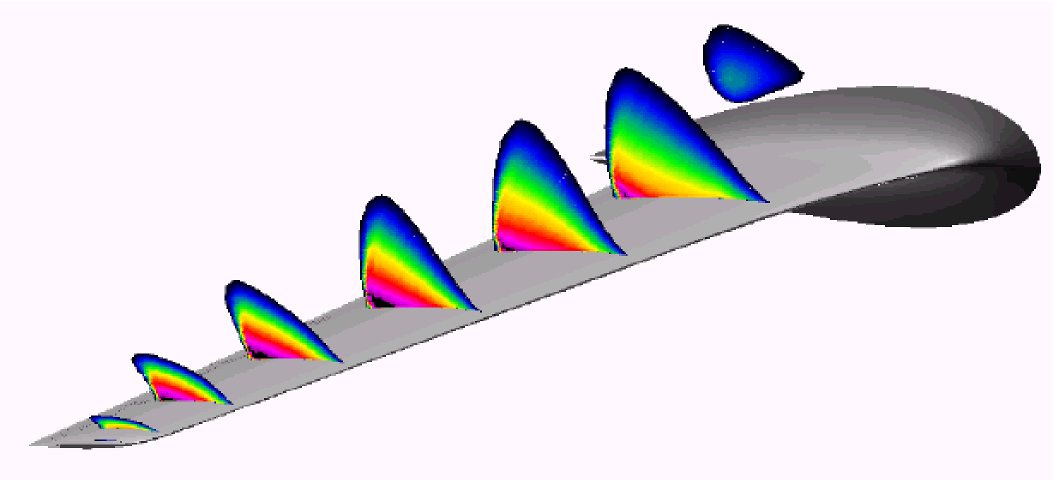
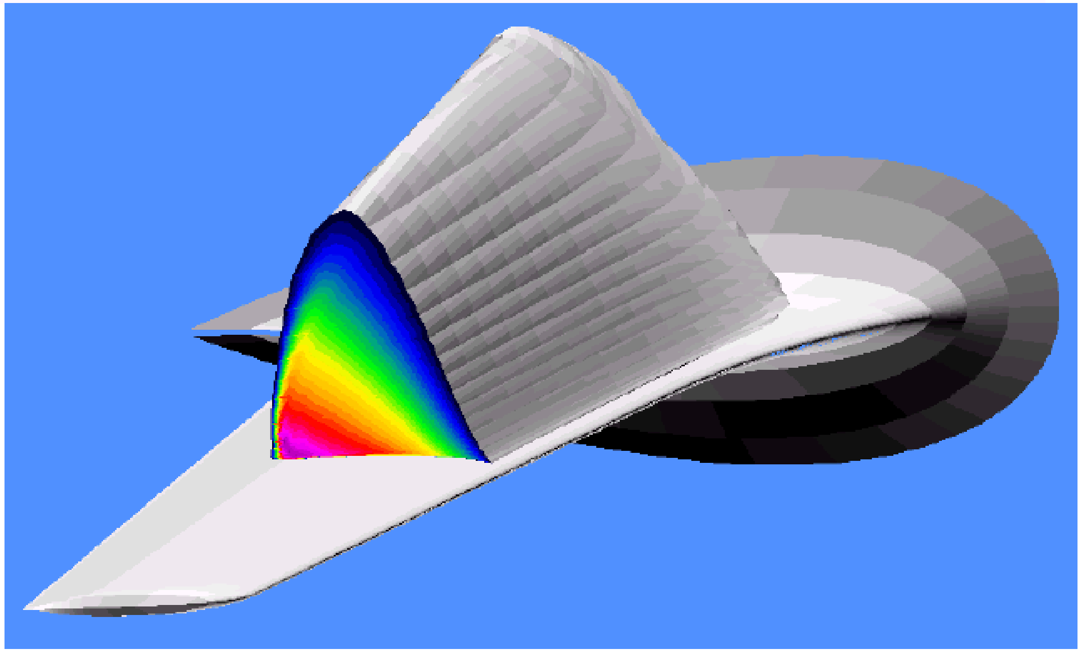
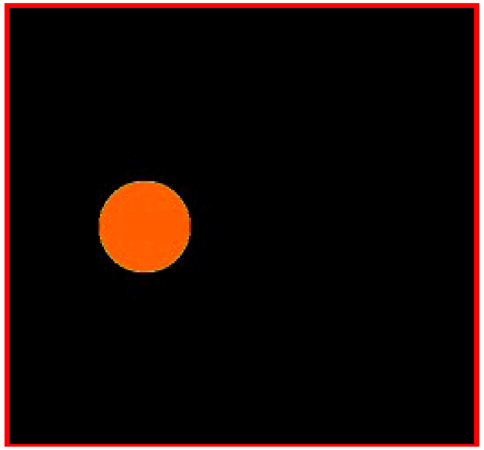
Volume Visualization

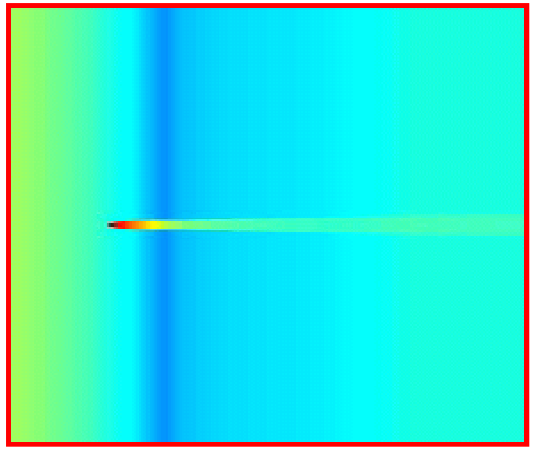
Part 2 (out of 3)

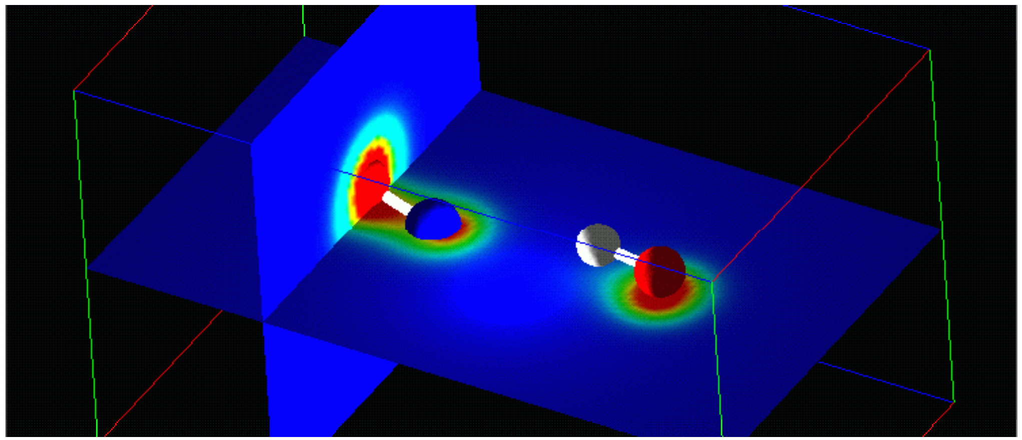


Scalar-clipping, combination with 3D



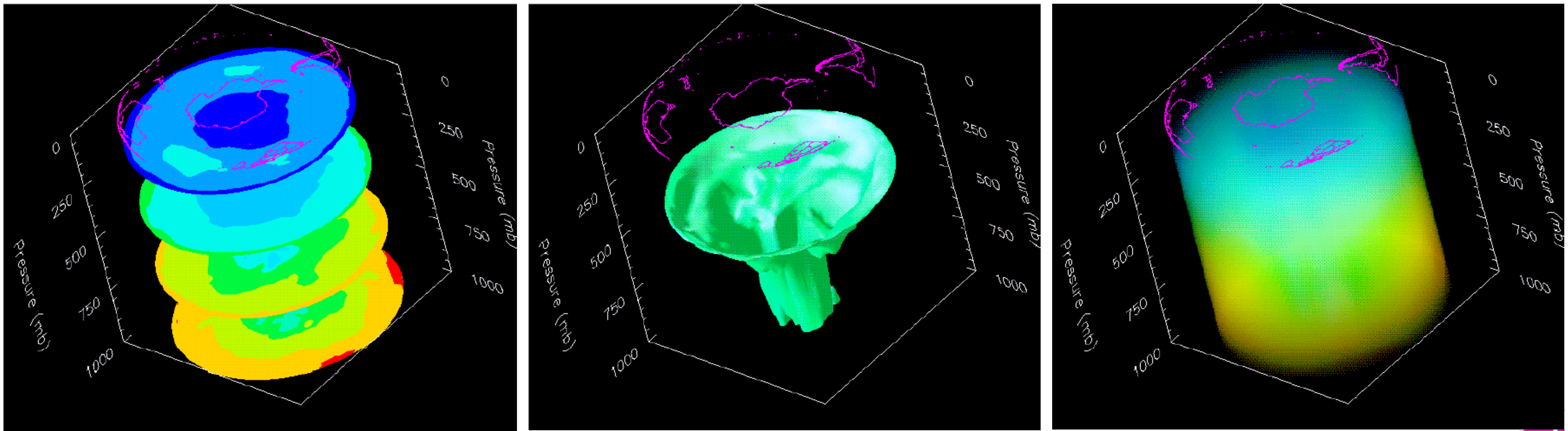






Slices vs. Iso-Surfaces. vs. Volume Rendering

- Comparison ozon-data over Antarctica:
  - Slices: selective (z), 2D, color coding
  - Iso-surface: selective (f_0), covers 3D
  - Vol. rendering: transfer function dependent, “(too) sparse – (too) dense”



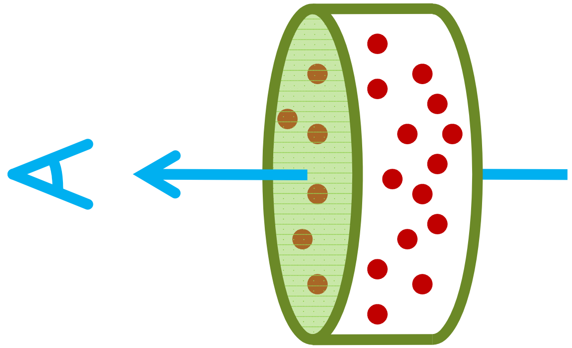
Optical Models for Volume Rendering

Display of

Semi-Transparent Media

Modelling of Natural Phenomena

- Various models (Examples):
  - Emission only (light particles)
  - Absorption only (dark fog)
  - Emission & absorption (clouds)
  - Single scattering, w/o shadows
  - Multiple scattering
- Two approaches:
  - Analytical model (via differentials)
  - Numerical approximation (via differences)



Emission, Differential Model

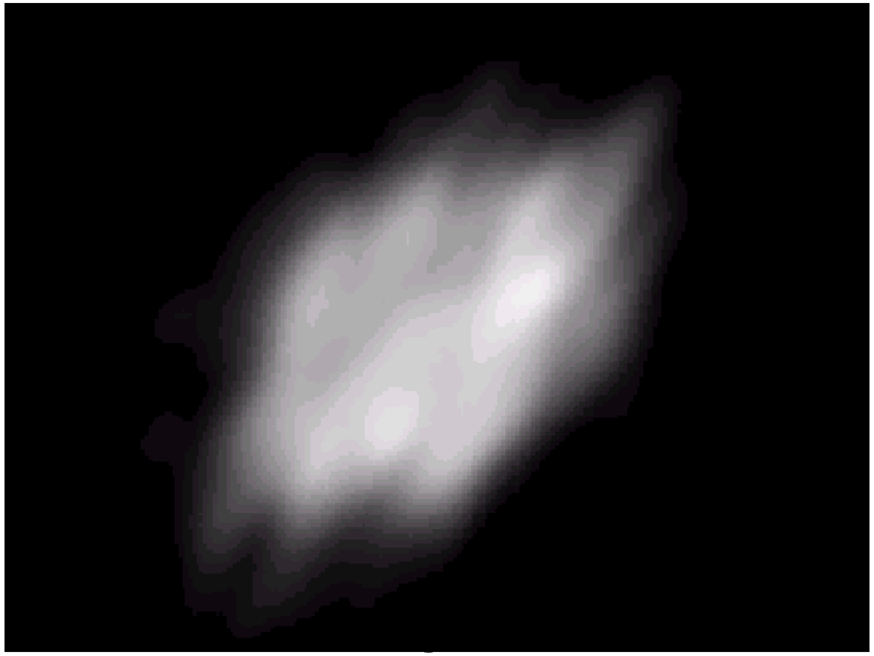
- Continuous emission model:
  - Question: how much light (**I** like intensity) is added along an infinitely short ray segment in the volume
  - Differential d**I**/dt = g(t) …
    volume emits light (corresponding to thickness)
  - Glow factor g(t)
  - Integration results in: $\mathbf{I}(s) = \mathbf{I}_0 + \int_{t \in [0,s]} g(t)dt$
  - Overall emission contrib.: $G(0,s) = \int_{t \in [0,s]} g(t)dt$
  - Unrealistic, because no absorption

Emission, Numerical Approximation

- Discrete emission model:
  - Question: how much light (C like color) is added within a small, but finite volume extent
  - C_i … contribution of vol. extent i (thickness 1)
    $\Rightarrow$ adding emission of extent i results in
    $Out_i = In_i + C_i \Leftrightarrow Out_i = Out_{i-1} + C_i$
  - Accumulation:
    $Out_i = In_j + C_j + \ldots + C_{i-1} + C_i$
    $Out_i = In_j + \Sigma_{j \le k \le i} C_k$
  - Example:
    pixel value = background + $\Sigma_{k \in N} C(\mathbf{ray}(k))$

Emission Only

- Differential model:
  - $\mathbf{I}(s) = \mathbf{I}_0 + \int_{t\in[0,s]} g(t)dt$
- Discrete approximation:
  - $Out_s = In_0 + \Sigma_{s\geq k\in N} C_k$
- Example:



Absorption, Differential Model

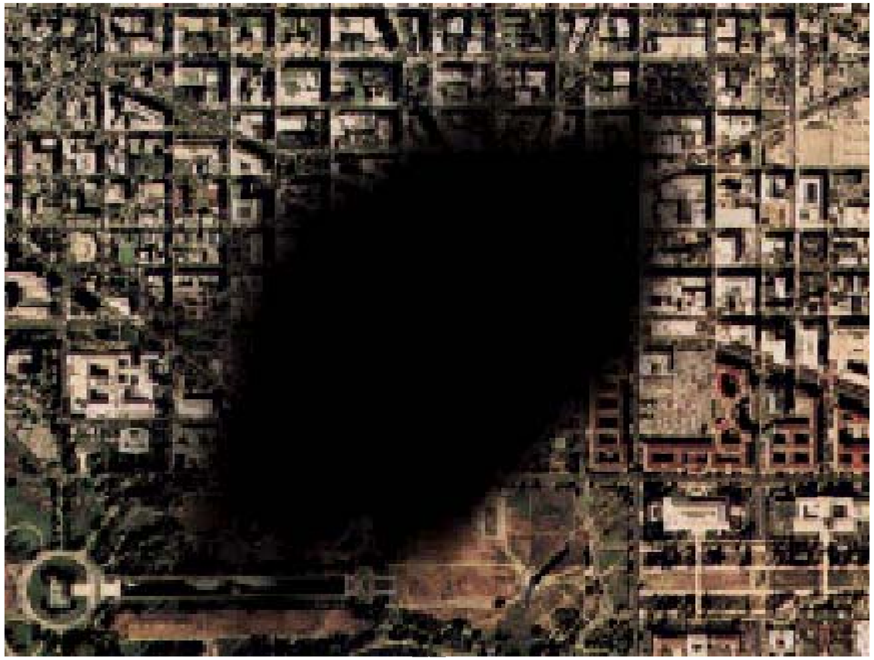
- Continuous absorption model:
  - Question: how much light (in % of $\mathbf{I}_0$) remains after traversal of ray segment through the volume
  - Differential $d\mathbf{I}/dt = -\tau(t)\mathbf{I}(t)$ …
    light ($\mathbf{I}$) is partially absorbed (τ)
  - Extinction coefficient $\tau(t)$, e.g., 30%
  - Integration results in: $\mathbf{I}(s) = \mathbf{I}_0 \cdot \exp(-\int_{t\in[0,s]} \tau(t)dt)$
  - Total transparency: $T(0,s) = \exp(-\int_{t\in[0,s]} \tau(t)dt)$
  - Total absorption: $\alpha(0,s) = 1 - T(0,s)$

Absorption, Numerical Approximation

- Discrete approximation model:
  - Question: how much light (in % of $\mathbf{I}_0$) remains after traversal of small, but finite volume extent
  - α_i … opacity of volume extent i (per unit)
    $\Rightarrow$ result after traversal of extent i
    $Out_i = In_i \cdot (1-\alpha_i) \Leftrightarrow$ $Out_i = Out_{i-1} \cdot (1-\alpha_i)$
  - Akkumulation: $Out_i = In_j \cdot (1-\alpha_j) \cdot \ldots \cdot (1-\alpha_i)$
    $Out_i = In_j \cdot \Pi_{j \le k \le i}(1-\alpha_k)$
  - Unit sampling: unit distance between α_i samples!!

Absorption Only

- Differential model:
  - $\mathbf{I}(s) = \mathbf{I}_0 \cdot \exp(-\int_{t\in[0,s]}\tau(t)dt)$
- Discrete approximation:
  - $Out_s = In_0 \cdot \Pi_{s\geq k\in N}(1-\alpha_k)$
- Example:



Emission and Absorption

- Continuous model (no scattering):
  - At each position is given:
    - Emission $g(t)$
    - Extinction coefficient $\tau(t)$
  - Differential $d\mathbf{I}/dt = g(t) - \tau(t)\mathbf{I}(t)$
  - Emission $g(t)$ attenuated by $T(t,s)$
  - Only Emission: $\mathbf{I}_0 + \int_{t\in[0,s]} g(t)\, dt$
  - With Absorption: $\mathbf{I}_0 \cdot T(0,s) + \int_{t\in[0,s]} g(t) \cdot T(t,s)\, dt$
  - Emission und Absorption:

$$\mathbf{I}_0 \cdot \exp\left(-\int_{u\in[0,s]} \tau(u)du\right) + \int_{t\in[0,s]} g(t) \cdot \exp\left(-\int_{u\in[t,s]} \tau(u)du\right) dt$$

Numerical Approximation

- Discrete model (compositing):
  - For each volume extent i:
    - Contribution C_i
    - Opacity α_i, transparency $1-\alpha_i$
  - $Out_i = In_i \cdot (1-\alpha_i) + C_i \cdot \alpha_i$ (Std.-compositing)
  - Convex combination
    from background and own contribution
  - $Out_s = In_0 \cdot \prod_{s \geq k \in N} (1-\alpha_k) + \sum_{s \geq k \in N} C_k \cdot \alpha_k \cdot \prod_{s \geq l > k} (1-\alpha_l)$
  - Opacity-weighted colors: $C_i \cdot \alpha_i$ instead of C_i

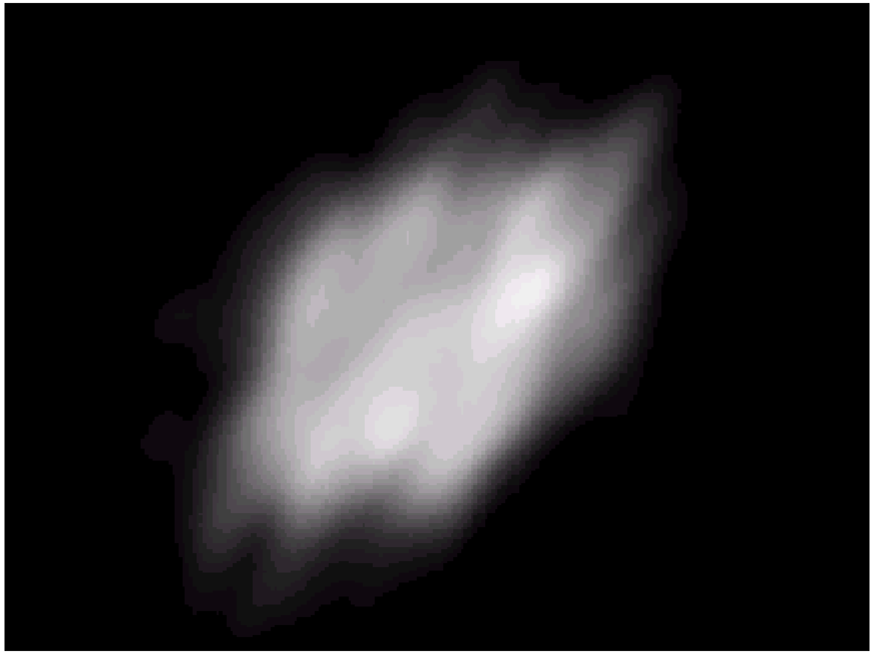
Emission and Absorption

- Differential model:
  - $\mathbf{I}(s) = \mathbf{I}_0 \cdot T(0,s) + \int_{t \in [0,s]} g(t) \cdot T(t,s)\, dt$
  - $\mathbf{I}(s) = \mathbf{I}_0 \cdot \exp(-\int_{u \in [0,s]} \tau(u) du)$
    $+ \int_{t \in [0,s]} g(t) \cdot \exp(-\int_{u \in [t,s]} \tau(u) du)\, dt$

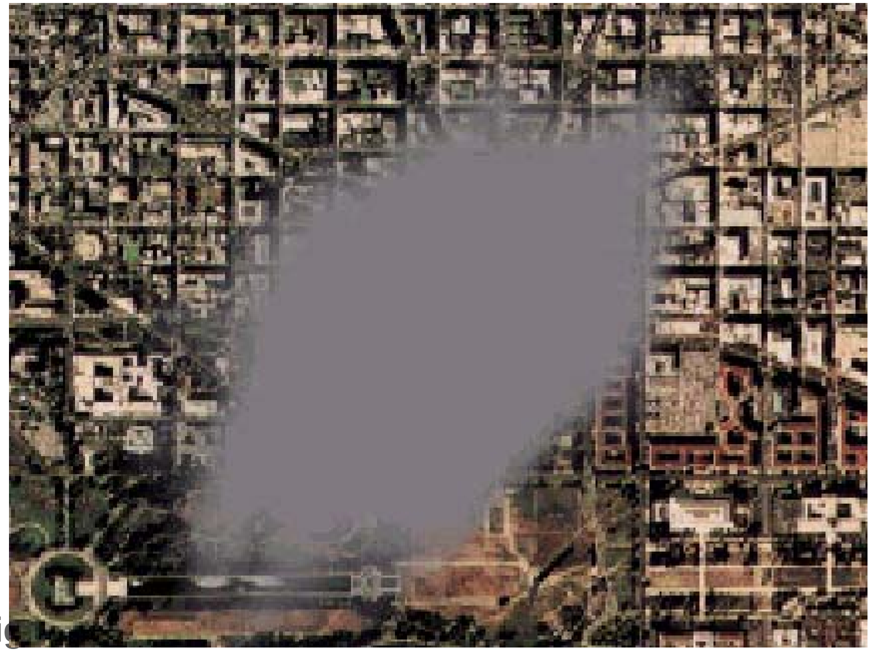
- Discrete Approximation:
  - $Out_i = In_i \cdot (1-\alpha_i) + C_i \cdot \alpha_i$ (Compositing)
  - $Out_s = In_0 \cdot \Pi_{s \geq k \in N} (1-\alpha_k)$
    $+ \Sigma_{s \geq k \in N} C_k \cdot \alpha_k \cdot \Pi_{s \geq l > k} (1-\alpha_l)$

Emission or/and Absorption

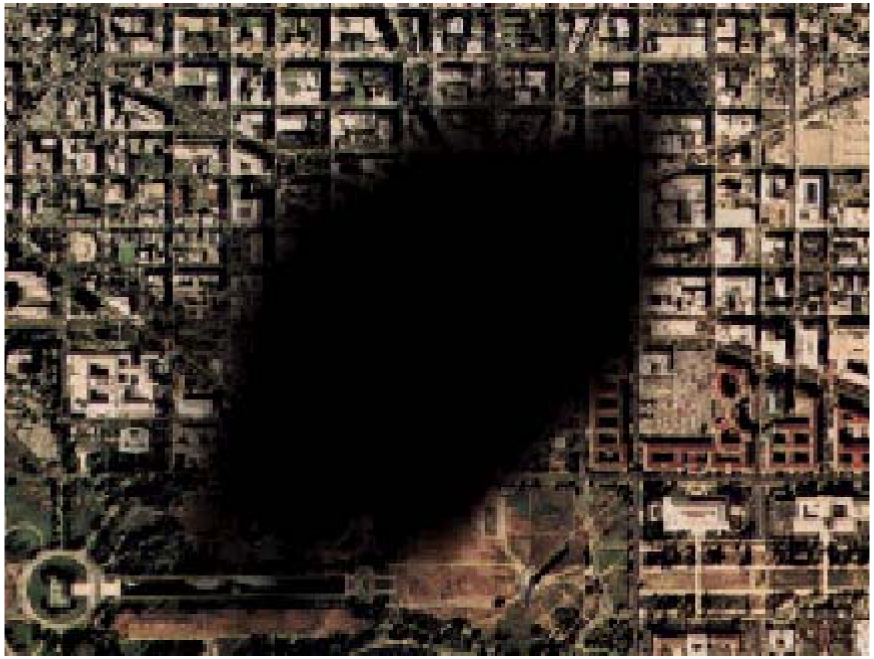
Emission only



Emission and Absorption



Absorption only



Scattering

- **Scattering**: particles deviate light at a position
  - BRDF (bidirectional reflectance distribution function)
  - Single scattering
    - Too little light in the interior
  - Single scattering with shadows
  - Multiple Scattering
    - Radiosity techniques
    - Very realistic, very costly

Literature

- Paper (more details):
  - Nelson Max: "**Optical Models for Direct Volume Rendering**" in *IEEE Transactions on Visualization and Computer Graphics*, Vol. 1, No. 2, June 1995

Ray Casting / Compositing

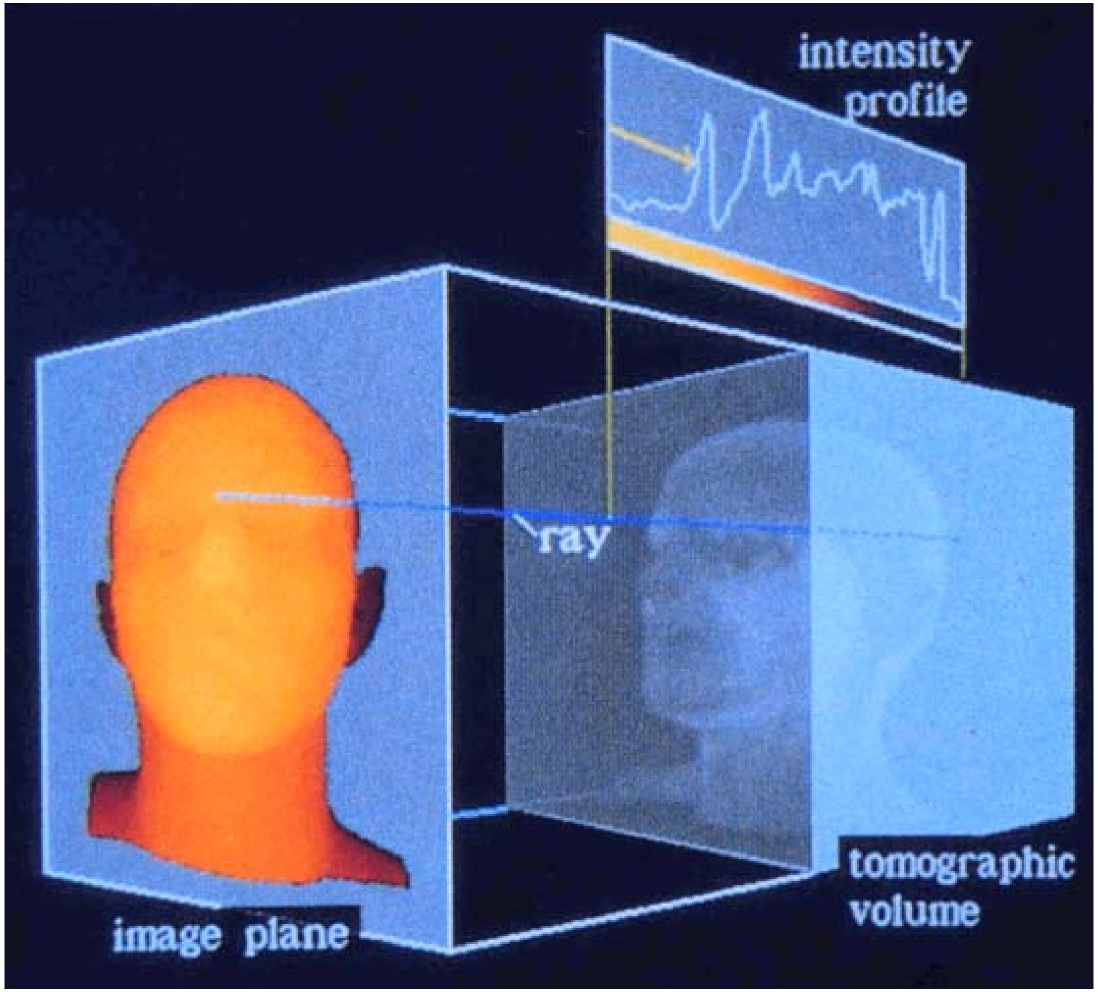
Classical
Image-Order Methods

Ray Tracing vs. Ray Casting

- Ray Tracing: method from image generation
- In volume rendering: only viewing rays
  $\Rightarrow$ therefore Ray Casting
- Classical image-order method
- Ray Tracing: ray – object intersection
  Ray Casting: no objects, density values in 3D
- In theory: take all density values into account!
  In practice: traverse volume step by step
- Interpolation necessary for each step!

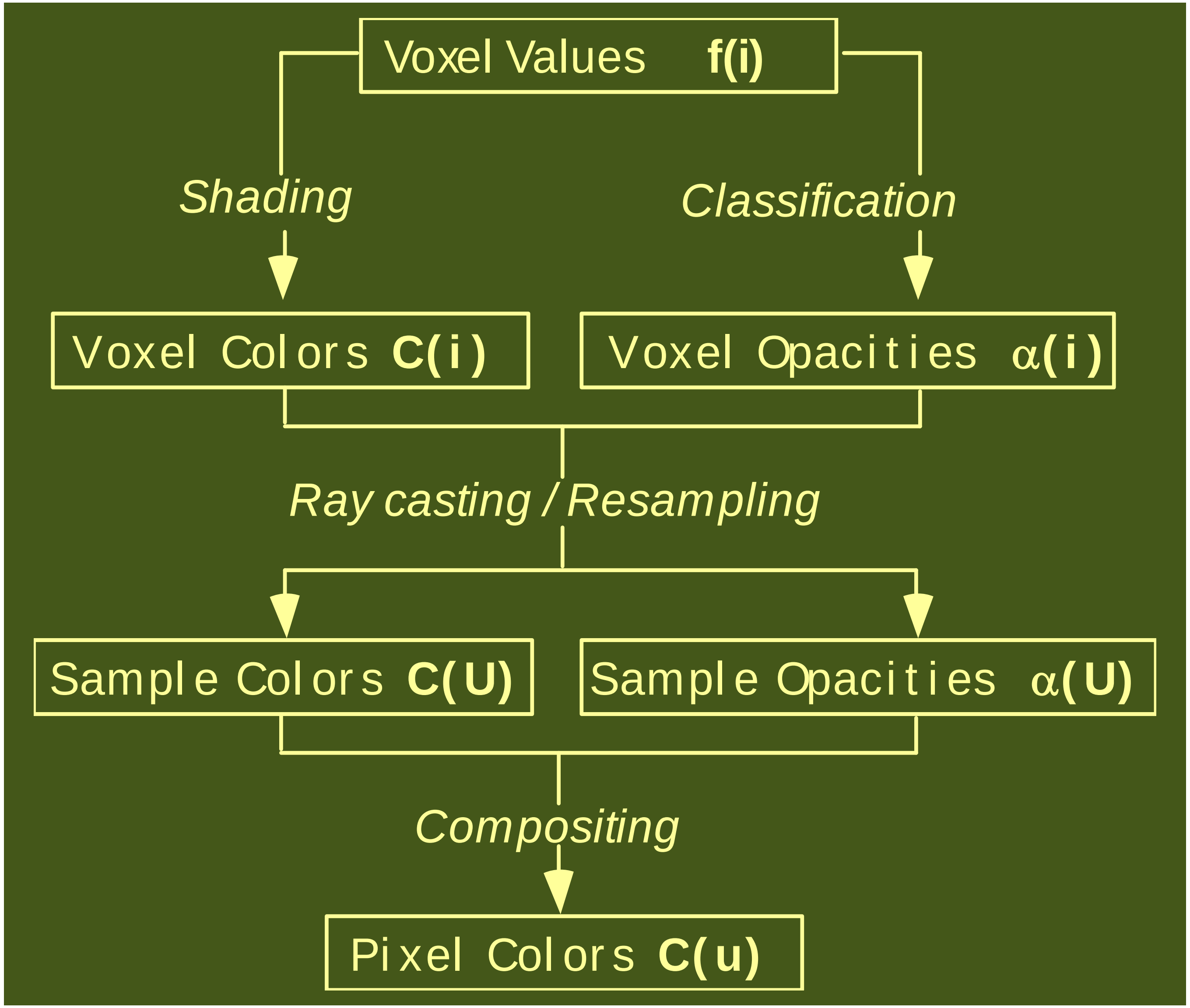
Ray Traversal through Volume Data

- Context:
  - Volume data: 1D value defined in 3D – $f(\mathbf{x}) \in R^1$, $\mathbf{x} \in R^3$
  - Ray defined as half-line: $\mathbf{r}(t) \in R^3$, $t \in R^1 > 0$
  - Values along Ray: $f(\mathbf{r}(t)) \in R^1$, $t \in R^1 > 0$ (intensity profile)

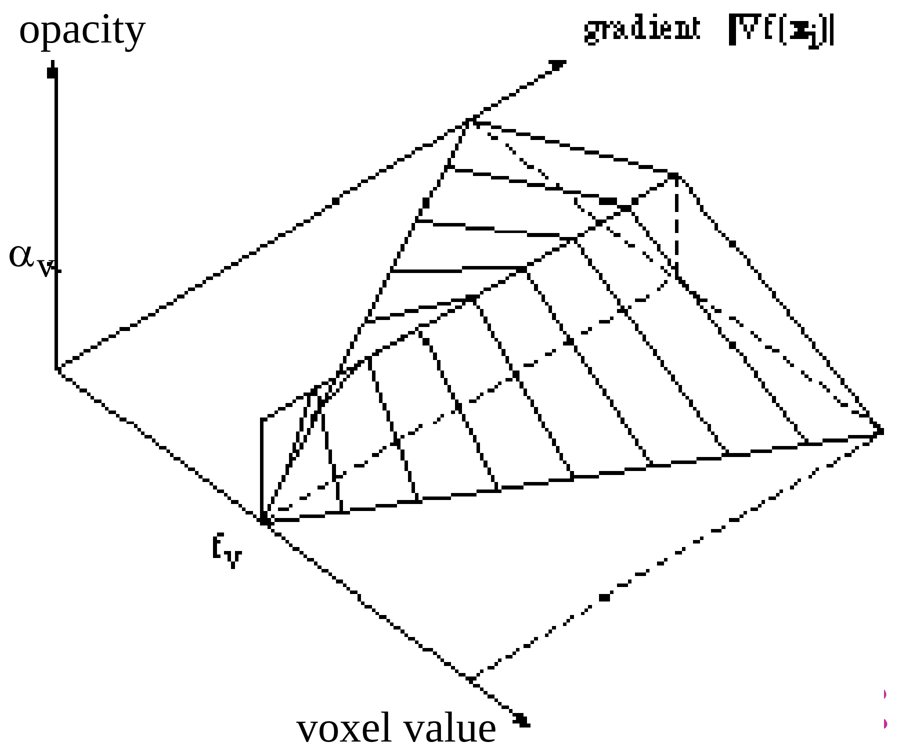


Standard Ray Casting

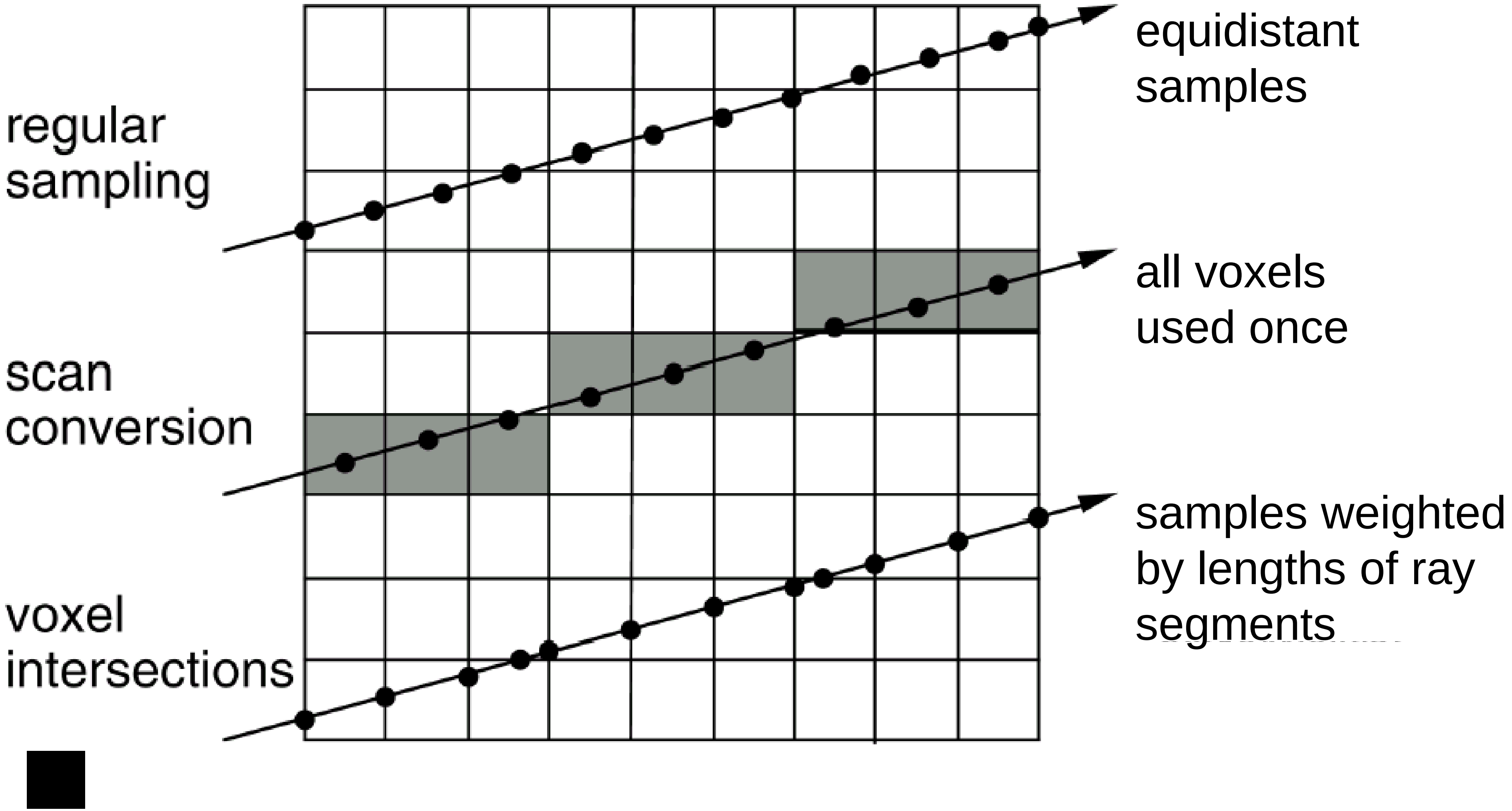
- Levoy '88:
- 1. C(i), α(i)
  (from TF)
- 2. Ray casting, interpolation
- 3. Compositing



- 1. Step:
  - Shading, f(i)→C(i):
    - Apply transfer function
    - diffuse illumination (Phong), gradient ≈ normal
  - Classification, f(i)→α(i):
    - Levoy '88, gradient enhanced
    - Emphasizes transitions



2. Ray Traversal – Three Approaches



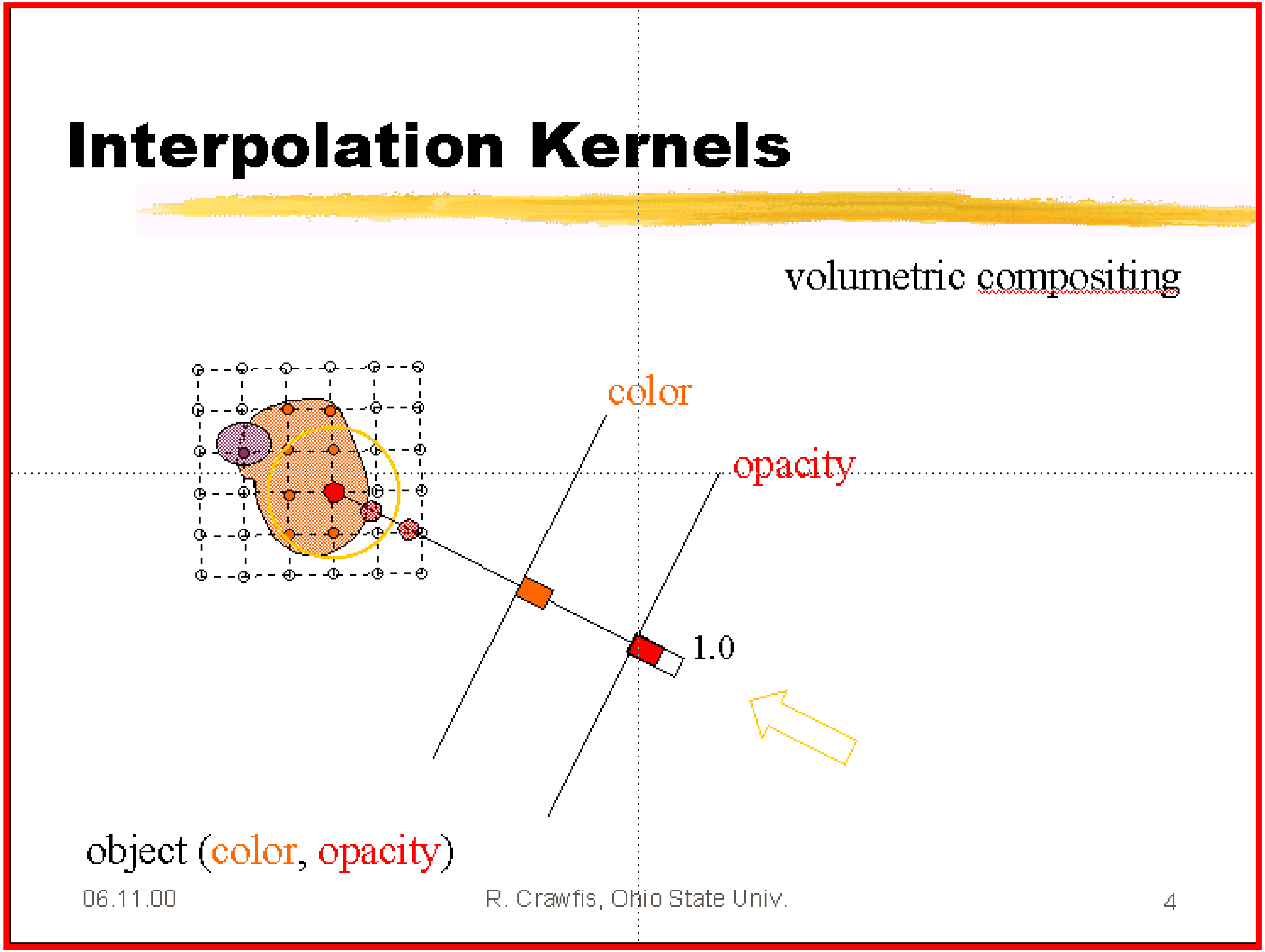
2. Ray Traversal, Interpolation

- Voxel-based vs. cell-based traversal
- Tri-linear (interpolation within a cell) vs. bi-linear (interpolation within a cell face)
- Tri-linear:
  - first 4* in z-direction (interpolated square),
  - then 2* in y-direction (interpolated line),
  - then 1* in x-direction (interpolated value)
- Unit sampling vs. variable sample distances – compositing different!!

Compositing: F2B vs. B2F

- Back-to-Front (B2F):
  - $Out_i = In_i \cdot (1-\alpha_i) + C_i \cdot \alpha_i$, $In_{i+1} = Out_i$ …
  - Depending on local transparency $(1-\alpha_i) \Rightarrow$ convex combination of old In_i & new C_i
  - Example:
    - Voxel i: C_i = red, α_i=30%; so far: In_i = white
    - Result of compositing: 70% white + 30% red
- Front-to-Back (F2B):
  - $Col = Col + (1-\alpha_{akk}) \cdot C_i \cdot \alpha_I$ … accumulated color
  - $\alpha_{akk} = \alpha_{akk} + (1-\alpha_{akk}) \cdot \alpha_i$ … accumulated opacity

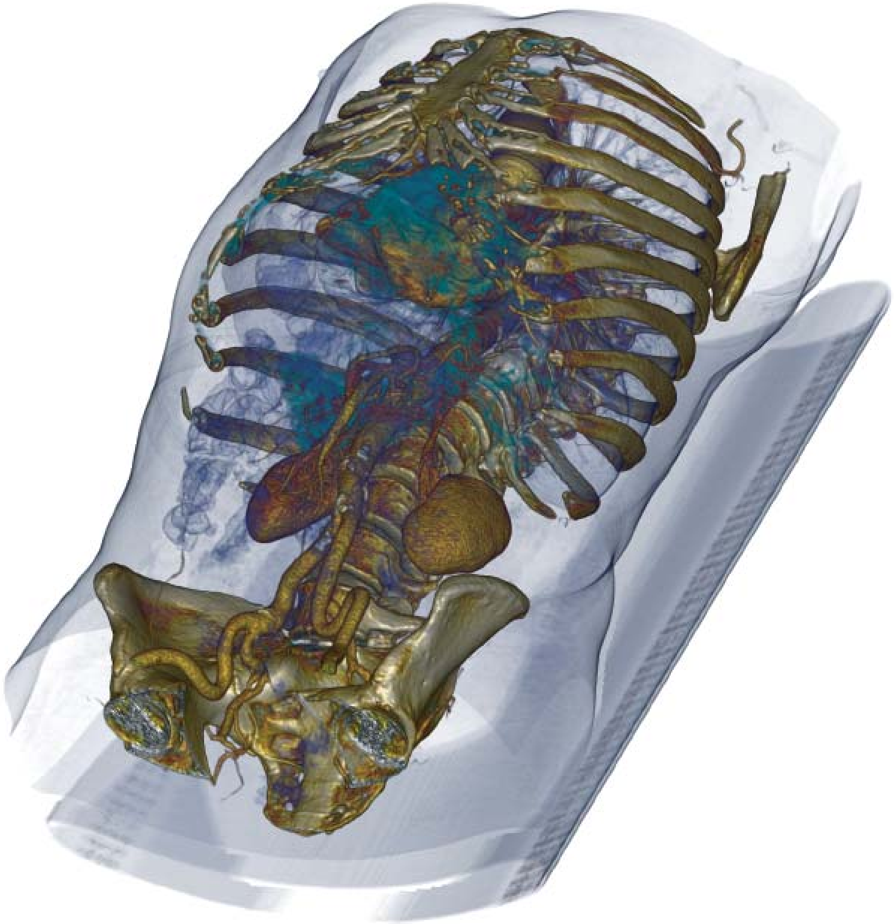
Front-to-Back Compositing

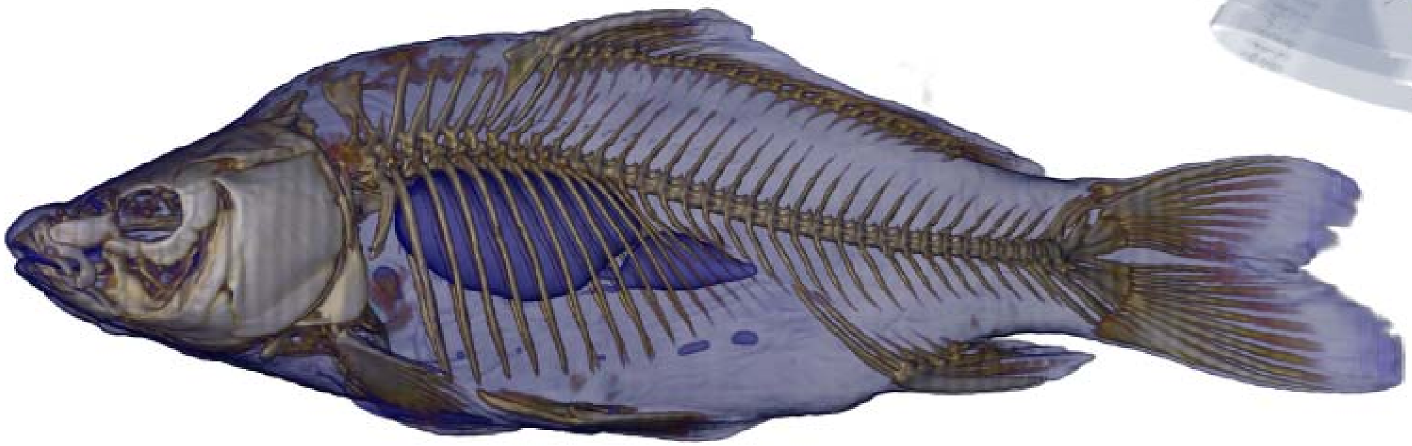


Ray Casting – Examples

- CT scan of human hand (244x124x257, 16 bit)

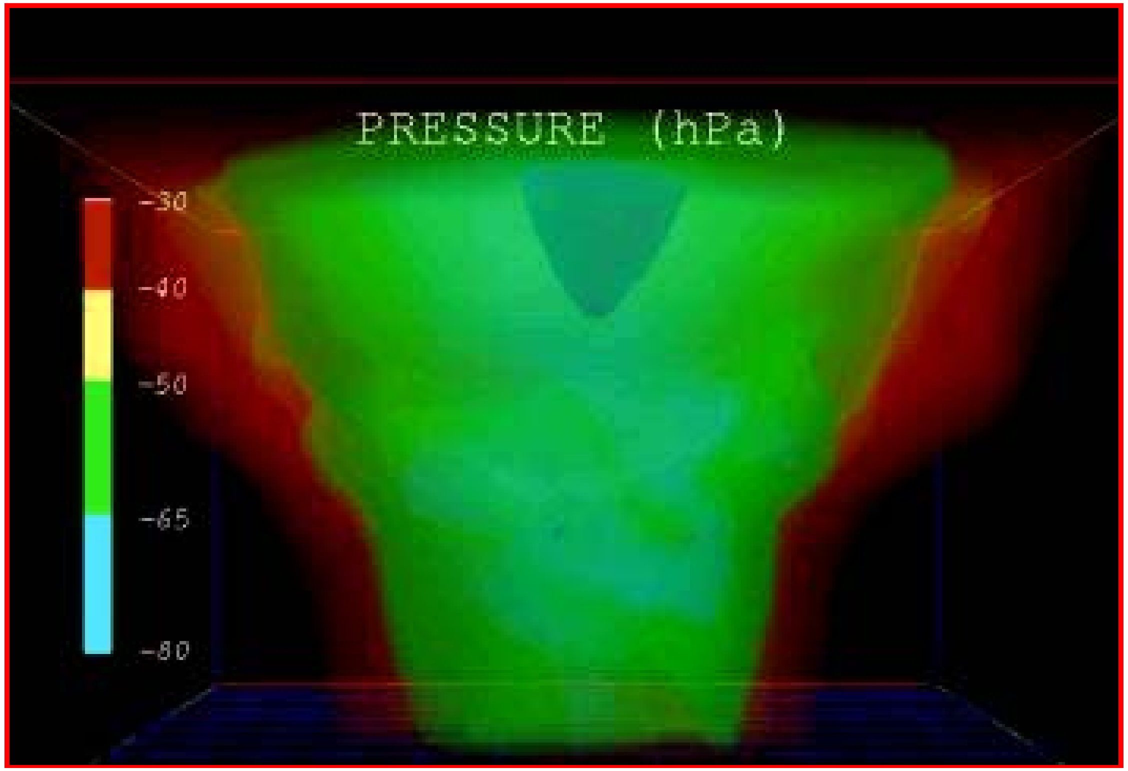
Ray Casting – Examples

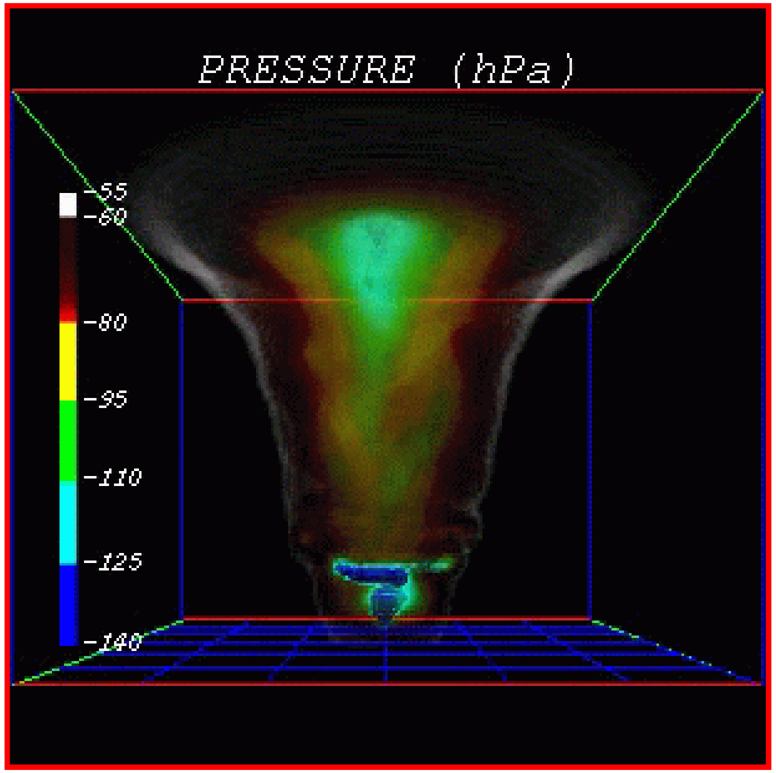




Ray Casting – Further Examples

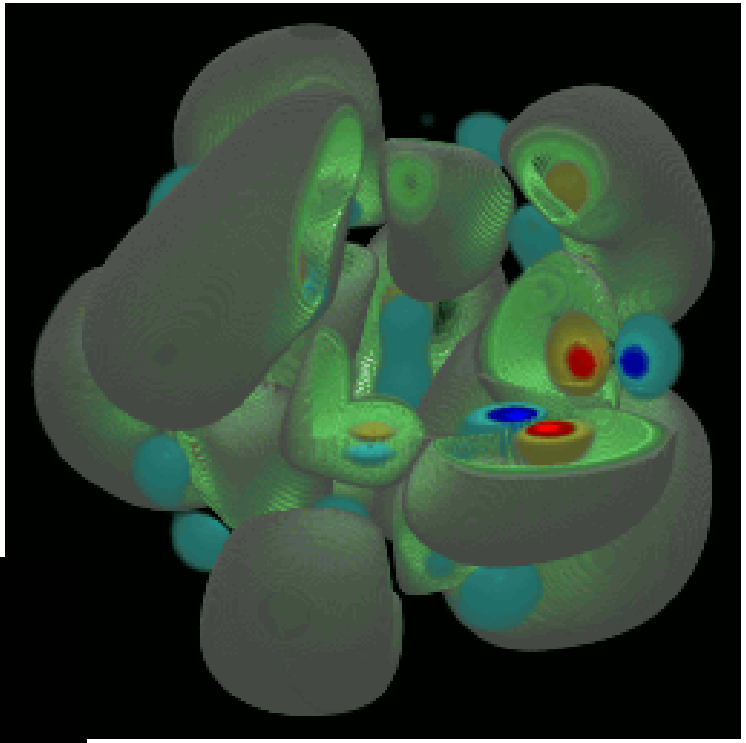
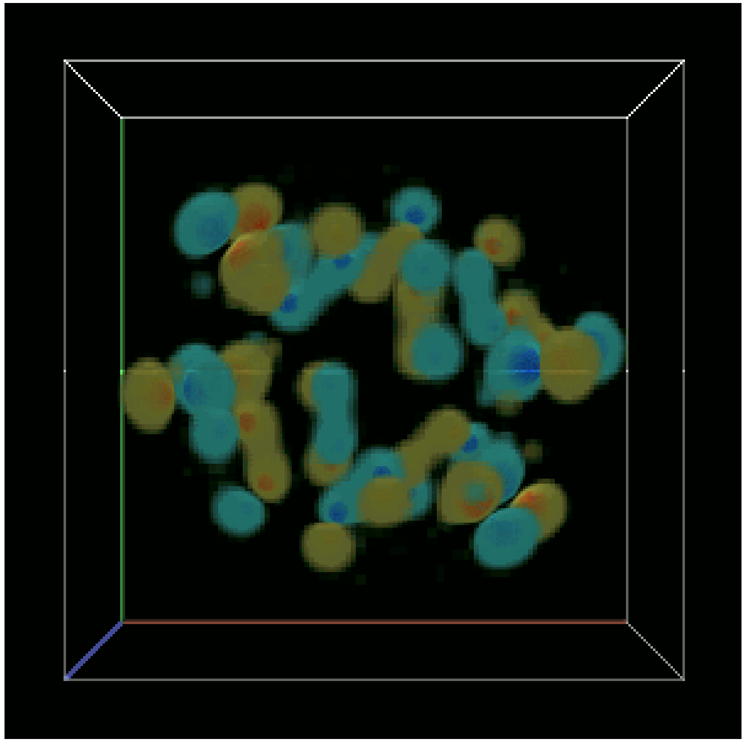
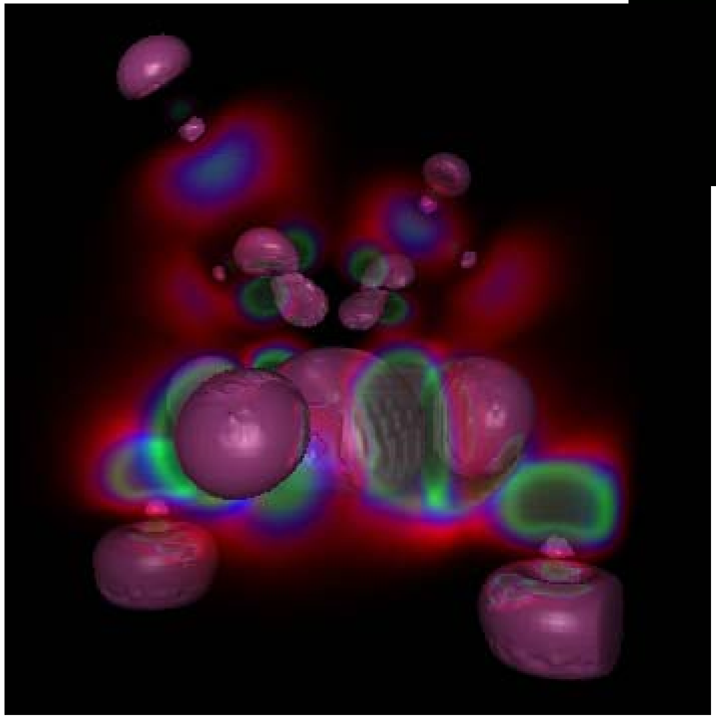
- Tornado Visualization:





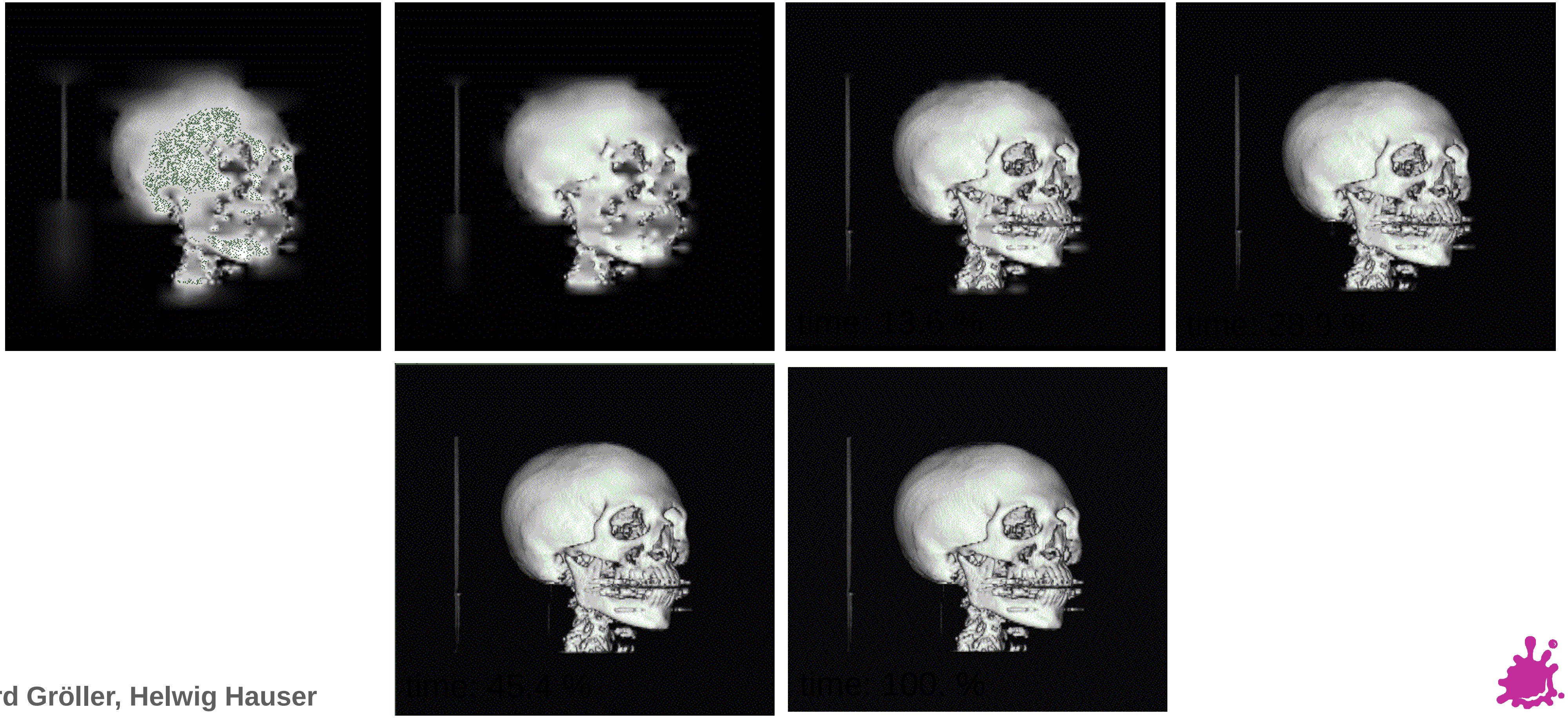
Ray Casting – Further Examples

- Molecular data:

Acceleration - Progressive Refinement

- First render every $2^n \times 2^n$-th pixel,
  then render the $2^{n-1} \times 2^{n-1}$-th pixel inbetween,
  aso. (until interruption or completion)



Literature

- Paper (more details):
  - Marc Levoy: "**Display of Surfaces from Volume Data**" in *IEEE Computer Graphics & Applications*, Vol. 8, No. 3, June 1988

Acknowledgement

- For material for this lecture unit:
  - Nelson Max (LLNL), Marc Levoy (Stanford)
  - Hans-Georg Pagendarm (DLR, Göttingen)
  - Lloyd Treinish (IBM)
  - Roberto Scopigno,
    Claudio Montani (CNR, Pisa)
  - Roger Crawfis (Ohio State Univ.)
  - Michael Meißner (GRIS, Tübingen)
  - Torsten Möller
  - etc.