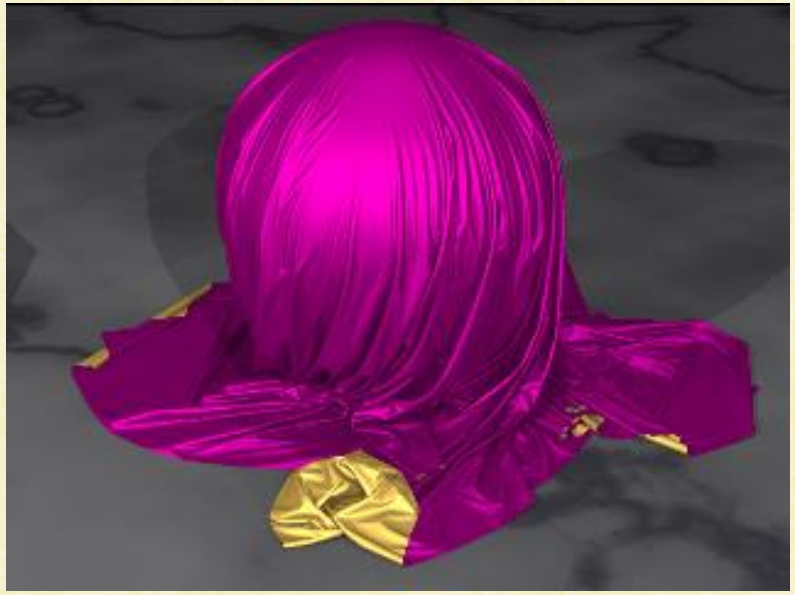
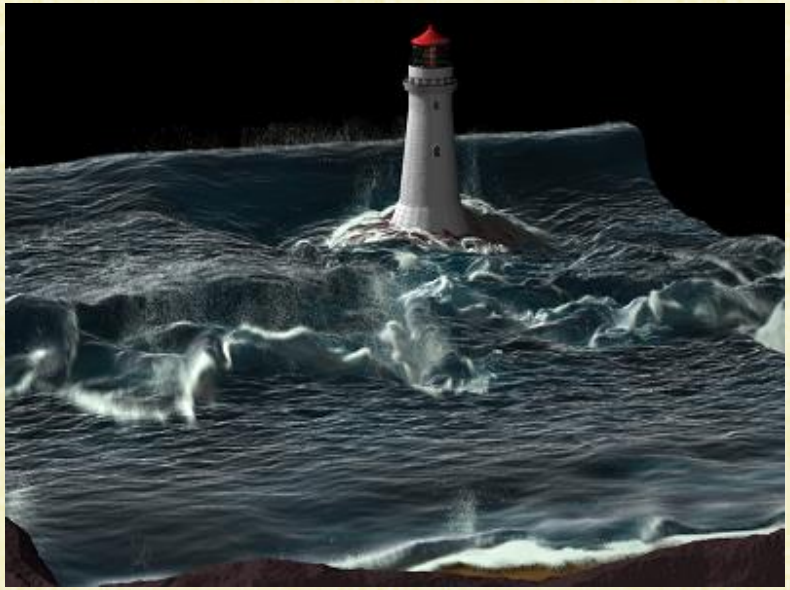
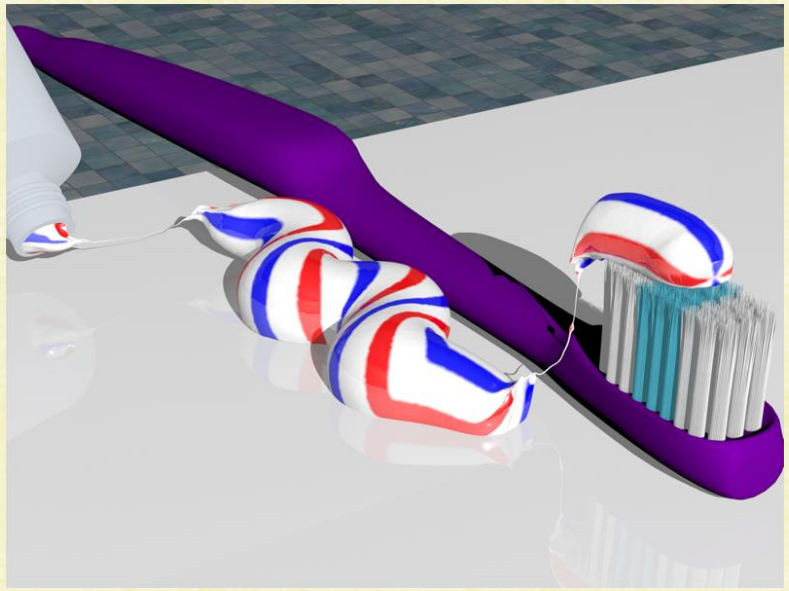
More Geometric Modeling

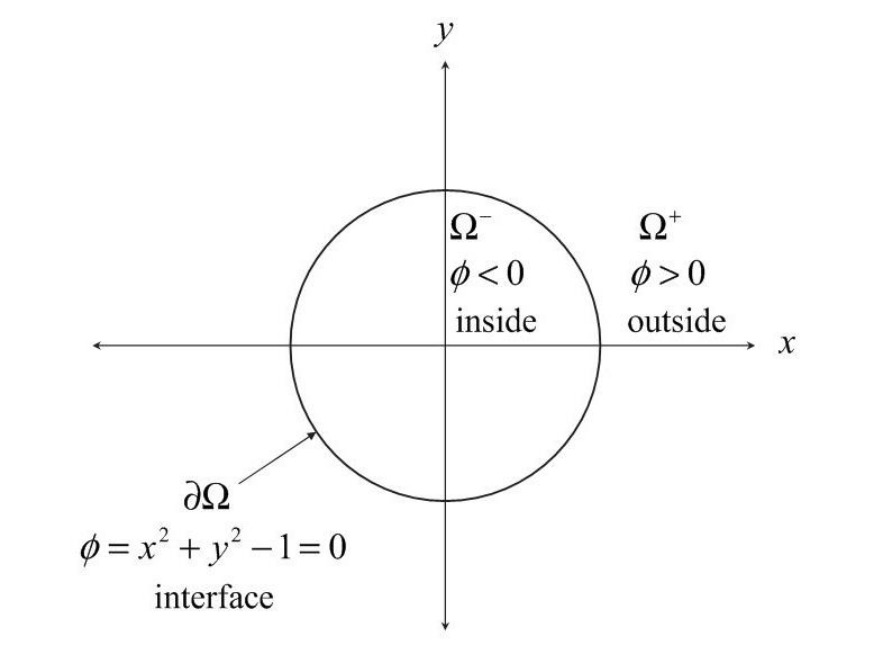


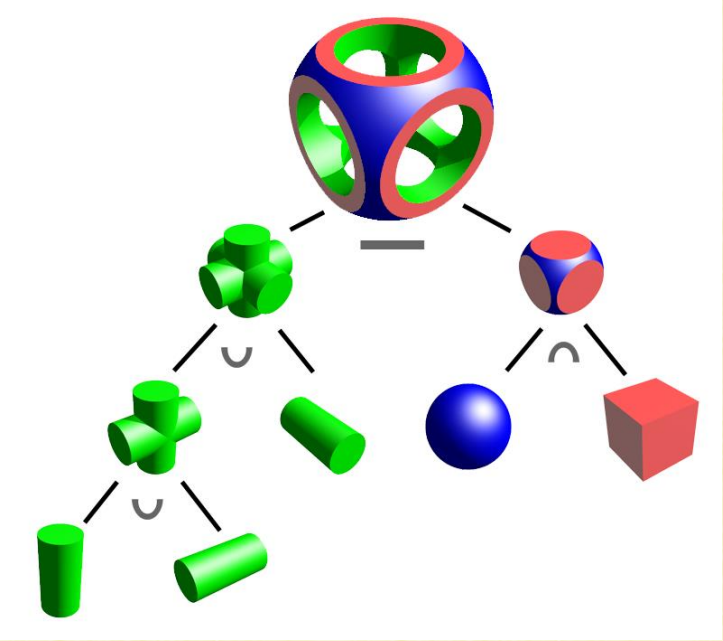




Implicit Surfaces

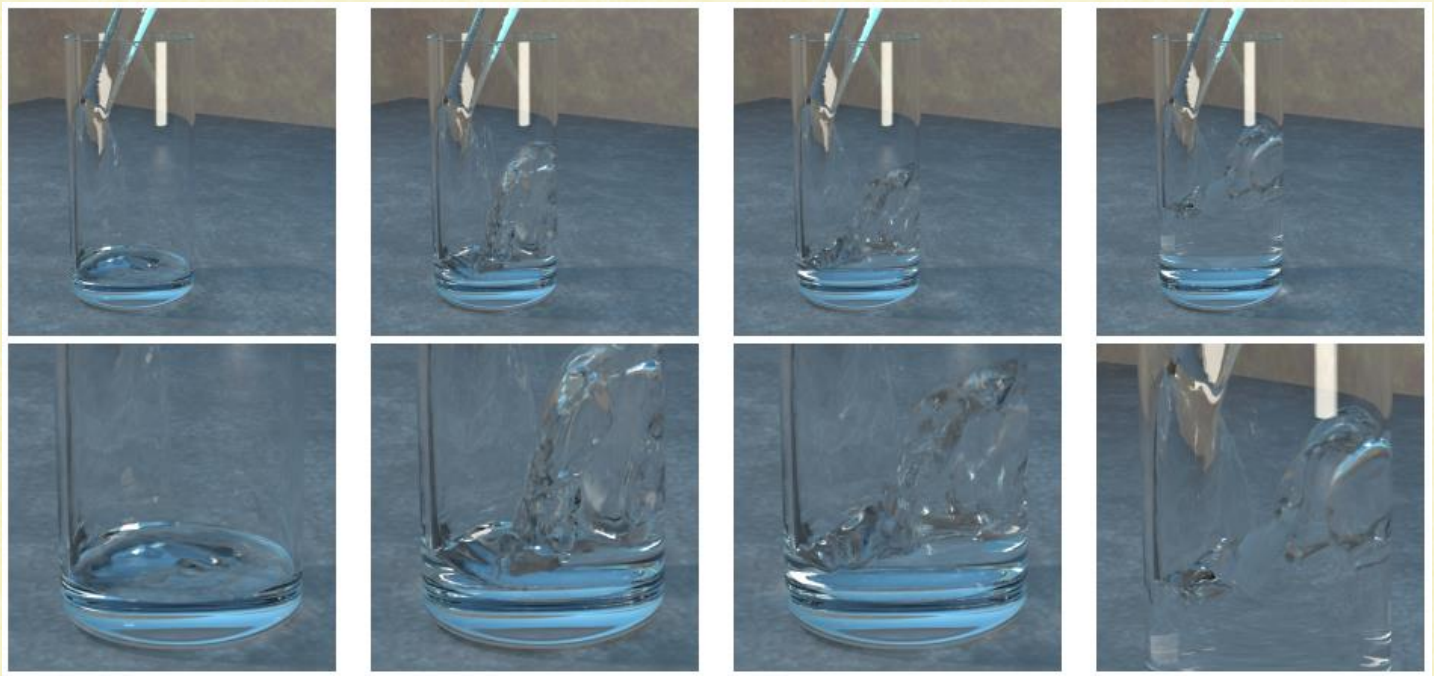
- Define a function $\phi(x)$ over $\forall x \in R^3$
- Interior Ω^- is defined by $\phi(x) < 0$, and exterior Ω^+ is defined by $\phi(x) > 0$
- The surface $\partial\Omega$ is defined by $\phi(x) = 0$
  - As we have already seen, planes/spheres (and lines/rays/circles in 2D) are defined by implicit functions
  - Easy to ray trace implicitly defined geometry
- Easy to check whether a point x is inside/outside: just evaluate $\phi(x)$
- Constructive Solid Geometry (CSG) operations: union, difference, intersection, etc.

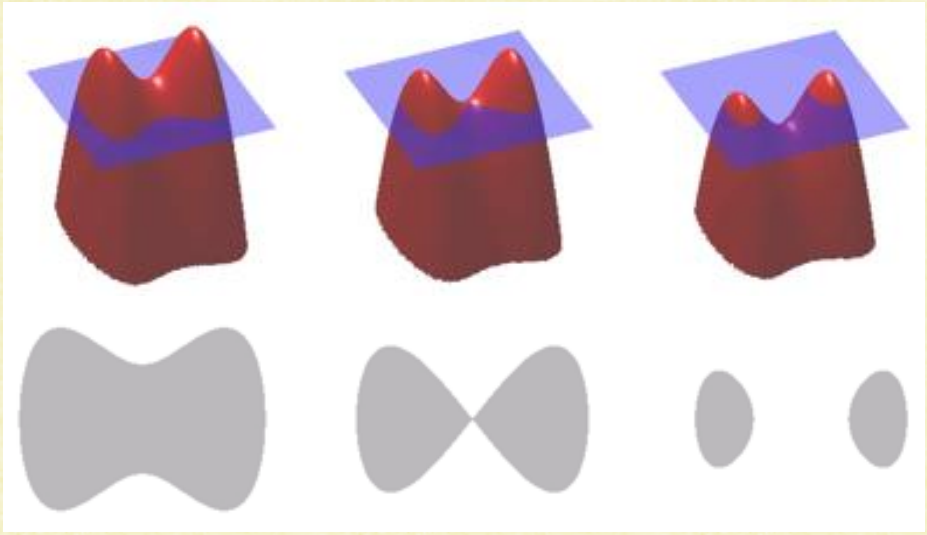


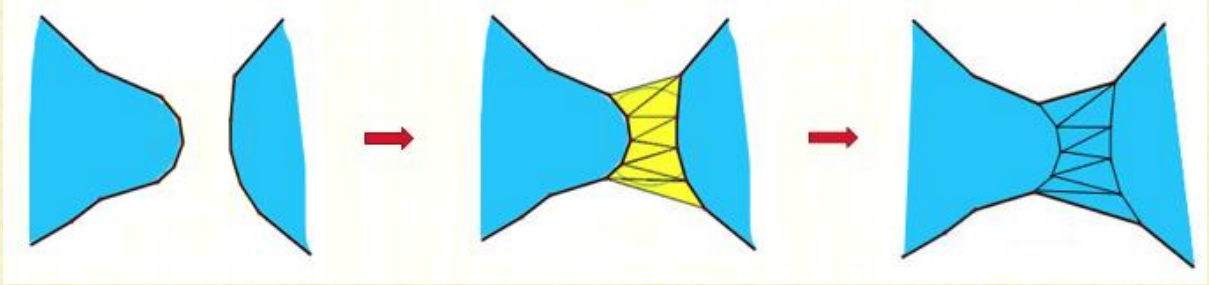


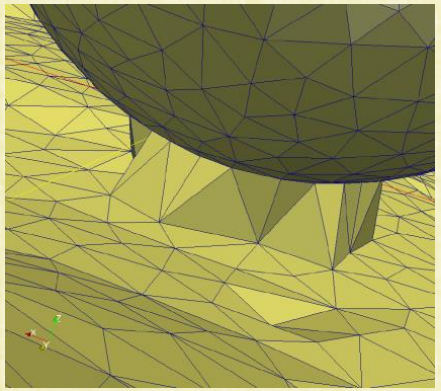
Topological Change

- Greatly superior to triangle meshes for topological change!



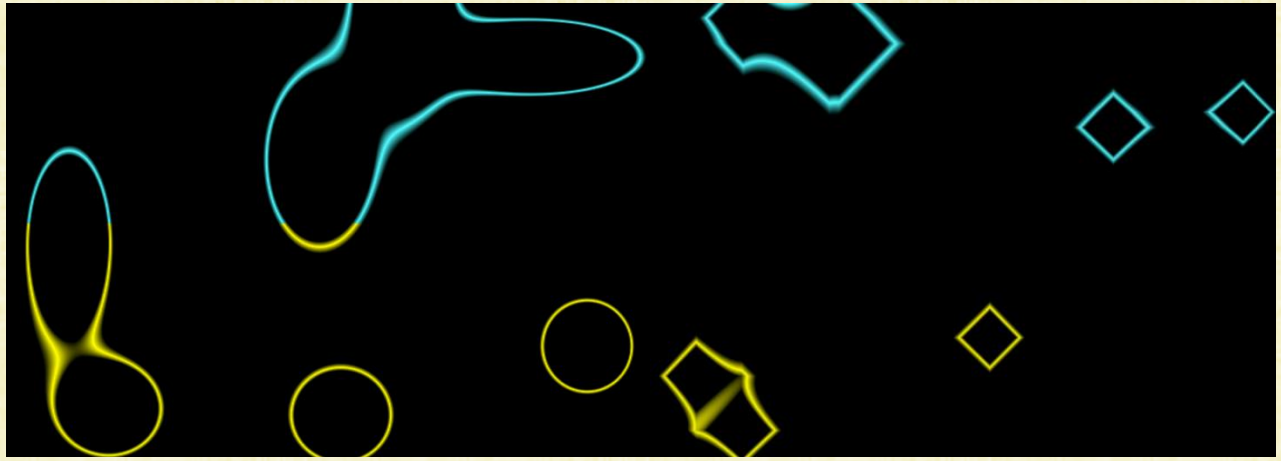


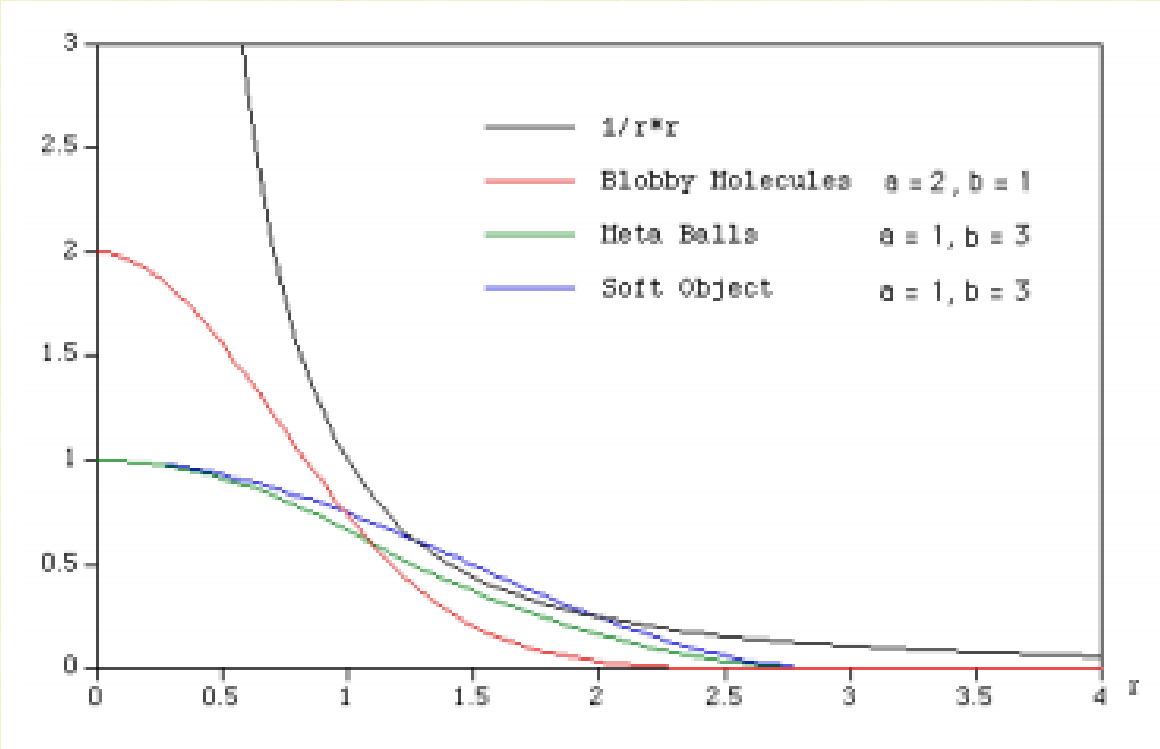




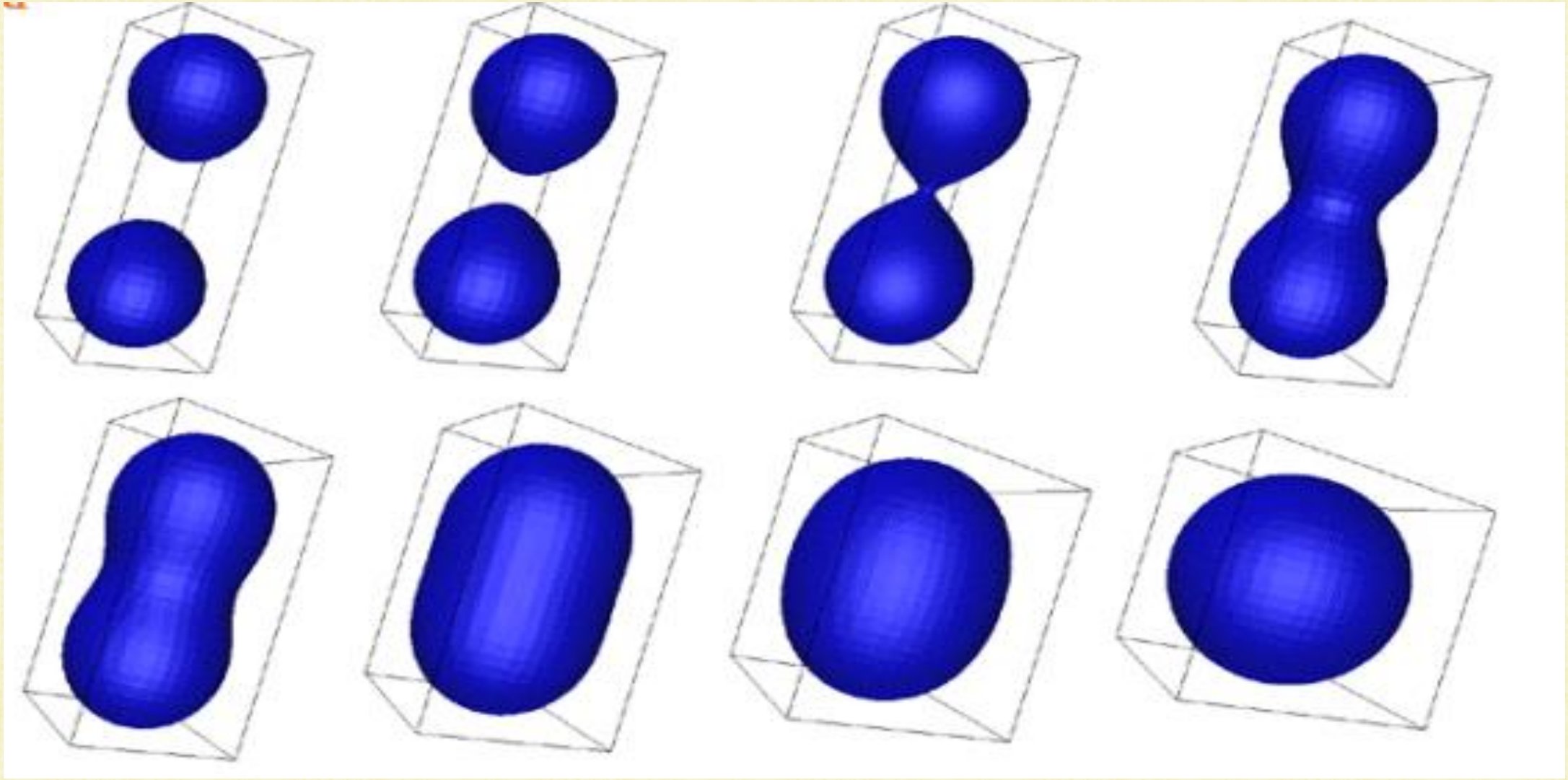
Blobbies

- Each blob is defined as a density function around a particle
- Blob kernels can be: 2D ellipses, 2D diamonds, 3D spheres, etc.
- For each pixel, the aggregate density is summed from all overlapping blobs
- Also known as:
  - Metaballs (in Japan), Soft objects (in Canada and New Zealand)
  - Slightly different density kernel functions

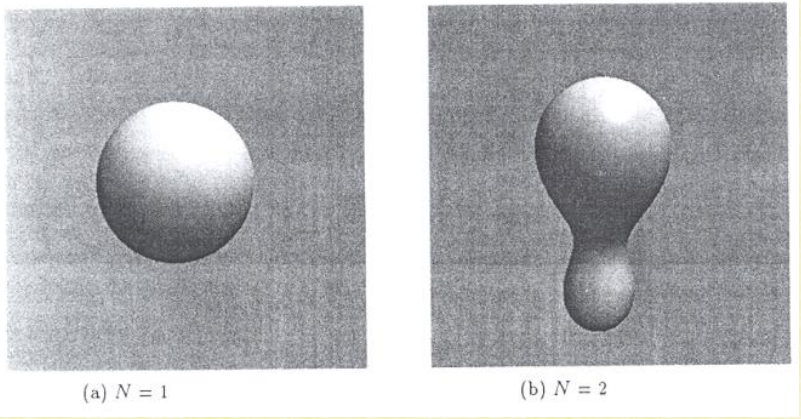




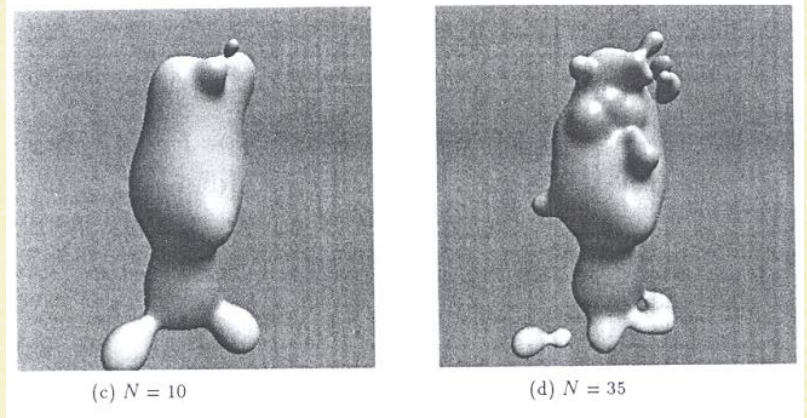
Topological Change



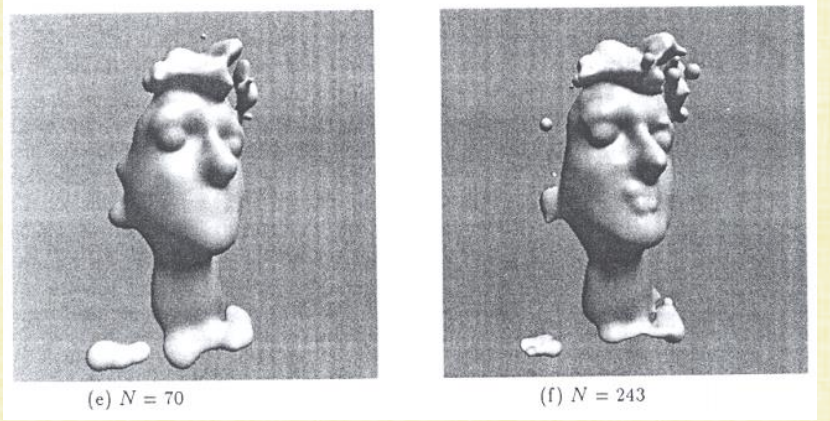
Blobby Modeling



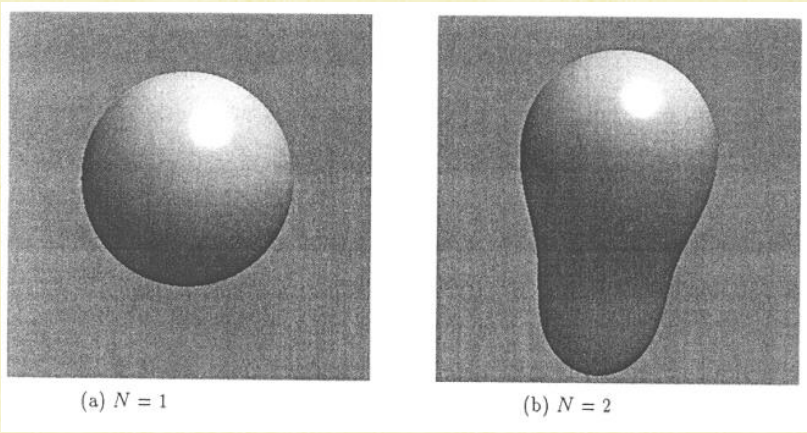
(a) $N = 1$ (b) $N = 2$



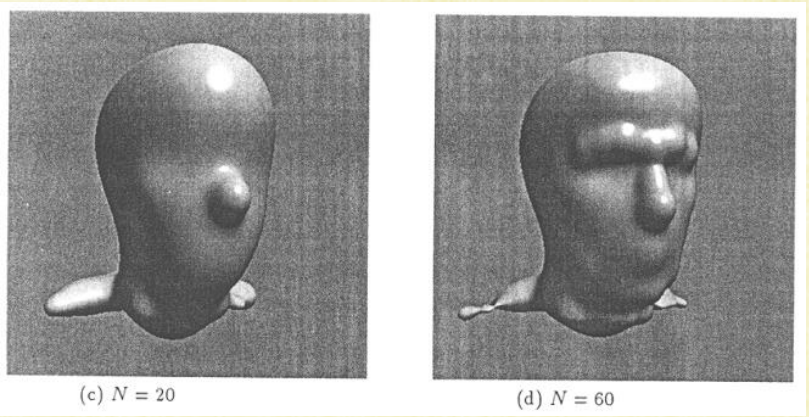
(c) $N = 10$ (d) $N = 35$



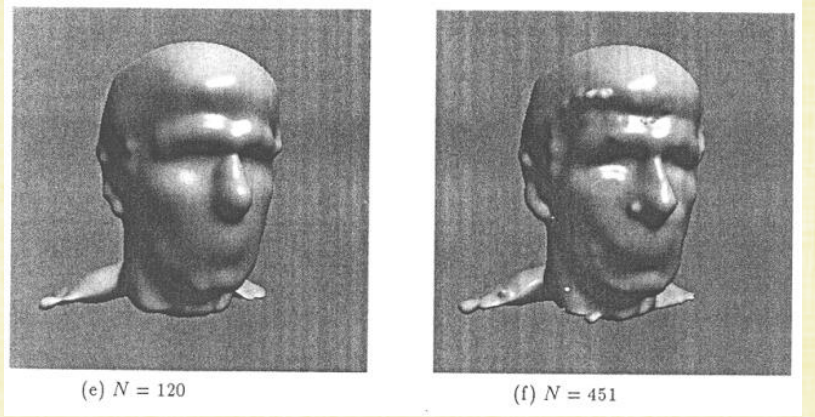
(e) $N = 70$ (f) $N = 243$



(a) $N = 1$ (b) $N = 2$



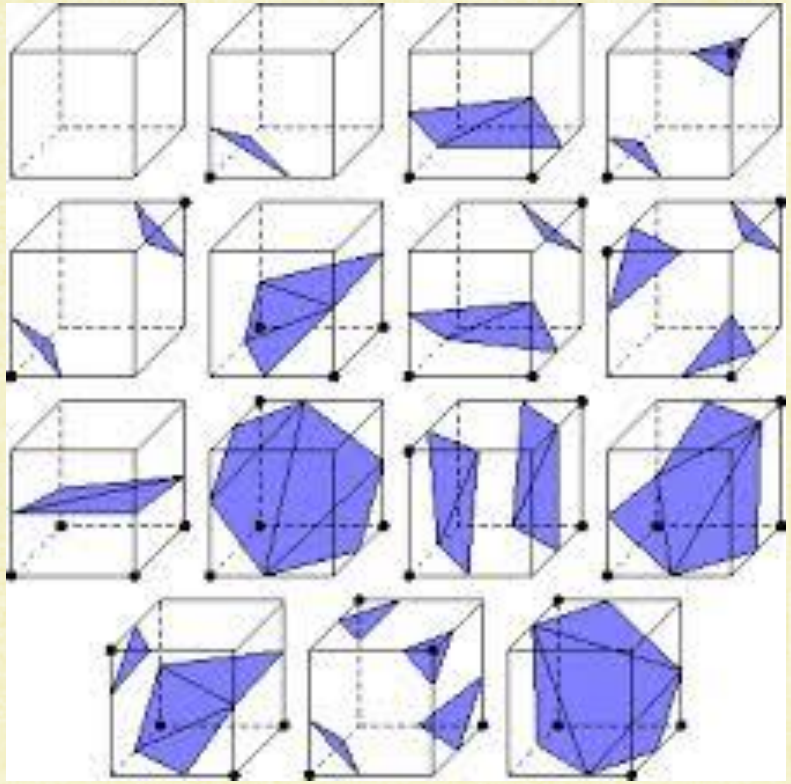
(c) $N = 20$ (d) $N = 60$

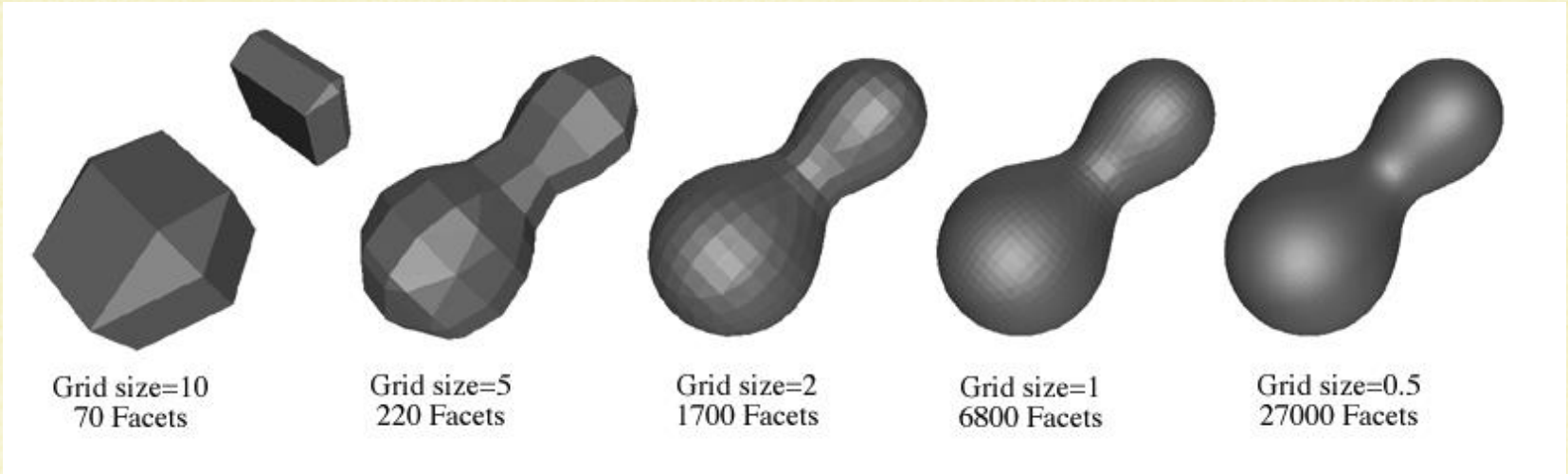


(e) $N = 120$ (f) $N = 451$

Marching Cubes (or Marching Tetrahedra)

- Turns an implicit surface into triangles
  - Define the implicit surface on a 3D grid
  - For each grid cell, use the topology of the volume to construct surface triangles

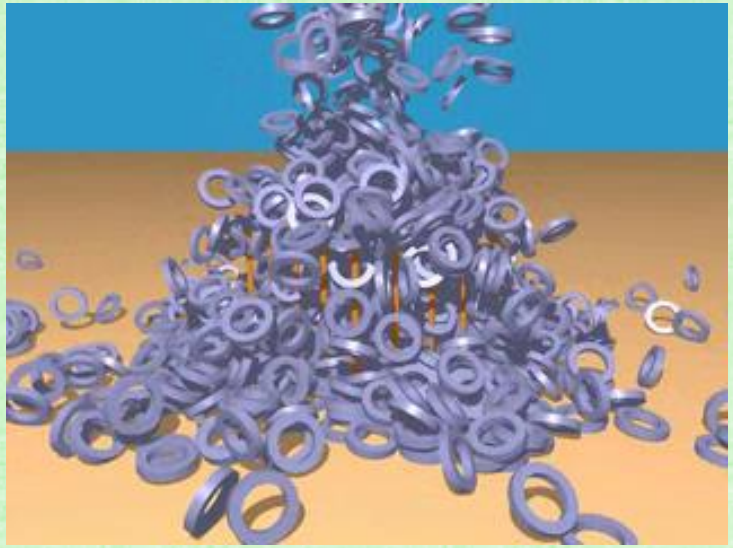


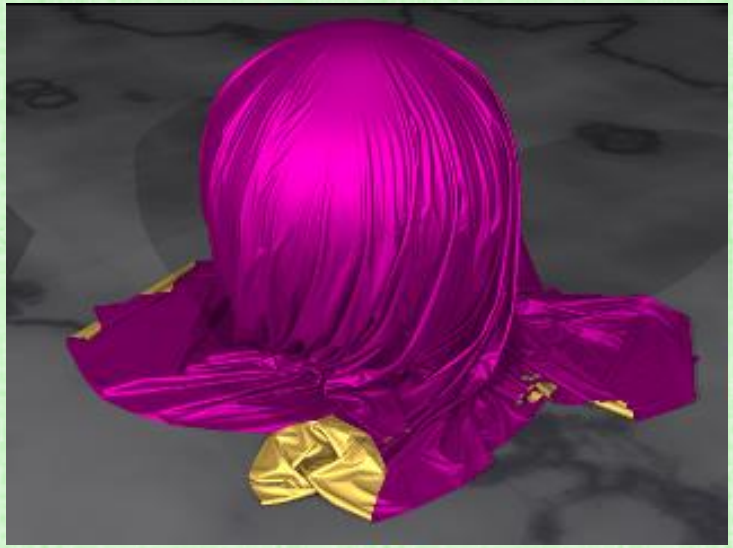


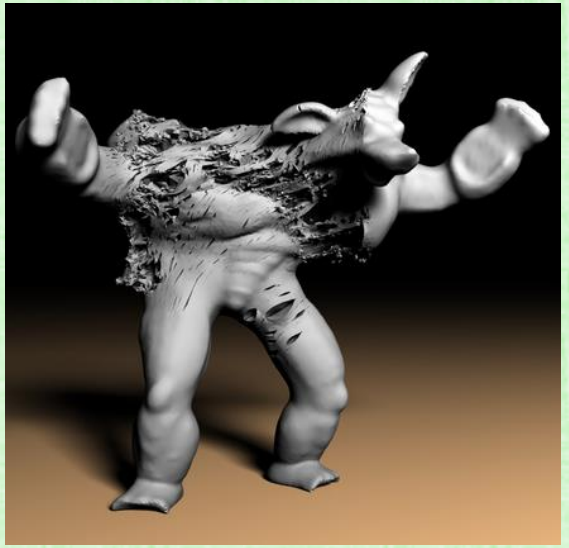
Netwon's Second Law (for Physics Simulations)

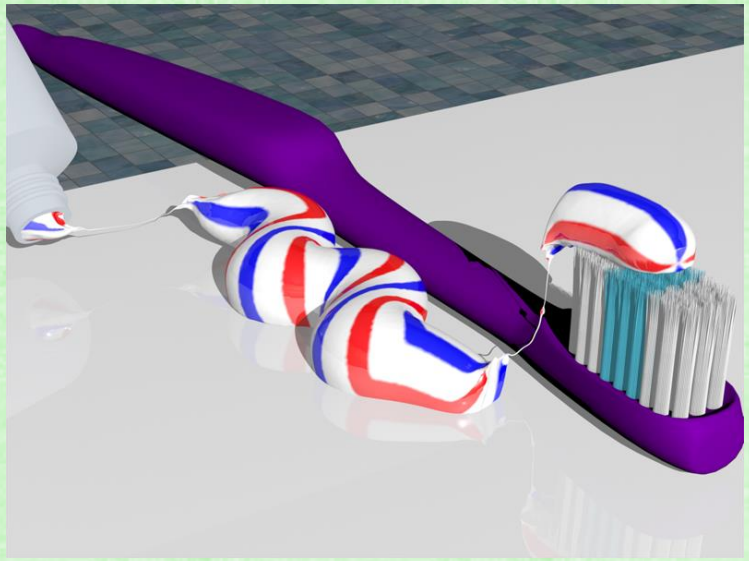
- Kinematics describe position $X(t)$ and velocity $V(t)$ as function of time t
  - $\frac{dX(t)}{dt} = V(t)$ or $X'(t) = V(t)$
- Dynamics describe responses to external stimuli
  - Newton's second law $F(t) = MA(t)$ is a dynamics equation
  - $V'(t) = A(t)$ implies $V'(t) = \frac{F(t)}{M}$ as well as $\frac{\mathrm{d}^2X(t)}{dt^2} = X''(t) = \frac{F(t)}{M}$
- Combining kinematics and dynamics gives: $\begin{pmatrix} X'(t) \\ V'(t) \end{pmatrix} = \begin{pmatrix} V(t) \\ \frac{F(t,X(t),V(t))}{M} \end{pmatrix}$
  - Note: forces often depend on position/velocity
- Much of the physical world can be simulated with Newton's second law: computational mechanics (FEM), computational fluid dynamics (CFD), etc.
  - Create degrees of freedom, specify forces, and solve the resulting ordinary differential equations (ODEs)
  - Spatially interdependent forces lead to partial differential equations (PDEs)

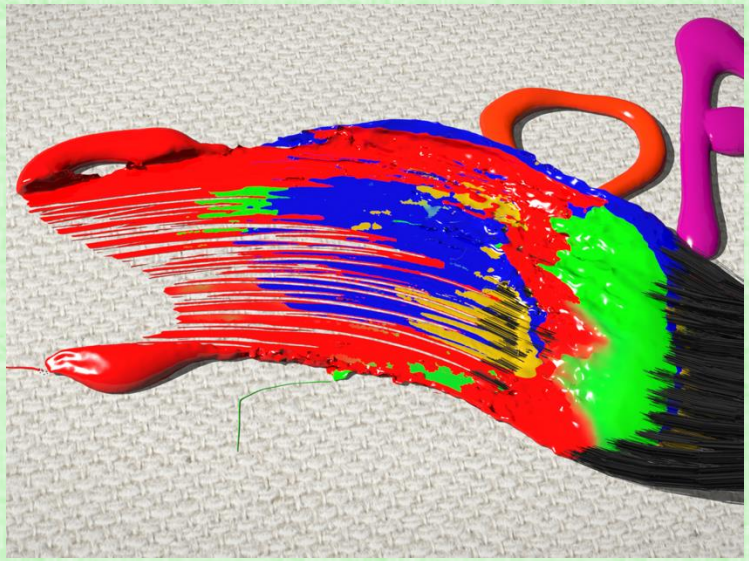
Computational Mechanics (FEM)

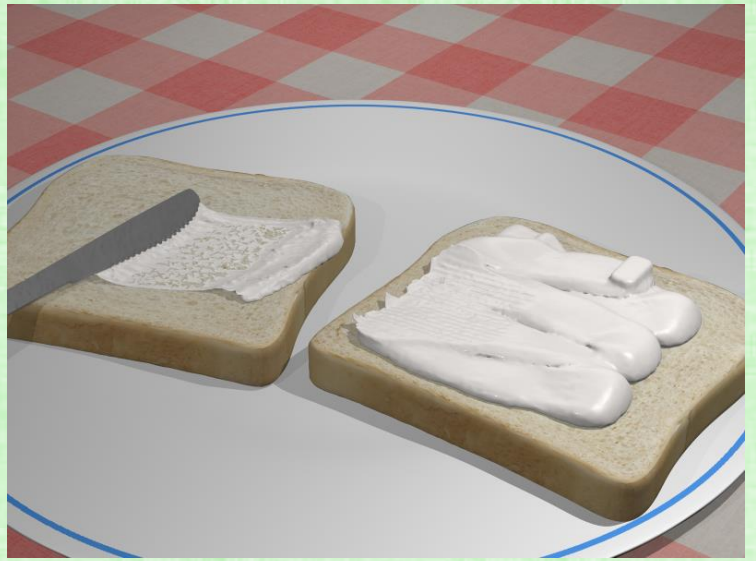




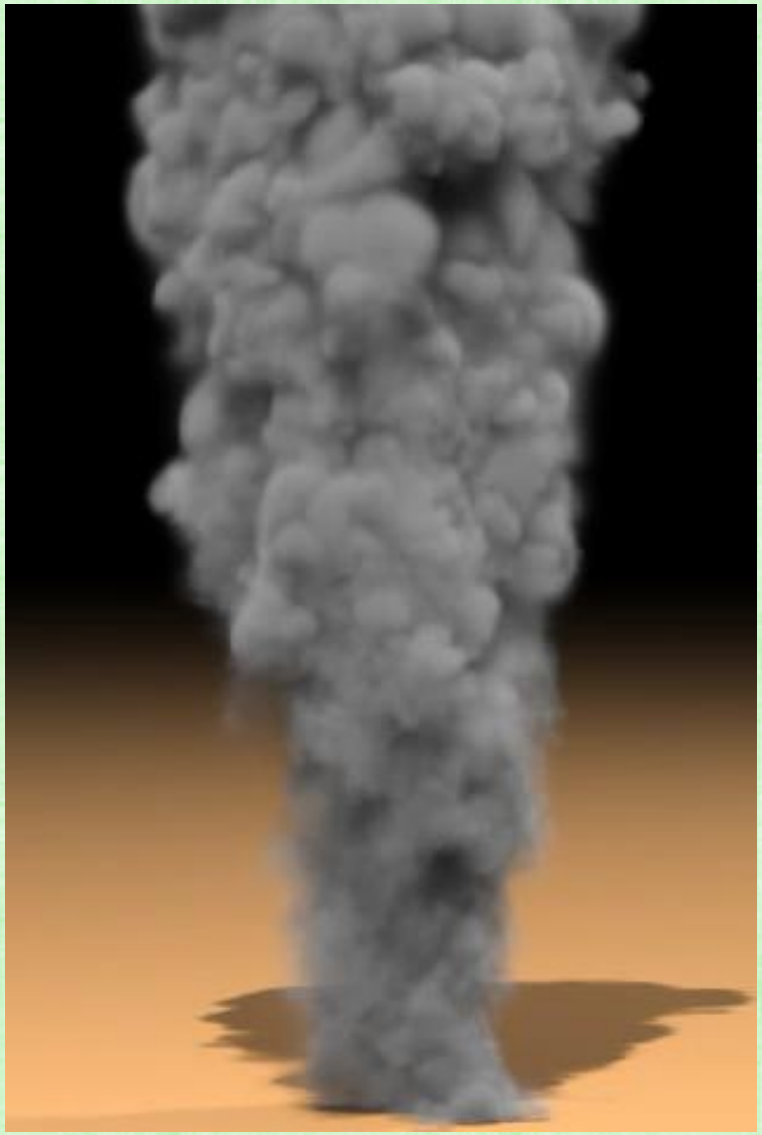


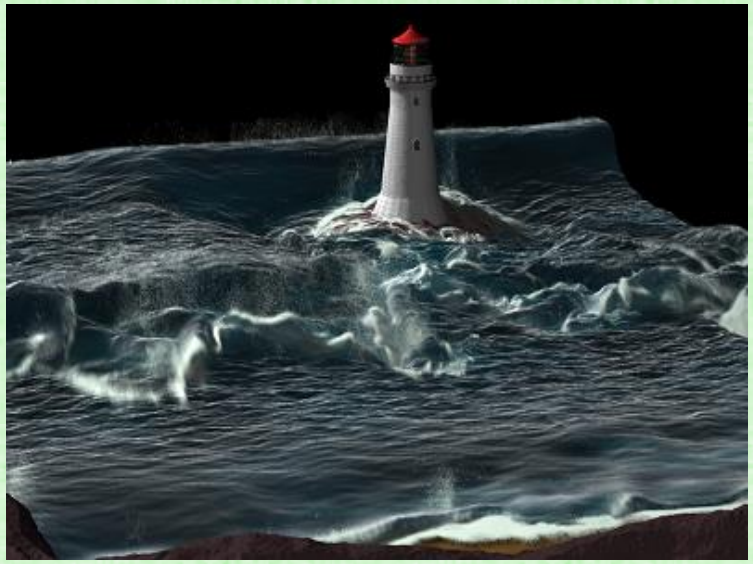


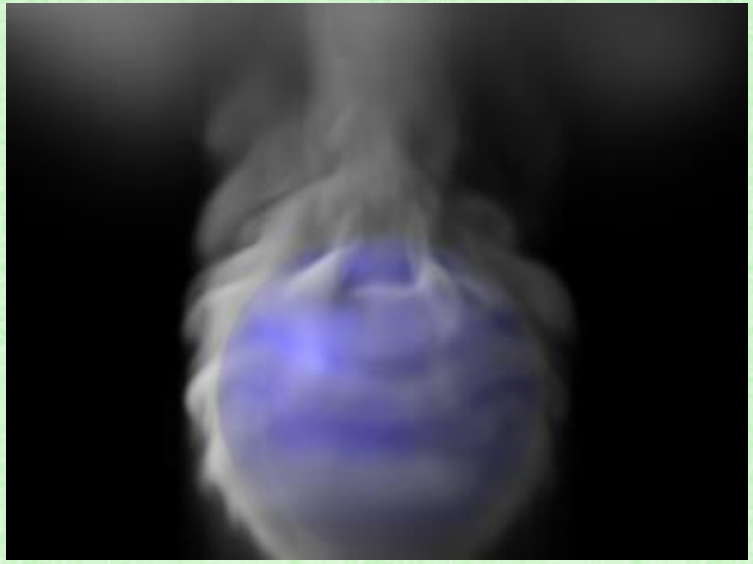


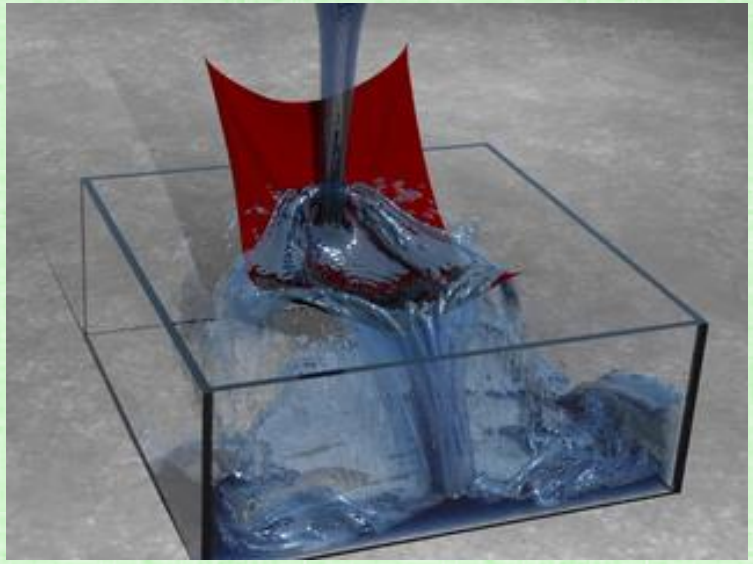


Computational Fluid Dynamics (CFD)

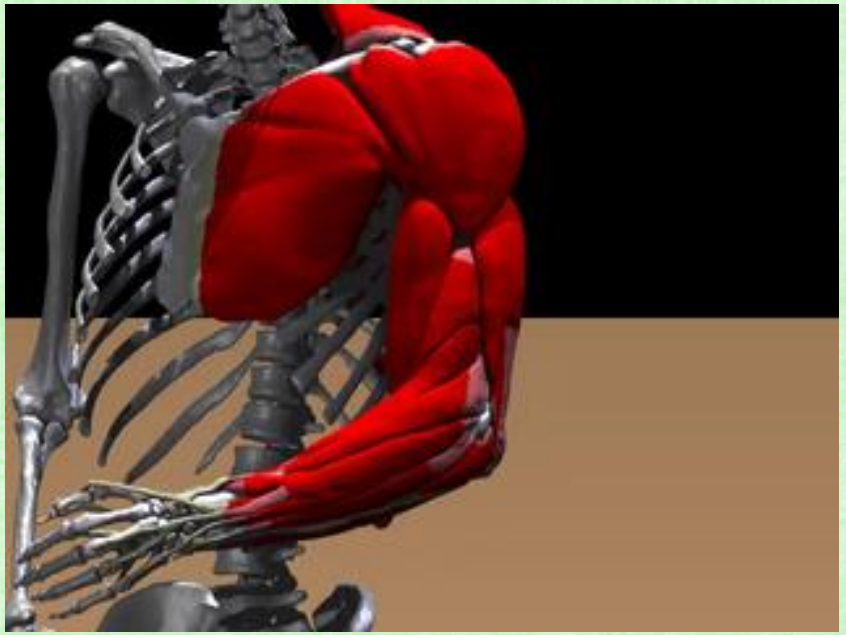


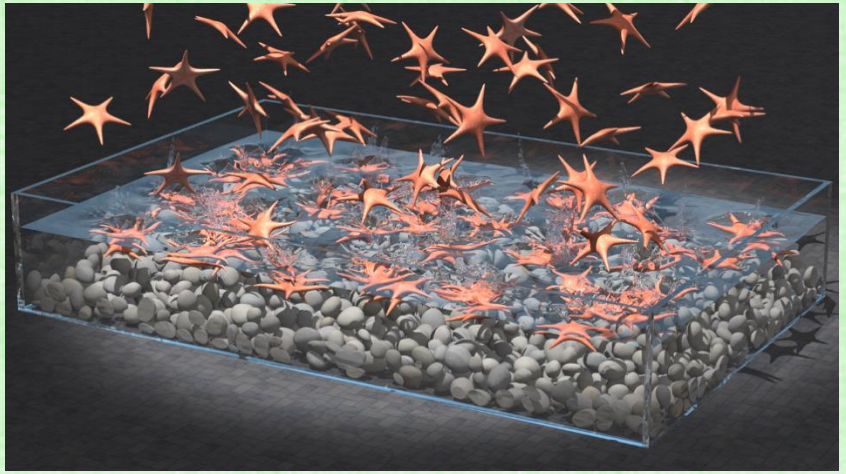






Computational Biomechanics

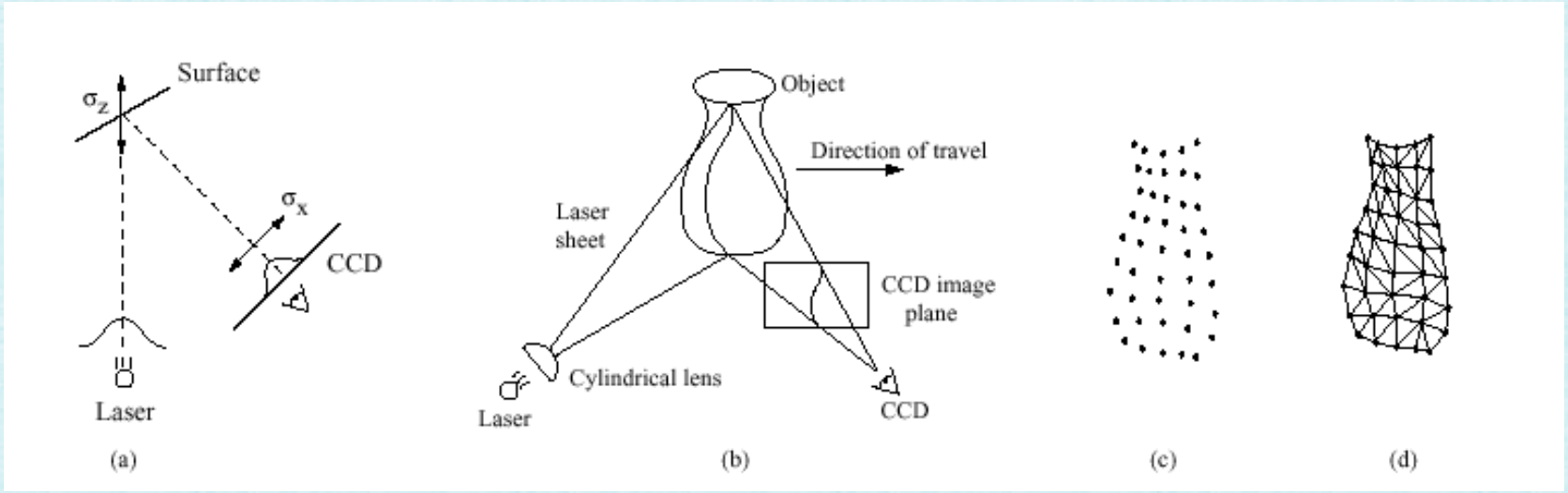


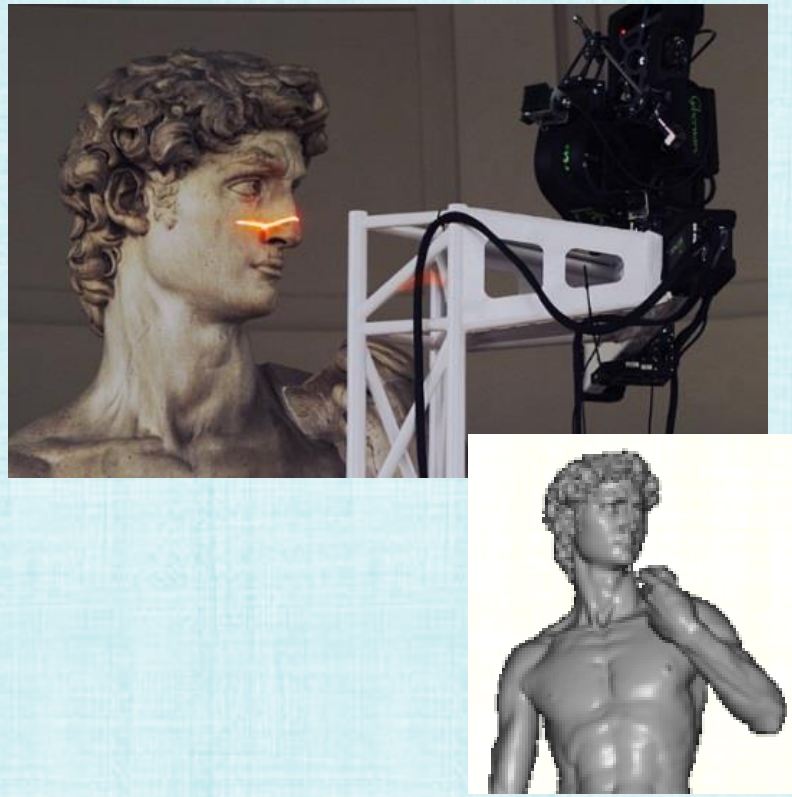


Classical Computer Vision

Range Scanners

- Senses 3D positions on an object's surface, and returns a range image:
  - $m \times n$ grid of distances (m points per laser sheet, n laser sheets)
- Multiple range images are aligned with transformations
  - Transformations determined via Iterative Closest Point (ICP) and related/similar methods
- Aligned range images are combined using a zippering algorithm





Range Scanners

- Each sample point in the $m \times n$ range image is a potential vertex in a triangle mesh
- Special care is required to avoid joining together vertices separated by depth discontinuities

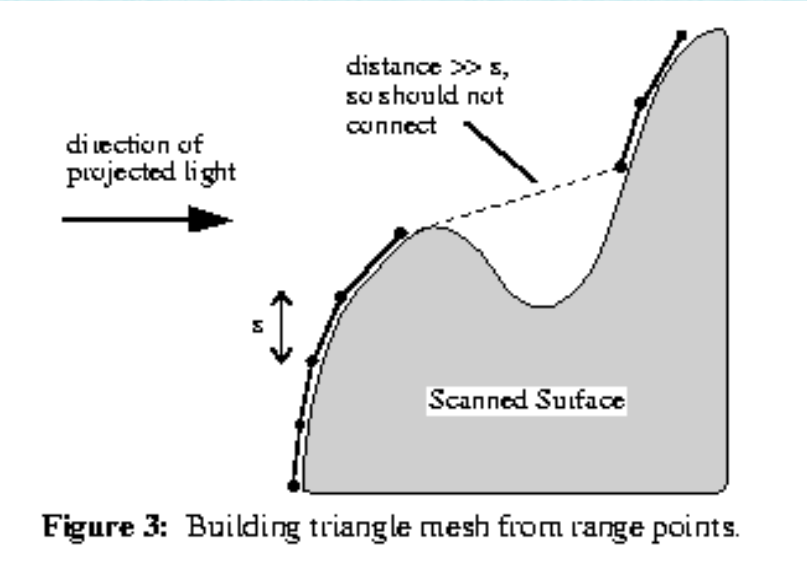
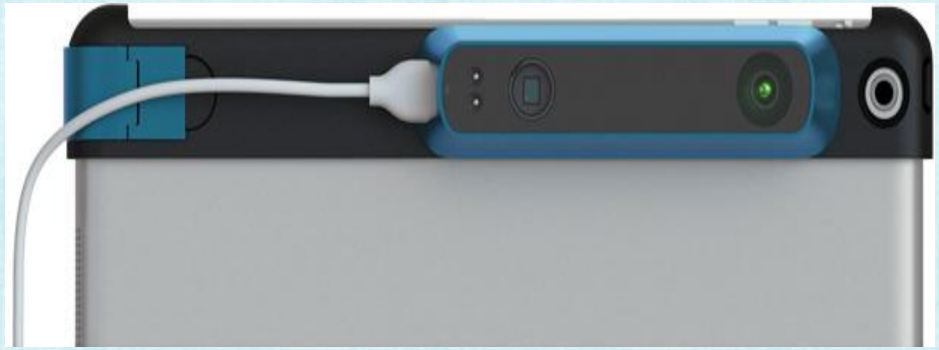
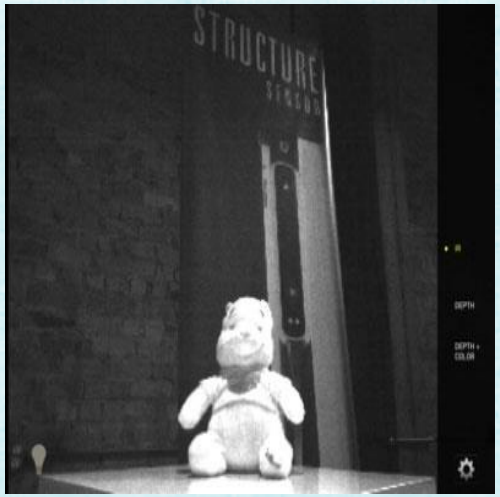
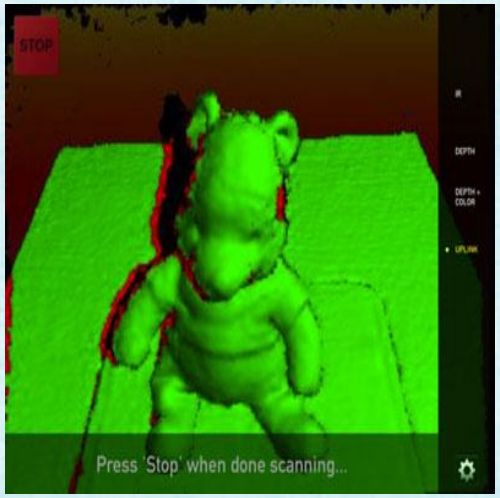


Figure 3: Building triangle mesh from range points.

Scanning w/Mobile Devices







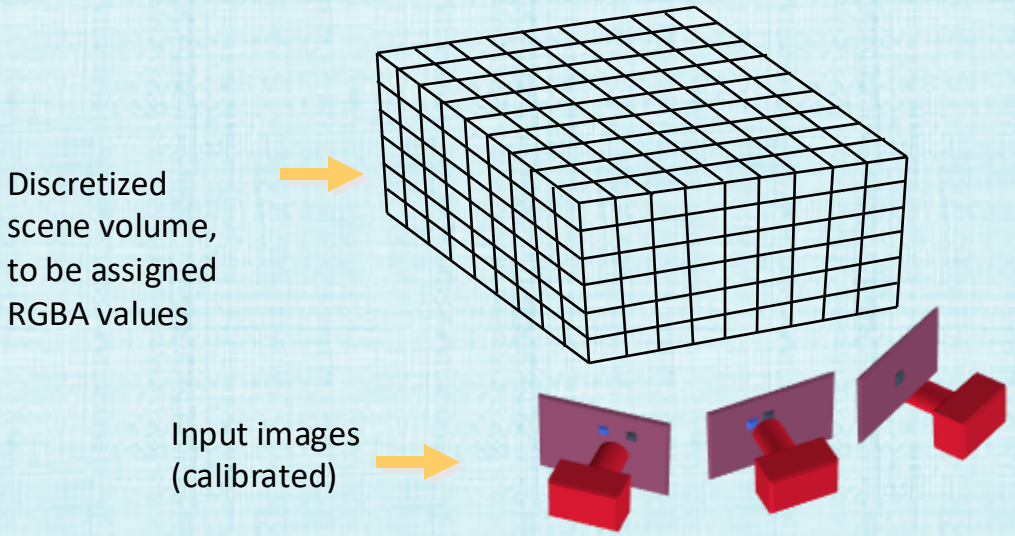
Structure Sensor for iPad

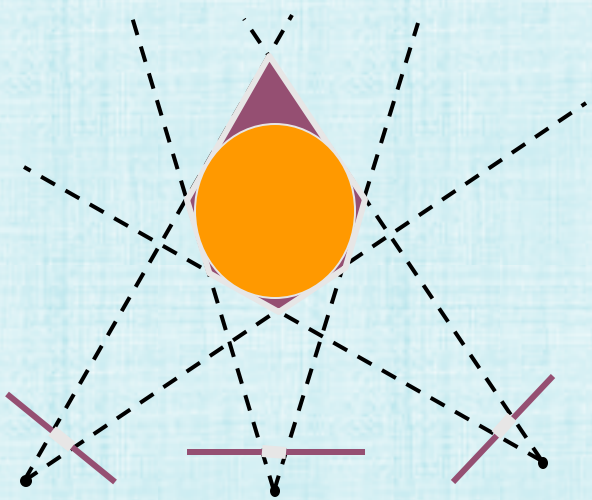
AUTODESK® 123D®

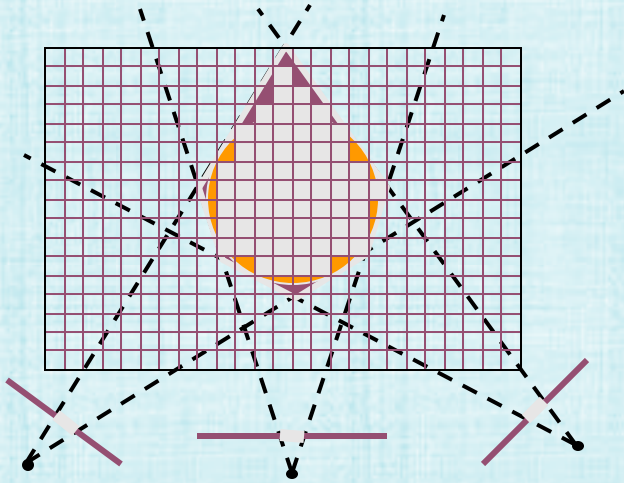
Autodesk 123D Catch

Voxel Carving

- Requires multiple images (from calibrated cameras) taken from different directions
- Construct a voxelized 3D model:
  - For each image, delete (carve away) voxels outside the object silhouette
- Colors can be projected onto the geometry

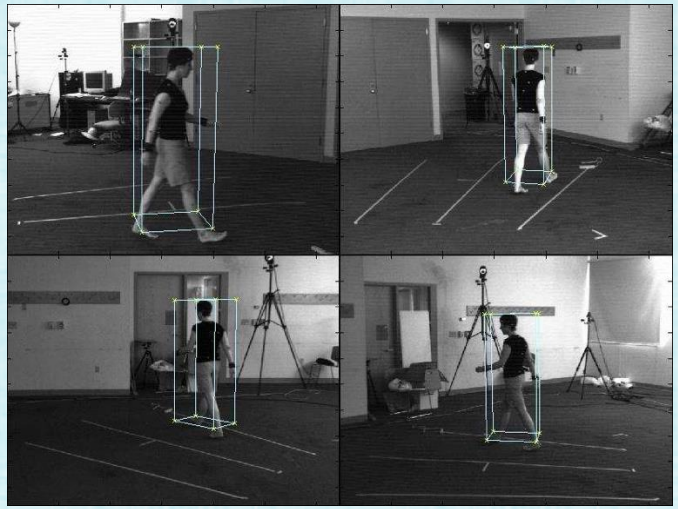




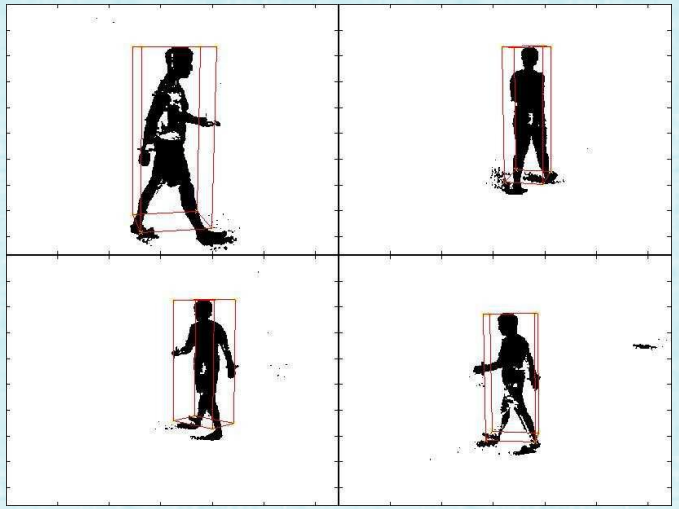


Voxel Carving

Original image

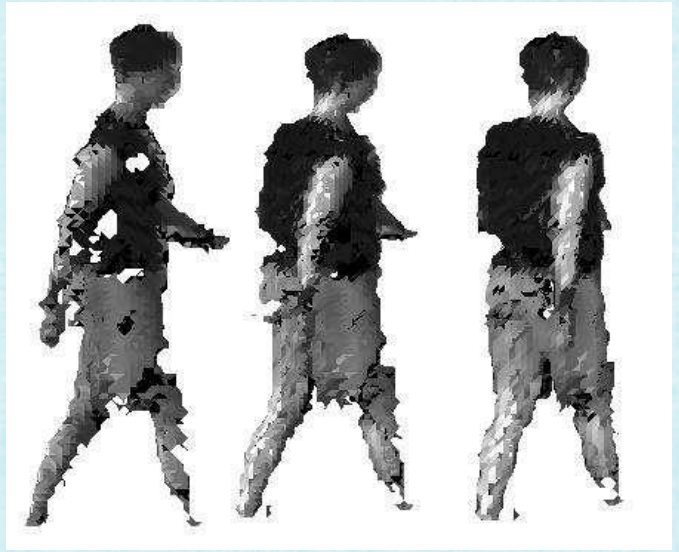


Extracted silhouettes



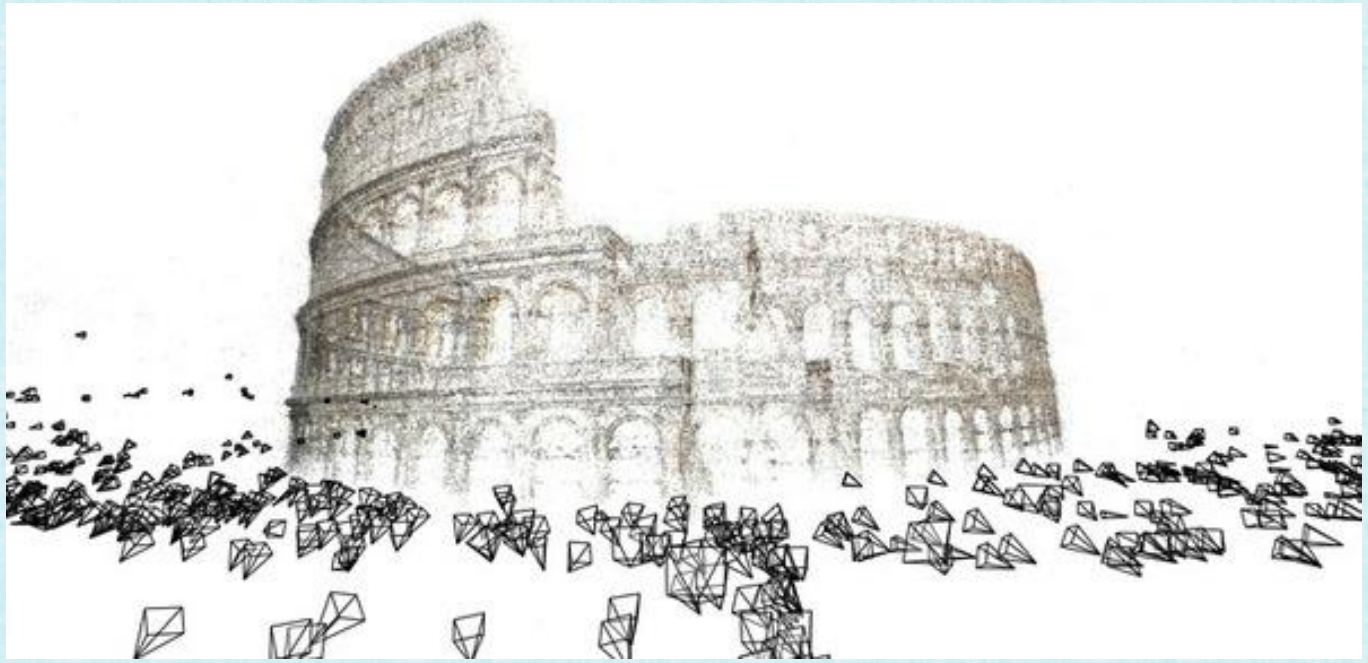
Carved out voxels

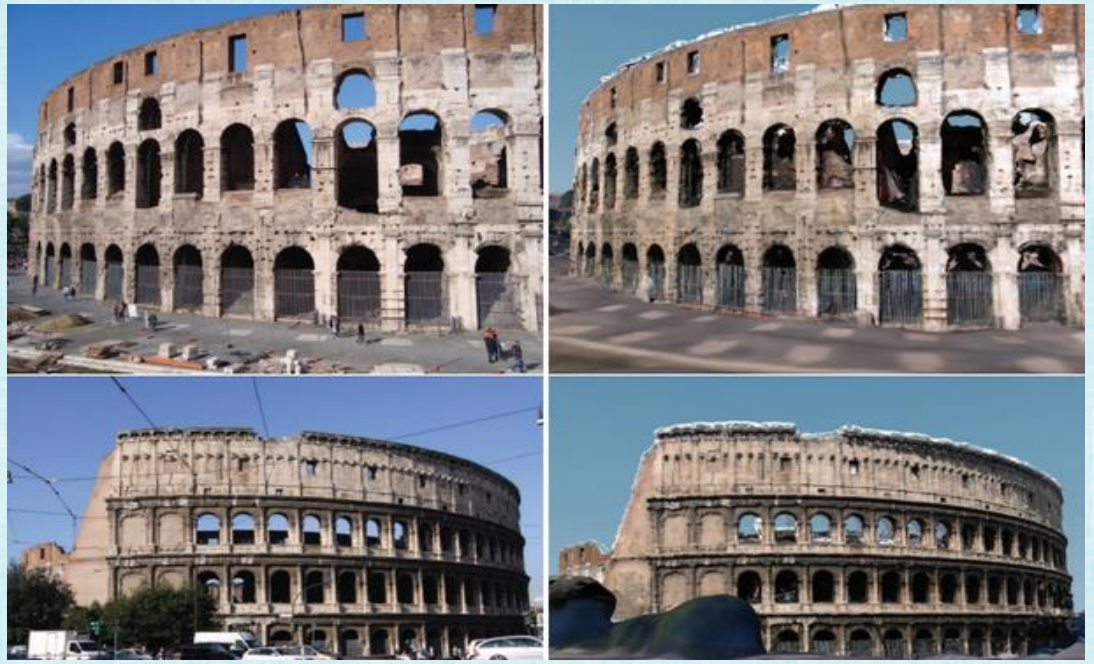
Back-projecting colors



Reconstruction from Large Photo Collections

- Collect a large number of photos (e.g. from google images)
- Predict relative camera position/orientation for each image
- The position of a point that is visible in multiple images can be triangulated
- Obtain a sparse point cloud representation of the object
- Dense reconstruction algorithms can be used to improve the results

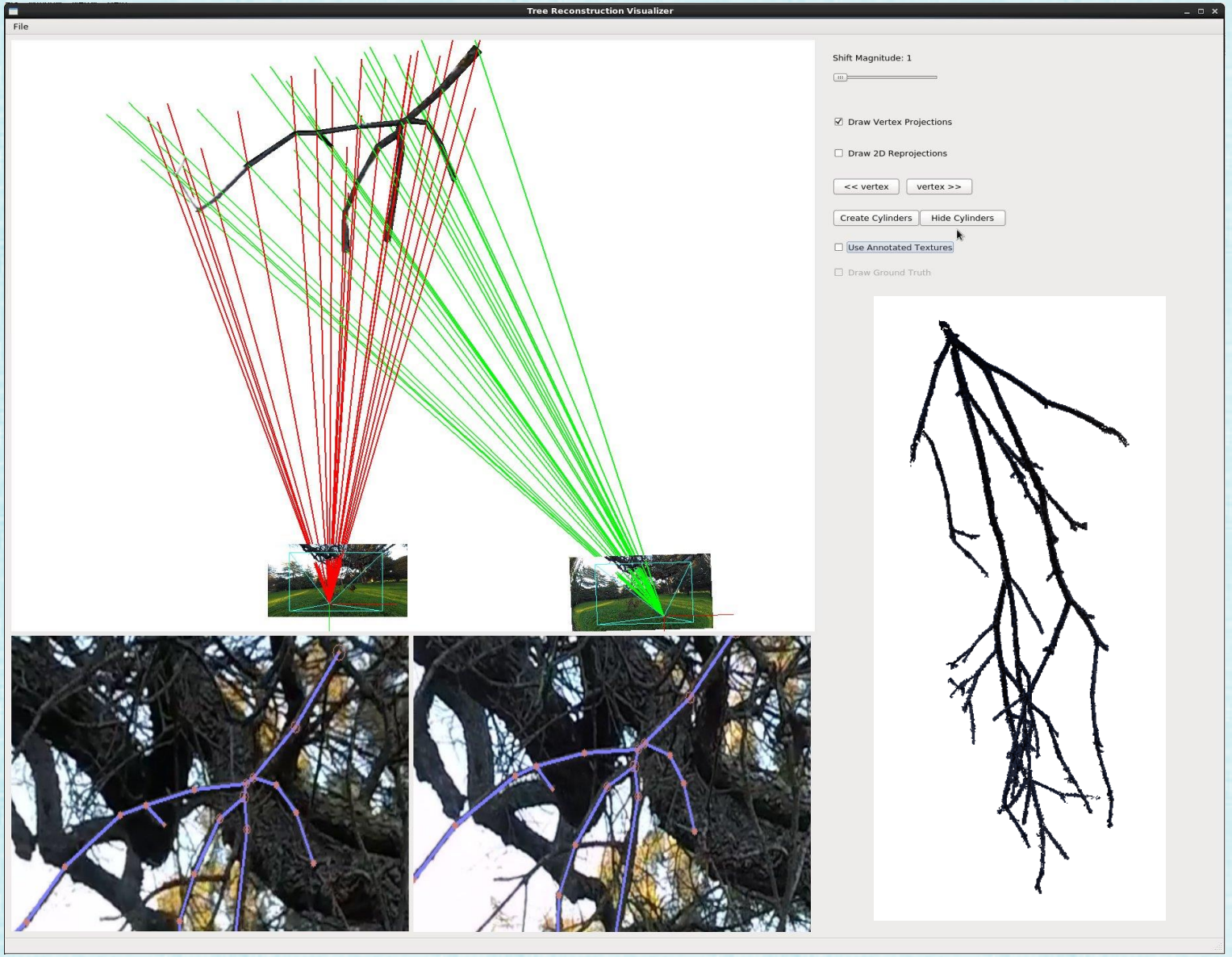




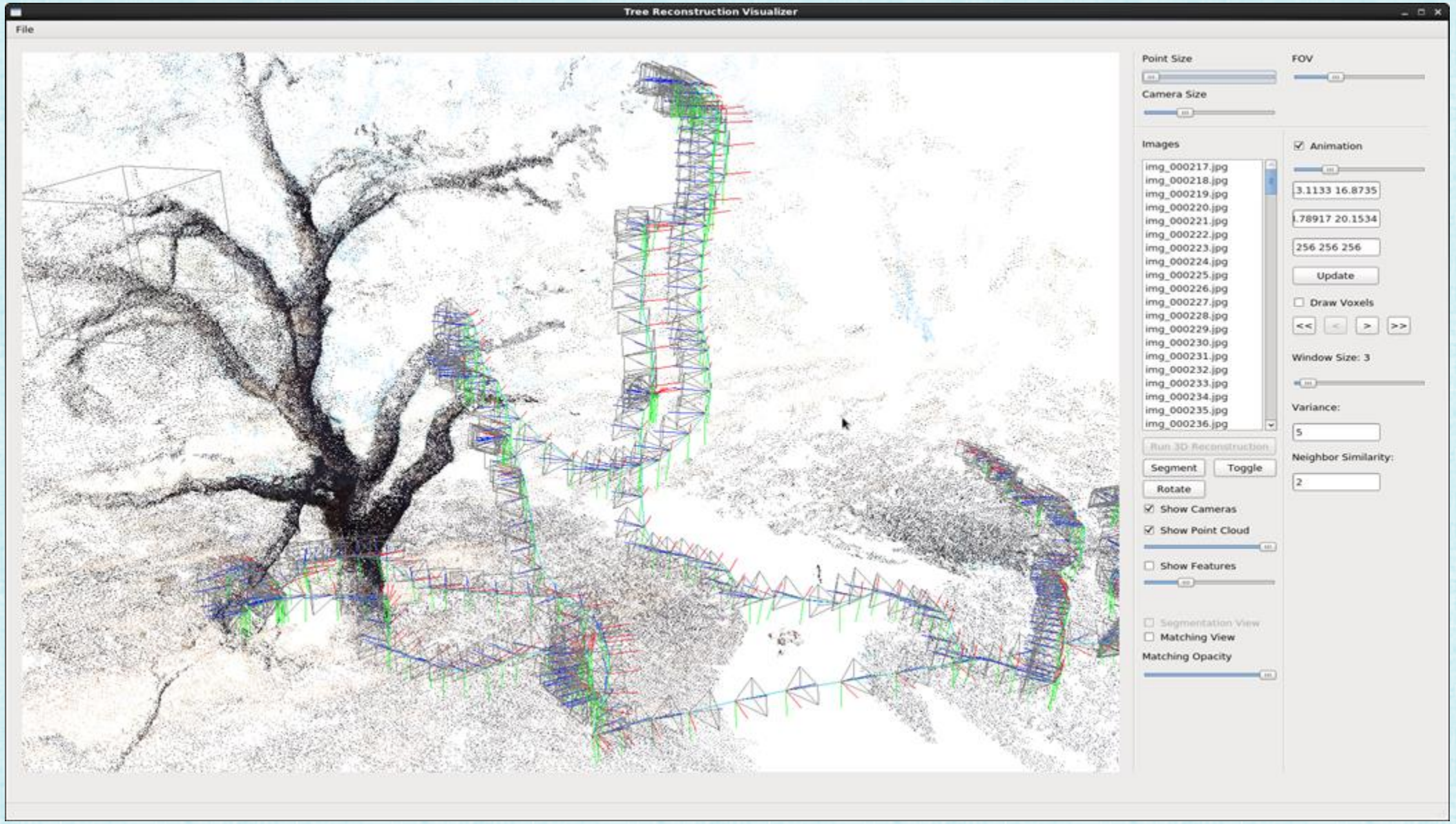
2D photos

3D geometry

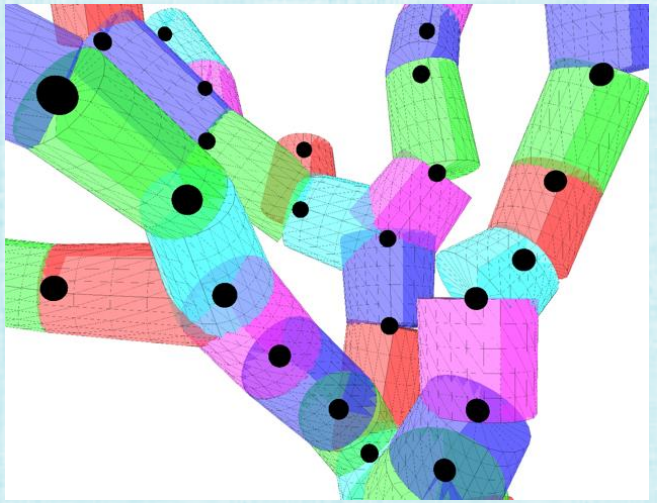
Drones for Trees



Drones for Trees



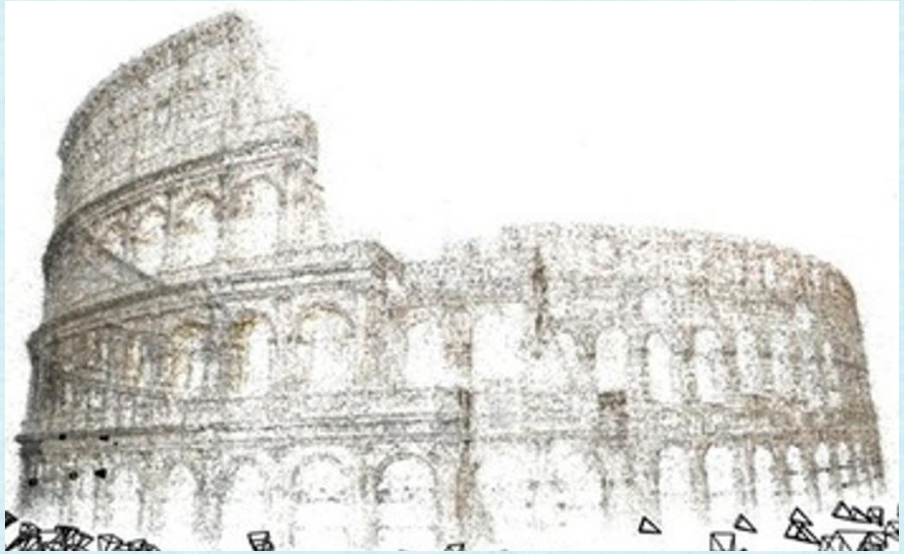
Drones for Trees

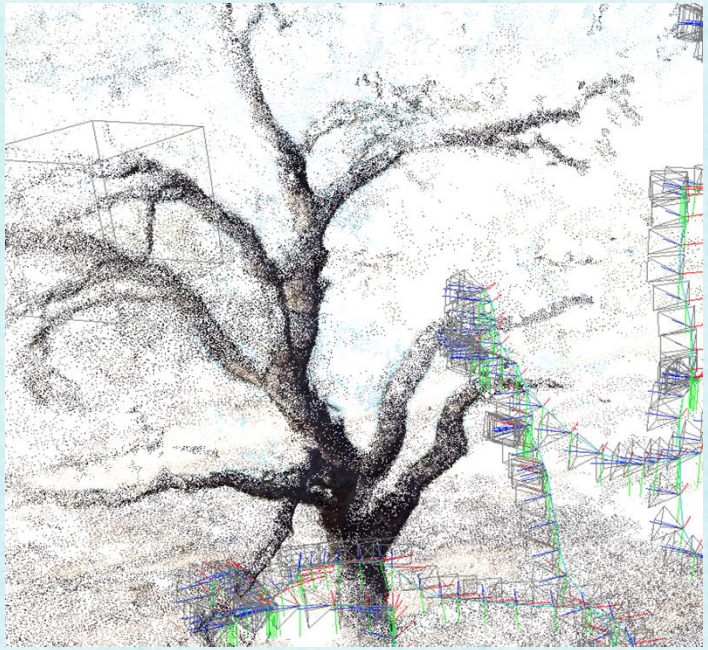


Drones for Trees

Noise & De-Noising

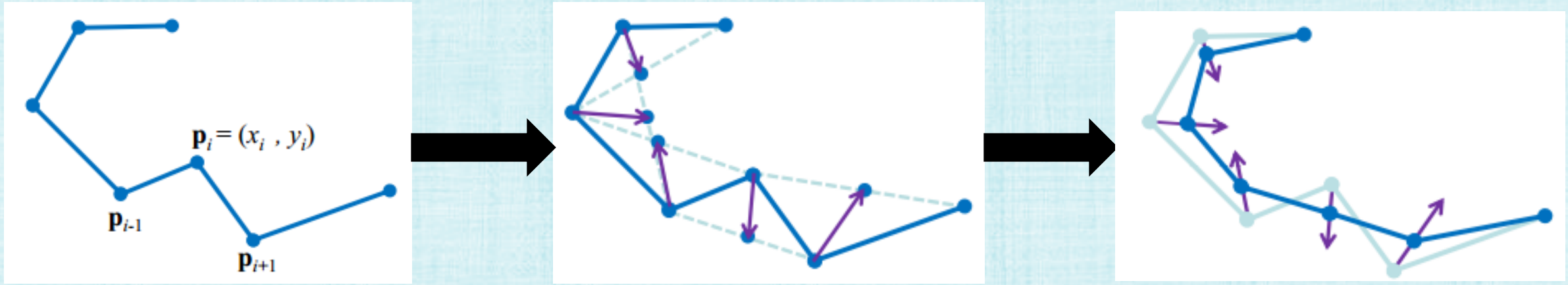
- Computer Vision algorithms use real-world sensors/data
- This results in noise corruption, which is the biggest drawback to such methods
- Denoising/smoothing algorithms are very important in order to alleviate these issues





Laplacian Smoothing

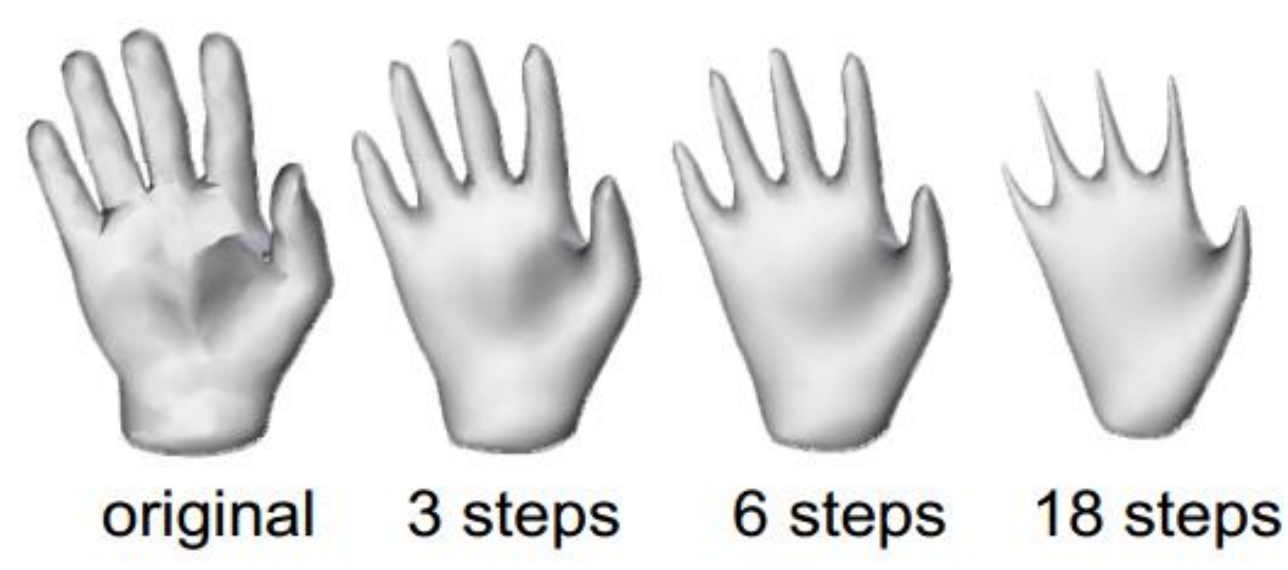
- Compute a Laplacian estimate using the one ring of vertices about a point
  - Similar to differential coordinates
- E.g., on a curve: $L(p_i) = \frac{1}{2}\left((p_{i+1} - p_i) + (p_{i-1} - p_i)\right) = \frac{p_{i+1} - 2p_i + p_{i-1}}{2}$
- Then, update $p_i^{new} = p_i + \lambda L(p_i)$ where $\lambda \in (0,1)$
- Repeat several iterations



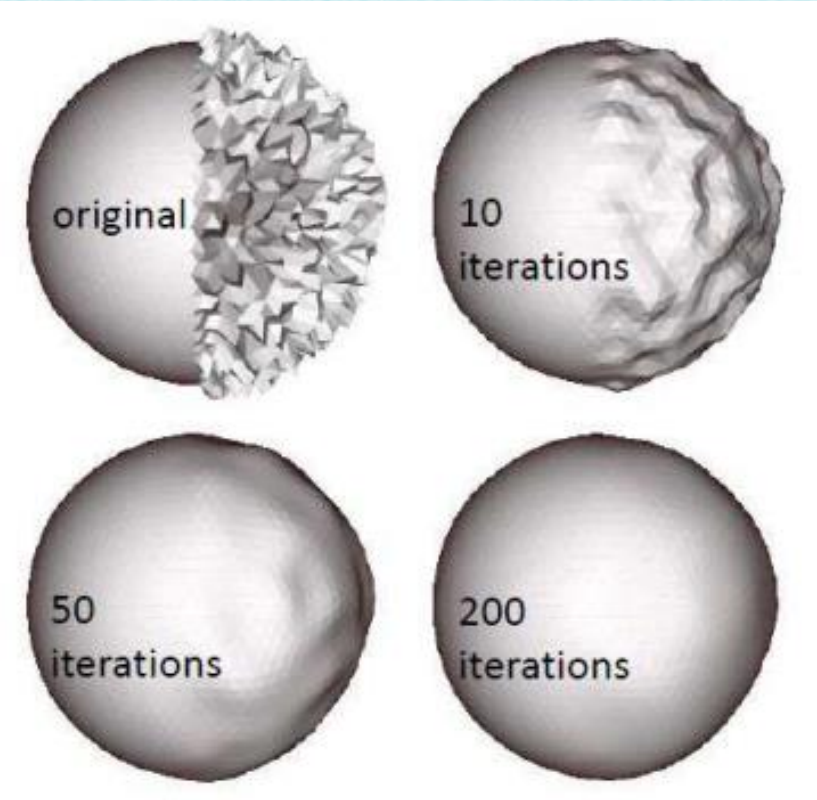
Taubin Smoothing

- Laplacian smoothing suffers from volume loss
- Taubin smoothing periodically performs an inflation step to add back volume:

$$p_i^{new} = p_i - \mu L(p_i) \quad \text{with} \quad \mu > 0$$



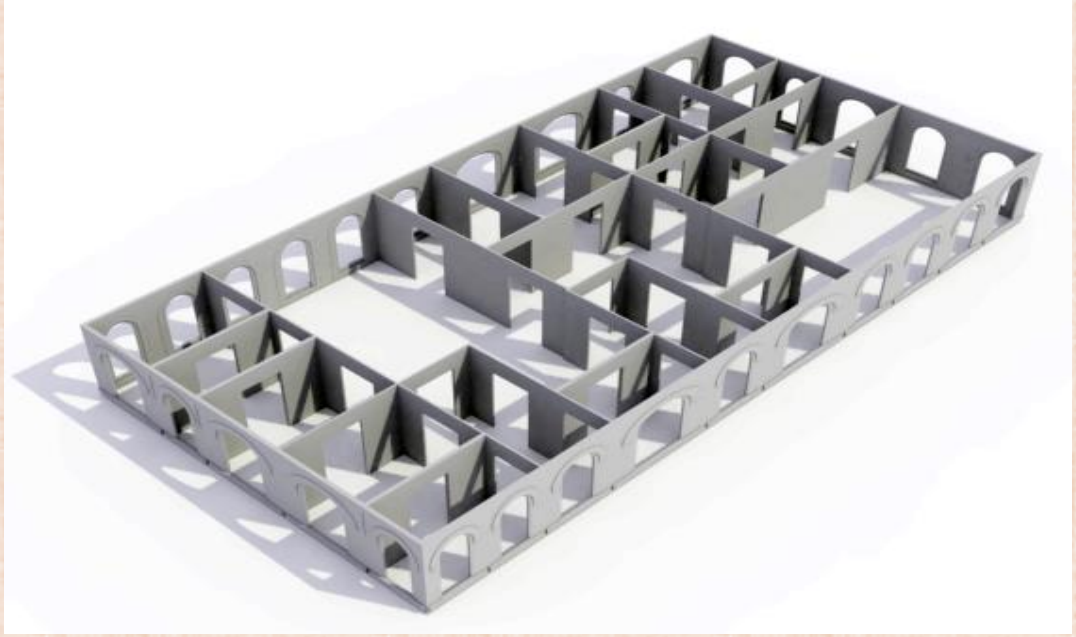
Laplacian smoothing (only)



Taubin smoothing

Procedural Methods (for Geometry Construction)

- Generate geometry with an algorithm
  - Typically used for complex or tedious-to-create models
  - Perturb the algorithm to make variations of the geometry
- Start with a small set of data
- Use rules to describe high level properties of the desired geometry
- Add randomness, and use recursion

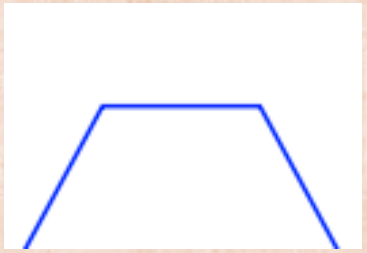


L-Systems

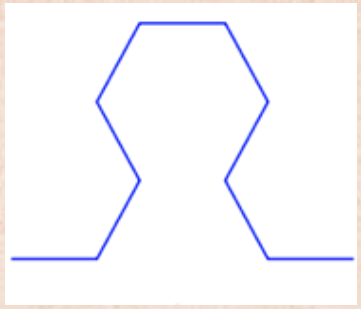
- Developed by a biologist (Lindenmayer) to study algae growth
- A recursive formal grammar:
  - An alphabet of symbols (terminal and non-terminal)
  - Production rules: non-terminal symbols recursively create new symbols (or sequences of symbols)
- Start with an initial string (axiom), and apply production rules
- A translator turns symbols into geometric structures

Nonterminals: A and B both mean “draw forward”
Terminals: +/- mean "turn” right/left (respectively) by 60 degrees
Production Rules: A → B + A + B and B → A − B − A

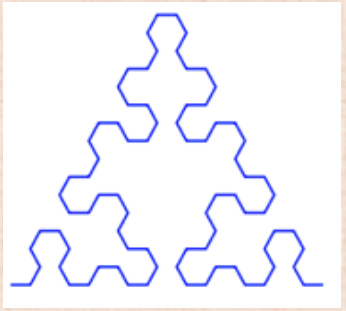
Intial Axiom: A



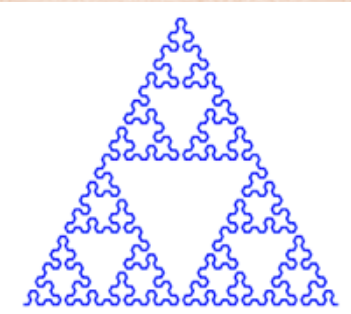
B+A+B



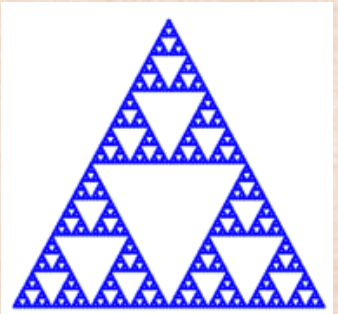
A-B-A + B+A+B + A-B-A



B+A+B-(A-B-A)-(B+A+B)
+A-B-A +B+A+B +A-B-A
+B+A+B-(A-B-A)-(B+A+B)



Etc.



Sierpinski
Triangle

L-System + Stack = Branches

- Nonterminals: X is no action, F is draw forward
- Terminals: +/- means turn right/left by 25 degrees
  - **[means to store current state on the stack**
  - **] means to load the state from the stack**
- Initial Axiom: X
- Production Rules: X → F − [[X]+X] + F [+FX] − X, F → FF

L-Systems

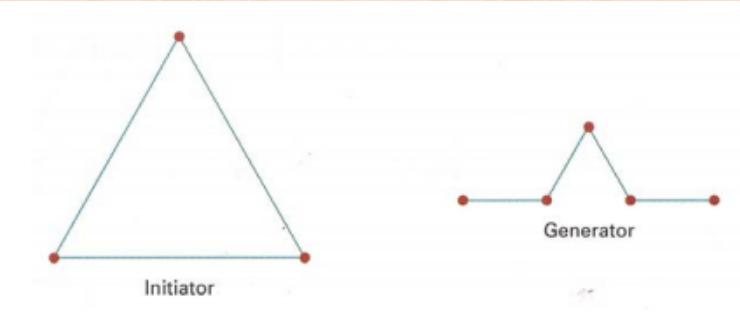
- Easily extended to 3D
- Model trunk/branches as cylinders
- As recursion proceeds:
  - shrink cylinder size
  - vary color (from brown to green)

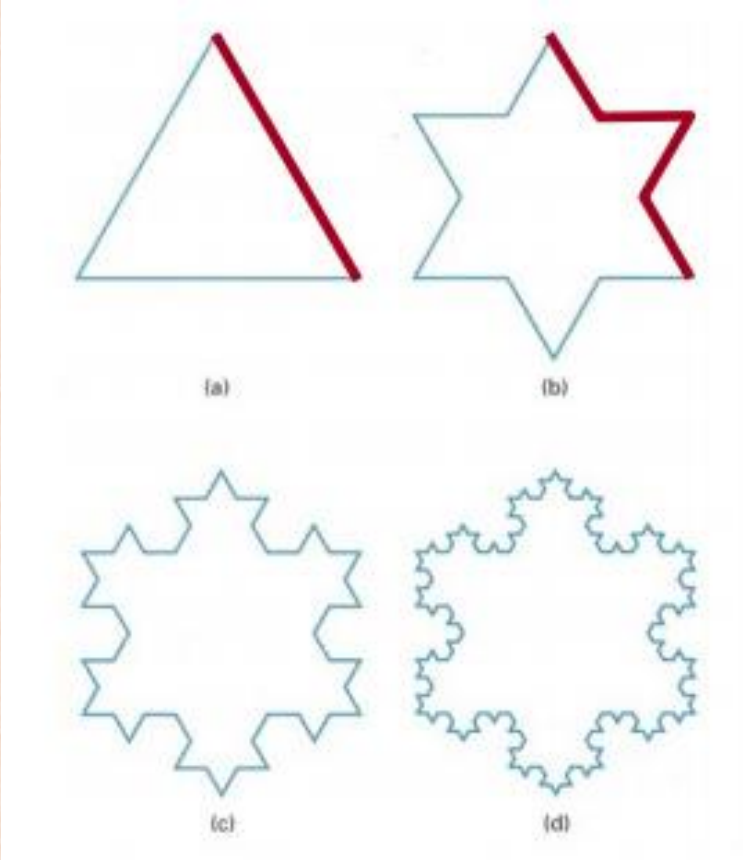
- Add more variety with a stochastic L-system
  - Multiple (randomly-chosen) rules for each symbol

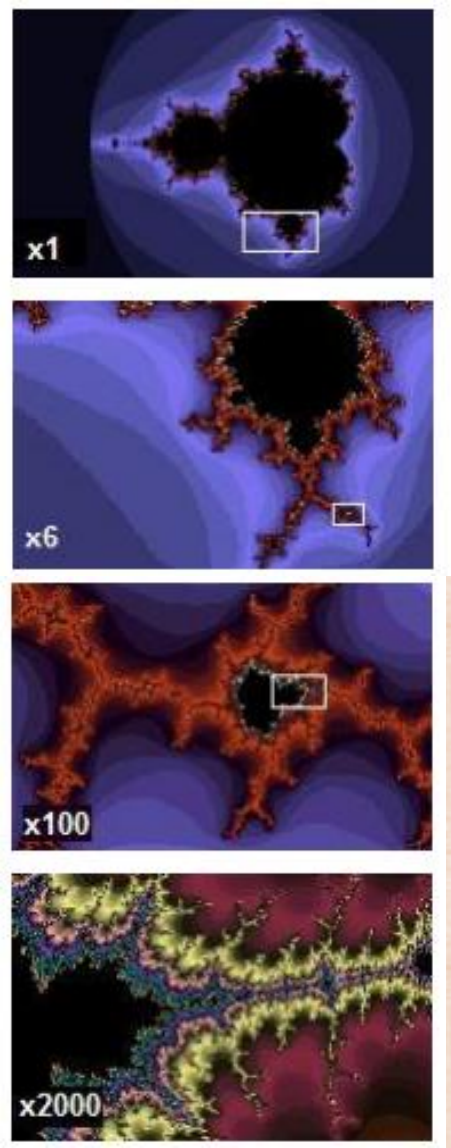
- Practice and experimentation is required in order to obtain good results

Fractals

- Initiator: start with a shape
- Generator: replace subparts with a (scaled) generator
- Repeat



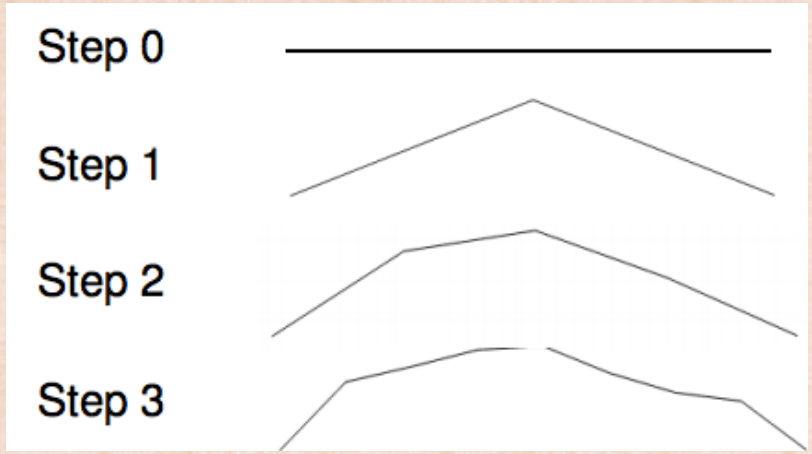




Fractals

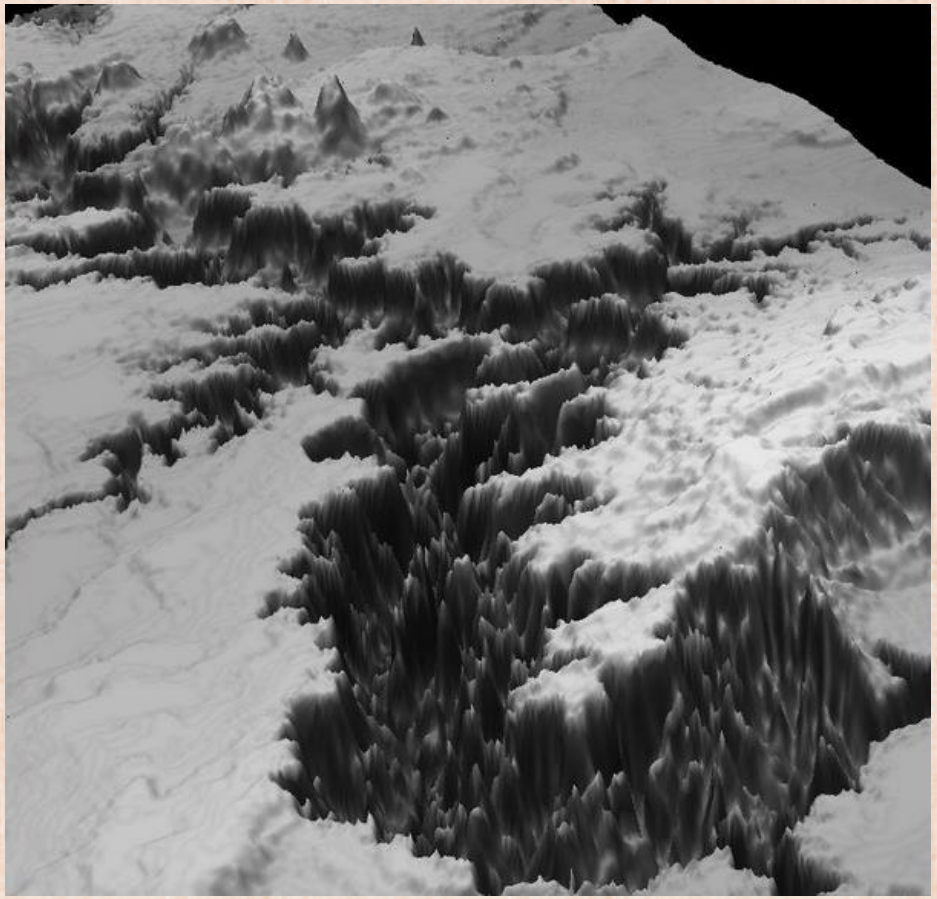
- Add randomness to the new vertex locations

- E.g., can create an irregular 2D silhouette (for far away mountains)



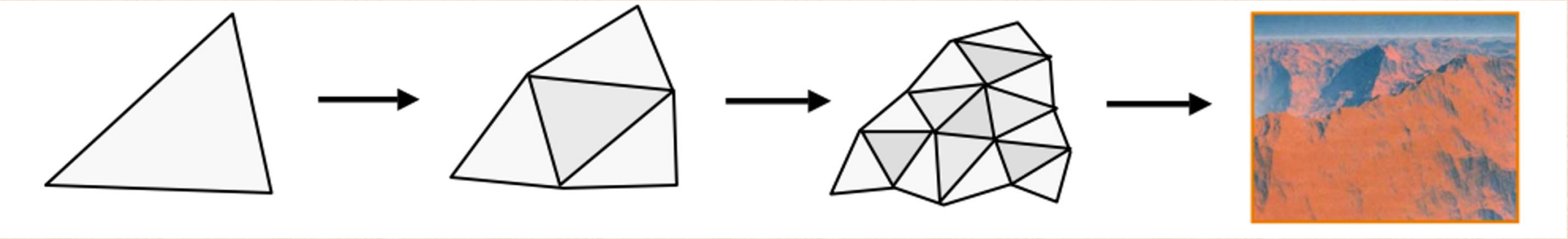
Height Fields

- Start with a 2D fractal (or any 2D grey-scale image)
- Place the image on top of a ground plane (subdivided into triangles)
- For each triangle vertex, displace its height based on the local pixel intensity



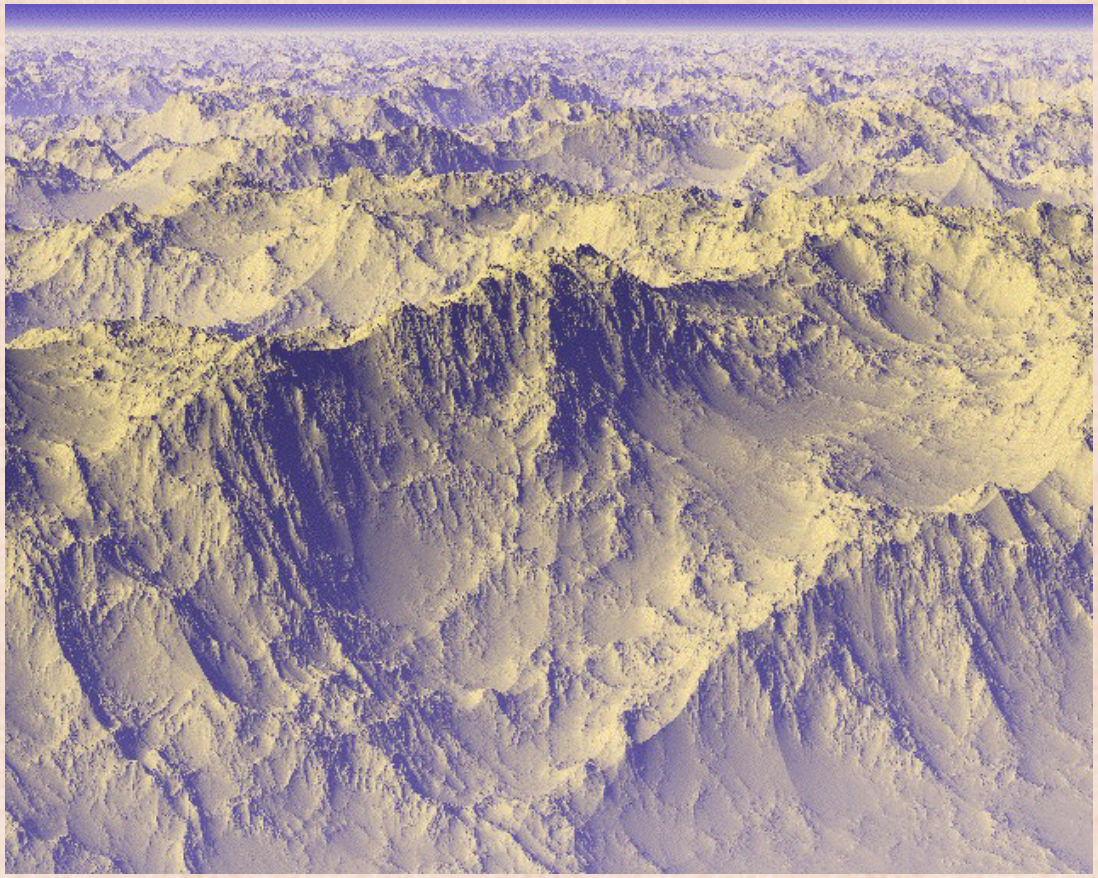
3D Landscapes

- Initiator: start with a shape
- Generator: replace random subparts with a self-similar (somewhat random) pattern

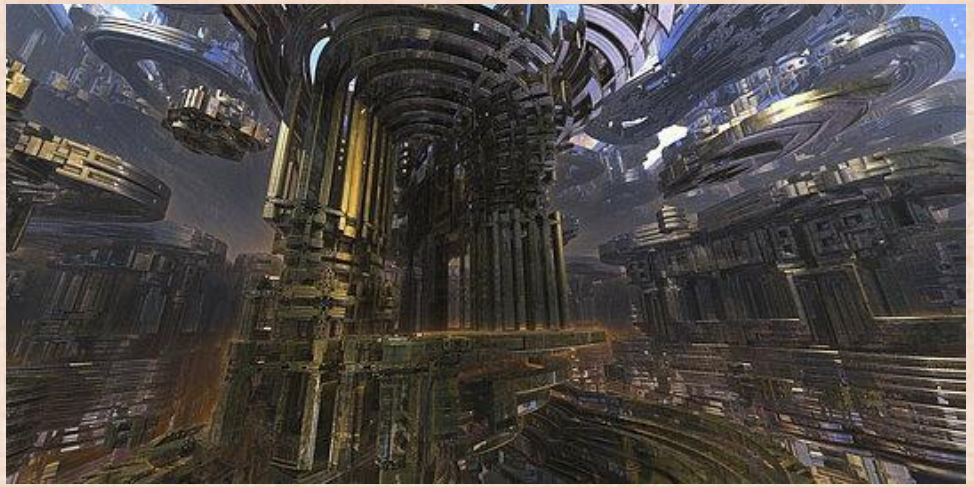


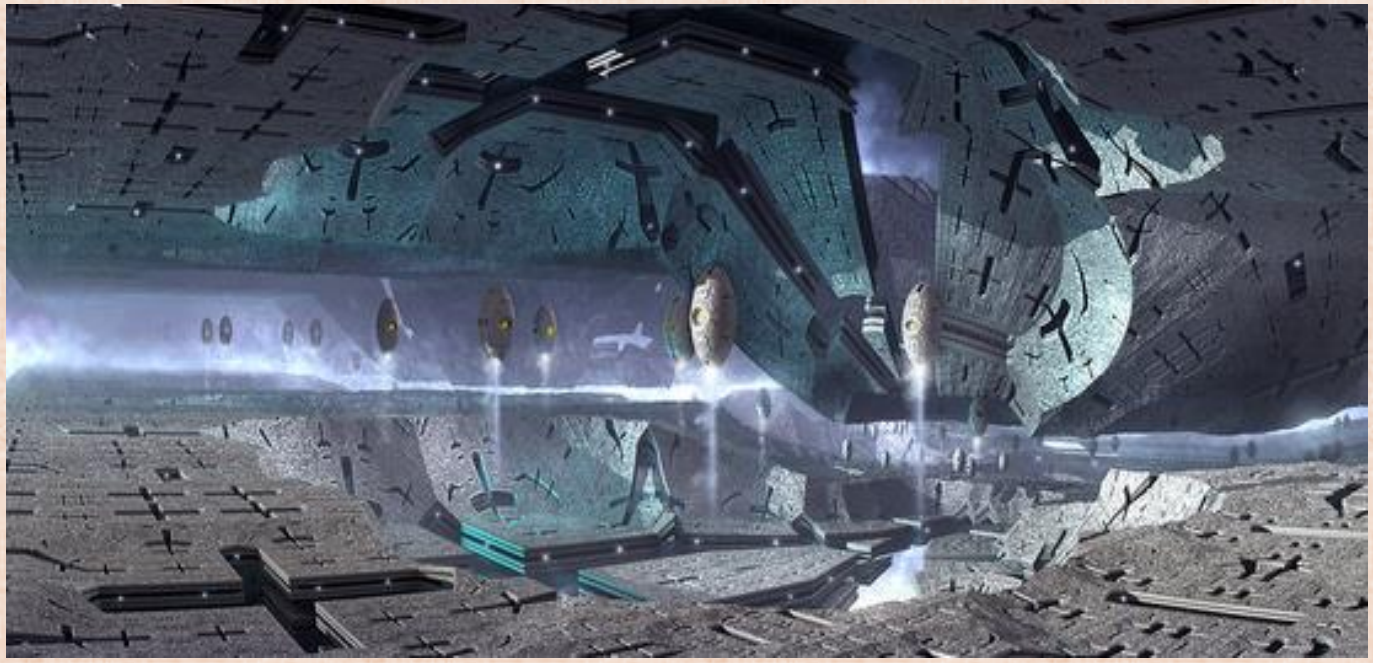
- Similar to subdivision, but with much more interesting rules for setting vertex positions

3D Landscapes



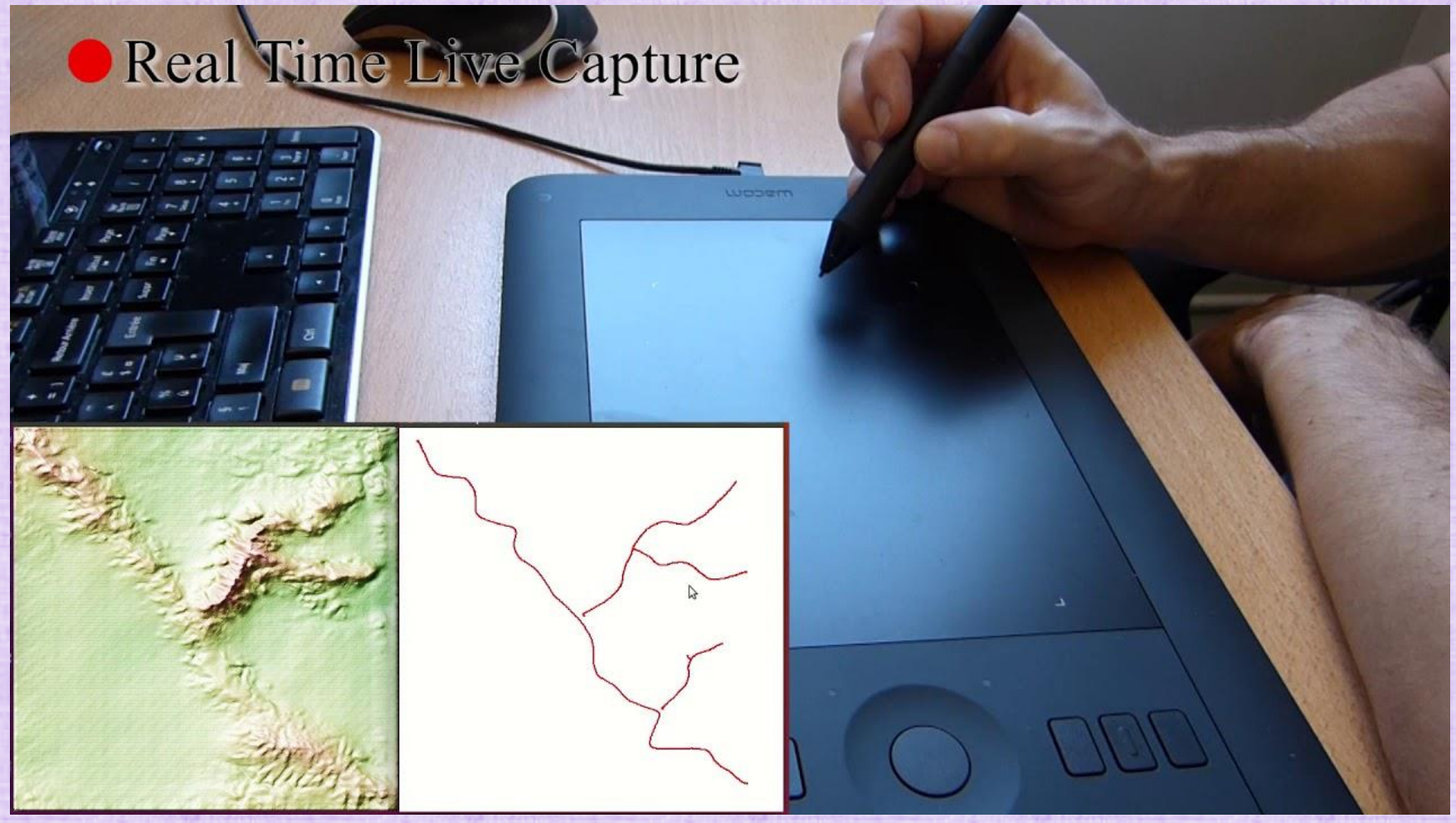
Fractal Worlds





Machine Learning

- Interactive Example-Based Terrain Authoring with Generative Adversarial Networks
  - Siggraph 2017



Generative AI

Rapidly Generate 3D Assets for Virtual Worlds with Generative AI

Jan 03, 2023 +21 Like Discuss (0)

By Gavriel State

Generative AI

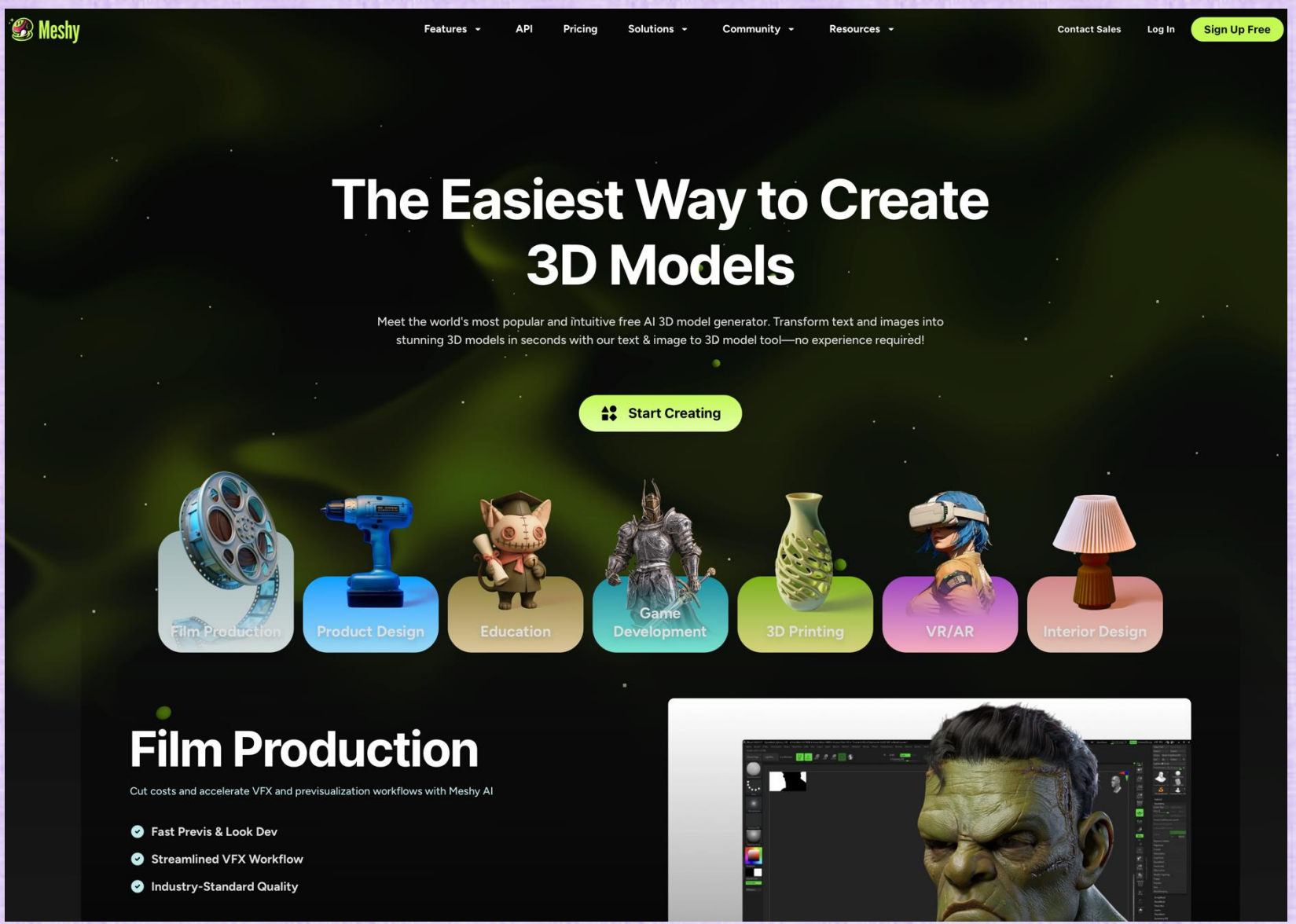
InstantMesh: Efficient 3D Mesh Generation from a Single Image with Sparse-view Large Reconstruction Models

Jiale Xu[1,2] Weihao Cheng[1] Yiming Gao[1] Xintao Wang[1*†] Shenghua Gao[2*] Ying Shan[1]
[1]ARC Lab, Tencent PCG [2]ShanghaiTech University
https://github.com/TencentARC/InstantMesh

Figure 1. Given a single image as input, our InstantMesh framework can generate high-quality 3D meshes within 10 seconds.

https://huggingface.co/spaces/TencentARC/InstantMesh
(dead link)

Meshy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Meet the world's most popular and intuitive free AI 3D model generator. Transform text and images into stunning 3D models in seconds with our text & image to 3D model tool—no experience required!
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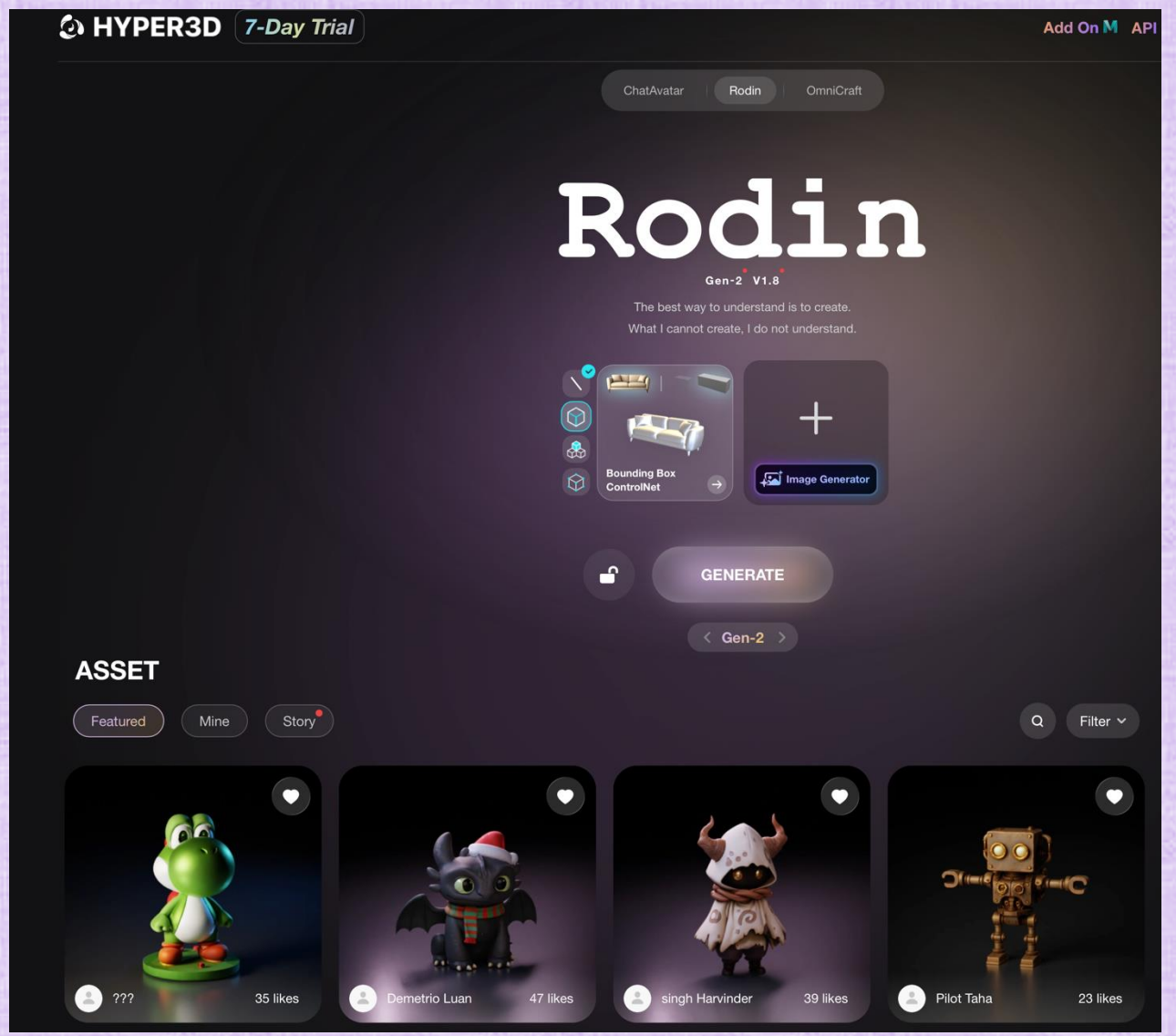
Streamlined VFX Workflow
Industry-Standard Quality

Hyper3D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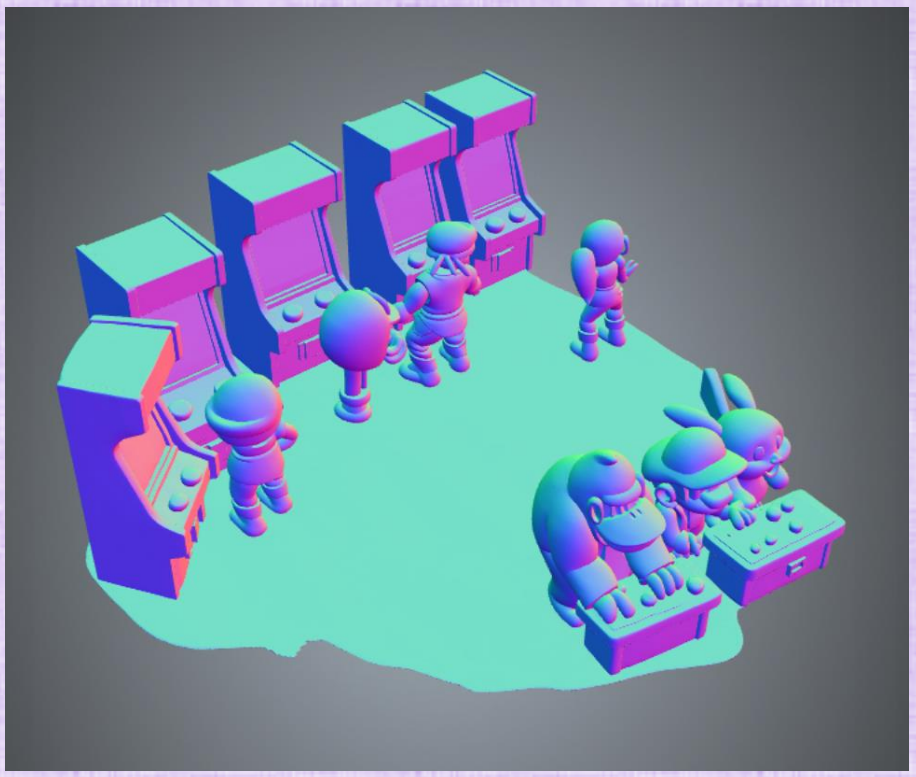
Rodin
OmniCraft
Rodin
Gen-2 V1.8
The best way to understand is to create.
What I cannot create, I do not understand.
Bounding Box ControlNet
Image Generator
GENERATE
Gen-2
ASSET
Featured
Mine
Story
Filter
???
35 likes
Demetrio Luan
47 likes
singh Harvinder
39 likes
Pilot Taha
23 likes

Text to Image to Geometry

ChatGPT



Hyper3D

Text to MetaHuman

Figure 14: The reference image was generated via a ChatGPT prompt, and it was subsequently used to create a video via LTX Studio. The top row shows selected images from the video, and the bottom row shows the result of our pipeline.