



Fast 3D Recognition and Pose. Viewpoint Feature Histogram

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Willow Garage Outline

1. Motivation
2. F/PFH
3. Priors
4. VFH
5. Examples/Results
6. Conclusion



Motivation (1/2)

Got Robots. Now what?



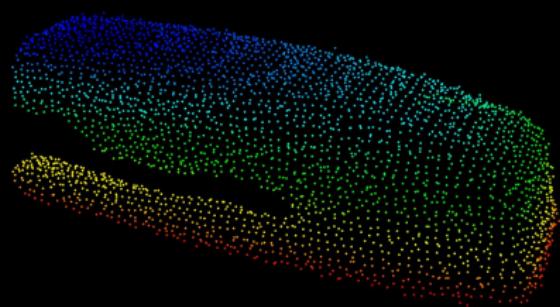
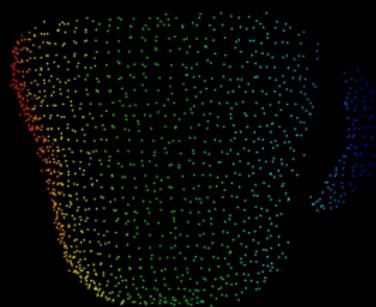


Motivation (2/2)

Wanted: Recognition and 6D Pose

Something along the lines of:

- ▶ Input:



- ▶ Output:

Object 1: ID=XX, Pose=YY
Object 2: ID=XX, Pose=YY

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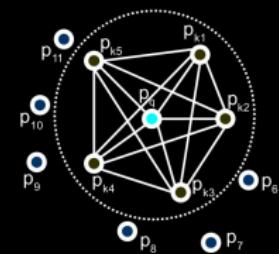
Point Feature Histograms (PFH) (1-4/4)

Basic Concepts :: PCL/Features/(F)PFHEstimation

Rusu et al, *Learning Informative Point Classes for the Acquisition of Object Model Maps*, ICARCV'08

Rusu et al, *Fast Point Feature Histograms (FPFH) for 3D Registration*, ICRA'09

- ▶ For every point pair $\langle(p_s, n_s); (p_t, n_t)\rangle$, let
 $u = n_s, v = (p_t - p_s) \times u, w = u \times v$

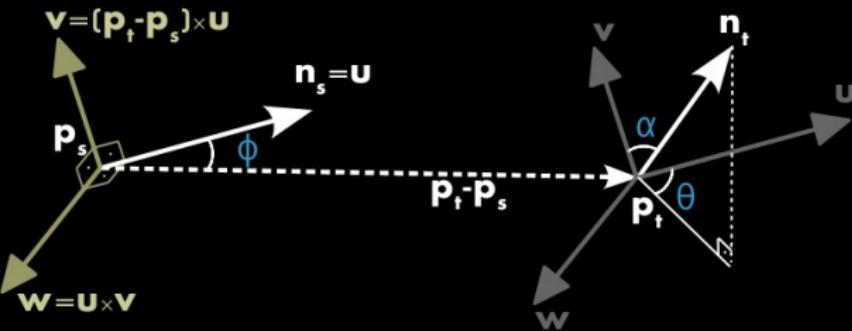


$$\left. \begin{array}{l} f_0 = \langle v, n_j \rangle \\ f_1 = \langle u, p_j - p_i \rangle / ||p_j - p_i|| \\ f_2 = ||p_j - p_i|| \\ f_3 = \text{atan}(\langle w, n_j \rangle, \langle u, n_j \rangle) \end{array} \right\} i_{hist} = \sum_{x=0}^{x \leq 3} \left\lfloor \frac{f_x \cdot d}{f_{xmax} - f_{xmin}} \right\rfloor \cdot d^x$$



Point Feature Histograms (PFH) (1-4/4)

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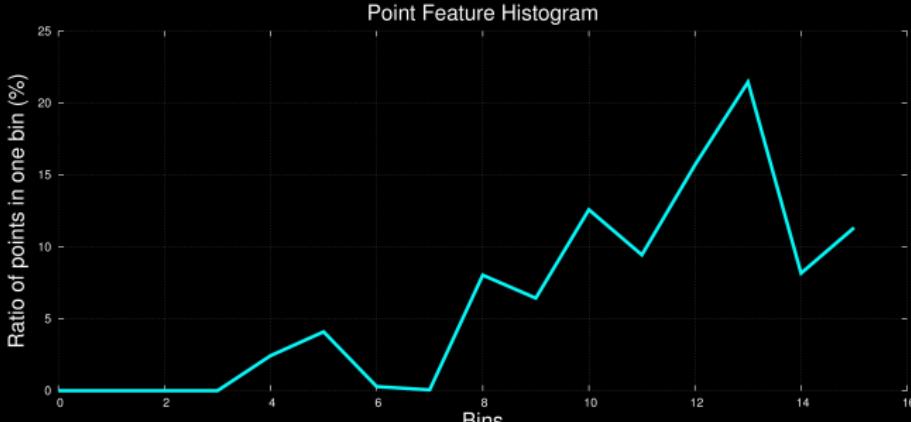
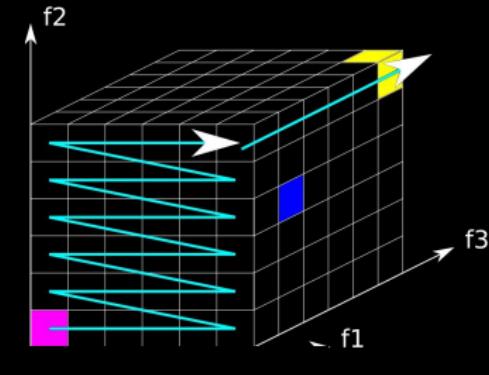
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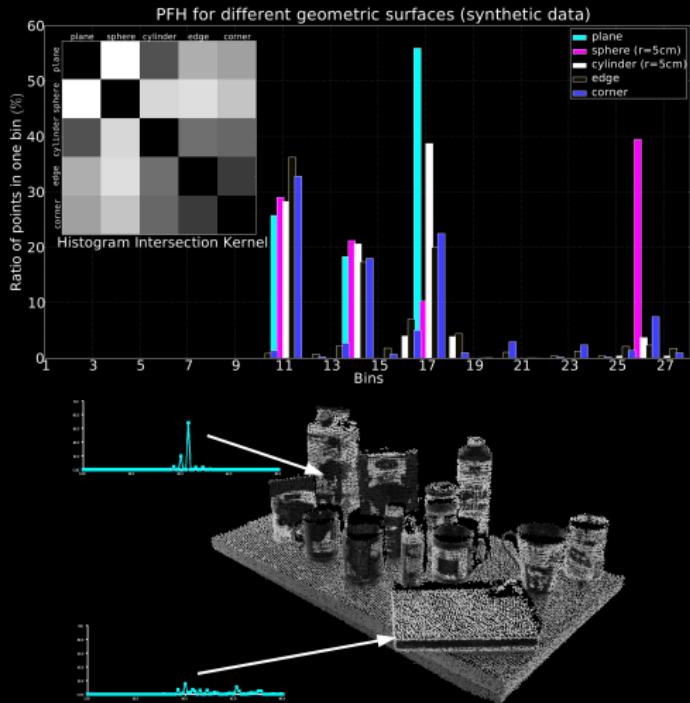
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Point Feature Histograms (PFH) (1-4/4)

Points lying on different geometric primitives



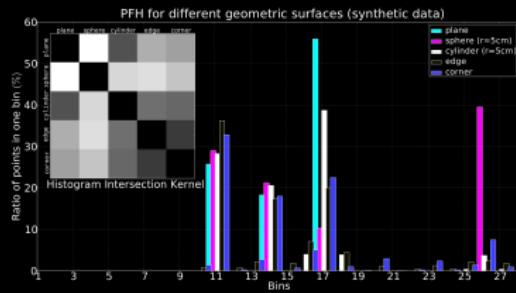
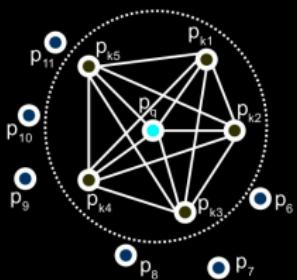


Fast Point Feature Histograms (FPFH) (1/2)

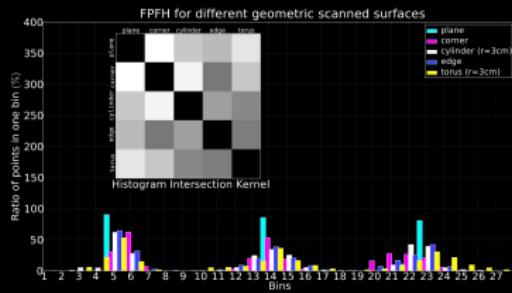
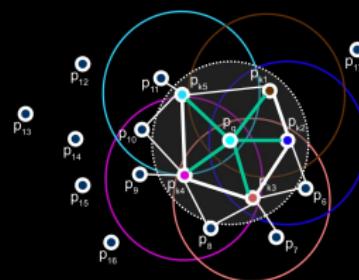
Basic Concepts

Re-formulate:

$$FPFH(p) = SPF(p) + \frac{1}{k} \sum_{i=1}^k \frac{1}{\omega_k} \cdot SPF(p_k)$$



Point Feature Histograms (PFH)

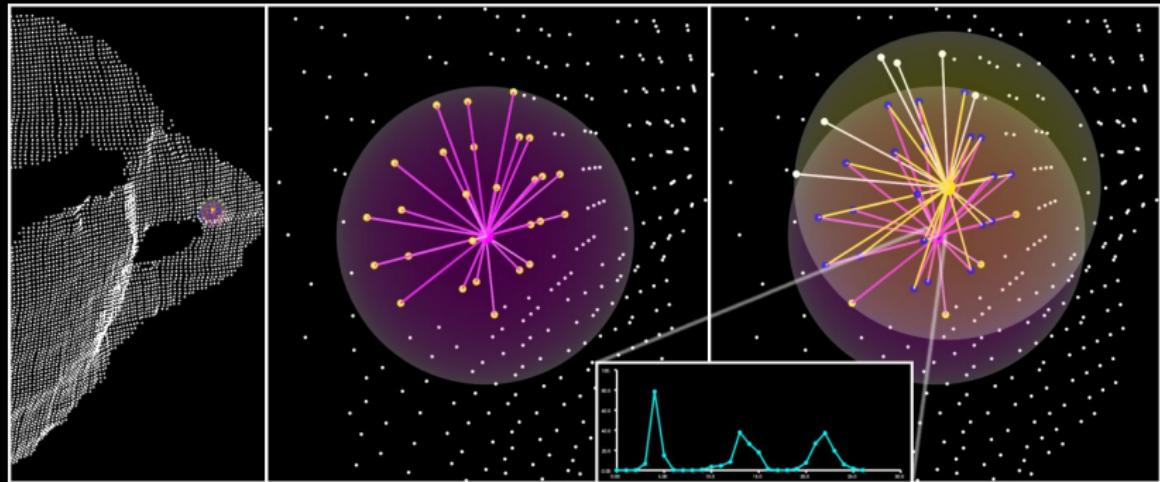


Fast Point Feature Histograms (FPFH)



Fast Point Feature Histograms (FPFH) (2/2)

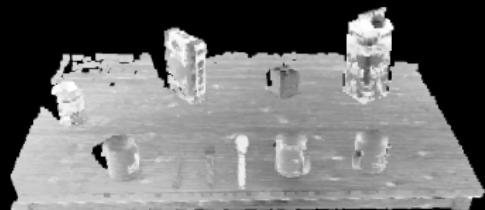
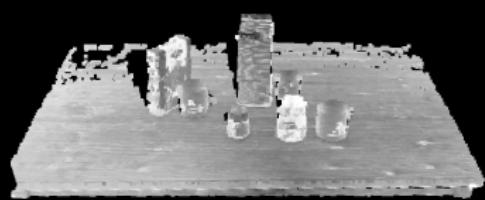
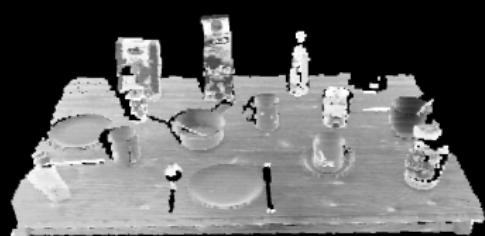
Theoretical formulation





(F)PFH Usage (1/3)

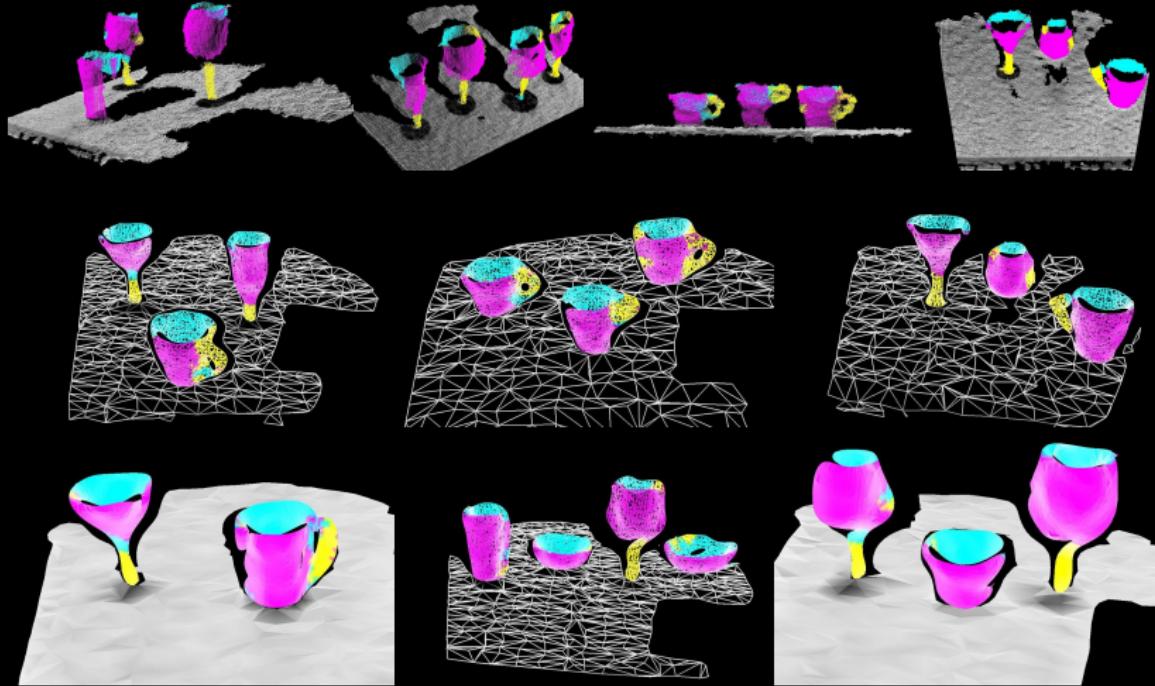
Classification results using FPFH and CRF: 97.36%





(F)PFH Usage (2/3)

Classification results using FPFH and CRF: 98.27%

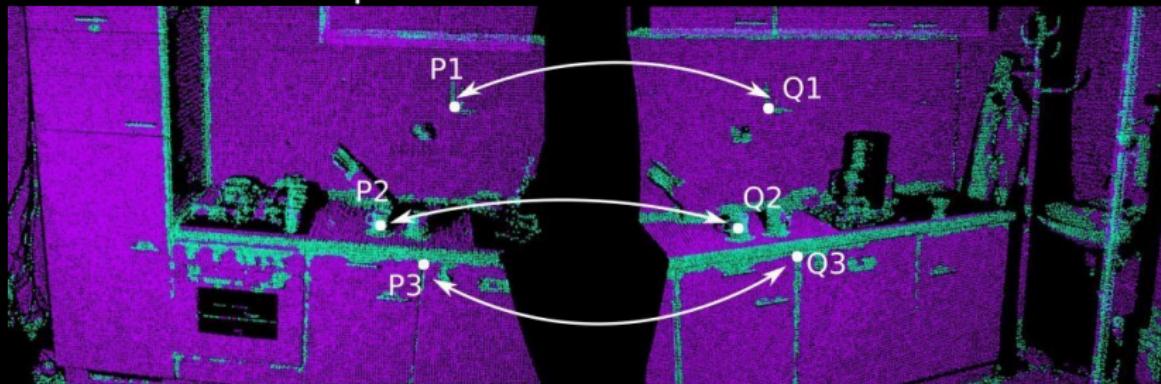




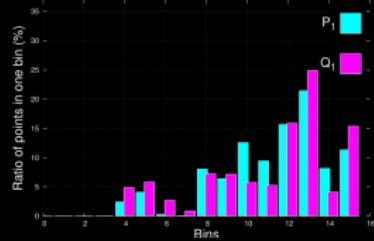
(F)PFH Usage (3/3)

Multiple Scans :: PCL/Registration/IterativeClosestPoint

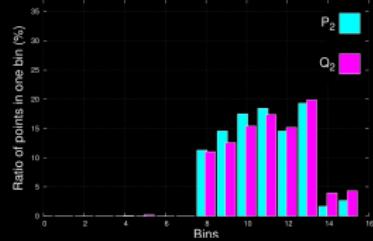
points on similar surfaces



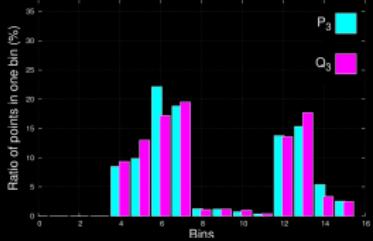
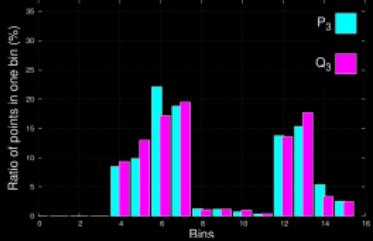
Persistent Feature Points Histograms



Persistent Feature Points Histograms



Persistent Feature Points Histograms



Willow Garage Outline

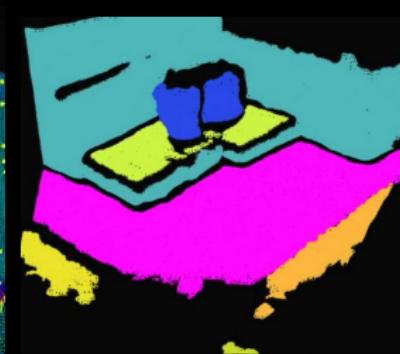
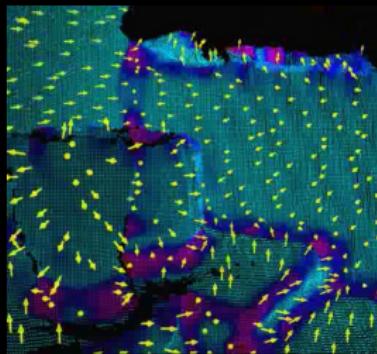
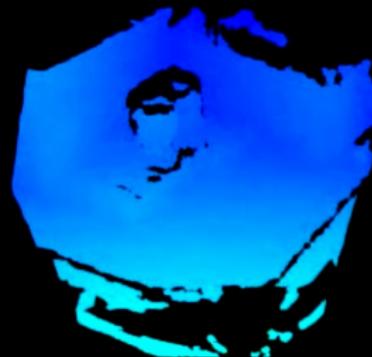
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Priors

Assumptions and Constraints

- ▶ Dense depth + decent surface normal estimates
- ▶ Some form of prior segmentation, attention filter, etc (**light clutter segmentation** - not the purpose of this paper)
- ▶ the acquisition viewpoint



- ▶ VFH is **meta-local** and operates on **point clusters** (!)

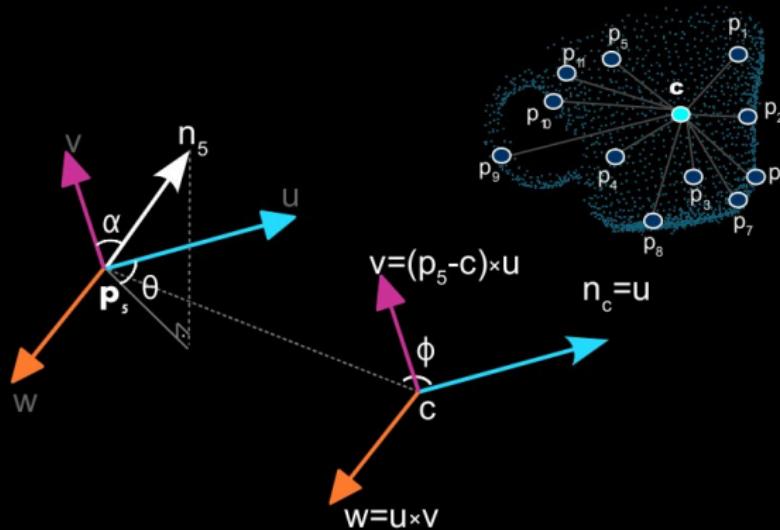
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Willow Garage VFH

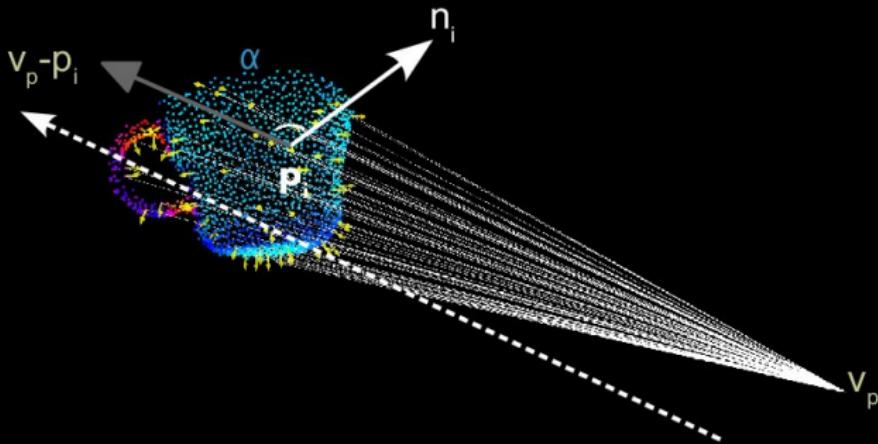
Theoretical formulation: first component

- 1 fixed point $c = \bar{p} = \frac{1}{k} \cdot \sum_{i=1}^k p_i$
- $\alpha = v \cdot n_j$, $\phi = u \cdot \frac{(p_j - p_i)}{d}$, $\theta = \arctan(w \cdot n_j, u \cdot n_j)$

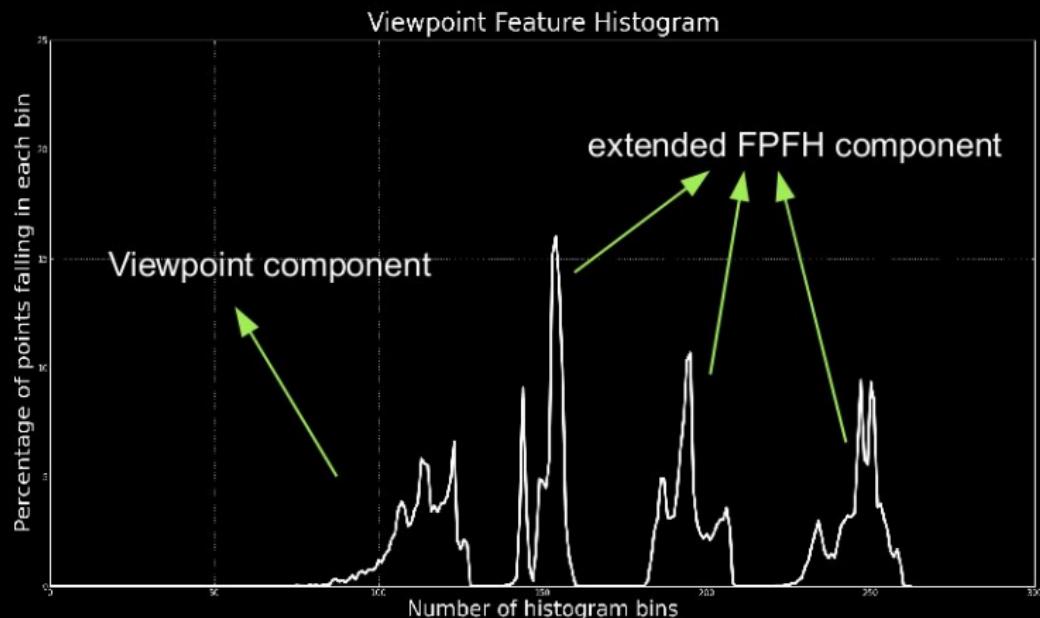


Theoretical formulation: second component

- add angles between viewpoint V_p and centroid normal:
 $\beta = \mathbf{n} \cdot V_p$



Theoretical formulation



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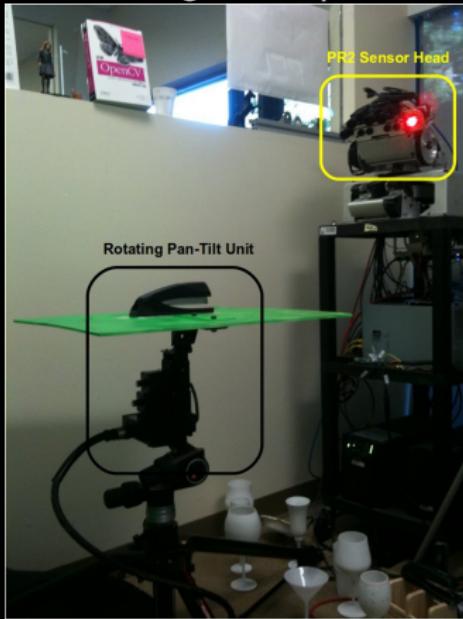


Usage Examples/Results (1/9)

“Training”

How to acquire data:

- ▶ Something like a pan-tilt unit works well...



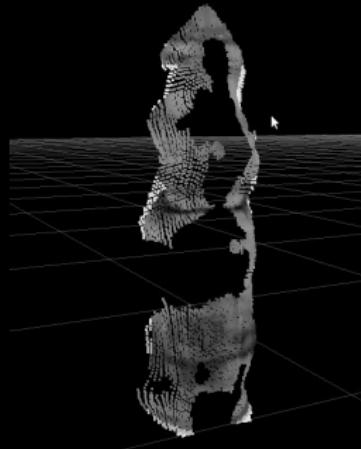
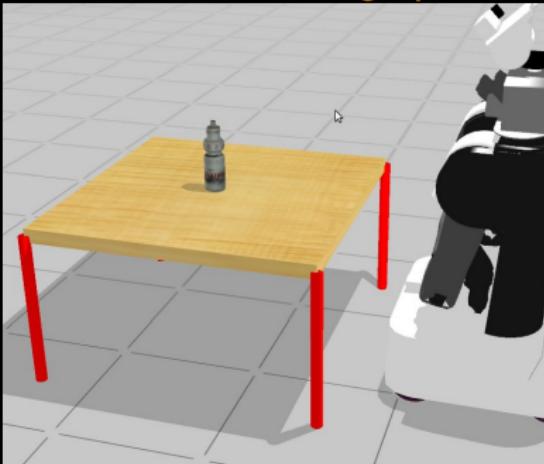


Usage Examples/Results (2/9)

“Training”

How to acquire data:

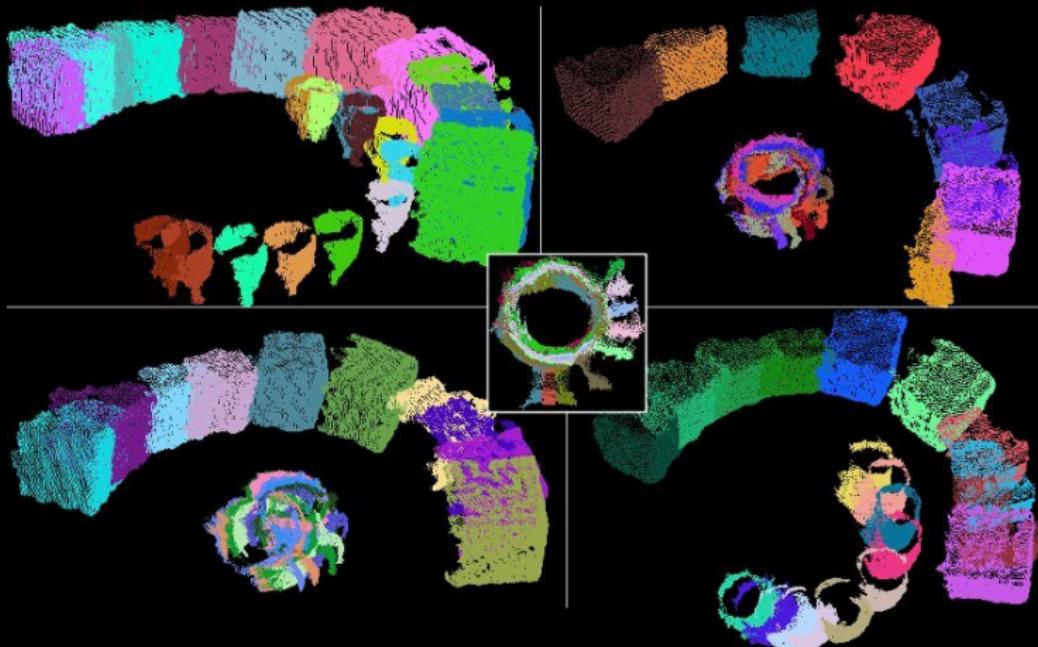
- ▶ Simulated camera views for a similar camera model + identical **stereo image processing code**





Usage Examples/Results (3/9)

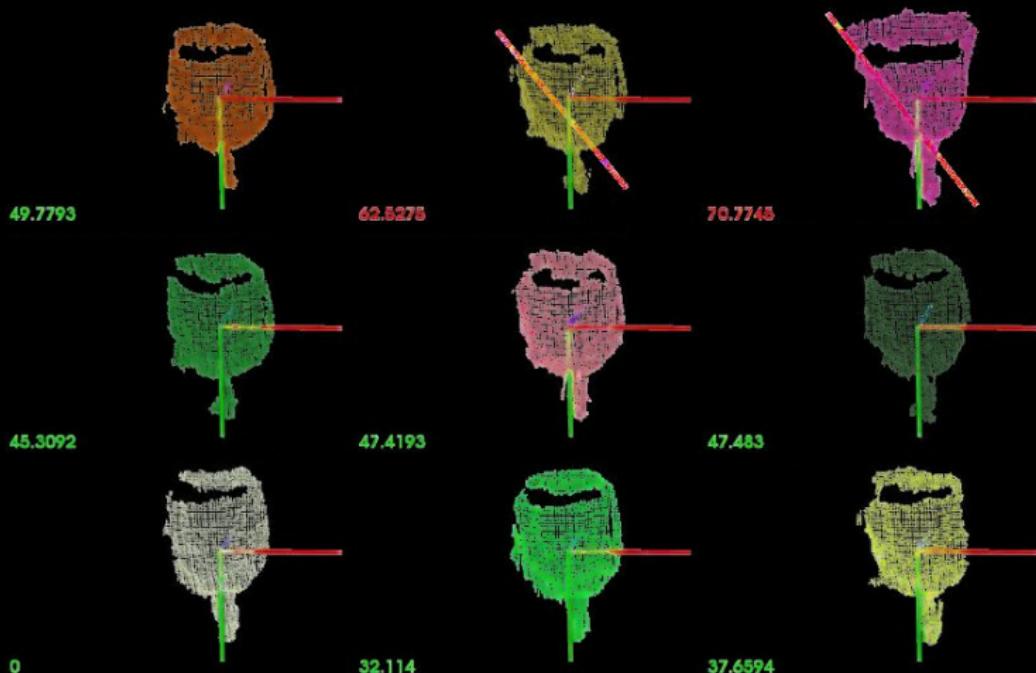
“Training”





Usage Examples/Results (4/9)

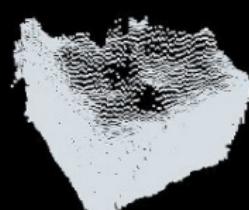
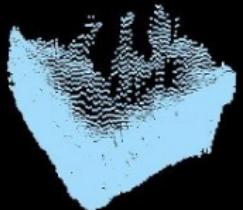
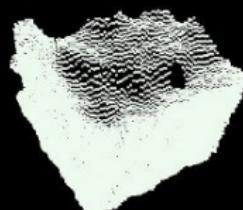
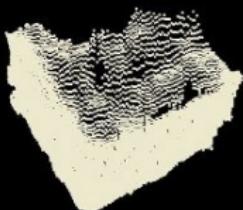
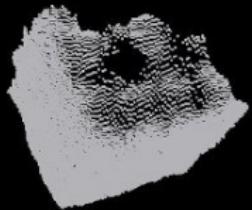
Test on Train





Usage Examples/Results (5/9)

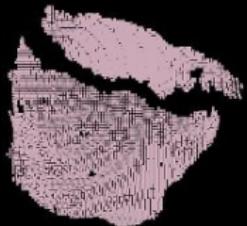
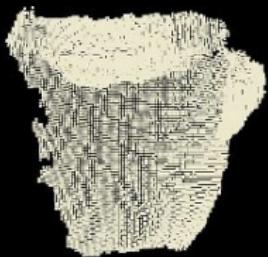
How to use and interpret the results





Usage Examples/Results (6/9)

How to use and interpret the results





Usage Examples/Results (7/9)

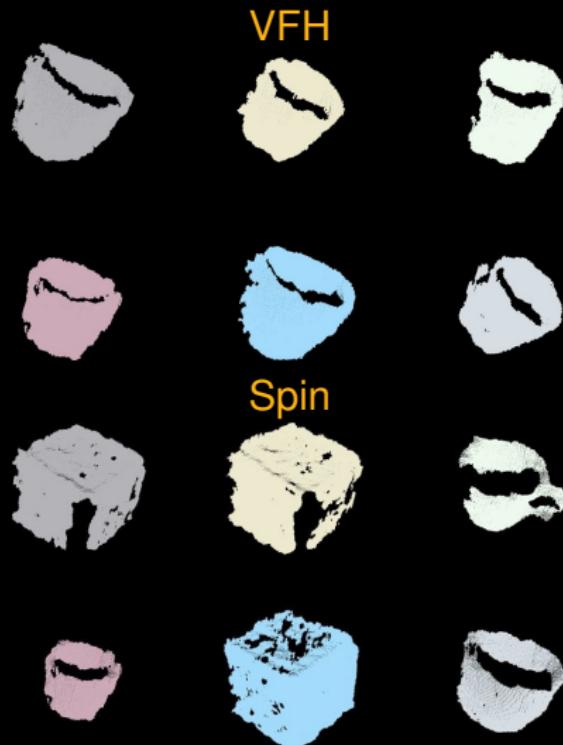
How to use and interpret the results





Usage Examples/Results (8/9)

How to use and interpret the results



Usage Examples/Results (9/9)

Performance Indicators

Numbers are not relevant - use them as indicators:

- ▶ extremely fast (SSE optimized implementation in PCL <http://pcl.ros.org>): $\approx 0.3\text{ms}$ / point cluster
- ▶ scales very well (kudos to FLANN): tried it on ≈ 55000 scenes
- ▶ recognition performance (%50 + 1, first 10 NN, capped on $d_{th} = 50$):

Method	Object	Pose
	Recognition	Estimation
VFH	98.52%	98.52%
Spin	75.3%	61.2%

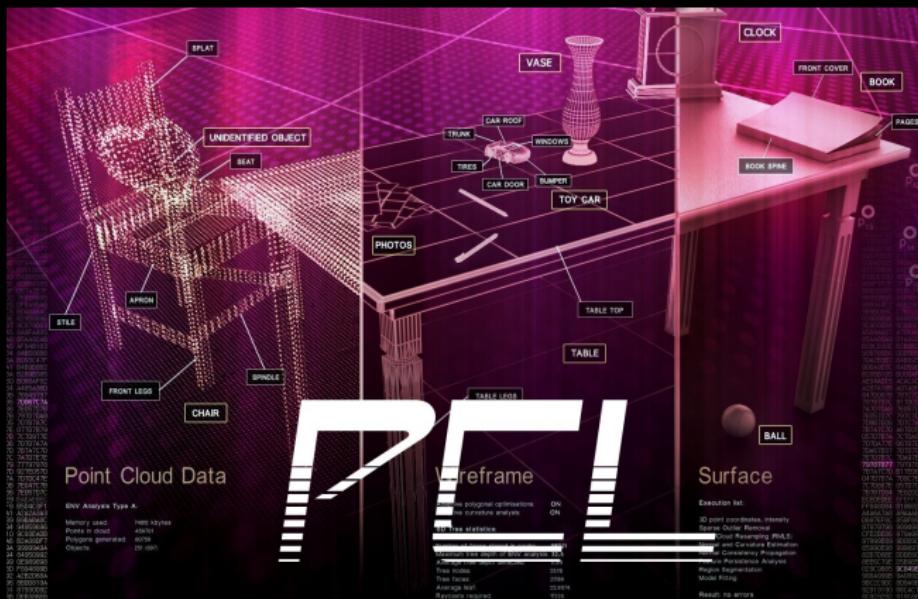
- ▶ good behavior for synthetic data simulation (advantage if CAD models already exist)

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Open Source! Go try it out and let us if it's useful or not!



POINT CLOUD LIBRARY

<http://pcl.ros.org>