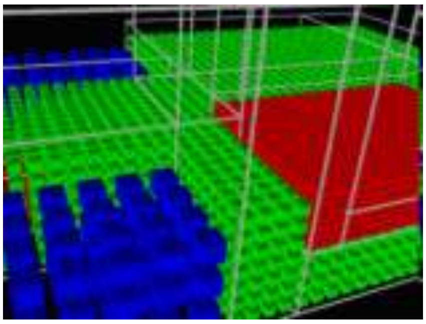
Introduction to volumetric visualization

Incluindo slides disponibilizados por
Chuck Hansen e Luciana Nedel

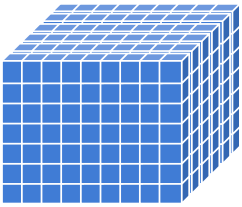
C. Freitas (2009)

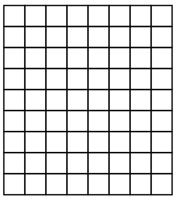
Volumetric data

- Data associated to positions or regions in a 3D space
  - Structured grids

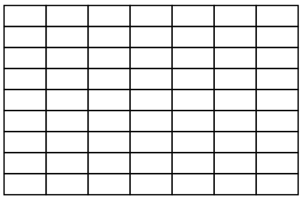


Wikipedia (Berkeley)

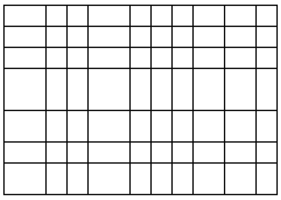




cartesian



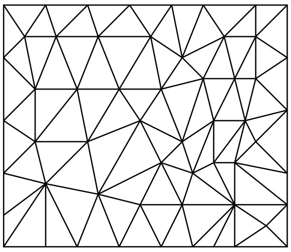
regular

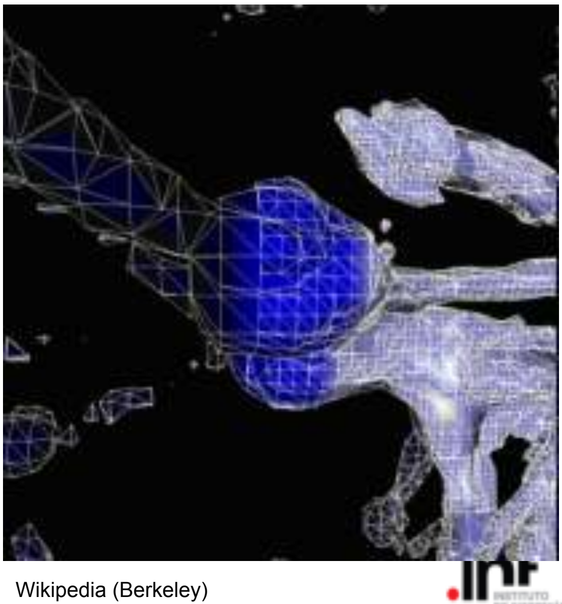


rectilinear

Volumetric data

- Data associated to positions or regions in a 3D space
  - Unstructured grids

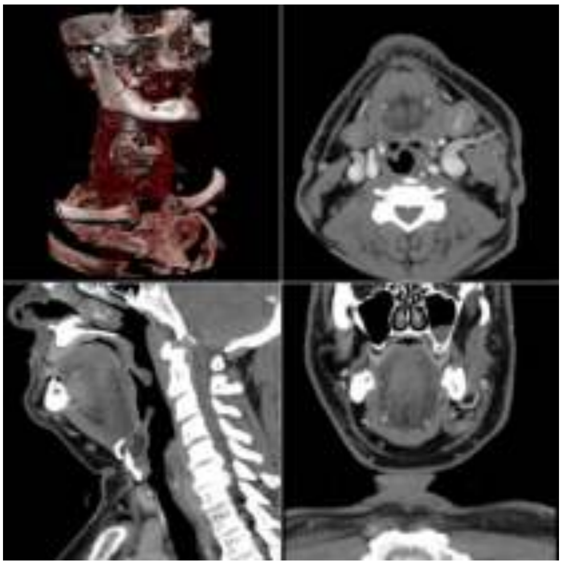


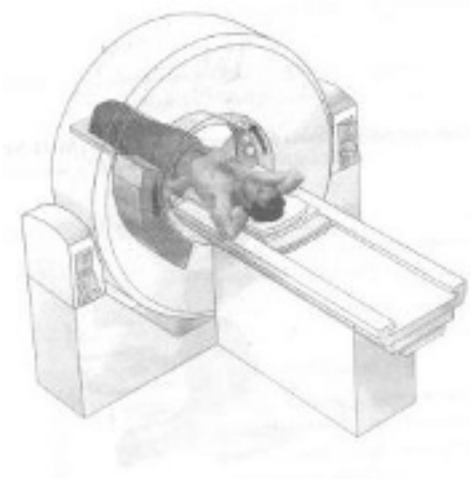


Wikipedia (Berkeley)

Acquisition: structured

- CT - Computed tomography

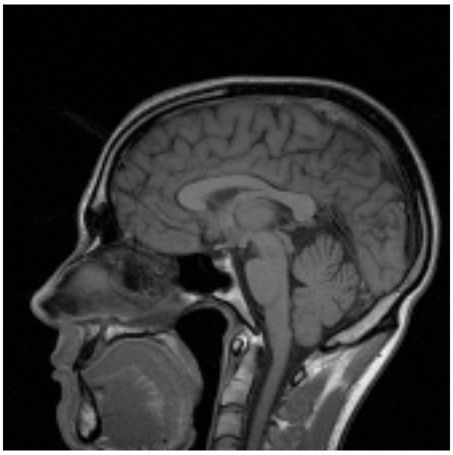




Hounsfield 1967

Acquistion: structured

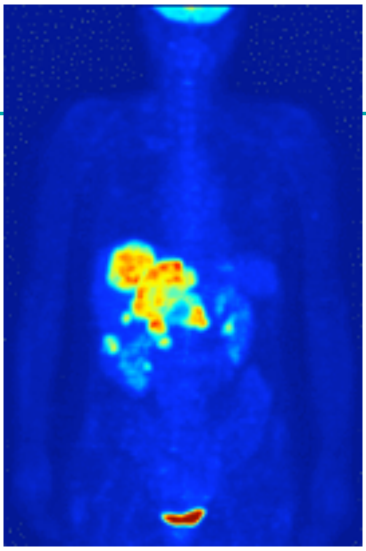
- MRI - Magnetic Resonance Imaging
  - A large magnetic field is applied to the object, which aligns hydrogen nuclei
  - Water content in the tissue is measured



Lauterbur 73

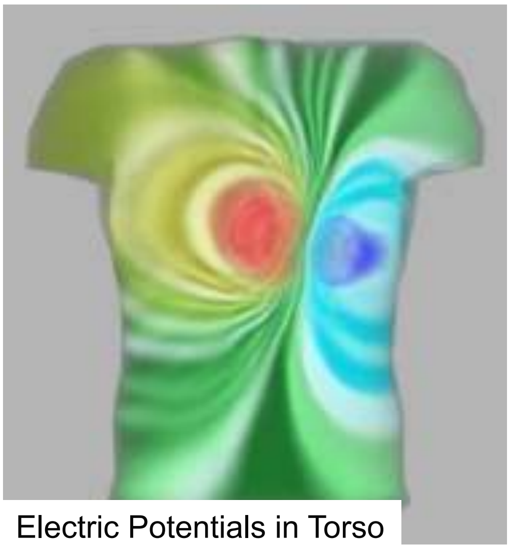
Acquisition: structured

- PET - Positron Emission Tomography
  - A radioactive isotope (into a medium) is injected into the body
  - Positron emission from decay interacts with electrons to create gamma rays
  - Gamma rays are detected to find position of isotopes in body

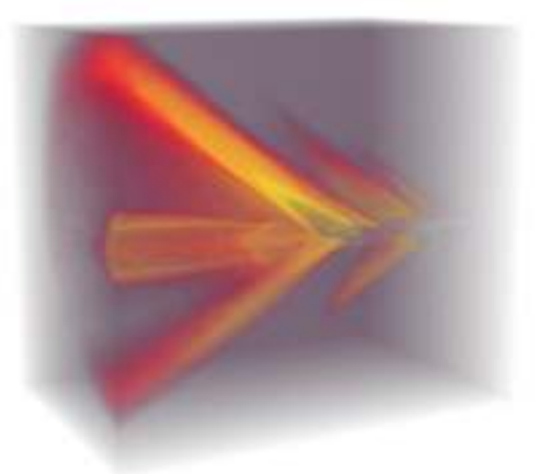


Computational simulation: (un)structured

- Computational fluid dynamics
- Structural mechanics



Electric Potentials in Torso
[MacLeod et al 94]

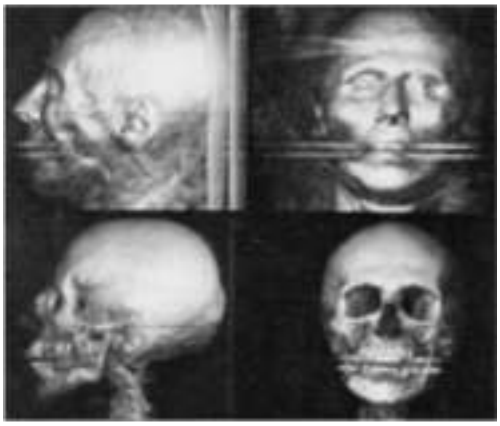


Turbulence around fighter jet
[Neely and Batina 92]

Visualization

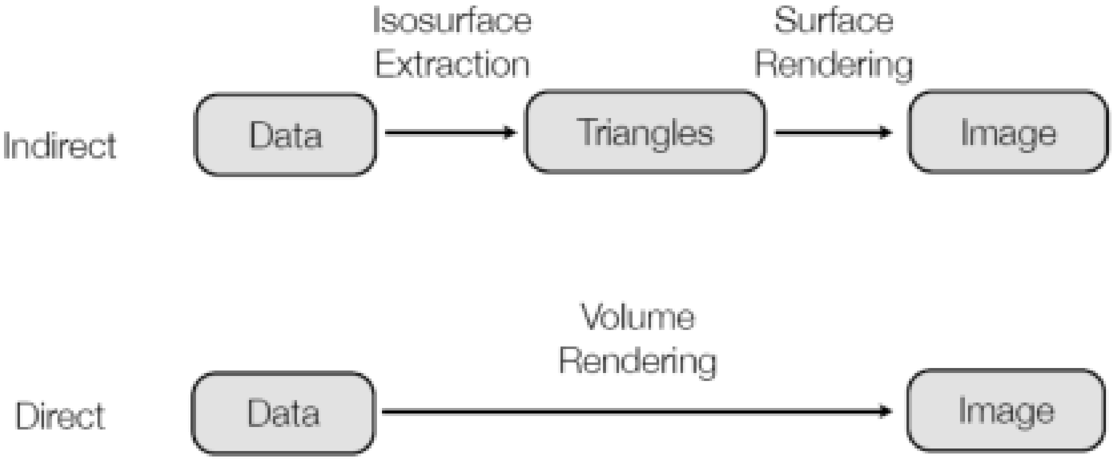
- Each voxel can contribute to the image
- Voxels can be discarded from the image depending on user interest on specific strutuctures within the volume

Ray casting [Levoy 88]

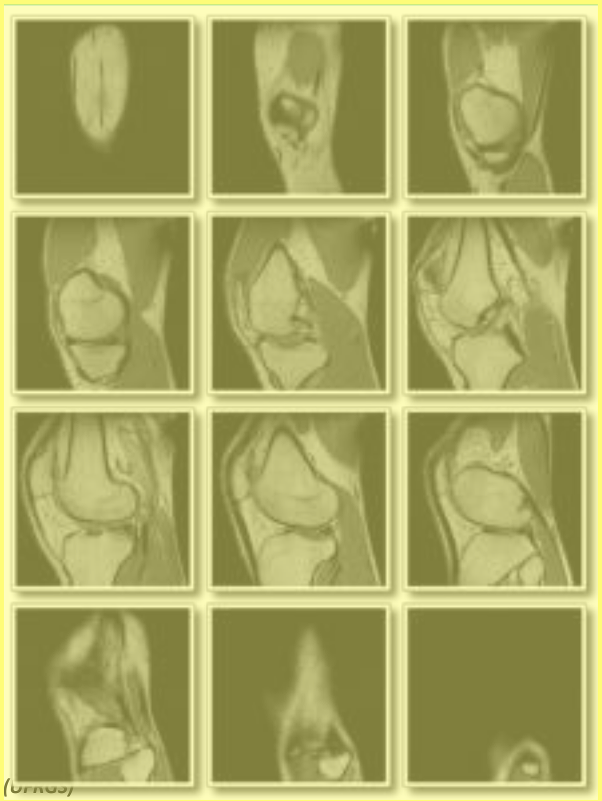


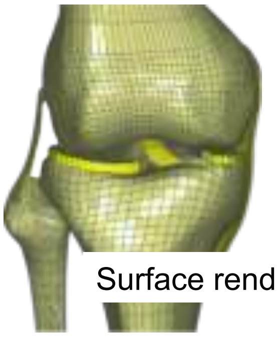
http://www.fovia.com/gallery.php

Volume visualization approaches

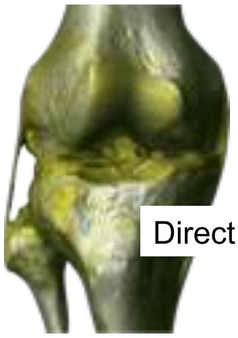


Volume visualization approaches





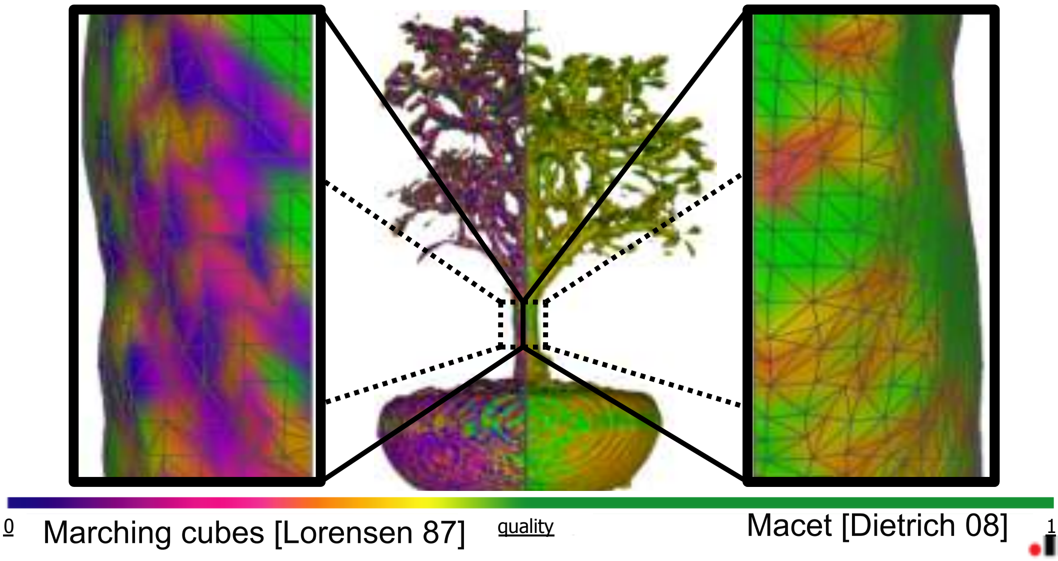
Surface rendering



Direct rendering

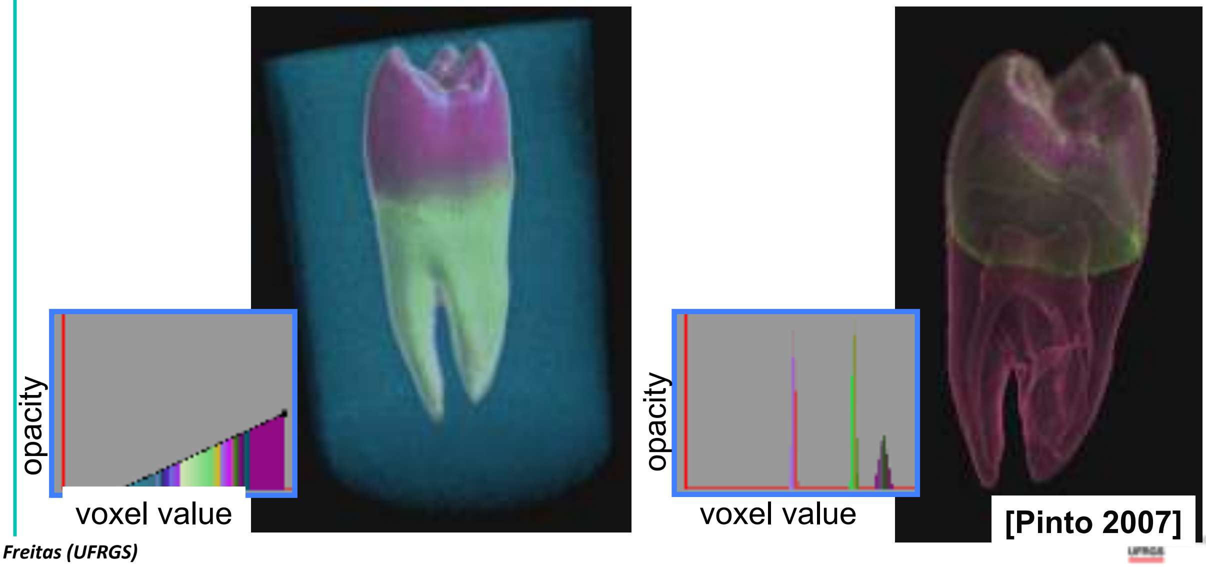
Surface rendering

- An isosurface is extracted from the data set
- Different methods extract different meshes



Direct volume rendering

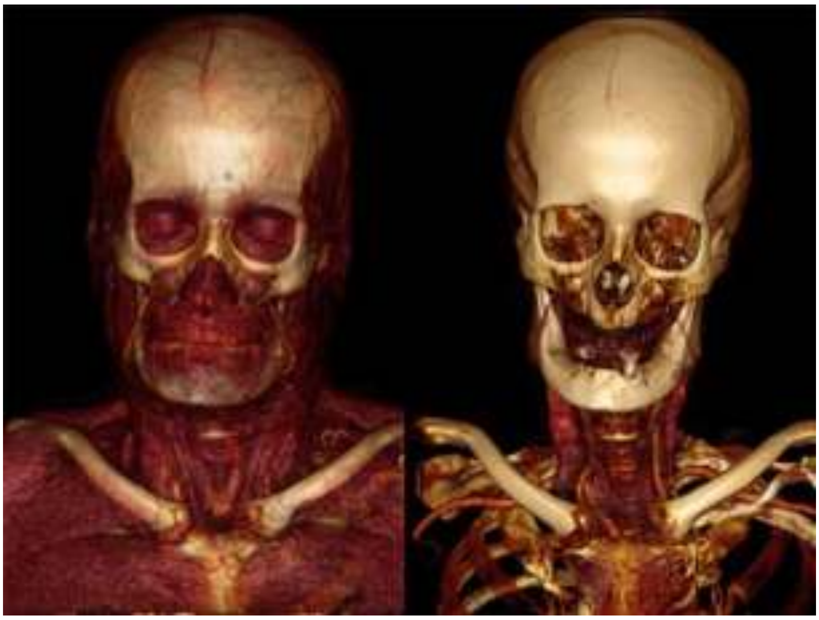
- Mapping from value to opacity and/or color
- Different mappings produce different images



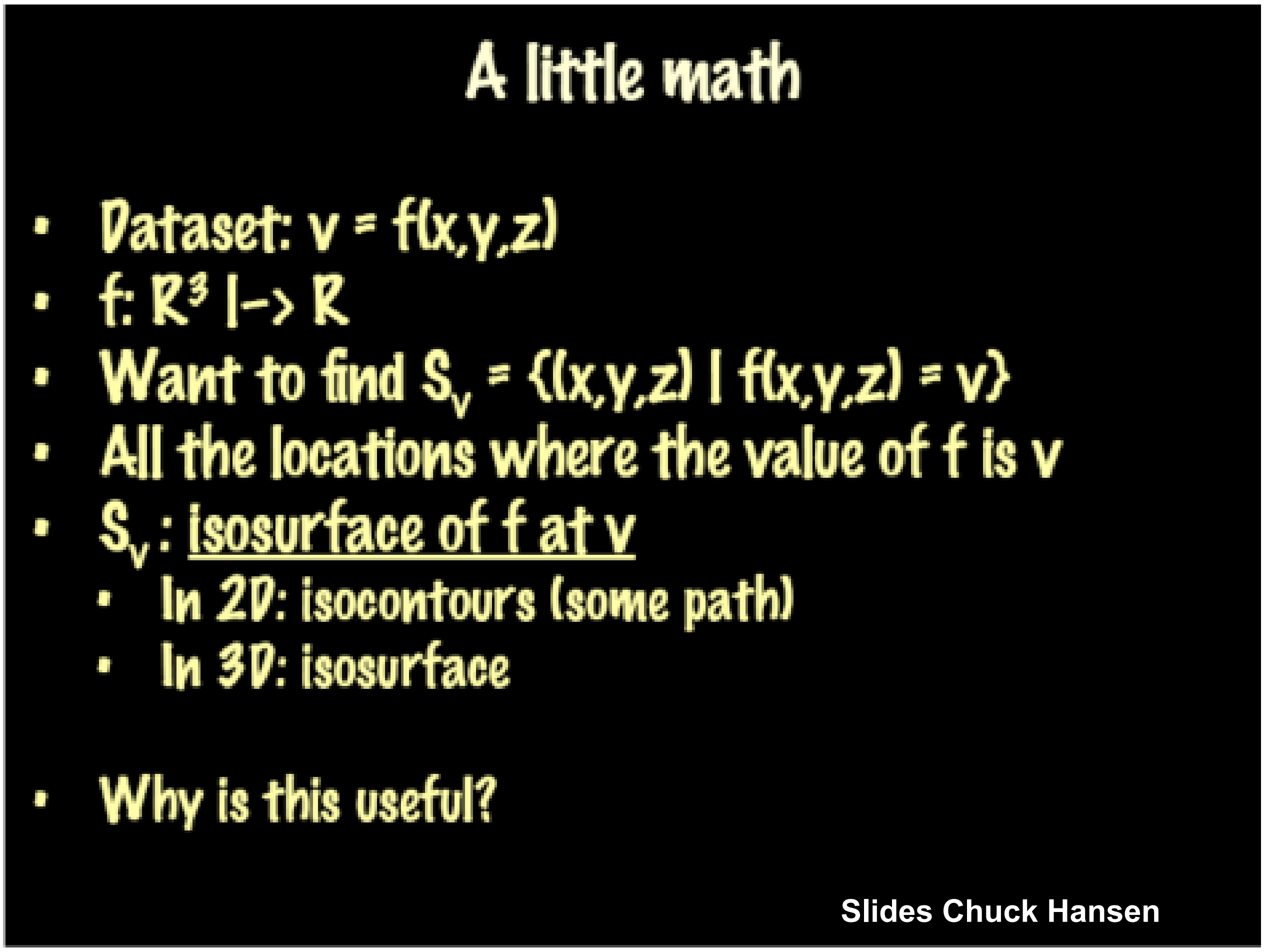
[Pinto 2007]

Isosurface extraction

- How do we specify the part of the volume corresponding to the desired inner structure?



C. Freitas (UFRGS)



A little math

- Dataset: $v = f(x,y,z)$
- $f: R^3 \mapsto R$
- Want to find $S_v = \{(x,y,z) \mid f(x,y,z) = v\}$
- All the locations where the value of f is v
- S_v : <u>isosurface of f at v</u>
  - In 2D: isocontours (some path)
  - In 3D: isosurface

- Why is this useful?

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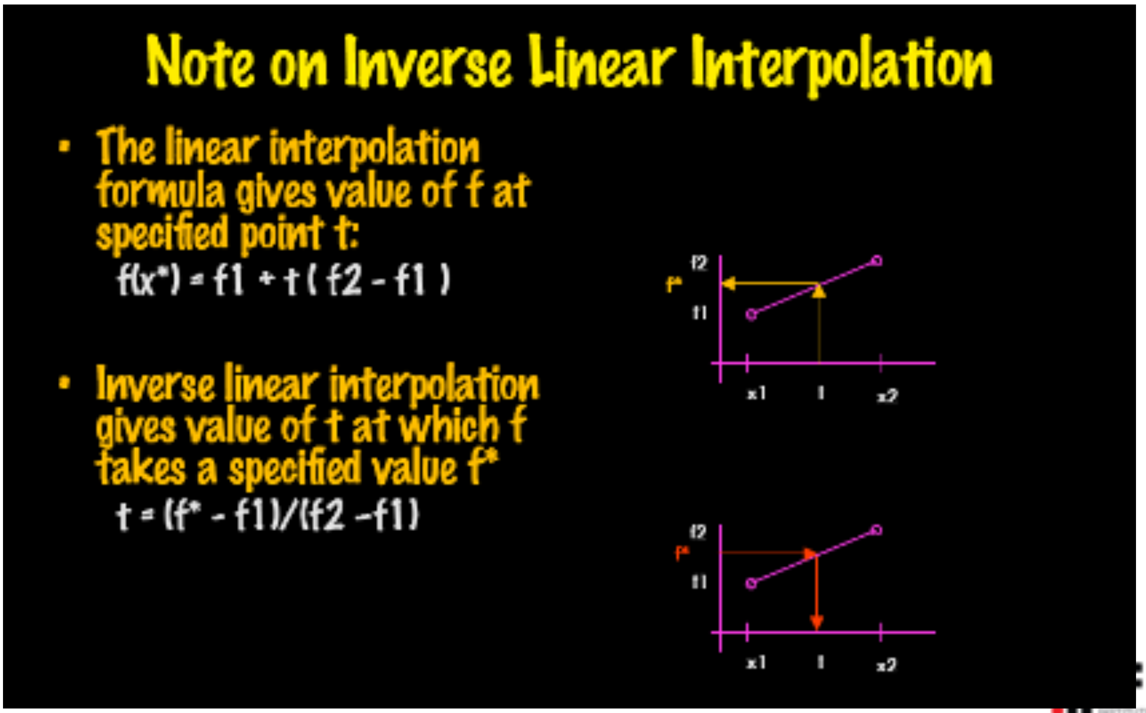
Surface extraction



Note on Inverse Linear Interpolation

- The linear interpolation formula gives value of f at specified point t:

  $f(x^*) = f1 + t(f2 - f1)$

- Inverse linear interpolation gives value of t at which f takes a specified value f*

  $t = (f^* - f1)/(f2 - f1)$

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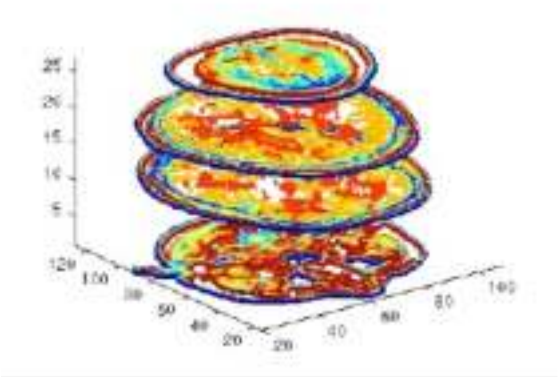
Surface extraction

- Take a slice through the 3D volume, often orthogonal to one of the axes
- Obtain the 2D contour of the structures in each slice
- Connect adjacent contours forming polygons



Surface extraction

7

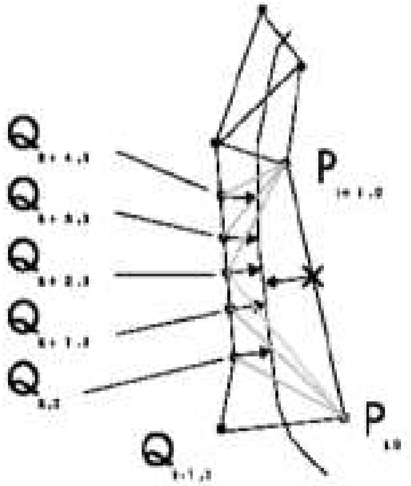
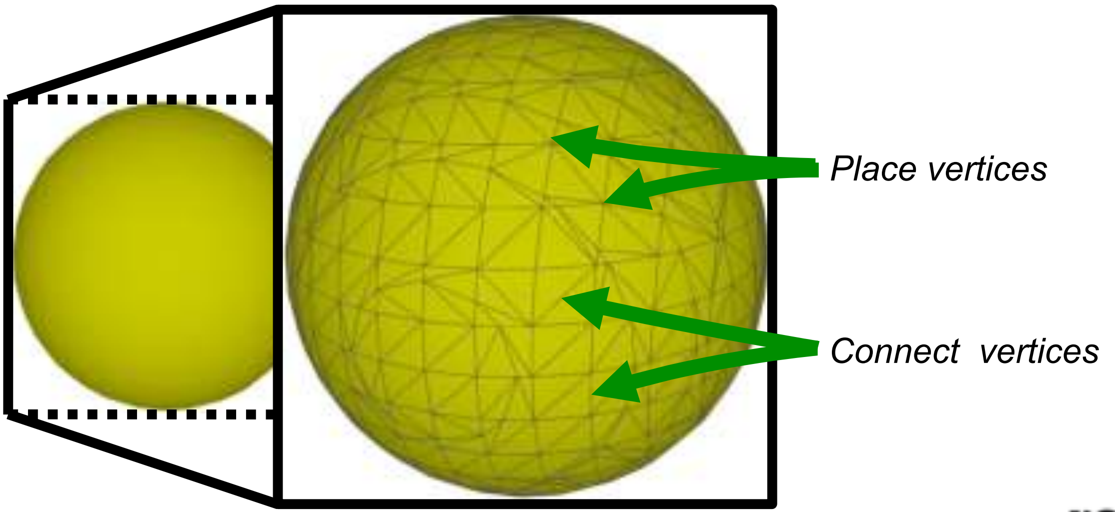
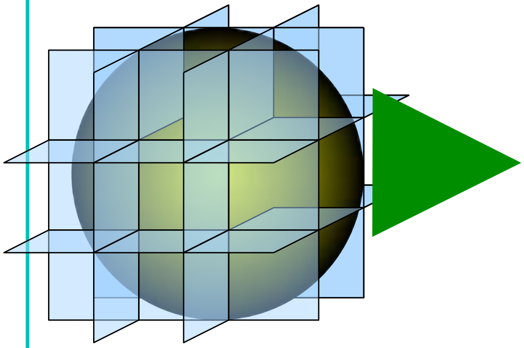


Fig. 6. Vertices $Q_{k,0}$ through $Q_{k+4,0}$ are connected to $P_{i,0}$ or $P_{i+1,0}$ resp. due to their correspondences on the medial axis.

Surface extraction



Marching Cubes (MC) (Lorensen e Cline, 1987)



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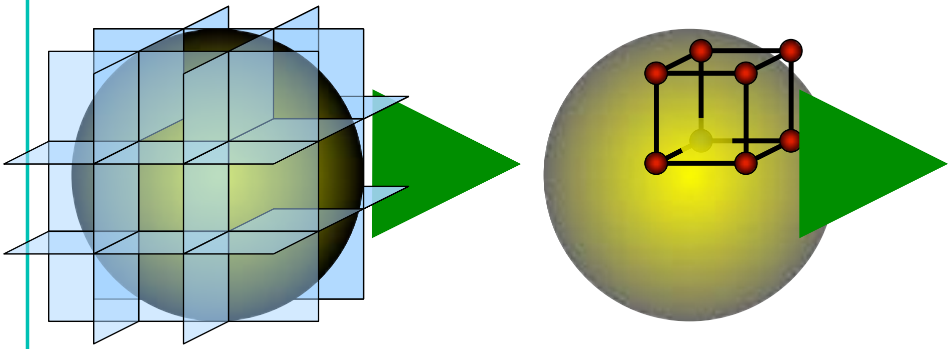

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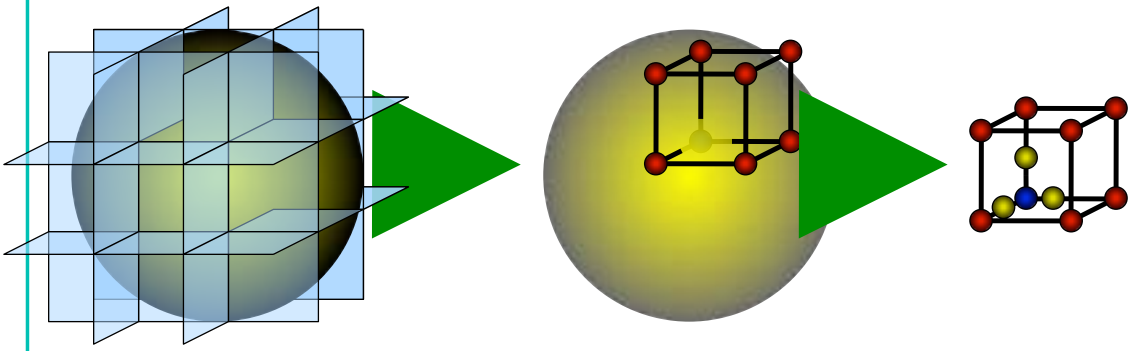

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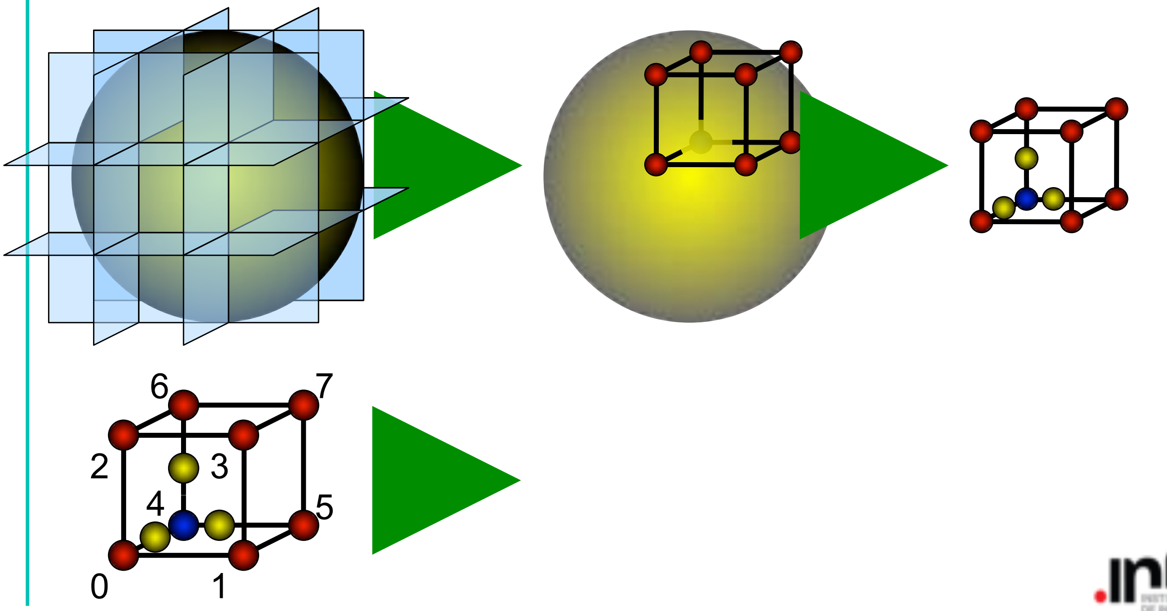

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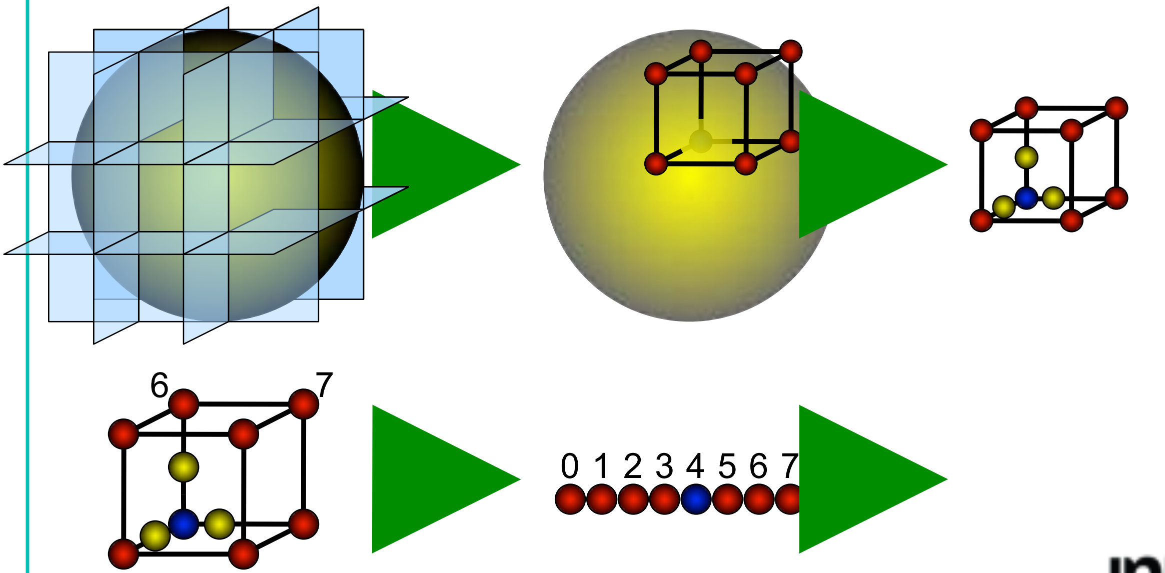

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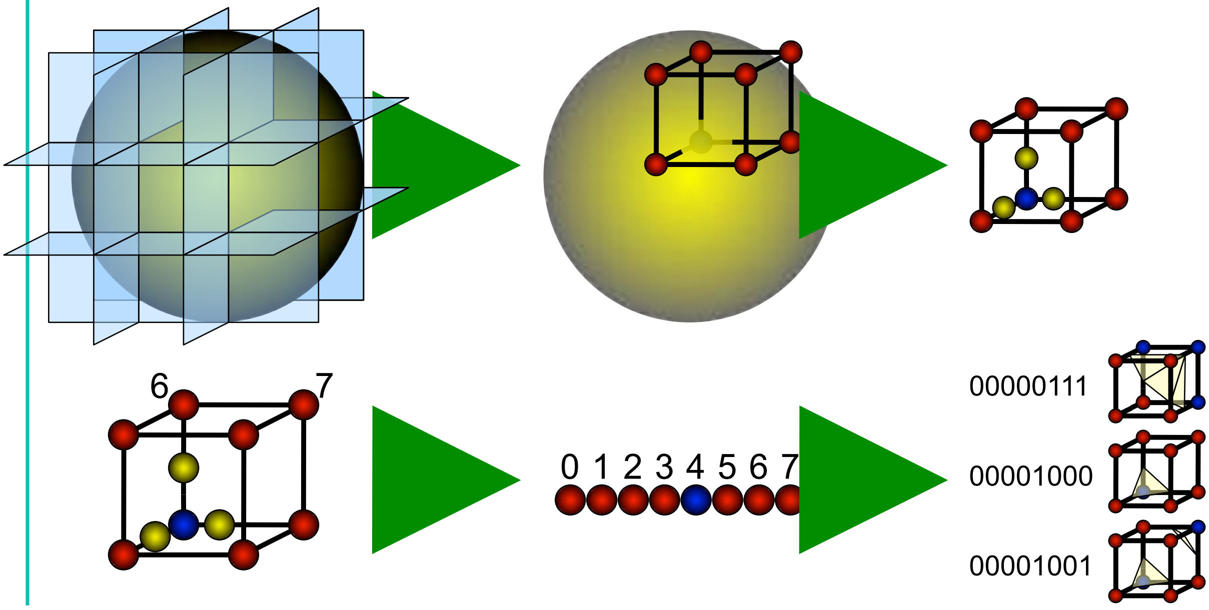


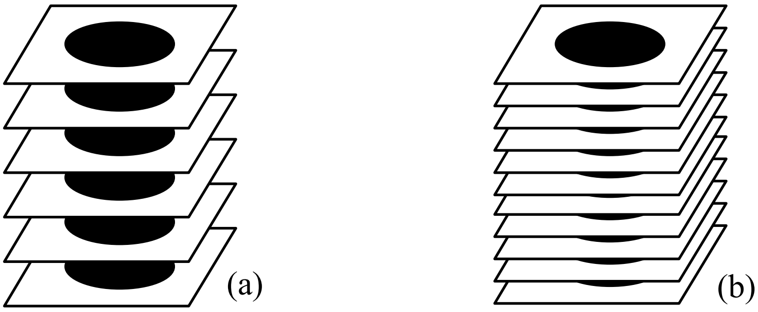
00000111

00001000

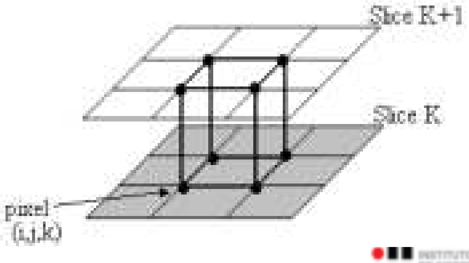
00001001

Surface extraction

- Marching cubes [Lorensen and Cline 87]

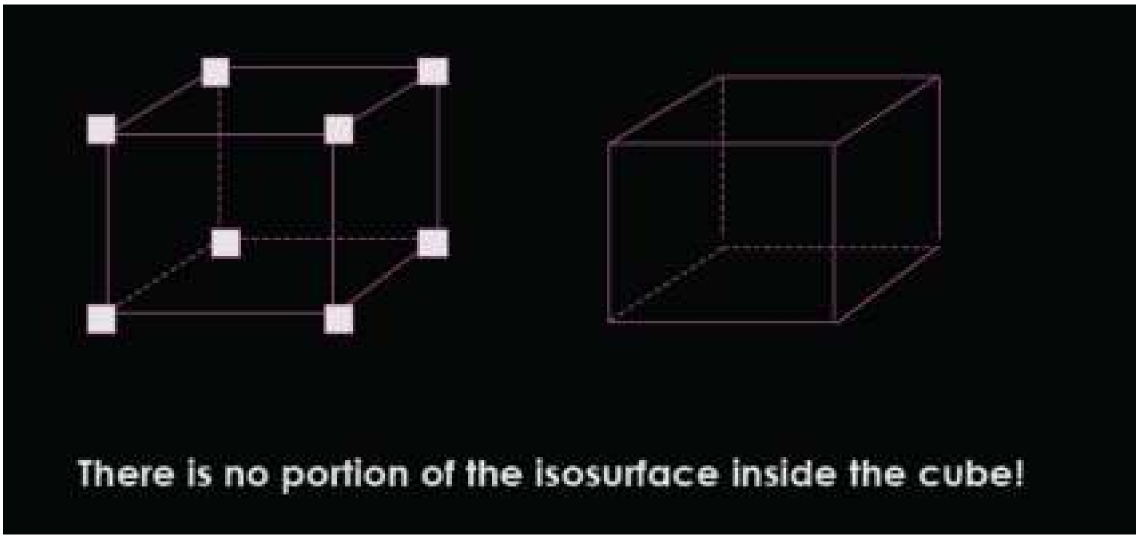


- Two adjacent slices form cubes

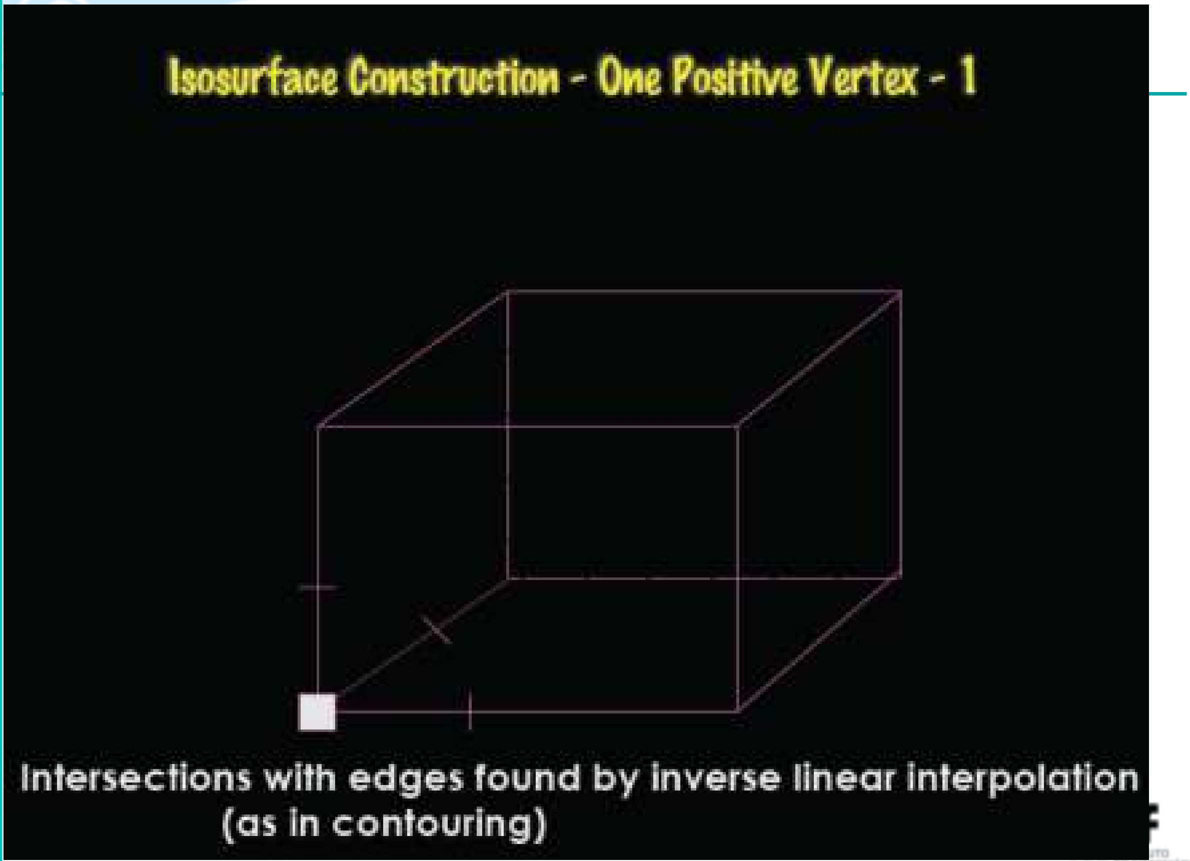


Marching cubes (Lorensen e Cline, 1987)

- Observing how a surface “passes through” a voxel

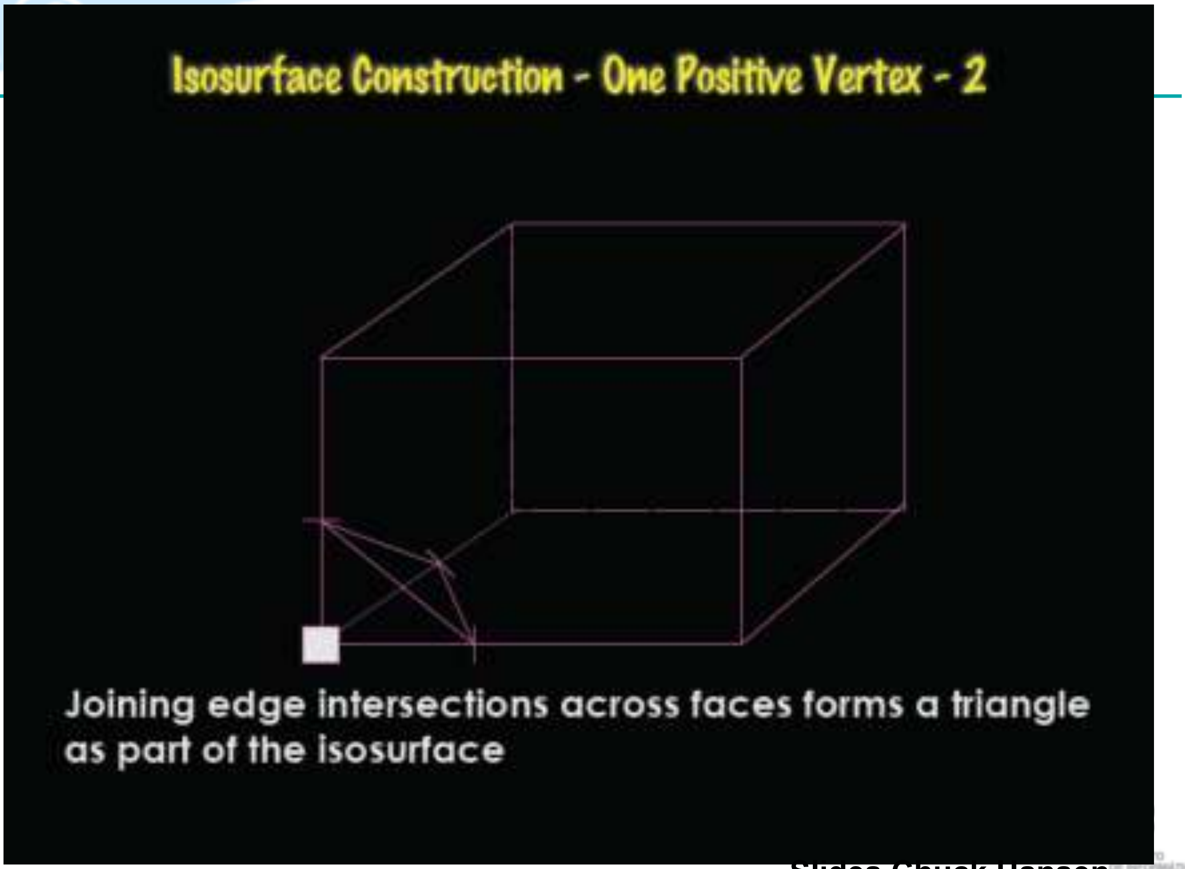


There is no portion of the isosurface inside the cube!



Isosurface Construction - One Positive Vertex - 1

Intersections with edges found by inverse linear interpolation (as in contouring)



Isosurface Construction - One Positive Vertex - 2

Joining edge intersections across faces forms a triangle as part of the isosurface

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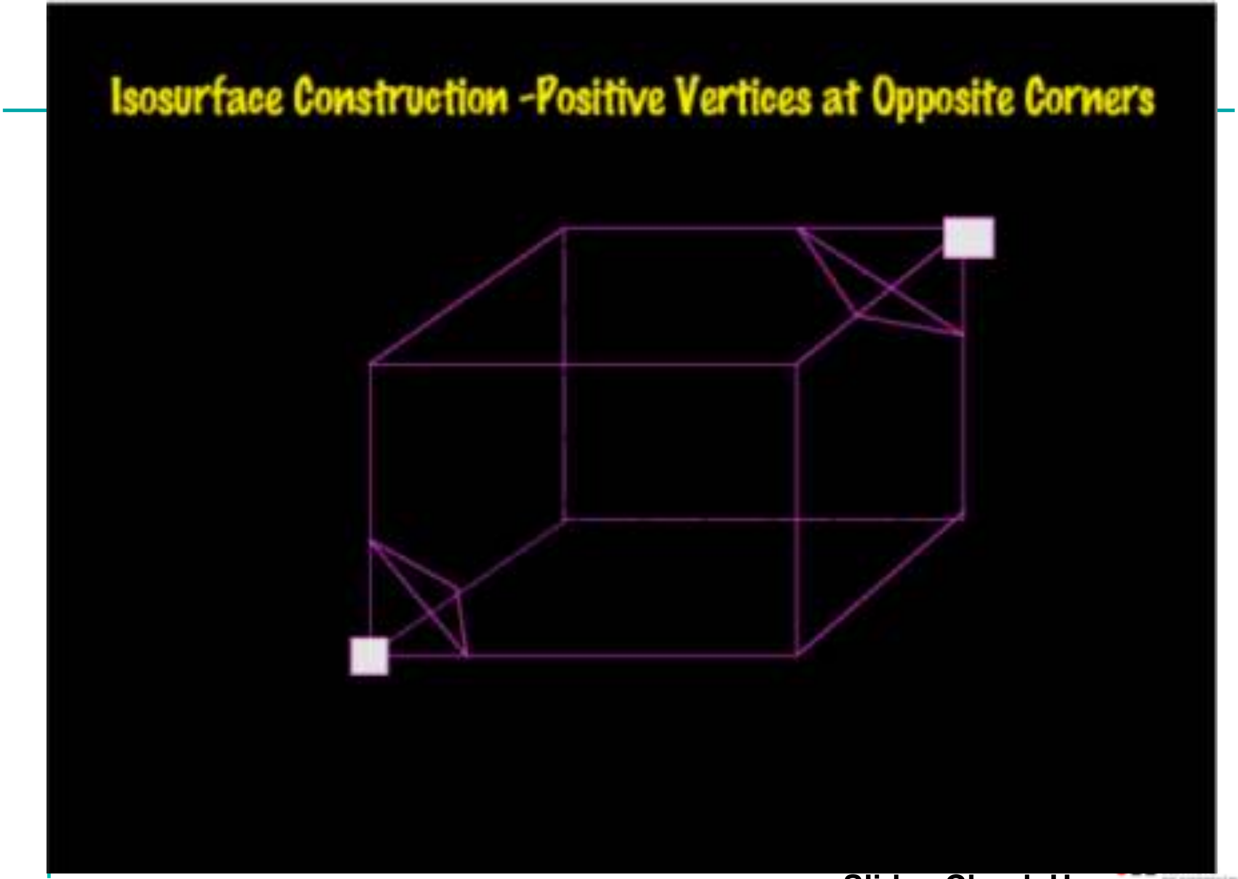
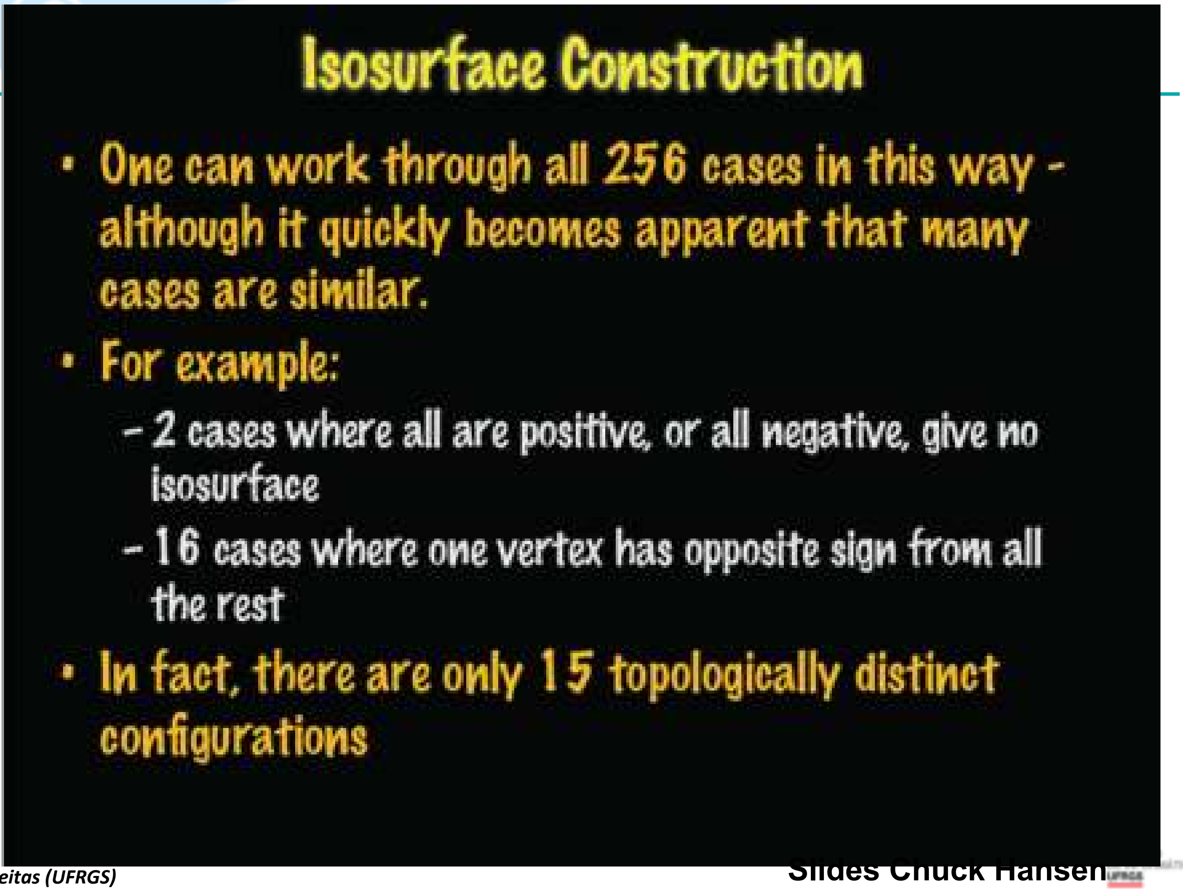


Isosurface Construction -Positive Vertices at Opposite Corners

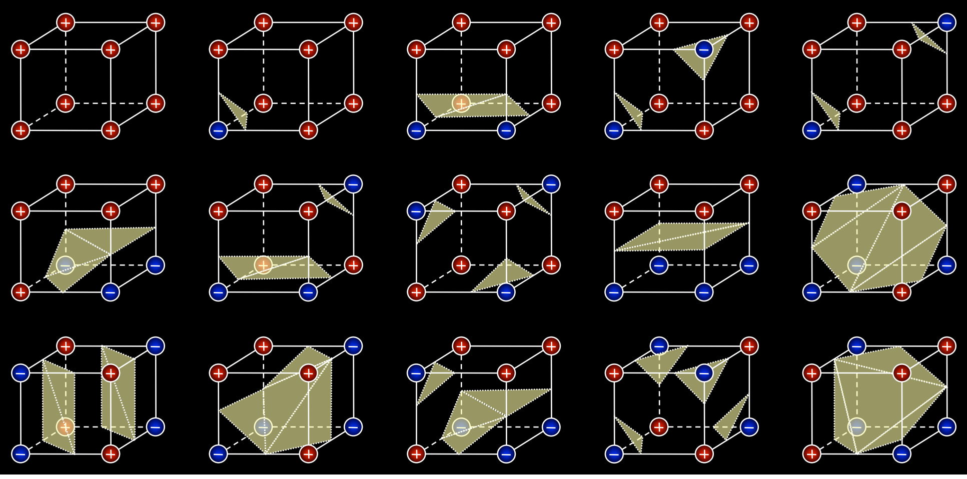


Isosurface Construction

- One can work through all 256 cases in this way - although it quickly becomes apparent that many cases are similar.
- For example:
  - 2 cases where all are positive, or all negative, give no isosurface
  - 16 cases where one vertex has opposite sign from all the rest
- In fact, there are only 15 topologically distinct configurations

Marching Cubes (MC) (Lorensen e Cline, 1987)

- 15 cases to be analyzed while moving the logical cube



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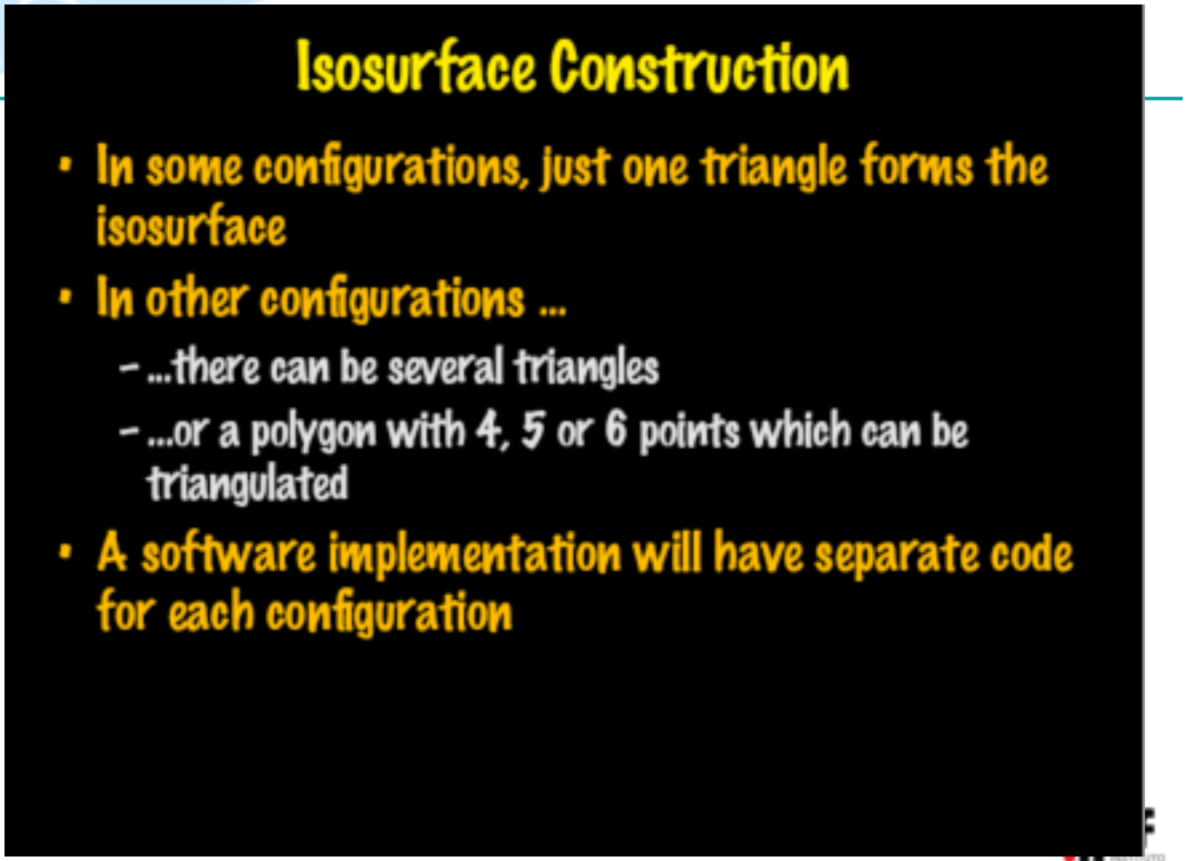

Isosurface Construction

- In some configurations, just one triangle forms the isosurface
- In other configurations ...
  - ...there can be several triangles
  - ...or a polygon with 4, 5 or 6 points which can be triangulated
- A software implementation will have separate code for each configuration

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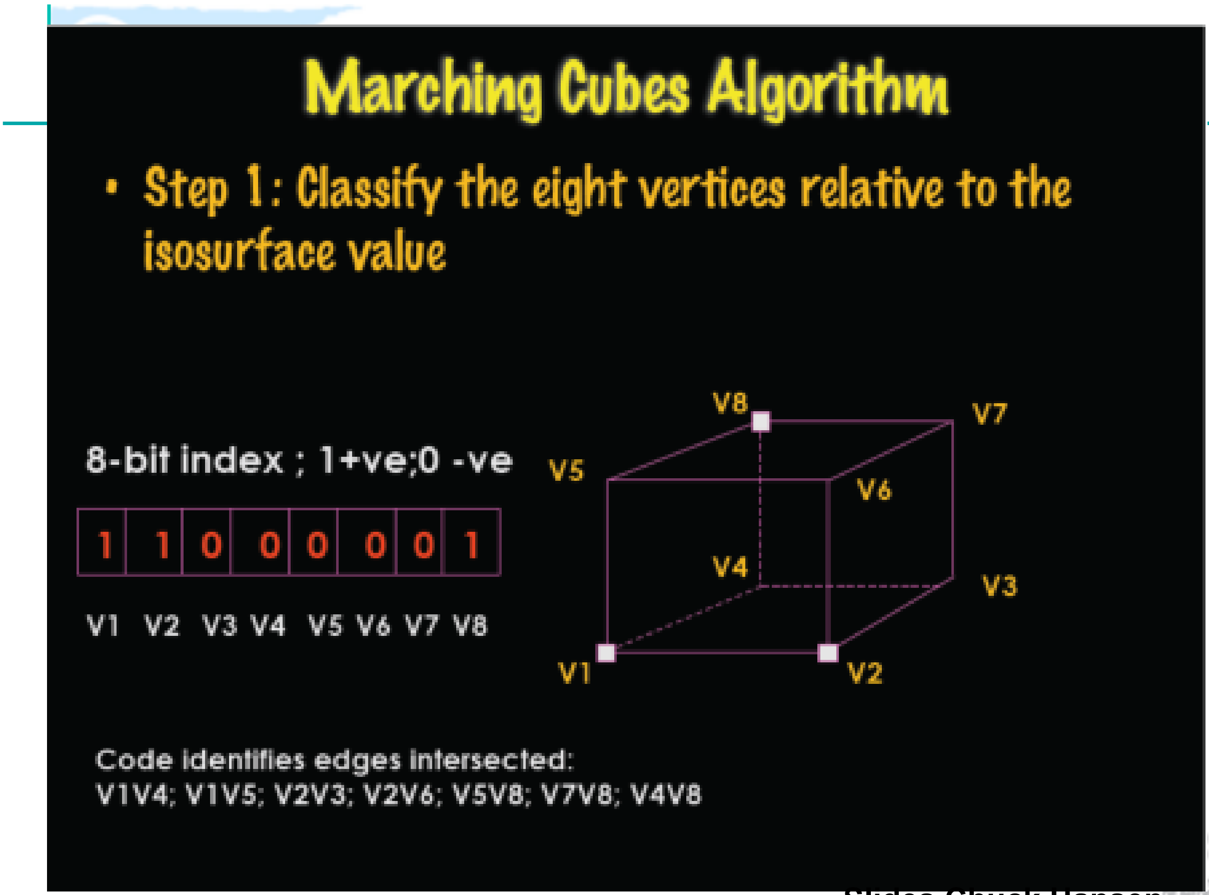


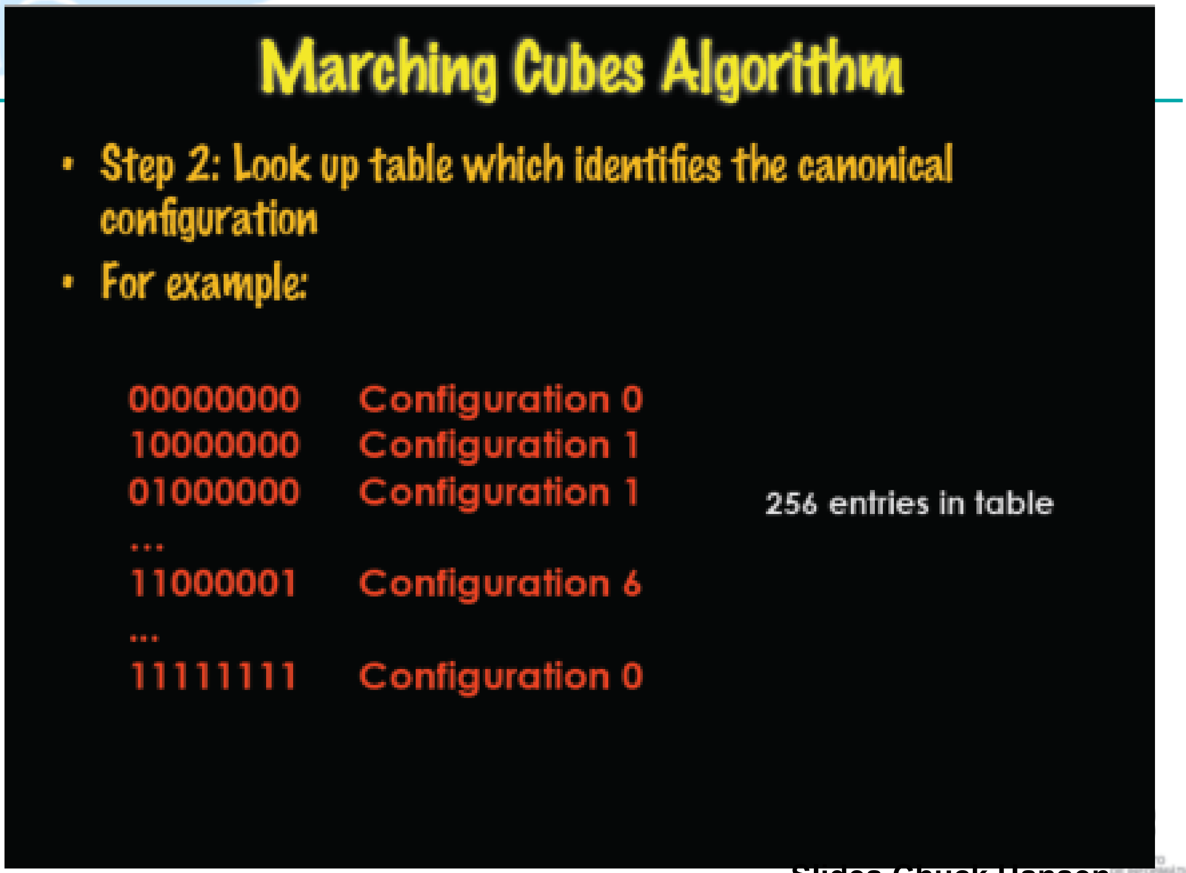
Marching Cubes Algorithm

- Step 1: Classify the eight vertices relative to the isosurface value

8-bit index ; 1+ve;0 -ve

1	1	0	0	0	0	0	1
V1	V2	V3	V4	V5	V6	V7	V8

Code identifies edges intersected:
V1V4; V1V5; V2V3; V2V6; V5V8; V7V8; V4V8

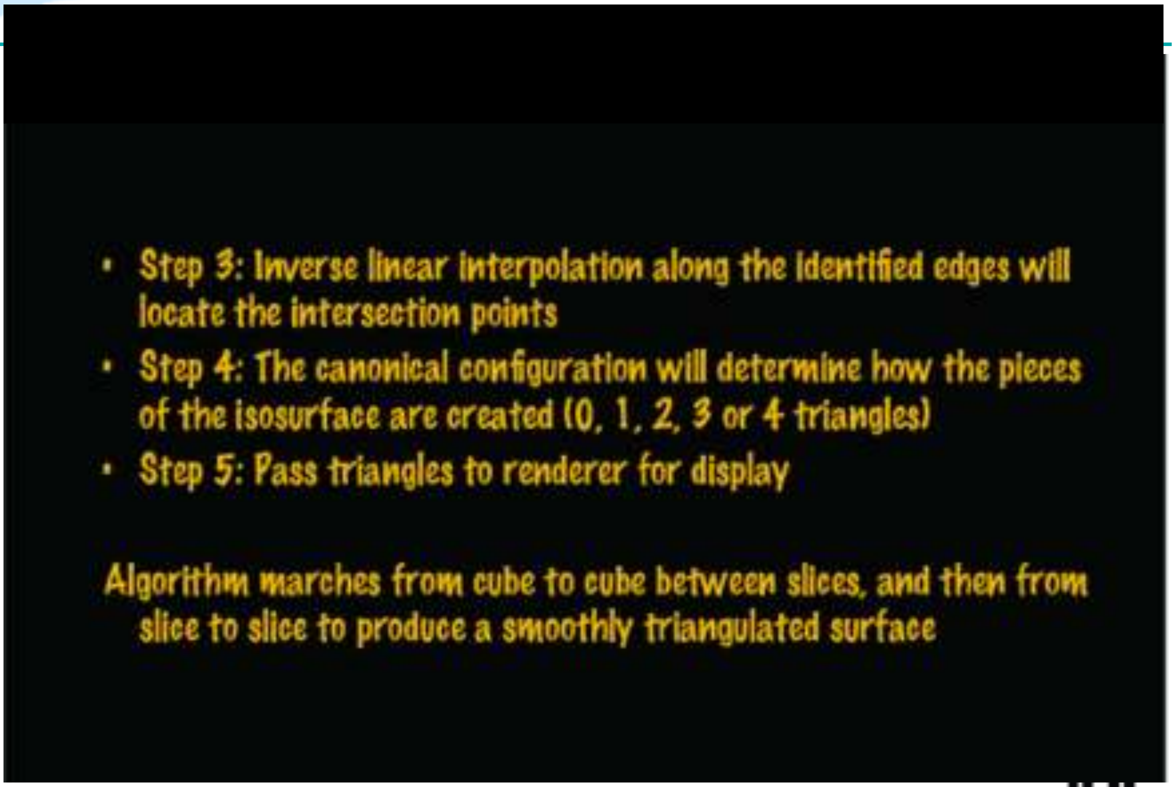


Marching Cubes Algorithm

- Step 2: Look up table which identifies the canonical configuration
- For example:

00000000	Configuration 0
10000000	Configuration 1
01000000	Configuration 1
...	
11000001	Configuration 6
...	
11111111	Configuration 0

256 entries in table



- Step 3: Inverse linear interpolation along the identified edges will locate the intersection points
- Step 4: The canonical configuration will determine how the pieces of the isosurface are created (0, 1, 2, 3 or 4 triangles)
- Step 5: Pass triangles to renderer for display

Algorithm marches from cube to cube between slices, and then from slice to slice to produce a smoothly triangulated surface

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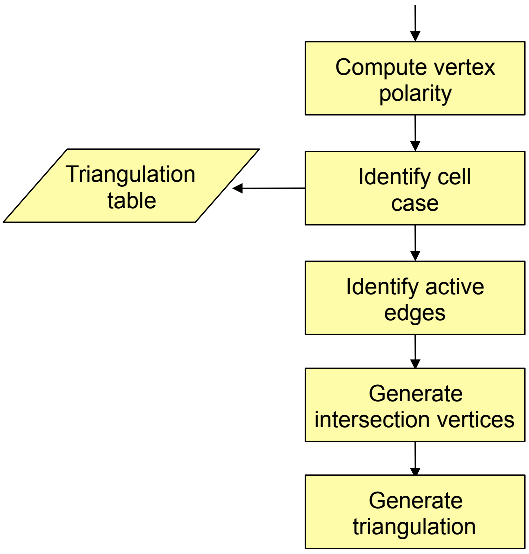
Marching Cubes (MC) (Lorensen e Cline, 1987)



Compute vertex polarity

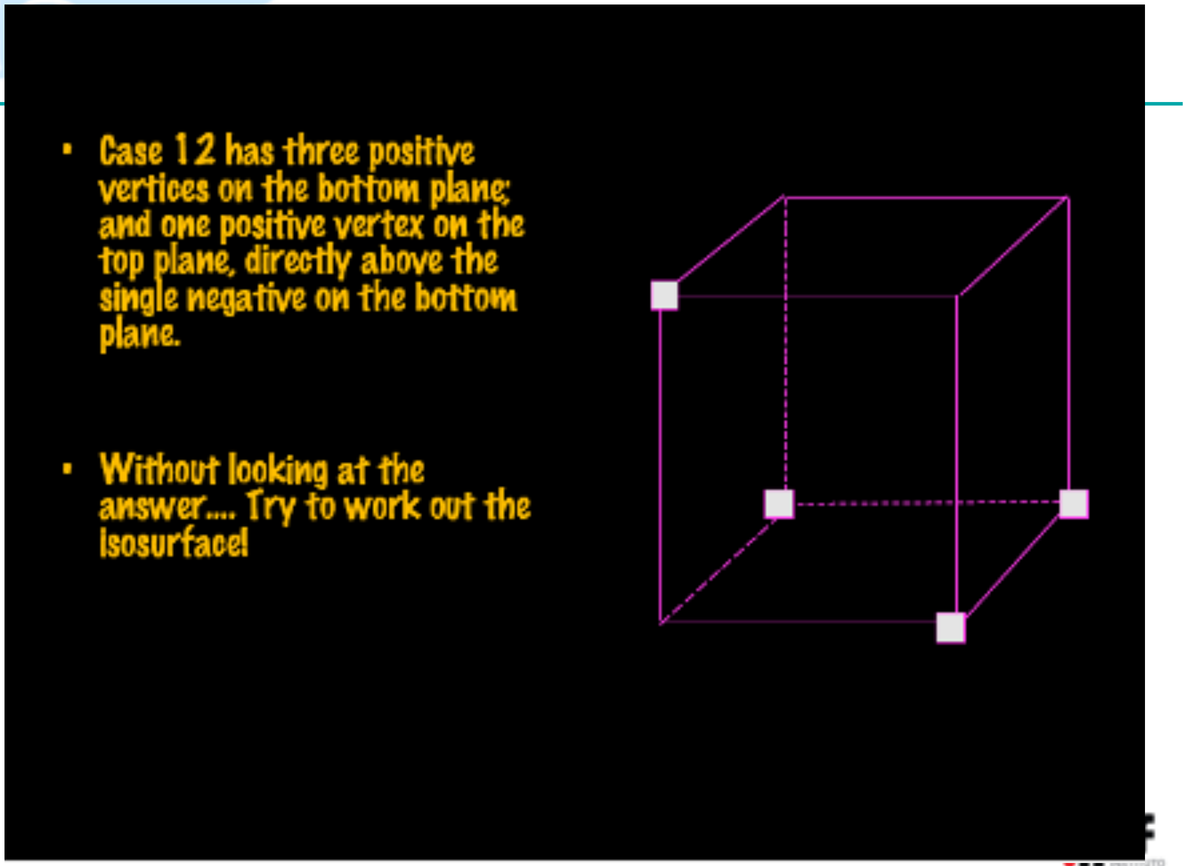
Identify cell case

Triangulation table

Identify active edges

Generate intersection vertices

Generate triangulation



- Case 12 has three positive vertices on the bottom plane; and one positive vertex on the top plane, directly above the single negative on the bottom plane.
- Without looking at the answer.... Try to work out the Isosurface!

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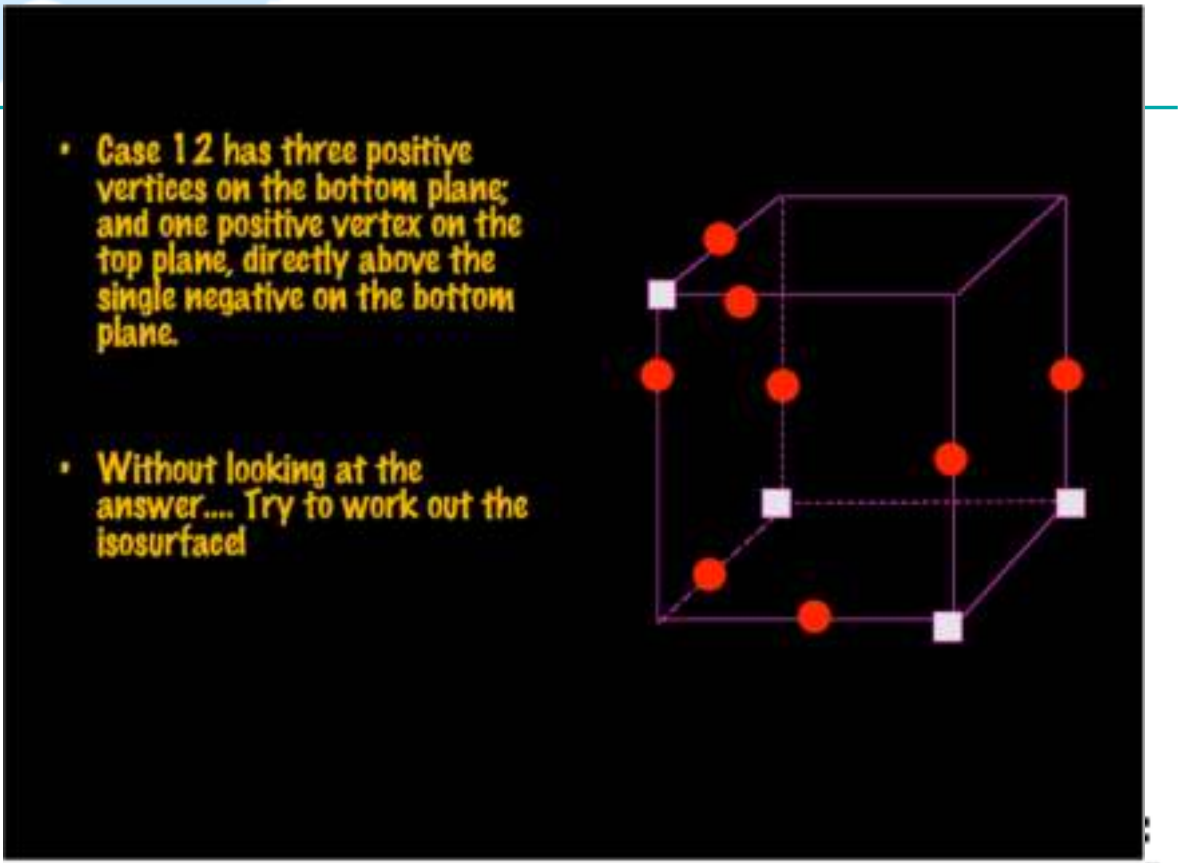

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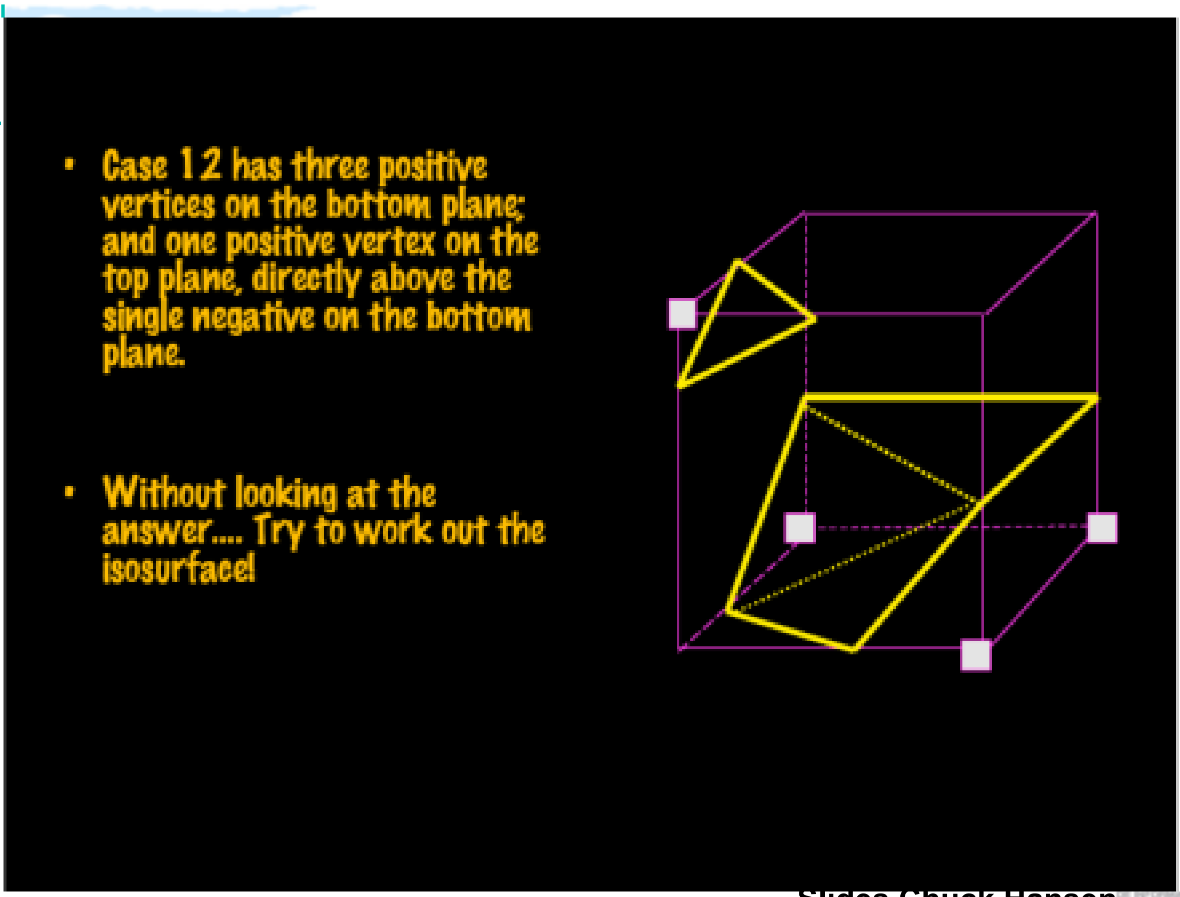

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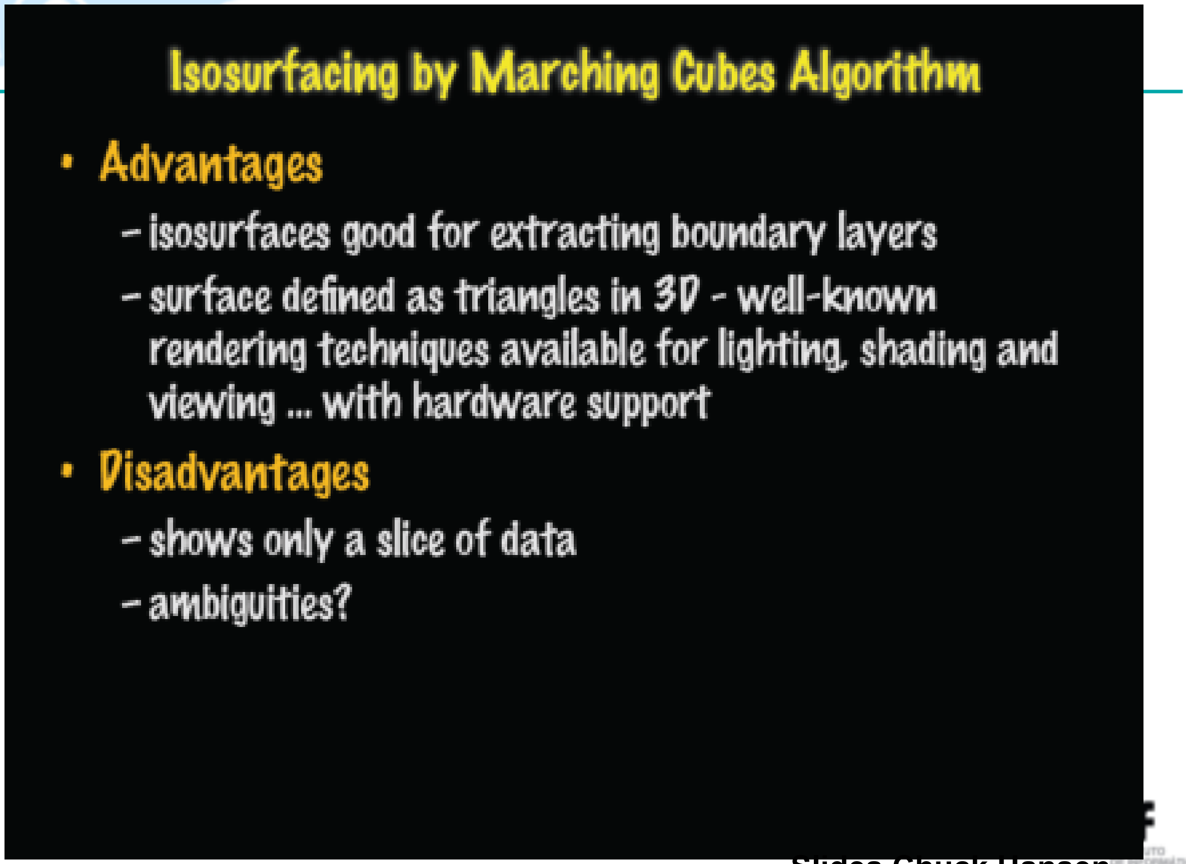
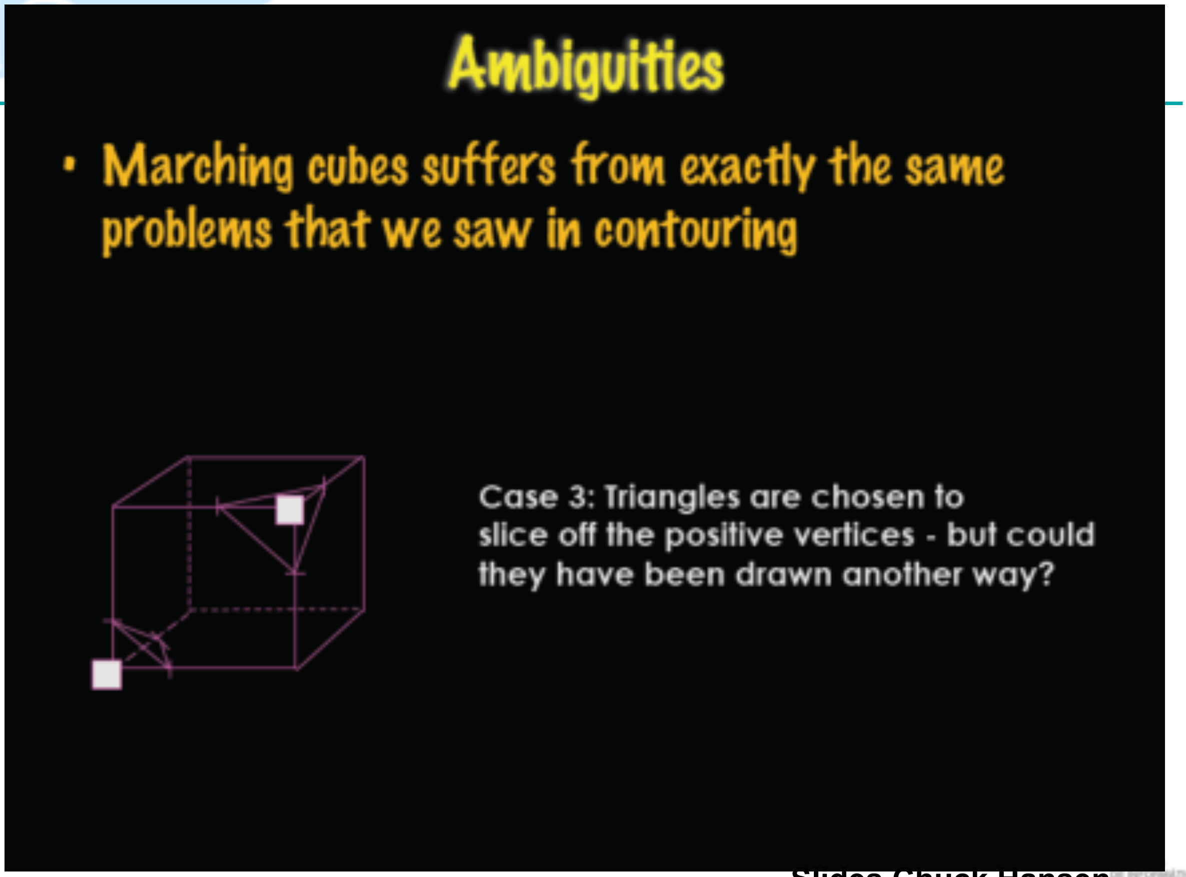


Isosurfacing by Marching Cubes Algorithm

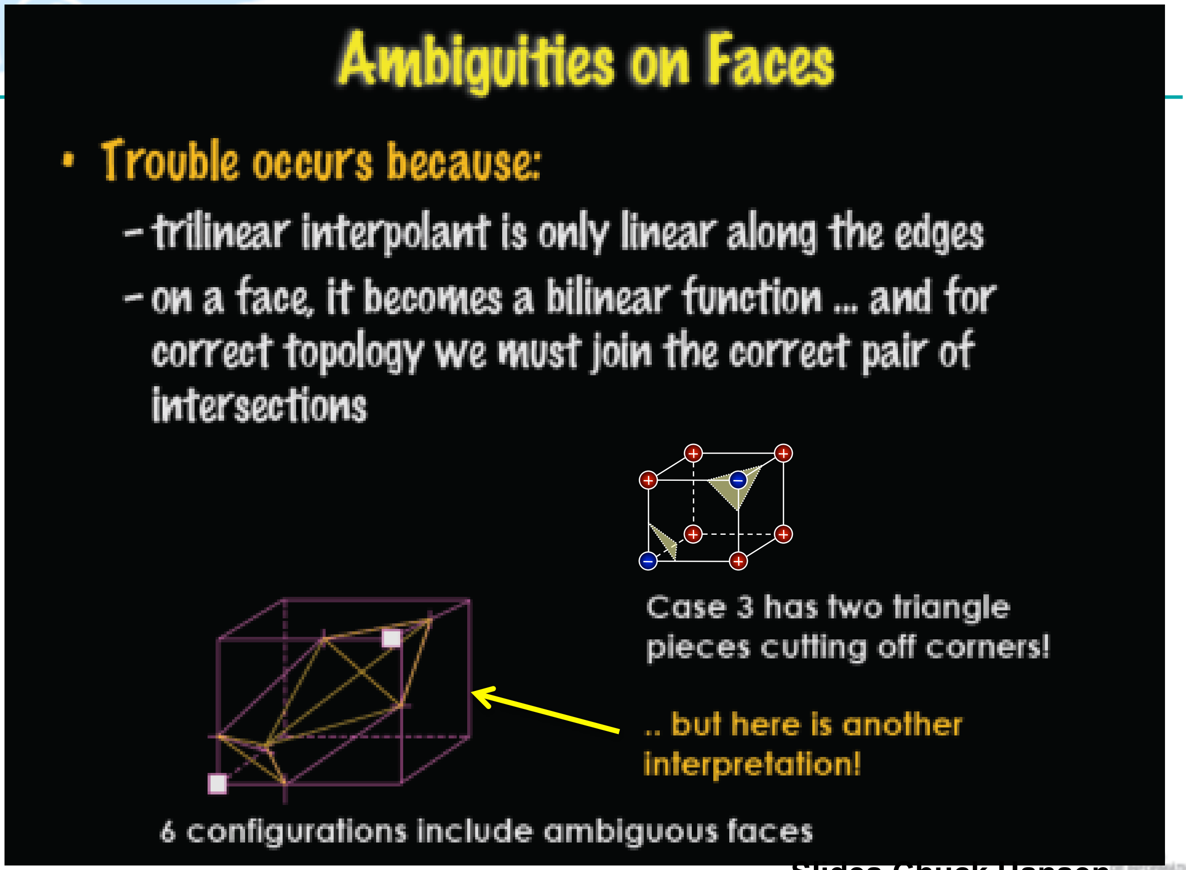
- Advantages
  - isosurfaces good for extracting boundary layers
  - surface defined as triangles in 3D - well-known rendering techniques available for lighting, shading and viewing ... with hardware support
- Disadvantages
  - shows only a slice of data
  - ambiguities?



Ambiguities

- Marching cubes suffers from exactly the same problems that we saw in contouring

Case 3: Triangles are chosen to slice off the positive vertices - but could they have been drawn another way?



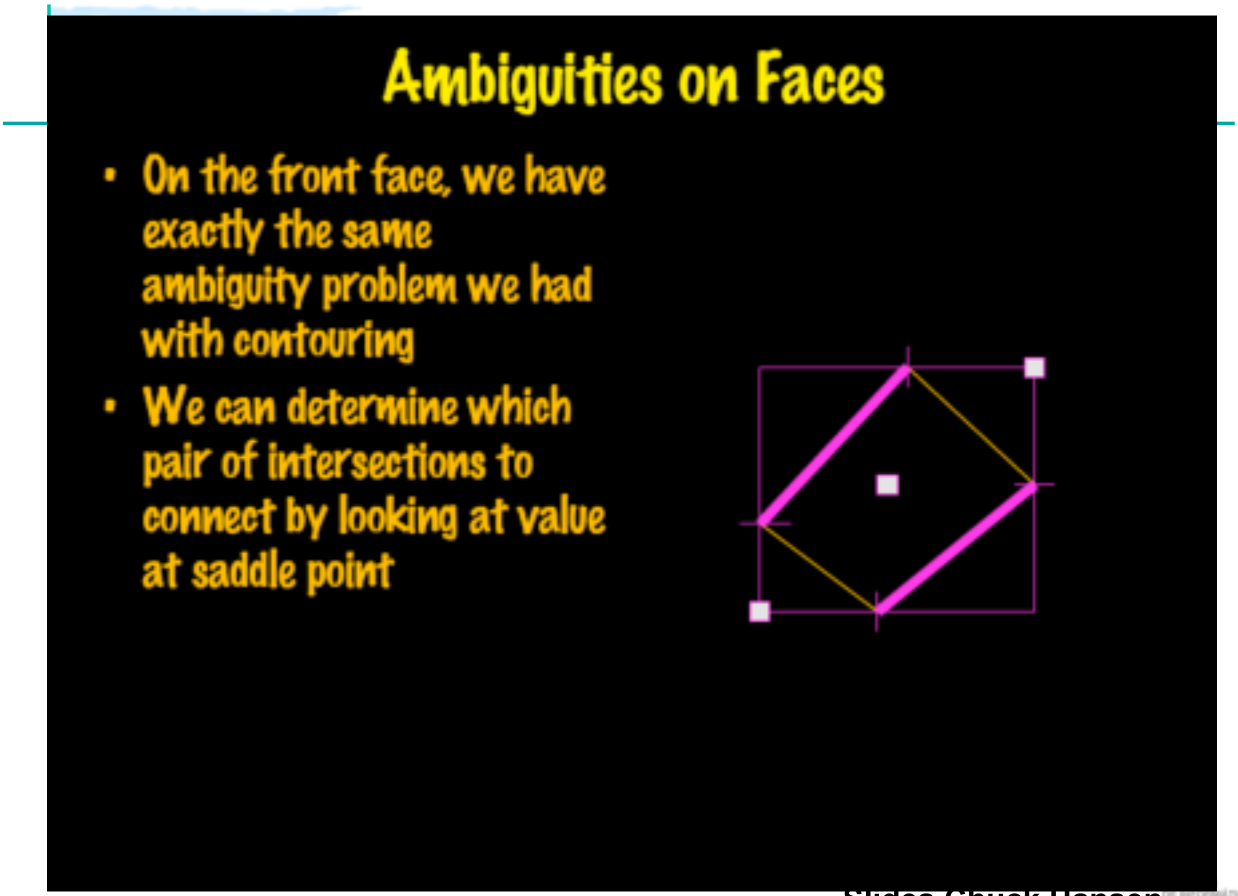
Ambiguities on Faces

- Trouble occurs because:
  - trilinear interpolant is only linear along the edges
  - on a face, it becomes a bilinear function ... and for correct topology we must join the correct pair of intersections

Case 3 has two triangle pieces cutting off corners!

.. but here is another interpretation!

6 configurations include ambiguous faces



Ambiguities on Faces

- On the front face, we have exactly the same ambiguity problem we had with contouring
- We can determine which pair of intersections to connect by looking at value at saddle point

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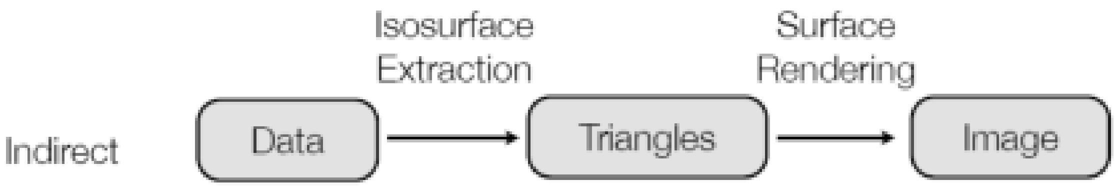
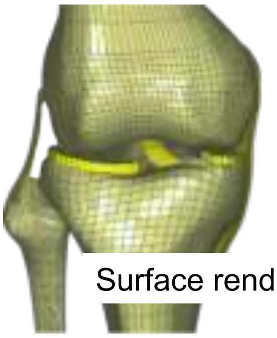
Volume visualization approaches

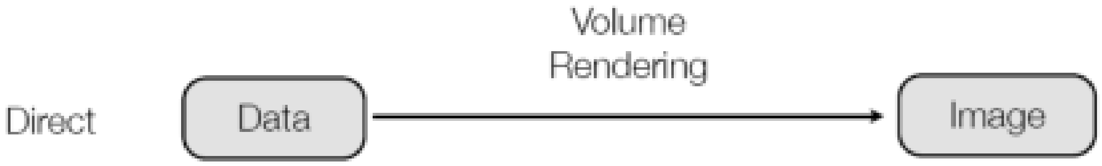




Surface rendering

Volume visualization approaches

Direct rendering



Direct volume rendering

- The data is considered to represent a semi-transparent, light-emitting medium (which absorbs light too)
  - Based on laws of physics
- Volume data is used as a whole
- Color and opacity are used to distinguish materials within the volume

Pinto, 2007

Direct volume rendering

- Three stages of volume rendering
  - **Sampling**: Selecting the steps through the volume
  - **Classification**: Computing a color and opacity for a step
  - **Compositing:** Blending together classified steps into a final image

Direct volume rendering

- Three stages of volume rendering
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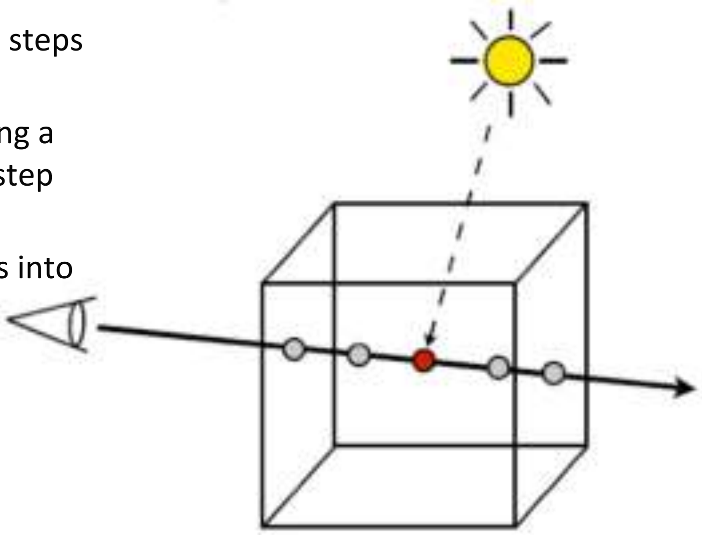
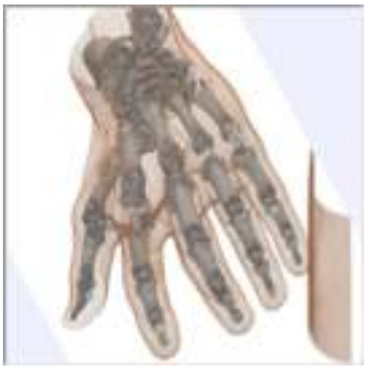
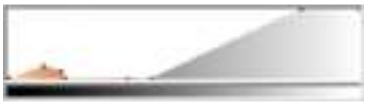
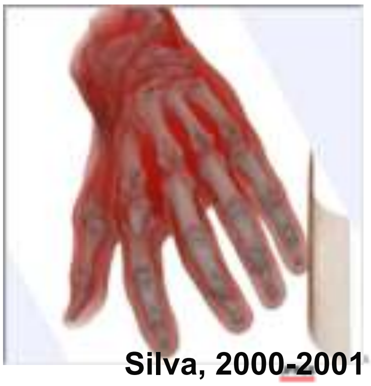


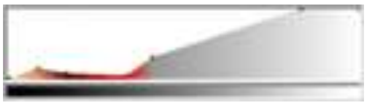
Direct volume rendering

- Three stages of volume rendering
  - **Sampling**: Selecting the steps through the volume
  - **Classification**: Computing a color and opacity for a step
  - **Compositing**: Blending together classified steps into a final image







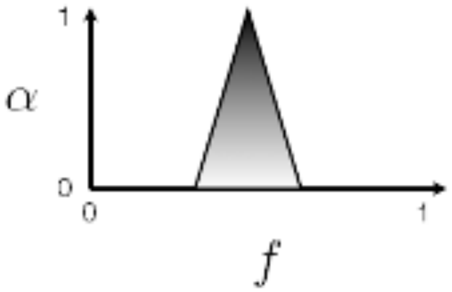


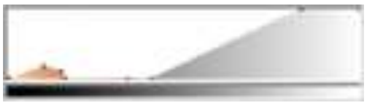
Silva, 2000-2001

Direct volume rendering

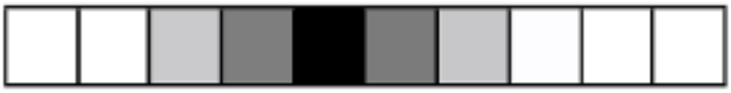
- **Classification**: Use of a transfer function

$$f(x) = \mathbf{R} \rightarrow \mathbf{R}^4, s \rightarrow (r,g,b,\alpha)$$





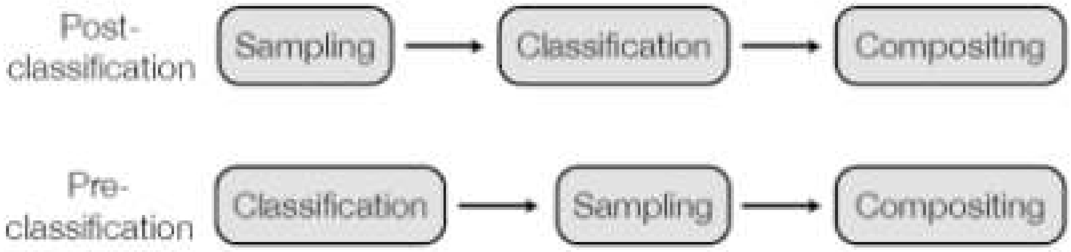
Look up table



Silva, 2000-2001

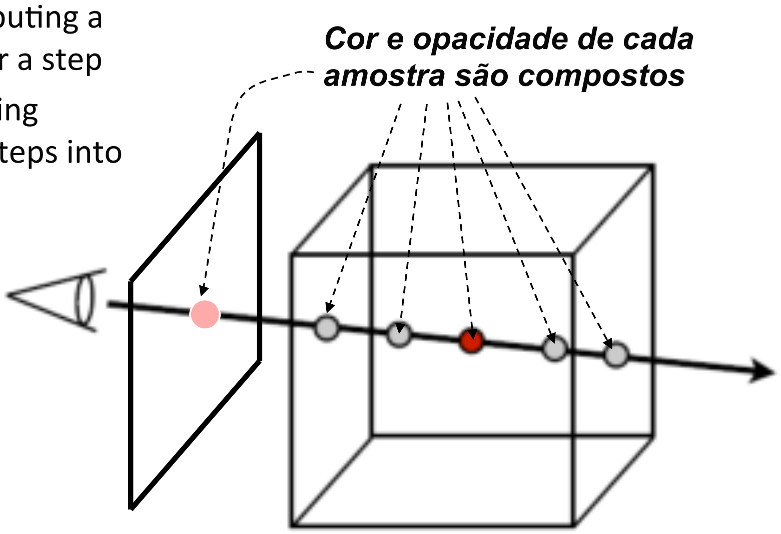
Direct volume rendering

- Three stages of volume rendering
  - Sampling: Selecting the steps through the volume
  - Classification: Computing a color and opacity for a step
  - Compositing: Blending together classified steps into a final image



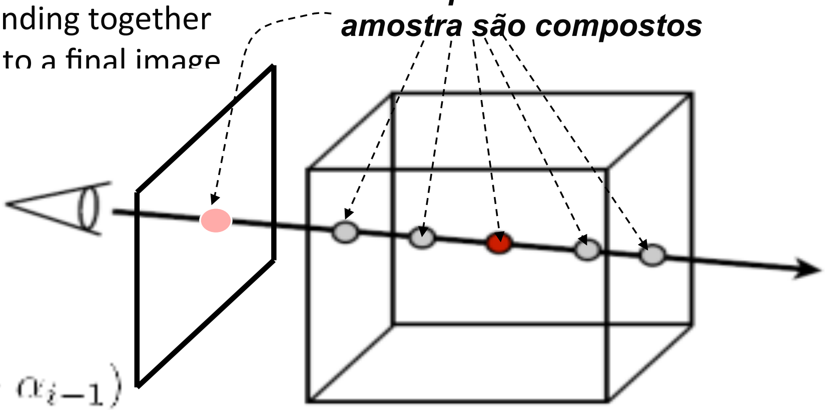
Direct volume rendering

- Three stages of volume rendering
  - **Sampling**: Selecting the steps through the volume
  - **Classification**: Computing a color and opacity for a step
  - **Compositing**: Blending together classified steps into a final image



Direct volume rendering

- Three stages of volume rendering
  - **Sampling**: Selecting the steps through the volume
  - **Classification**: Computing a color and opacity for a step
  - **Compositing**: Blending together classified steps into a final image



Cor e opacidade de cada amostra são compostos

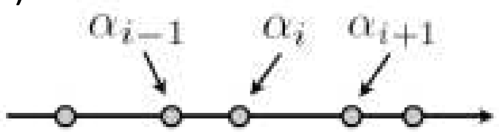
Ray casting: front to back

$$c_i = c_{i-1} + c_i\alpha_i(1 - \alpha_{i-1})$$

$$\alpha_i = \alpha_{i-1} + \alpha_i(1 - \alpha_{i-1})$$

Direct volume rendering

- Image-based (backward projection)
  - Ray-casting (front to back)



$$c_i = c_{i-1} + c_i\alpha_i(1 - \alpha_{i-1})$$

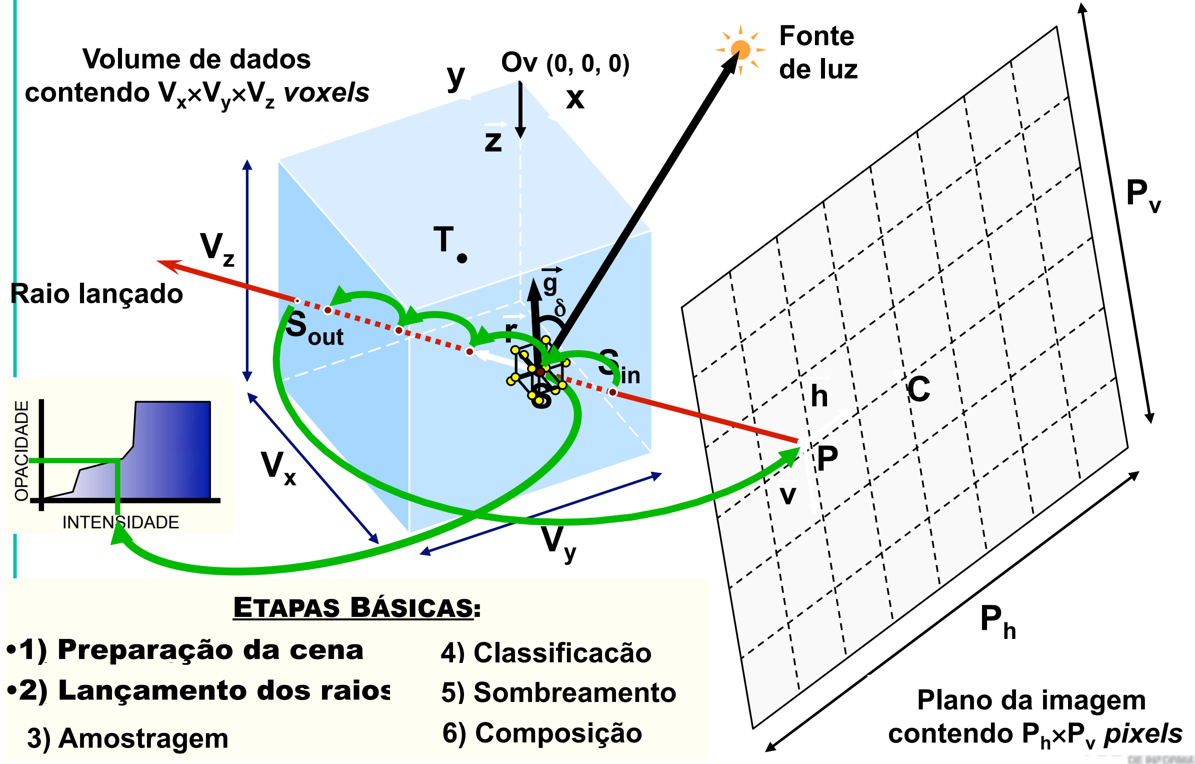
$$\alpha_i = \alpha_{i-1} + \alpha_i(1 - \alpha_{i-1})$$

- Object-based (forward projection, back to front)
  - Splatting
  - Texture mapping

$$c_i = c_i\alpha_i + c_{i+1}(1 - \alpha_i)$$

Ray casting

Silva, 2000-2001

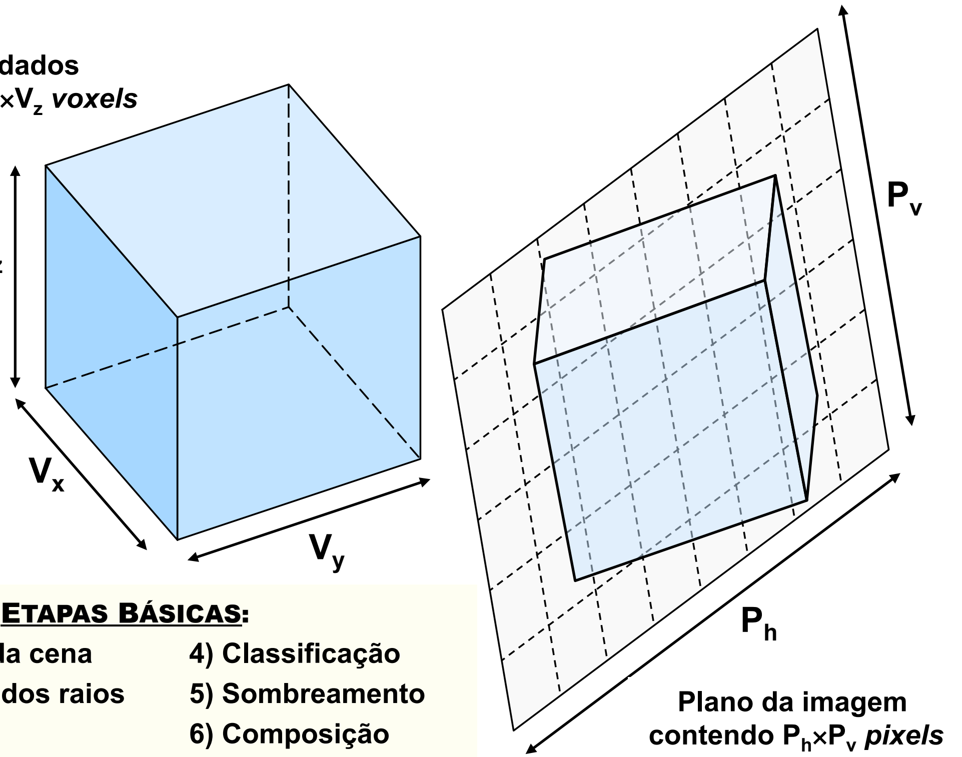


ETAPAS BÁSICAS:

- **•1) Preparação da cena**
- **•2) Lançamento dos raios**
- 3) Amostragem
- 4) Classificacão
- 5) Sombreamento
- 6) Composição

Ray casting

Silva, 2000-2001



Volume de dados
contendo $V_x \times V_y \times V_z$ *voxels*
V_z
V_x
V_y
P_v
P_h
Plano da imagem
contendo $P_h \times P_v$ *pixels*

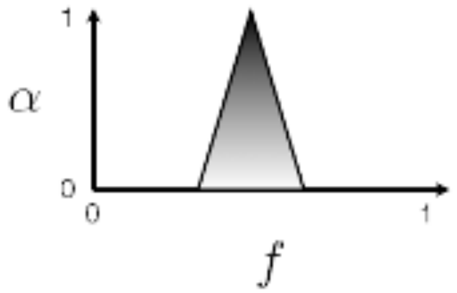
ETAPAS BÁSICAS:

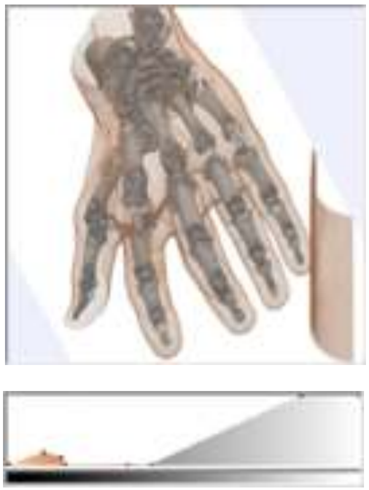
- 1) Preparação da cena
- 2) Lançamento dos raios
- 3) Amostragem
- 4) Classificação
- 5) Sombreamento
- 6) Composição

Transfer functions

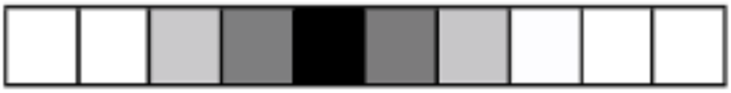
- **Classification: color and opacity**

$$f(x) = \mathbf{R} \rightarrow \mathbf{R}^4, s \rightarrow (r, g, b, \alpha)$$



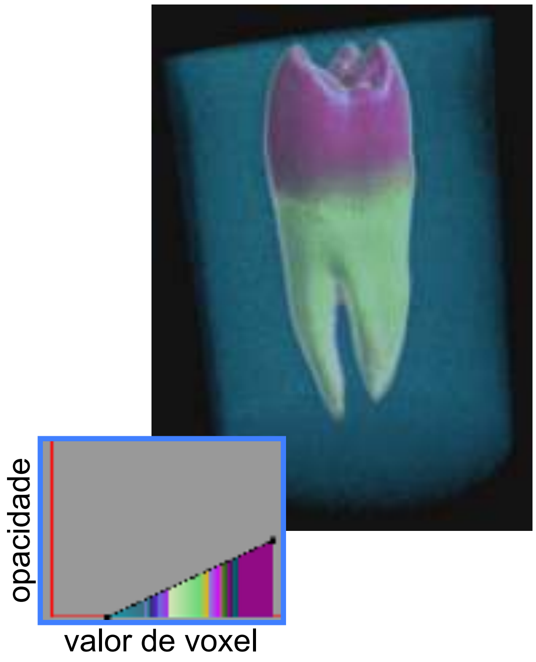


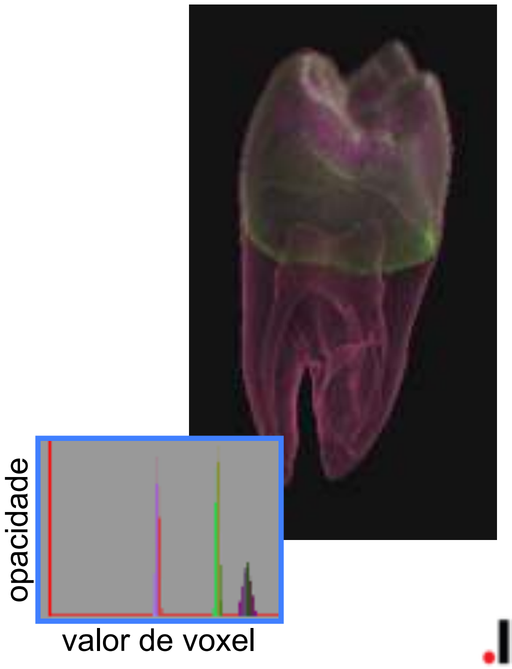
Look up table



Silva, 2000-2001

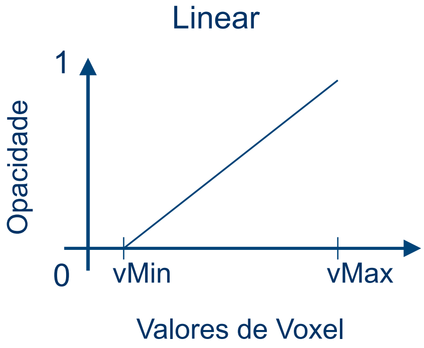
Transfer functions





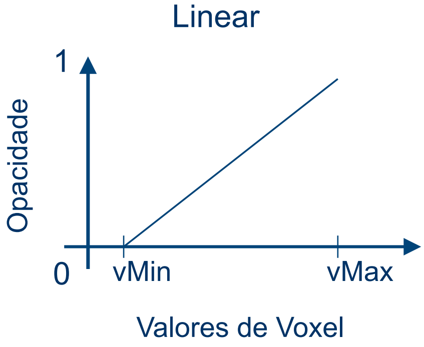
❖ FTs de opacidade 1-D

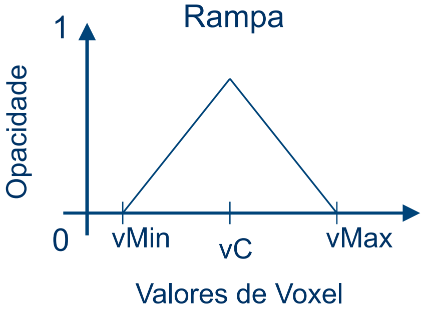
$$\alpha = f(v)$$



❖ FTs de opacidade 1-D

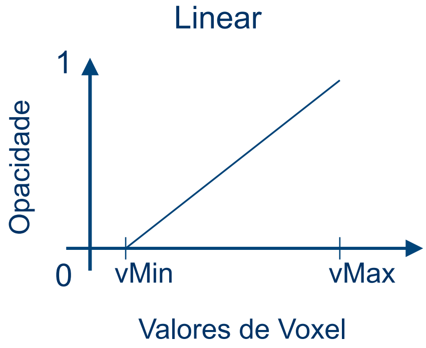
$$\alpha = f(v)$$

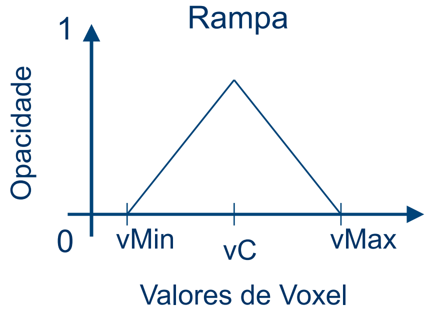


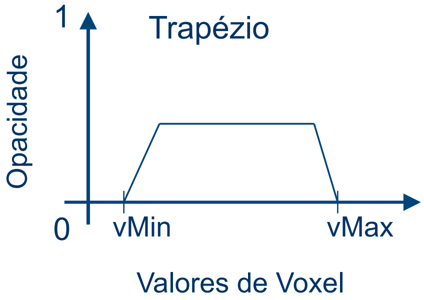


❖ FTs de opacidade 1-D

$$\alpha = f(v)$$

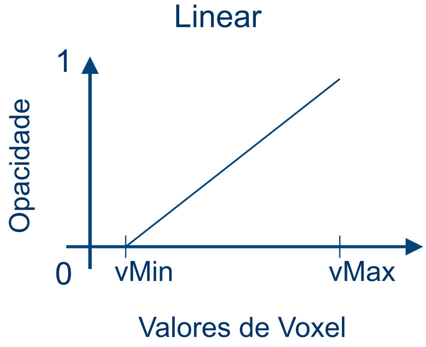


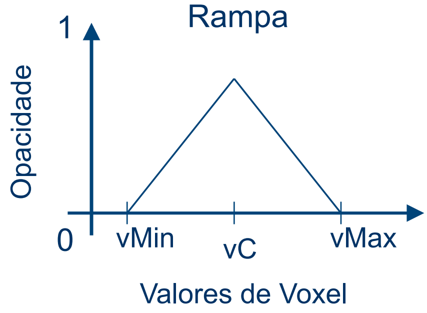


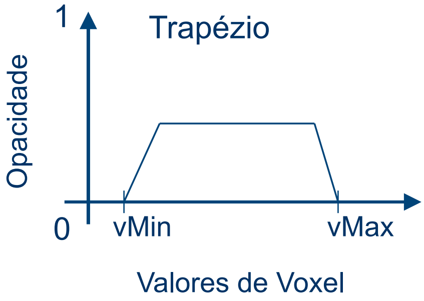


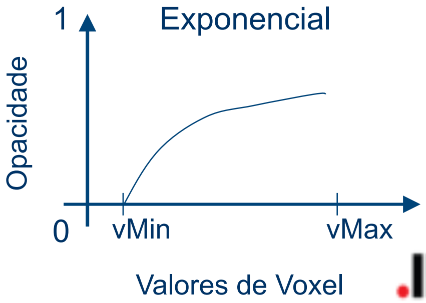
❖ FTs de opacidade 1-D

$$\alpha = f(v)$$

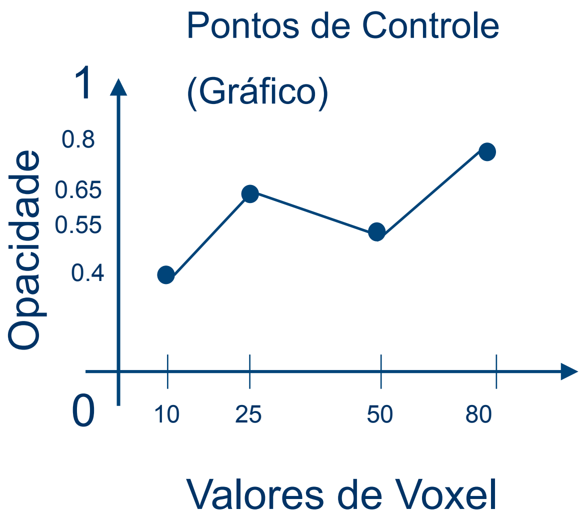




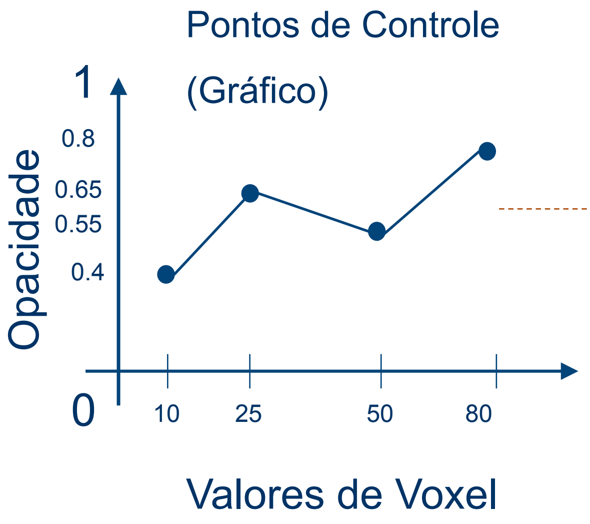




❖ Especificação Manual de FTs



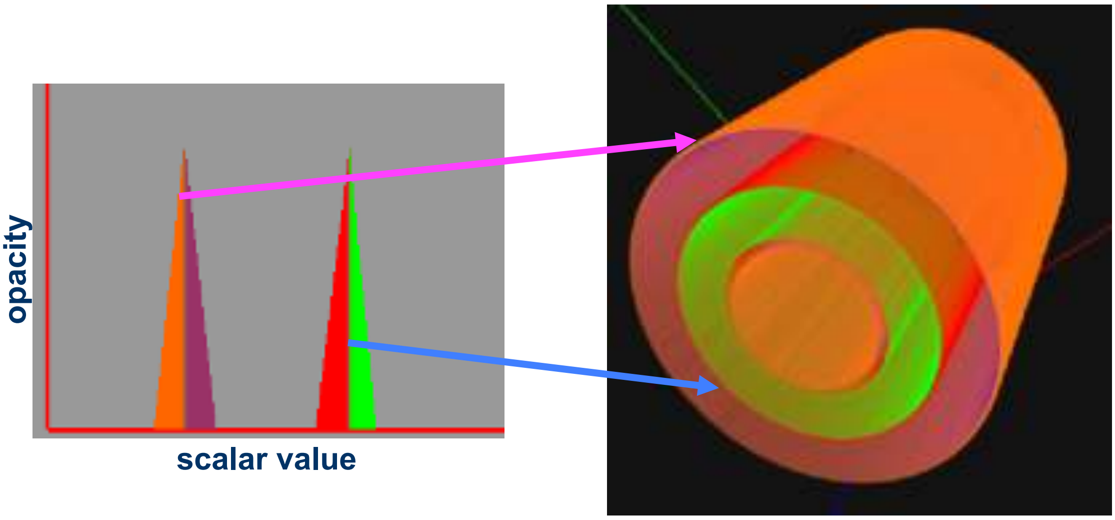
❖ Especificação Manual de FTs



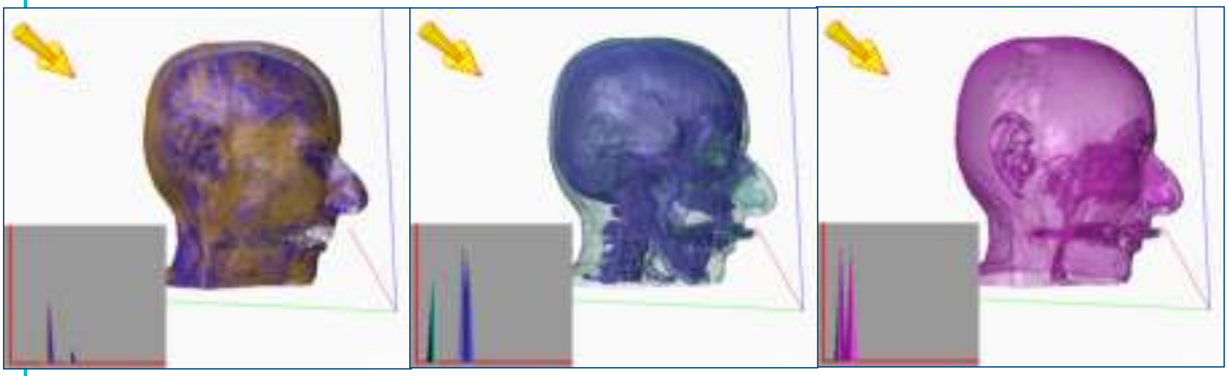
Lookup Table Resultante

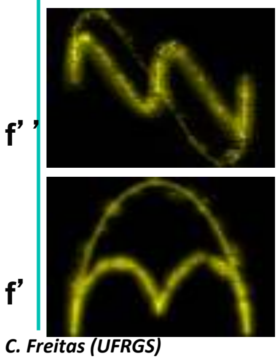
0.4	0.42	0.46	0.48	0.5	0.52	...	0.8
10	11	12	13	14	15	...	80

Enhancing transition zones



Transfer functions

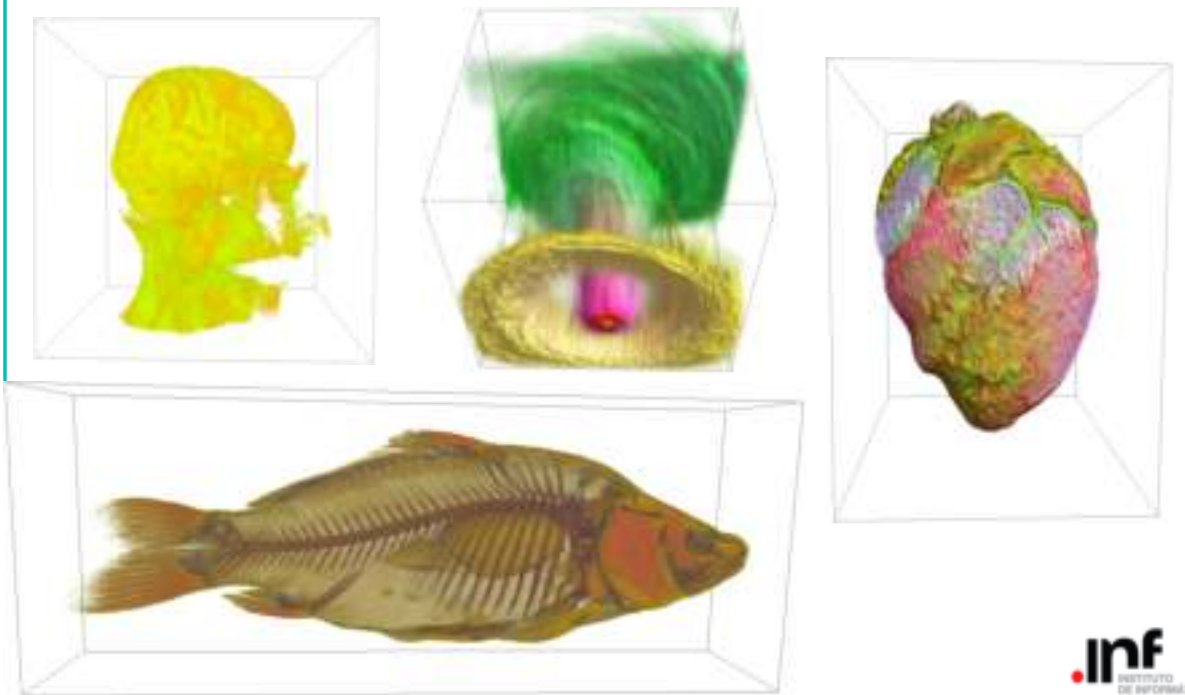




- Valores escalares de voxel são ordenados de acordo com a distância estimada até a borda mais próxima (Kindlmann e Durkin, 1998).

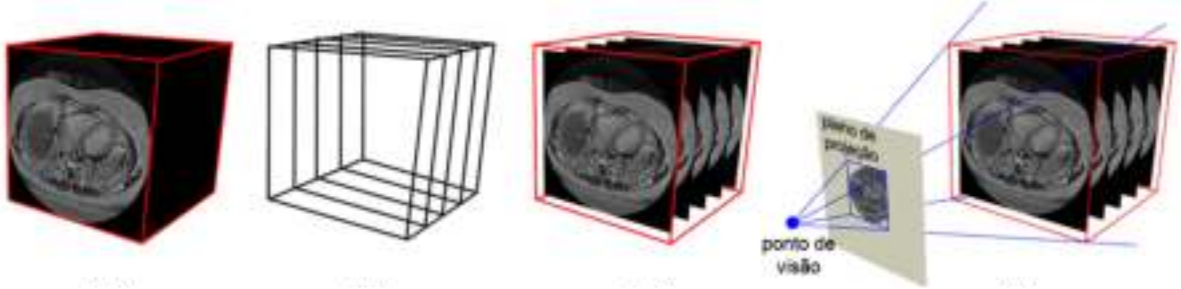
- Sorteia-se, entre os primeiros, um pequeno número de valores de voxel. Estes recebem opacidade elevada e descontinuidade de cor.

Results



Direct volume rendering

- Image-based (backward projection)
  - Ray-casting
- Object-based (forward projection)
  - Texture mapping


plano de projeção
ponto de visão