PCL - SURFACE RECONSTRUCTION

TOYOTA CODE SPRINT

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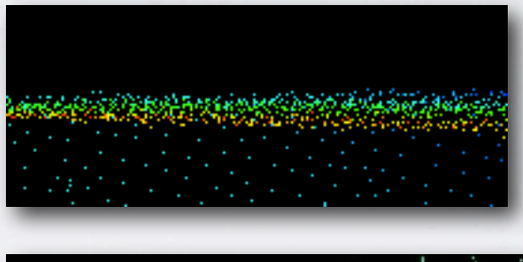
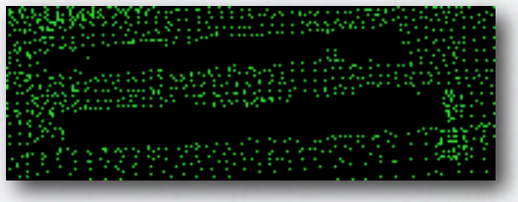
PROBLEM DESCRIPTION 1/2

- *3D revolution* due to cheap RGB-D cameras (Asus Xtion & Microsoft Kinect)

- Affordability comes with poor quality:
  - high level of noise in both the depth and the color images
  - quantization artifacts
  - missing pixels
  - various color image distortions, specific to webcam sensors and optics





PROBLEM DESCRIPTION 2/2

Incapability of the Kinect to record transparent or shiny objects

MOTIVATION

- 3D points are sampling surfaces - no dimension, orientation, etc. (see surflets)
- point neighborhoods and features capture some aspects of these surfaces
- in some cases we are interested in the actual surface
- Knowing the real surface enables:
  - more accurate feature extraction
  - smoothing and resampling (hole filling)
  - collision and occlusion checks
  - texture mapping
  - fitting and recognition

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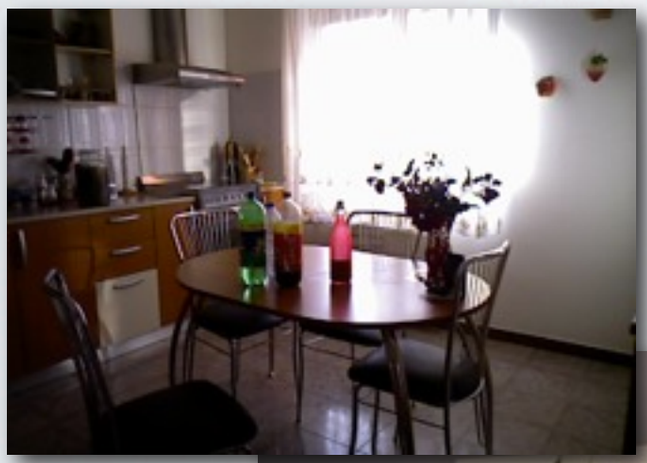
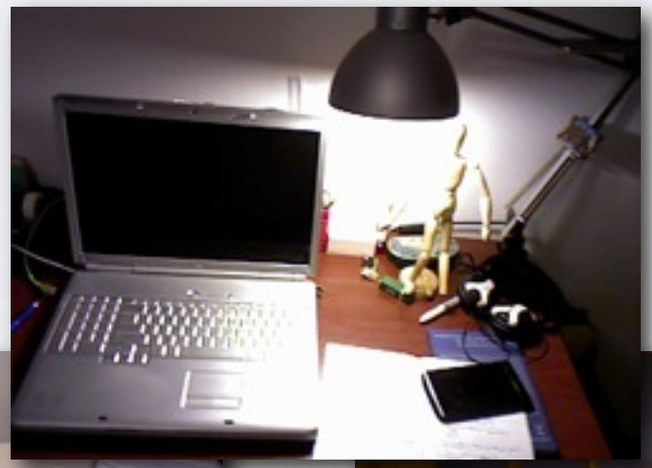
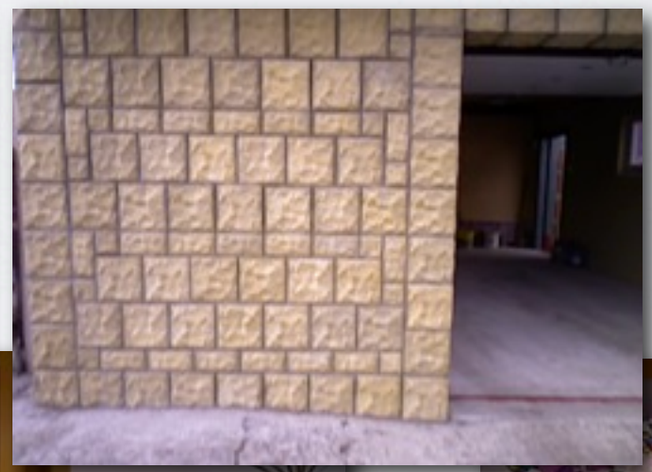
DATASET COLLECTION

- 30 realistic situations that a personal robot might face in an undirected human environment
- captured so that to simulate a robot movement and to record all the known sensor artifacts
- all available at `http://svn.pointclouds.org/data/Toyota`


pcl::surface REVAMP

- `CloudSurfaceProcessing`
  - PointCloud to PointCloud for better surface approximation
  - e.g., `MovingLeastSquares, BilateralUpsampling`
- `MeshConstruction`
  - PointCloud to PolygonMesh, convert cloud to mesh without modifying vertex positions
  - e.g., `ConcaveHull, ConvexHull, OrganizedFastMesh, GreedyProjectionTriangulation`
- `SurfaceReconstruction`
  - PointCloud to PolygonMesh, generate mesh with a possibly modified underlying vertex set
  - e.g., `GridProjection, MarchingCubes, SurfelSmoothing, Poisson`
- `MeshProcessing`
  - PolygonMesh to PolygonMesh, improve input meshes by modifying connectivity and/or vertices
  - e.g., `EarClipping, MeshSmoothingLaplacianVTK, MeshSmoothingWindowedSincVTK, MeshSubdivisionVTK`

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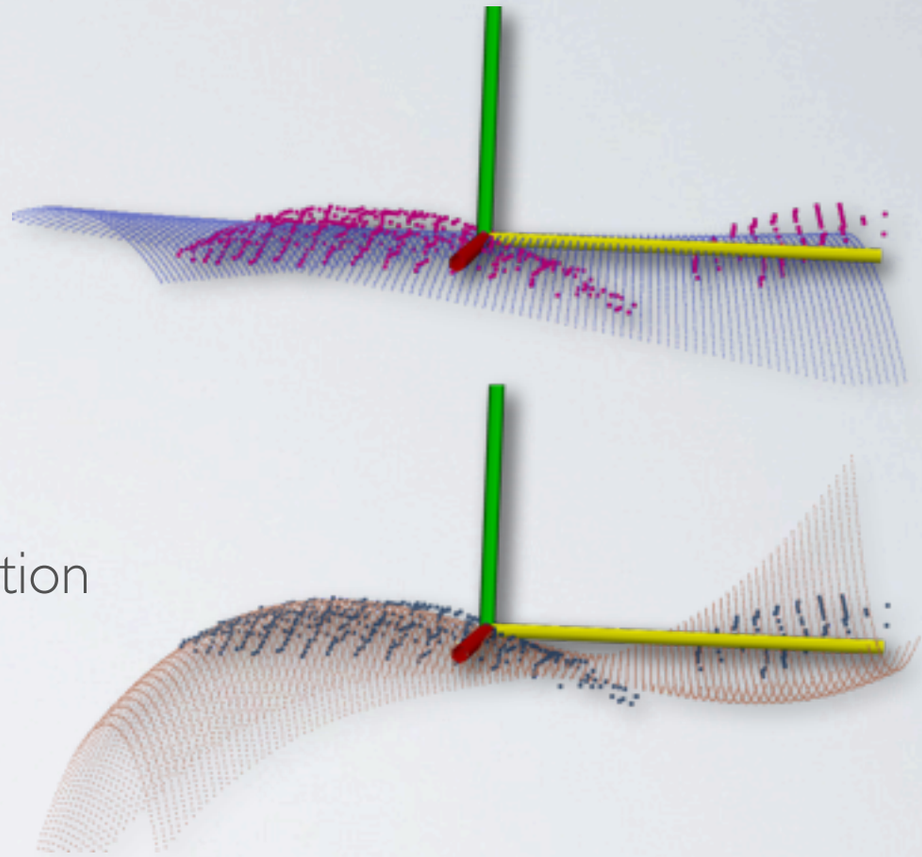
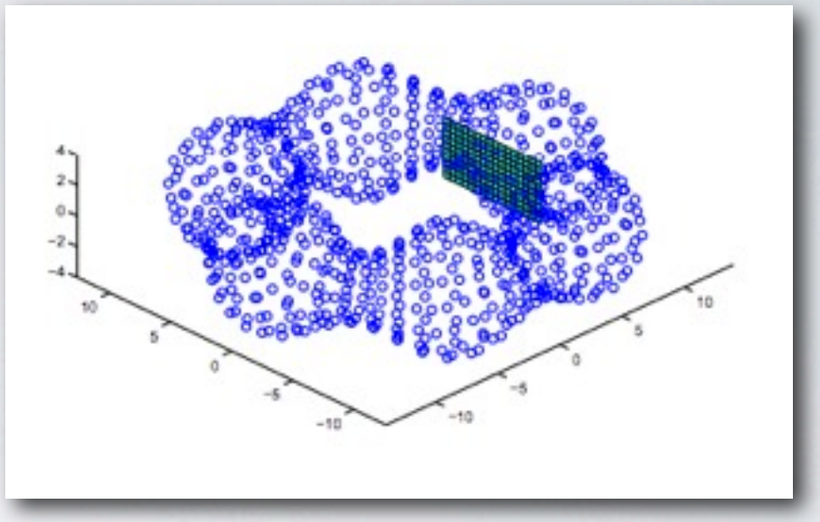
MOVING LEAST SQUARES 1/2



- Approximation of the underlying surface with an analytical function
- Based on a (weighted) neighborhood
- Height-map along a tangent normal onto which the query point is projected
- Complexity of the used function (and of the tangent estimation) define accuracy/runtime
- Having a function enables accurate computation of normals, surface curves, and up/down-sampling

MOVING LEAST SQUARES 2/2

M. Levin, *Mesh-independent surface interpolation ,Geometric Modeling for Scientific Visualization* Springer-Verlag, 2003, 37-49



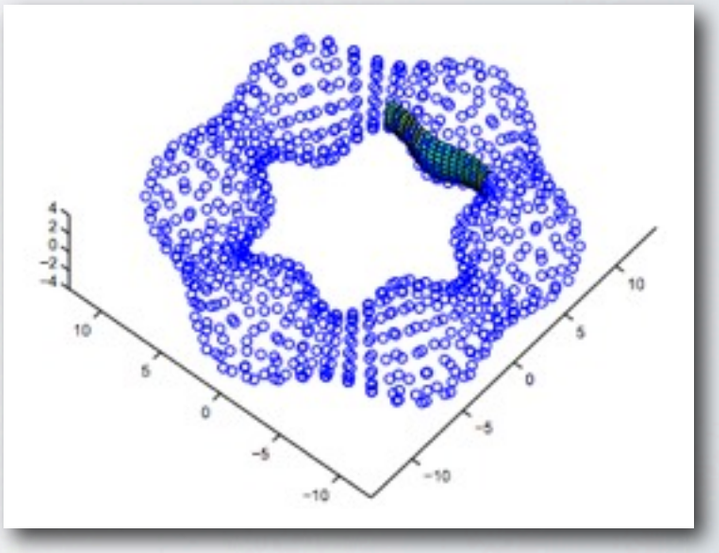
1. Fit plane to local surface (PCA)

2. Fit a polynomial function in the set of distances from the points to the surface.

$$\sum_{i=1}(p(x_i) - f_i)^2\theta(||r_i - r||)$$

$$\theta(x) = e^{-(\frac{x}{\sigma_r})^2}$$

3. Project points back to surface



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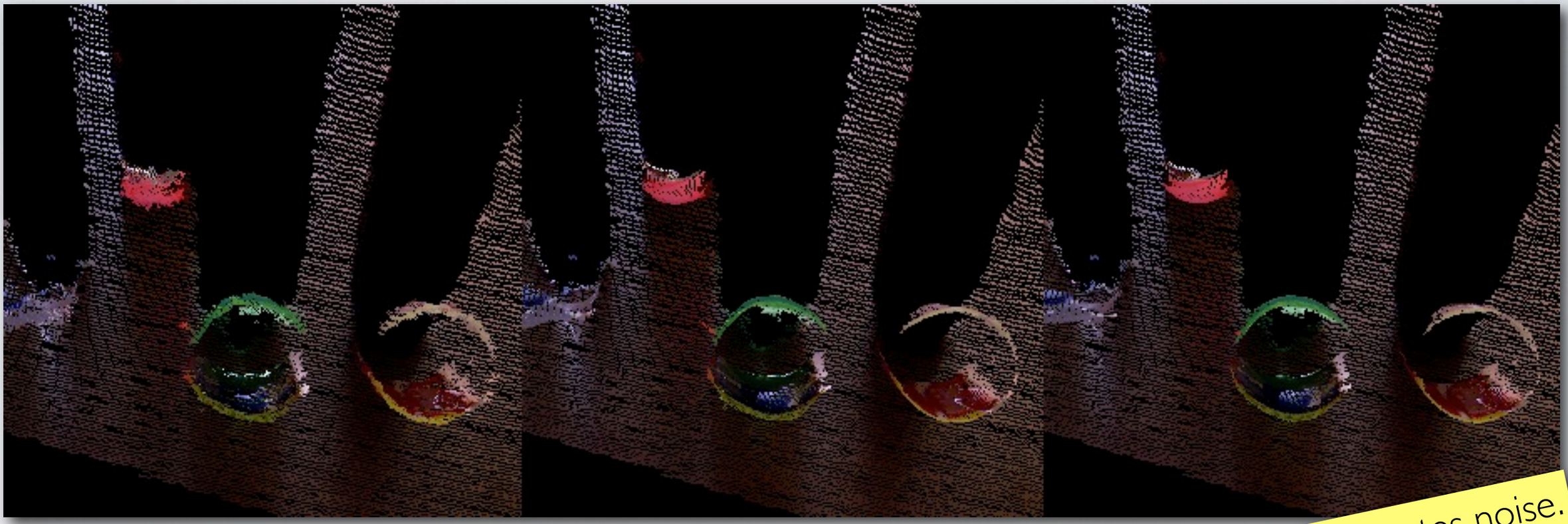
MOVING LEAST SQUARES
1.SMOOTHING 1/3



MLS applied on the Bottles dataset

from left to right:

- original scan
- MLS smoothed with search radius = 3 cm and second order polynomial fitting
- MLS smoothed with search radius = 5 cm and second order polynomial fitting

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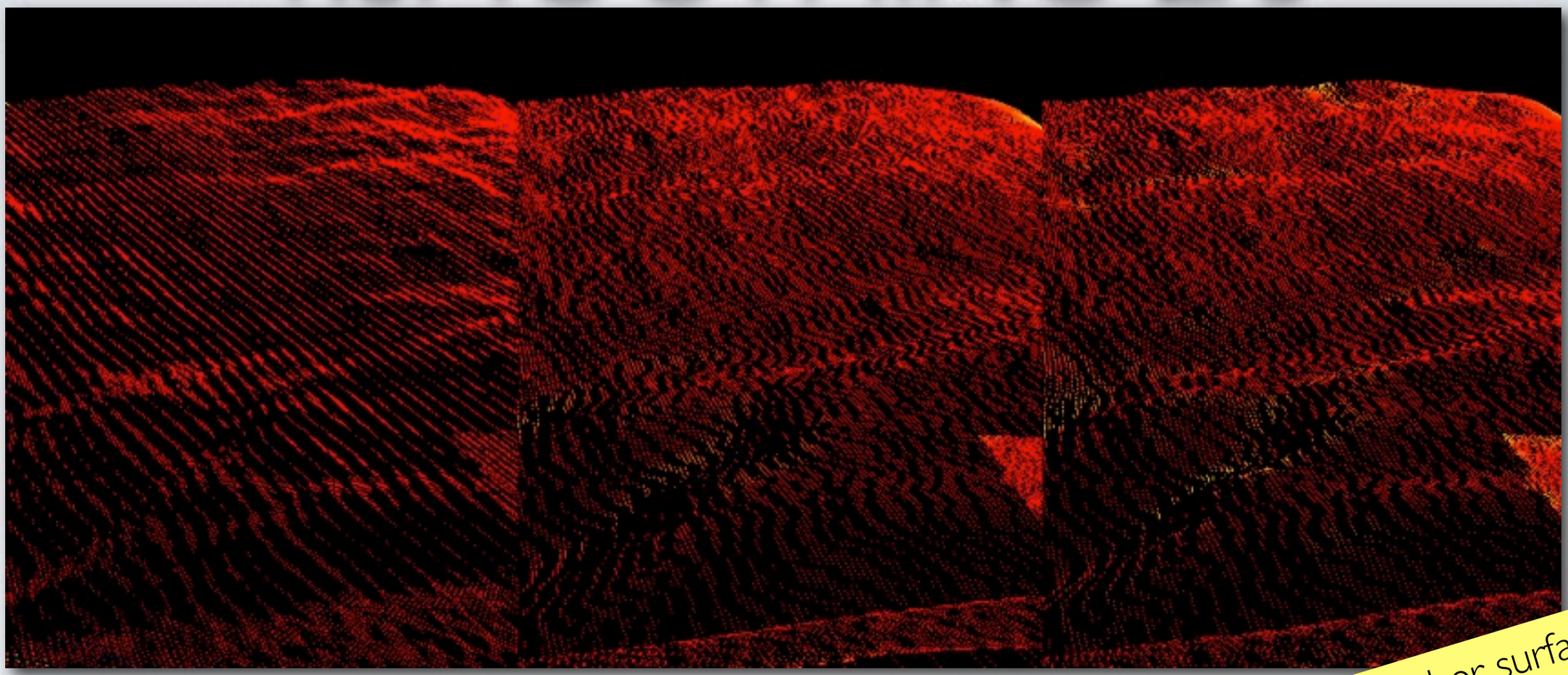
MOVING LEAST SQUARES
1.SMOOTHING 2/3



MLS applied on the Bed Sheets dataset

Smoother surfaces.

from left to right:

- original scan
- MLS smoothed with search radius = 5 cm and second order polynomial fitting
- MLS smoothed with search radius = 3 cm and second order polynomial fitting

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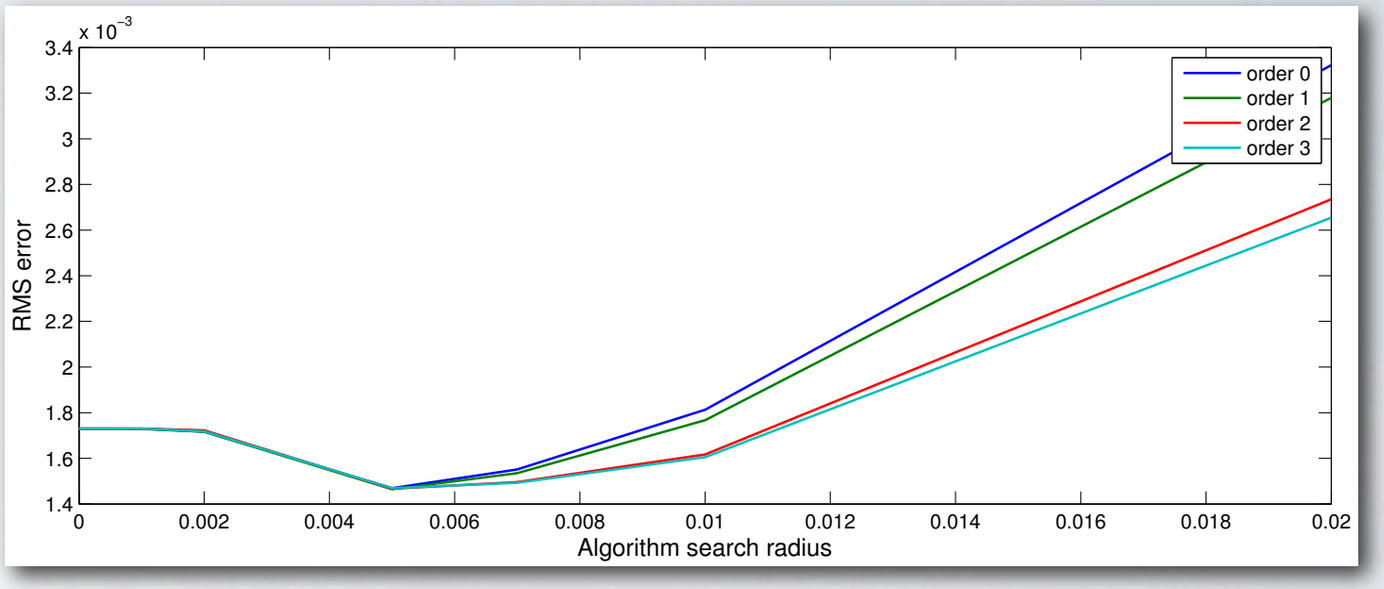
MOVING LEAST SQUARES
1.SMOOTHING 3/3



- Adding noise to original Stanford Bunny dataset with standard deviation 0.001 (resulting in RMSE of 0.00173)

- Best result at search_radius=0.005, improvement of RMSE with 15% (similarly for the Dragon dataset)

- Varying the order of the polynomial fitting: higher order beneficial when large surface/ curvature variance in neighborhood

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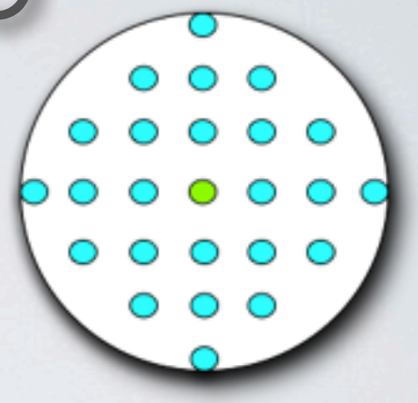
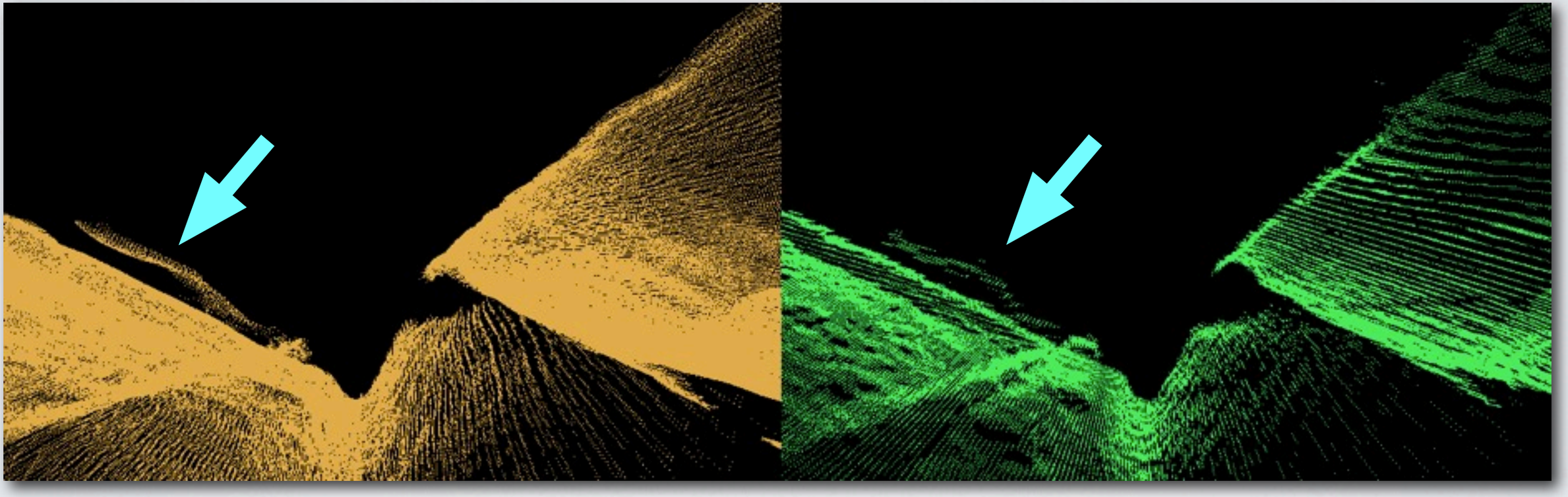
MOVING LEAST SQUARES
2. UPSAMPLING 1/6

SAMPLE_LOCAL_PLANE



Door Handle dataset



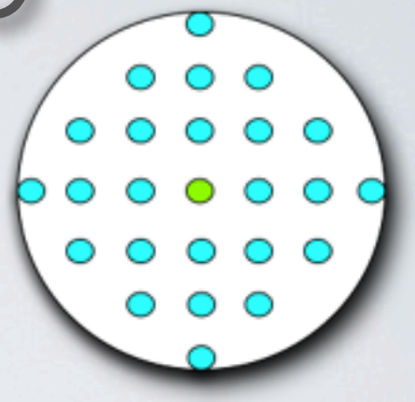
After

Before

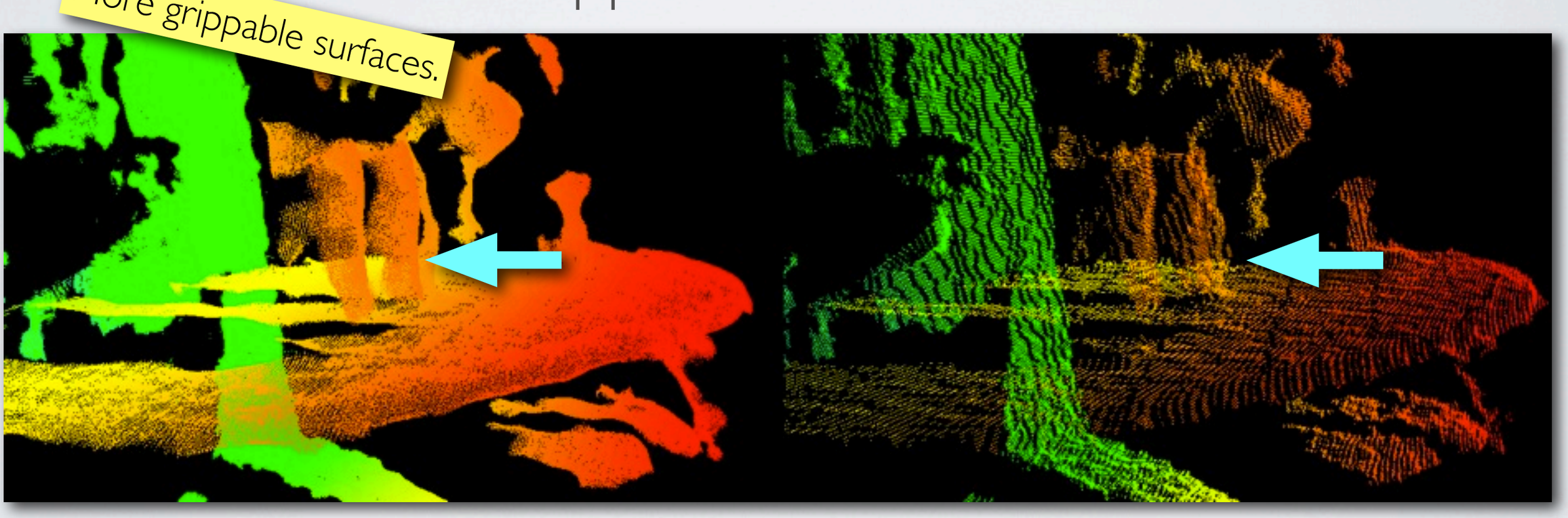
pcl tocs

MOVING LEAST SQUARES
2. UPSAMPLING 2/6

SAMPLE_LOCAL_PLANE



Tupperware dataset



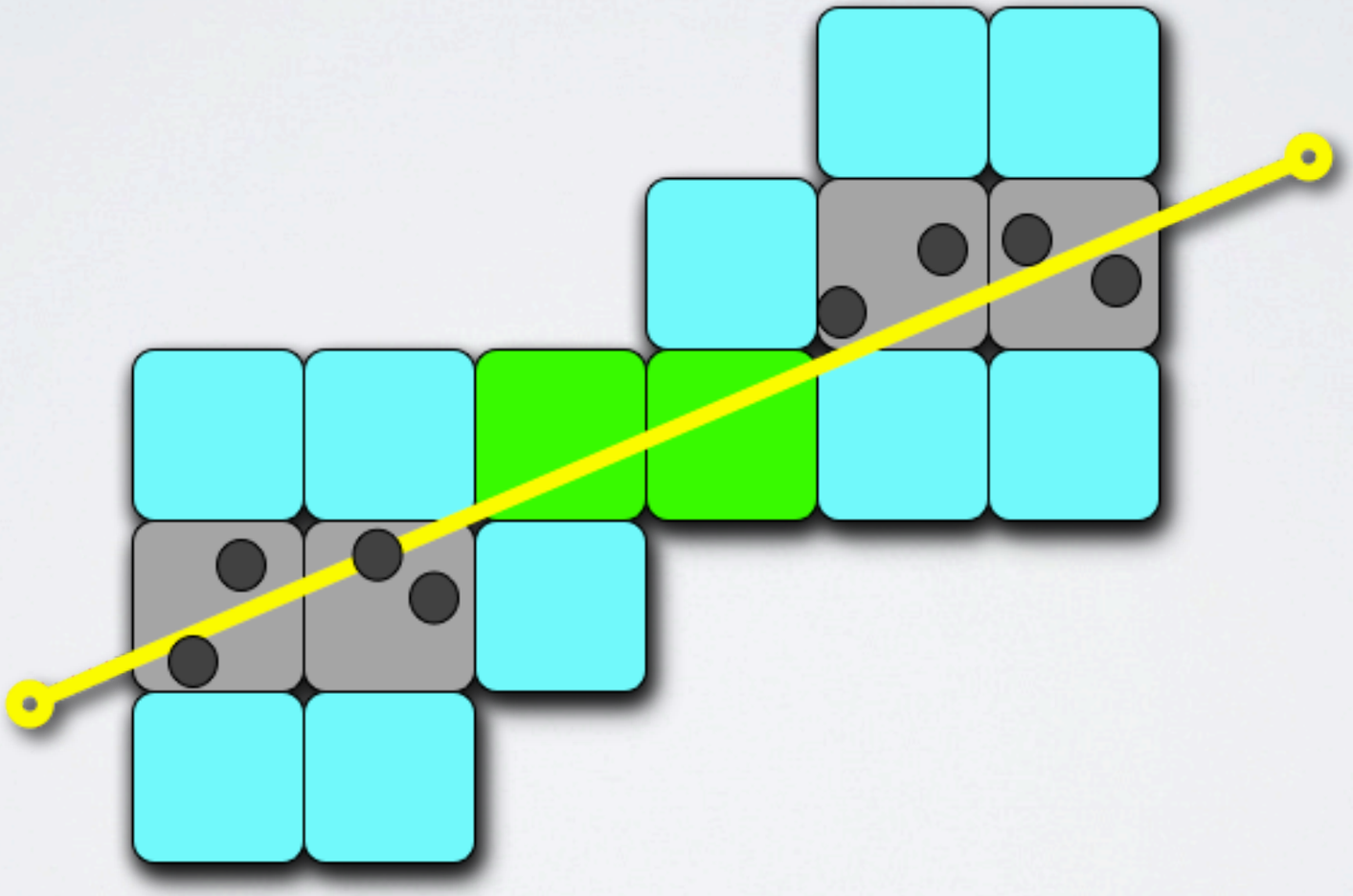
After

Before

pcl tocs

MOVING LEAST SQUARES
2. UPSAMPLING 3/6

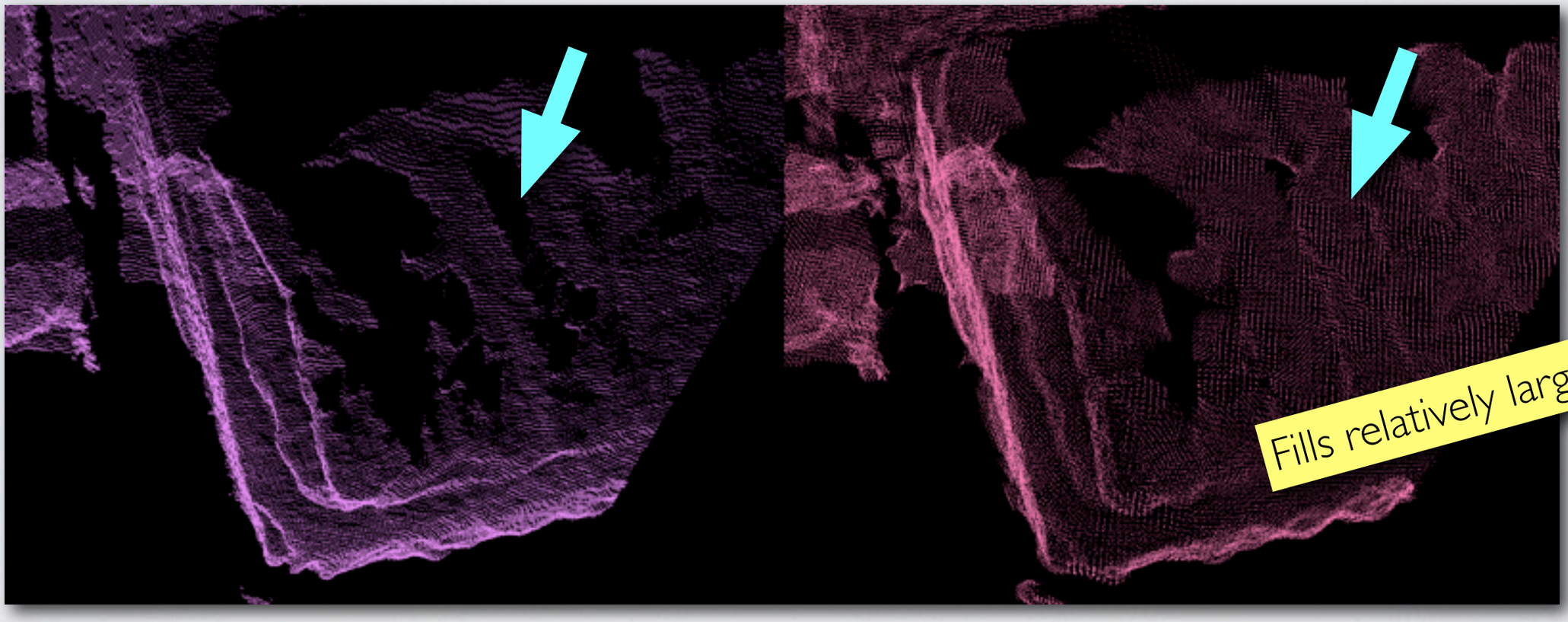
VOXEL_GRID_DILATION



MOVING LEAST SQUARES
2. UPSAMPLING 4/6

VOXEL_GRID_DILATION

Computer Screen dataset

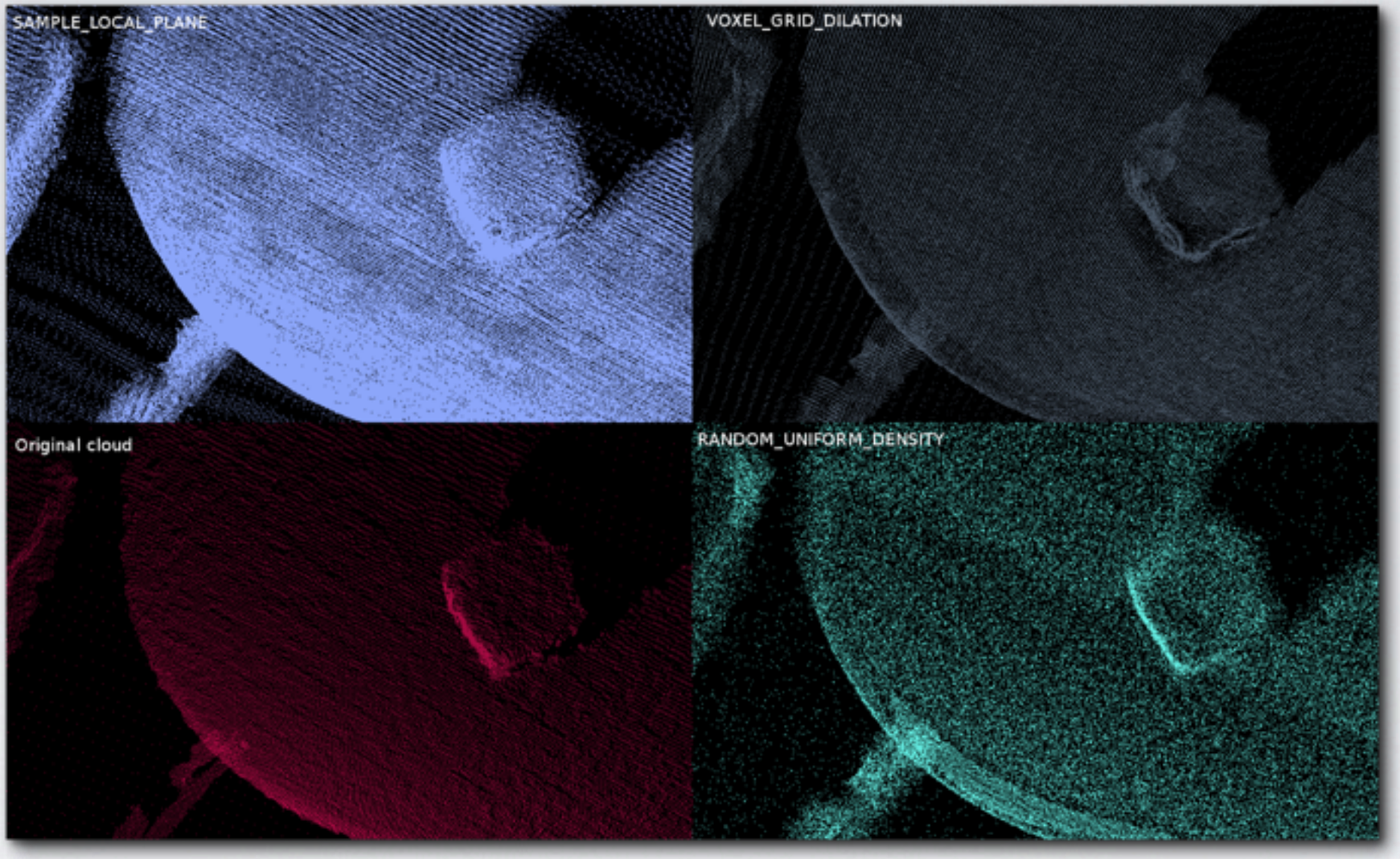


Before

After

pcl tocs

MOVING LEAST SQUARES
2. UPSAMPLING 5/6



Sample locally fitted polynomial in different ways.

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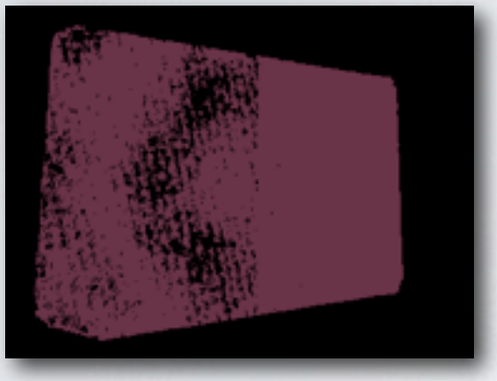
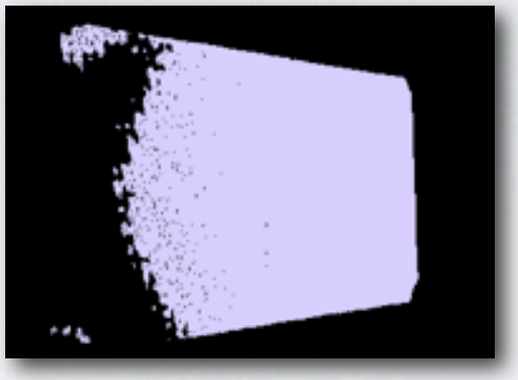
MOVING LEAST SQUARES
2. UPSAMPLING 6/6

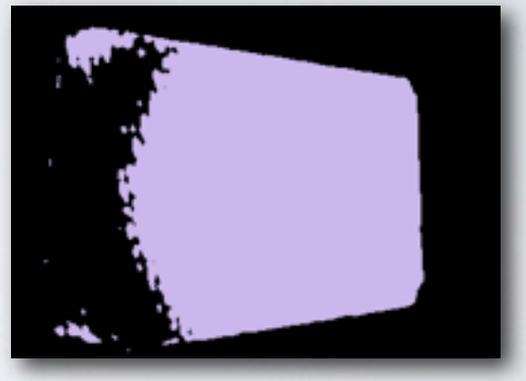
Plane fitting quality (images show inliers)



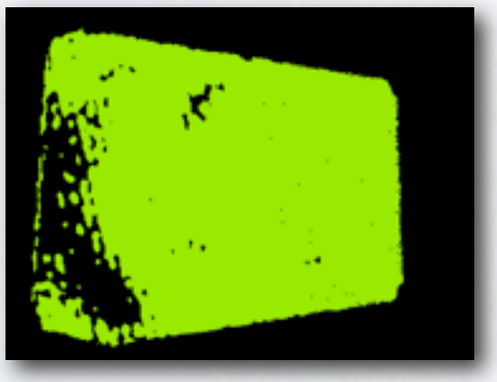
original



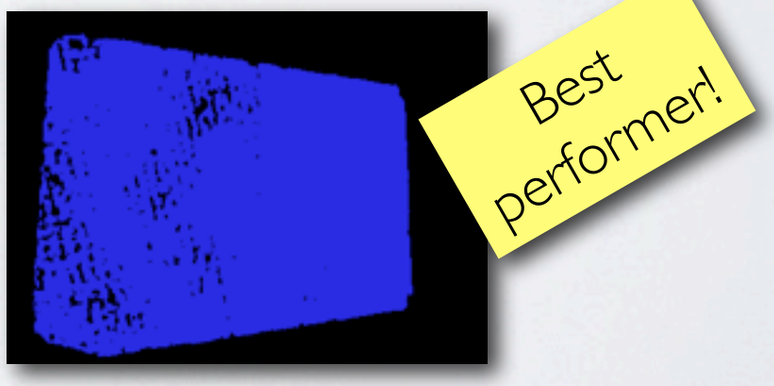
MLS, no upsampling



SAMPLE_LOCAL_PLANE



RANDOM_UNIFORM_DENSITY



VOXEL_GRID_DILATION

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BILATERAL FILTERING UPSAMPLING 1/4

- Kinect modes:
  - 640x480 RGB image + 640x480 depth image at 30Hz
  - 1280x1024 RGB image + 640x480 depth image at 15 Hz

Why not use the better quality RGB image to enhance the depth map?

$$\tilde{S}_p = \frac{1}{k_p} \sum_{q_d \in \Omega} S_{q_d} f(||p_d - q_d|| g(||\tilde{I}_p - \tilde{I}_q||)$$

J. Kopf, *Joint Bilateral Upsampling*, *ACM Transactions on Graphics* (Proceedings of SIGGRAPH 2007)

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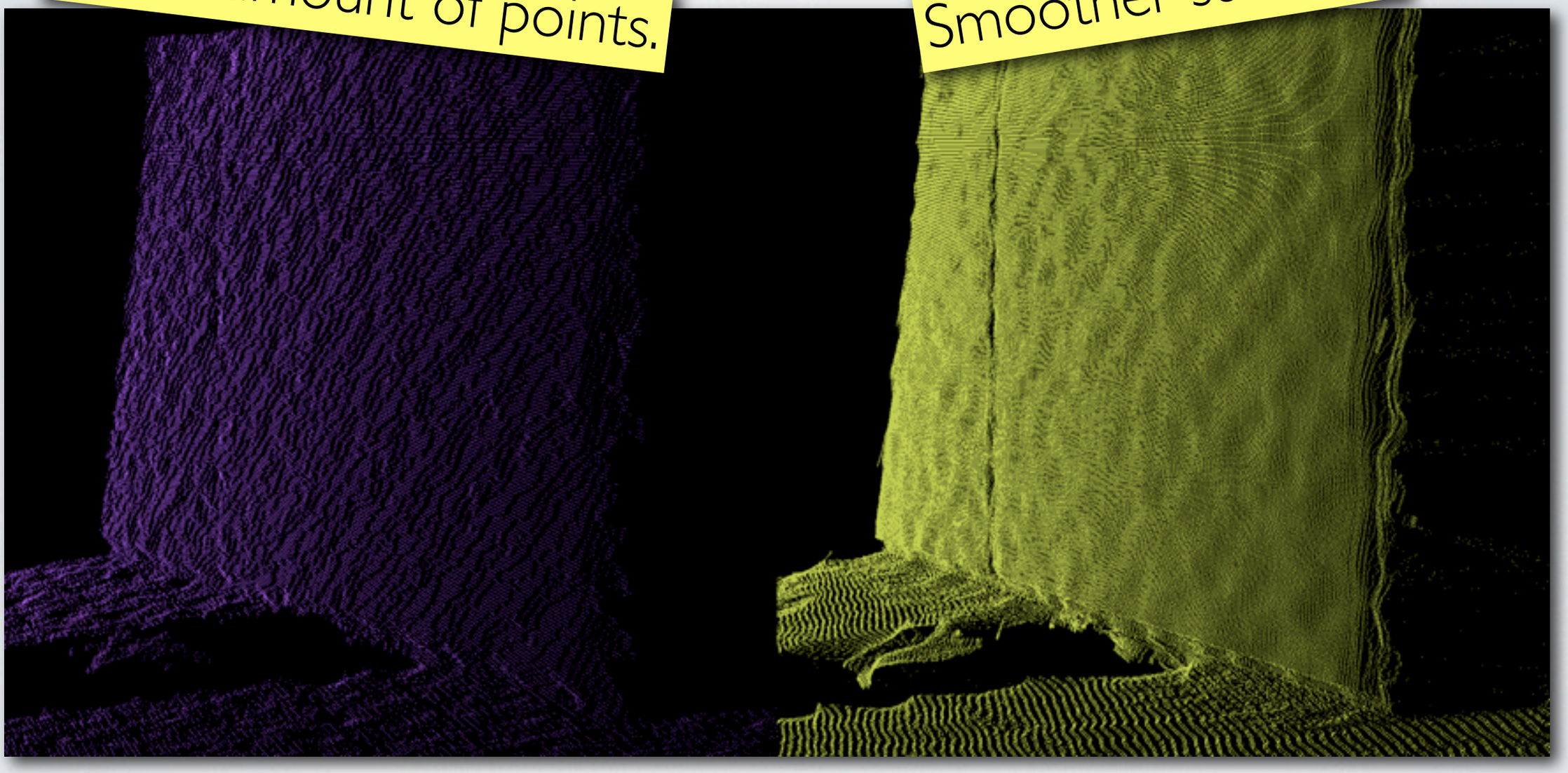
BILATERAL FILTERING UPSAMPLING 2/4

4x the amount of points.

Smoother surfaces.



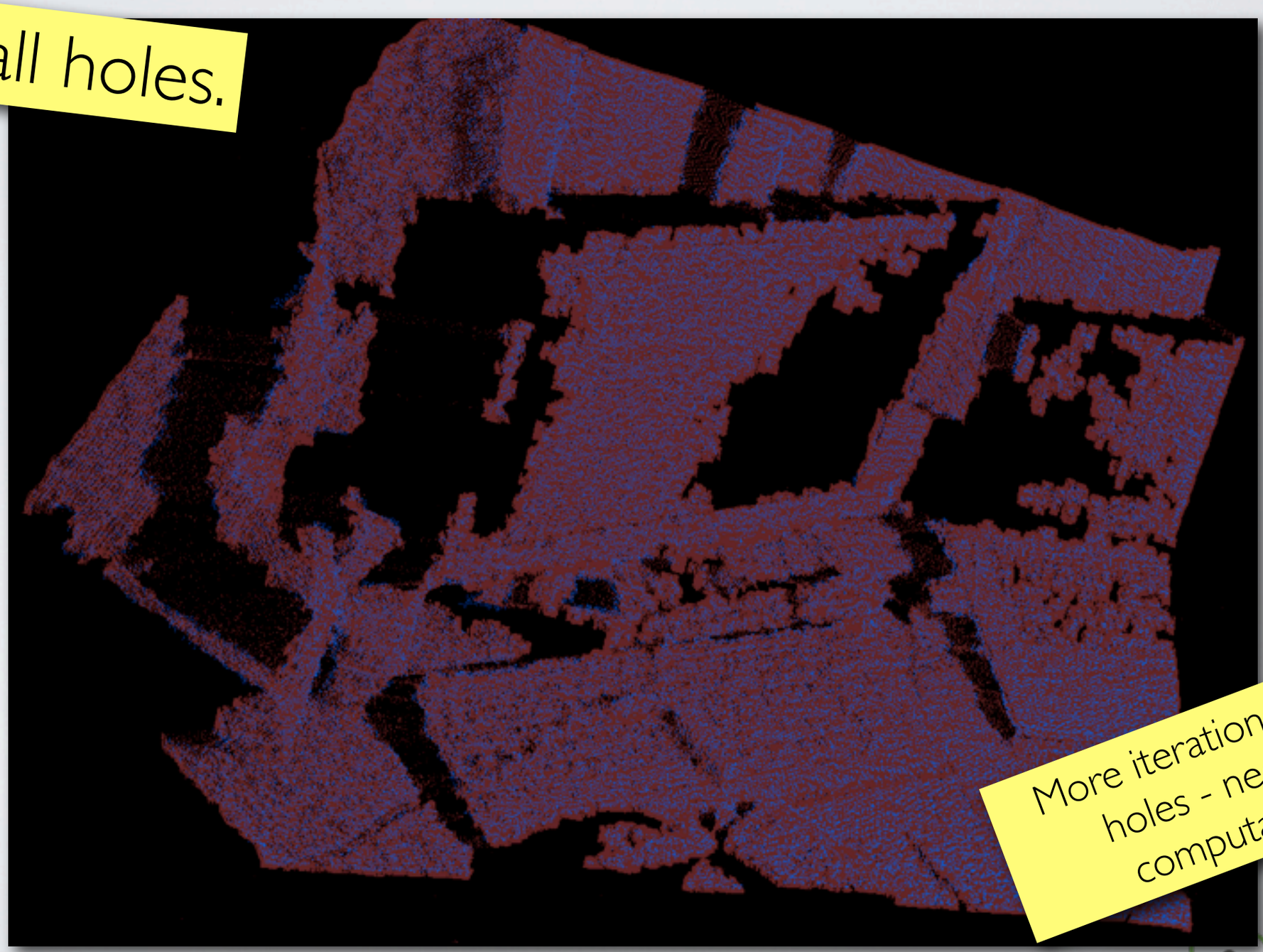
original

upsampled

pcl tocs

BILATERAL FILTERING UPSAMPLING 3/4

Fills small holes.



More iterations - fill larger holes - needs more computation time

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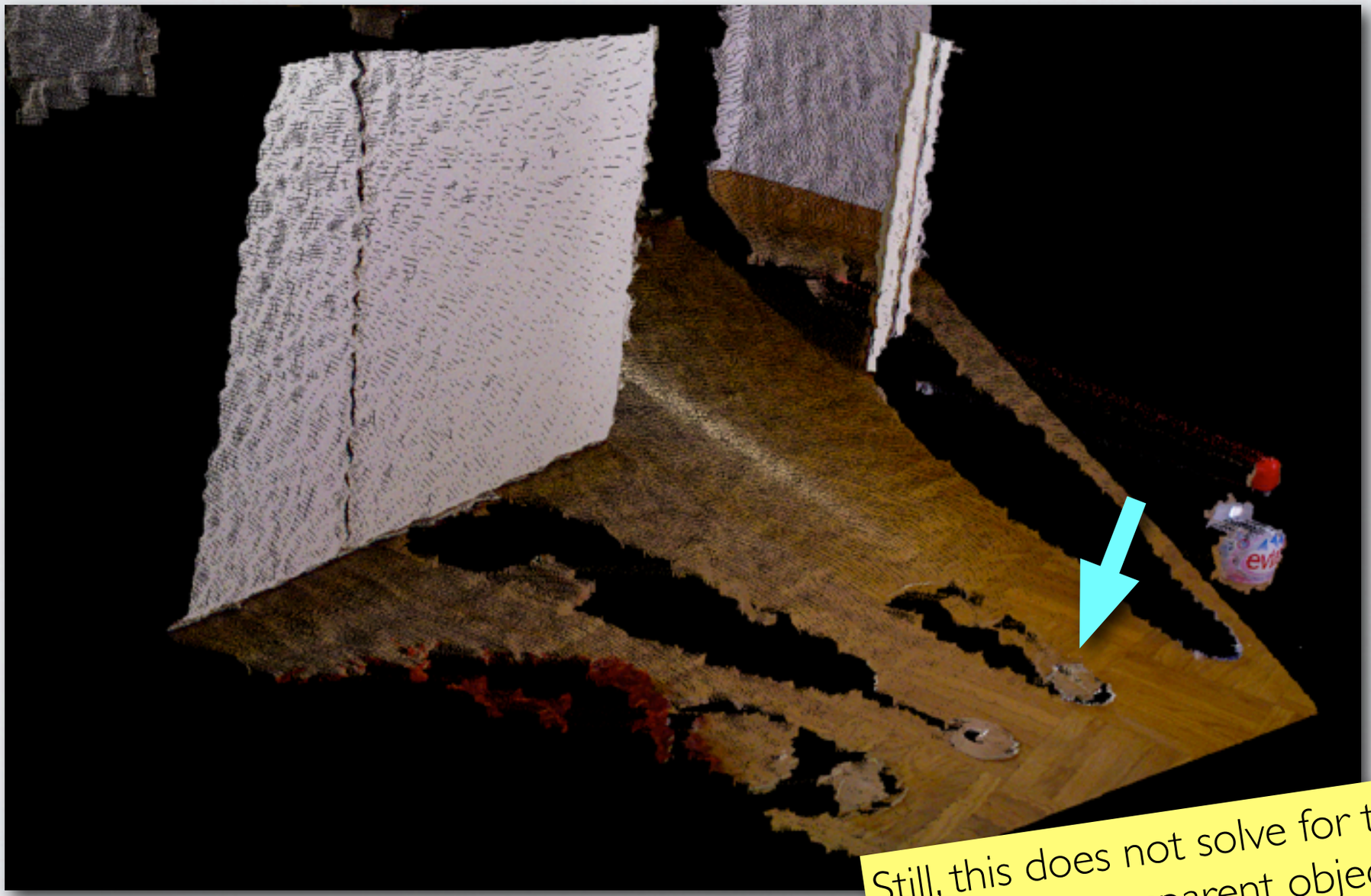
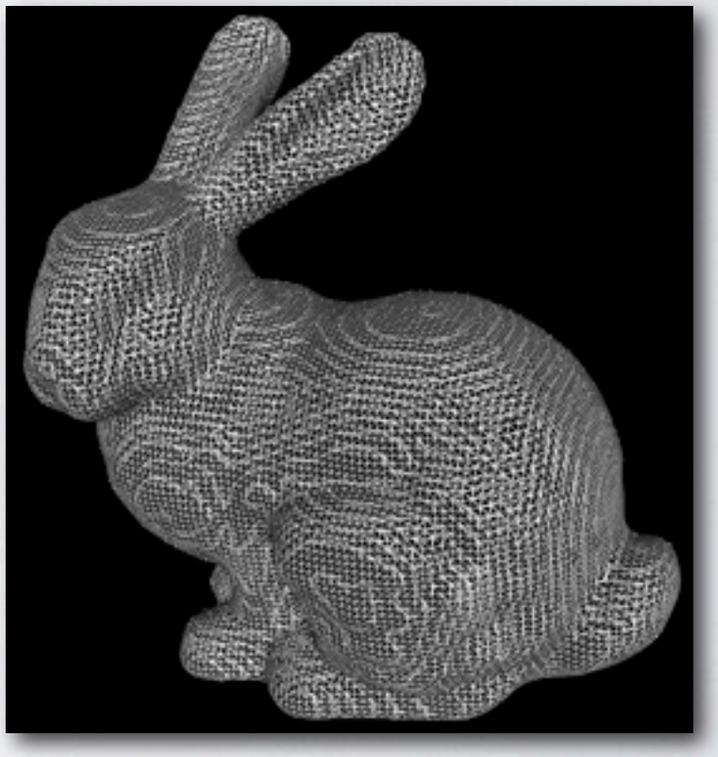
BILATERAL FILTERING UPSAMPLING 4/4



Still, this does not solve for the problem of transparent objects ...

MARCHING CUBES

- Have implementations of 2 classical methods:
  - Hoppe et al.: $SDF(x_i) = min_{x_j \in N}(n_j \cdot (x_i - x_j))$
  - RBF: $SDF(x_i) = \sum_i w_i \Phi(||x - c_i||)$



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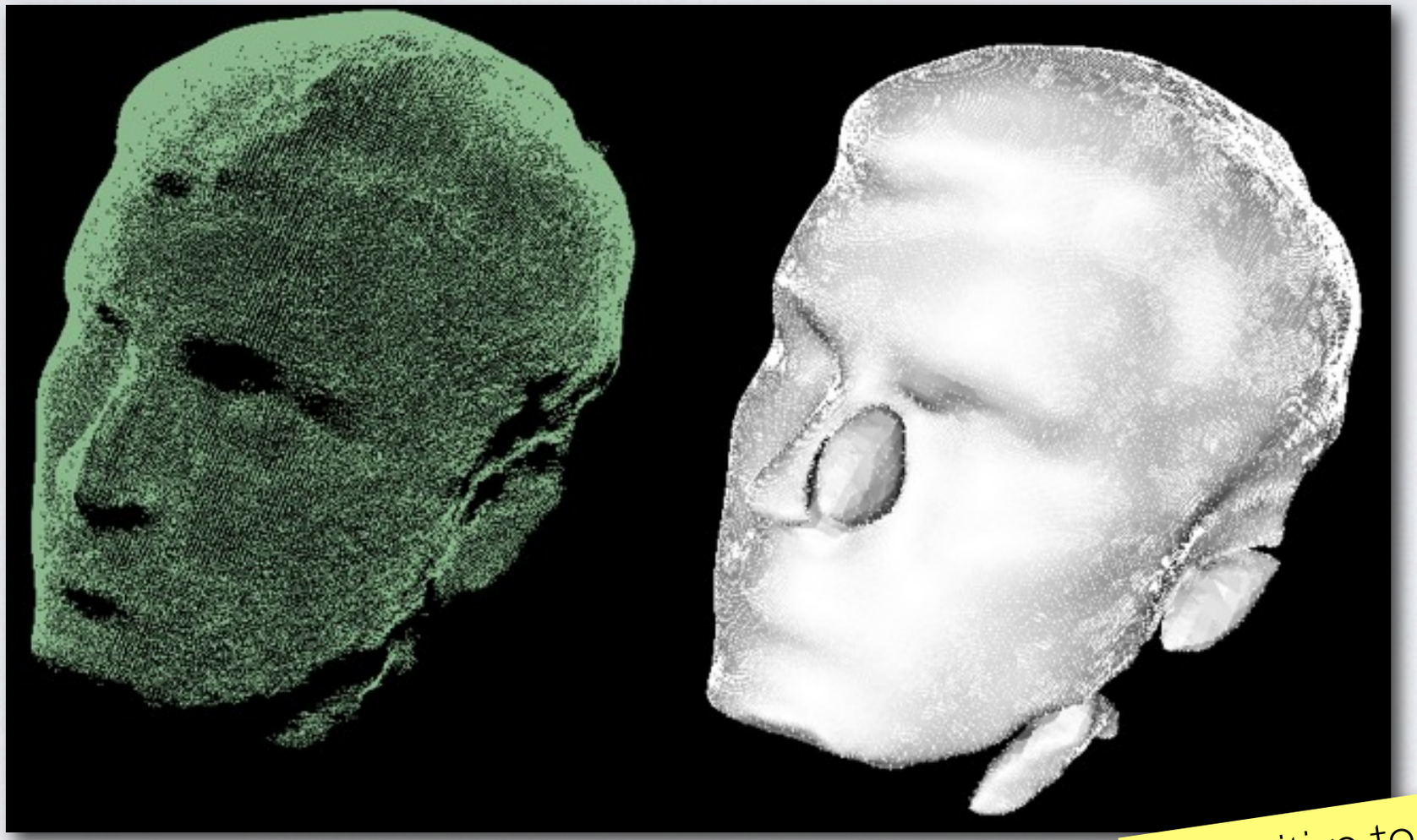
POISSON SURFACE RECONSTRUCTION

M. Kazhdan, *Poisson Surface Reconstruction,*
Symposium on Geometry Processing
(June 2006)



Sensitive to noise.

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OTHER METHODS

- Mesh Operations from VTK
  - MeshSmoothingLaplacianVTK
  - MeshSmoothingWindowedSincVTK
  - MeshSubdivisionVTK
- OrganizedFastMesh (demo)
- ConcaveHull, ConvexHull - use QHull library
- GridProjection - work of WG intern, Rosie Li

Need to convert between data types.

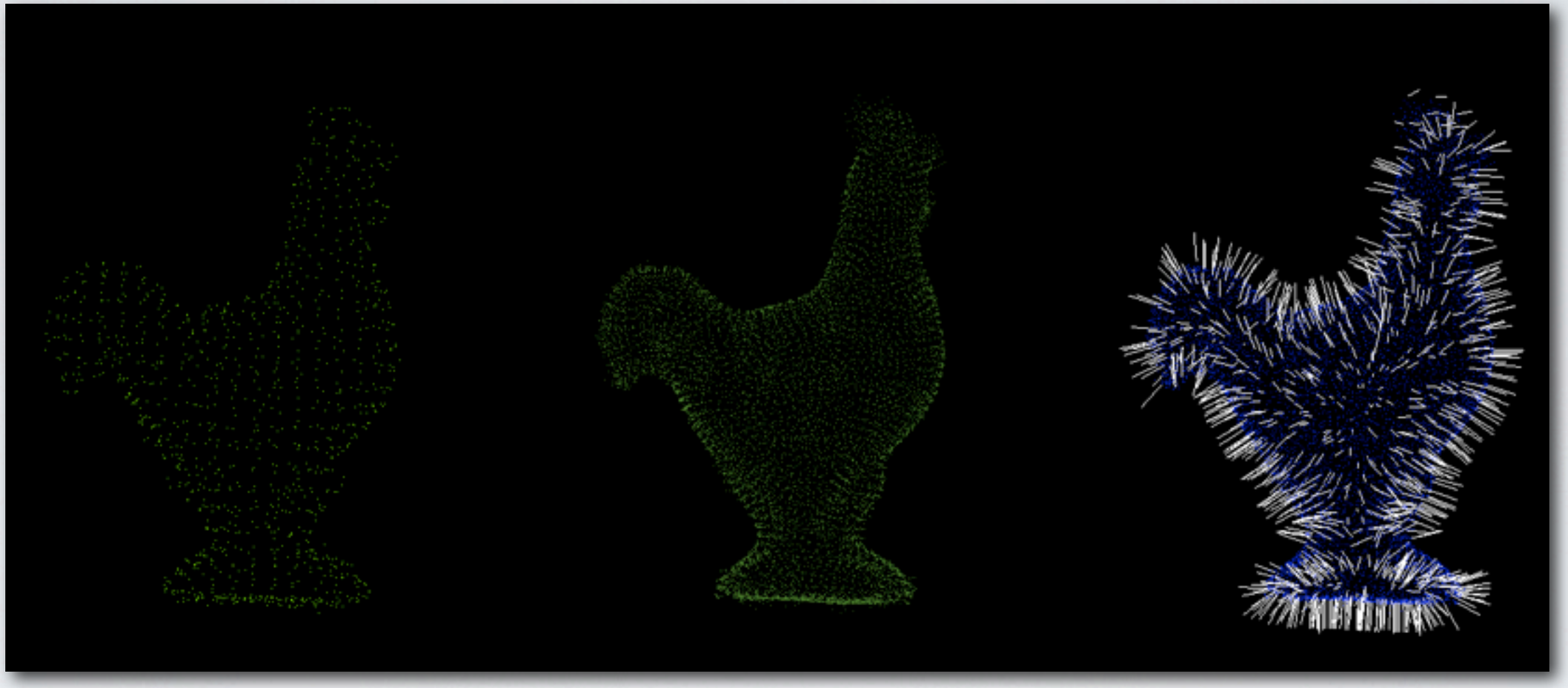
RECONSTRUCTION PIPELINE EXAMPLE 1/4

```
#include <pcl/common/common.h>
#include <pcl/io/pcd_io.h>
#include <pcl/features/normal_3d_omp.h>
#include <pcl/surface/mls.h>
#include <pcl/surface/poisson.h>
#include <pcl/io/vtk_io.h>

using namespace pcl;

int
main (int argc, char **argv)
{
  if (argc != 3)
  {
    PCL_ERROR ("Syntax: %s input.pcd output.ply\n", argv[0]);
    return -1;
  }

  PointCloud<PointXYZ>::Ptr cloud (new PointCloud<PointXYZ> ());
  io::loadPCDFile (argv[1], *cloud);
```

RECONSTRUCTION PIPELINE EXAMPLE 2/4

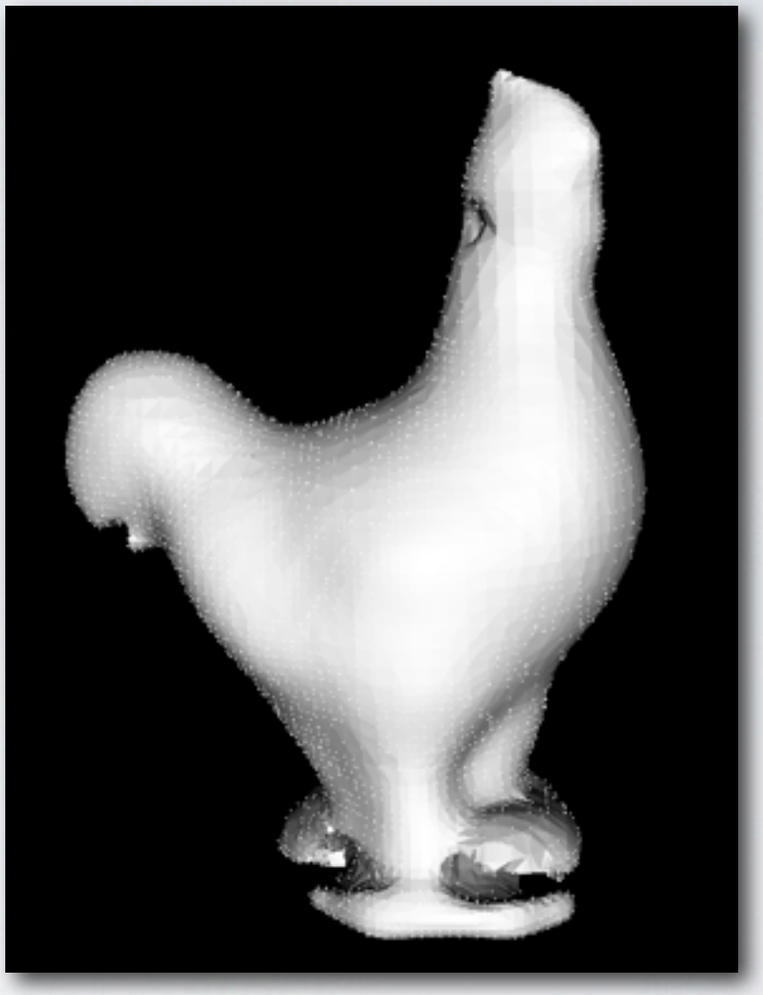
```
MovingLeastSquares<PointXYZ, PointXYZ> mls;
mls.setInputCloud (cloud);
mls.setSearchRadius (0.01);
mls.setPolynomialFit (true);
mls.setPolynomialOrder (2);
mls.setUpsamplingMethod (MovingLeastSquares<PointXYZ, PointXYZ>::SAMPLE_LOCAL_PLANE);
mls.setUpsamplingRadius (0.005);
mls.setUpsamplingStepSize (0.003);

PointCloud<PointXYZ>::Ptr cloud_smoothed (new PointCloud<PointXYZ> ());
mls.process (*cloud_smoothed);

NormalEstimationOMP<PointXYZ, Normal> ne;
ne.setNumberOfThreads (8);
ne.setInputCloud (cloud_smoothed);
ne.setRadiusSearch (0.01);
Eigen::Vector4f centroid;
compute3DCentroid (*cloud_smoothed, centroid);
ne.setViewPoint (centroid[0], centroid[1], centroid[2]);

PointCloud<Normal>::Ptr cloud_normals (new PointCloud<Normal> ());
ne.compute (*cloud_normals);

for (size_t i = 0; i < cloud_normals->size (); ++i)
{
  cloud_normals->points[i].normal_x *= -1;
  cloud_normals->points[i].normal_y *= -1;
  cloud_normals->points[i].normal_z *= -1;
}

PointCloud<PointNormal>::Ptr cloud_smoothed_normals (new PointCloud<PointNormal> ());
concatenateFields (*cloud_smoothed, *cloud_normals, *cloud_smoothed_normals);
```

RECONSTRUCTION PIPELINE EXAMPLE 3/4



RECONSTRUCTION PIPELINE EXAMPLE 4/4

```
  Poisson<PointNormal> poisson;
  poisson.setDepth (9);
  poisson.setInputCloud
(cloud_smoothed_normals);
  PolygonMesh mesh;
  poisson.reconstruct (mesh);

  io::saveVTKFile (argv[2], mesh);

  return 0;
}
```



THANKS!