Introducción a la Fotografia 3D

UBA/FCEN Marzo 27 – Abril 12 2013

Clase 5 : Lunes Abril 8

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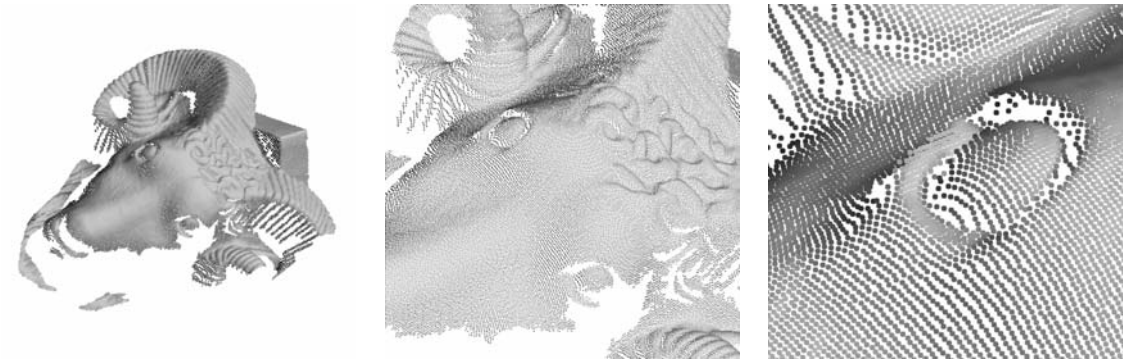
Brown University

BROWN

Course Schedule

- Introduction
- The Mathematics of 3D Triangulation
- 3D Scanning with Swept-Planes
- Camera and Swept-Plane Light Source Calibration
- ***Reconstruction and Visualization using Point Clouds***
- Combining Point Clouds Recovered from Multiple Views

Visualizing Point Clouds:
Point-based Rendering via Splatting



- Swept-plane scanner produces a *colored point cloud*: a set of 3D points
- Problem: how to render a point cloud to make it look like as a continuous surface?
- Splatting: render points as overlapping colored disks
- If normal vectors are measured as well, render points as shaded ellipses

***See the SIGGRAPH 2009 course: Point Based Graphics – State of the Art and Recent Advances by Markus Gross.**

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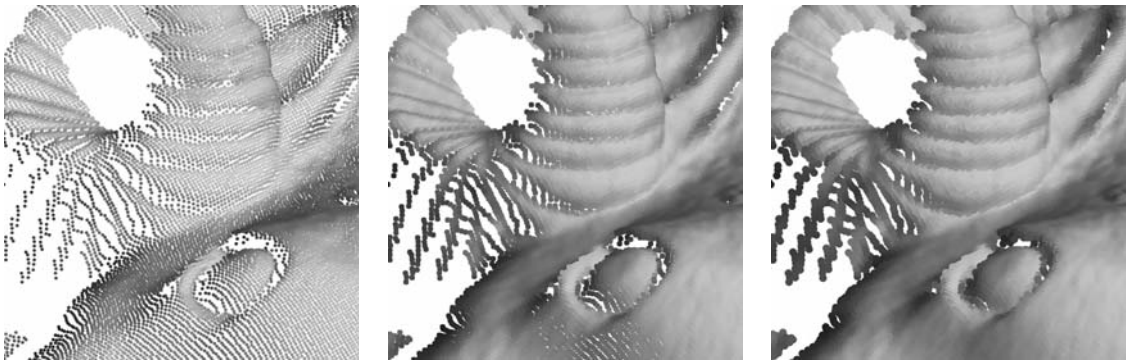
Point-based Rendering via Splatting



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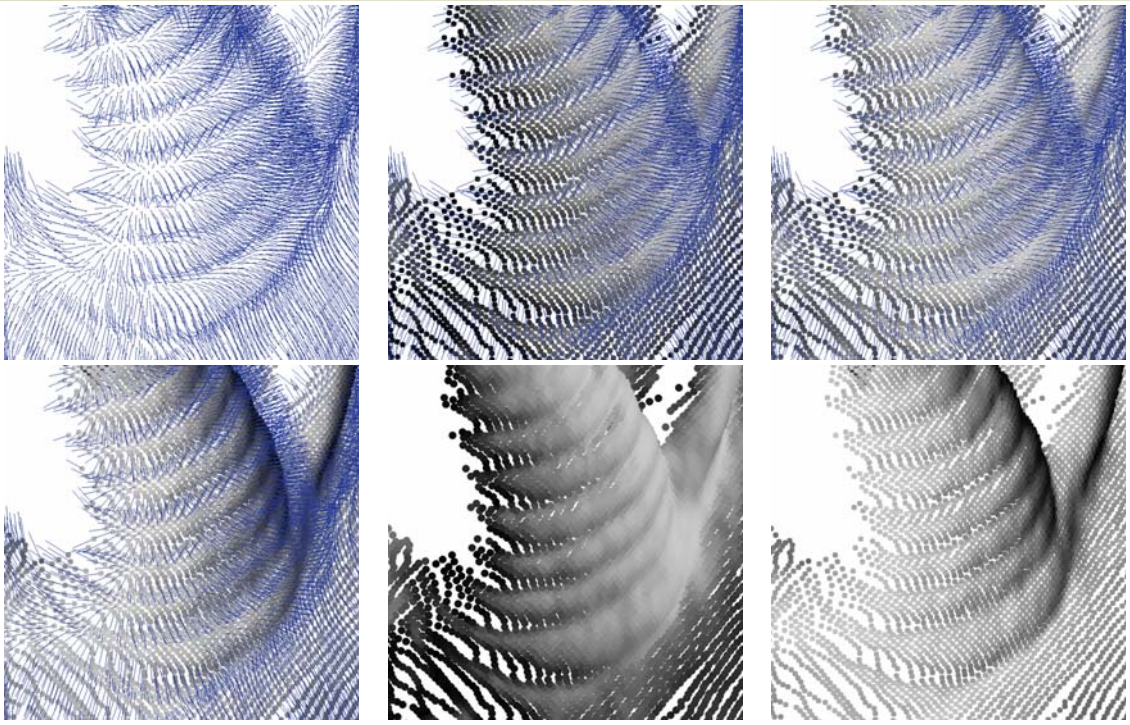
Visualizing Point Clouds:
Splatting with normal vectors and colors



Visualizing Point Clouds:
File Formats

- No standard file format to store point clouds
- Point = (x,y,z) plus (R,G,B) and/or (Nx,Ny,Nz)
- It is easy to create an ad-hoc file format
- Scene graph based file format: VRML
- International standard: ISO/IEC 14772-1:97 VRML'97
- PointSet node includes coordinates (x,y,z) and optional colors (R,G,B), but no normals

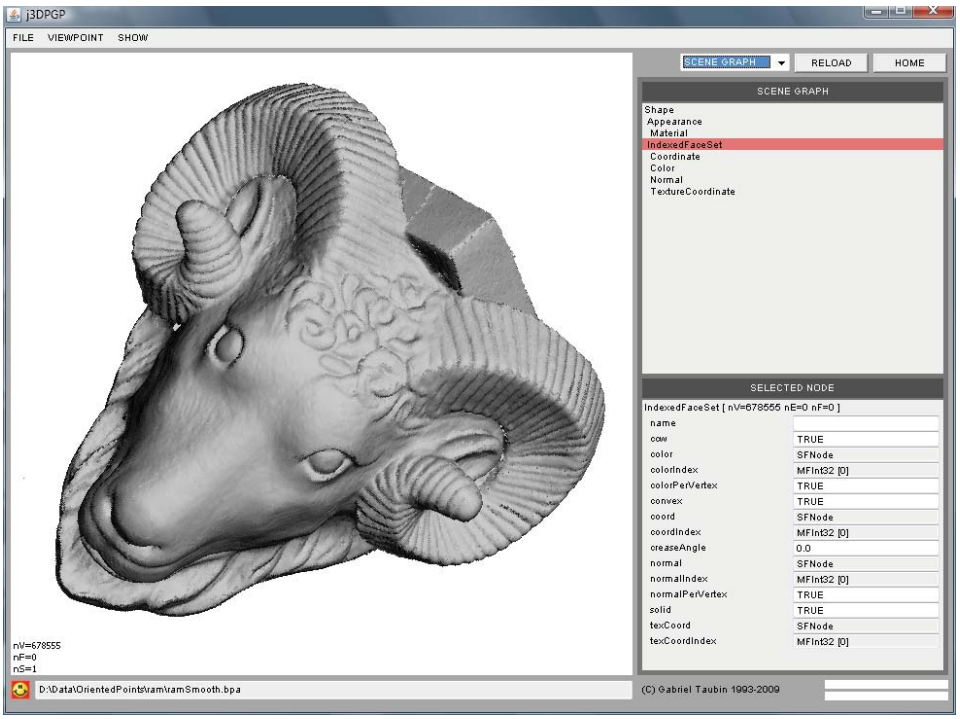
```
PointSet {
 coord Coordinate {
  point [
    0 -1  2,     1  0  0,
-2  3 -1
  ]
 }
 color Color {
  color [
   1 0 0,   0 1 0,    1 1 0
  ]
 }
}
```

Visualizing Point Clouds:
File Formats

- IndexedFaceSet node designed to store a polygon mesh can be used to store point clouds with optional colors and/or normal vectors
- Store point coordinates as vertices
- Store point colors as colors per vertex
- Store point normal vectors as normals per vertex
- Degenerate polygon mesh with no faces is valid VRML syntax

```
IndexedFaceSet {
 coord Coordinate {
  point [
    0 -1  2,
    1  0  0,
   -2  3 -1
  ]
 }
 colorPerVertex TRUE
 color Color {
  color [
   1 0 0,
   0 1 0,
   1 1 0
  ]
 }
 normalPerVertex TRUE
 normal Normal {
  vector [
   1 0 0,
   0 1 0,
   0 0 1
  ]
 }
}
```

Visualizing Point Clouds:
BYO3D Java Viewer



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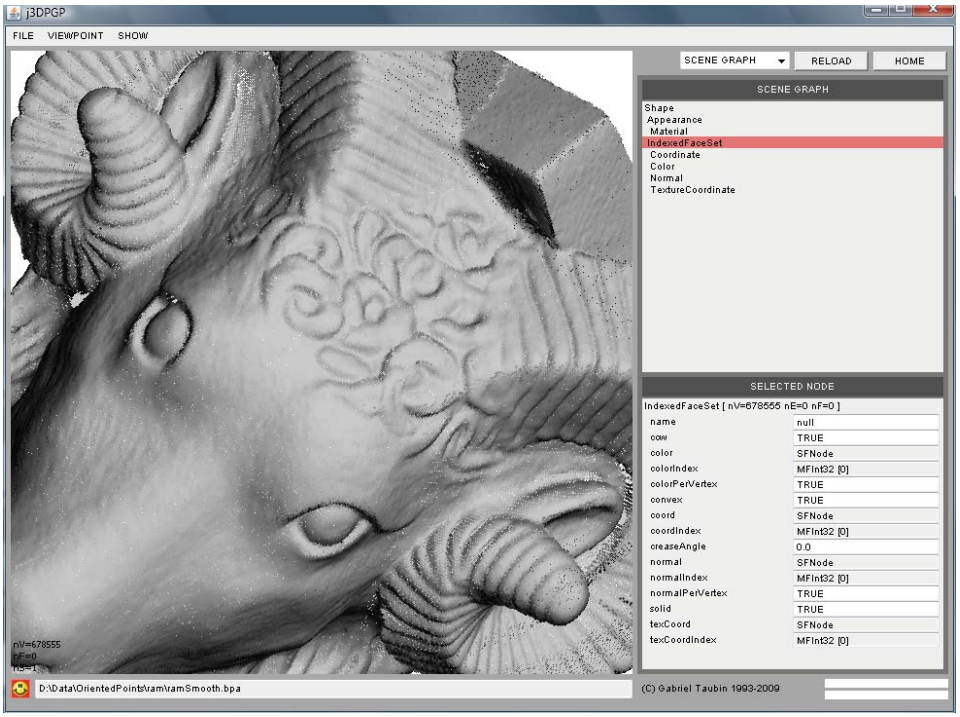

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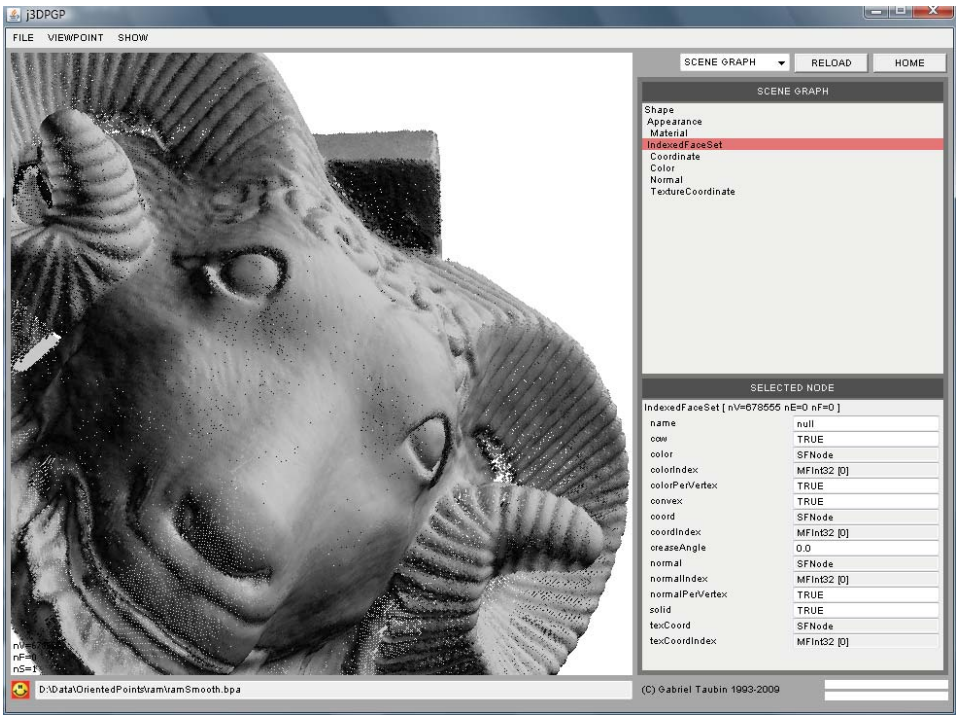

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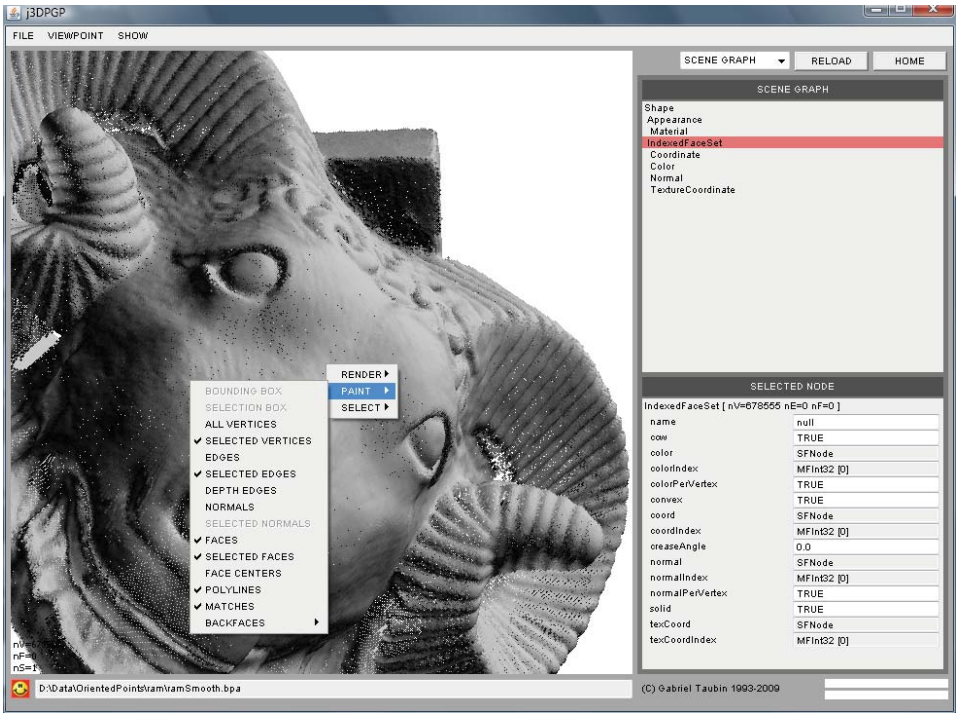

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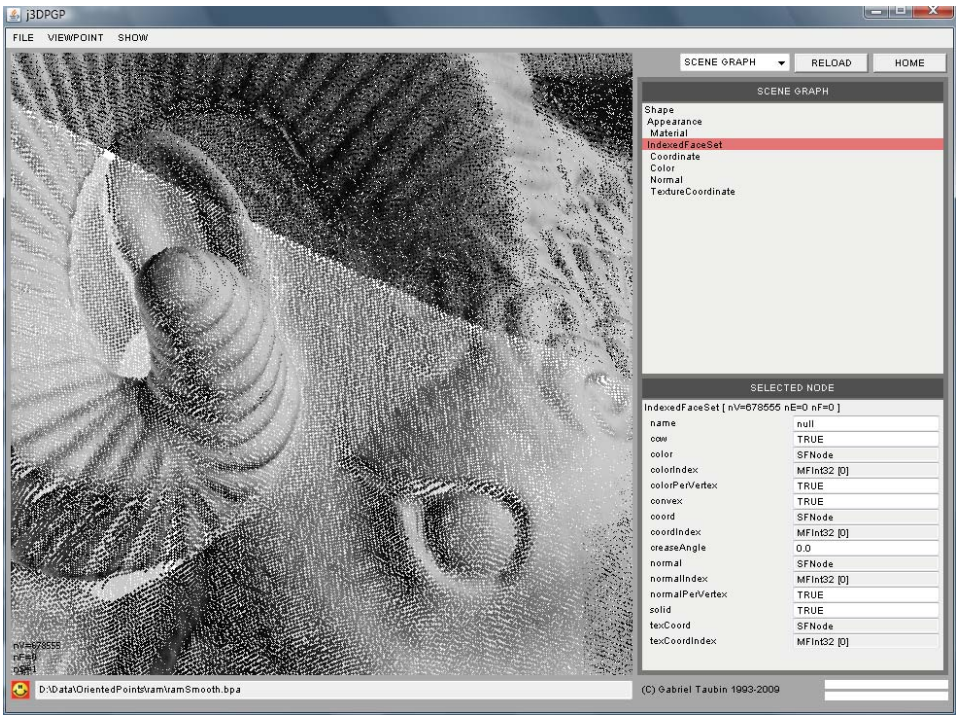

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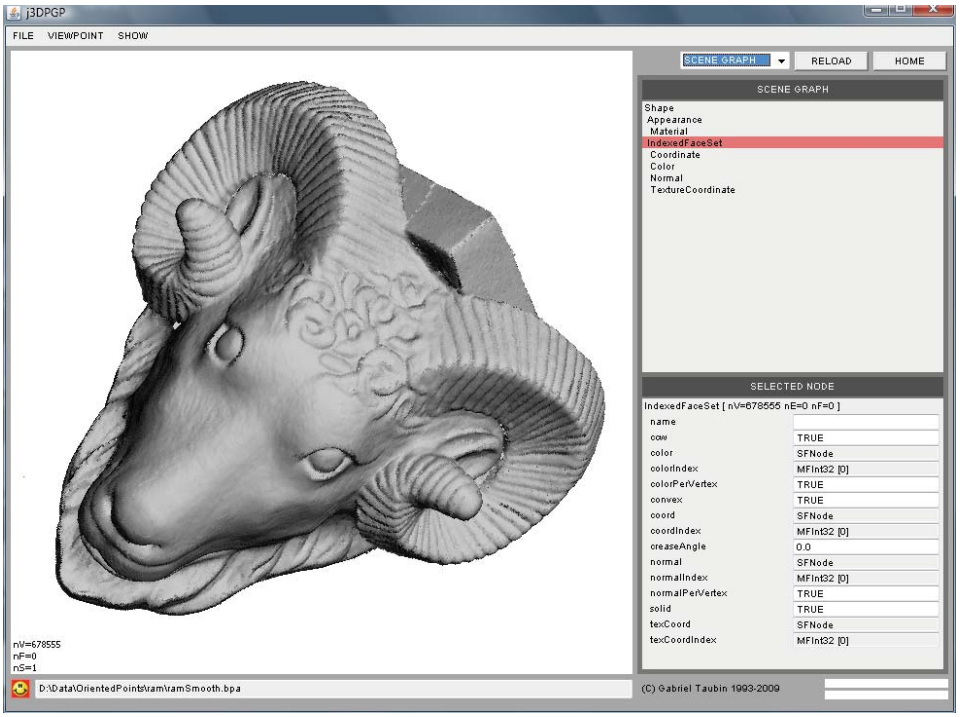
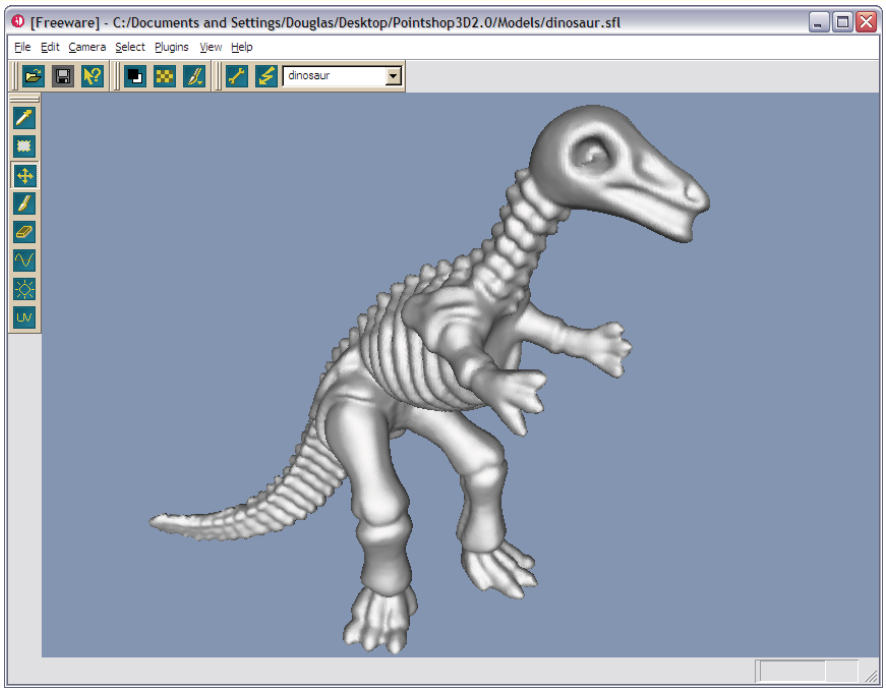
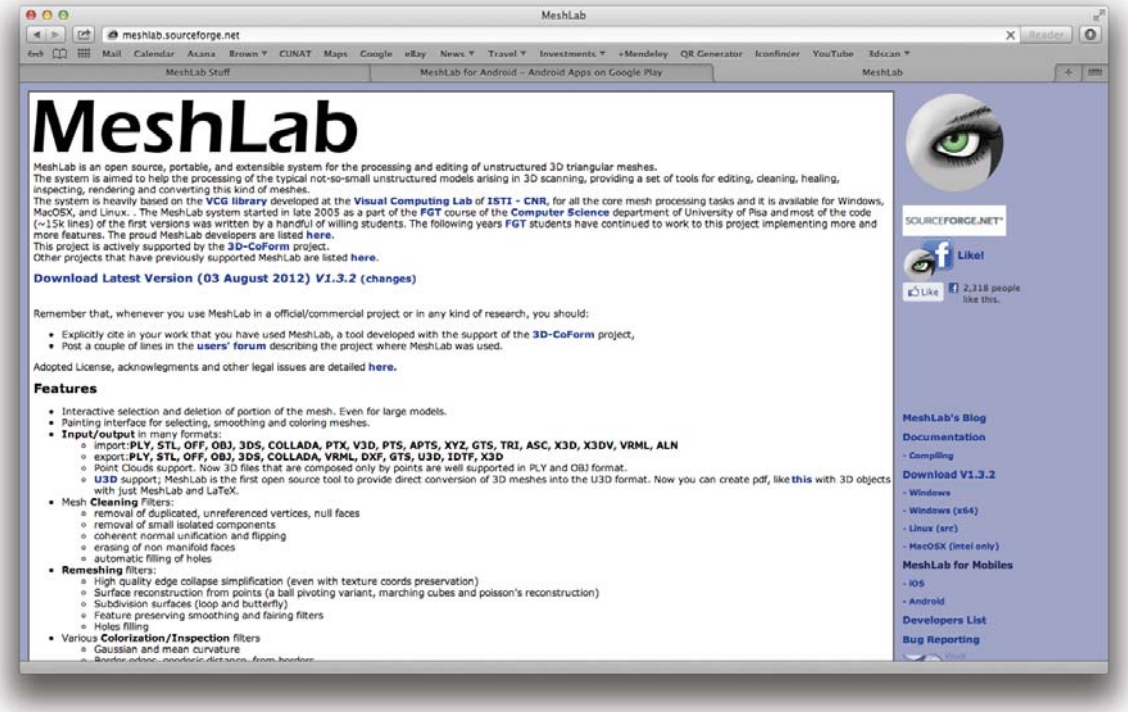


Visualizing Point Clouds:
Pointshop 3D [Zwicker et al. 2002]



M. Zwicker, M. Pauly, O. Knoll, M. Gross. Pointshop 3D: An Interactive System for Point-Based Surface Editing. ACM SIGGRAPH, 2002

Visualizing Point Clouds:
MeshLab



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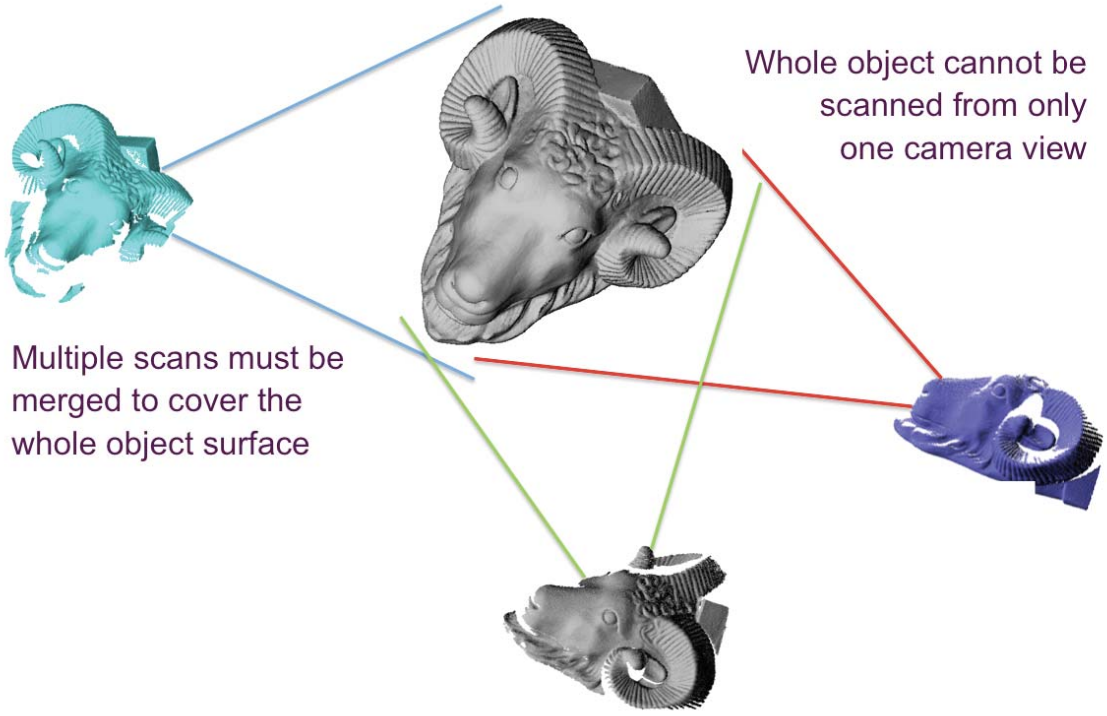
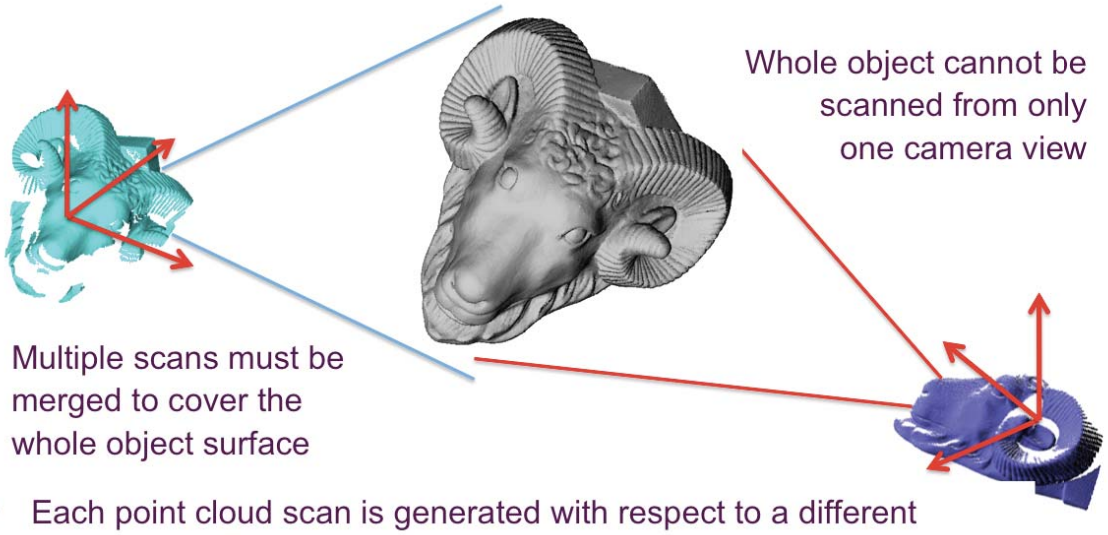
Merging Multiple Point Cloud Scans



Merging Multiple Point Cloud Scans



- Each point cloud scan is generated with respect to a different camera coordinate system

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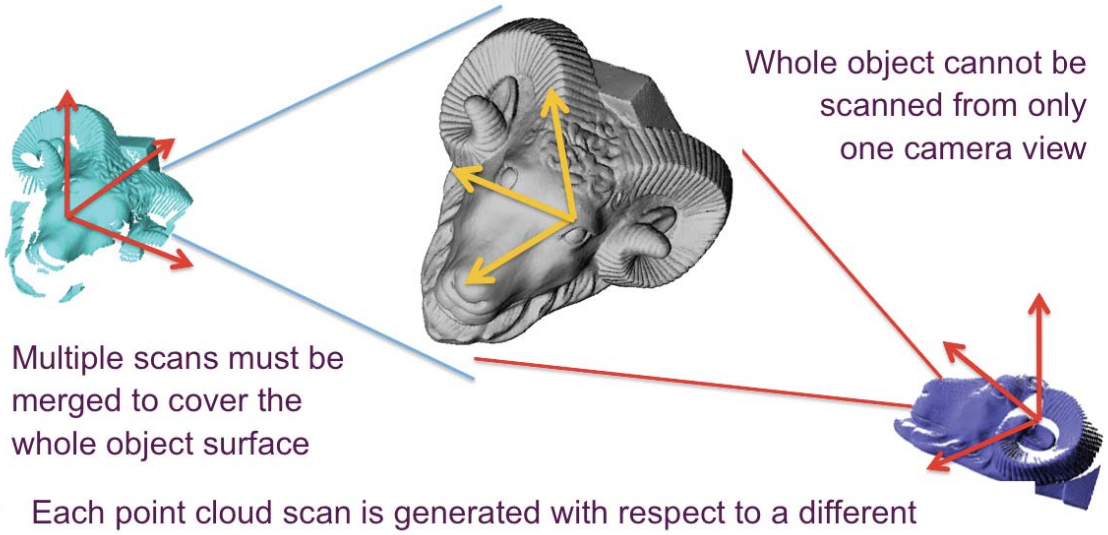
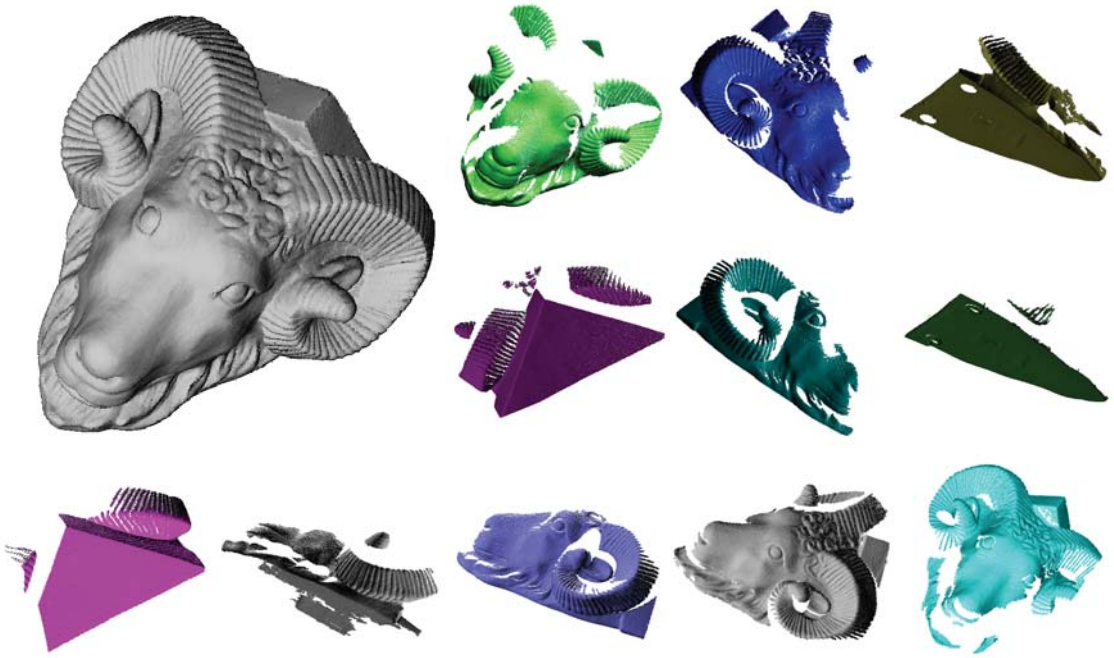
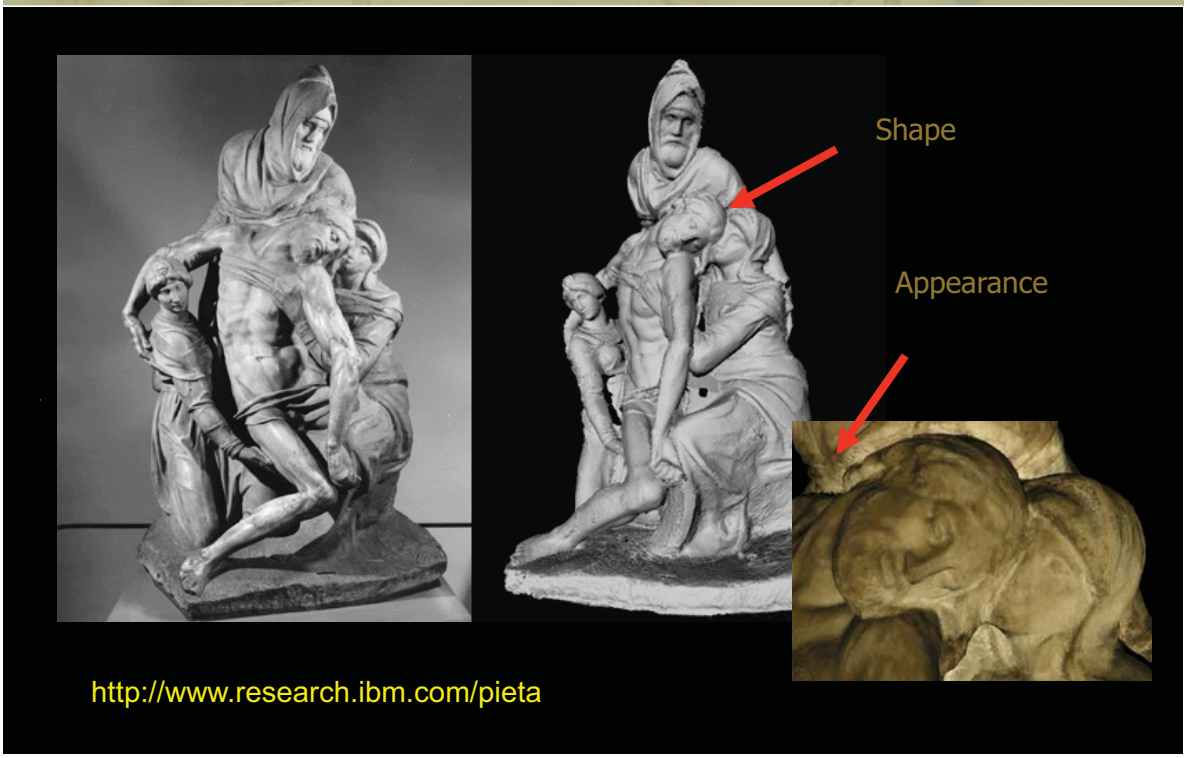


- Each point cloud scan is generated with respect to a different camera coordinate system
- Relative position and orientation of each scan with respect to a global coordinate system must be determined to produce a single merged point cloud

Merging Point Cloud Scans

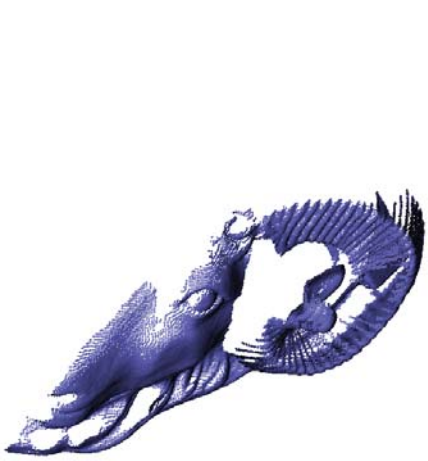


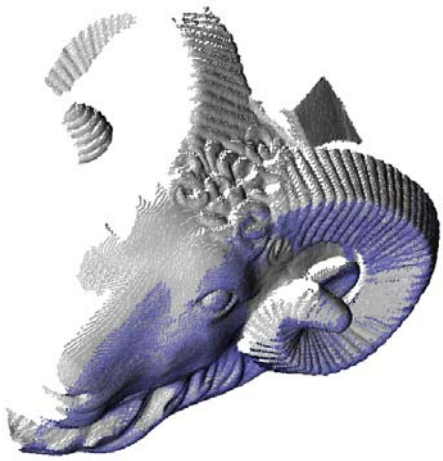
Complex Models May Require 100s of Scans



Merging Point Cloud Scans

- Incremental registration and merging
- Followed by global relaxation to remove accumulated errors





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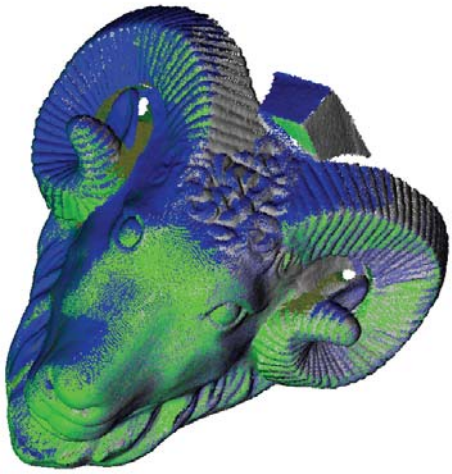

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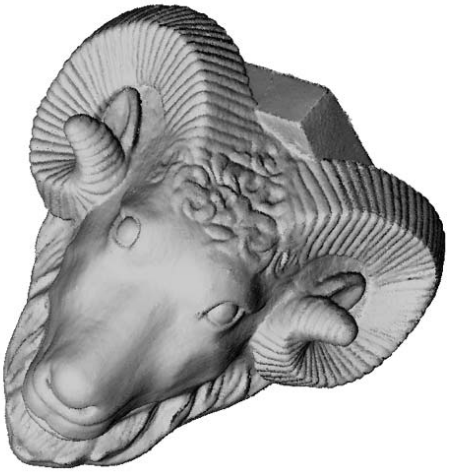
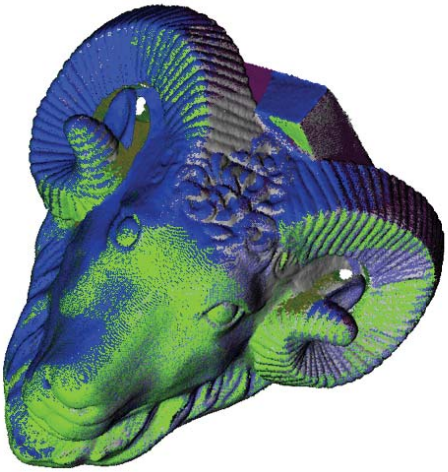
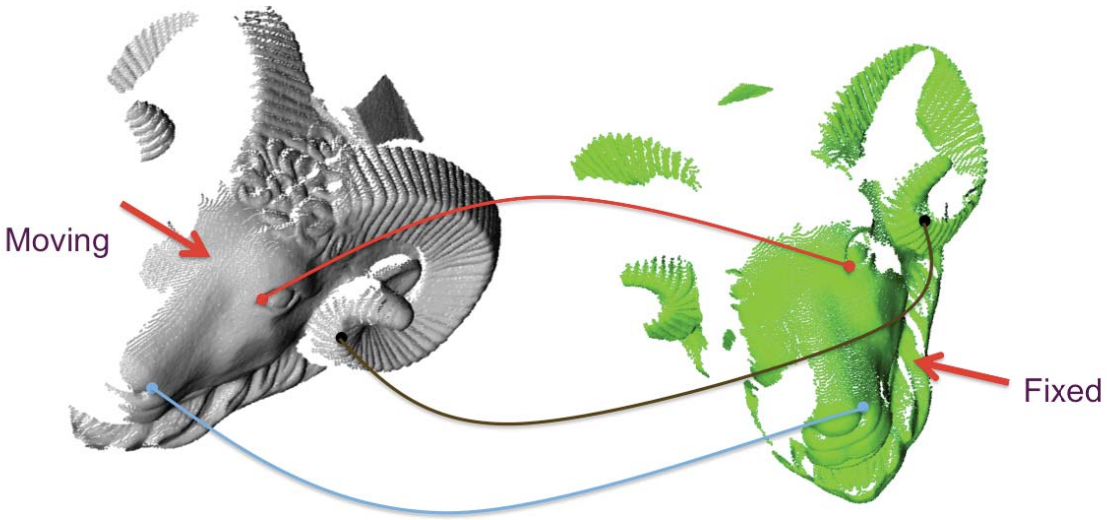




Merging Two Point Cloud Scans

- Select at least 3 pairs of corresponding points, but ideally N>>3



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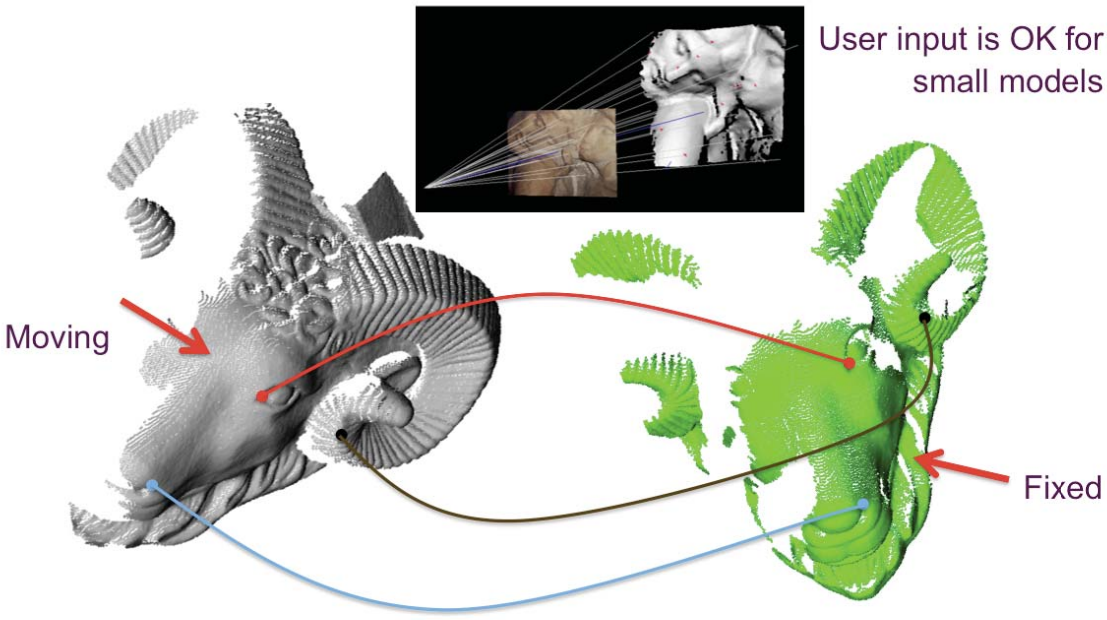
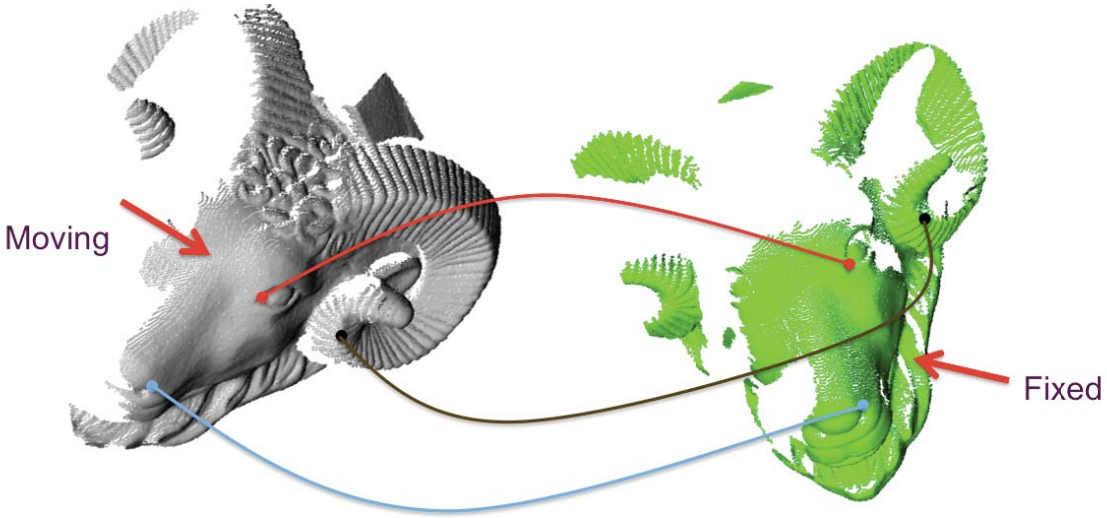


Merging Two Point Cloud Scans

- Select at least 3 pairs of corresponding points, but ideally N>>3
- Solve in close form for the matching rigid body transformation
- Refine solution using the Iterative Closest Point Algorithm (ICP)



P. Besl, N.D. McKey, A method for Registration of 3D Shapes.
IEEE Transactions on PAMI, 1992

Computing the Matching Transformation

- Given N pairs of corresponding 3D points $(p_1,q_1),...,(p_n,q_n)$ we are looking for a rotation matrix R and a translation vector T so that

$$Rp_j + T = q_j \quad j = 1,...,n$$

- In general, solution does not exists: solve in the Least-Squares sense
- Now we are looking for the minimizer of the quadratic energy function

$$E(R,T) = \frac{1}{n}\sum_{j=1}^{n} \left\| Rp_j + T - q_j \right\|^2$$

- This problem has a closed form solution

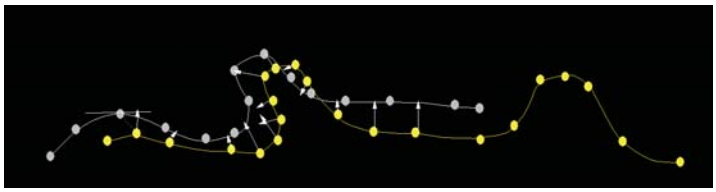
$$R = V^t U, \quad T = \bar{q} - R\bar{p}$$

- Where

$$\bar{p} = \frac{1}{n}\sum_{j=1}^{n} p_j \quad \bar{q} = \frac{1}{n}\sum_{j=1}^{n} q_j \quad M = \frac{1}{n}\sum_{j=1}^{n} (p_j - \bar{p})(q_j - \bar{q})^t$$

- And $M = U\Delta V^t$ is the Singular Value Decomposition (SVD) of M

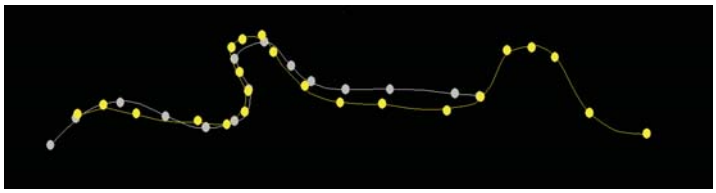
Iterative Closest Point Algorithm (ICP)



1. Automatically select N points $p_1,\ldots,p_n$
2. Find closest corresponding points $q_1,\ldots,q_n$
3. Solve in close form for the matching rigid body transformation which minimizes the energy function

$$E(R,T) = \frac{1}{n}\sum_{j=1}^{n}\left\| Rp_j + T - q_j \right\|^2$$

4. Repeat 1-3 while until convergence



Finding Closest Points

- Problem: find the point of the set $D = \{p_1,\ldots,p_n\}$ closest to the point q
- Naïve algorithm: sequential search O(N)
- Too expensive if the same computation must be performed for many points $q_1,\ldots,q_n$
- Efficient algorithm requires space partition data structure Quadtree/Octree, BSP tree