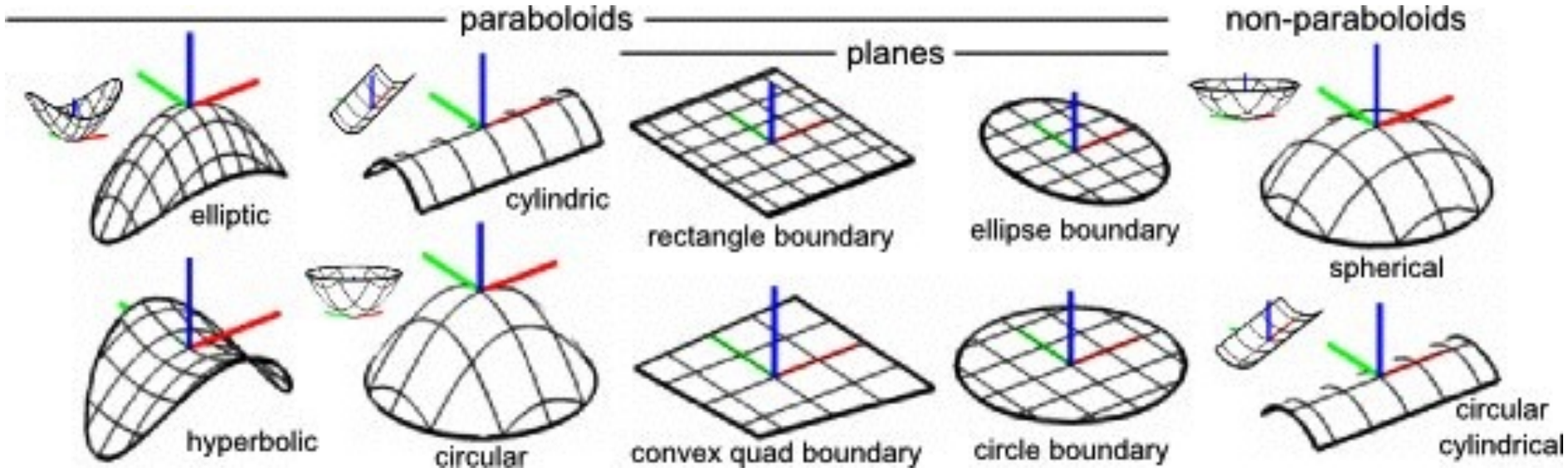
The Surface Patch Library (SPL)

Open-Source MATLAB toolbox: www.ccs.neu.edu/research/gpc/spl



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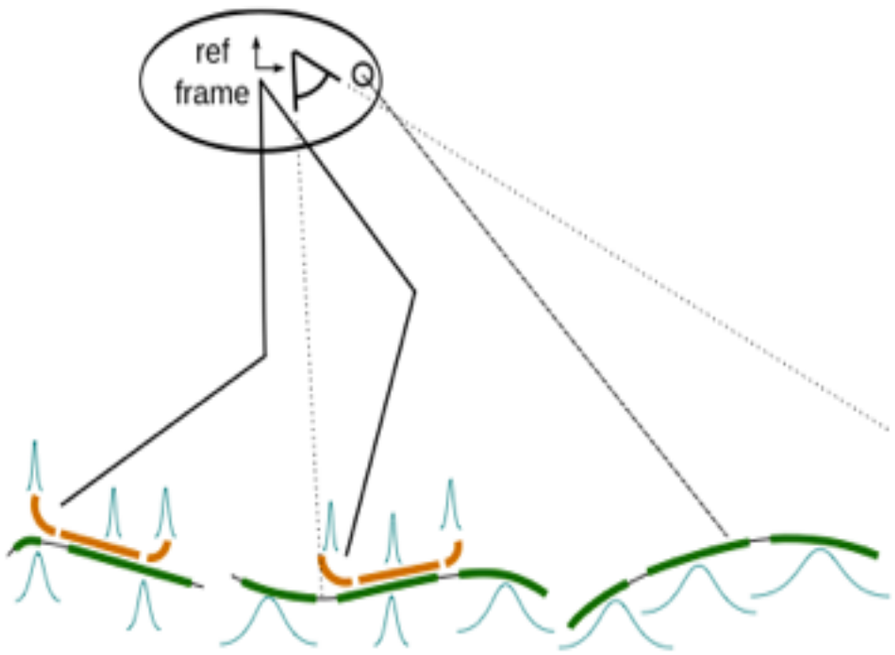
ICRA 2014 Workshop: MATLAB/Simulink for Robotics Education and Research

Perceiving Rough Terrain for Bipedal Locomotion

The “Hiking Task”

How bipedal robots should **perceive** and **model** an unknown rough terrain for potential navigation on it?

***Idea**: when humans are hiking on 3D rock surfaces, they consider a **sparse** set of footholds.*



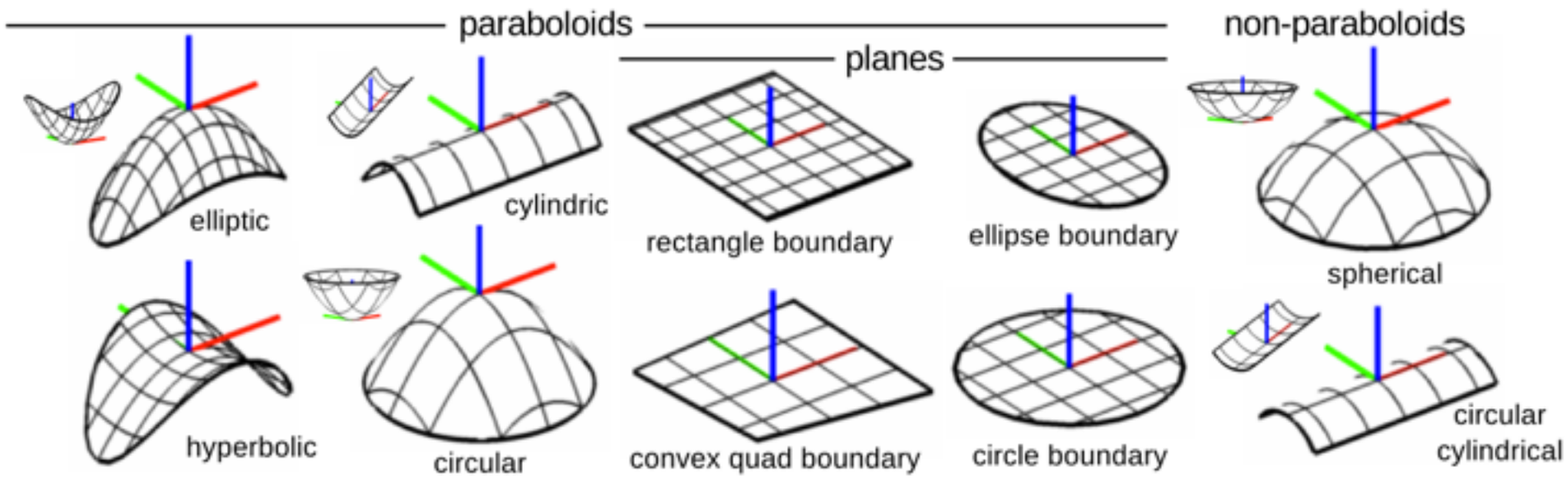
Sparsity of Footholds for Bipedal Robots requires:

- modeling local contact surface areas
- online perception algorithms to find them
- handling uncertainty for reliability

Modeling Bounded Curved Patches

The **S**urface **P**atch **L**ibrary is an open-source MATLAB toolbox for prototyping 3D rough terrain perception algorithms

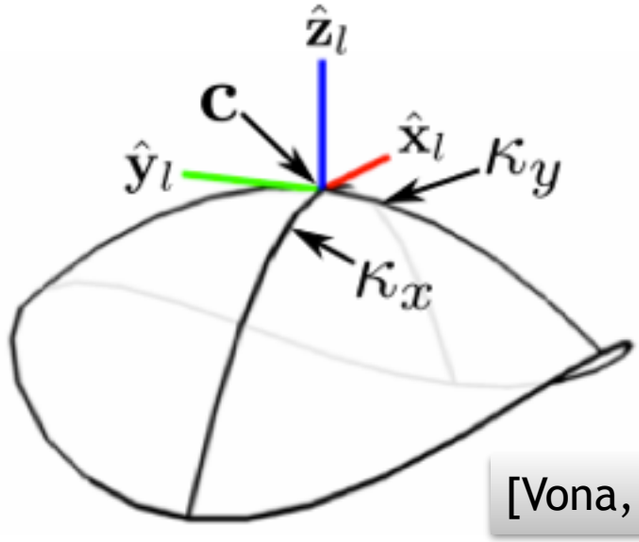
10 bounded curved-surface patch types for 3D contact regions




```
testpatchplot(1:10, {'aw',3,'as',1.5,'bw',2,'gw',1});
```

Bounded Curved Patch:

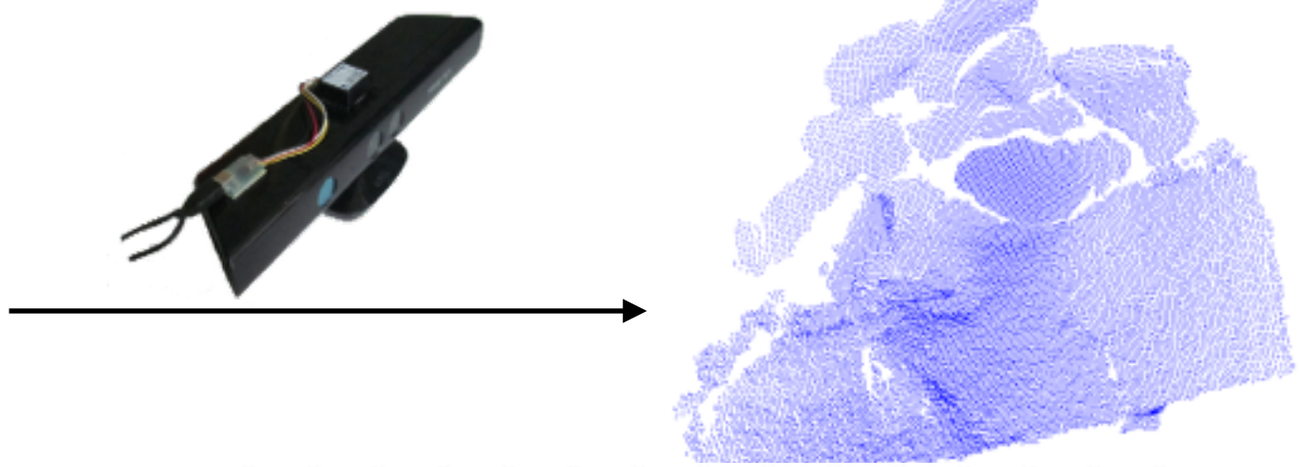
- *curvature*: $k \in R^2$
- *pose*: $(r,c) \in R^3 \times R^3$
- *bounds*: $d \in R^{1\text{-}5}$



[Vona, Kanoulas – IROS 2011]

Input 3D Point Cloud and Uncertainty Representation

Input: 640x480 3D point cloud from range sensor

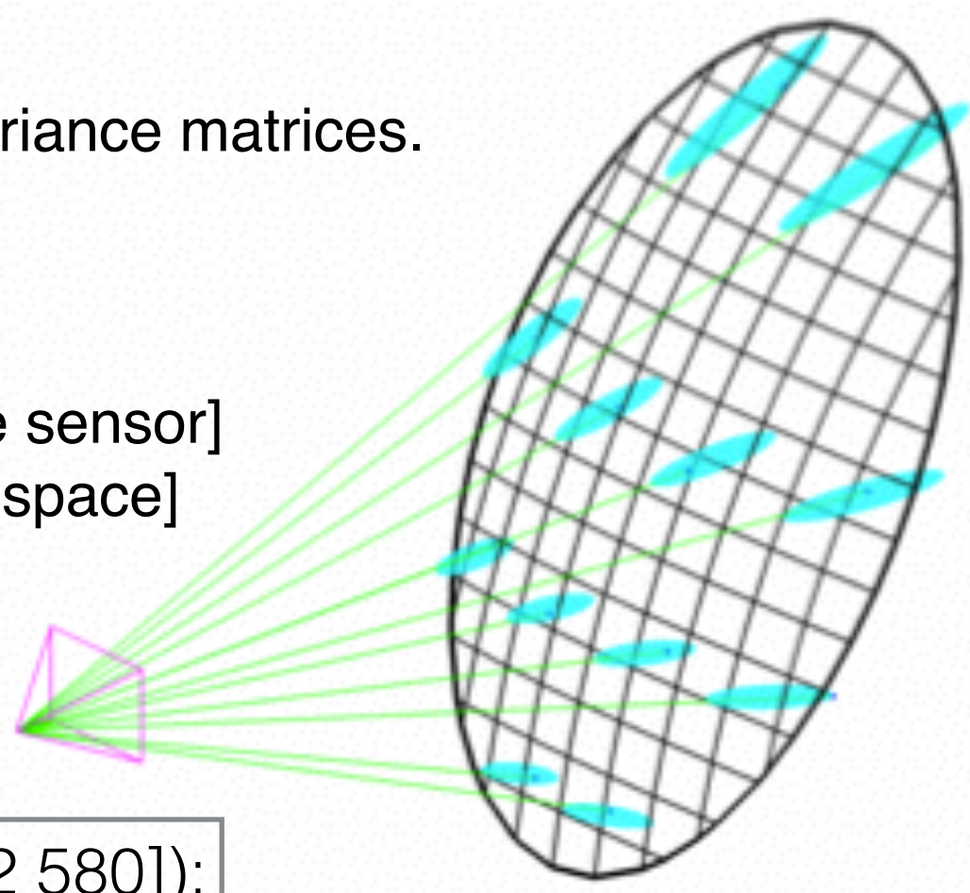


Uncertainty: Gaussian modeling with covariance matrices.

Two kinds of uncertainty:

- of the input points [associated with the sensor]
- of the fitted patch [in patch parameter space]

```
testrangecovar('stereo', [5 0.03 7.5e-2 580]);
```



95% probability error ellipsoid
for stereo range sensing.

Patch Fitting with Uncertainty Propagation

Given a set of 3D points q_i with uncertainty Σ_i, fit a patch p

Levenberg-Marquardt Least Squares

$$\mathbf{p}_{\text{opt}} = \underset{\mathbf{p} \text{ near } \mathbf{p}_0}{\operatorname{argmin}}\ r,\ r \triangleq \sum_{i=1}^{N} e_i^2,\ e_i \triangleq f(\mathbf{q}_i, \mathbf{p})$$

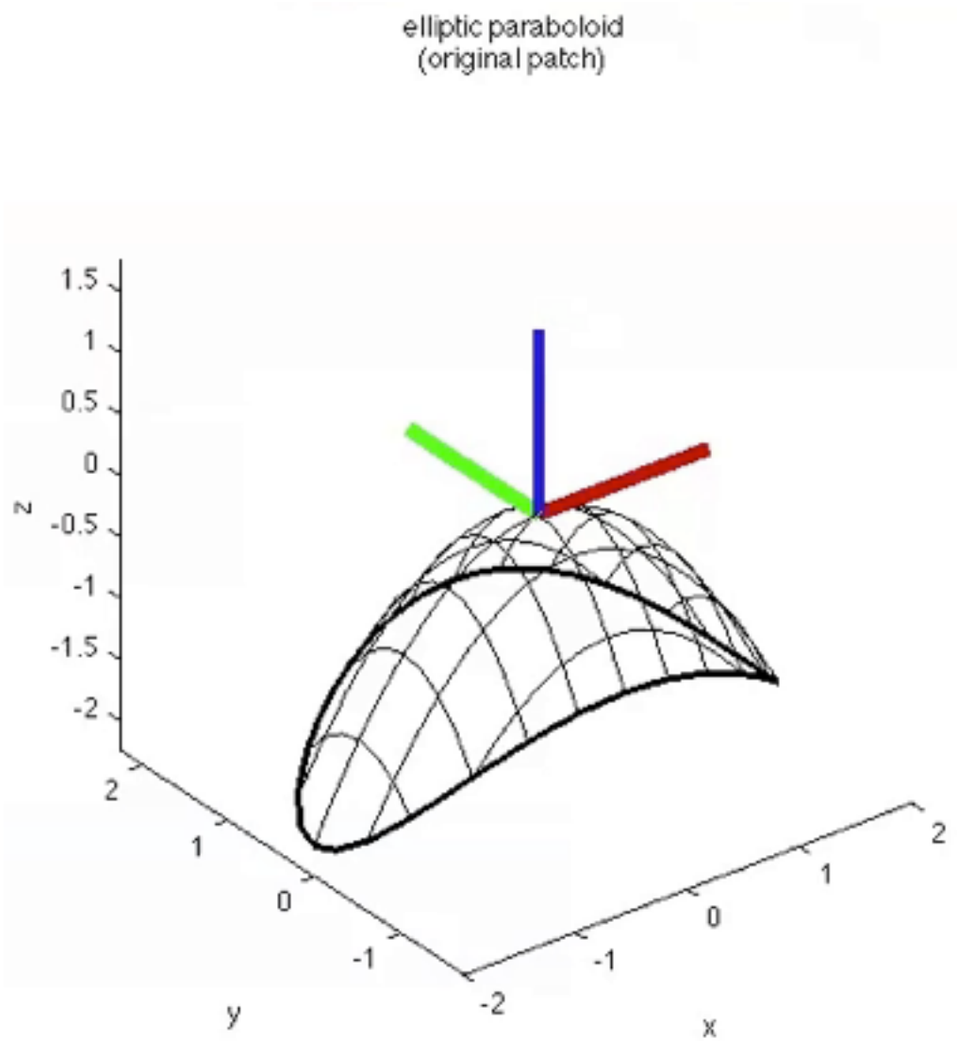
uncertainty propagation

$$\sigma_i = \sqrt{\operatorname{var}(f(\mathbf{q}_i, \mathbf{p}))} \triangleq \sqrt{v_f(i, \mathbf{p})}$$

$$v_f(i, \mathbf{p}) \triangleq \left(\frac{\partial f}{\partial \mathbf{q}}(\mathbf{q}_i, \mathbf{p})\right) \Sigma_i \left(\frac{\partial f}{\partial \mathbf{q}}(\mathbf{q}_i, \mathbf{p})\right)^T$$

weighted Levenberg-Marquardt

$$F(i, \mathbf{p}) \triangleq f(\mathbf{q}_i, \mathbf{p})/\sigma_i = f(\mathbf{q}_i, \mathbf{p})/\sqrt{v_f(i, \mathbf{p})}$$



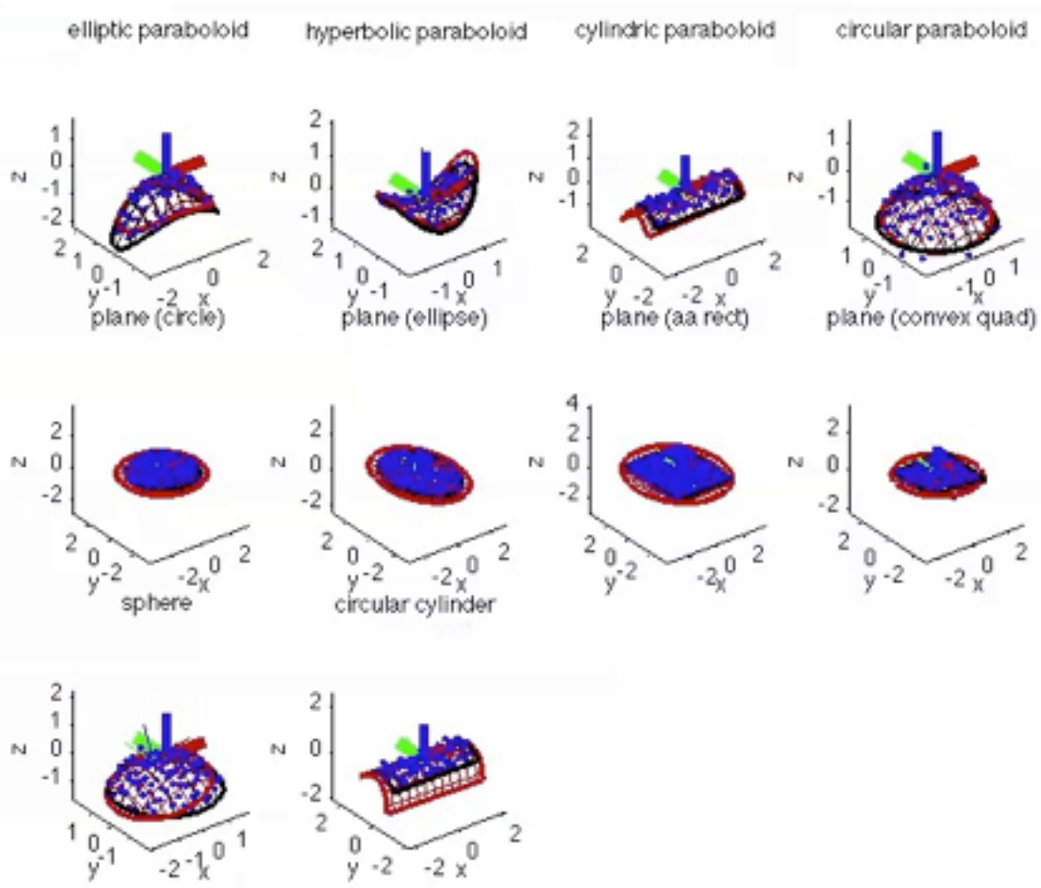
testpatchfit(1,'dbg',3);

Real-time, non-linear fitting algorithm, including quantified uncertainty.

[Vona, Kanoulas – IROS 2011]

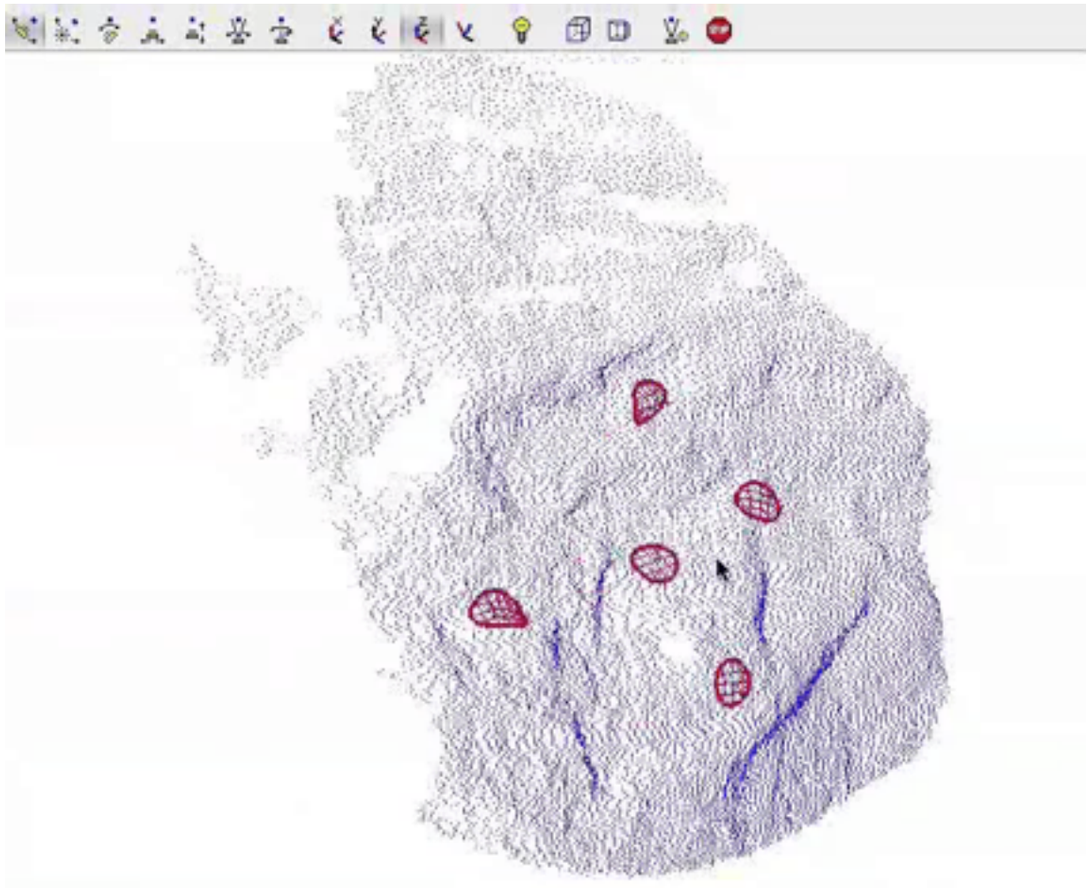
Patch Fitting with Uncertainty Propagation

Patch Fitting



testpatchfit(1:10,'dbg',6);

Interactive Segmentation

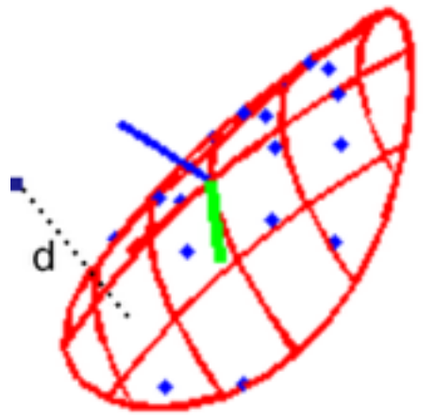


demomanseg();

[Vona, Kanoulas – IROS 2011]

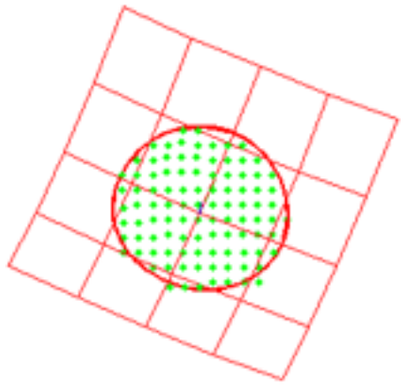
Patch Validation

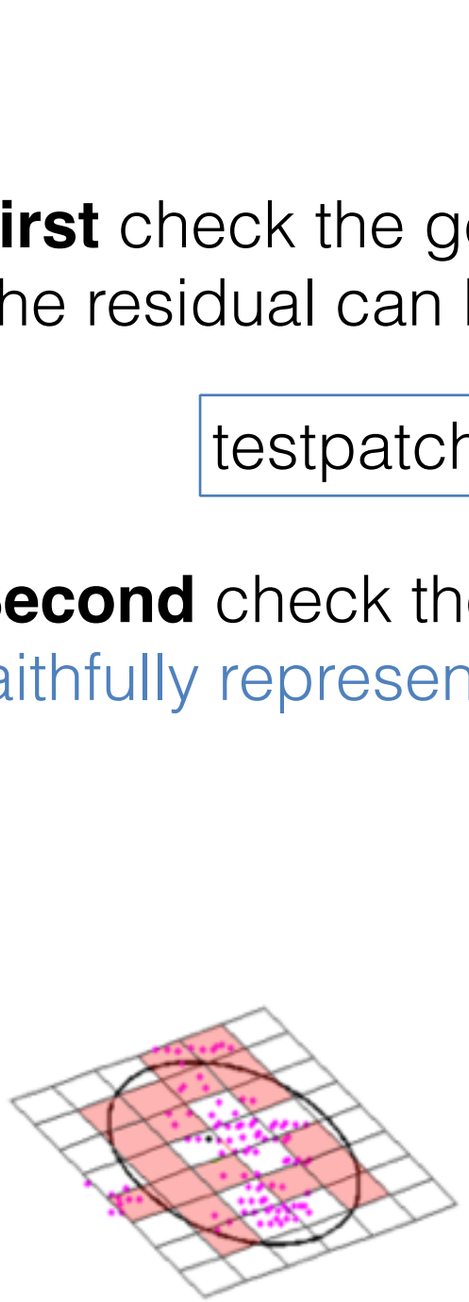
First check the geometric residual (patch fit quality): $res = \Sigma_{i=1}^{N} d_i^2$
The residual can be bad due to: 1) outliers, or 2) local minima in LM

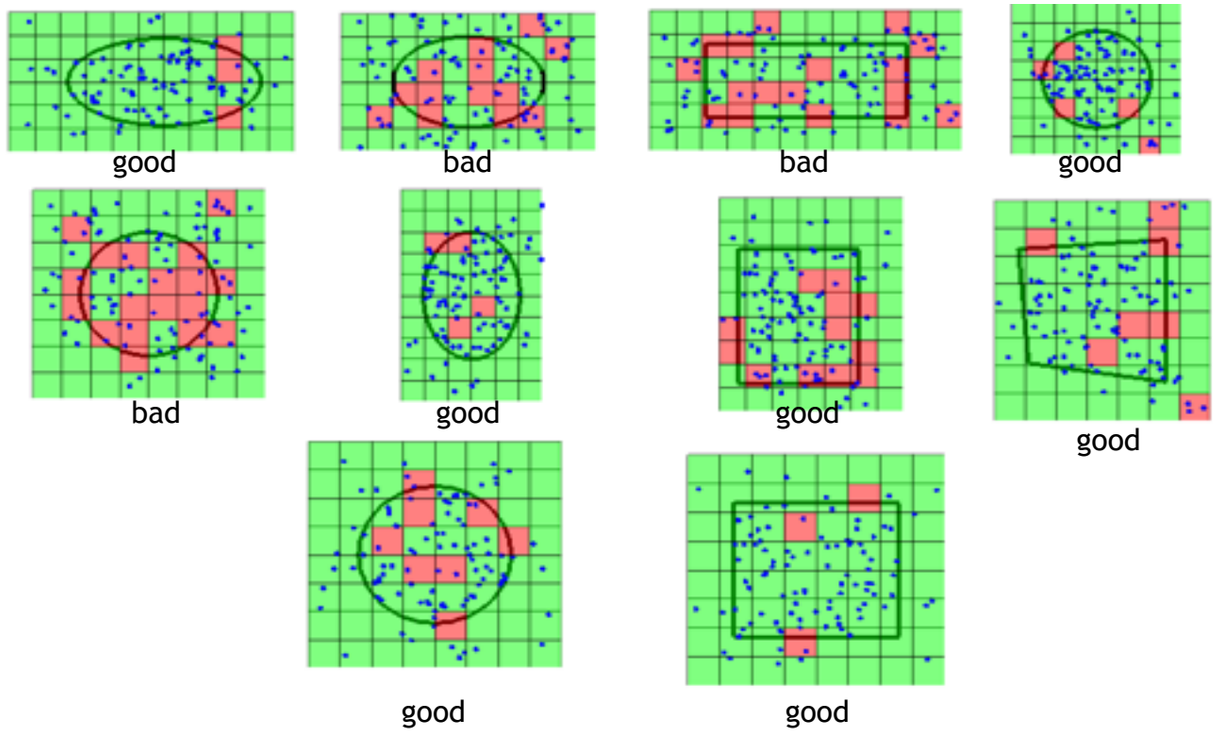


testpatchresidual();

Second check the coverage: a patch may fit the data but still not faithfully represent the surface.







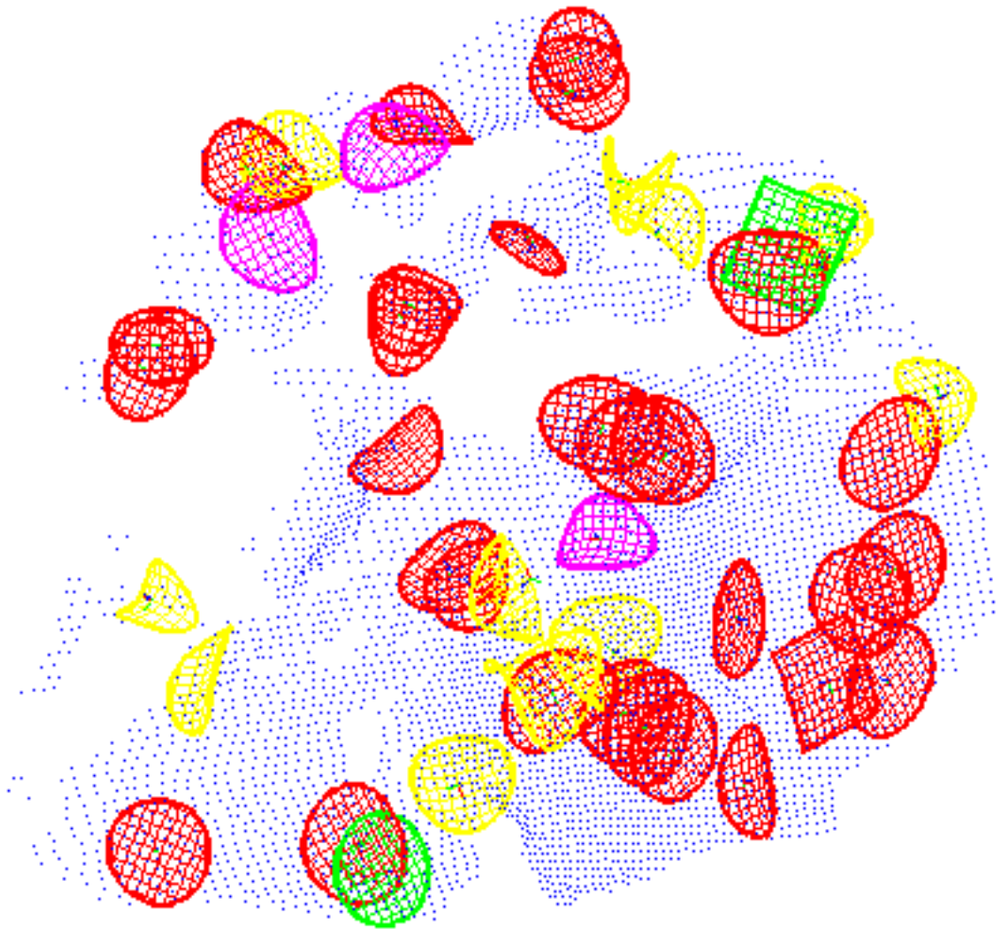
testpatchcoverage();

100 pts/patch, 50 cells/patch, 4ms/patch in Matlab
Good cell: 5 pts threshold
Bad patch: less than 20% good cells
Green: good cells **Red**: bad cells

[Kanoulas, Vona – ICRA 2013]

Automatic Patch Fitting Segmentation

fit **30** uniformly random paraboloids with ellipse boundaries



red patches **valid**

Rejection Colors

- yellow: curvature ([-30,30])
- purple: residual (0.01)
- green: coverage

demoautoseg();

[Kanoulas, Vona – ICRA 2013]

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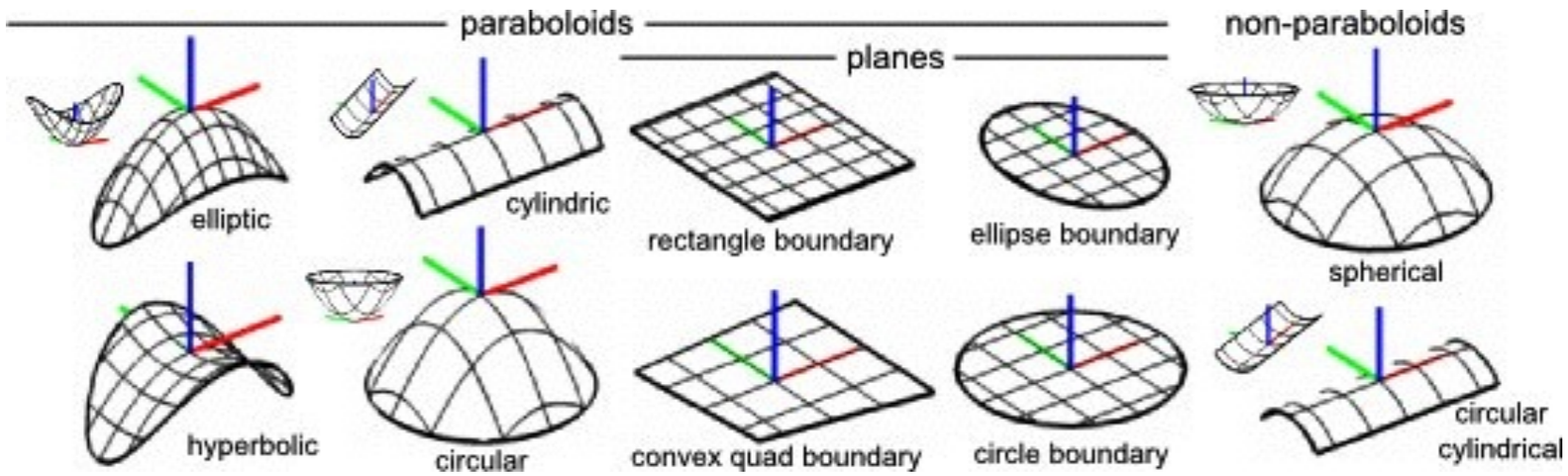
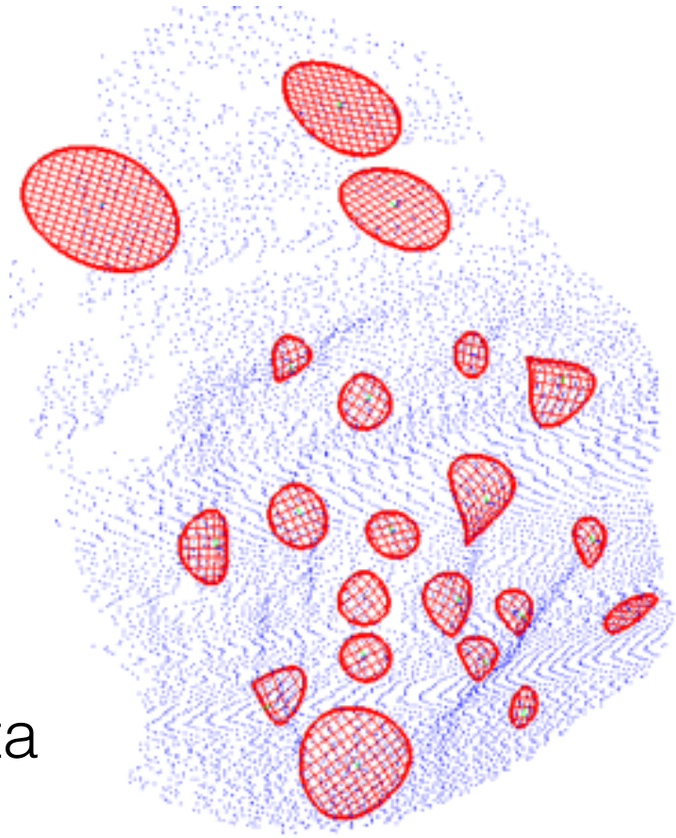
Prototyping 3D rough terrain perception algorithms

Marsette Vona and Dimitrios Kanoulas, "Curved Surface Contact Patches with Quantified Uncertainty", IROS 2011

Dimitrios Kanoulas and Marsette Vona, "Sparse Surface Modeling with Curved Patches", ICRA 2013





- models of 10 types of bounded curved surfaces
- an algorithm to fit patches to potentially noisy sensor data
- an algorithm to validate patches
- uncertainty is quantified throughout using covariance matrices
- the patches can model local contact regions both in the environment