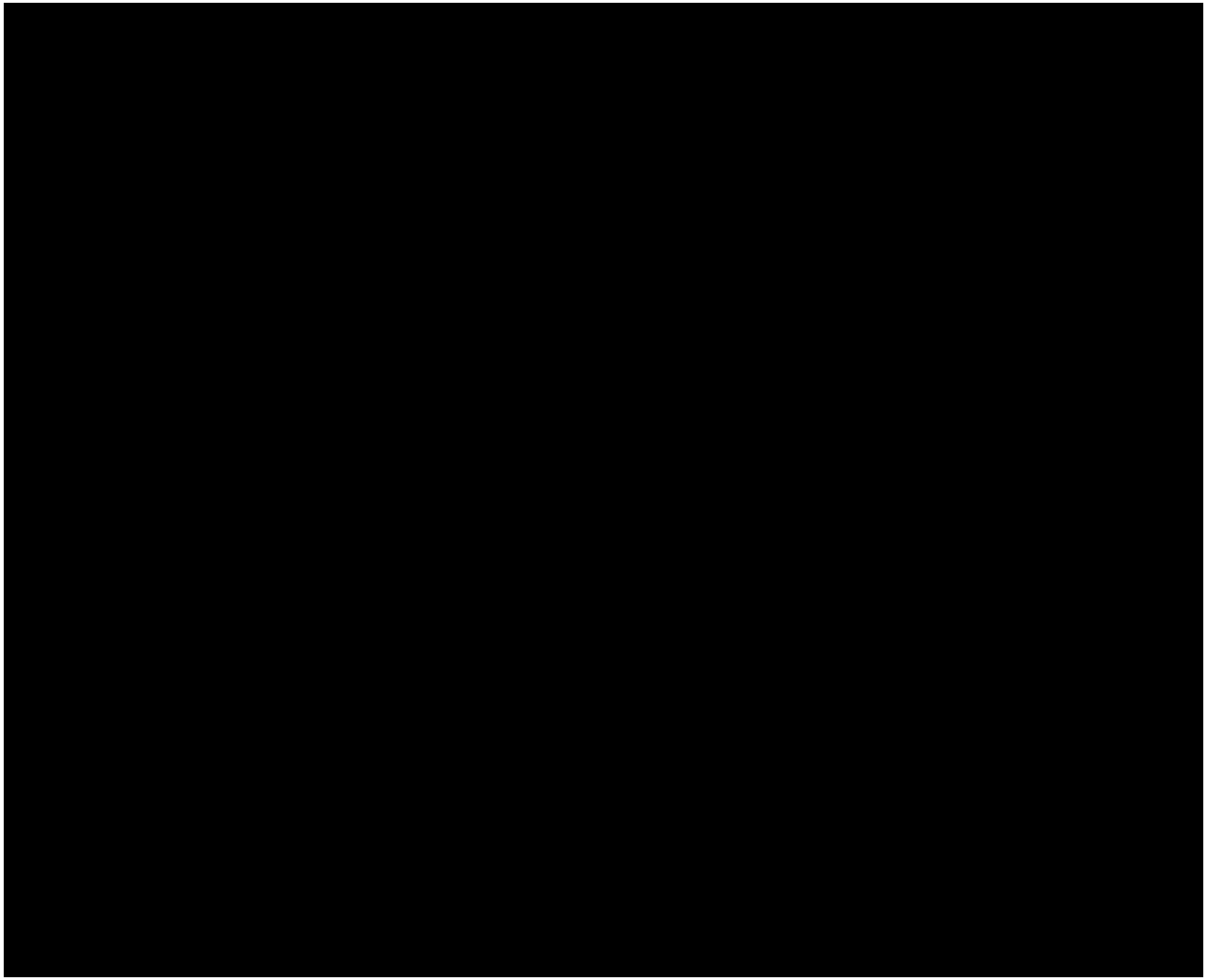


Endoscopic Sinus Surgery Planning System (From: [Krüger, 2008])
Realistic visualization of wetness effects for maximum similarity to intraoperative views

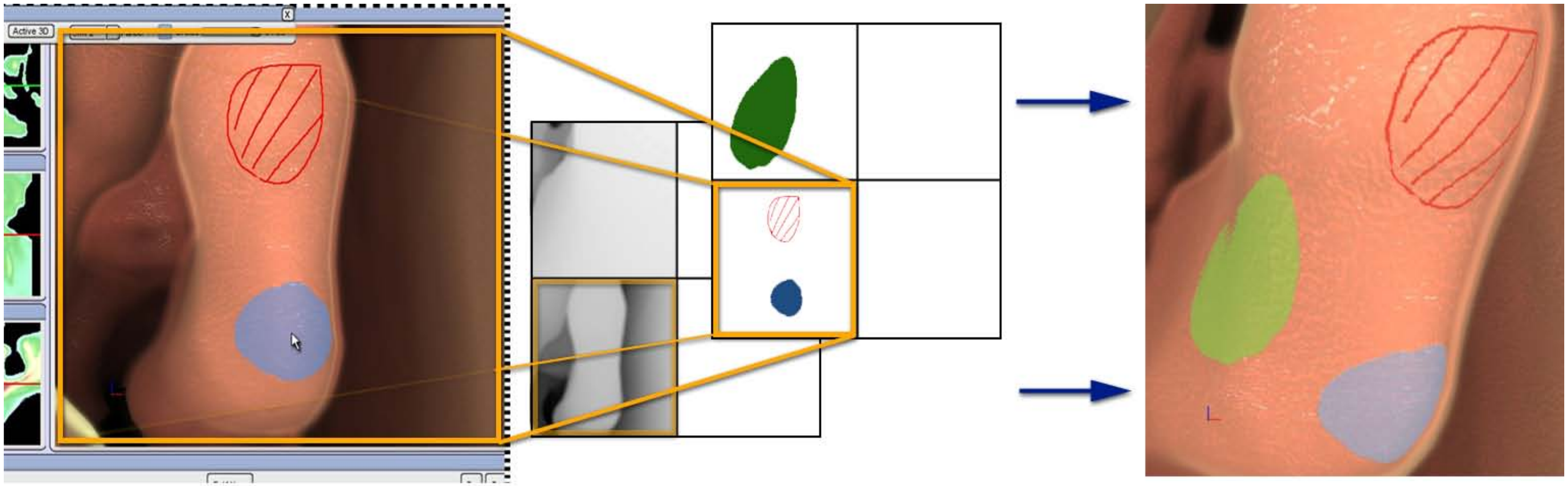
Applications: Functional Sinus Surgery



First user interface: too complex, too many settings and parameters. Improved UI applied to 125 patients (Krüger et al., 2008)

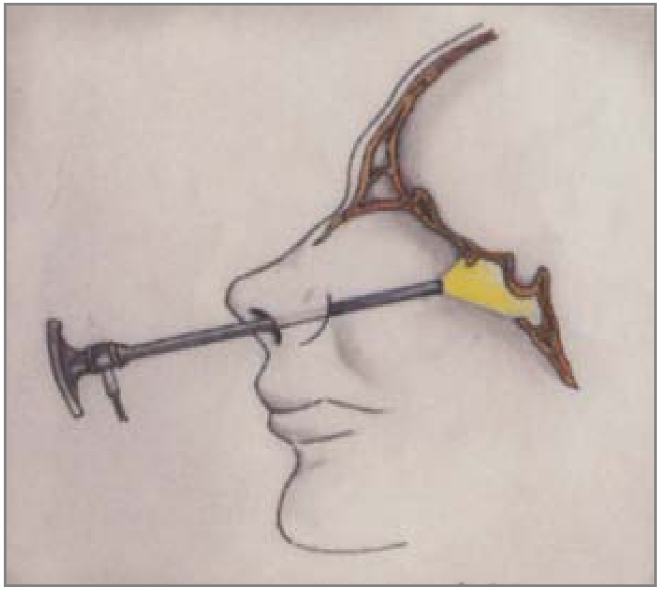


Applications: Functional Sinus Surgery



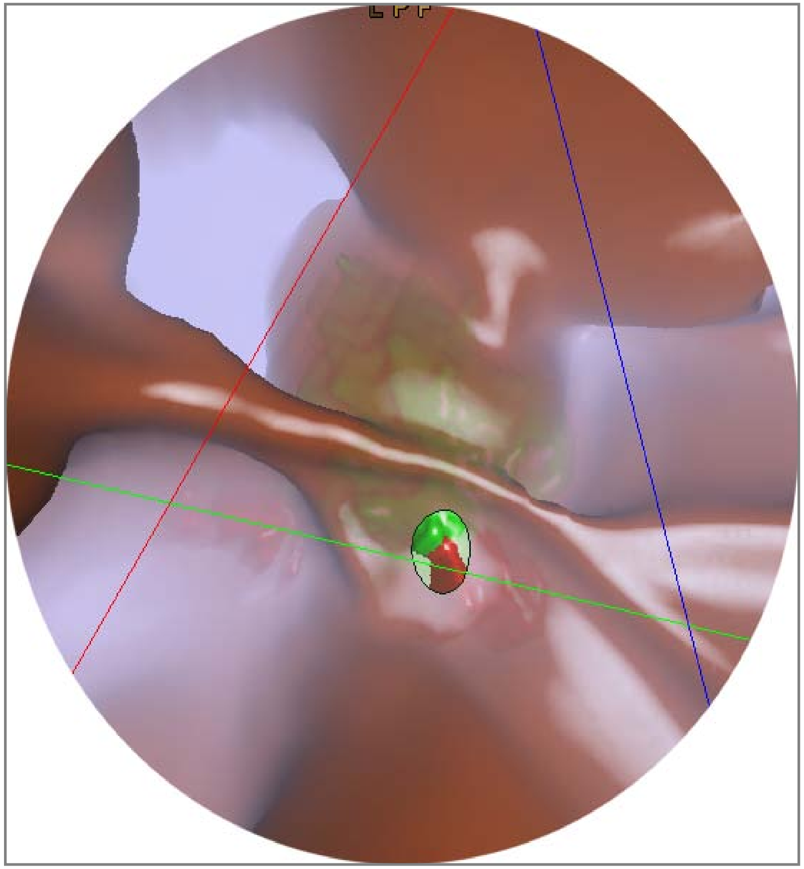
Feedback: Drawing and annotation facility is crucial for surgical planning and collaborative discussions.

Applications



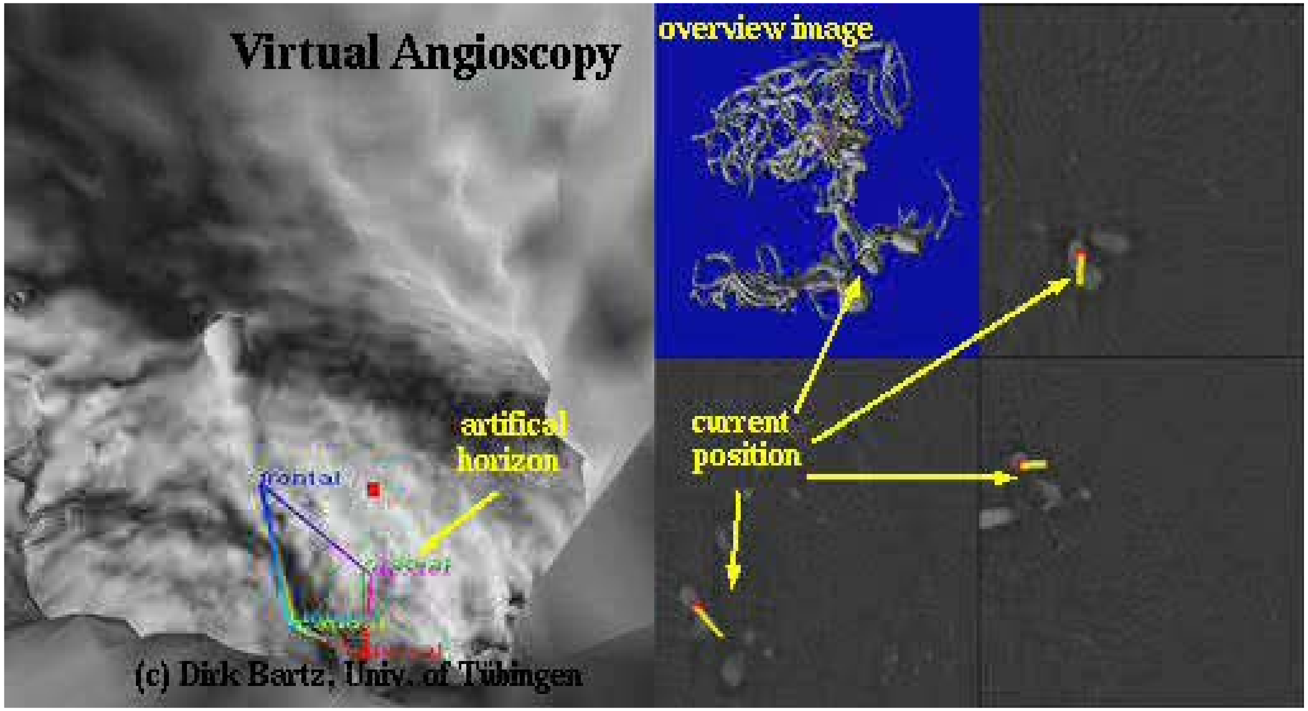
Virtual Endoscopy for Minimally-Invasive Surgery of the Pituitary Gland.

Benign tumors in this region are frequent and minimally-invasive removal is the state-of-the-art treatment. Several risk structures have to be considered.



Images are courtesy of André Neubauer, VRVis Wien.

Applications



Virtual endoscopy for diagnosis of cerebral aneurysms and planning neurointerventions (From: [Bartz et al. 2001])

Commercial Systems

Rendering, interaction and navigation techniques are similar to research prototypes. Careful integration in hospital information systems and clinical workflows are essential.

In particular, for virtual colonoscopy

- Philips EasyVision Endo 3D
- Viatroxnix V3D Viewer/Colon
- GE Advantage Winodws
- Vital Images Vitrea2/CT Colonography

Most of them

- use raycasting as rendering mode,
- provide (semi-)automatic path planning and
- guided as well as manual navigation

Conclusion

- Virtual endoscopy for intervention planning has great potential. However, the added planning time hampered wide-spread use so far.
- Requirements, with respect to accuracy, strongly depend on application area.
- Virtual endoscopy cannot be used when examination of tissue sample is necessary.
- Validation and clinical evaluation are crucial aspects. The book by Rogalla et al. (Virtual Endoscopy and Related 3D Techniques) provides an excellent overview on these aspects.

Acknowledgement

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- André Neubauer, Katja Bühler, VR Vis Wien
- Arno Krüger, Univ. of Magdeburg

References (1)

[Bartz 2001] D. Bartz, Ö. Gürvit, M. Lanzendörfer, A. Kopp, A. Küttner, and W. Straßer. Virtual Endoscopy for Cardio Vascular Exploration. In Proc. of ComputerAssisted Radiology and Surgery, pp. 960–964, 2001

[Bartz 2003] D. Bartz, D. Mayer, J Fischer, S Ley A del Rio, S Thust, CP Heussel, HU Kauczor, and Wolfgang Straßer. Hybrid Segmentation and Exploration of the Human Lungs. In Proc. of IEEE Visualization, pp. 177–184, 2003

[Bartz 2005] D. Bartz. Virtual Endoscopy in Research and Clinical Practice. Computer Graphics Forum, 24(1):111–126, 2005

[Fenlon 1999] H. Fenlon, D. Nunes, P. Schroy, M. Barish, P. Clarke, and J. Ferrucci. A Comparison of Virtual and Conventional Colonoscopy for the Detection of Colorectal Polyps. New England Journal of Medicine, 341(20):1496–1503,1999

[Han00] Han, P.; Pirsig, W.; Ilgen, F.; Gorich, J.; Sokiranski, R.: Virtual Endoscopy of the Nasal Cavity in Comparison with Fiberoptic Endoscopy. In: European Archives of Oto-Rhino-Laryngology 257 (2000), Nr. 10, pp. 578–583

[Hong97] Hong, L. ; Muraki, S.; Kaufman, A.; Bartz, D.; He, T.: Virtual Voyage: Interactive Navigation in the Human Colon. In: Computer Graphics 31 (1997), pp. 27–34

[Krüger07] A. Krüger, K. Stampe, B. Preim: Haptisch unterstützte Interaktion für die Operationsplanung von Nasennebenhöhlen-Eingriffen, Bildverarbeitung für die Medizin, pp. 341-345, 2007

[Krüger08] A. Krüger, C. Kubisch, G. Strauß, B. Preim: Sinus Endoscopy - Application of Advanced GPU Volume Rendering for Virtual Endoscopy. IEEE Trans. Vis. Comput. Graph. 14(6): 1491-1498 (2008)

References (2)

[Neubauer 2004] A. Neubauer, S. Wolfsberger, M. Forster et al. STEPS - An Application for Simulation of Transsphenoidal Endonasal Pituitary Surgery. In Proc. of IEEE Visualization, pp. 513–520, 2004

[Neubauer 2005] André Neubauer. Virtual Endoscopy for Preoperative Planning and Training of Endonasal Transsphenoidal Pituitary Surgery. PhD thesis, Technical University of Vienna, 2005

[Pickhard 2003] P. Pickhardt, J. Choi, I. Hwang et al.. Computed Tomographic Virtual Colonoscopy to Screen for Colorectal Neoplasia in Asymptomatic Adults. New England Journal of Medicine, 349(23):2191–2200, 2003

[Rogalla 2001] Rogalla et al., Virtual Endoscopy and Related 3D Techniques, Springer 2001

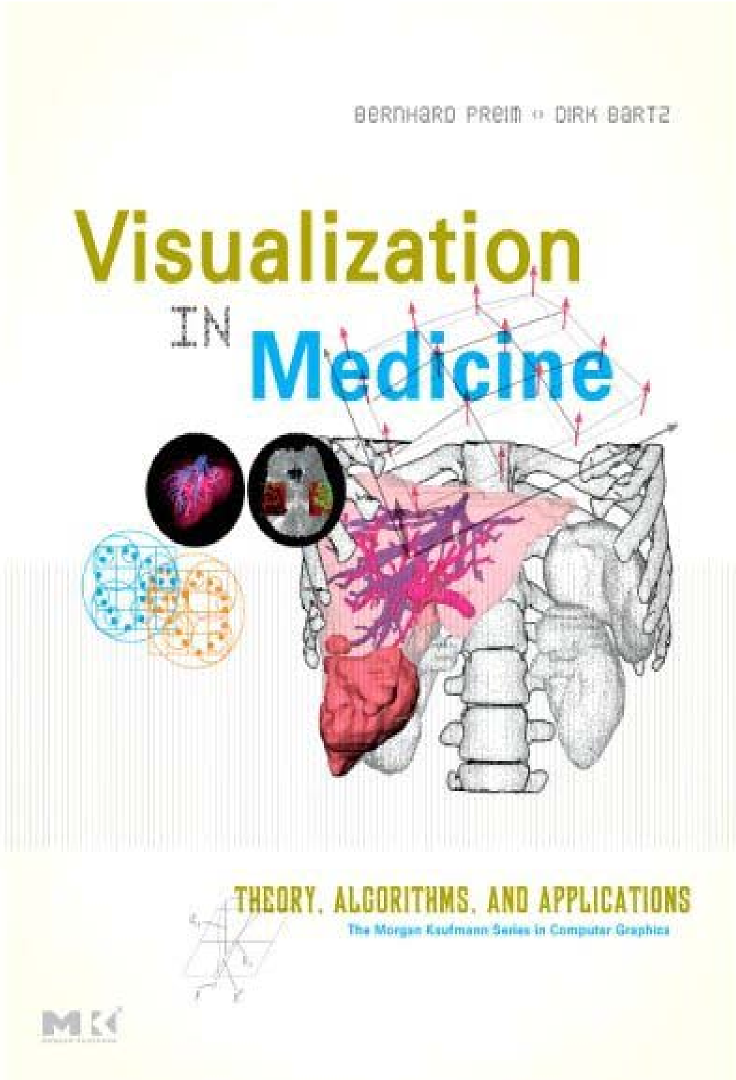
[Russ, 2010] C. Russ, C. Kubisch, F. Qiu, W. Hong, P. Ljung. Real-time Surface Analysis and Tagged Material Cleansing for Virtual Colonoscopy, Proc. of Volume Graphics 2010,

[Vilanova 1999] A. Vilanova, A. König, and E. Gröller. VirEn: Virtual Endoscopy System. Machine Graphics & Vision, 8(3):469–487, 1999

[Vilanova 2001] A. Vilanova, R.Wegenkittl, A. König, E. Gröller, and E. Sorantin. Virtual Colon Flattening. In Proc. of Eurographics/IEEE Symposium on Visualization, pp. 127–136, 2001

[Weghorst97] Weghorst, S.; Airola, C. ; Oppenheimer, P.: Formal Evaluation of the Madigan Endoscopic Sinus Surgery Simulator. University of Washing-ton, Human Interface Technology Laboratory. Technical Report R-97-34, 1997

More detail on all this



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4 Medical Volume Data in Clinical Practice
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9 Algorithms for Direct Volume Visualization
10 Exploration of Dynamic Medical Volume Data
11 Transfer Function Specification
12 Clipping, Cutting, Virtual Resection
13 Measurements in Medical Visualization
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15 Virtual Endoscopy
…