Visualisation, Rendering and Animation

2 VO / 1 KU

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Short videoversion Volume Rendering 2020

Graphics & Visual Computing

ACM Computing Curriculum

http://www.computer.org/education/cc2001/final/gv.htm

The area encompassed by Graphics and Visual Computing (GV) divided into 4 interrelated fields:

Computer graphics.
Visualization.
Virtual reality.
Computer vision.

Visualization

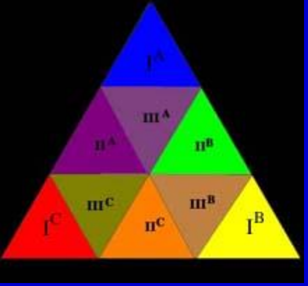
Visualization. ***The field of visualization seeks to determine and present underlying correlated structures and relationships in both scientific (computational and medical sciences) and more abstract datasets.***

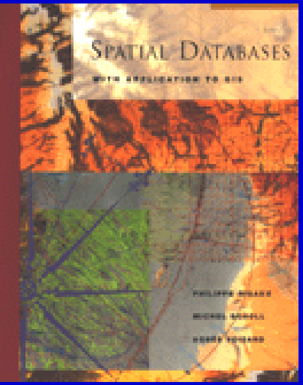
The prime objective of the presentation should be to communicate the information in a dataset so as to enhance understanding.

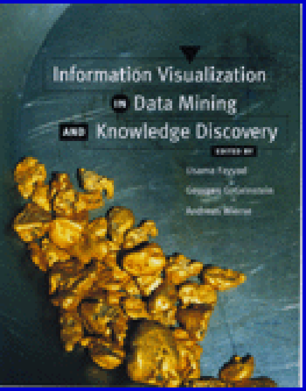
Although current techniques of visualization exploit visual abilities of humans, other sensory modalities, including sound and haptics (touch), are also being considered to aid the discovery process of information.

Xmas: https://www.cg.tuwien.ac.at/xmas/

Ch. Zach - ICG/VRVis

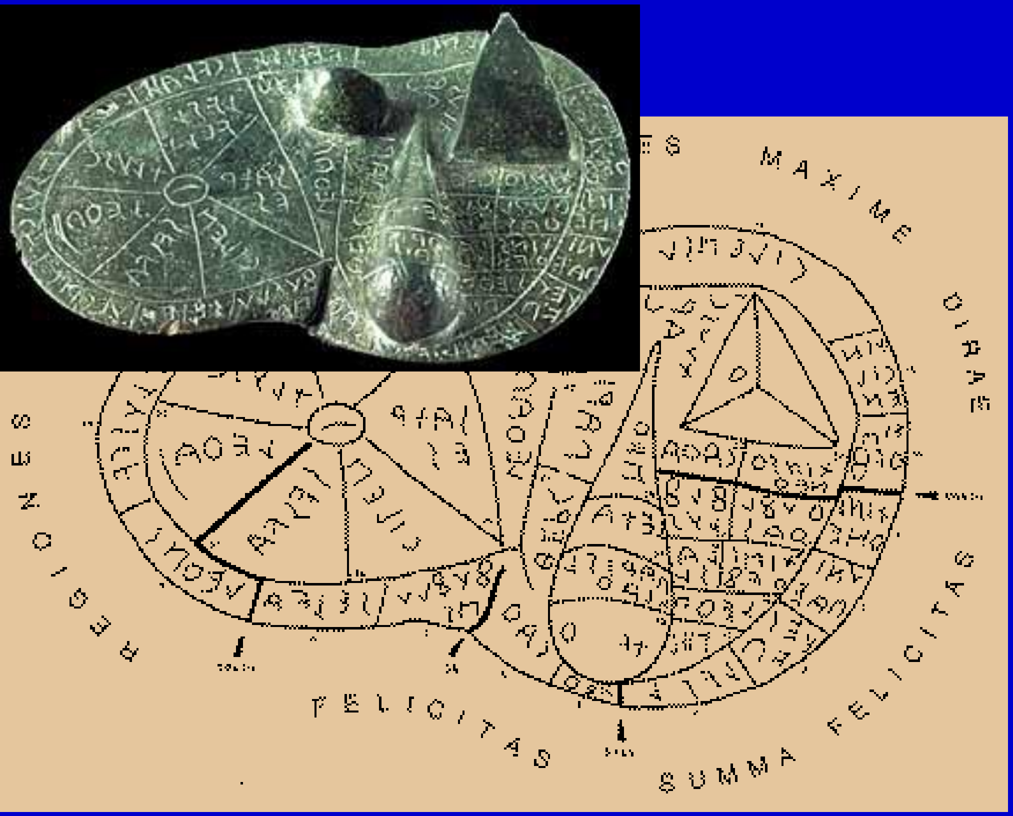






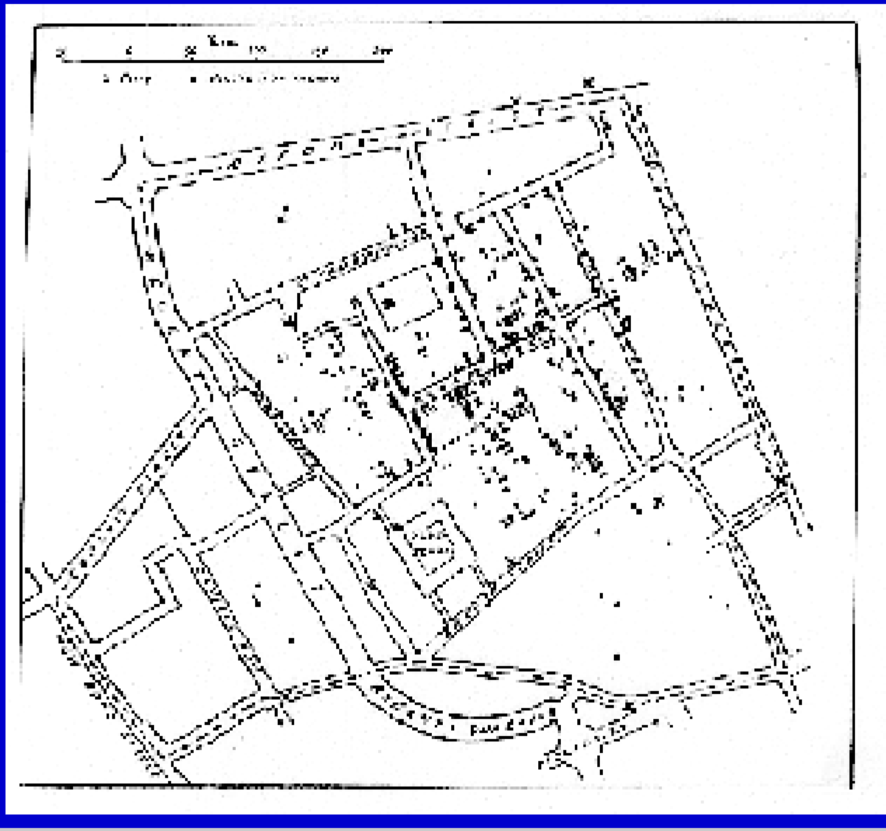
Da Vinci

Etruscan Liver, Cholera in London



Sheep Liver & Names of Gods

http://www.ou.edu/class/ahi4163/files/bronz12.html



The idea of representing data visually has been around for much longer than computer based visualisation. The linking of the spread of cholera to water supply provides an early example of the use of visualisation in problem analysis. During the 1853-54 cholera outbreak in London, Dr. John Snow identified a large grouping in the Soho area. He went on to plot the homes of the 500 victims who died in the first 10 days of September 1854 on a map of the area. This simple representation of the data he had collected showed that the grouping of cholera sufferers in the area was centred round a particular water pump. Investigation of this water pump established that it had been contaminated by a leaking cesspool.

Visualization

- (Scientific) Visualization… InfoVis

“The purpose of computing
is insight not numbers“
Richard Hamming

Visualization Goals

- *exploration/exploitation of data and information*
- *enhancing understanding of concepts and processes*
- *gaining new (unexpected, profound) insights*
- *making invisible visible (underlined by A. F.)*
- *effective presentation of significant features*
- *quality control of simulations, measurements*
- *increasing scientific productivity*
- *medium of communication/collaboration*
- *… and many others*

http://www.uni-paderborn.de/fachbereich/AG/agdomik/visualisierung/vis-report/tutorial/chapter1/tsld011.htm

Visualization Topics

ACM CC: Visualization: Topics:

- ***Basic viewing and interrogation functions for visualization***
- ***Visualization of vector fields, tensors, and flow data***
- ***Visualization of scalar field or height field: isosurface by the marching cubes method***
- ***Direct volume data rendering: ray-casting, transfer functions, segmentation, hardware***
- ***Information visualization: projection and parallel-coordinates methods***

Vis. Educational Goals

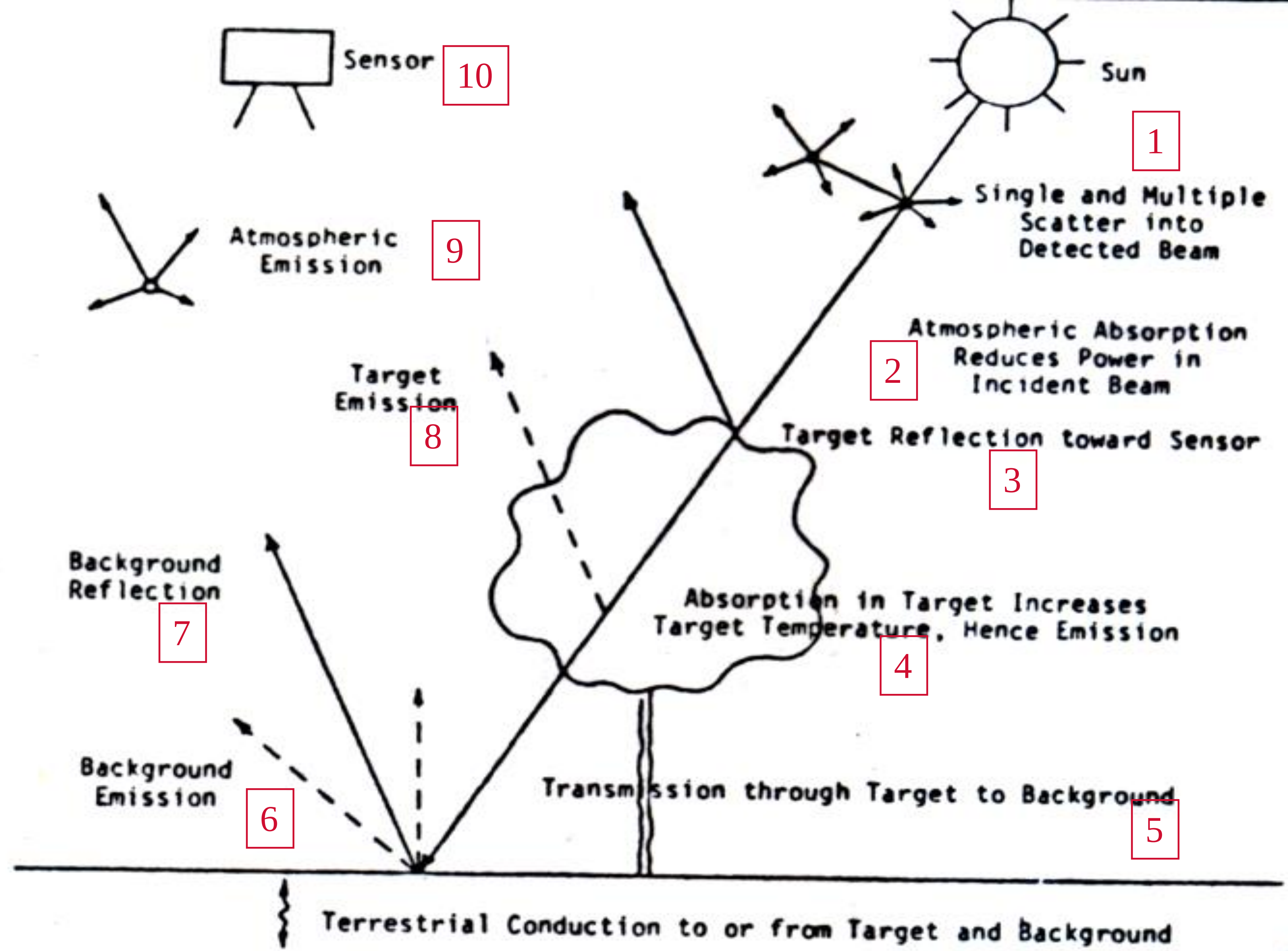
ACM CC: Visualization: *Learning objectives:*

- ***Describe the basic algorithms behind scalar and vector visualization.***
- ***Describe the tradeoffs of the algorithms in terms of accuracy and performance.***
- ***Employ suitable theory from signal processing and numerical analysis to explain the effects of visualization operations.***
- ***Describe the impact of presentation and user interaction on exploration.***

A Note on Light-Object Interaction

Figure 1: Spring Conference on Computer Graphics 1999 Proceedings cover page design motif, courtesy Jozef Martinka.

However, there are at least five various processes: 1. reflection, 2. transmission, 3. absorbtion, 4. emission, and 5. atmosphere. And, at least, ten different light-object interactions: (sun), 1. single and multiple scatter into detected beam, 2. atmospheric absorbtion, 3. target reflected toward sensor (here contributes the specular term), 4. absorbtion in target, 5. transmission through target, 6. background emission, 7. background reflection, 8. terrestrial conduction to or from target and background, 9. atmospheric emission, and 10. sensor [Lebe02]. Most of the ten light-object interactions are hidden in the ambient part of the lighting equation, including the very very questionable assumption that the light distribution in the scene is constant. The remaining two contributions are diffuse and specular ones. And the computationally cheaper Gouraud shaded images look blend…

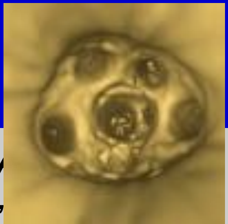

Sensor
10
Sun
1
Single and Multiple
Scatter into
Detected Beam
Atmospheric
Emission
9
Atmospheric Absorption
Reduces Power in
Incident Beam
2
Target
Emission
8
Target Reflection toward Sensor
3
Background
Reflection
7
Absorption in Target Increases
Target Temperature, Hence Emission
4
Background
Emission
6
Transmission through Target to Background
5
Terrestrial Conduction to or from Target and Background

Simplifying Illumination Model

- **Simplification of physical model:**
- **Light transport theory model (Maxwell)**
- **Rendering Equation (heat, Kajiya)**
- **Volume Rendering Equation**
- *Low-Albedo Situation (Ray Casting / Volume Rendering)*
- **Empiric models and heuristics**

Complexity ↓

- **Slide Idea by Dirk Bartz, Graz 2004, LIGHT?**



Rendering Spectrum

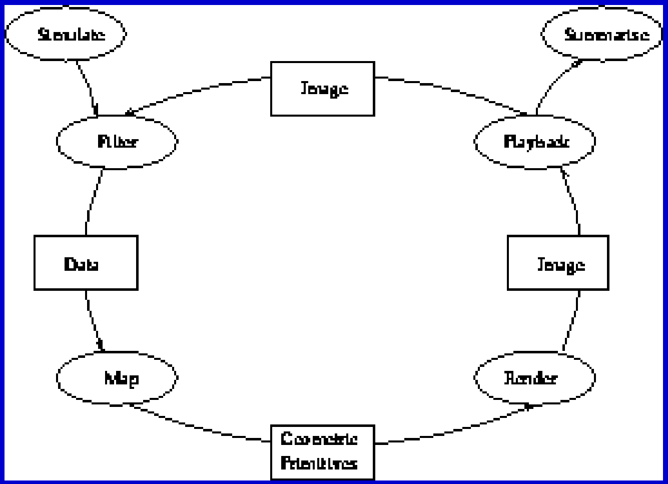
- *Images* — *Geometric models*
- *Appearance based* — *Physically based*

↔

- ***Lumigraph, light field, sprites, layers, bilboards, triangles, global illumination***

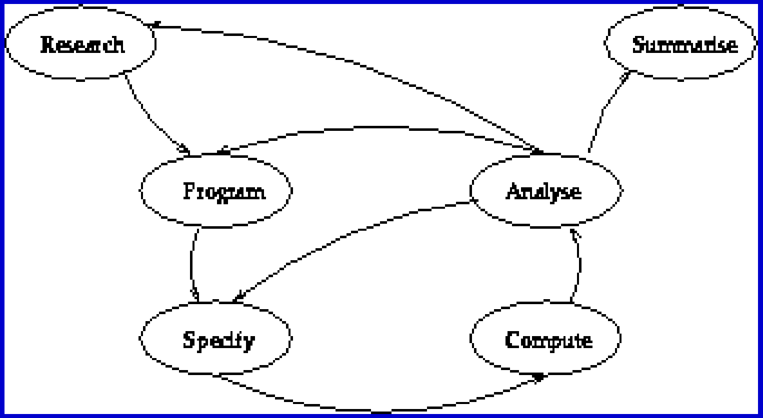
-
- *J. Lengyel 1998 Siggraph Paper, Haines-Moeller*

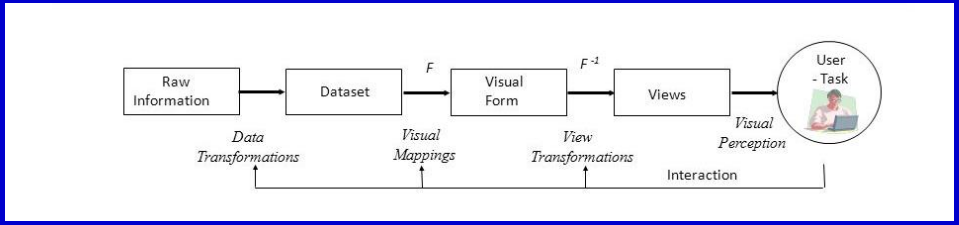
Visualization Workflows



Computational cycle

Analysis cycle





Data State Model [Chi]

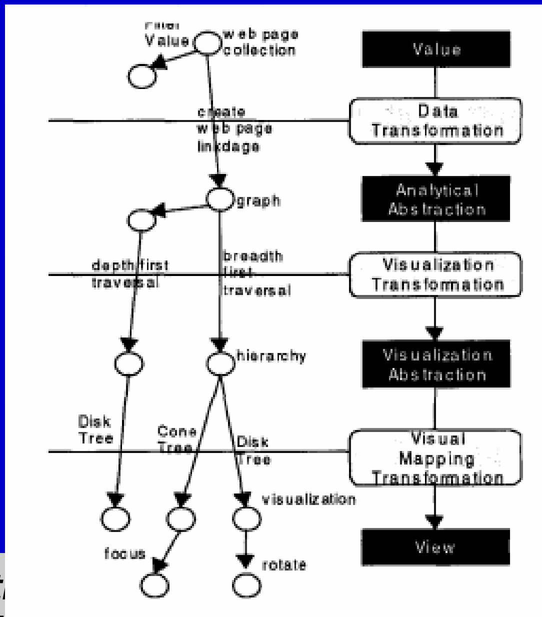
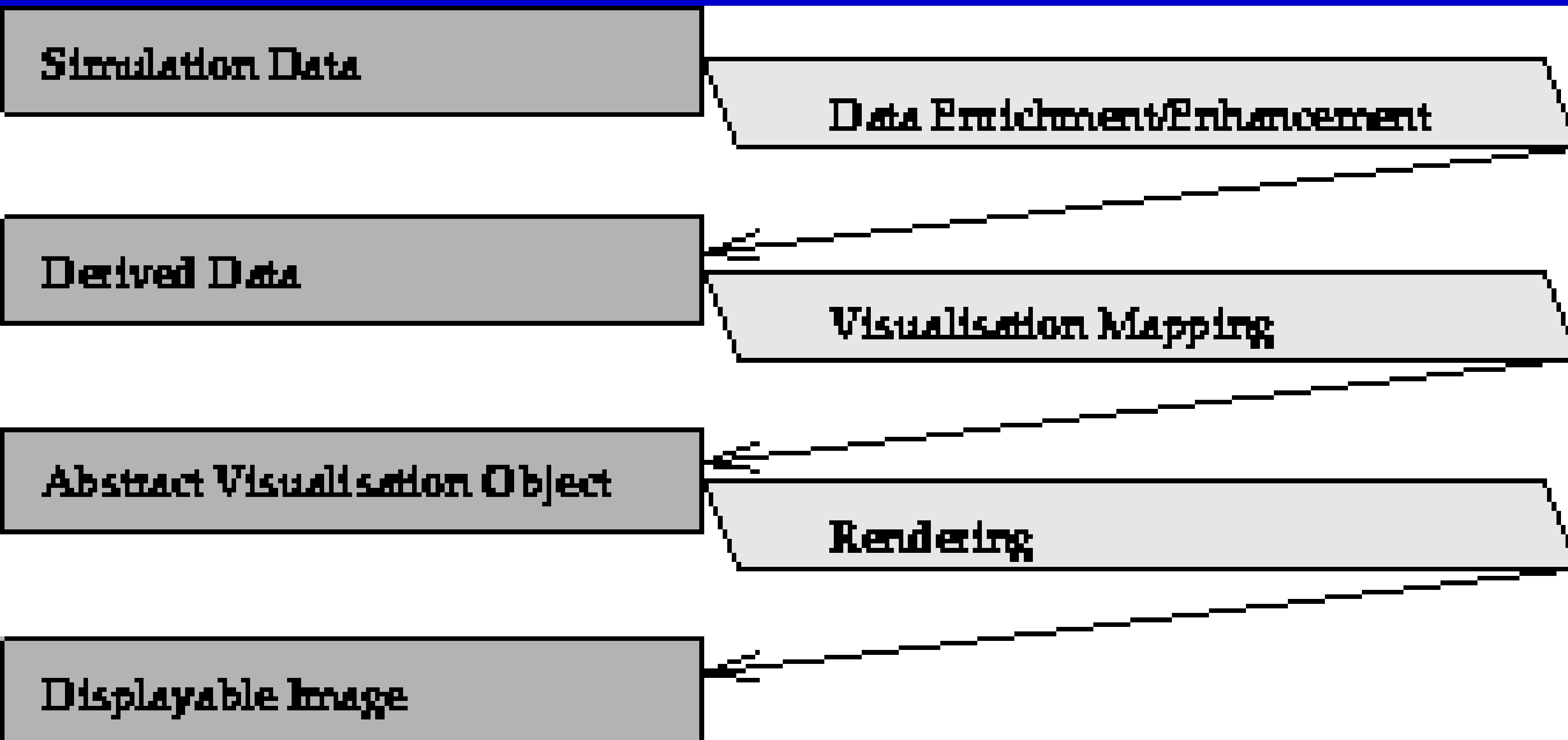


Figure 2: Data State Model applied to Web sites

Visualization Pipeline



Visualization of Data

- **1D**
- **2D**
- **3D**
- **4D**
- **nD**

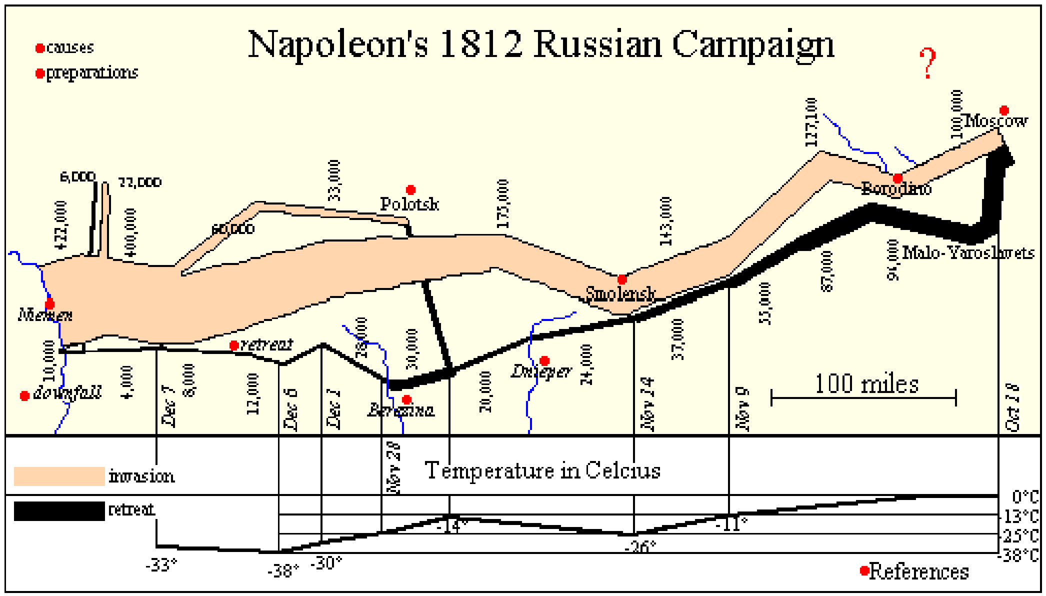
"to visualize":

form a mental vision, image, or picture of (something not visible or present to sight, or of an abstraction); to make visible to the mind or imagination

The Oxford English Dictionary

March of the Napoleon Army

Examples of Visualization



This graphic is an adaptation of M. Charles Joseph Minard´s „March of the Napoleon Army" by Sunny McClendon, as part of an Information Design Class at the University of Texas at Austin.

1D

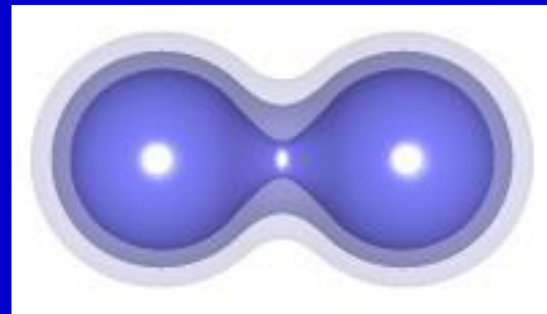
Earth in the Night

2D

http://antwrp.gsfc.nasa.gov/apod/ap001127.html

Volume .. Surface

sampled data



geometric model

3D reconstruction

image synthesis

discrete voxel space

isosurfacing

voxelization

continuous geometric space

volume rendering

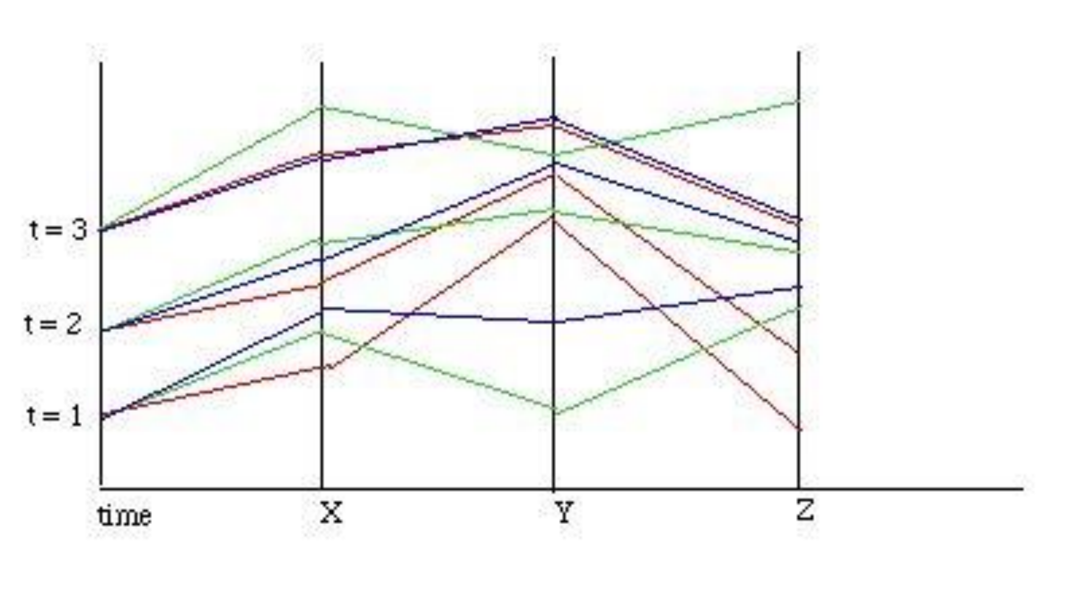
surface rendering

image

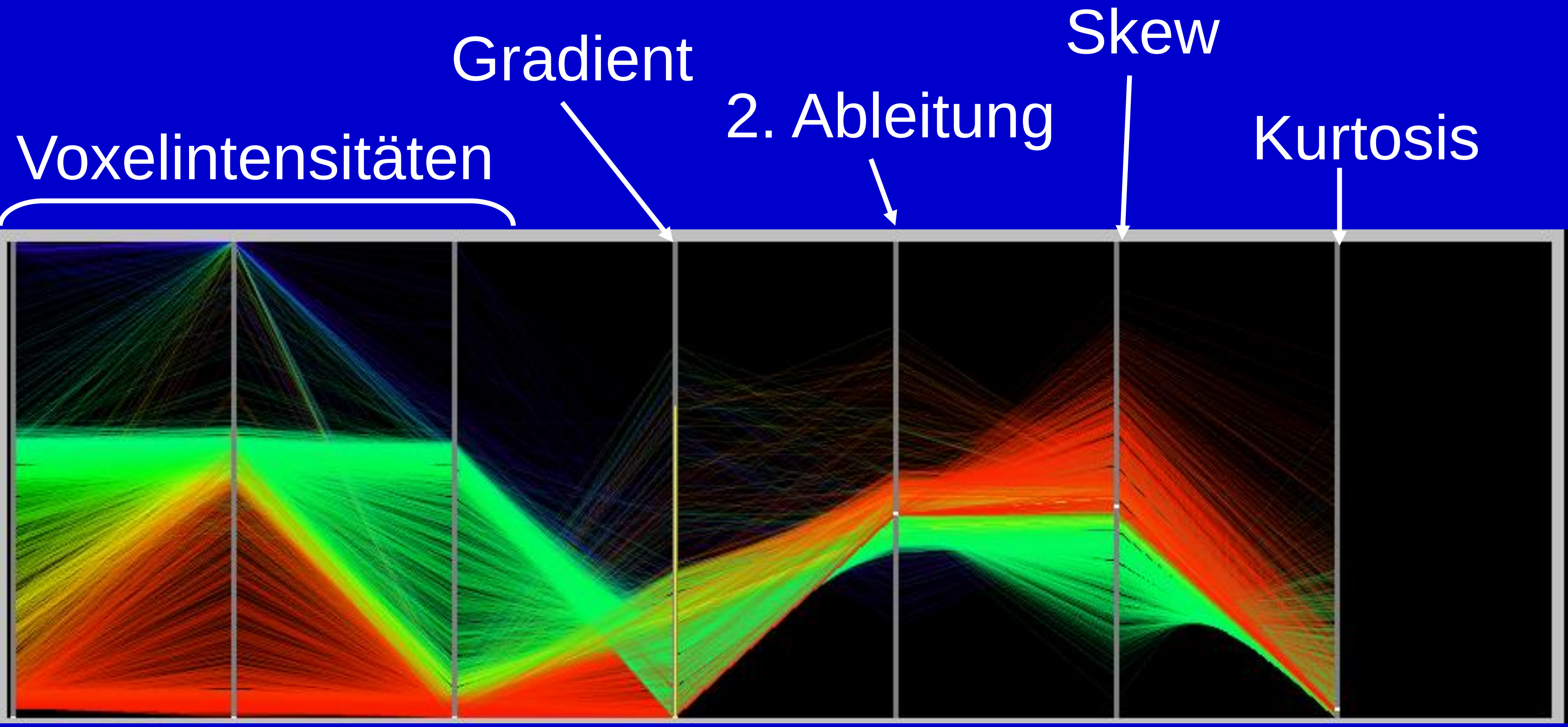
3D

Parallel Coordinates

- INSELBERG, A. DIMSDALE, B. 1990. "Parallel Coordinates: A Tool for Visualizing Multi-Dimensional Geometry," Proc. of the First IEEE Conference on Visualization. 361 (1990).
- ***http://www.caip.rutgers.edu/~peskin/epriRpt/ParallelCoords.html***



Volumendarstellung (19), Dr. Bartz



Human memory system [SHN97]

Short-term memory capacity:

- ***"The magical number seven - plus or minus two" (G. Miller, 1956) recognize seven "chunks" of information hold for 15 to 30 seconds forget or move to long-term memory***
- ***Short-term memory in conjunction with working memory***
- ***short term memory:*** *process perceptual input*
- ***working memory:*** *generate and implement solutions*
- *disruptions, anxiety cause loss of information*

http://www.uni-paderborn.de/fachbereich/AG/agdomik/visualisierung/vis-report/tutorial/chapter3/tsld012.htm

Human Visual System

- ***Self-defense and Survival:***
  - ***(sound, fast brain/amygdala)***
  - ***1. motion !!!***
  - ***2. shape (the longest vertical one first)***
  - ***3. color, texture, „structure“***
  - ***4. symbols recognition***
  - ***5. meaning .. ambiguity .. more***

Visualisation: Nutshell

- Problem-observe-model-simulate-analyze-solution
- Simulate/observe-filter-map-transform-display-analyze
- Scenarios: movie mode, tracking, interactive post-processing, steering
- Data: nominal (biological classification), quantitative
- Scalar fields, vector fields, tensor fields
- Coordinate representations: cartesian, curvilinear, special
- Data connectivity: scattered data (grid free), gridded 2/3D
- Grids: cartesian, structured, block.structured, hybrid
- Math models: linear, non-linear, discrete, iterative, ODE, PDE, integral, integro-differential

Visualisation: Nutshell

- *Representation - display of numerical data in visual form*
- *Select: shape, color, composition, dynamics, efficiency, interactivity, expressiveness… multi-faceted issue*
- *Ideas from: art, perception, cognition, GUI, design, computer graphics and image processing… „rennaisance teams“ (Donna Cox)*
- *Representation Types:*
- *Scalar: volume, isocontour, height field, scatter lot, image, contour plot, strip chart…*
- *Vector: ribbon, particles, hedge-hog, arrow plot*
- *Tensor: disk&shaft, ellipsoid*
- *Multivariate/nD: attribute mapping, glyphs (nature metaphors)*

Example 1: Particles

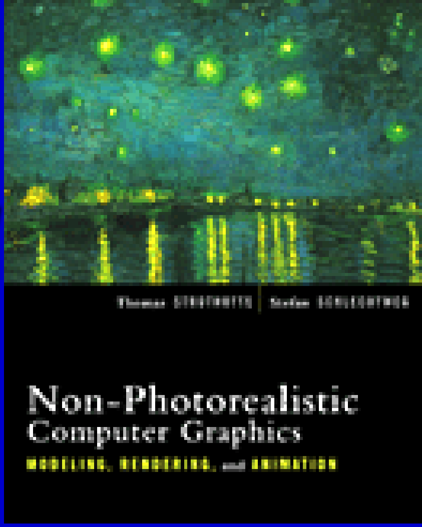
- 1. Release particle
- loop
- 2. Interpolate field to obtain velocity at particle location
- 3. Move particle
- 4. Display particle

- 1. Randomly, interactively, rake, screen mesh…
- 2. Interpolate using weighted sum
- 3. Move using forward Euler approximation
- $x(t+dt) = x(t) + dt * u(x(t), y(t))$
- $y(t+dt) = y(t) + dt * v(x(t), y(t))$
- 4. Particle attributes: color, trasparency, shininess… – particle tracing, streamlines, flow line, streak line, path line… it depends

E2: Algorithm Animation

- Book by M. Brown
- Historical survey by Hausner&Dobkin
- Algorithm: static-written, dynamic-runtime, default values, initialisation, profiling, history of each variable, ...
- Multiple views: global & local zoom, visual output, ...
- Speed: step by step, normal run
- Prepared input data for demos
- Error behavior, interactivity
- Automatic algorithm animation, input: C code, output: animation

E3: NPR, expressive..



- **NPR: non-photorealistic rendering** (Gooch&Gooch – the first book)
- **NPR >> expressive rendering [Hughes 34]**
- **3 types of abstraction:** simplify, factorize, schematize
- Mesh edges, silhouette, ridges, valleys…

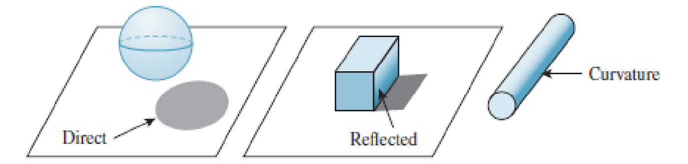
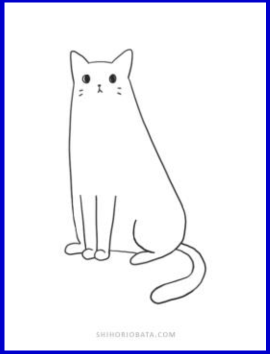
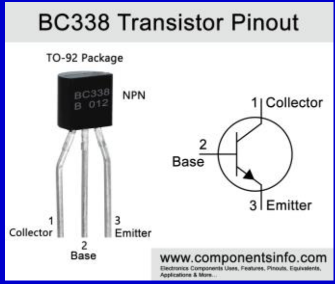


Figure 34.2: Three kinds of shadows (left to right): direct shadow, reflected shadow, and curvature shadow.

(b)





NPR Visualization

- http://mrl.nyu.edu/projects/image-analogies/artistic.html **(SIGGRAPH 2001)**

Vis – Open Problems

- Open Metaproblem – Success Story Missing
- 2 of 7 Millenium Prize Problems 2 000 000 $
- P = NP, includes Hamiltonian graphs
- Navier-Stokes equations: breeze & turbulence
- DNA Structure Understanding – Human Genome
- Hans Hagen – feature based visualization
- nD ~ Multidimensional >> SVAKOG

Vis – Conclusions 2

- 1D, 2D .. nD
- Animation
- Sonification
- InfoViz
- ...

"to visualize":

form a mental vision, image, or picture of (something not visible or present to sight, or of an abstraction); to make visible to the mind or imagination

The Oxford English Dictionary, 1989

Vis – Conclusions 3

- Strong Metaphors:
- Johny Mnemonic = NEUROMANCER
- Final Fantasy Surgery Scene
- Matrix or Holodeck in 2070?
- Augmented Reality 2018 GeoGebra
- Snow Crash? (cited by D. Schmalstieg)

Volume Rendering

Medical Visualization Success Story

Agenda

Medical Volume Visualisation

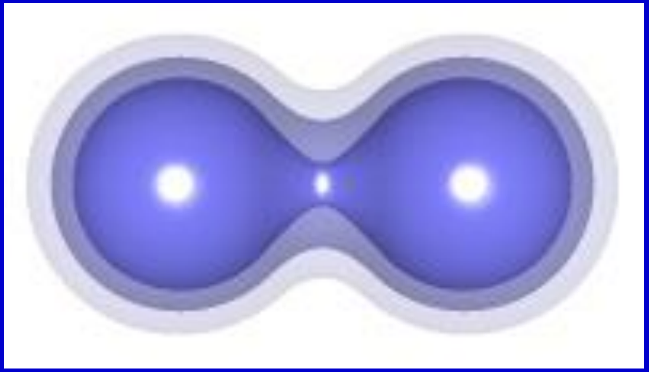
- Motivation
- Definitions
- Marching Cubes
- Contour Connectivity
- Segmentation
- Animation

Volume Graphics

Chen - Kaufman - Yagel (Eds.) 2000.

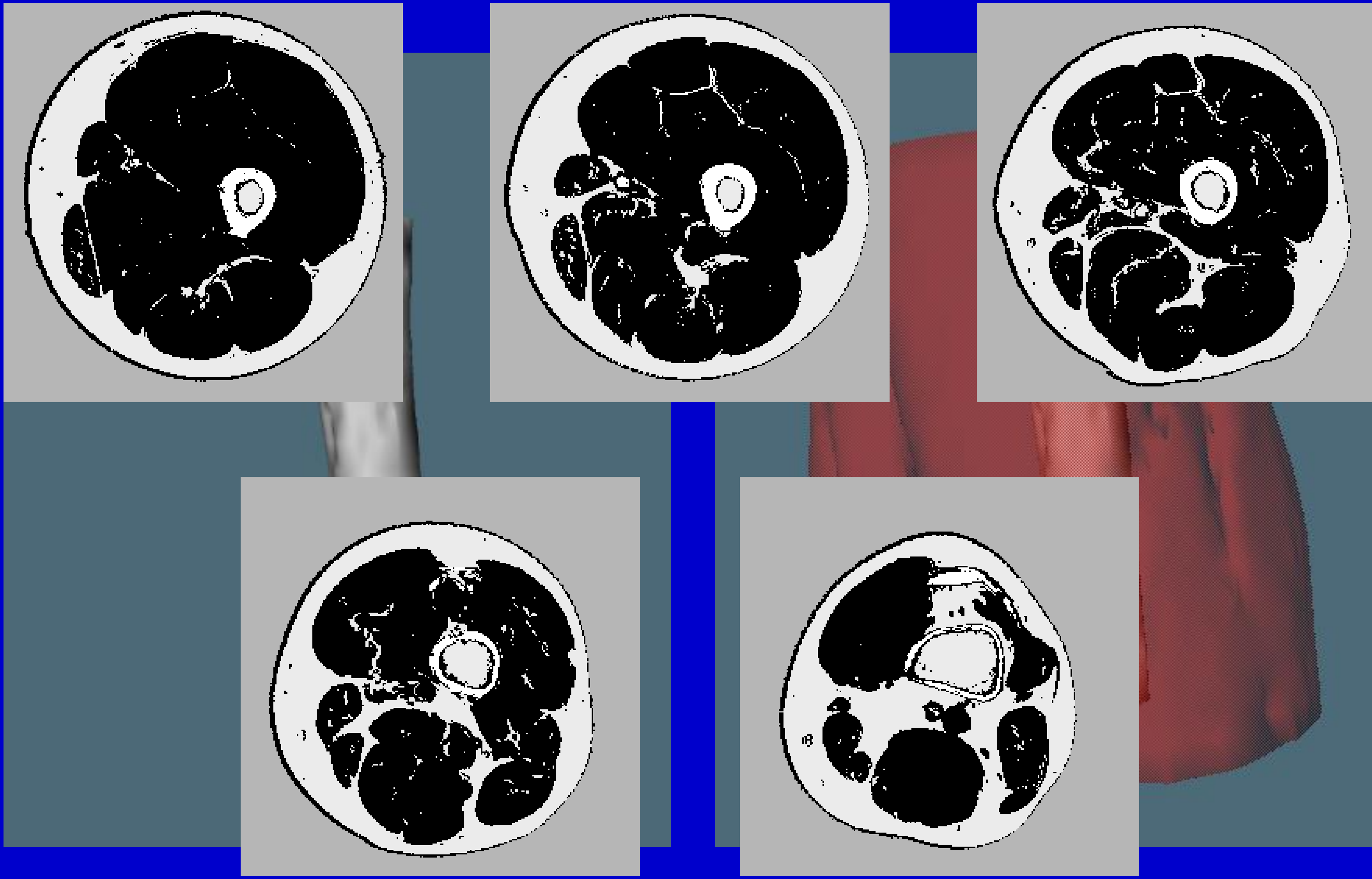
- Perspectives
- Discrete Modeling
- Complex Volumetric Objects, CVG (CSG)
- Volume Rendering
- Volume Animation
- Parallel & Distribute Environments
- Applications

Volume Graphics

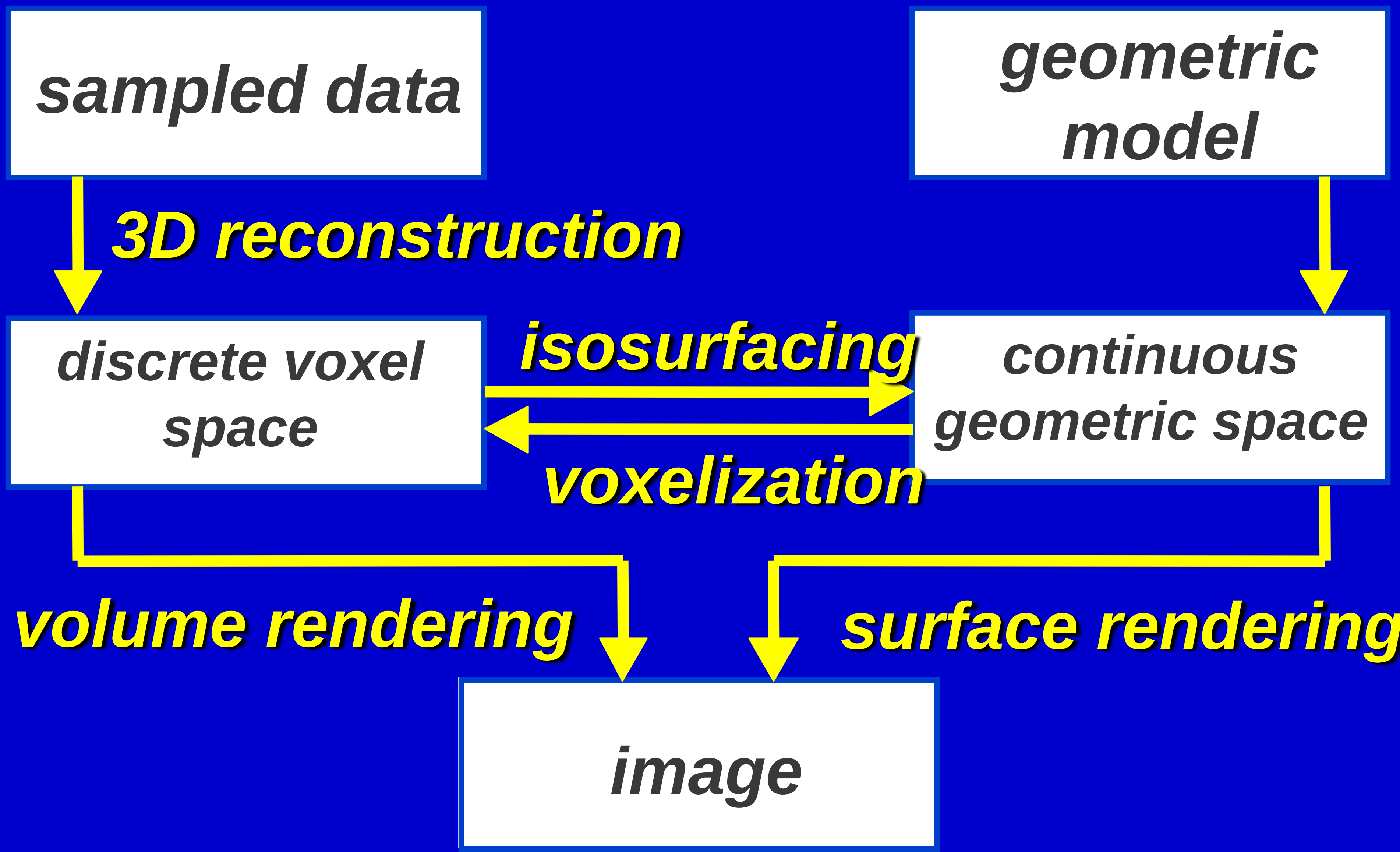


Gallery at e.g.:

- http://www.imm.dtu.dk/~janba/gallery/texvolvis.html
- **Book:**
  - ***Chen et al.***
  - ***London: February 2000***



Notations


sampled data
geometric model
3D reconstruction
discrete voxel space
isosurfacing
continuous geometric space
voxelization
volume rendering
surface rendering
image

Volume Visualization Algorithms

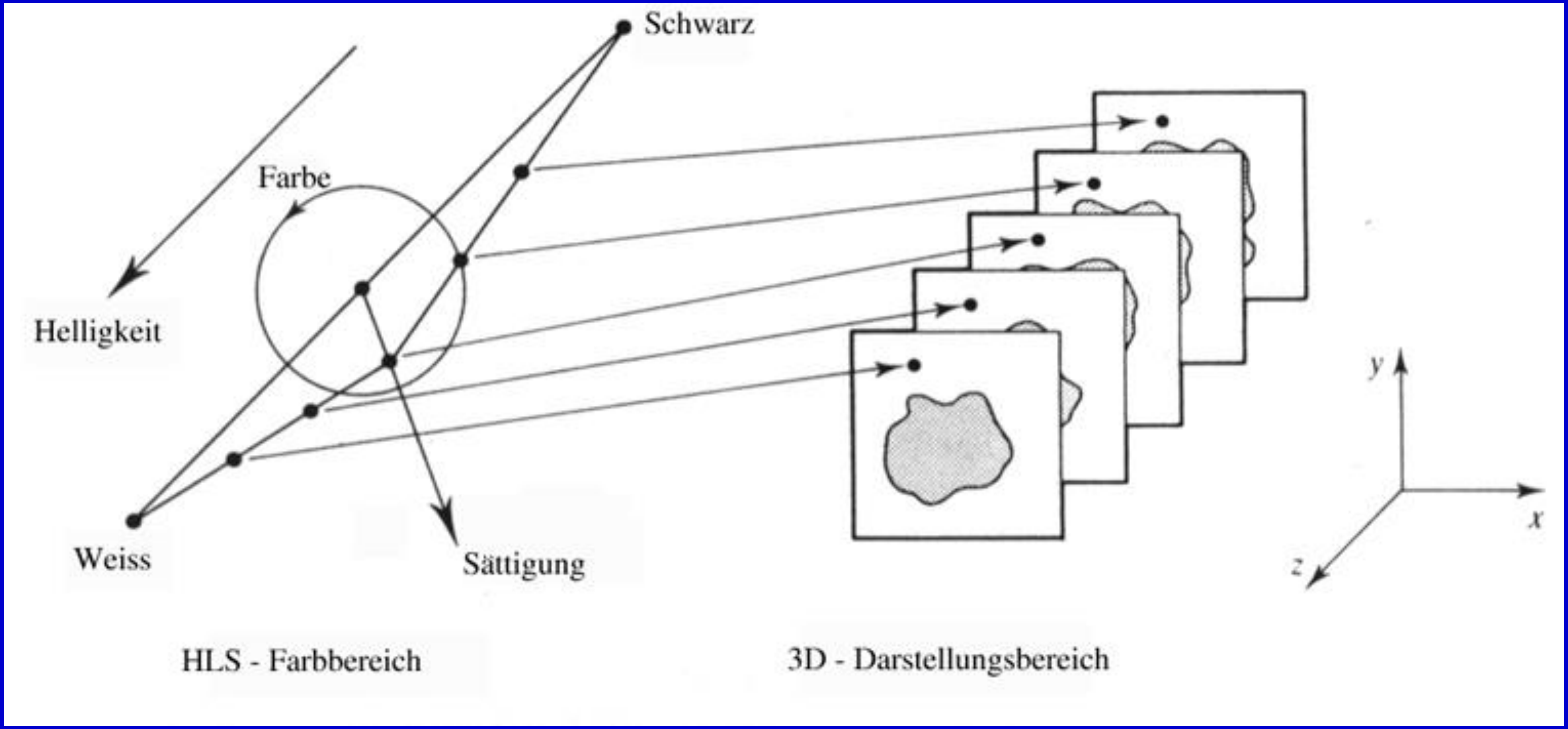
producing a surface	direct volume rendering	
	projection methods	image oriented methods
cuberille	v-buffer	ray casting
contour connecting	splatting	cell integration
marching cubes	slice shearing	sabella
dividing cubes		
march. tetrahedra		

The First Method

- **Binary Partitioned Space**
  - binar partition of human organ
  - extract the polygon surface
  - shaded representation using z-buffer
  - improve the visual
  - quality using
  - central difference-gradients:

$$\nabla V = \begin{pmatrix} \frac{1}{2}\left(V\left(x_{i+1}, y_j, z_k\right) - V\left(x_{i-1}, y_j, z_k\right)\right) \\ \frac{1}{2}\left(V\left(x_i, y_{j+1}, z_k\right) - V\left(x_i, y_{j-1}, z_k\right)\right) \\ \frac{1}{2}\left(V\left(x_i, y_j, z_{k+1}\right) - V\left(x_i, y_j, z_{k-1}\right)\right) \end{pmatrix}$$

2.5D Pseudo-color



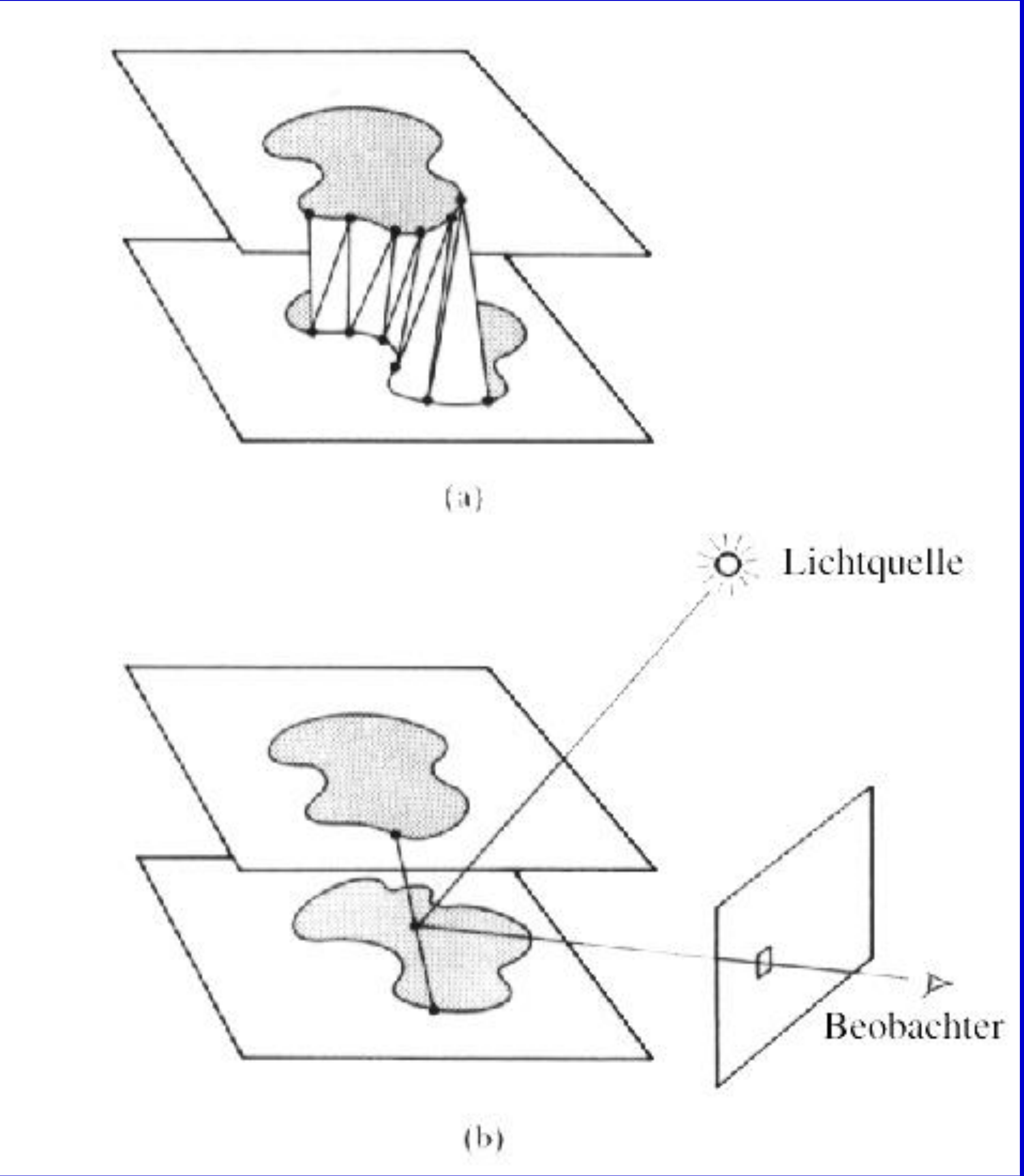
Methods with Inbetween Structures

Idea: Create the geometric representation utilizable/displayable using standard graphics libraries functionality.

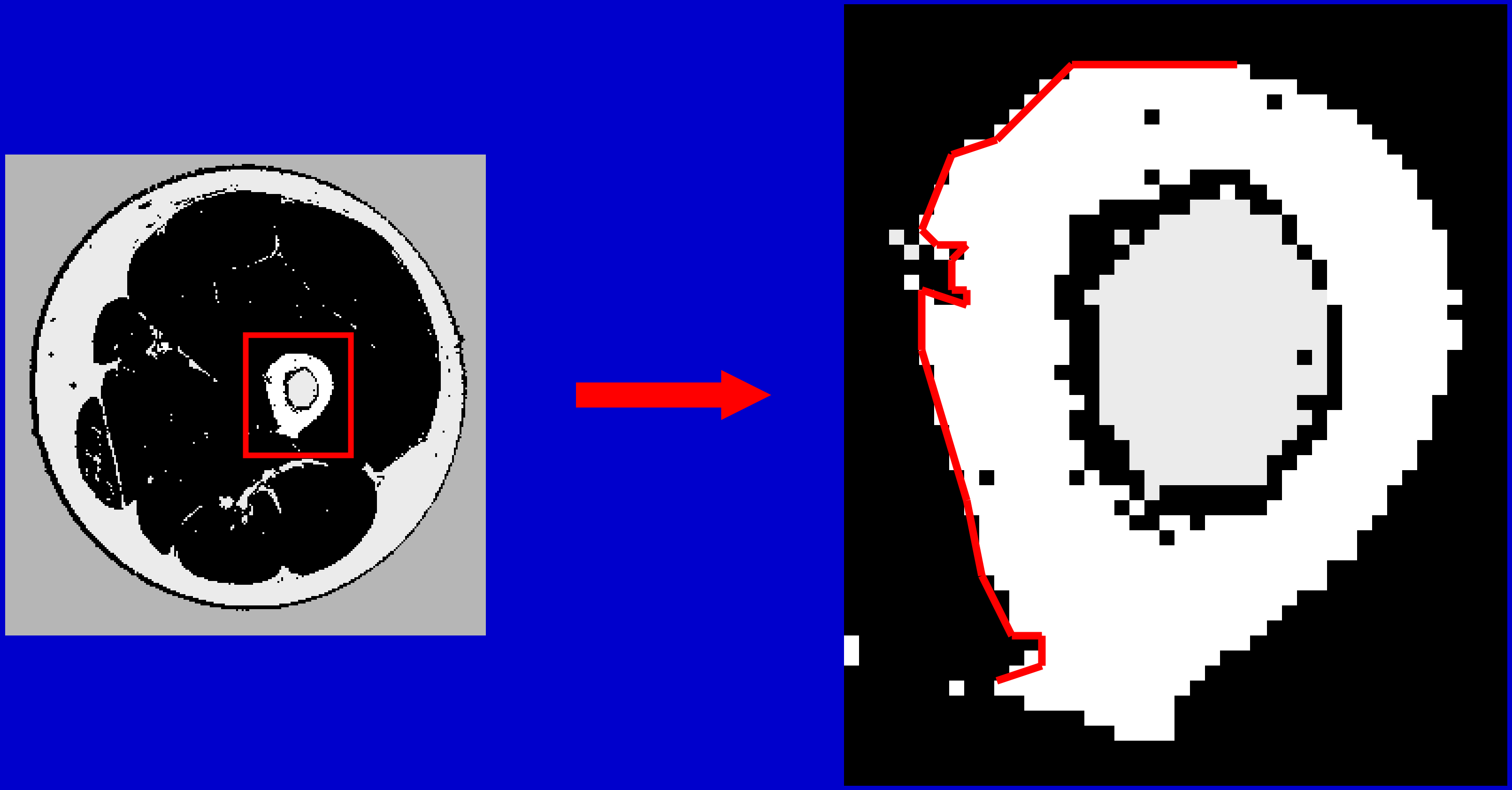
Method:

- extract the contours from 2D slices and connect them by surface
- Isovalue Surface Detector (Marching Cubes)

Drawback: interactive change of tissue type hard resp. costly

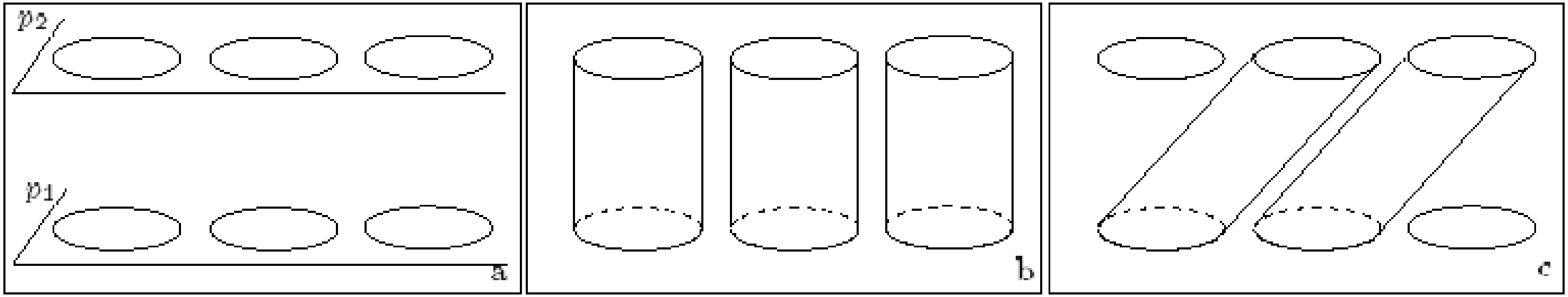

(a)
Lichtquelle
Beobachter
(b)

Contour Artifacts



Contour Connection

- Layered images segmentation
- Contour lines generation
- Geometry building
  - Connecting
  - 3D Delaunay (for parallel contours)



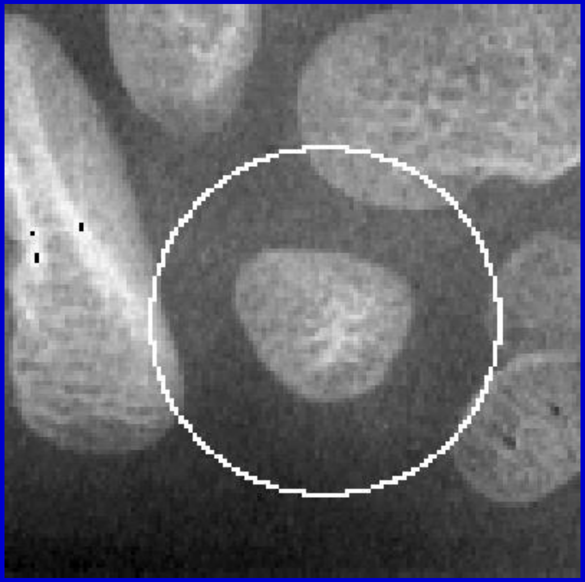
Segmentation

- **Surface-based Method**
  - Threshold value setting
  - Region growing
  - Split and Merge (see Quad-Tree)
  - Blobs – Scale Space
- **Edge-based Method**
  - Filter operations (create gradients, ...)
  - Active contour models (snakes)

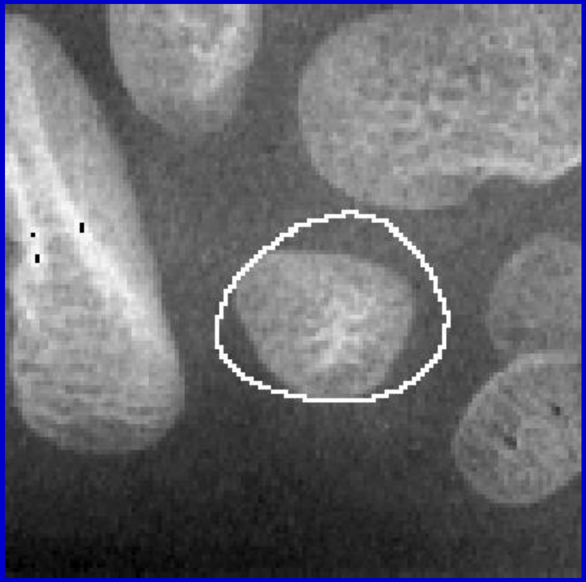
Snakes

- Define contour lines using splines
- Iterative energy minimisation
- Total energy:
  - internal contingents (tangents, curvature)
  - external contingents (graylevels, gradients)
- Advantage:
  - choice of initial conditions

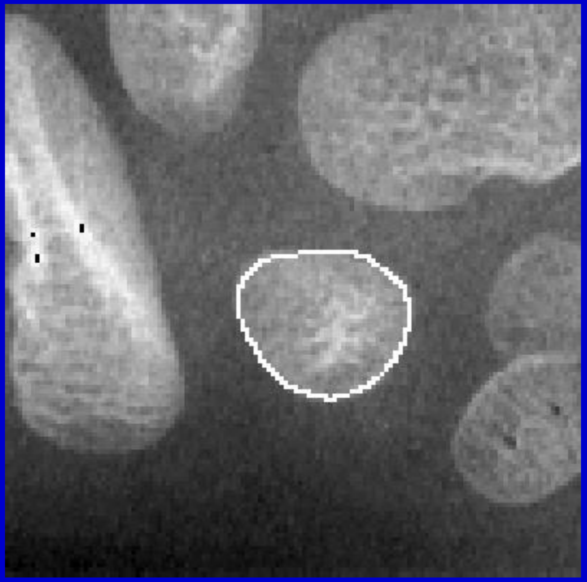
Snakes (M. Urschler, ICG)



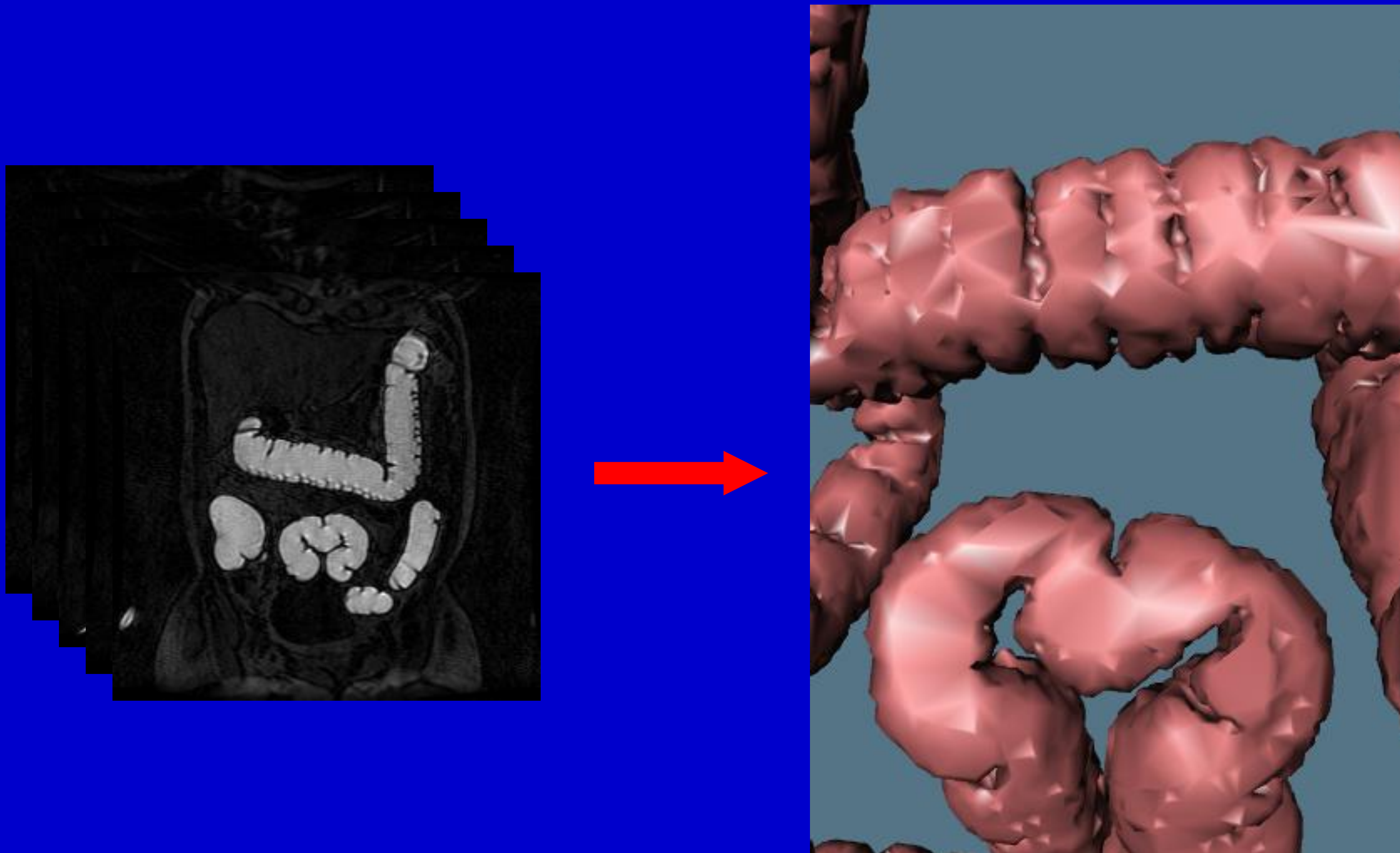
Initialise



Deform



Converge



Marching Cubes

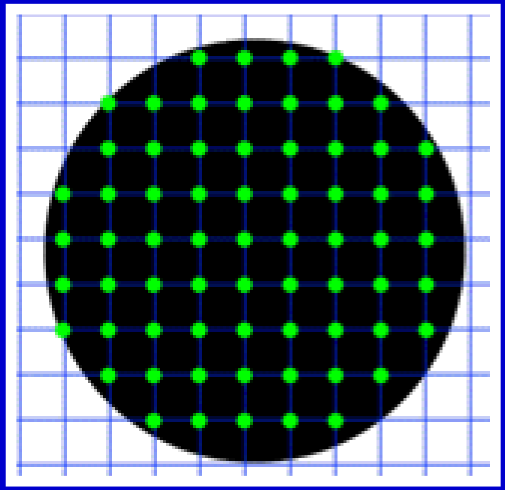
Algorithm:

Step 1: Find by thresholding the densities in given voxels („Flood Fill“-like method)

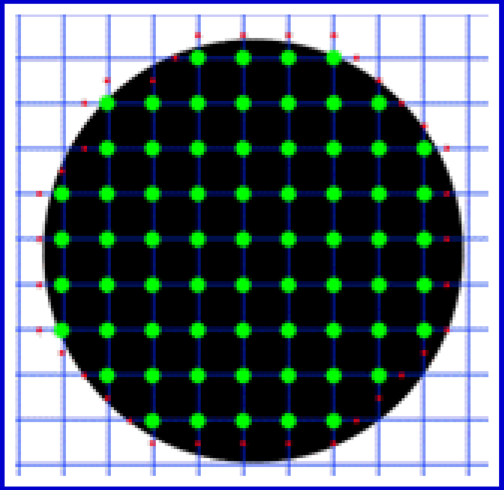
Step 2: Extract the surface through IN/OUT relation of the voxel corners. 8 corners ≊ 256 possible variations for the spanning surface parts

Disadvantage: One threshold per volume (eventually heuristics)

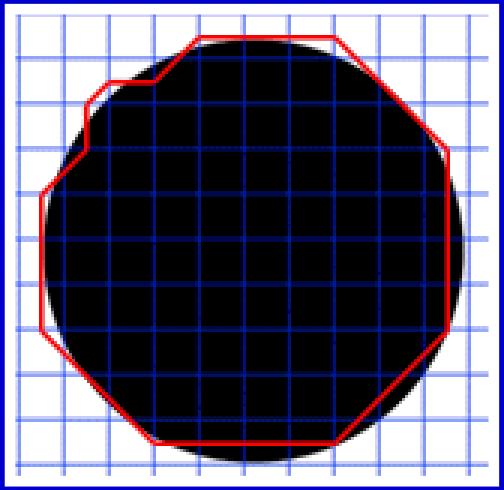
2D Example



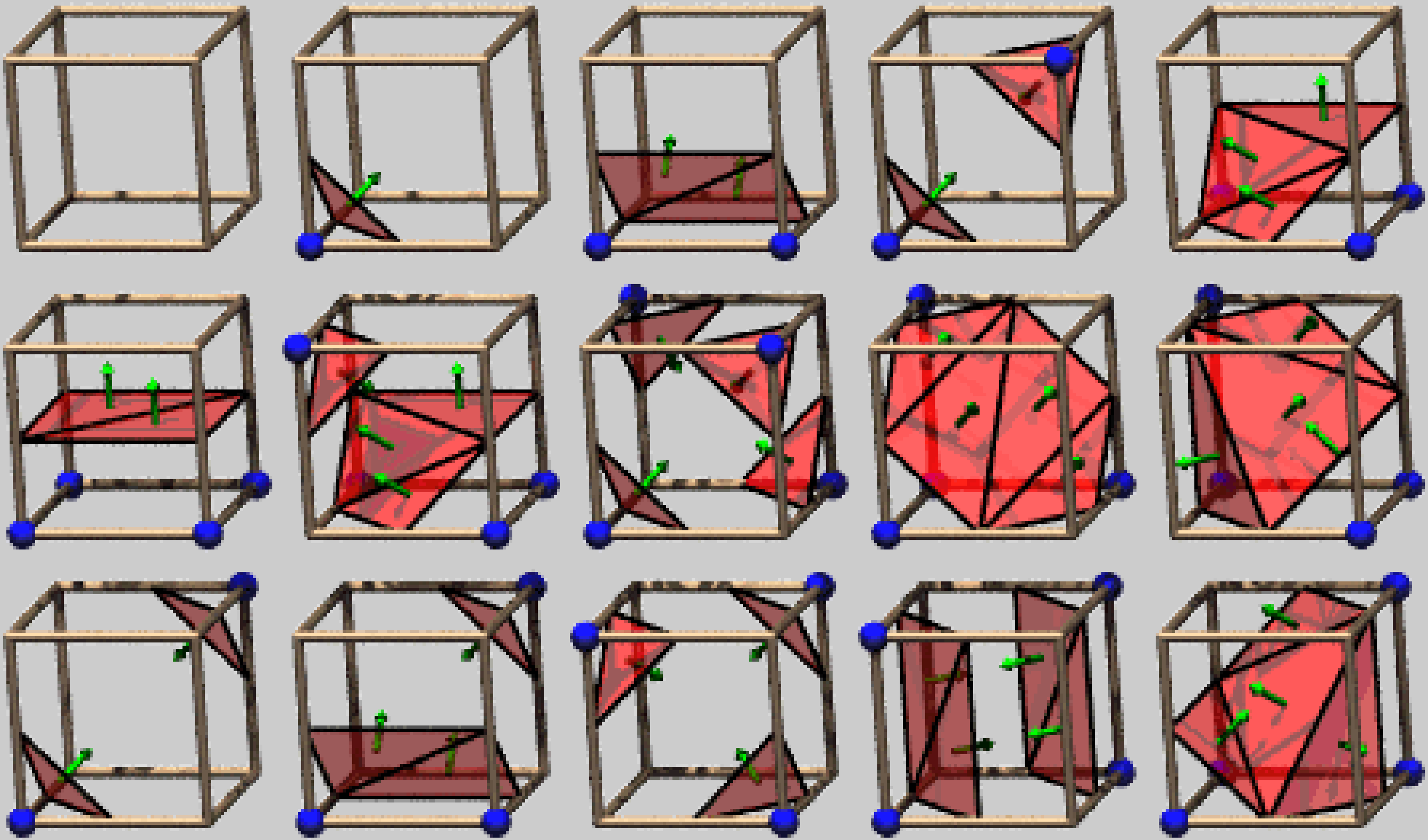
Original



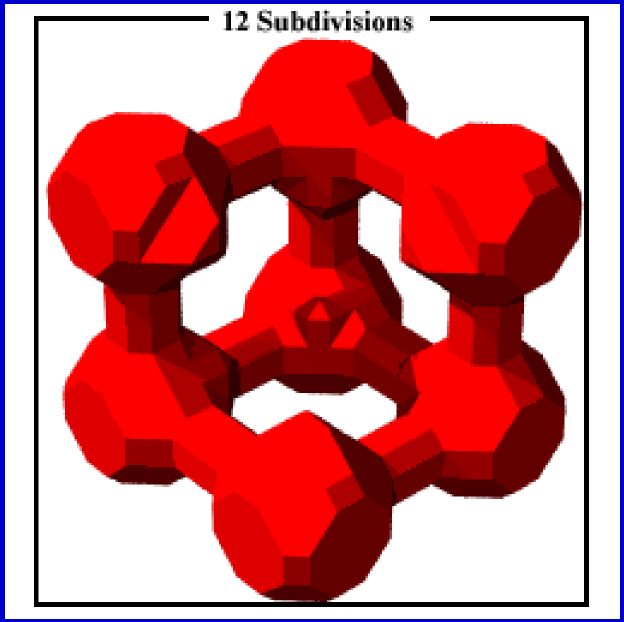
Raster Points

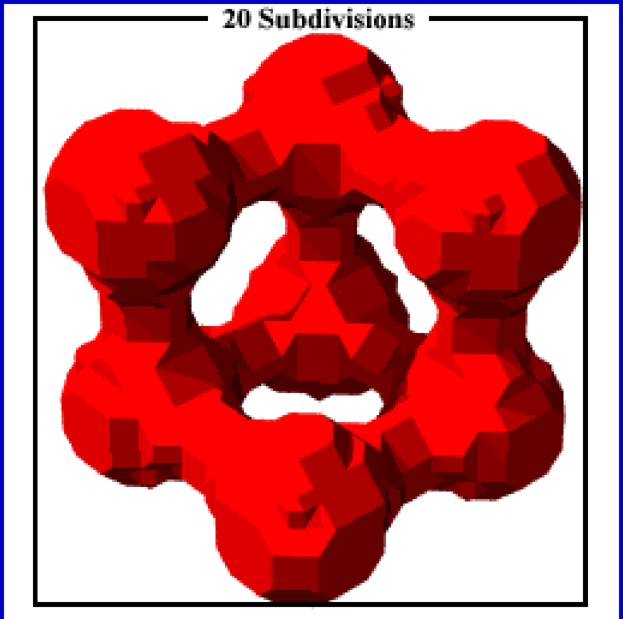


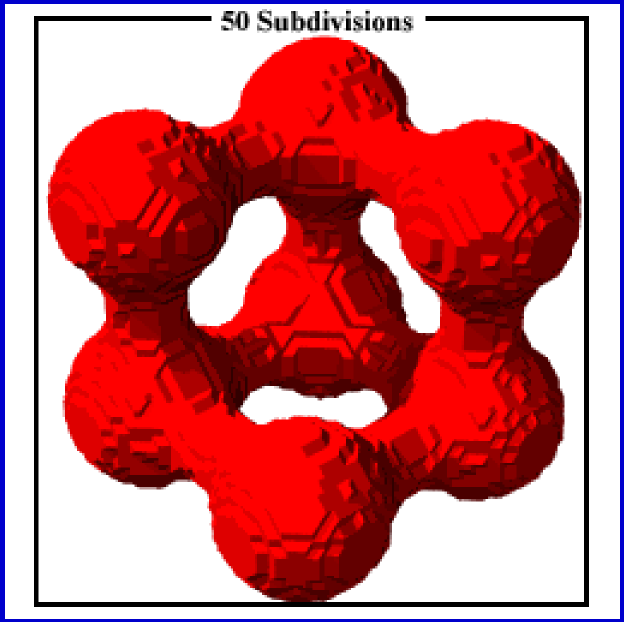
Contour Extracted

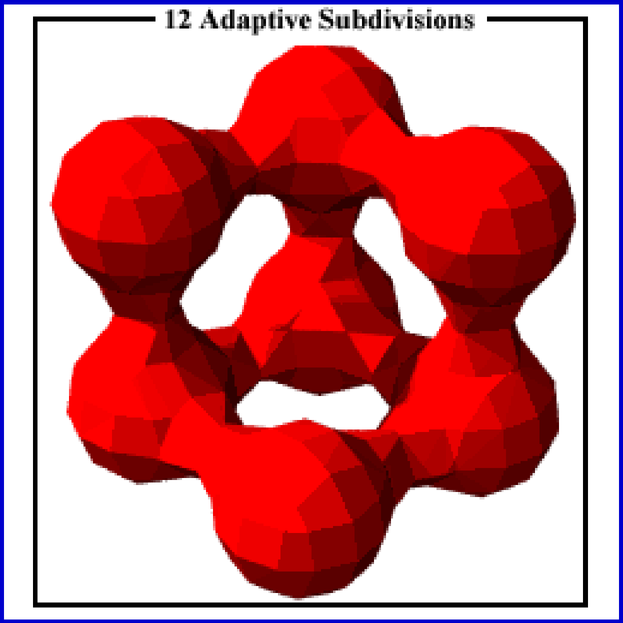


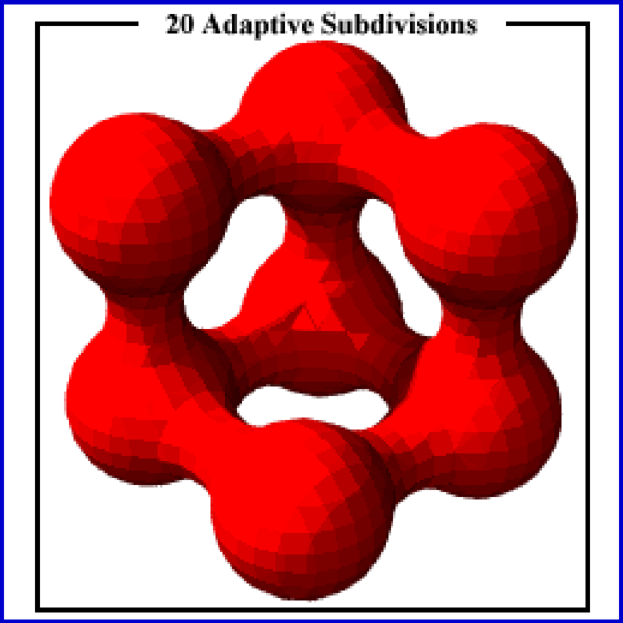
The 15 Cube Combinations


12 Subdivisions


20 Subdivisions


50 Subdivisions


12 Adaptive Subdivisions


20 Adaptive Subdivisions

Marching Cubes Summary

Advantages:

– automatic (non-interactive) method

Contras:

– segmentation
– fixed threshold value
– uniform cell size, typically 512*512*512

Improvements:

– Variable threshold value (topology)
– Adaptive mesh generation

Motivation

Relevant Application Areas:

- ***Visualising (Topology)***
- ***Measurement***
  - ***direct from volume data (profiles, volumina)***
  - ***geometric properties***
- ***Virtual Endoscopy***
- ***Simulation***
  - ***Surgery trainer (VR/AR)***
  - ***Stent placements/verification***
- ***Noninvasive Diagnostics!***

Simplifying Illumination Model

- **Simplification of physical model:**
- ***Light transport theory model (Maxwell)***
- ***Rendering Equation (heat, Kajiya)***
- ***Volume Rendering Equation***
- *Low-Albedo Situation (Ray Casting / Volume Rendering)*
- ***Empiric models and heuristics***

Complexity ↓

- ***Slide Idea by Dirk Bartz, Graz 2004***

Ray Casting

Disadvantages of the given method:

- Geometric inbetweens necessary
- binary decision

Remedy:

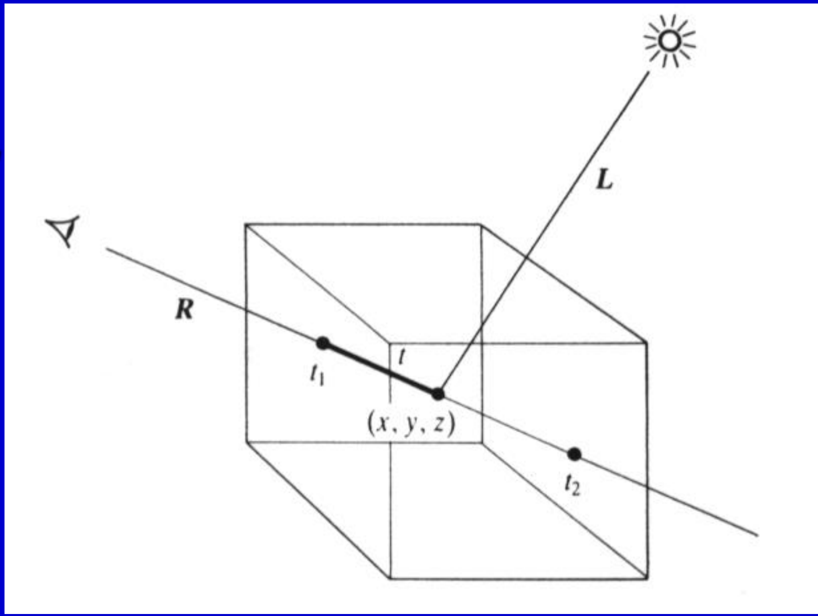
- Ray Tracing using transparent ev. semi-transparent voxels
- parallel rays casted through data volume

Light contribution of ray R

– *Intensity of volume element (voxel):*

$$I(x,y,z) = I(t)D(t)P(\cos(\Theta))$$

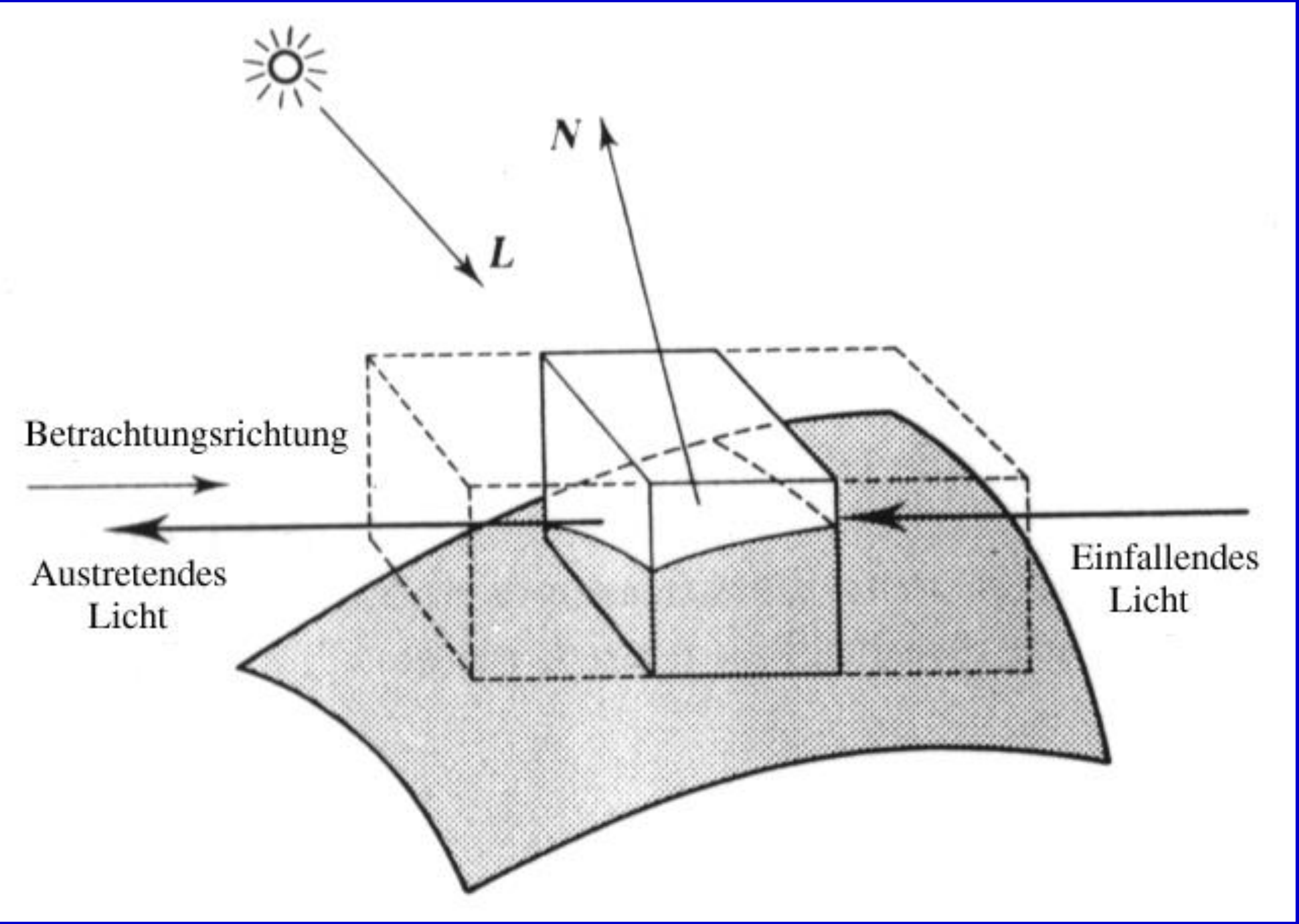
– *Attenuation along the ray:*

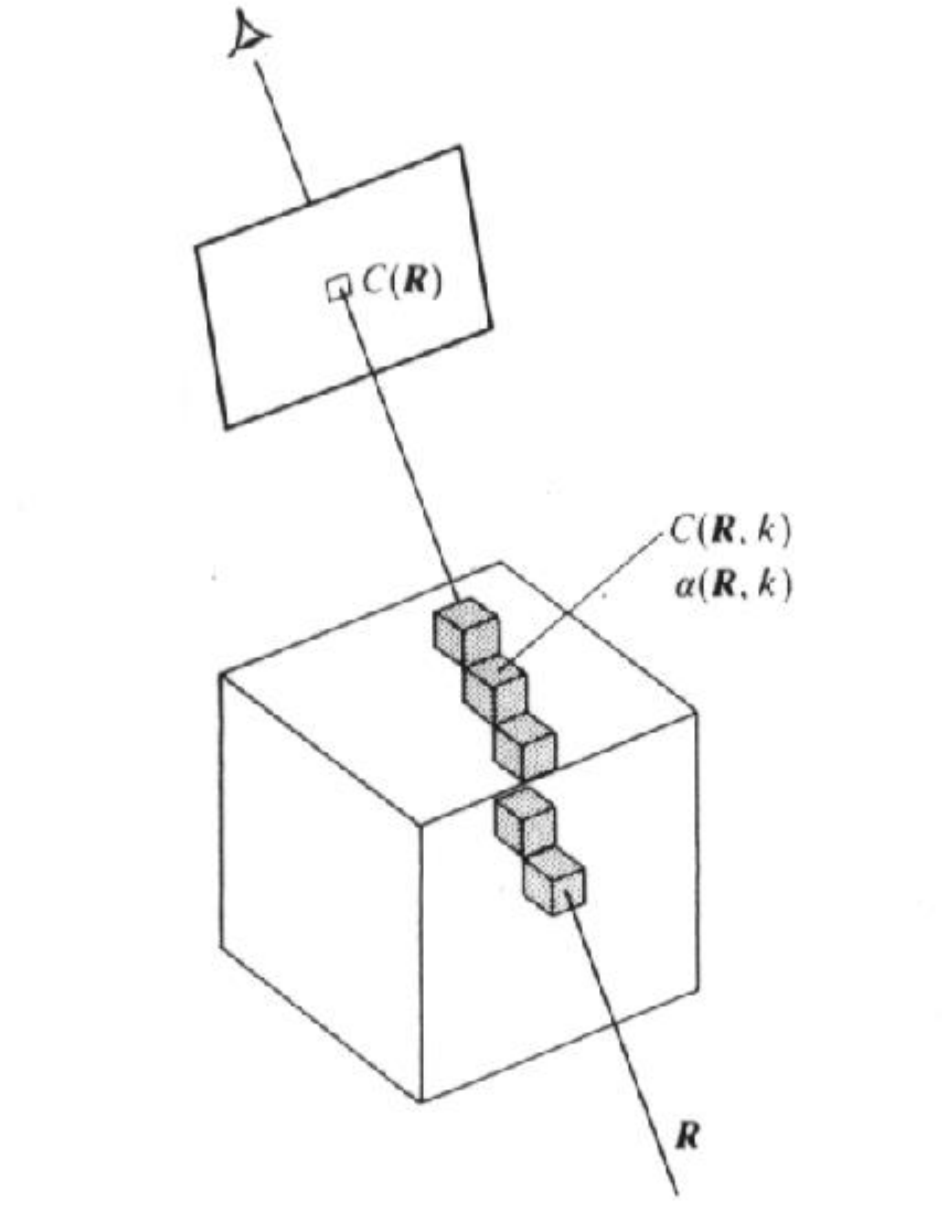


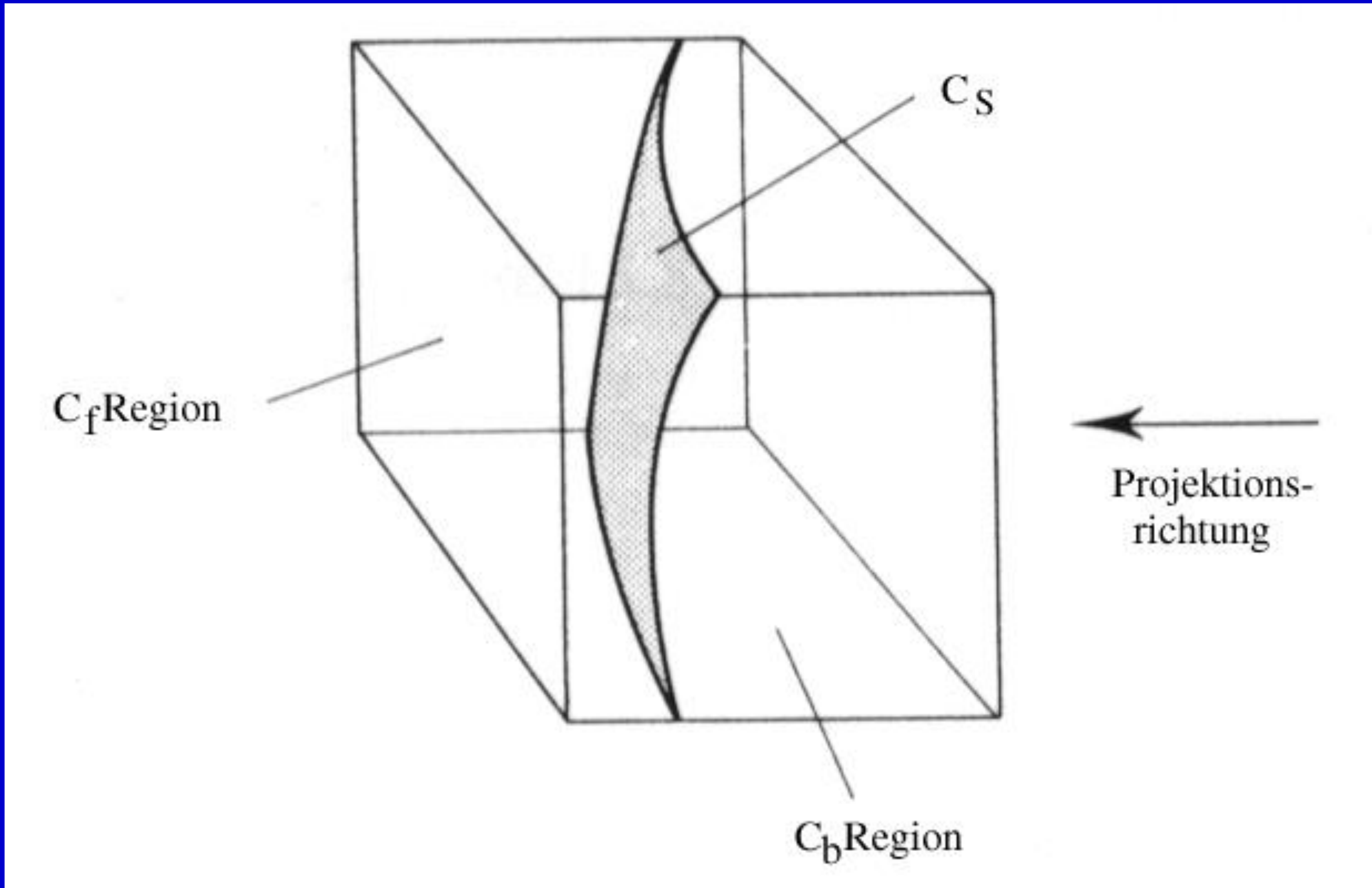
$$D(t) = \exp\left(-\tau \int_{t_1}^{t_2} D(s)ds\right)$$

– *Total light intensity:*

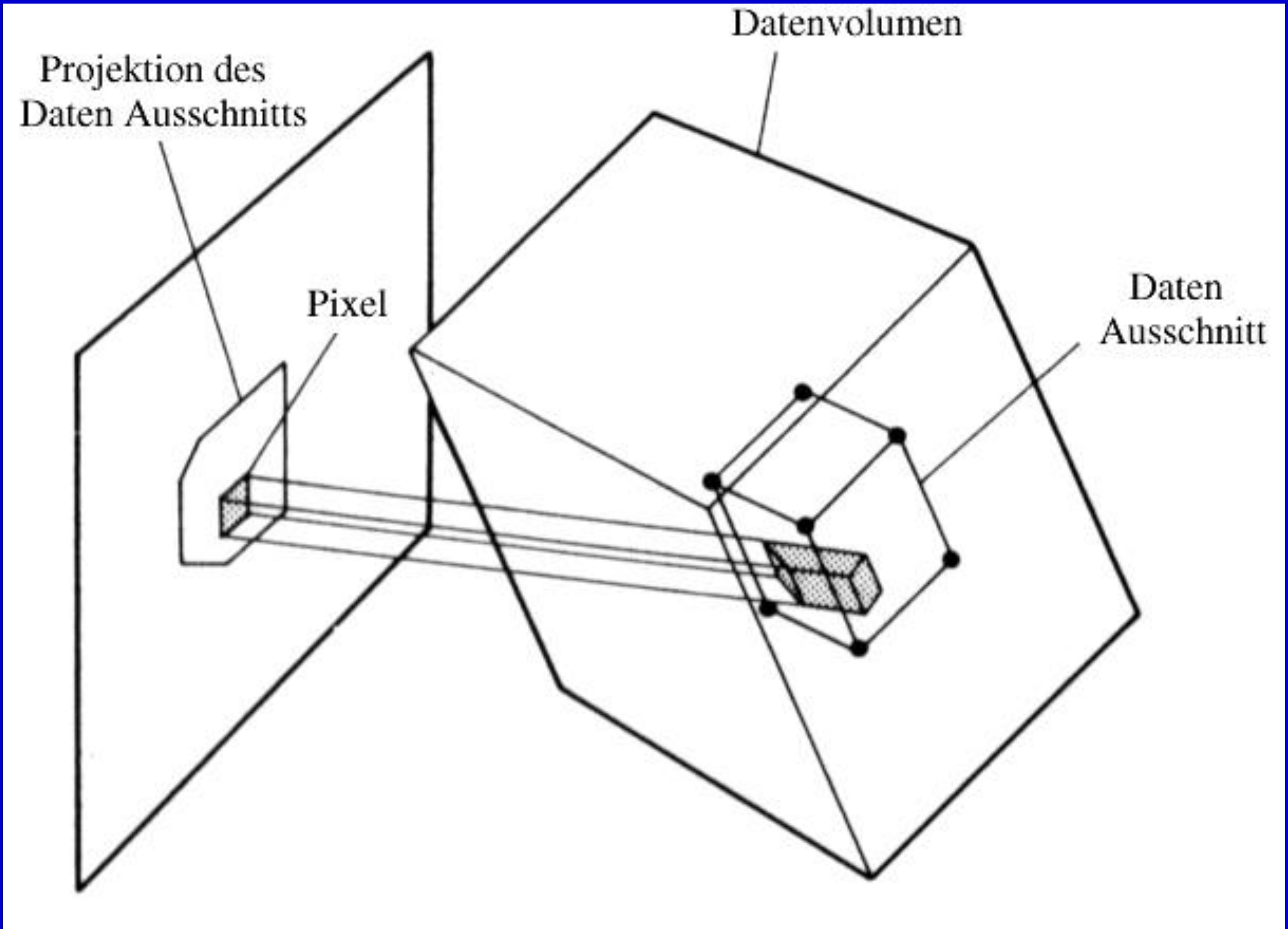
$$B = \int_{t_1}^{t_2} \exp\left(-\tau \int_{t_1}^{t} D(s)ds\right) I(t)D(t)P(\cos(\Theta))dt$$


N
L
Betrachtungsrichtung
Austretendes
Licht
Einfallendes
Licht

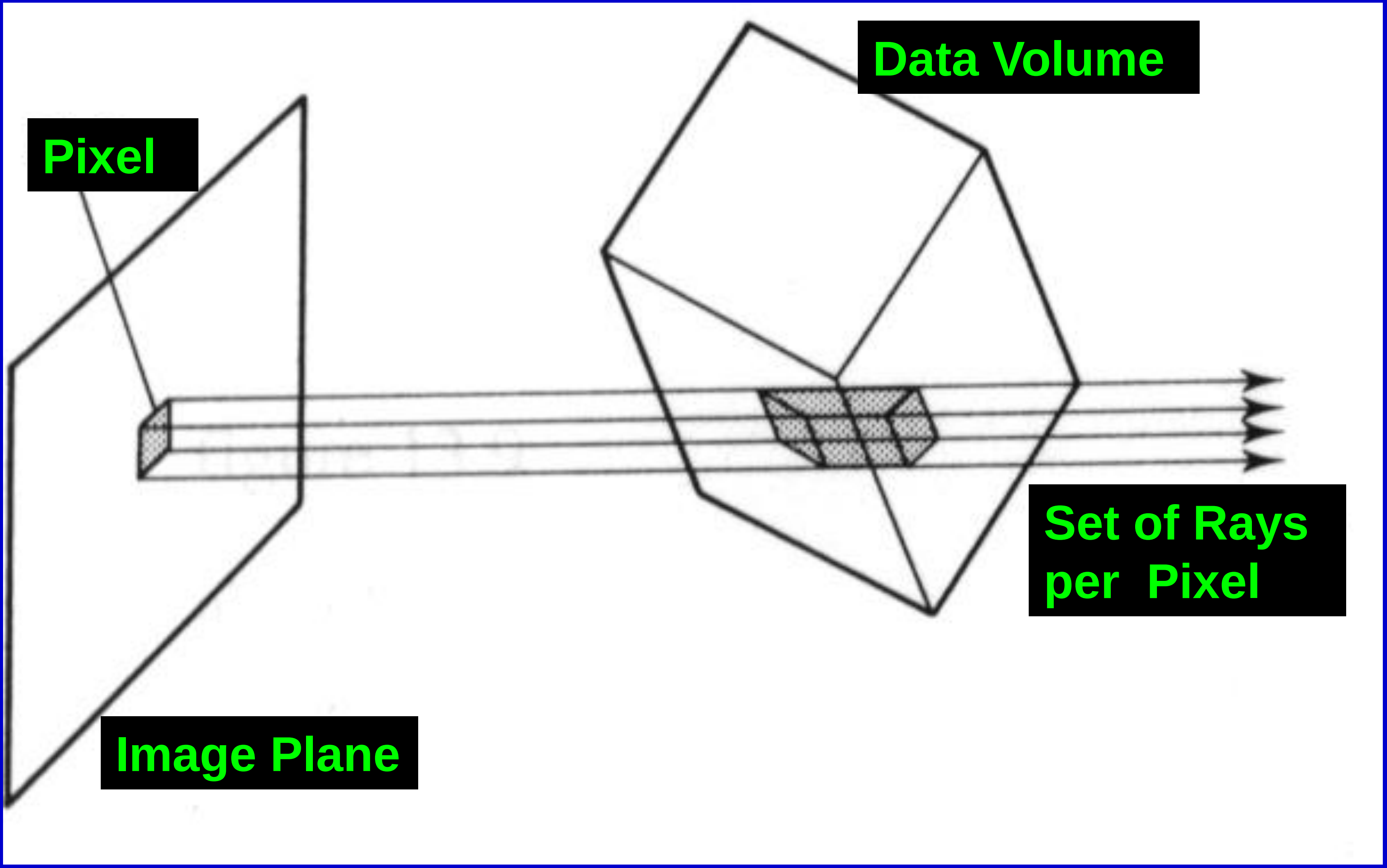

C(R)
C(R, k)
α(R, k)
R



C_S
C_fRegion
Projektions-
richtung
C_bRegion

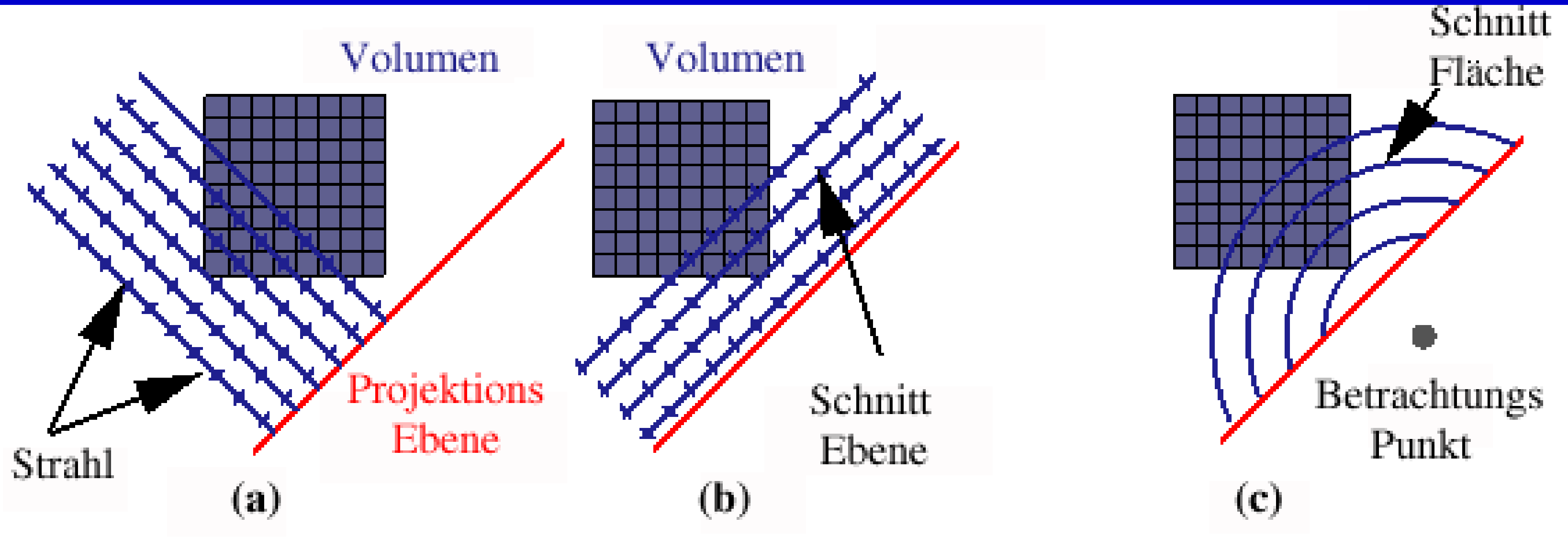


Datenvolumen
Projektion des
Daten Ausschnitts
Pixel
Daten
Ausschnitt

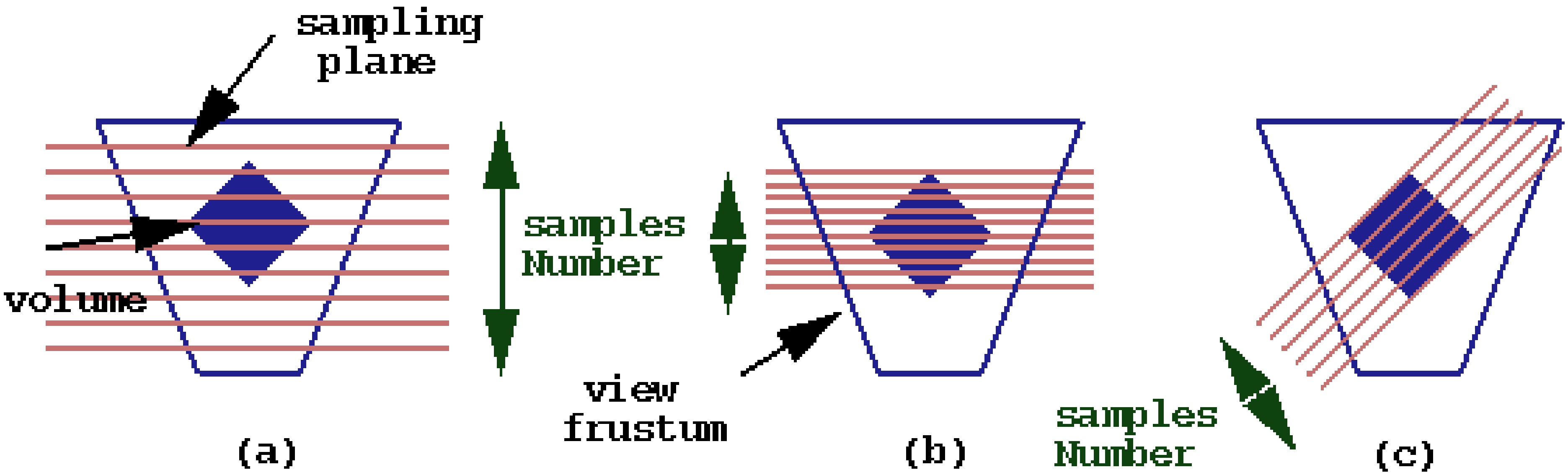


Data Volume
Pixel
Set of Rays per Pixel
Image Plane

3D Texturing

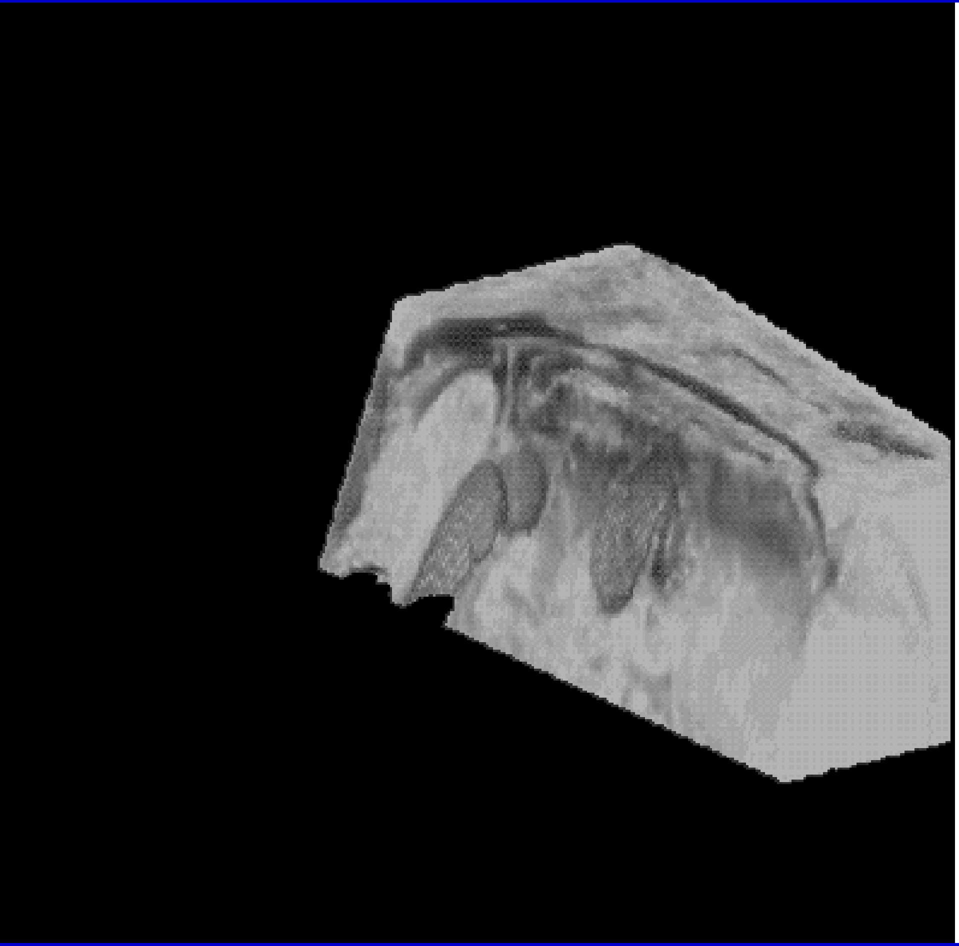


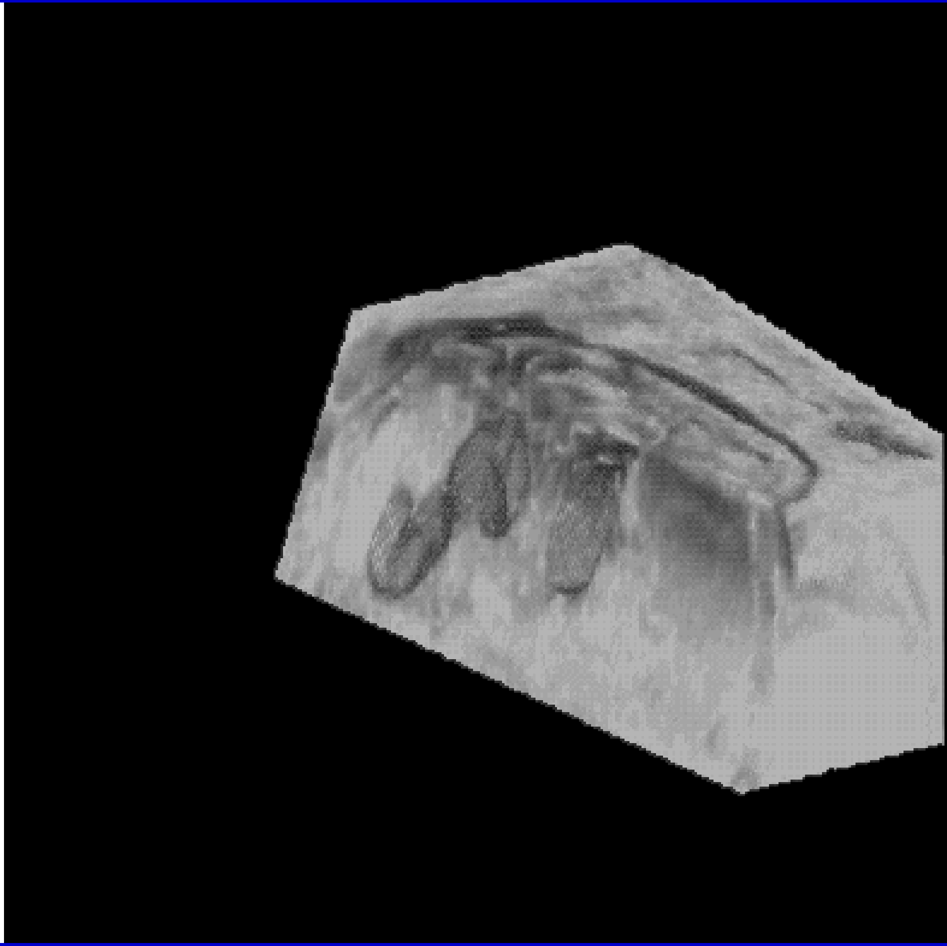
Sampling



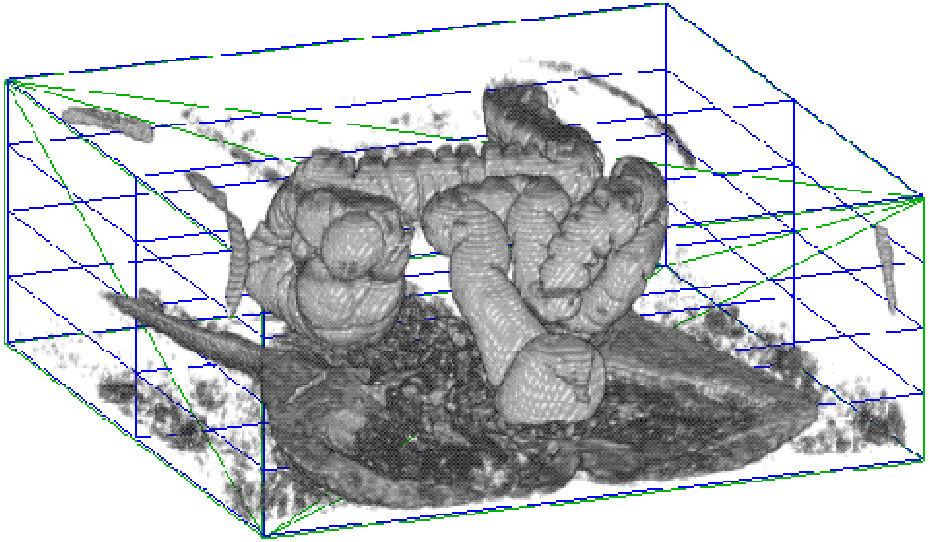
sampling
plane
volume
samples
Number
(a)
view
frustum
(b)
samples
Number
(c)

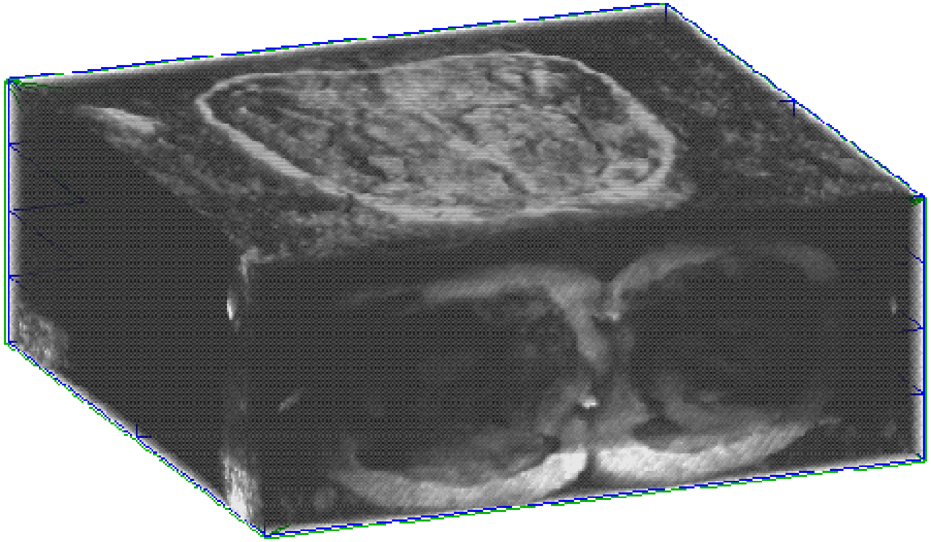
Clipping



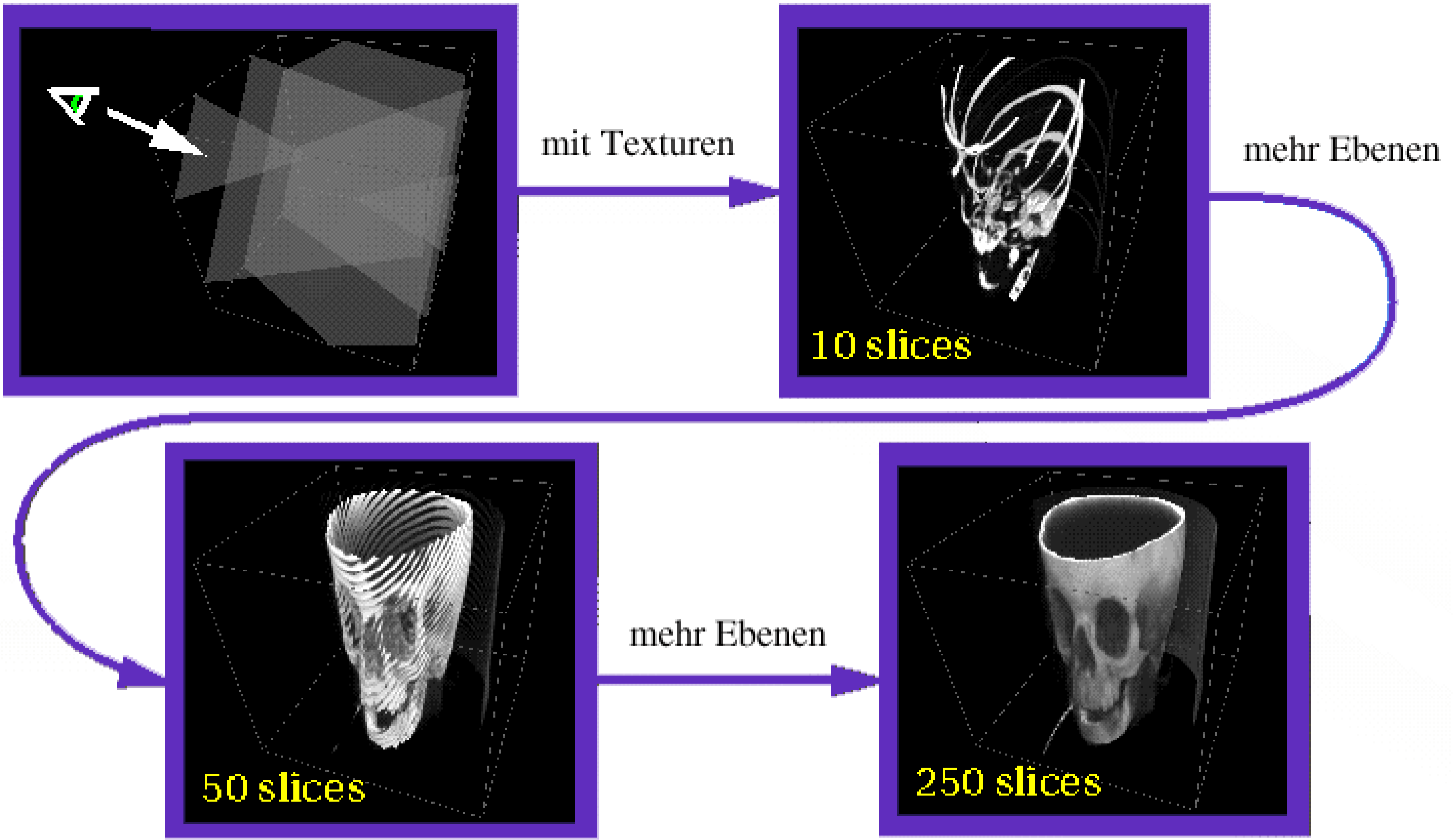


Transfer Functions (LUT)

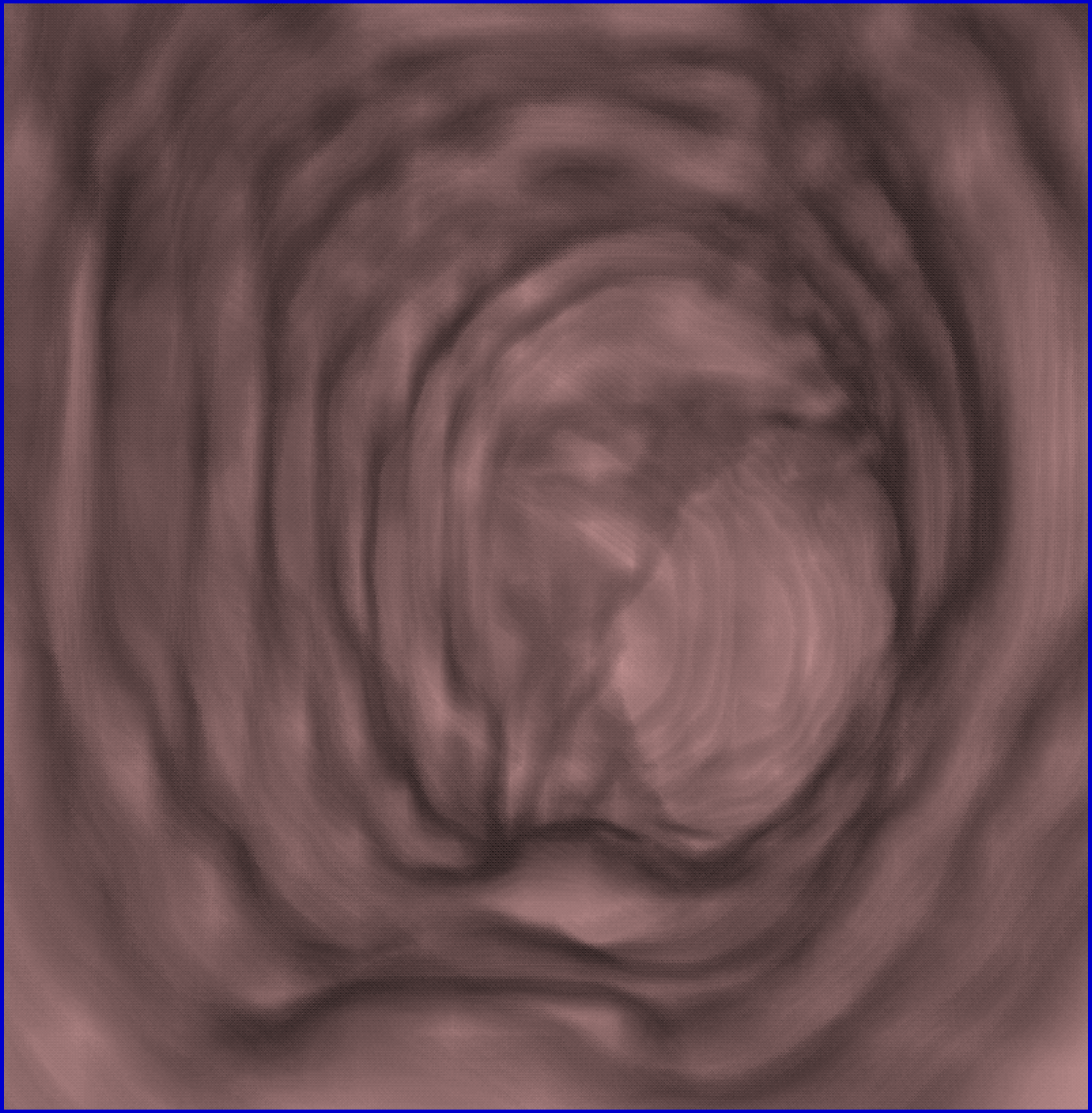




Results


mit Texturen
10 slices
mehr Ebenen
50 slices
mehr Ebenen
250 slices

Results



Navigation

Requirements:

- Automatic path finding
- Interactive control of camera parameters
- Virtual camera should stay afar from surfaces
- Camera should not leave the organ explored

Categories:

- Manual navigation
- Planned navigation
- Guided navigation

Manual Navigation

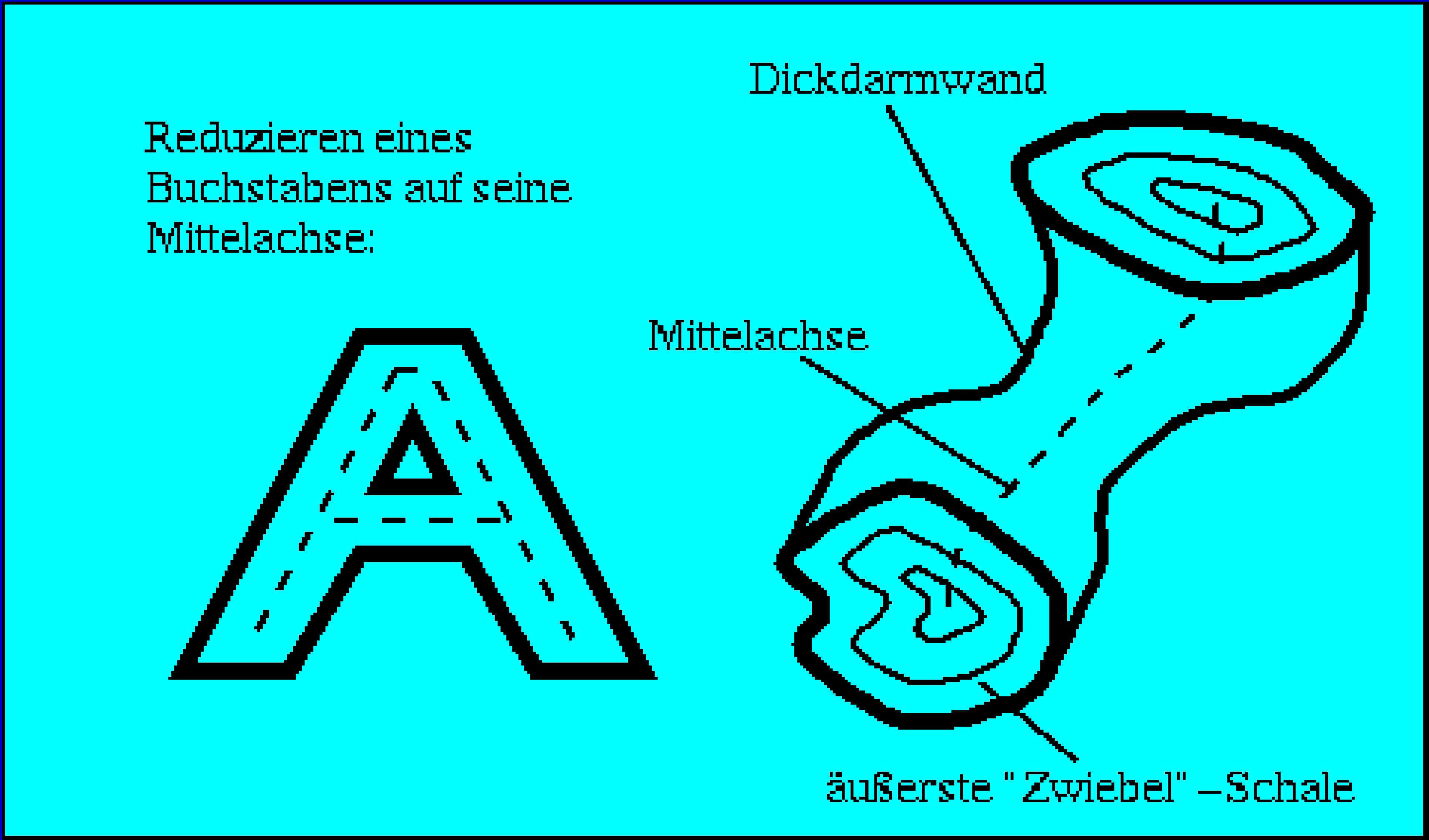
- 3 coordinates, 3 angles
- powerful computer required
- less intuitive
- orientation can be lost

Remedy: „Collision Detection“

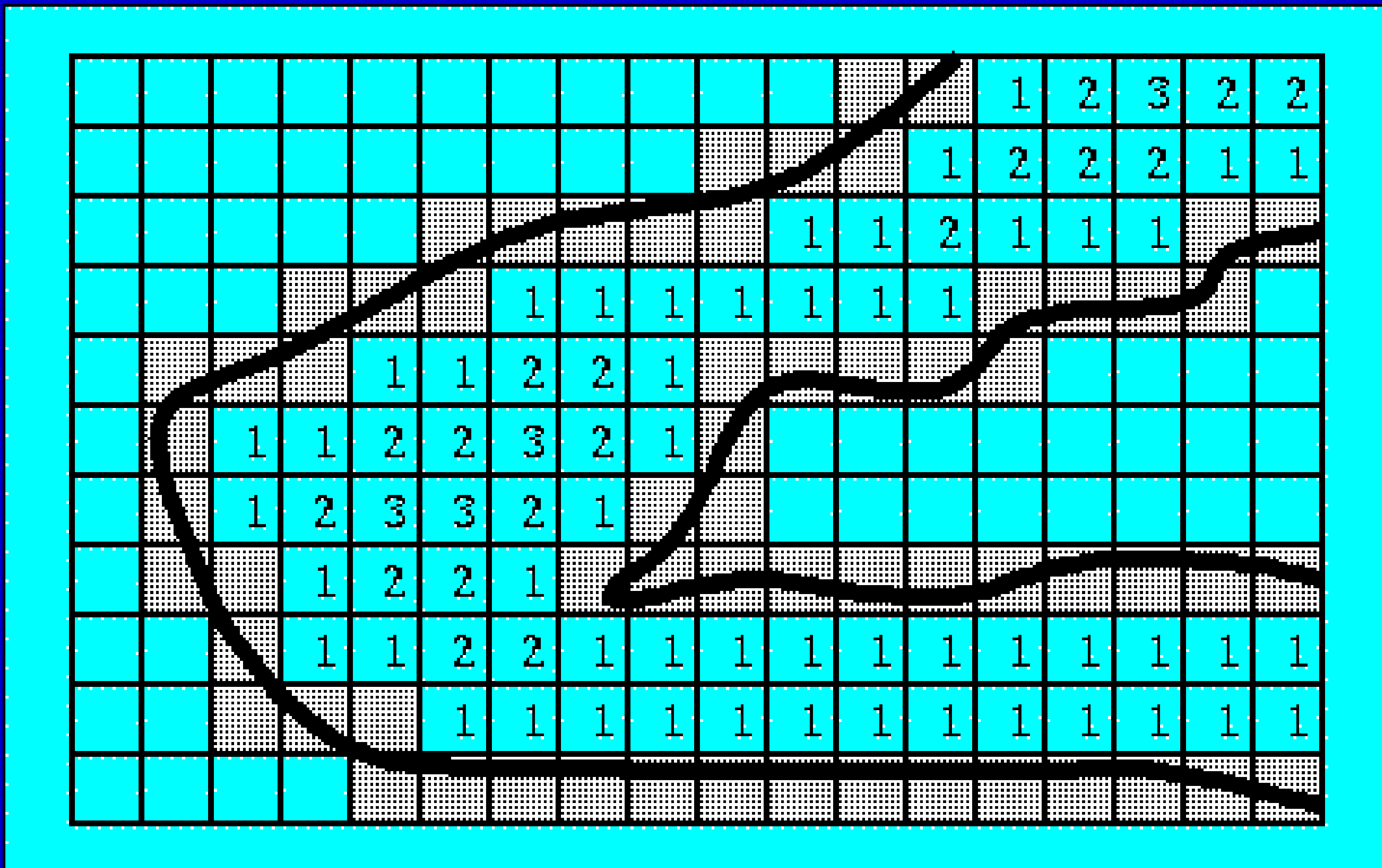
Planned Fly-through

- Startpoint .. endpoint: trajectory
- Compute the fixed price path,
- for slower computer, too
- No interaction

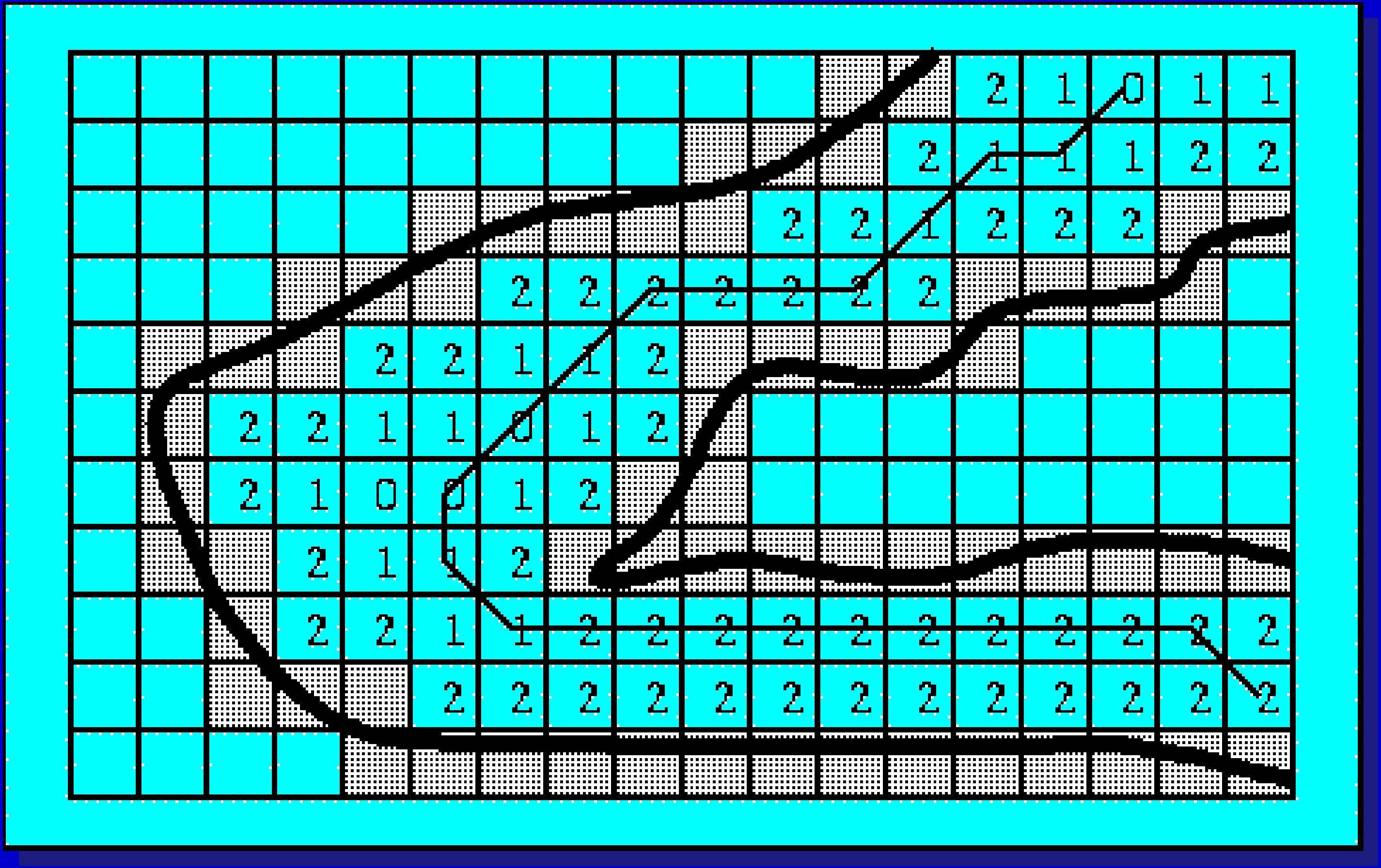
Planned: Medial Axis Fly



Planned: Least cost path (1)



Planned: minimum cost path (2)



Flying through: Virtual Voyage

- Submarine in the object interior
- It has the mass & inertia moment
- Forces:
  - submarine moving to the end of object
  - keeping distance from the walls (collision prevention)
  - user defined forces

Virtual Voyage: Forces

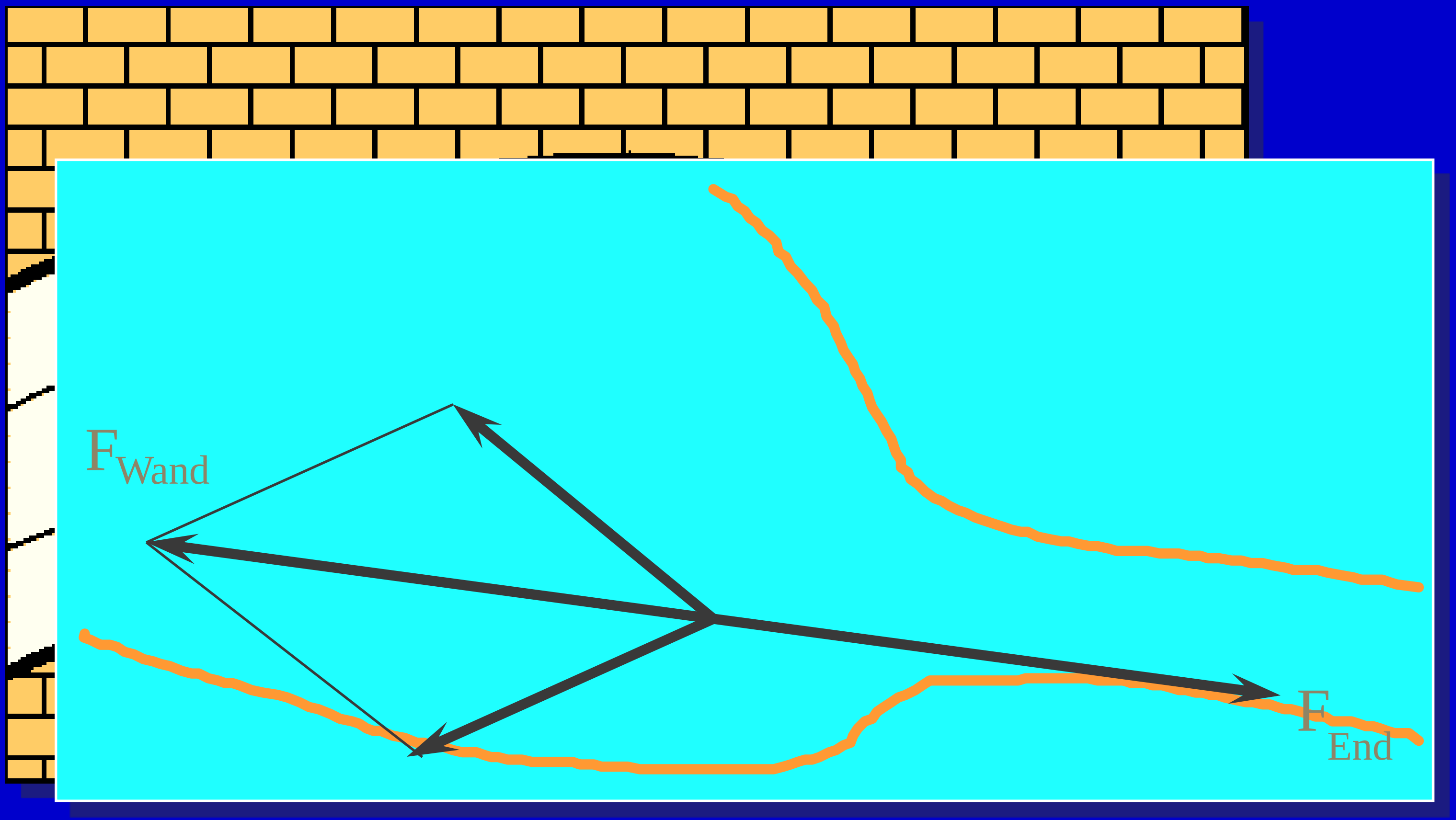
- Field of distances Dt
- Field of distances Ds

$$V(X) = \begin{cases} C_t * D_t(X) + C_s * (\rho / D_s(X) - 1)^2 & 0 \leq D_s \leq \rho \\ C_t * D_t(X) & sonst \end{cases}$$

$$\vec{F}_{Ende} + \vec{F}_{Wand} = -\nabla V(X)$$

Virtual Voyage:
Flaw: local minima

if transverse section getting smaller



Distance Field D_t

Algorithm:

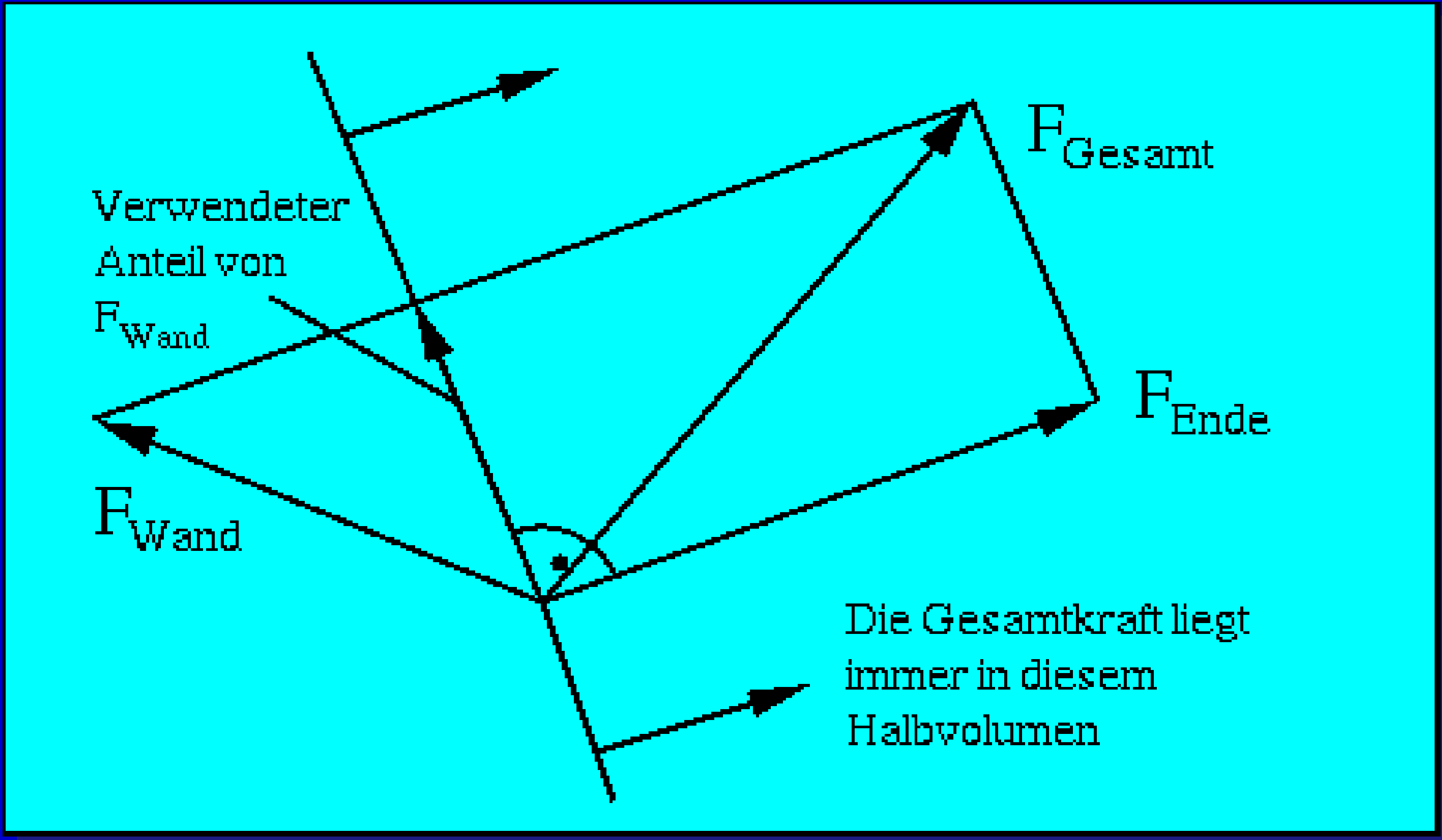
- Insert endpoint in Q_t, $D_t = 0$
- Fetch the first element from Q_t
- For 6 neigbours:
  - Insert all up to now unprocessed interior voxels with $D_t = D_t + 1$
  - Push voxels from boundary layer into Q_s with $D_s = 0$
- Repeat the couple of previous steps until Q_t is empy

D_s Computation

Algorithm:

- Use Q_s instead of D_t
- Fetch the first element from Q_s
- For 6 neighbours:
  - insert all unvisited inner voxels with $D_s = D_s + 1$
- Repeat until Q_s empty: the two above steps

Virtual Voyage: Improvement



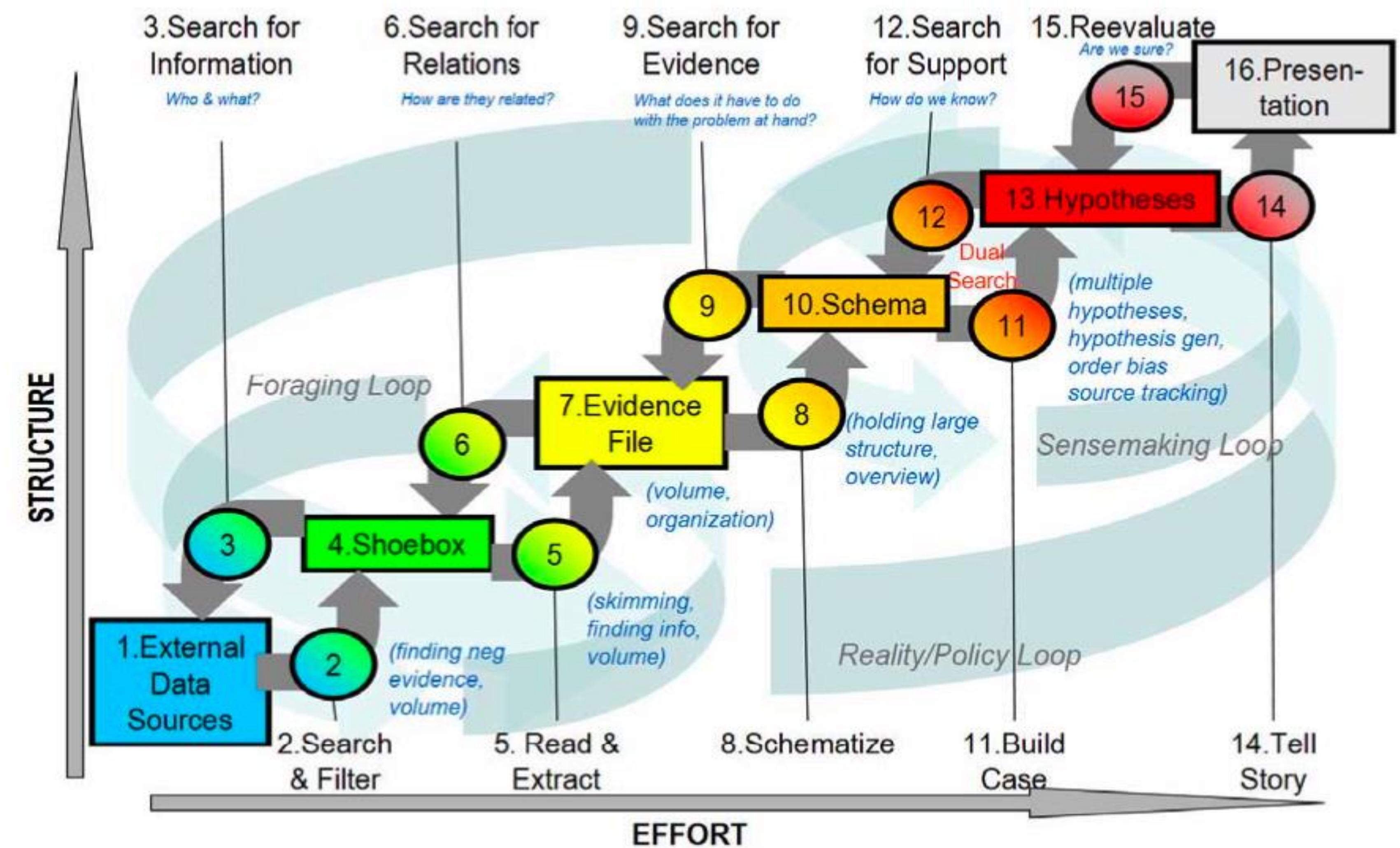


Figure 1.1: *The sensemaking process described by Pirolli & Card [PC05]. The Exploration process within visualization is analogous to the foraging loop, e.g. collecting evidence in a shoebox, while analysis is the consideration of this evidence. Ultimately any hypothesis or evidence found must be presented in one way or another.*

Xmas Tree in Heaven

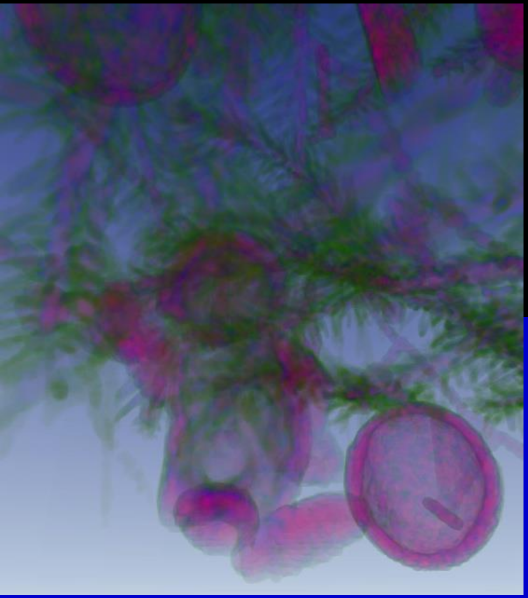
Christmas Tree Case Study:

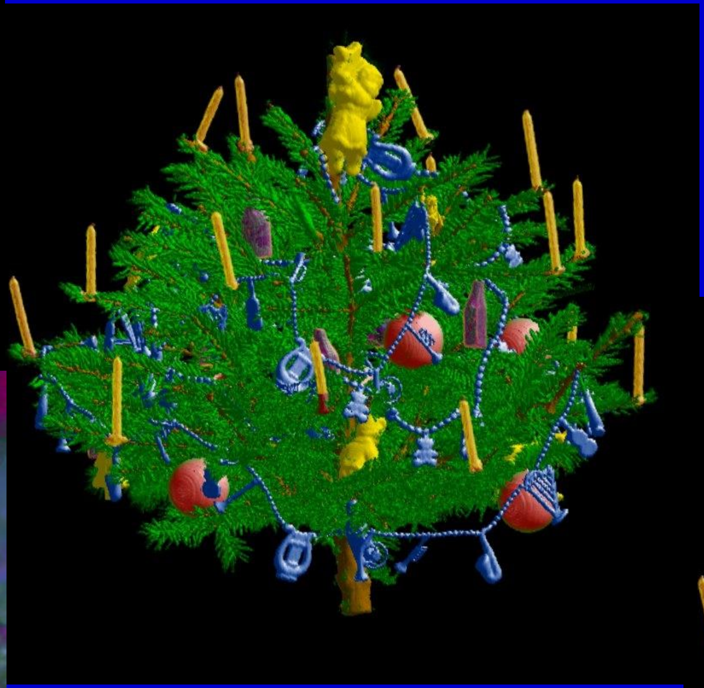
Computed Tomography as a Tool for Mastering Complex Real World Objects with Applications in Computer Graphics

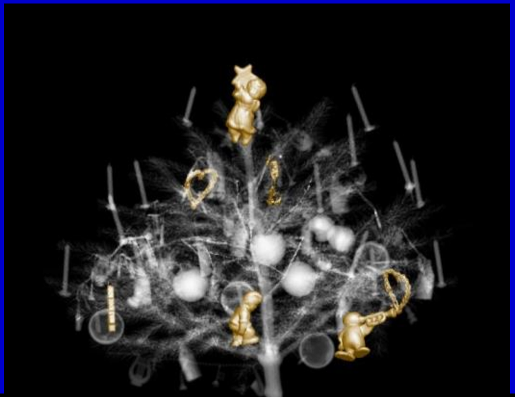
A. Kanitsar et (many) al. @ TU Wien

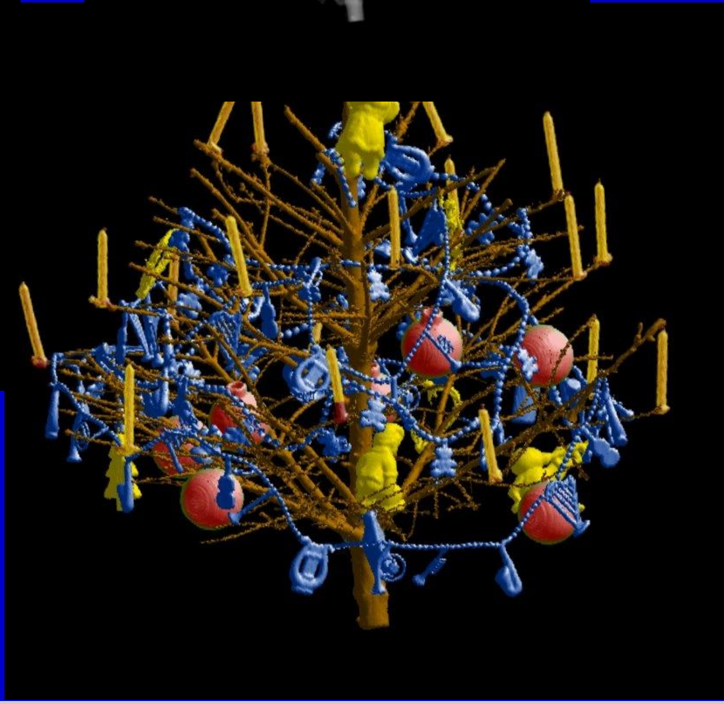
Xmas: https://www.cg.tuwien.ac.at/xmas/

Xmas Tree in Heaven

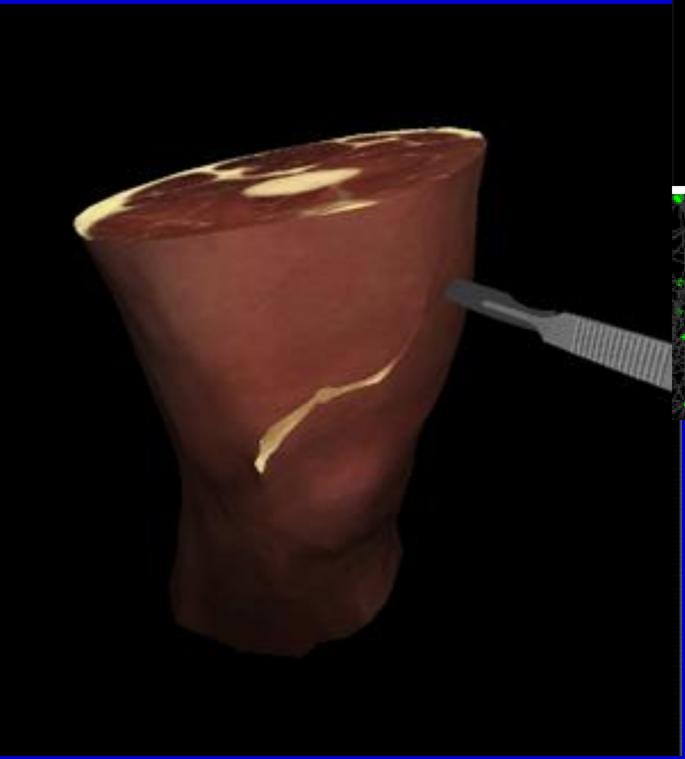


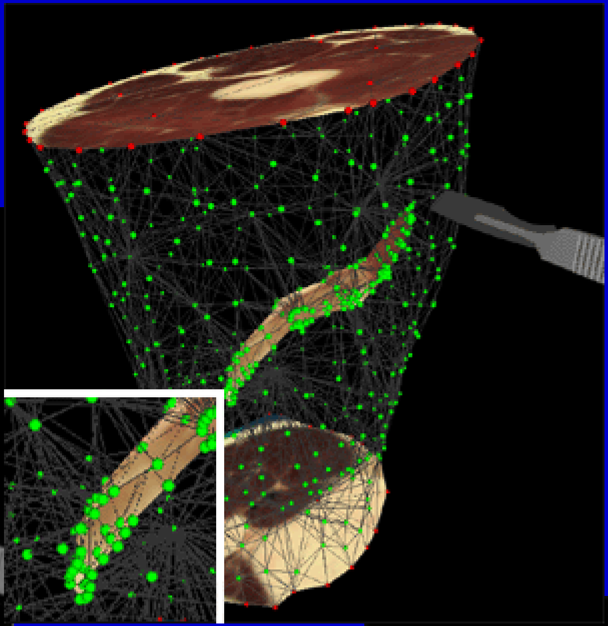






http://graphics.ethz.ch/~bielser/artist





Visualisation, Rendering and Animation

2 VO / 1 KU

Heinz Mayer, Franz Leberl & Andrej Ferko

Short videoversion Volume Rendering 2020