# Feature Sensitive Mesh Segmentation with Mean Shift

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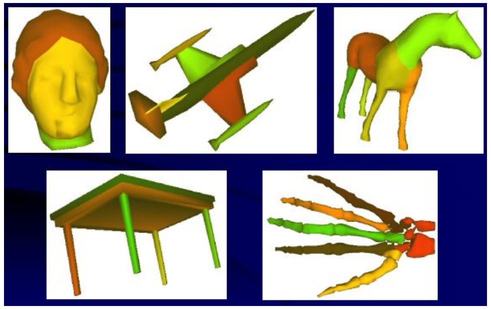
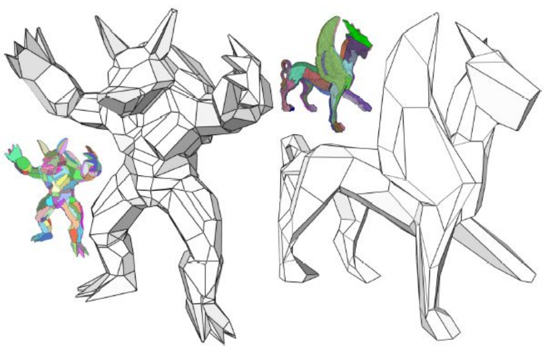
# Introduction (1) : Why segmentation?

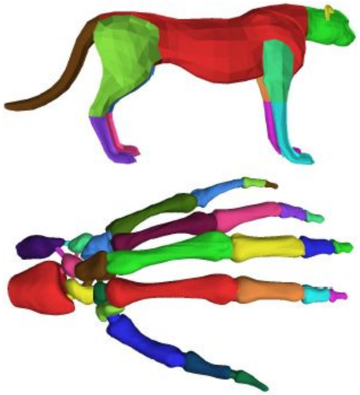
- ***Mesh Segmentation = basic GMP tool***
  - Shape understanding
  - Mesh simplification
  - Mesh matching, retrieval, animation
  - Texture mapping
  - ...



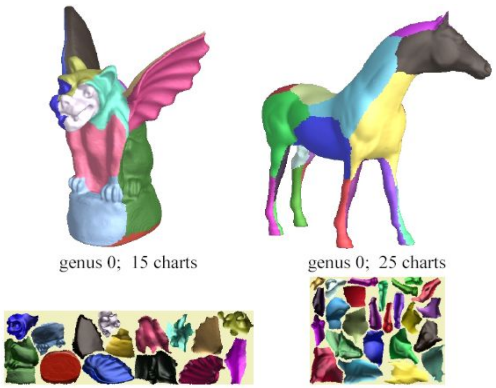
[Liu et al. 04]



[Cohen-Steiner et al. 04]



[Funkhouser et al. 04]




[Sander et al. 03]

# Introduction (2)

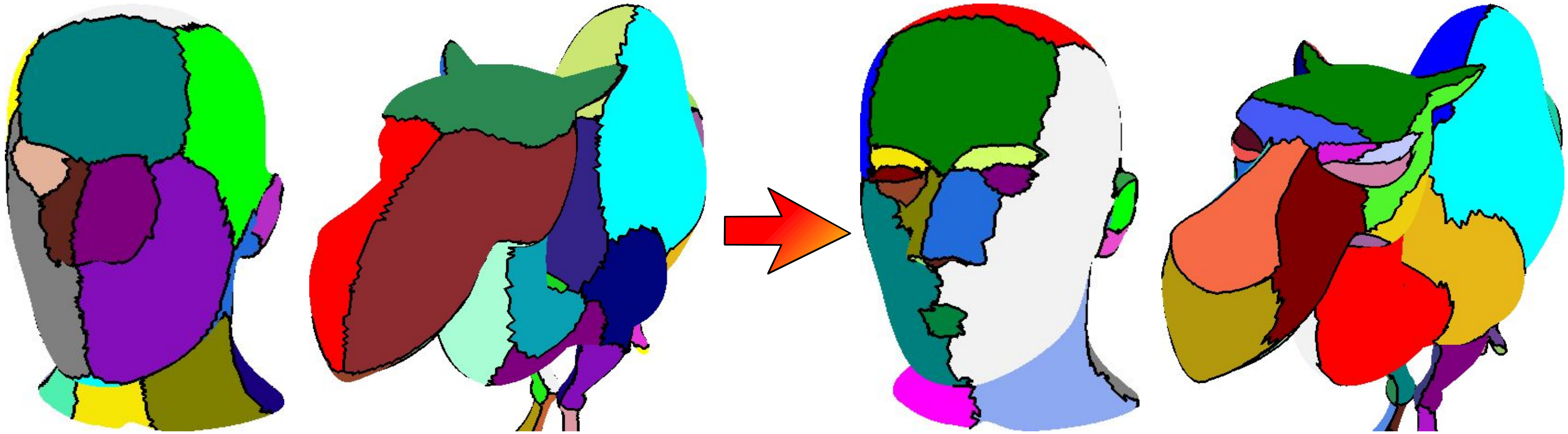
## What is the "meaningful" segmentation?

- Segmentation zoo ... many criteria, applications
- Perceptually meaningful features
  - *High variation points of surface normals (psychological experiments [Hoffman and Richards])*
  - *Feature = normals*

***Main idea behind our approach:***

- Enhance features via clustering the field of normals
  - *No change geometry. Change normals.*
- Segment a mesh according to the enhancement

# Contributions

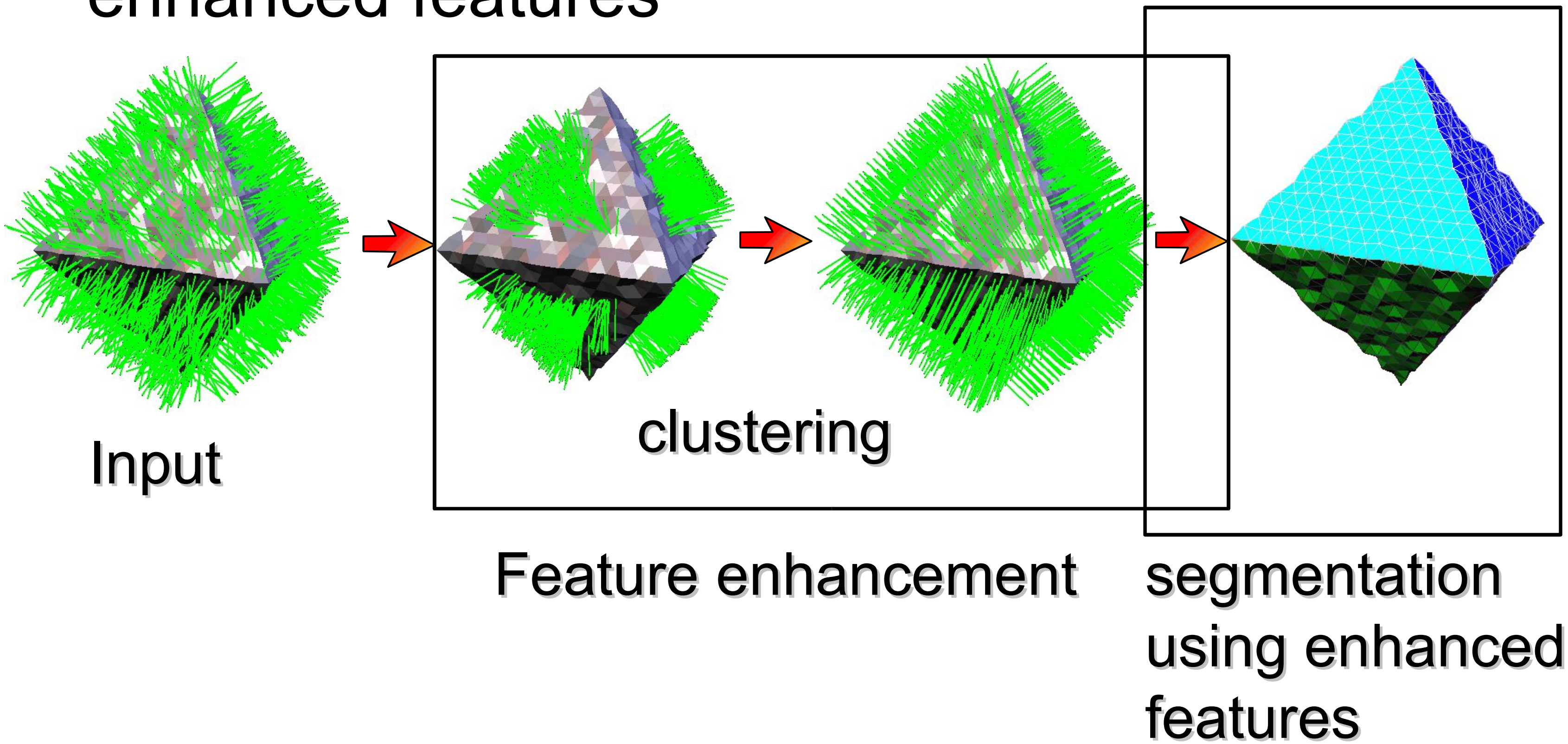


Without feature enhancement With feature enhancement

- Exploiting feature sensitivity
  - *Feature enhancing method*
  - *Segmentation method which exploit enhanced features*

# Our approach

- Enhance features
- Use a segmentation method adapted to enhanced features



# Enhancing features

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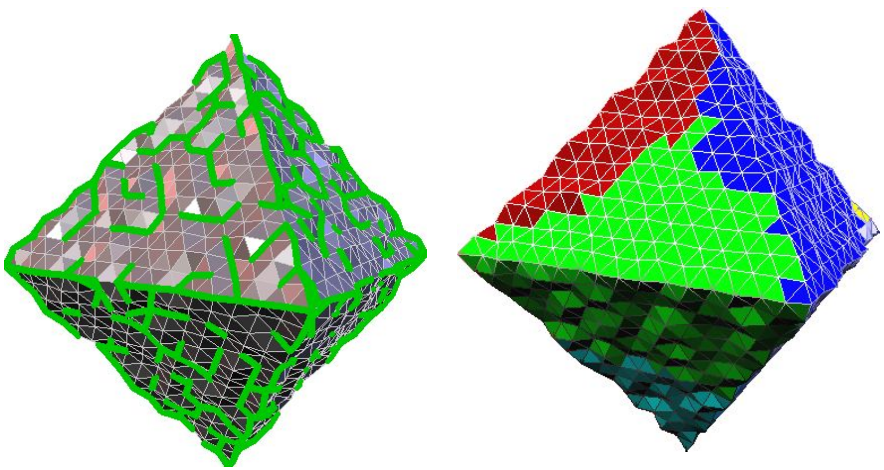
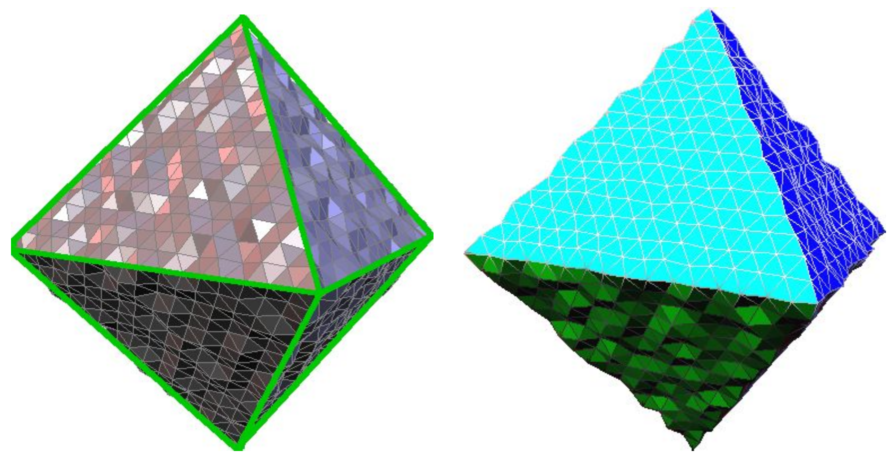
- Features = points of high variation of surface normals
- Clustering normals
  - ***Enhancing the important features + ignoring small-scale surface details***



Conventional mesh segmentation doesn’t work well because of small-scale surface details



The same segmentation method is applied to the same mesh with modified (clustered) normals

# Overview Demo

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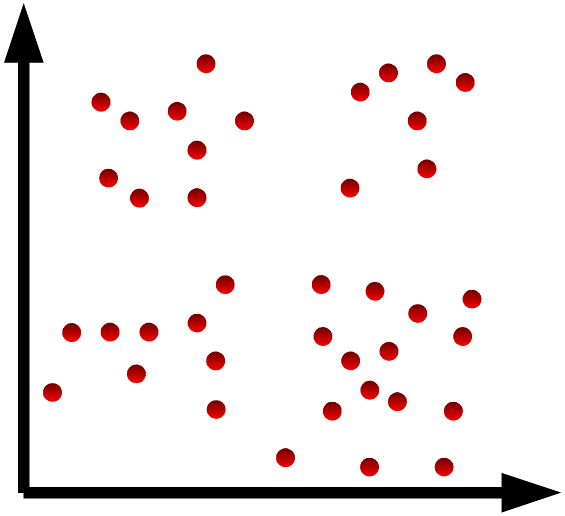
- Without feature enhancement with K-means
- Feature sensitive segmentation method

# Outline

- <u>Feature enhancement</u>
  - *<u>Mean Shift : What is Mean Shift?</u>*
  - *Mean Shift on a mesh*
- Feature sensitive segmentation
  - *Segmentation algorithm*
  - *Demo*
- Experimental results
- Conclusions

# Mean Shift : overview

- *Scattered data clustering in d-dim*
- *Theoretical foundation*
- Only one intuitive parameter
  - *kernel support size: h*



d-dim feature space
scattered data

# Mean Shift : overview

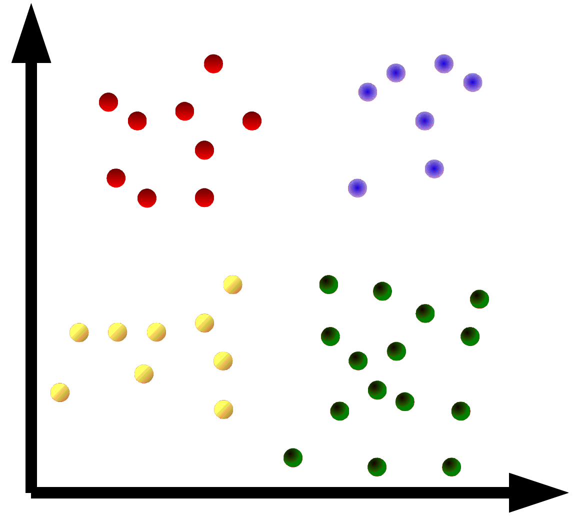
- *Scattered data clustering in d-dim [Fukunaga et al. 75]*
- Theoretical foundation
- Only one intuitive parameter
  - *kernel support size: h*

$$\nabla \hat{f}(\mathbf{x}) = \frac{2c}{Nh^{d+2}} \sum_{i=1}^{N} g\left( \left\| \frac{\mathbf{x} - \mathbf{x}_i}{h} \right\|^2 \right) \mathbf{m}(\mathbf{x})$$

Mean Shift vector

$$\mathbf{m}(\mathbf{x}) = \frac{\sum_{i=1}^{N} \mathbf{x}_i g\left( \left\| \frac{\mathbf{x}-\mathbf{x}_i}{h} \right\|^2 \right)}{\sum_{i=1}^{N} g\left( \left\| \frac{\mathbf{x}-\mathbf{x}_i}{h} \right\|^2 \right)} - \mathbf{x}$$

- Mode detection : $\nabla \hat{f}(\mathbf{x}) = 0$

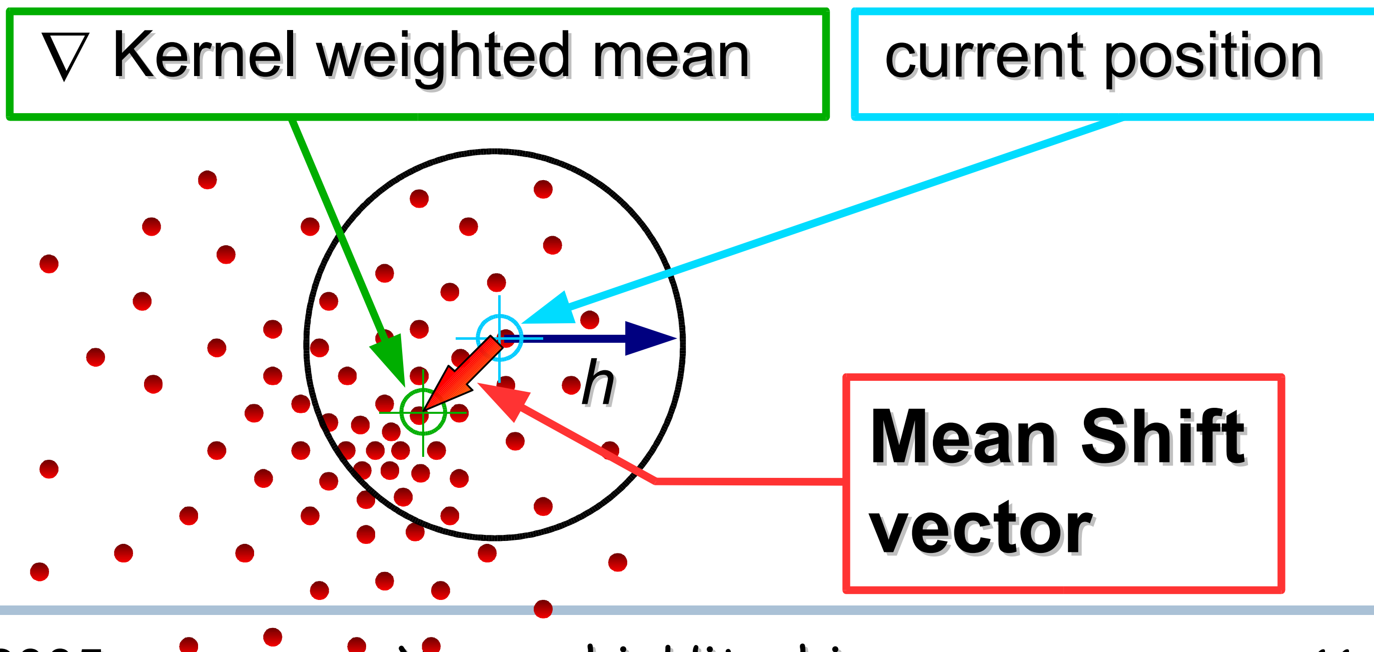


d-dim feature space clustering example

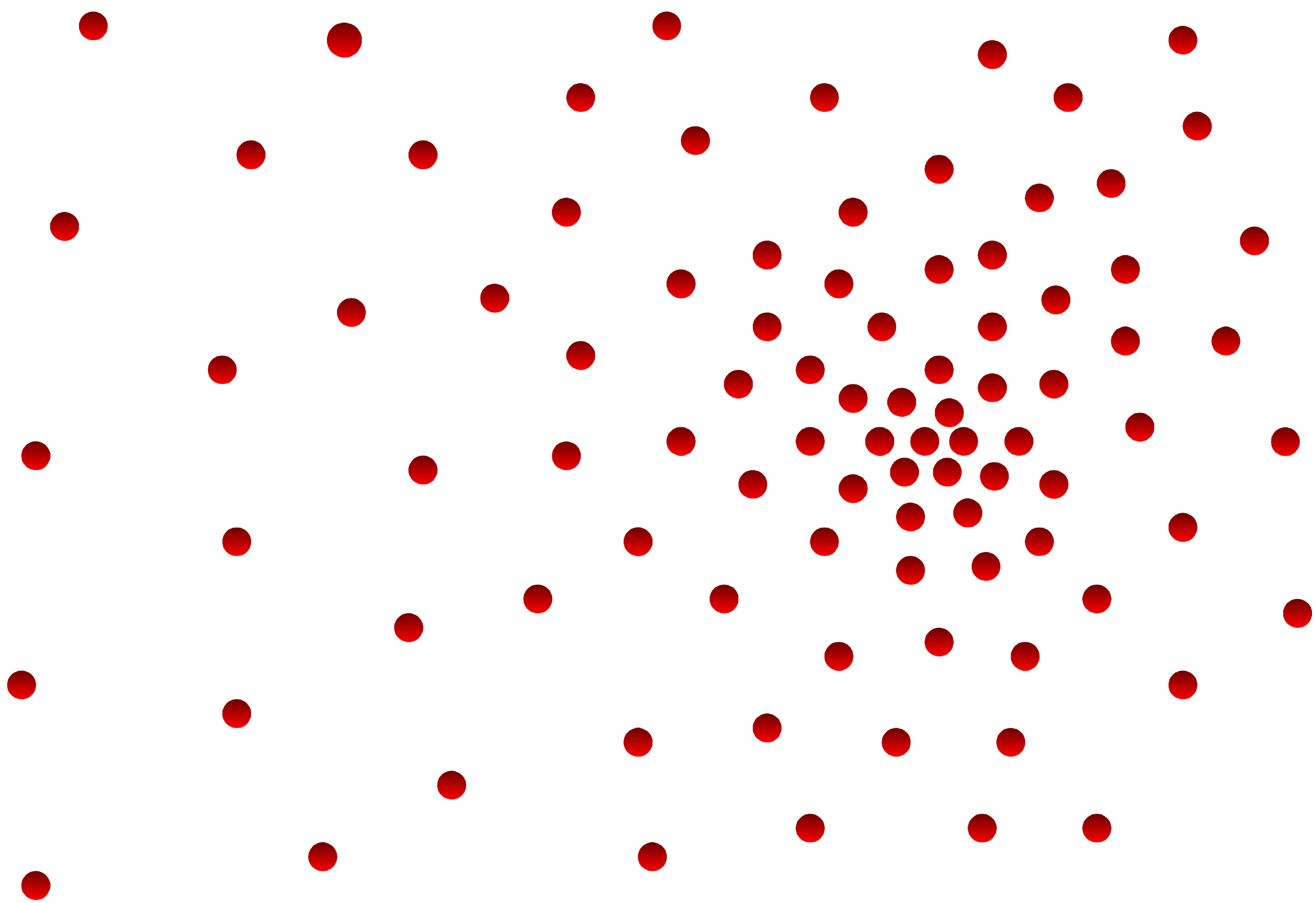
# Mean Shift vector : *m(x)*

- *Find the local densest direction*

$$\mathbf{m}(\mathbf{x}) = \underbrace{\frac{\sum_{i=1}^{N} \mathbf{x}_i g\left(\left\|\frac{\mathbf{x}-\mathbf{x}_i}{h}\right\|^2\right)}{\sum_{i=1}^{N} g\left(\left\|\frac{\mathbf{x}-\mathbf{x}_i}{h}\right\|^2\right)}} - \underbrace{\mathbf{x}}$$

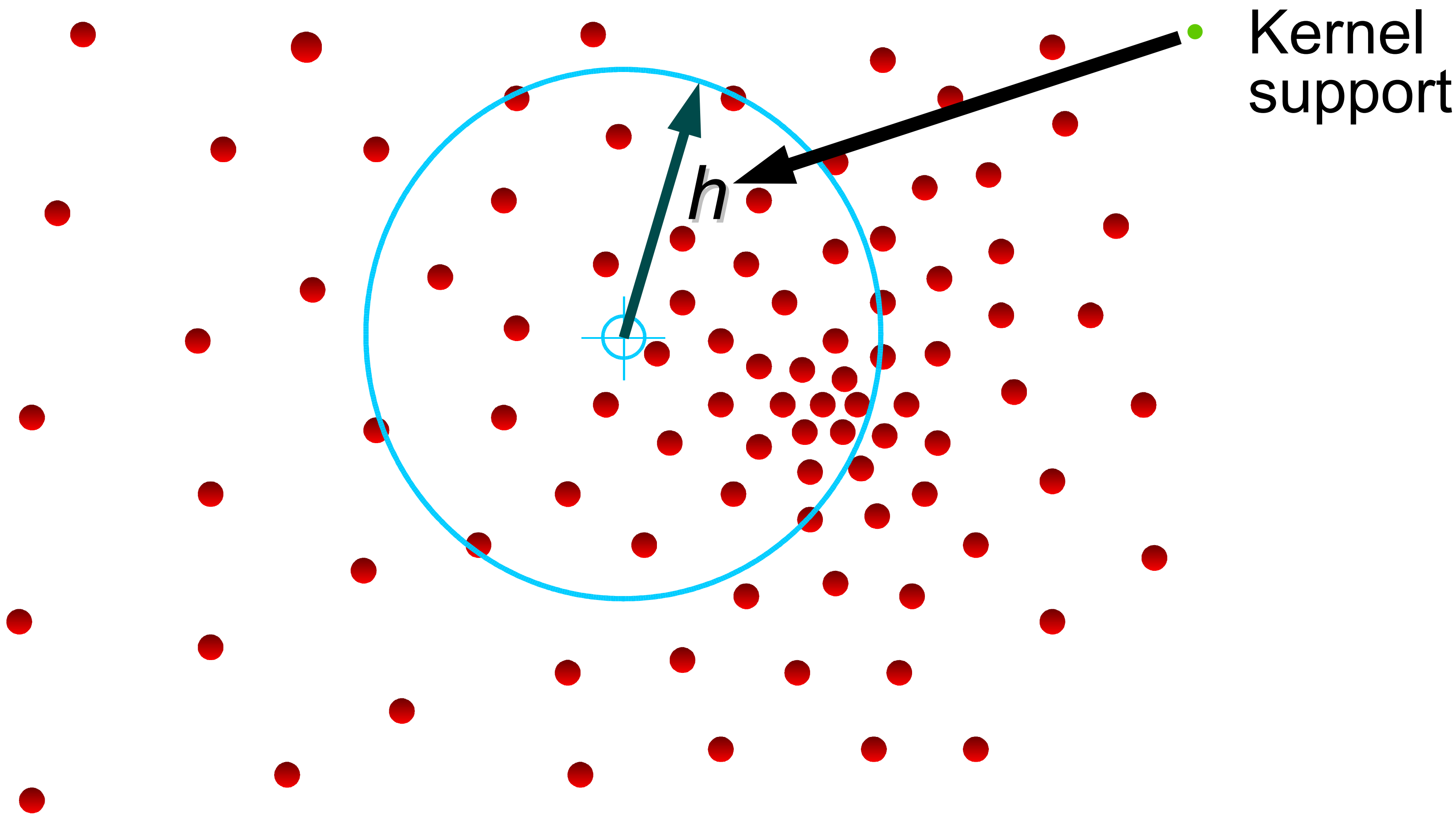


# How Mean Shift works
## [Ukrainitz and Sarel]



- Objective : Find the densest region

# How Mean Shift works
## [Ukrainitz and Sarel]




- Objective : Find the densest region

# How Mean Shift works
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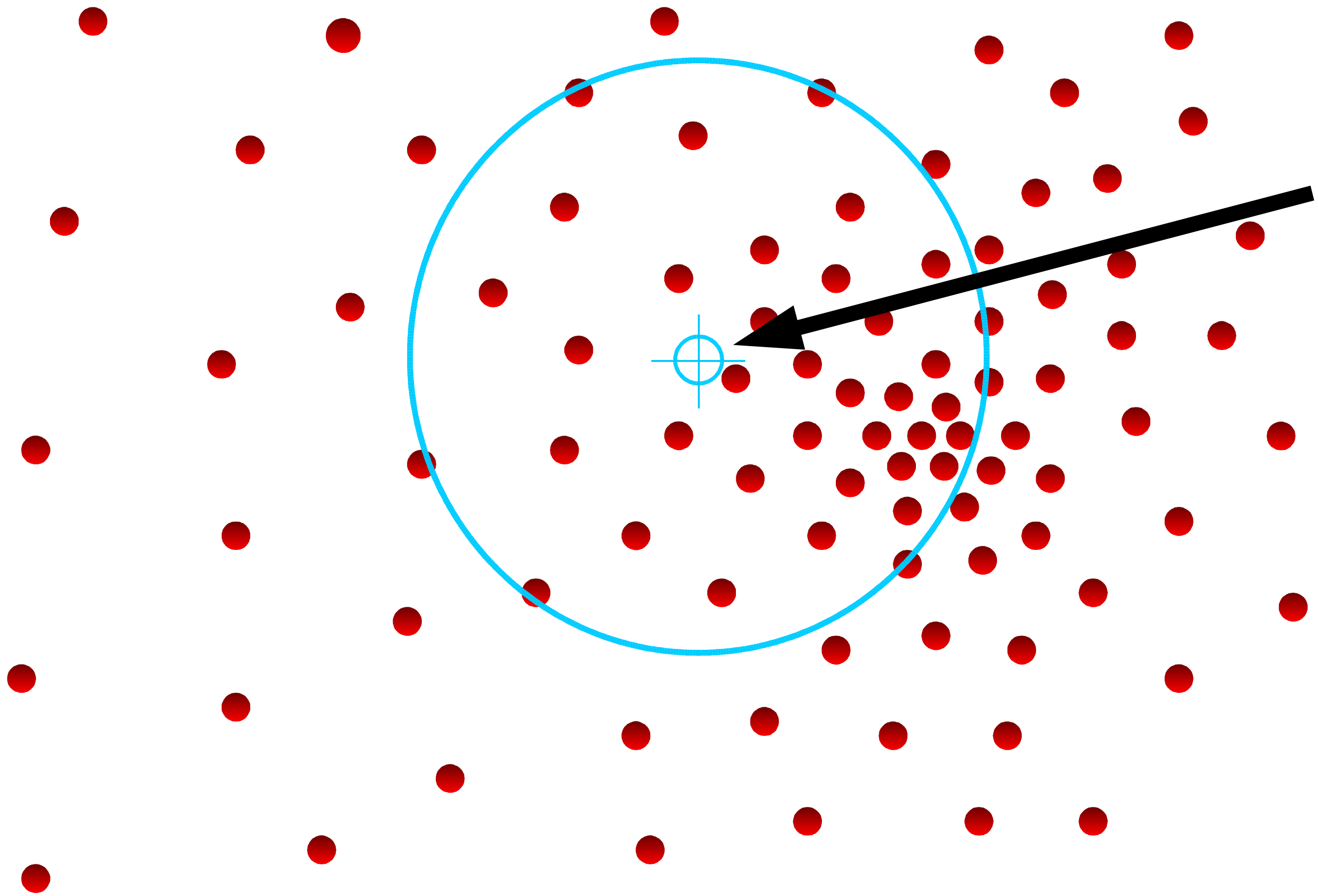
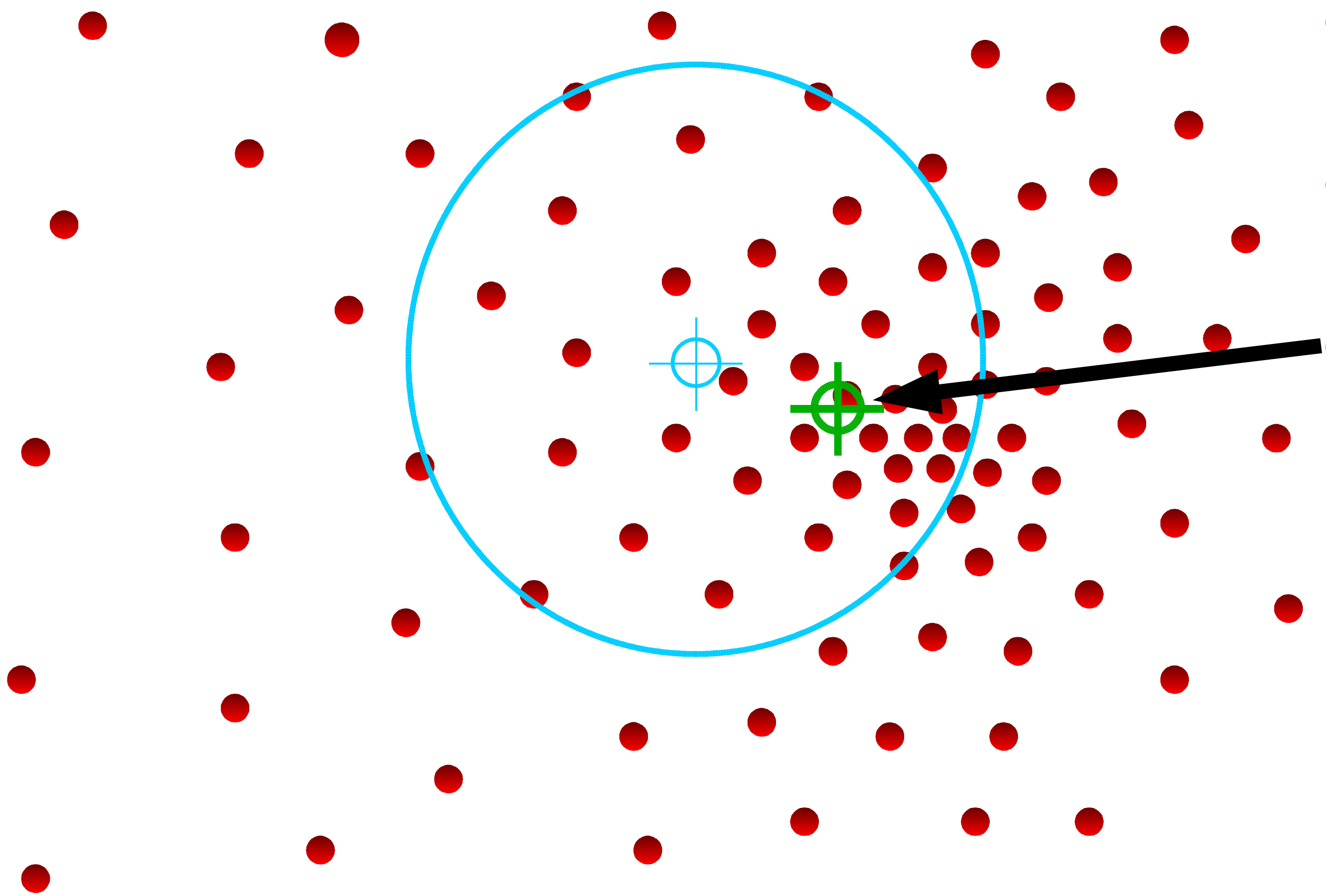


- Kernel support
- Center of region

- Objective : Find the densest region

# How Mean Shift works
## [Ukrainitz and Sarel]

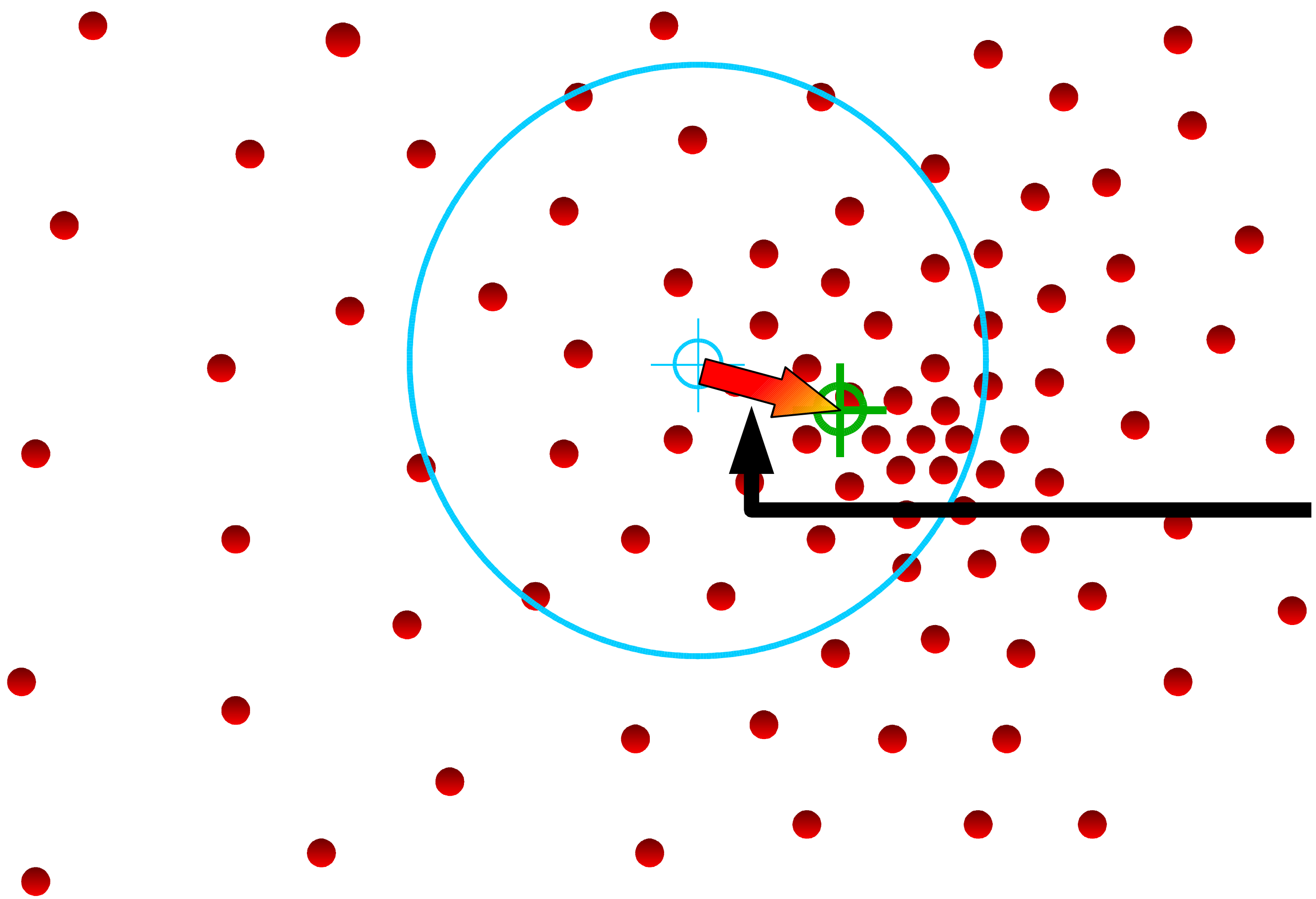


- Kernel support
- Center of region
- Center of mass

- Objective : Find the densest region

# How Mean Shift works

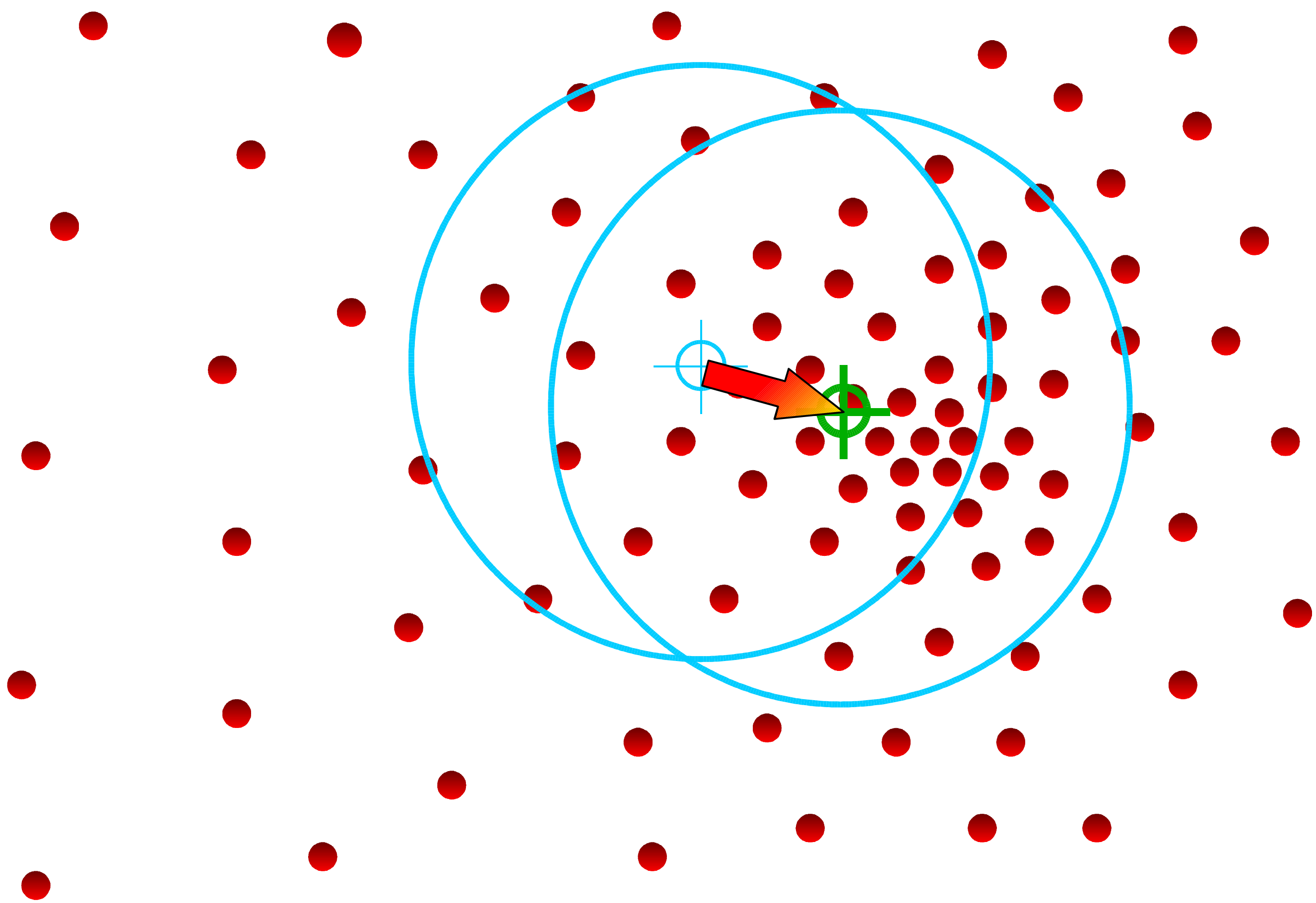
## [Ukrainitz and Sarel]



- Kernel support
- Center of region
- Center of mass
- Mean Shift vector

- Objective : Find the densest region

# How Mean Shift works
## [Ukrainitz and Sarel]



- Kernel support
- Center of region
- Center of mass
- Mean Shift vector

- Objective : Find the densest region

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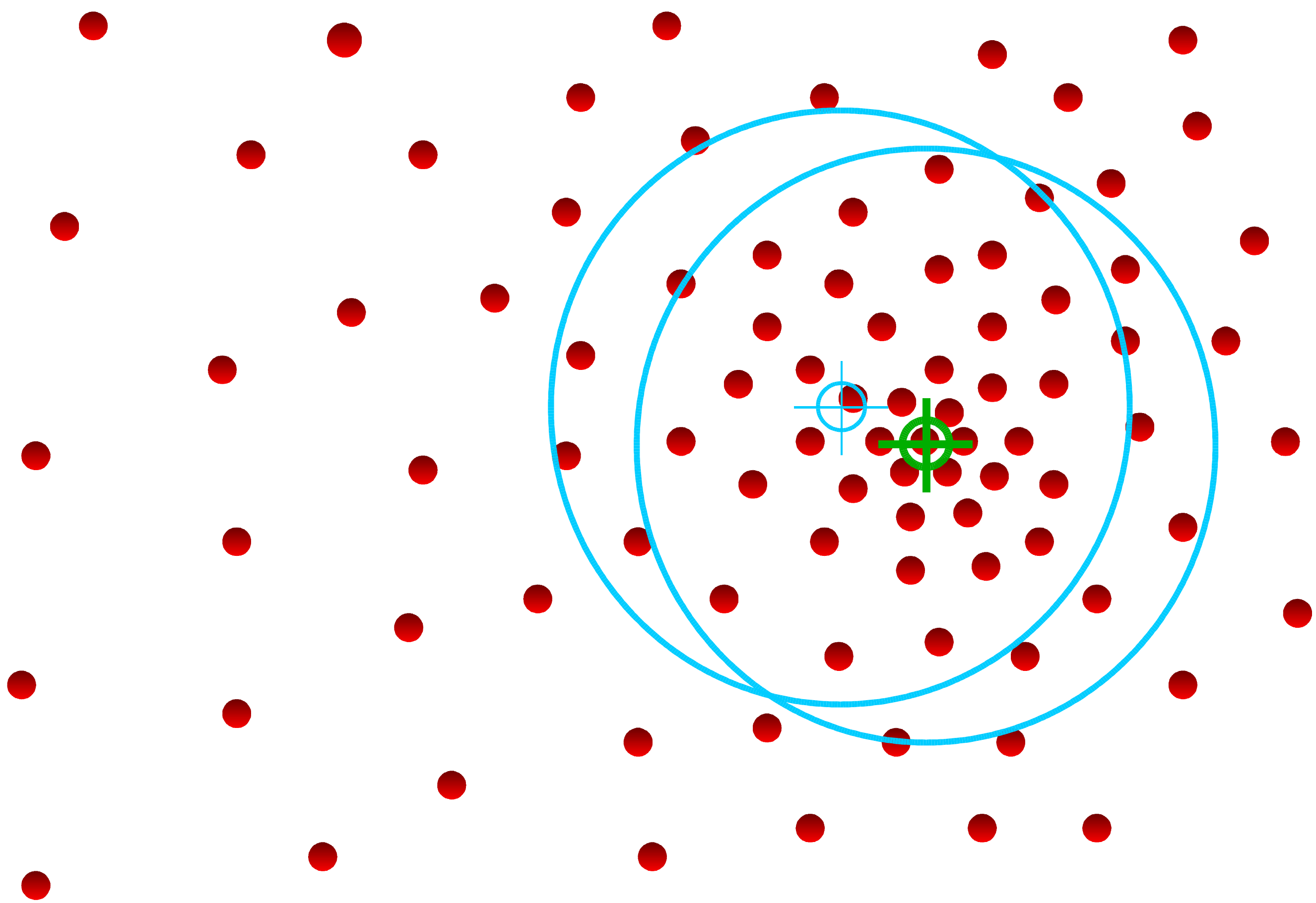
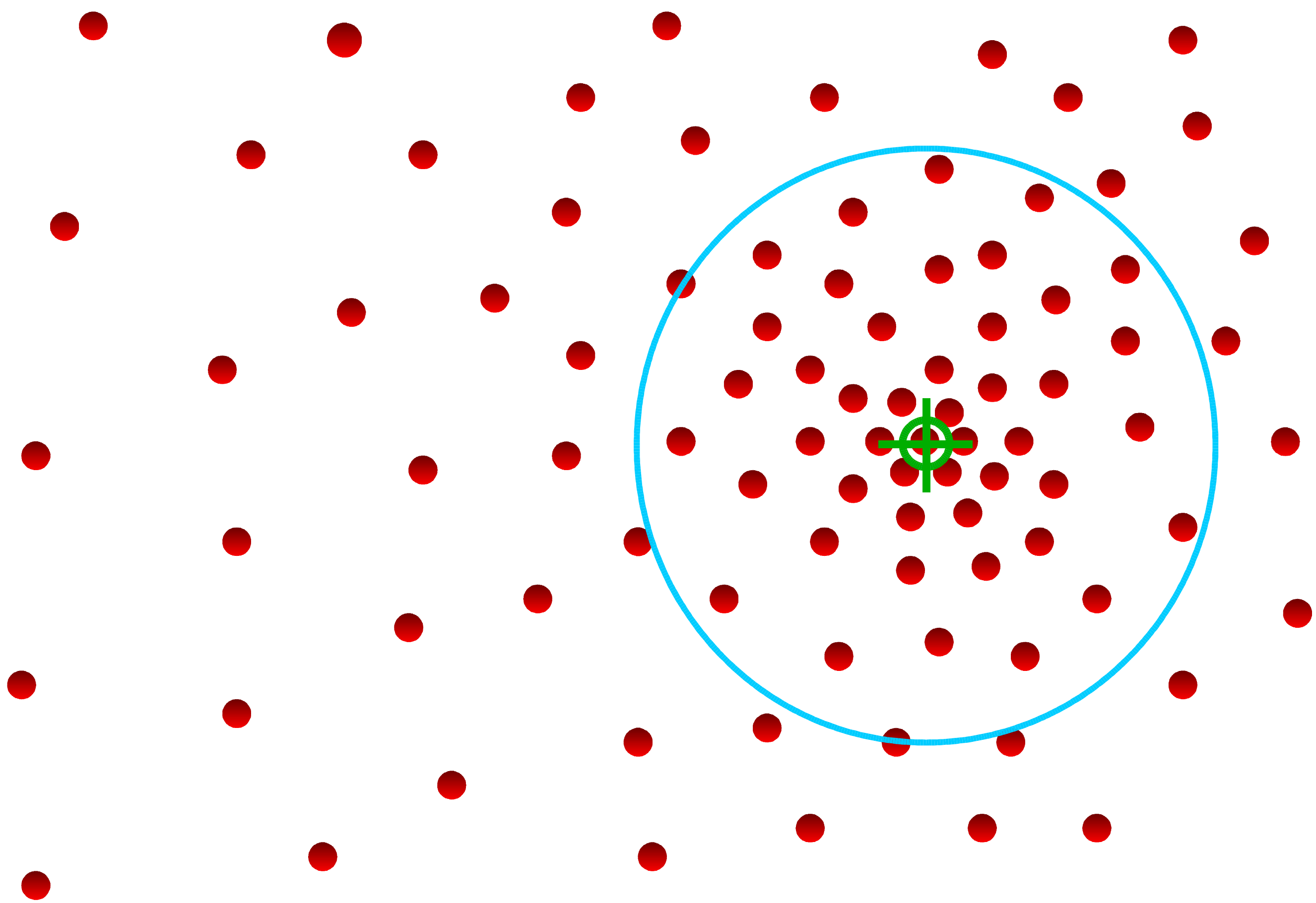


- Kernel support
- Center of region
- Center of mass
- Mean Shift vector

- Objective : Find the densest region

# How Mean Shift works

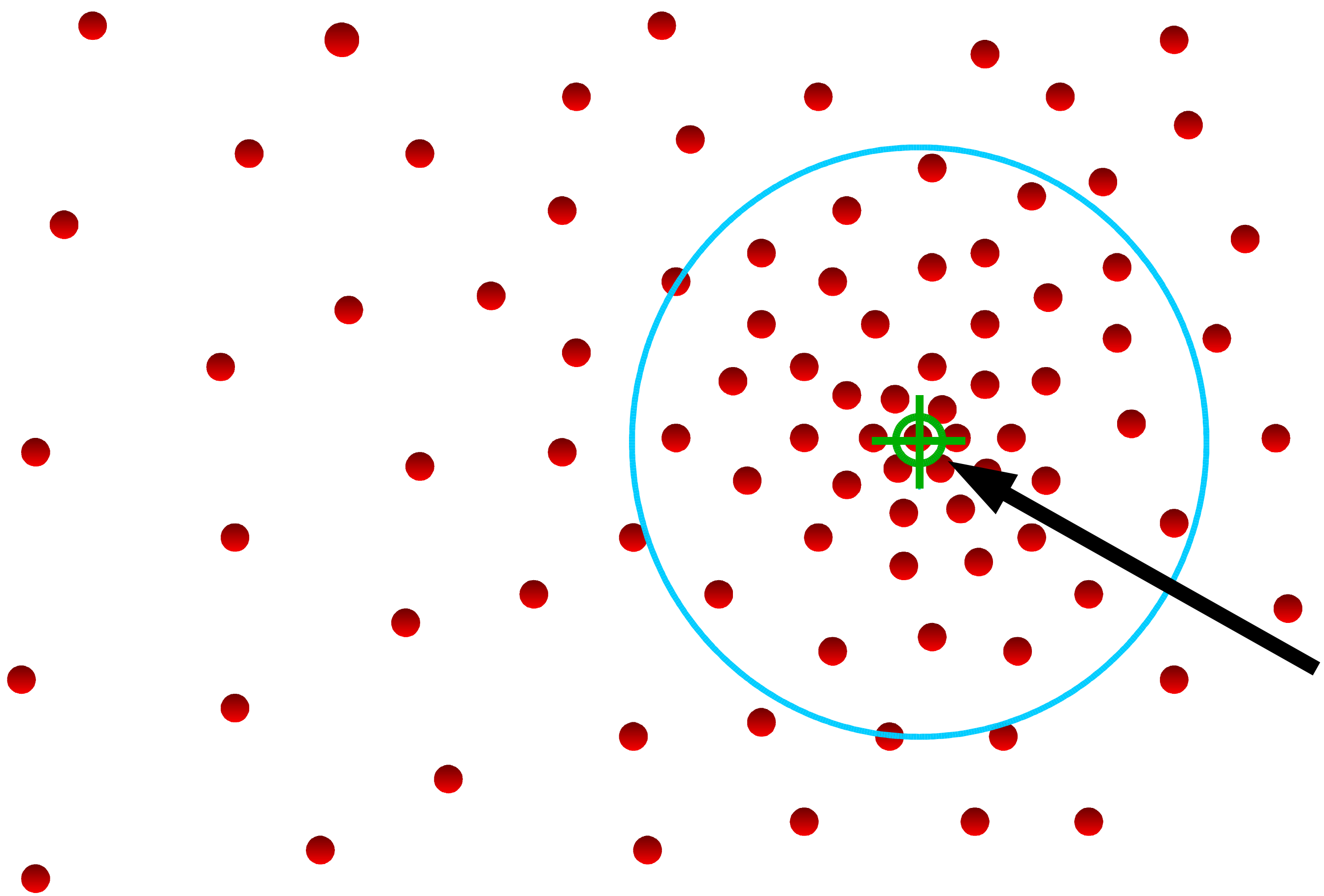
## [Ukrainitz and Sarel]



- Kernel support
- Center of region
- Center of mass
- Mean Shift vector

- Objective : Find the densest region

# How Mean Shift works
## [Ukrainitz and Sarel]



- Kernel support
- Center of region
- Center of mass
- Mean Shift vector
- Converged center
- Attraction point

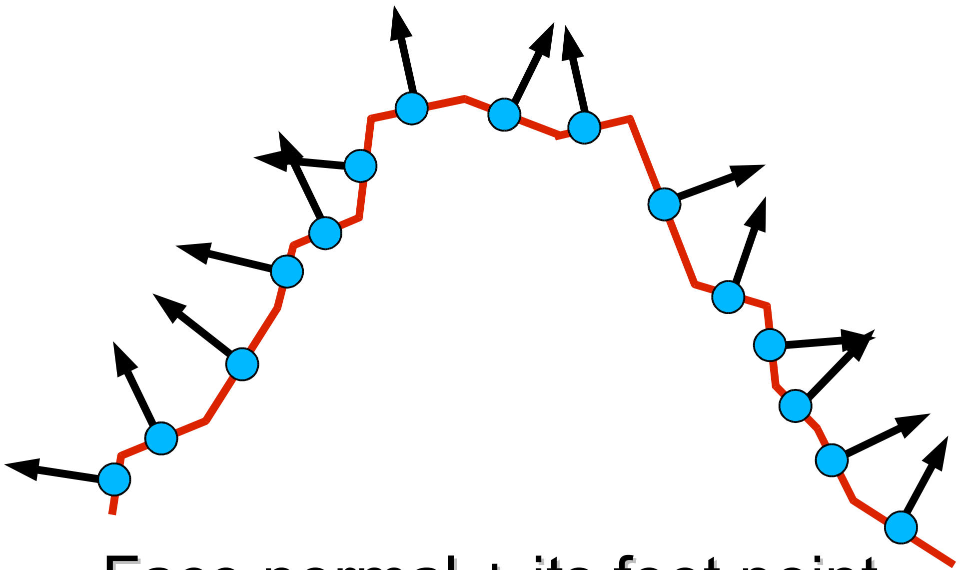
- Objective : Find the densest region

# Outline

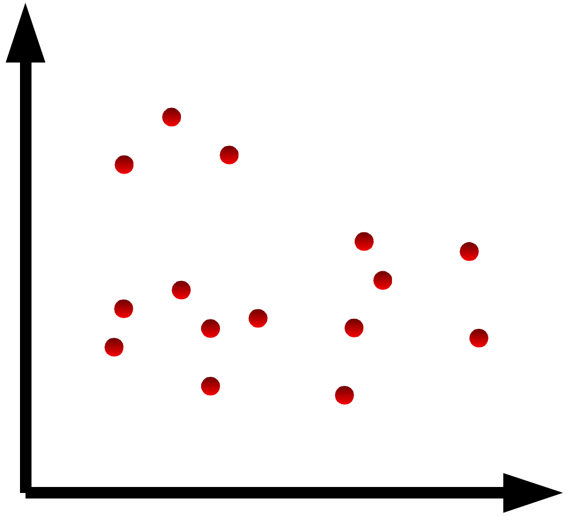
- <u>Feature enhancement</u>
  - *Mean Shift : What is Mean Shift?*
  - *<u>Mean Shift on a mesh</u>*
- Feature sensitive segmentation
  - *Segmentation algorithm*
  - *Demo*
- Experimental results
- Conclusions

# Feature enhancement:
## Clustering mesh normals with Mean Shift

- Feature space
  - *6-d points (position and normal) (5-d)*



Face normal + its foot point
(face centroid)

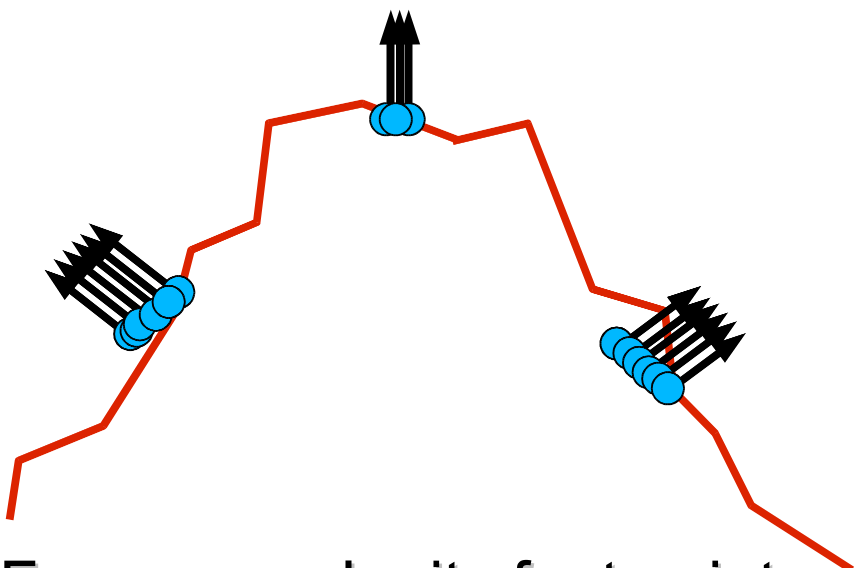


Feature space

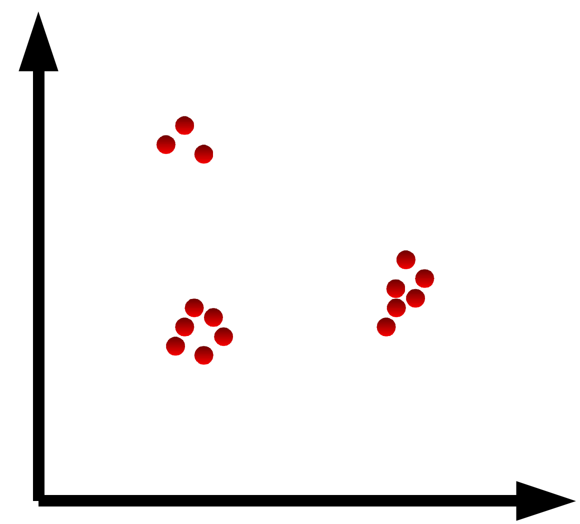
# Feature enhancement:

## Clustering mesh normals with Mean Shift

- Mean Shift process
  - *converge to attraction points in 6-dim space (basin of attraction)*



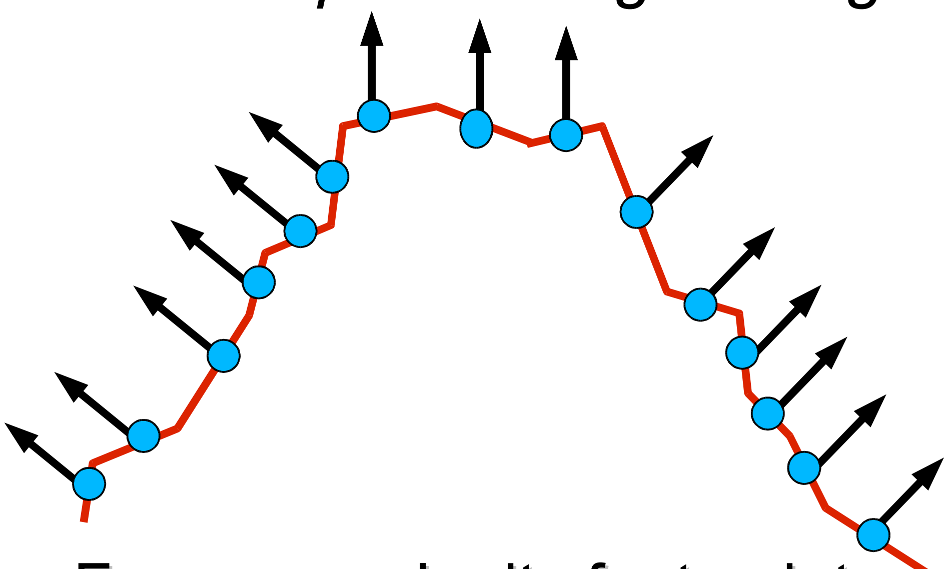
Face normal + its foot point (face centroid)



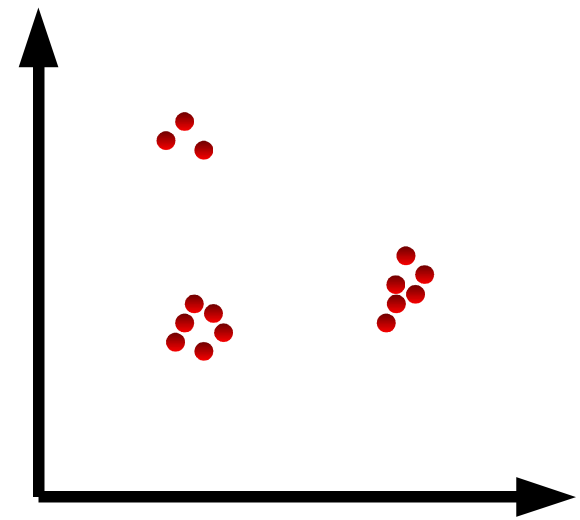
Feature space

# Feature enhancement:
## Clustering mesh normals with Mean Shift

- Back projecting normal to the original positions
  - *Feature preserving normal filtering*
  - *Preprocessing for segmentation*



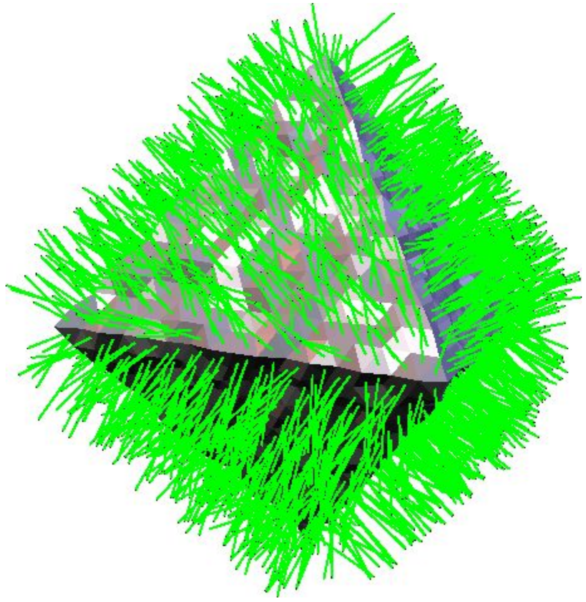
Face normal + its foot point (face centroid)



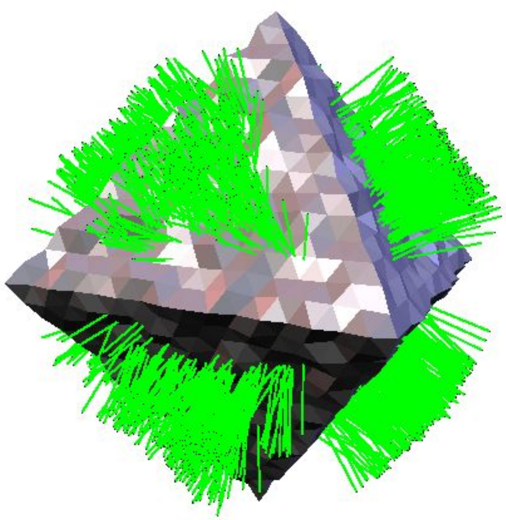
Feature space

# Enhanced normal example

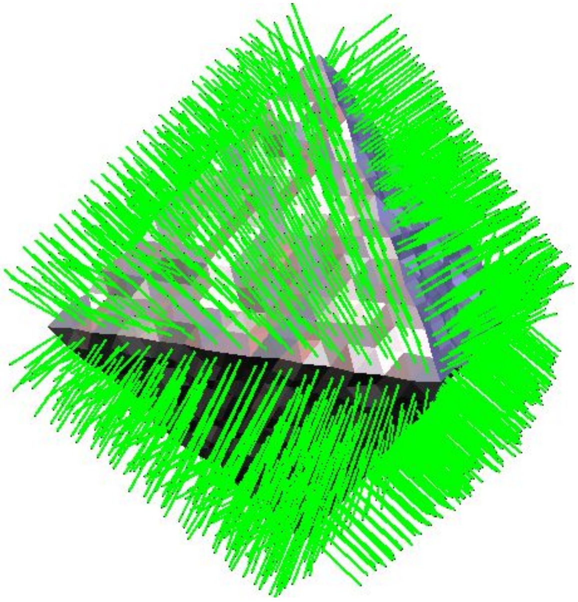
- Noisy octahedron : (additive Gaussian noise)
- Enhanced normal
  – *Normals are changed. No change geometry.*



original



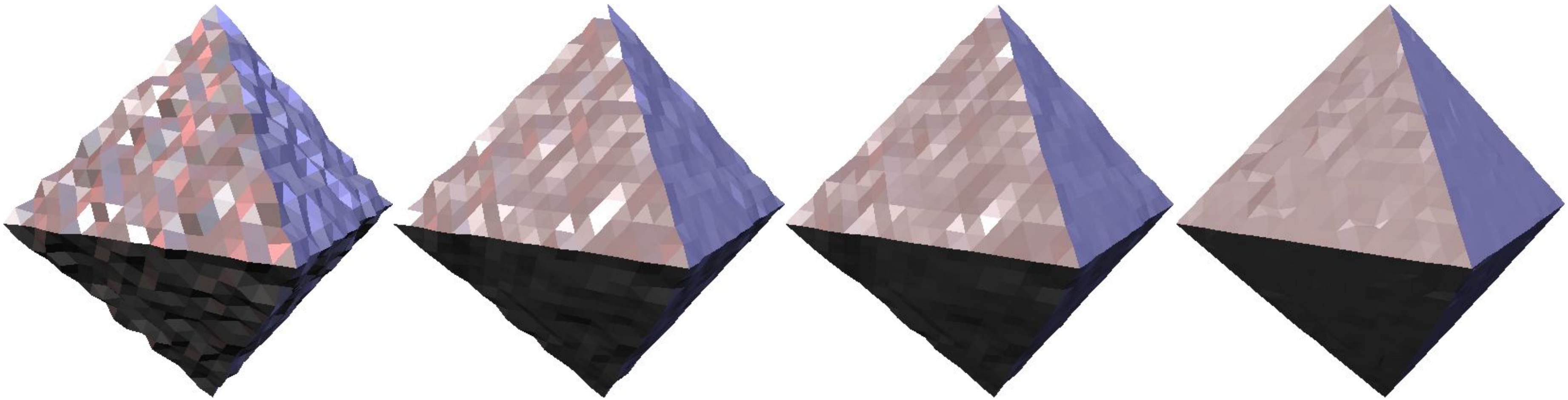
Mean Shift clustering



Back projection

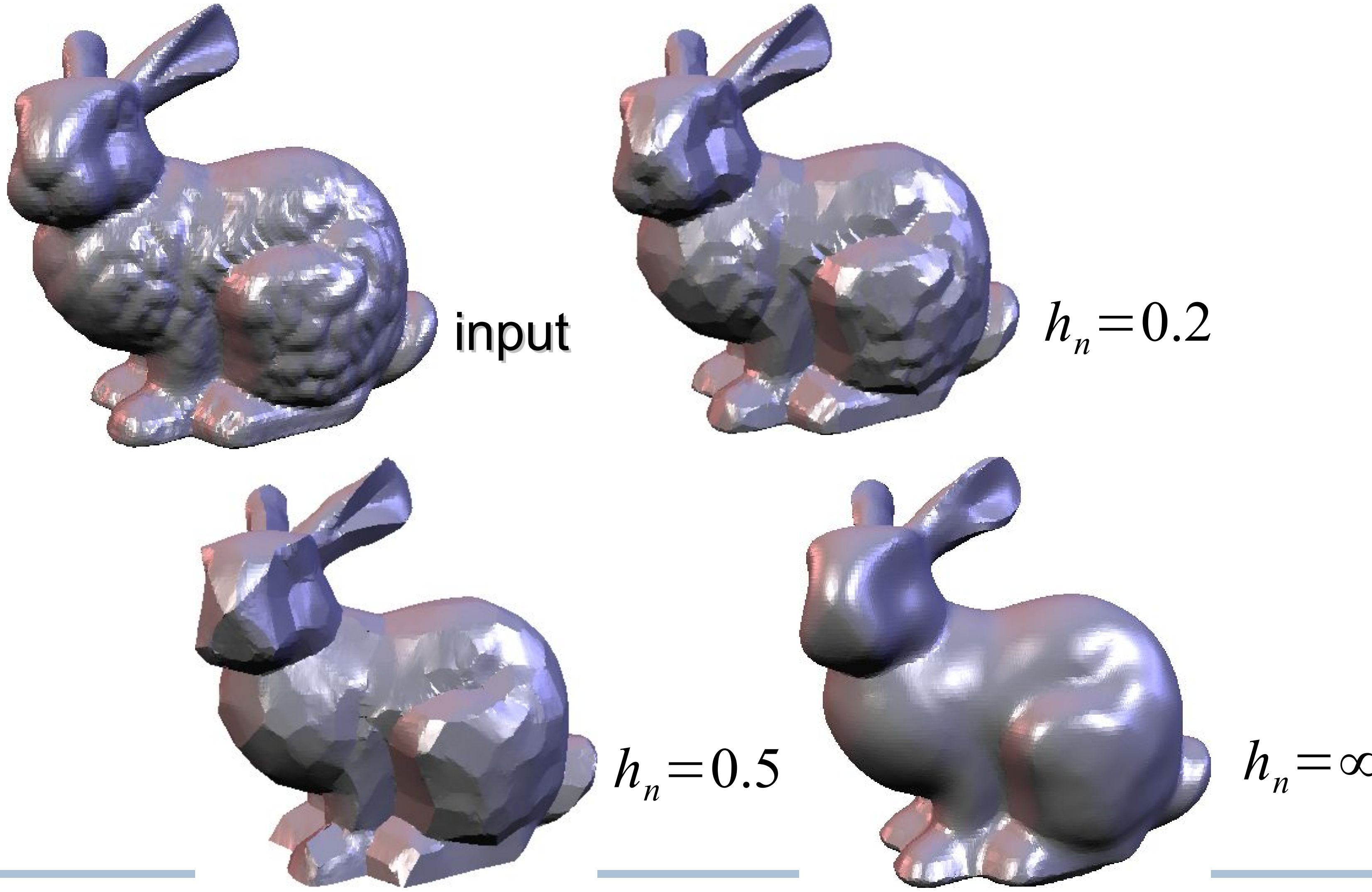
# Feature preserving noise removal with Mean Shift

- Denoise with local estimated normal [Ohtake et al. 01]
- Normal estimation by Mean Shift



input | one iter | two iters | converge

# Feature preserving smoothing with Mean Shift

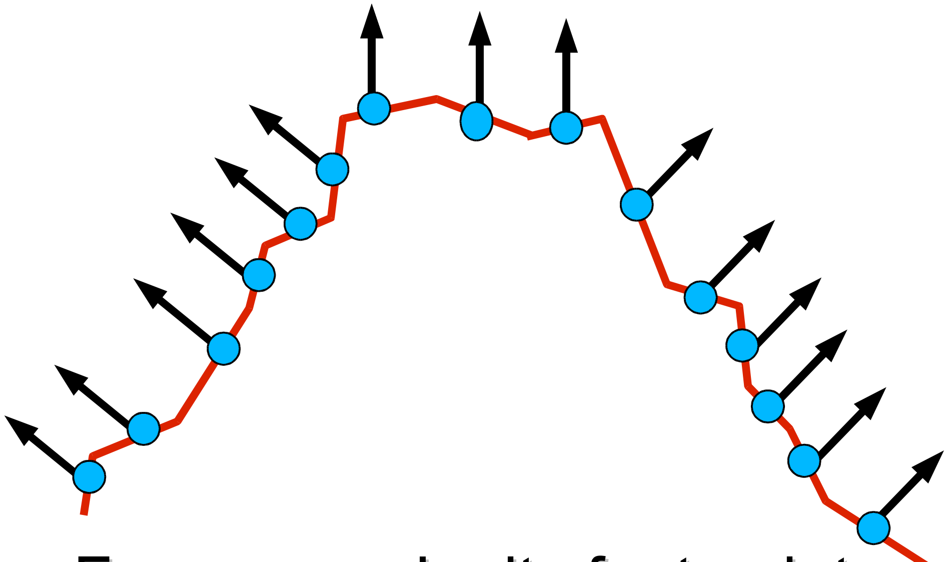


# Outline

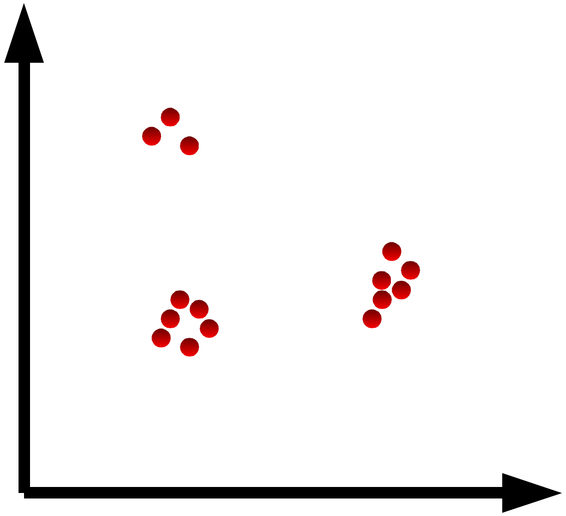
- Feature enhancement
  - *Mean Shift : What is Mean Shift?*
  - *Mean Shift on a mesh*
- Feature sensitive segmentation
  - *Segmentation algorithm*
  - *Demo*
- Experimental results
- Conclusions

# How to create a segmentation?

- Enhance features ≠ Segmentation
  - *Points are still scattered in the feature space*



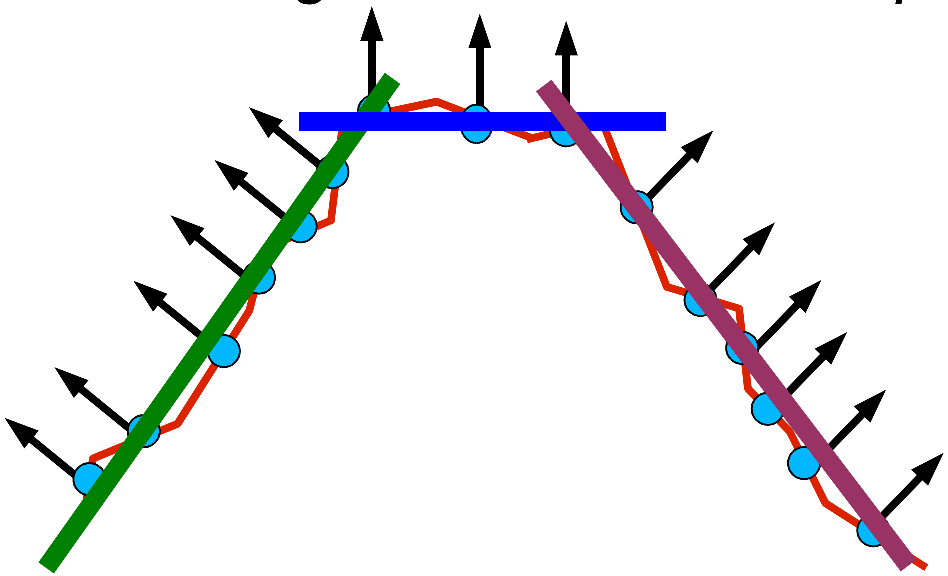
Face normal + its foot point (face centroid)



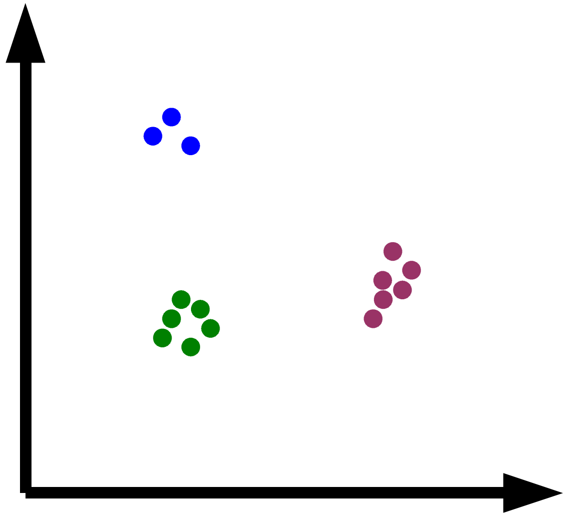
Feature space

# How to create a segmentation?

- Clustering ≠ Segmentation
  - *Points are still scattered in the feature space*
  - *Segmentation with respecting the clustering*



On a mesh : position & normal



Feature space

# Feature sensitive segmentation

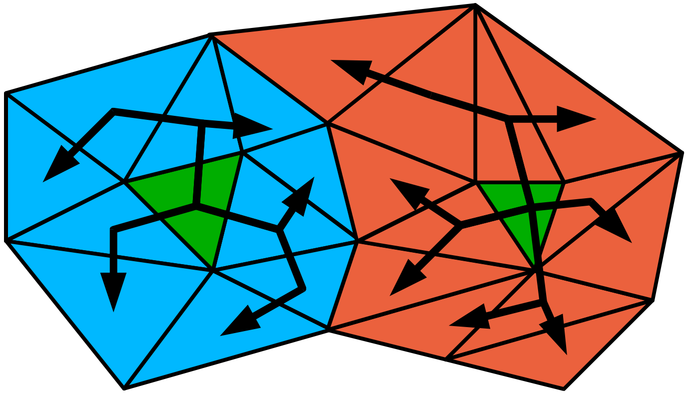
***How can we segment the points in the feature space?***

- Region growing [Shlafman 02, Sander 03, Cohen-Steiner 04, Comaniciu 02, Lèvy 02,...]
- Hierarchical clustering [Garland 01, ...]
- Spectral analysis [Liu 04, ...]
- Hybrids, others, ....

# Feature sensitive segmentation

***Using iterative region growing algorithm [Lloyd 82, Shlafman et al. 02, Sander et al. 03,...]***

- Segmentation with Volonoi-like region
  - *Calculate MST (Minimum Spanning Tree) from seeds*
  - *Seed optimization with Lloyd algorithm*



Growing from seeds with feature space distance

# Feature sensitive segmentation

- Selecting distance metric is the key of growing
  - *Feature*
    - ✓ Enhanced dihedral angle
  - *Mesh connectivity*
    - ✓ keep topology
- Segmentation method which adapts enhanced features
- → Feature enhancement + segmentation for it

# Outline

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  - *Mean Shift : What is Mean Shift?*
  - *Mean Shift on a mesh*
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- Conclusions

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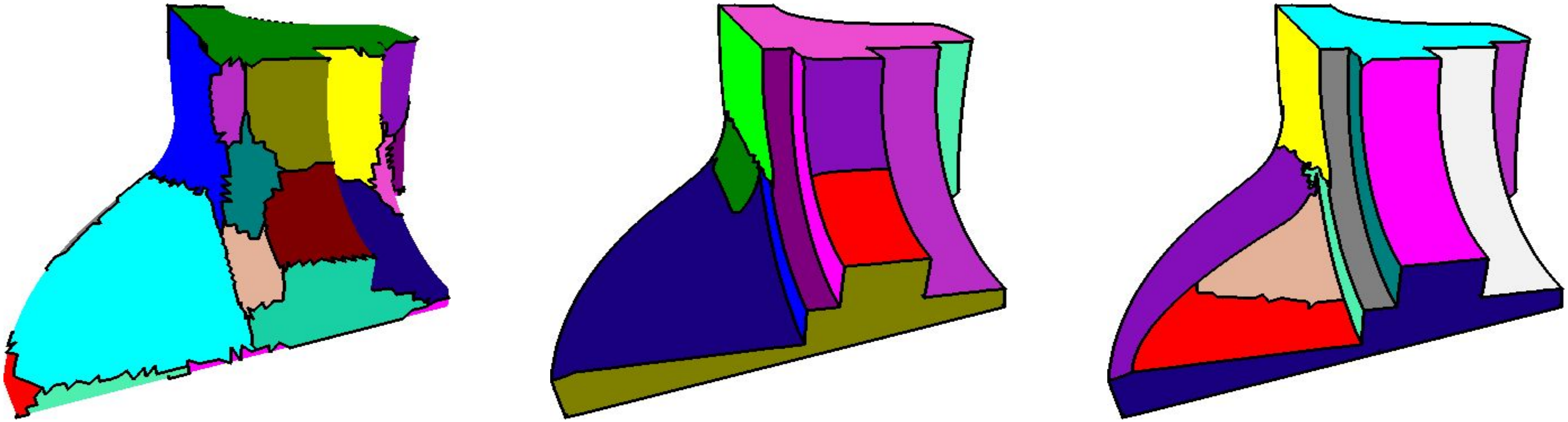
  - *Demo*
- <u>Experimental results</u>
- Conclusions

# Experimental Results (1)

– Fandisk: 12,944 tris., 20 charts



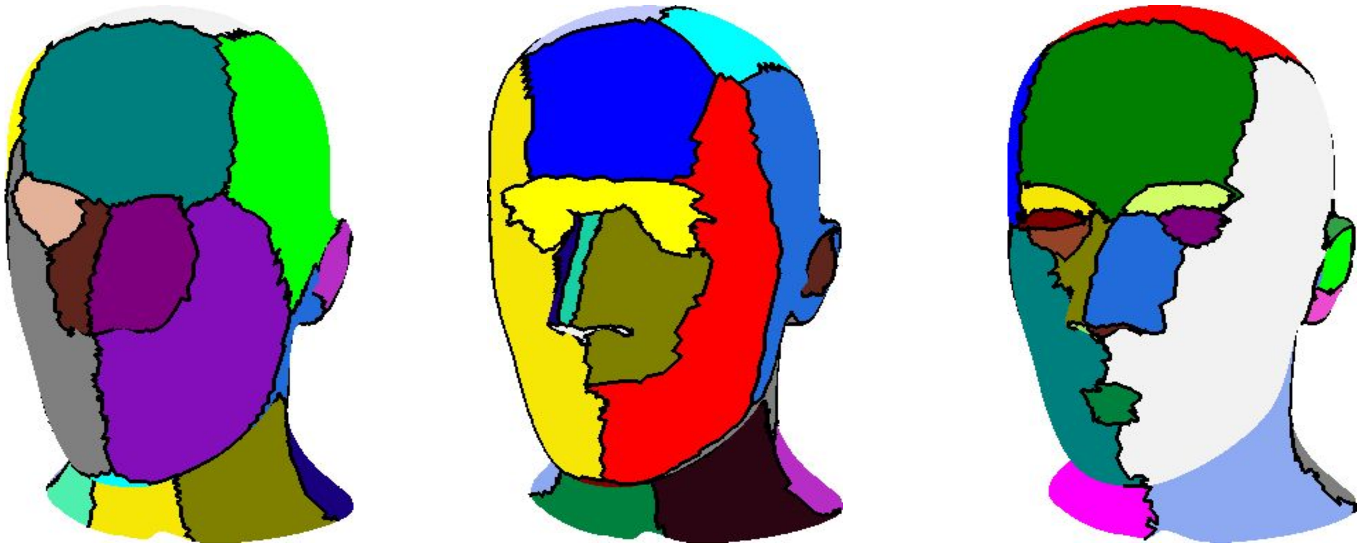
- MCGIM [Sander 03]
- 31.2 s

- VA [Cohen-Steiner 04]
- 12.7 s

- Our method
- 0.96+26.6 sec
- hg = 0.05, hn = 0.3

# Experimental Results (2)

– Mannequin: 21,680 tris., 30 charts



– MCGIM [Sander 03]
– 67.5 s

– VA [Cohen-Steiner 04]
– 32.1 s

– Our method
– 11.4+90.4 s
– hg = 0.1, hn = 0.3

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# Experimental Results (3)

– Camel: 78,144 tris., 80 charts

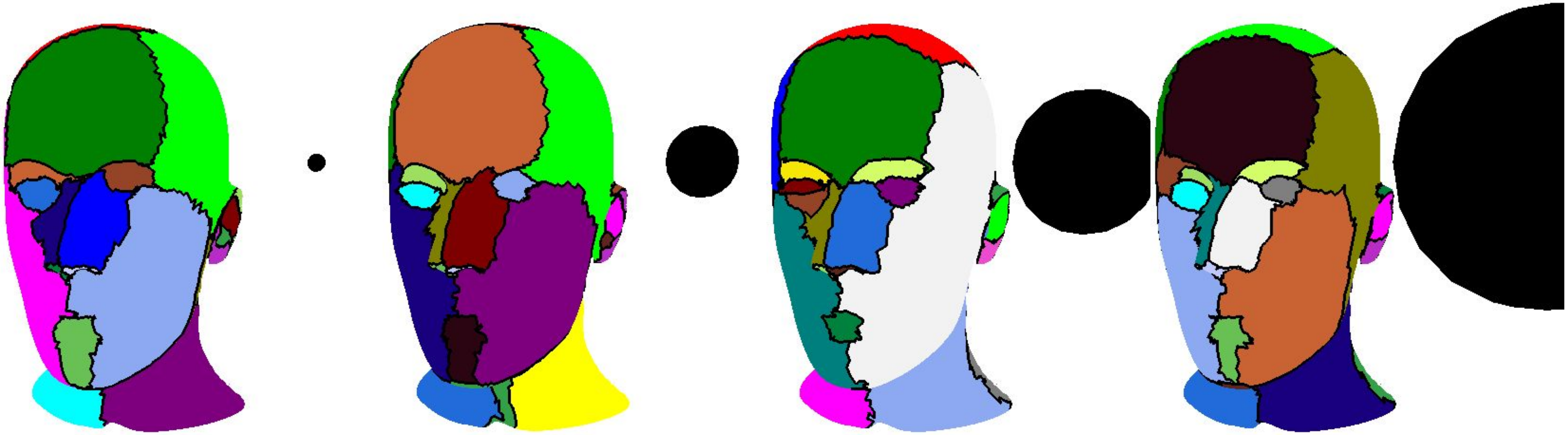
– MCGIM
– 1659 s

– VA
– 256 s

– Our method
– 11.5+1598 s
– hg = 0.015, hn = 0.3

# Experimental Results (5)

- Effect of support size and segmentation

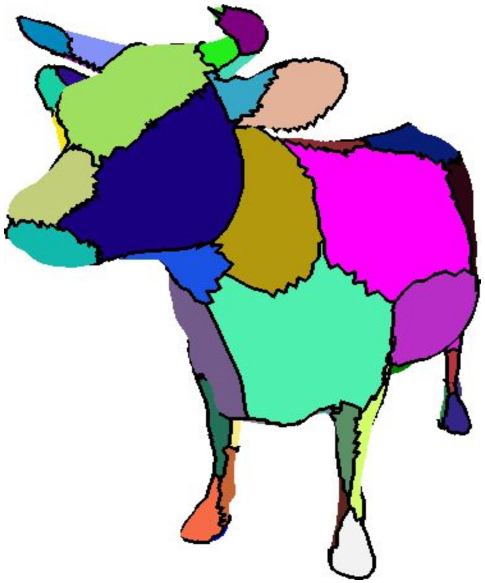


Black disk shows the geometric support size of Mean Shift

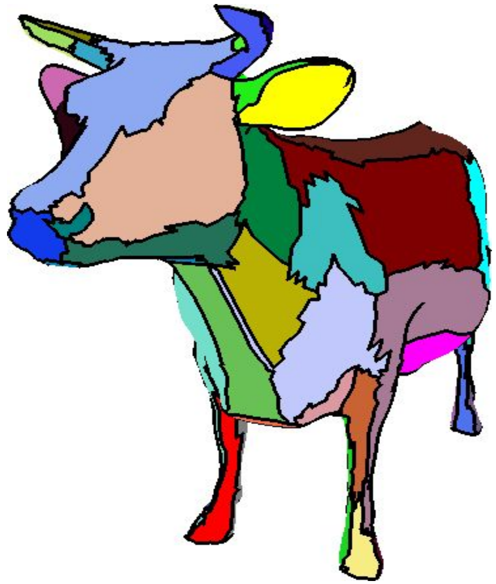
- Too small → small structure is considered features
- Too large → some features are smooth out

# Experimental Results (4)

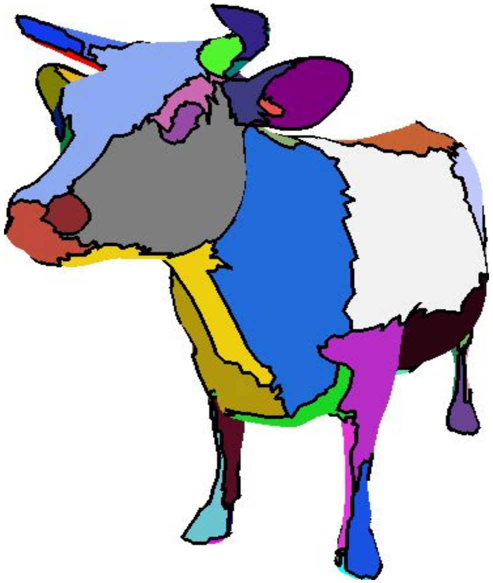
- Cow: 23,216 tris., 90 charts



- MCGIM
- 185 s

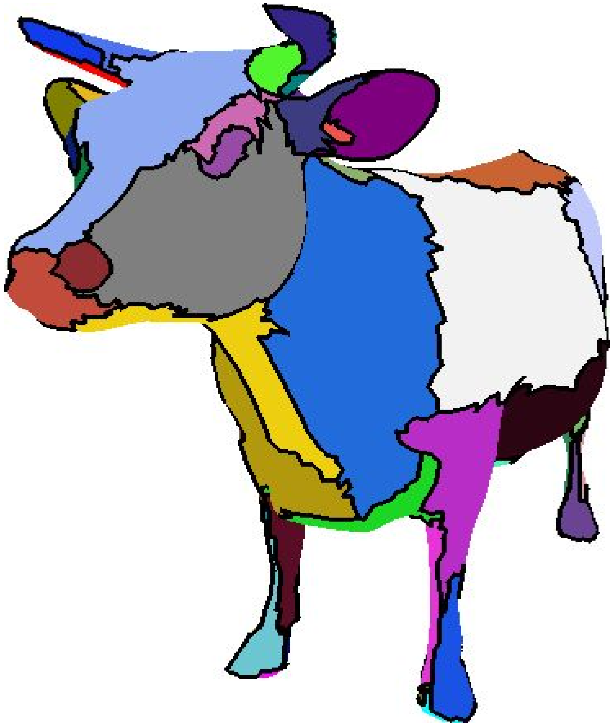


- VA
- 22.9 s



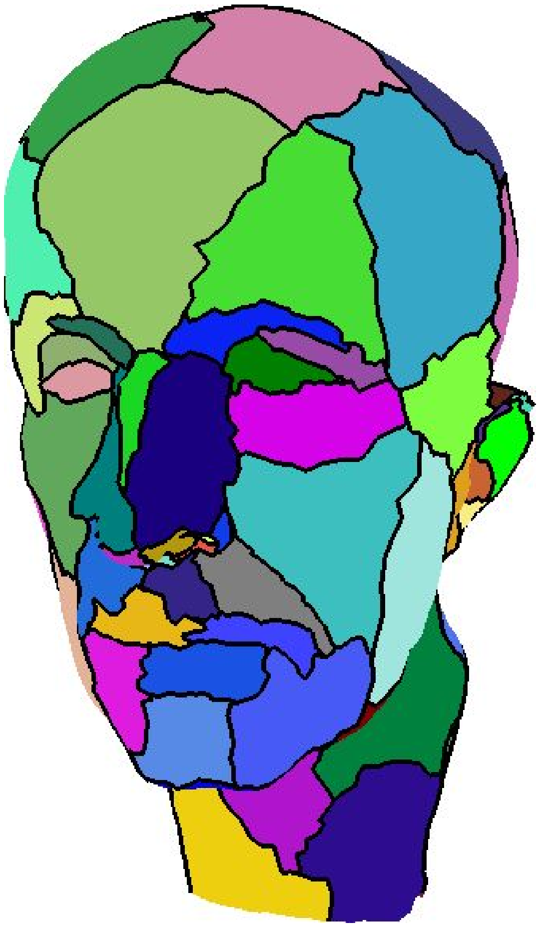
- Our method
- 0.95+225 s
- hg = 0.015, hn = 0.3

# Conclusion & Feature work



- Perceptually salient segmentation
- Enhancing surface features
  → *feature-sensitive*
- Segmentation via clustering
- User-specified parameters
  – *feature size + number of charts*
- Selecting the kernel support size
- K-means clustering instead of Mean Shift? (only one parameters)
- Can be easily extended to other criteria. (Curvatures, etc.)

Questions ?
(clusters of questions are also welcome)



# Resources. Thank you.

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- Mean Shift Intuitive description slides
  - *Advanced Topics in Computer Vision, Simon Ullman, Michal Irani, and Ronen Basri, Second semester (2003/04) course, 9 Mean Shift.*
    - http://www.wisdom.weizmann.ac.il/~deniss/vision_spring04/lectures_full.html
- Figures with [cite name] comes from the authors' paper or their web pages
- European FP6 NoE grant 506766 (AIM@Shape)
- Korean Ministry of Education through BK21program
- Korean Ministry of Information and Communication through the ITRC support