http://imgur.com/TRJonQk

Spatial Data Structures & Streamlines

http://i.imgur.com/ZcjC9KP.jpg

Today's Class

- Spatial Data Structures Motivation
- Spatial Data Structures
  - Uniform Grid
  - Nested Grid
  - Octree
  - K-d tree
  - Binary Space Partition
  - Bounding Volume Hierarchy
  - Oriented Bounding Boxes
- Readings for Today
  - "Farthest Point Seeding for Efficient Placement of Streamlines"
  - "Image Based Flow Visualization"
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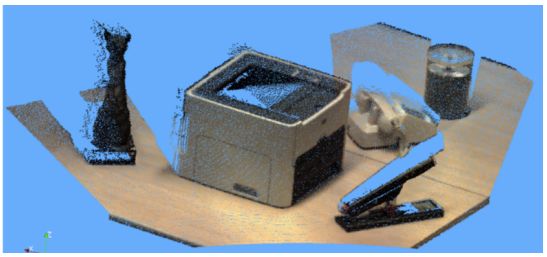
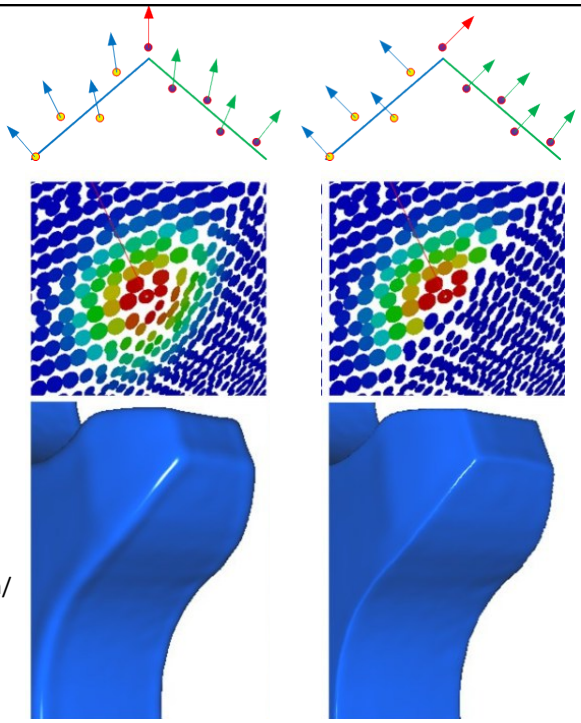
Motivation for Spatial Data Structures

- Closest Point
  - Collision detection
  - Surface normal estimation
- Line-Polygon Intersection
  - Ray casting (& recursive ray tracing)
  - Shadow calculation
- Want to do significantly better than the linear O(n), n = # of objects, brute force solution!



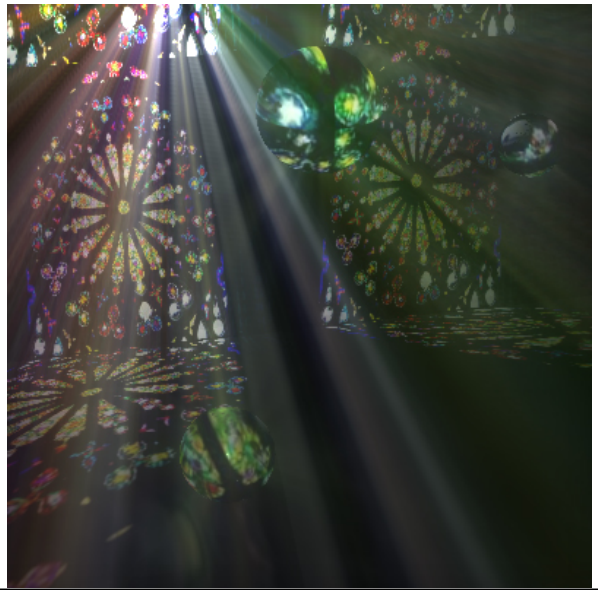
http://i.imgur.com/Xz3Z2iL.jpg

Surface Normal Estimation



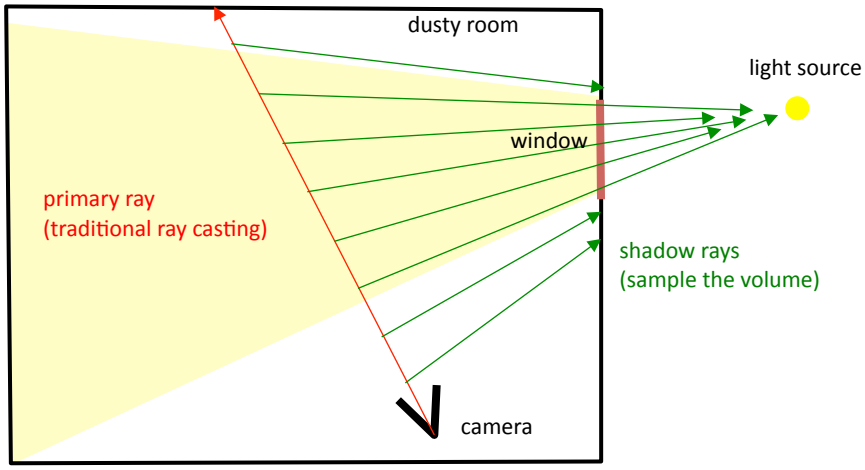
http://taylorwang.wordpress.com/

Light Rays in a Dusty Room



Annie Ding, MIT
6.837 Final Project
December, 2004

Ray Tracing Participating Media



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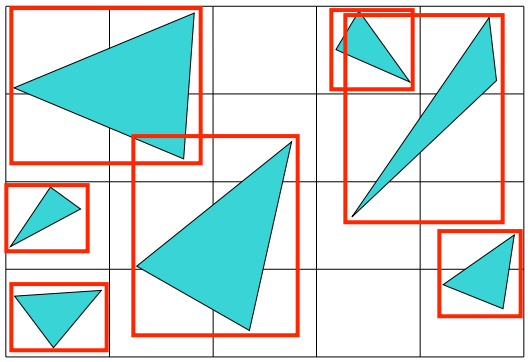
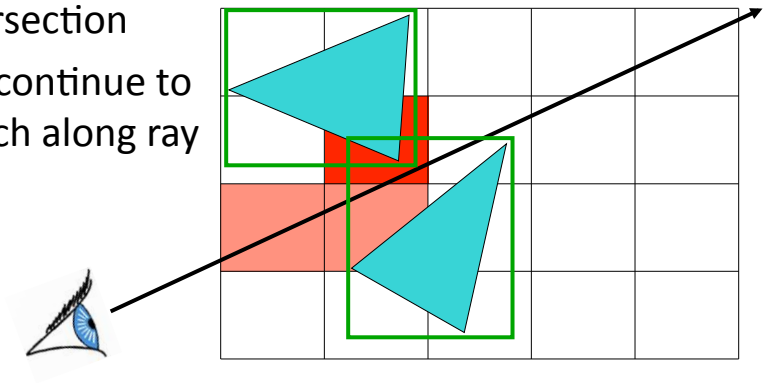
Search Pruning via Regular Grid

- Primitives that overlap multiple cells?
- Insert into multiple cells (use pointers)



Ray-Tracing within a Uniform Grid

- Does the current cell contain an intersection?
- Yes: return closest intersection
- No: continue to march along ray



Regular Grid Discussion

- Advantages?
  - easy to construct
  - easy to traverse
- Disadvantages?
  - may be only sparsely filled
  - geometry may still be clumped

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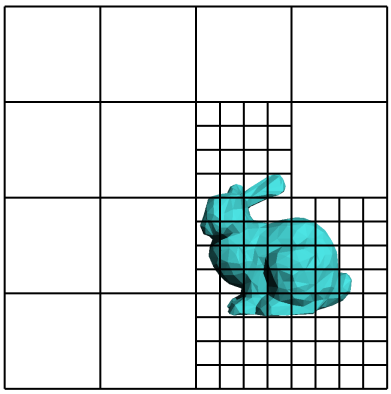
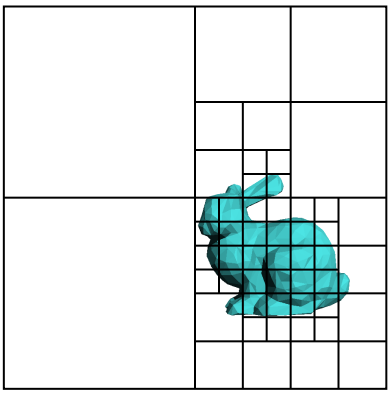
Adaptive Grids

- Subdivide until each cell contains no more than *n* elements, or maximum depth *d* is reached



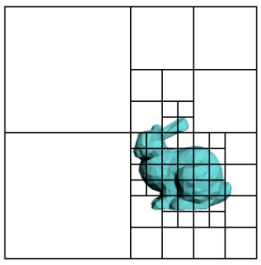
Nested Grids



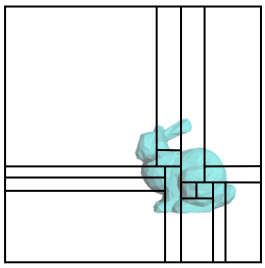
Octree/(Quadtree)

Variations of Adaptive Grids

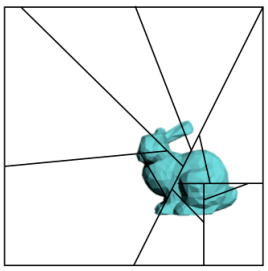
- **When to split?** When a cell contains "lots" of geometry, but has not yet reached the max tree depth
- **Where to split?**
  - Quadtree/Octree: split *every* dimension in half, always axis aligned
  - kd-tree: choose *one* dimension (often the largest dimension) and split it axis aligned (but not necessarily at the midpoint)
  - Binary Space Partition (BSP): choose a *arbitrary* cut plane
- **Which one is best?** It depends…. Often they are all equally good!



Quadtree/Octree



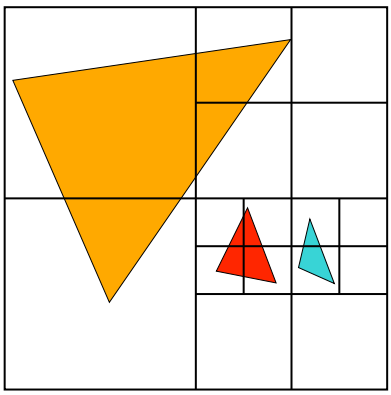
kd tree



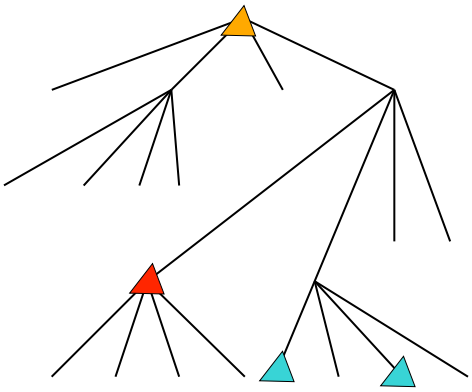
BSP Tree

Primitives in an Adaptive Grid

- Can live at intermediate levels, or be pushed to lowest level of grid

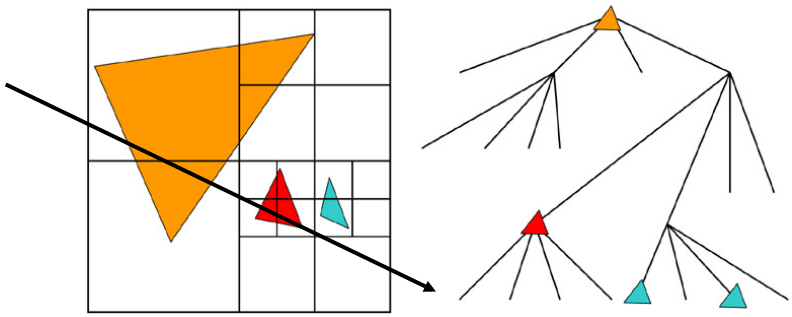


Octree/(Quadtree)



Adaptive Grid Discussion

- Advantages?
  - grid complexity matches geometric density
- Disadvantages?
  - more expensive to traverse (binary tree, lots of pointers)



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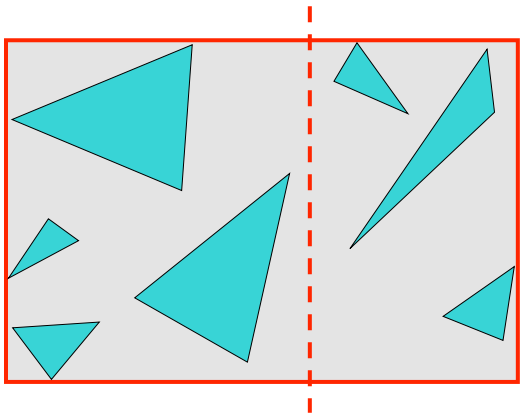
Bounding Volume Hierarchy

- Find bounding box of objects
- Split objects into two groups
- Recurse



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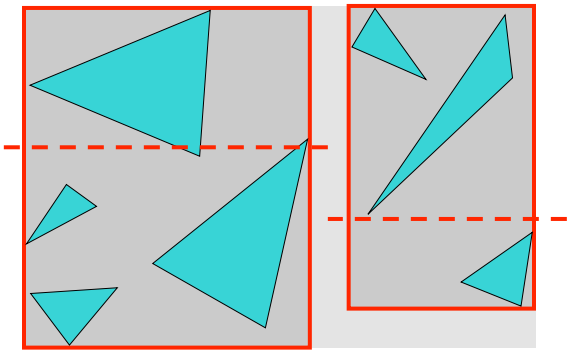
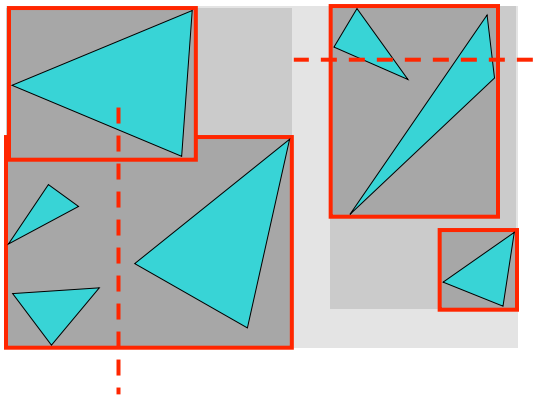


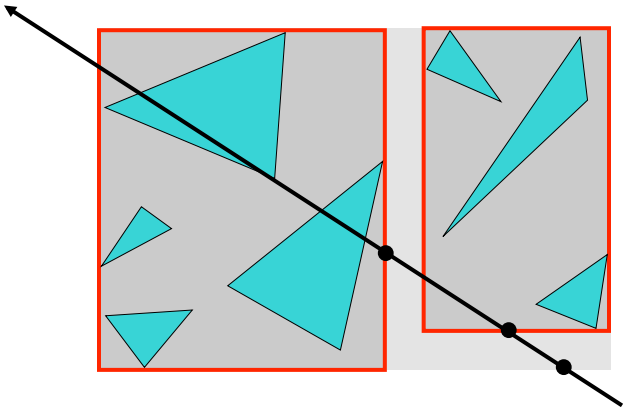
Where to split objects?

- At midpoint OR
- Sort, and put half of the objects on each side OR
- Use modeling hierarchy



Intersection with BVH

- Check sub-volume with closer intersection first

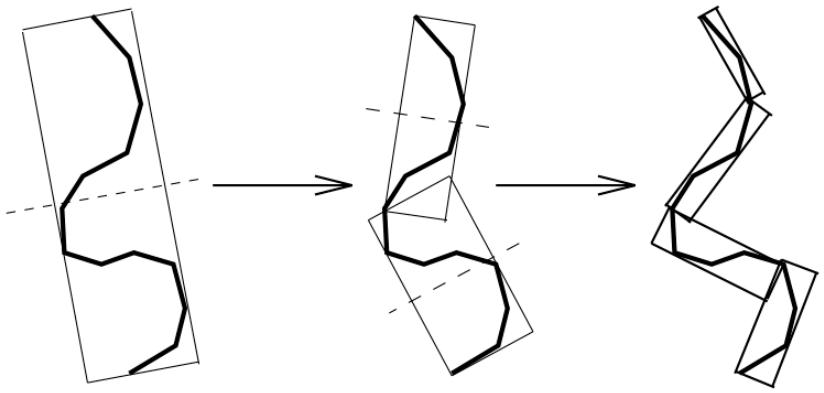


Bounding Volume Hierarchy Discussion

- Advantages
  - easy to construct
  - easy to traverse
  - binary
- Disadvantages
  - may be difficult to choose a good split for a node
  - poor split may result in minimal spatial pruning

Oriented Bounding Box (OBB):

- generalization of the (axis-aligned) BVH



OBB-Tree: A Hierarchical Structure for Rapid Interference Detection, Gottschalk, Lin, & Manocha, SIGGRAPH 1996.

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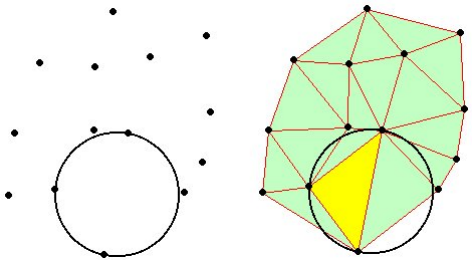
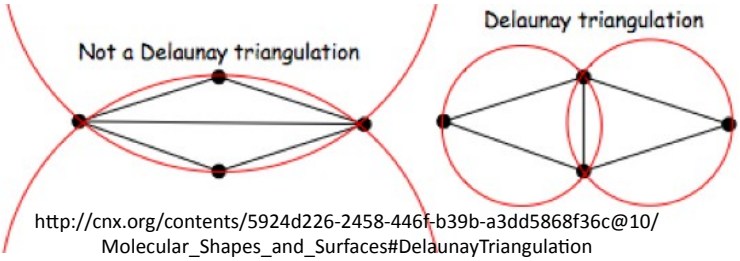
Delaunay Triangulation

http://www.ian-ko.com/resources/triangulated_irregular_network.htm

- Contains a triangle connecting 3 points if and only if the circumcircle does not contain any other points from the set

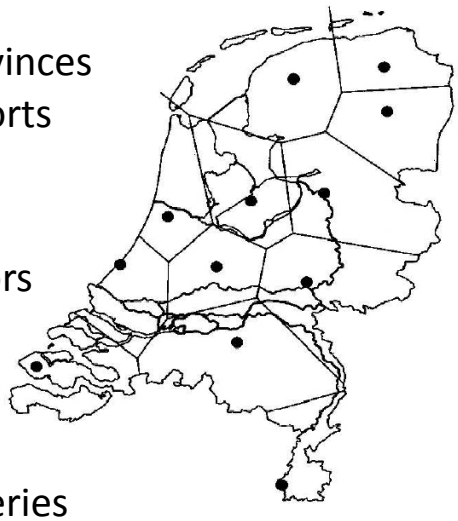




http://cnx.org/contents/5924d226-2458-446f-b39b-a3dd5868f36c@10/Molecular_Shapes_and_Surfaces#DelaunayTriangulation

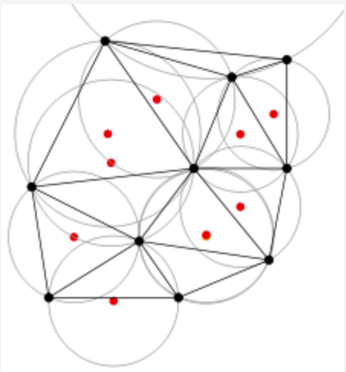
Voronoi Diagram/Cells/Regions

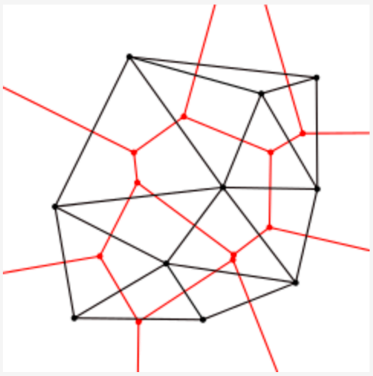
- How to re-district the Netherlands into provinces so that everyone reports to the closest capital
- Cell edges are the perpendicular bisectors of nearby points
- 2D or 3D
- Supports efficient *Nearest Neighbor* queries



http://ccc.inaoep.mx/~rodrigo/robotica/Trigui.pdf

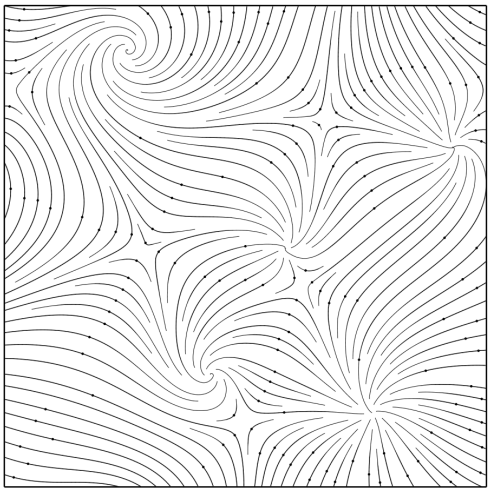
Delaunay / Voronoi Duality





https://en.wikipedia.org/wiki/Delaunay_triangulation

- "Farthest Point Seeding for Efficient Placement of Streamlines", Mebarki, Alliez, & Devillers, IEEE Visualization 2005.



- Start at the furthest away
- Favors long streamlines
- Retain uniformity with increasing density
- 200X Faster, but comparable quality to previous techniques
- Streamline:
  - curve that is everywhere tangent to the vector/flow field,
  - path traced by a massless particle dropped into a steady flow field
  - Stops at boundary or when it gets too close to another streamline
  - Streamlines are better if they uniform, of desired density, and longer rather than shorter
  - Termination points of streamline will be inferred as flow field singularities (source & sink), so avoid misinterpretations…

How to choose seedpoints for streamline placement?

- Uniform grid: streamlines won't be evenly placed & undesirable patterns
- Randomly placed: Does not improve upon uniform
- Turk & Banks use "streamlets" & energy decreasing optimization to combine, delete, create, lengthen, & shorten streamlets
  - High quality but slow
- Jobard & Lefer seed new streamlines near existing streamlines
  - Faster, but can have empty spaces
- Verma et al. seed streamlines near critical points
  - Good capture of flow features, but poor density control

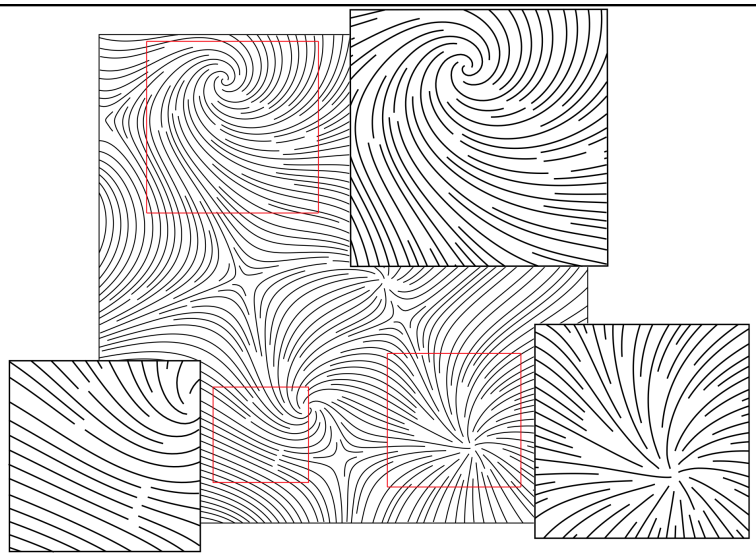


Figure 2: Local seeding strategy produces empty spaces due to the consecutive stopping of a series of streamlines (bottom right closeup). Some discontinuities also appear near singularities (top right closeup) and in laminar areas (bottom left closeup). Figure reproduced from [12].

- Data structures are important for streamline computation!
- Implemented in C++! Open source (CGAL)!
- Amazing results
  - fast,
  - looks pretty good, but not perfect when zoomed in, those artifacts not discussed in paper
  - Curious about adding color, texture, or animation
  - How could it extend to 3D?
- Detailed writing
  - Great Diagrams
  - Pseudocode: "confident I could implement it"
    "even a data structures student could implement it!"
- Good comparison to prior work
- Motivation could be presented more compellingly
- How is the step size chosen?

- Choose seedpoints that are furthest away from ALL existing streamlines (center of biggest void)
  - Favors long streamlines
  - Amenable to multiresolution placement (each streamline placed increases density)
- Use Delaunay Triangulation
  - Find (approximate?) biggest cavities
  - add point to triangle with largest circumcircle diameter
  - Integrate forward & backward to trace curve through flow (steady state flow only?)
  - Only re-add triangles to priority queue if their circumcircle is bigger than threshhold for density & saturation.
- Ok to be somewhat sloppy/inaccurate about the Delaunay triangulation
  - when streamlines form tight curls
  - Use local maximum circumcircle
- Advanced Features
  - Variable density, Multiresolution

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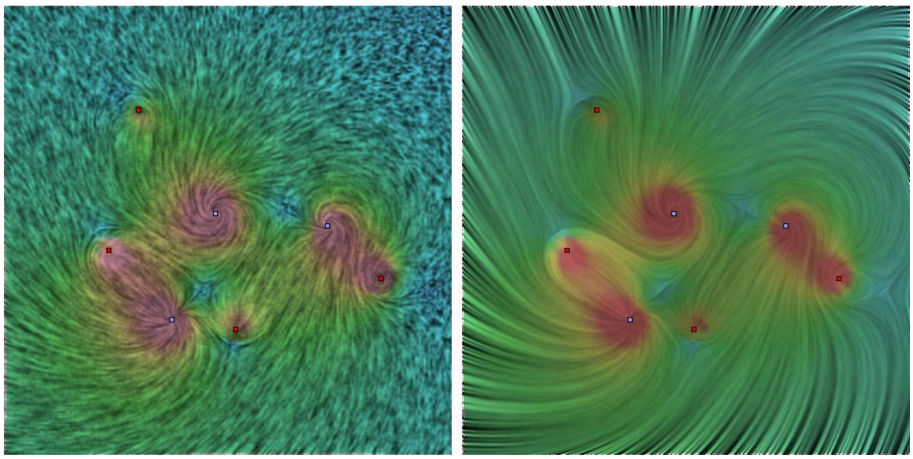
- "Image Based Flow Visualization", Jarke J. van Wij, SIGGRAPH 2002.



- Advection: "the transfer of heat or matter by the flow of a fluid, especially horizontally in the atmosphere or the sea"
- Blend warped previous frame w/ a selected background image
- Applications: Weather, climate, industrial processes, cooling, heating
- Moving particles, streamlines, moving textures, topological images
- Contributions:
  - Handles unsteady flow
    - W/ other techniques, hard to reconstruct flow
  - Efficient
    - Best performance to date (50 fps) by using graphics card features
  - Easy to implement
    - Other techniques need user to place particles (with poor placement, important features can be missed)
    - Small amount of code!

- White noise
- Pink noise: remove high frequency from white noise, both in space & time

- Pathline: position of a particle in a dynamic flow field
- Streamline: same as pathline, but for single point in time (or a constant/steady flow field)

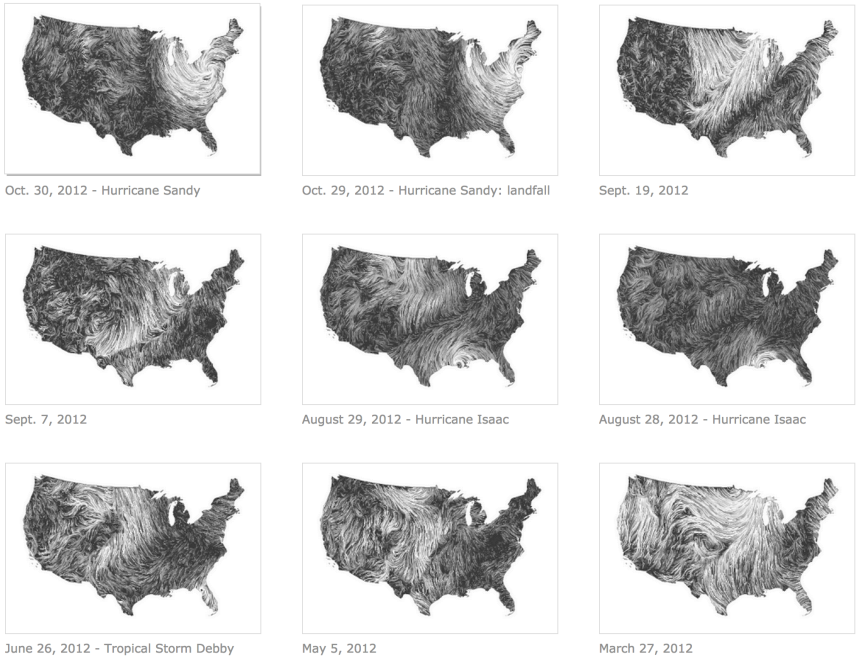
- Particle & streamline tracking: focus on world space coordinates
- Line integral convolution: focus on screen space coordinates
- Image Based Flow Visualization: focus on images as basic primitive

- Data structures are essentially irrelevant for image based flow visualization!
- Implemented in Object Pascal (??)

- Frequency analysis (yeah "Signals & Systems"!) to understand & create background images to minimize artifacts from undersampling
- If G changes over time, then texture will "move with the flow"
  - not new random image, but spots that appear & disappear (cosine, square, exponential decay, sawtooth)
- Computation
  - Distorted mesh calculated on CPU
  - Rendering & blending on GPU
- Lots of control over results
  - Background image choice
  - Dye injection
  - Alpha values choice (decay)

- Good attempt to compare running time of different algorithms from different eras on different hardware
- Great discussion/comparison of results
- Method was unintuitive (author should take that as a compliment, right?) & really clever
  - "Work smarter not harder"
- How does resolution affect quality?
- What is coarse vs fine texture?
- Produces a visual result, but can't be used other than to "look at" (results can't be fed back into simulation/ computation)
- Somewhat confused about "dye" and "decay of dye"
- What is the motivation for this paper?
- Use of gradient/color to help reader understand direction of flow is very important

Wind Map, Fernanda Viégas and Martin Wattenberg http://hint.fm/wind/



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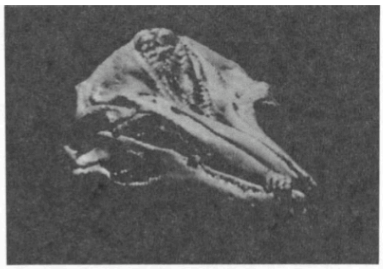
Volume Rendering

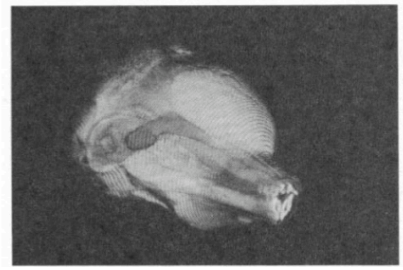
- Try to display a 3D data set (the whole thing, not just a surface)
- Must determine the opacity of every pixel (voxel)
- Often called the "transfer function"
- Almost always medical images

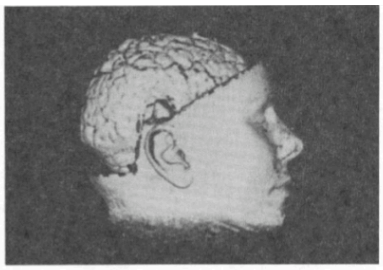
http://idav.ucdavis.edu/~okreylos/ResDev/VolVis/LinkSupersampling.html

Readings for Friday: *(pick one)*

- "A survey of algorithms for volume visualization", T. Todd Elvins, 1992







Readings for Friday: *(pick one)*

- "Hardware-Accelerated Volume Rendering", Pfister et al., *from the* Visualization Handbook 2004

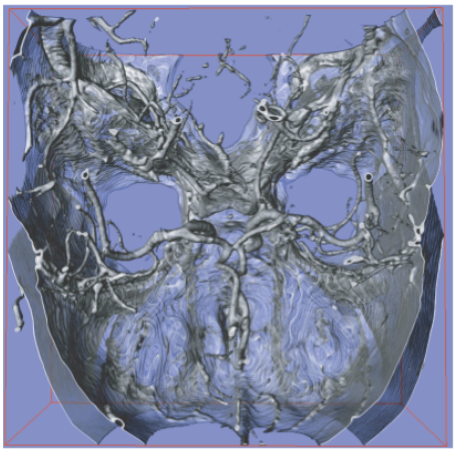
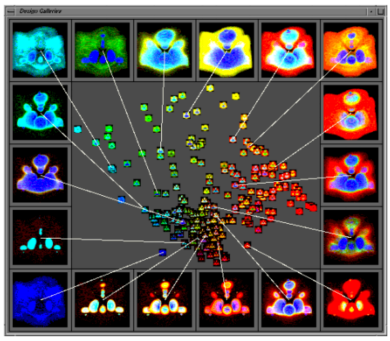
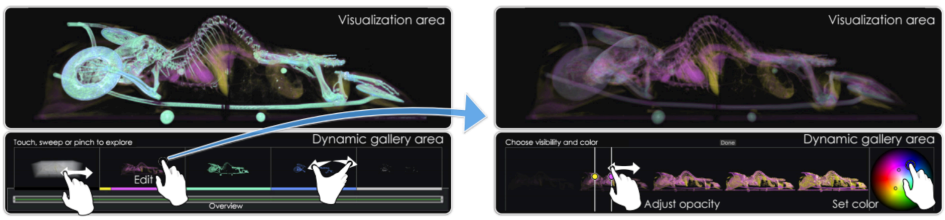


Figure 12: *CT Angiography of a human brain* ($512^2 \times 128$). *Transparent rendering of a non-polygonal shaded iso-surface with 2D multi-textures on an NVIDIA GeForce-4Ti. Image courtesy of Christof Rezk-Salama, University of Erlangen, Germany.*

Readings for Friday: *(pick one)*

- "Intuitive Exploration of Volumetric Data Using Dynamic Galleries" Jönsson, Falk, & Ynnerman IEEE Visualization 2015





Readings for Friday: *(pick one)*

- "Anisotropic Ambient Volume Shading"
  Ament & Dachsbacher, IEEE Visualization 2015