D-Charts: Quasi-Developable Mesh Segmentation

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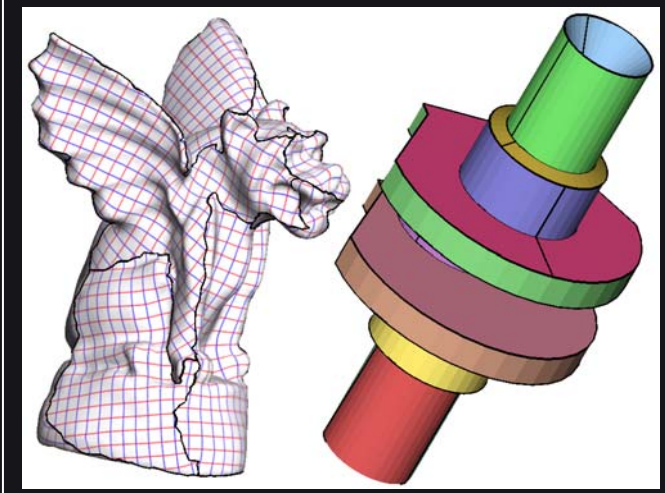
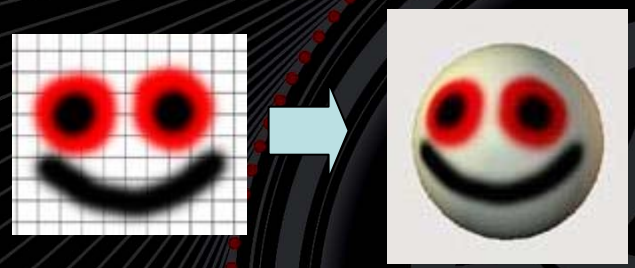


Motivation

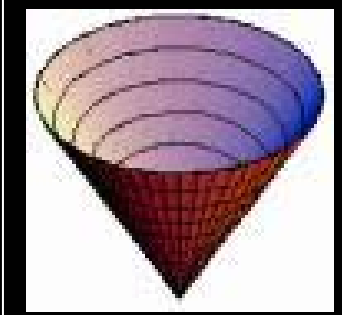
- Mesh segmentation into compact charts that unfold with minimal distortion

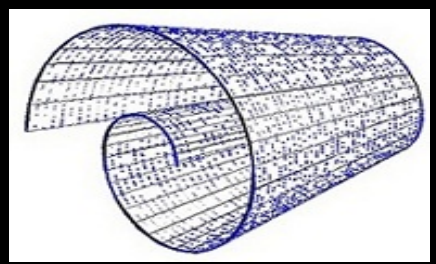
- Applications
  - Parameterization for mapping
    - Textures, Bumps, BRDFs, displacement maps, etc.
    - Geometry Images
  - Patterns for sewing, metal forging
  - CAD
    - Reverse engineering
    - Surface reconstruction



Developable surfaces

- Developable surfaces:
  - Surfaces that unfold onto the plane with zero distortion
  - Gaussian curvature is zero at every point
- Find a quasi-developable segmentation





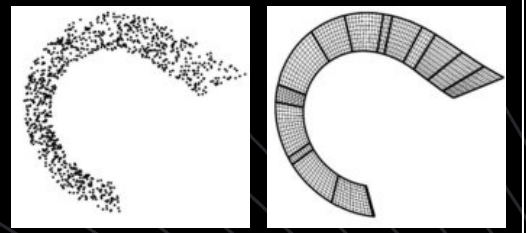
Previous work

- Texture atlas generation
  - [Levy et al. ’02], [Zhou et al. ’04]
  - [Garland et al. ’01], [Sander et al. ’03] Planar
- Feature based
  - [Katz and Tal ‘03]
  - [Gelfand and Guibas ‘04]

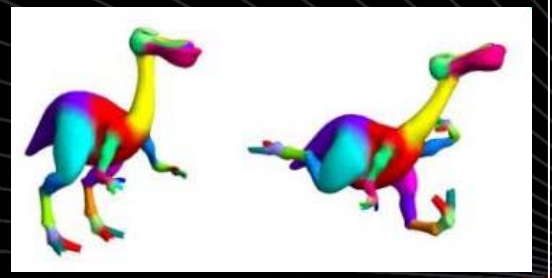
Not developable

- Patterns:
  - [McCartney et al. ‘99]
  - [Mitani and Suzuki ‘04] Not compact
- Developable surfaces
  - [Leopoldseder and Pottmann ‘98]
  - [Peternell ‘04]

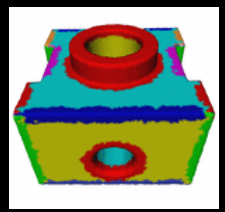
Not segmentation



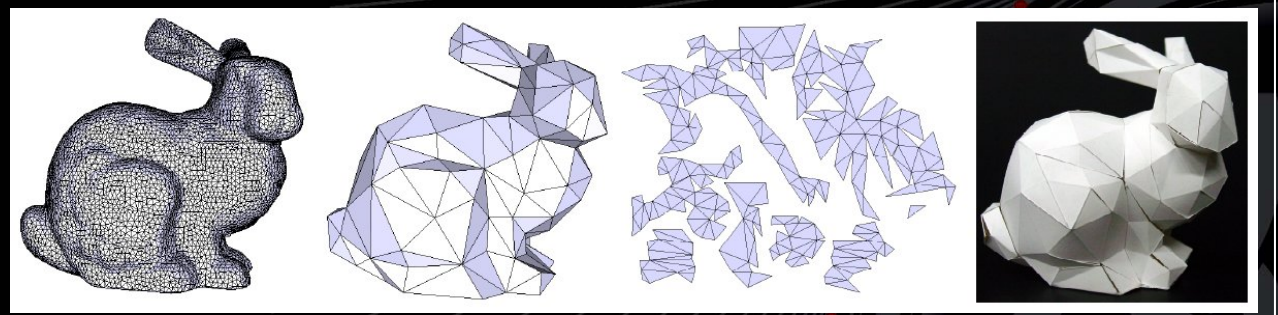
[Pottman et al. ’01]



[Katz and Tal ‘03]



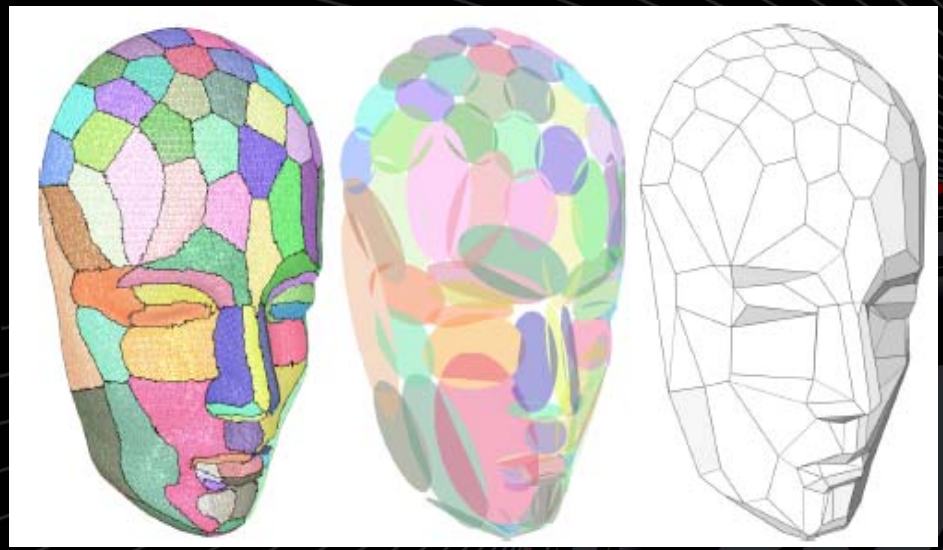
[Gelfand and Guibas ’04]



[Mitani and Suzuki ‘04]

Lloyd based segmentation

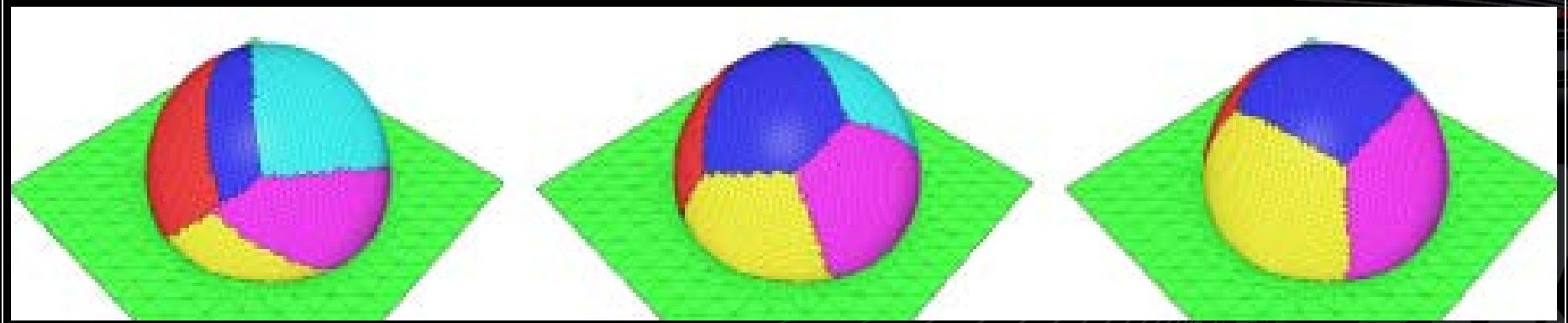
- We use Lloyd segmentation approach
- Introduced by [Cohen-Steiner et al. ‘04] - planar charts
- Various extensions presented at EG ‘05
- Charts represented by proxies:
  - Normal to plane
  - Seed triangle
- Challenges:
  - Developable proxies
  - Bound error



[Cohen Steiner et al. ‘04]

Lloyd based segmentation – Framework

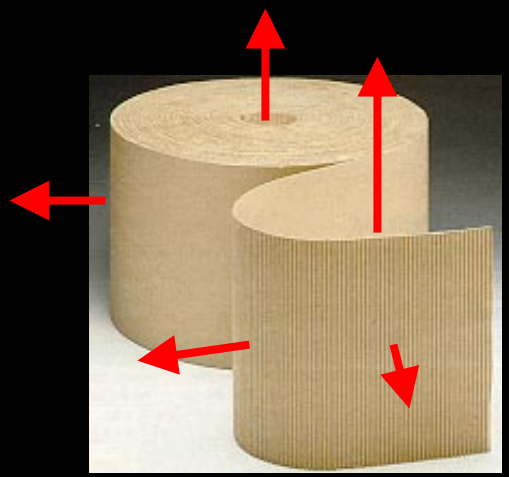
- Lloyd iterations:
  1. Select random triangles to act as seeds
  2. Grow charts around seeds using a greedy approach
  3. Find new proxy for each chart
  4. Repeat from step 2 until convergence

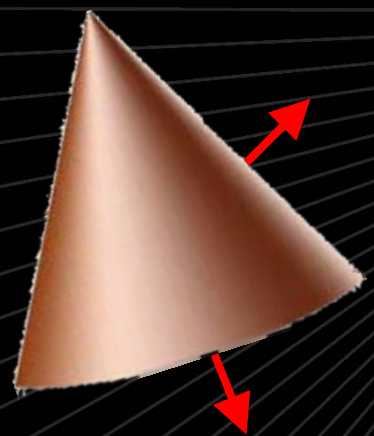


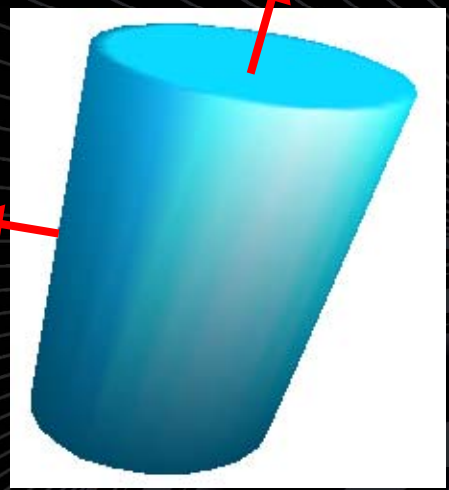
[Cohen Steiner et al. ‘04]

Devlopable surfaces of constant slope

- Developable surfaces – Hard to capture
  - Start with subset, broaden later
- Constant angle between surface normal and axis → Developable chart
- Proxy: <axis, angle> $\langle N_c, \theta_c \rangle$



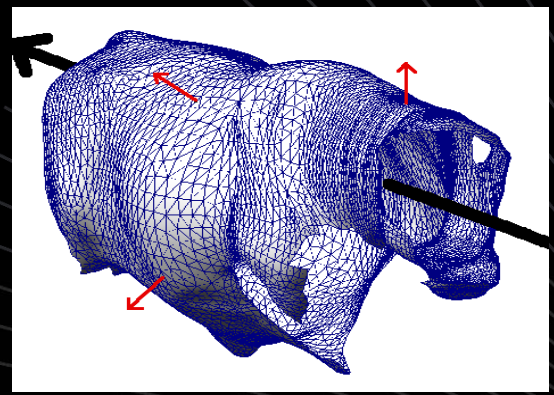




Fitting error

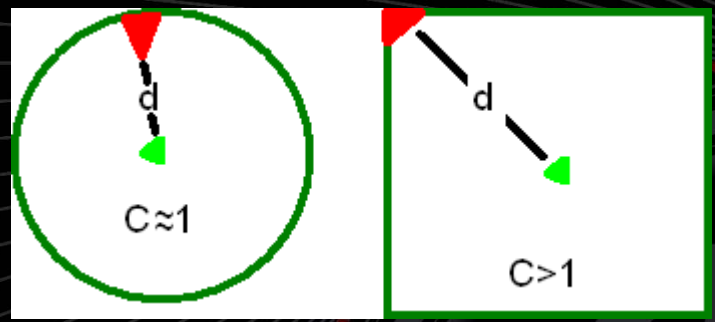
- Measures how well triangle fits a chart

$$F(C,t) = (N_C \cdot n_t - \cos\theta_C)^2$$



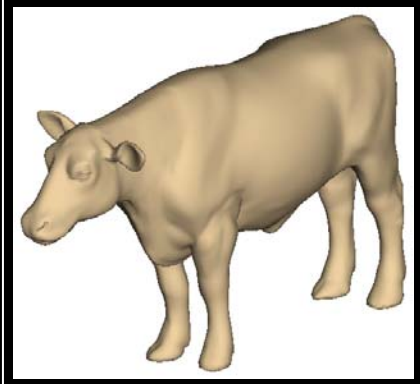
- Combine with compactness

$$C(C,t) = \pi \frac{D(S_c,t)^2}{A_C}$$

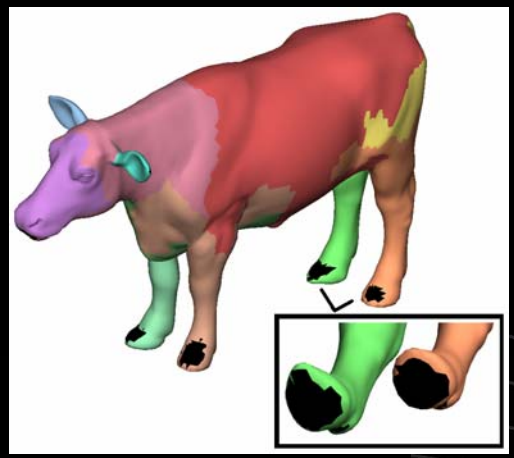


$$Cost(C,t) = A_t F(C,t)^{\alpha} C(C,t)^{\beta}$$

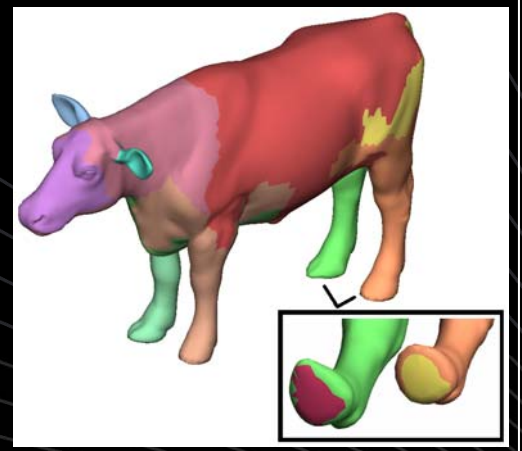
Algorithm overview



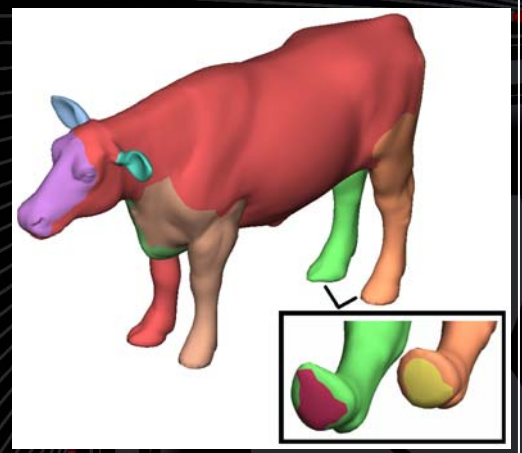
Bounded Lloyd iterations



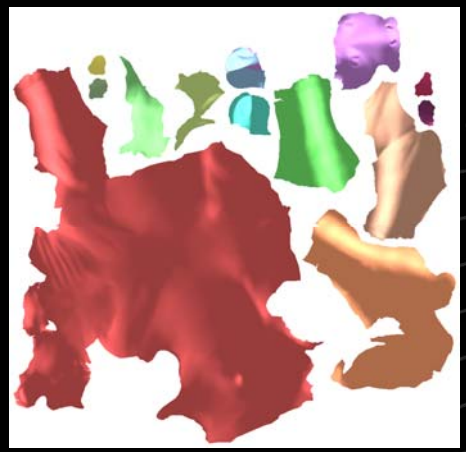
Hole Filling

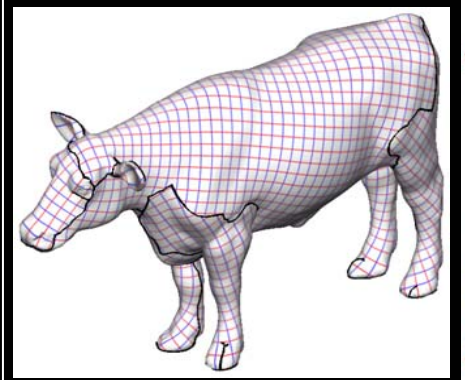


Merging



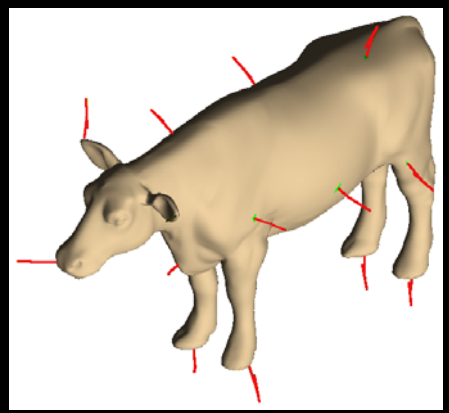
Post-Processing & Parameterization

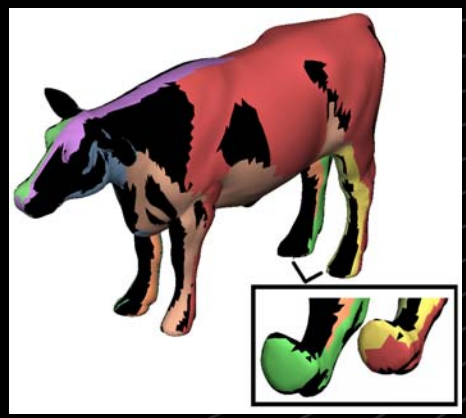


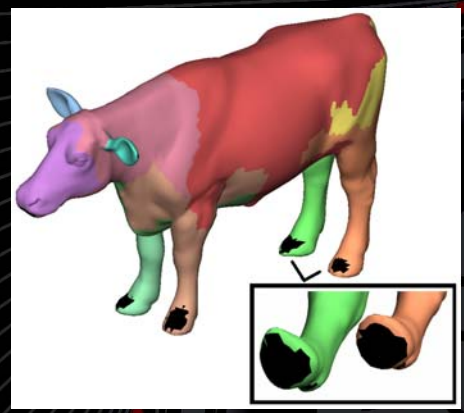


Bounded Lloyd iterations

- Initialization
  - Random / Furthest point seeds
  - Compute initial proxy
- Bounded Growing/Reseeding iterations
- Termination

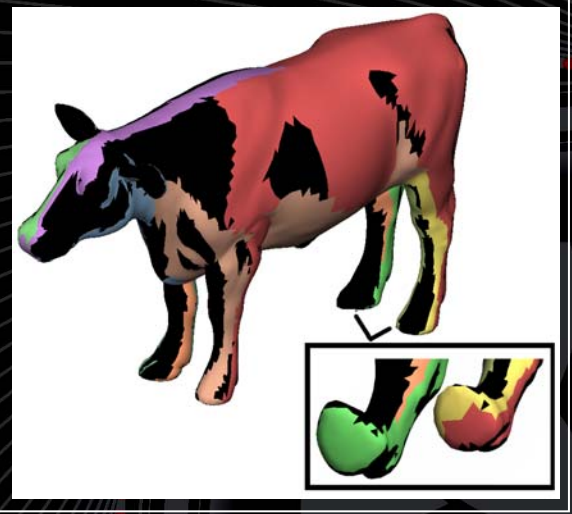






Bounded Lloyd iterations – Growing

- Use greedy approach
  - Prioritize by $Cost(C,t)$
- Bound *Fitting Error*
  - *Guarantee (nearly) developable charts*



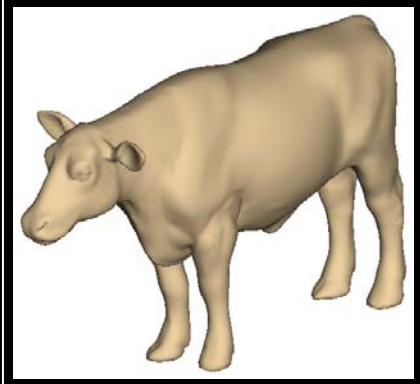
Bound Lloyd iterations – Reseeding

- Find new proxy

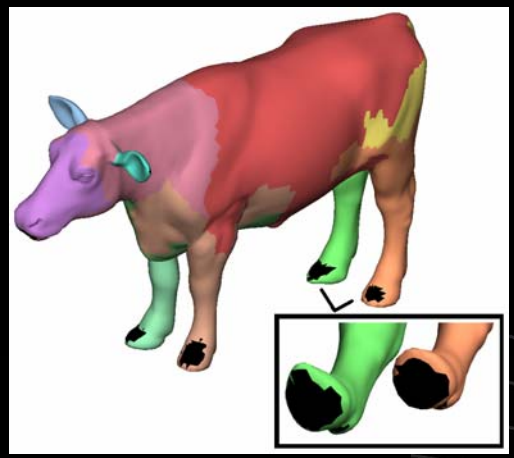
$$\min_{N_C,\theta_C} \frac{1}{A_C} \sum_{t \in C} A_t F(C,t) \text{ s.t. } \|N_C\| = 1$$

- Find new seed
  - Minimal *Fitting Error*
  - Close to center of chart

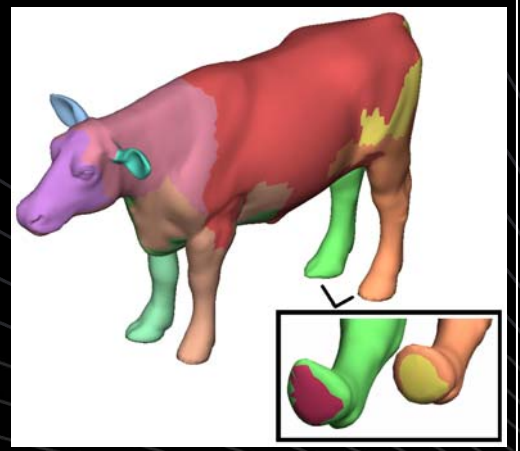
Algorithm overview



Bounded Lloyd iterations

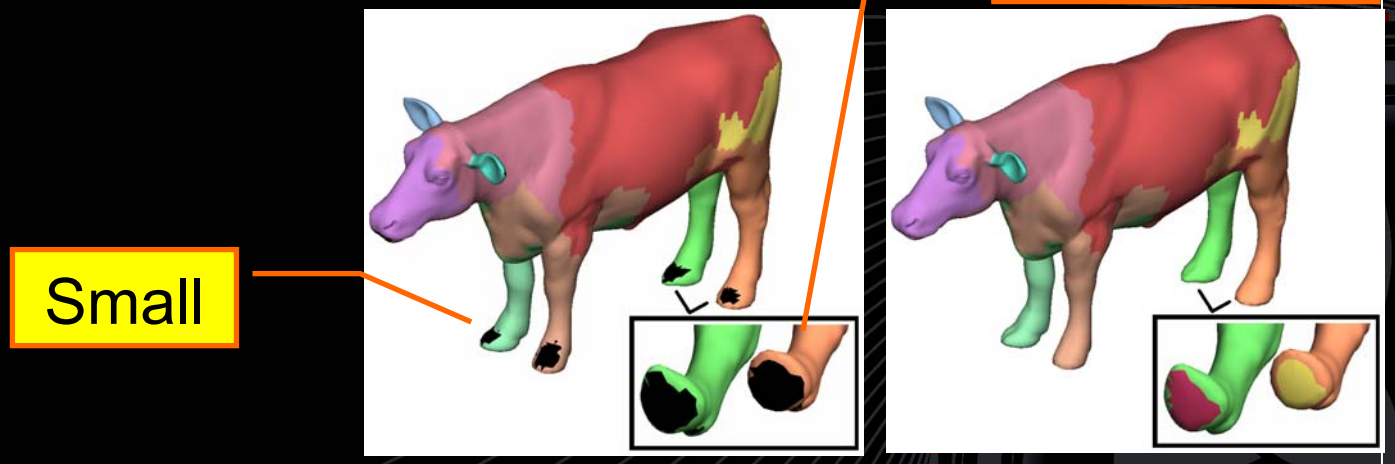


Hole Filling

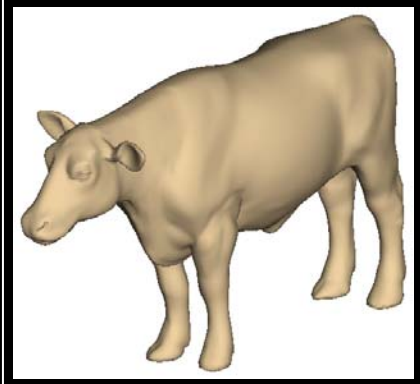


Hole filling

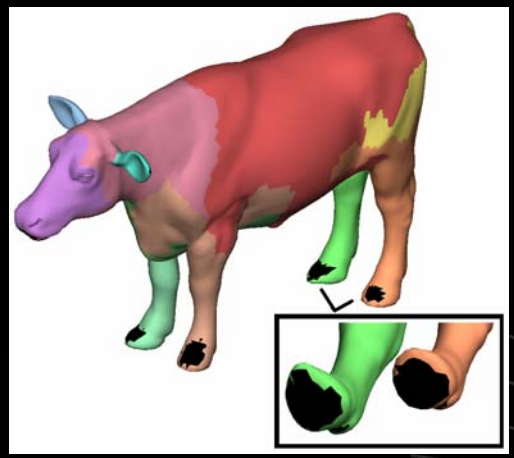
- Bound on *Fitting Error*
  - ➡ *Unclassified triangles*
- Fill holes
  - Large holes ➡ New proxy
  - Small holes ➡ Grow neighbors



Algorithm overview



Bounded Lloyd iterations



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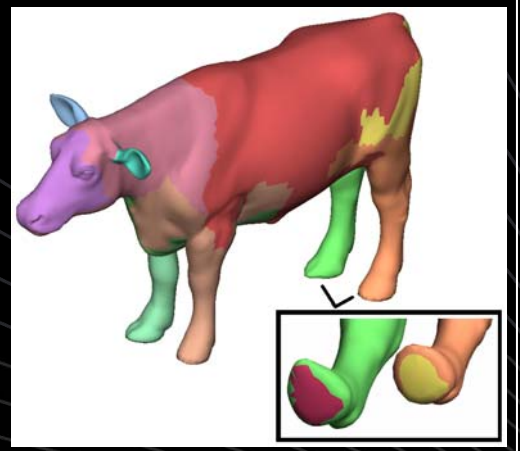
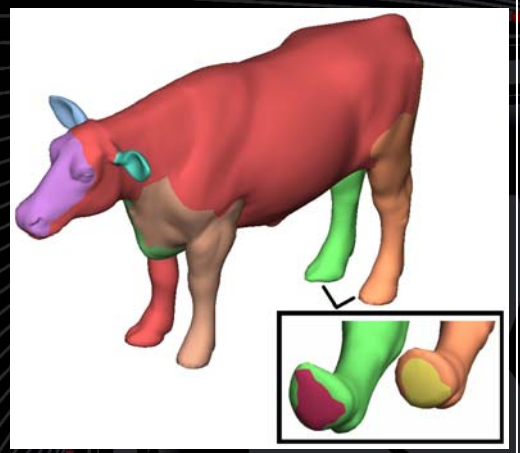
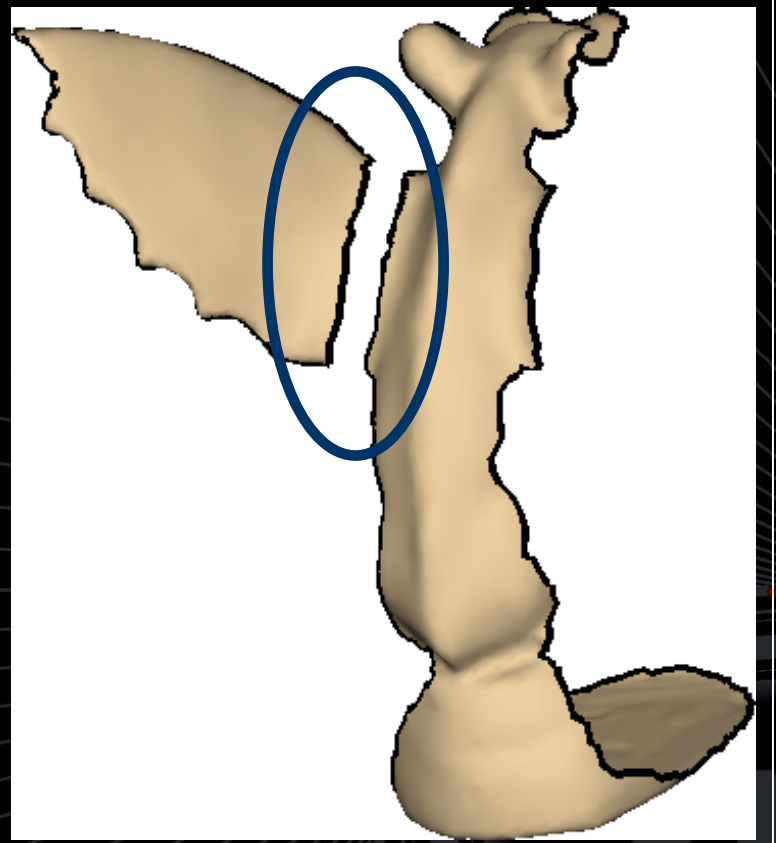


Merging

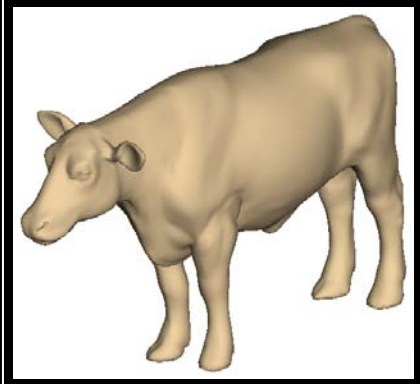


Merging

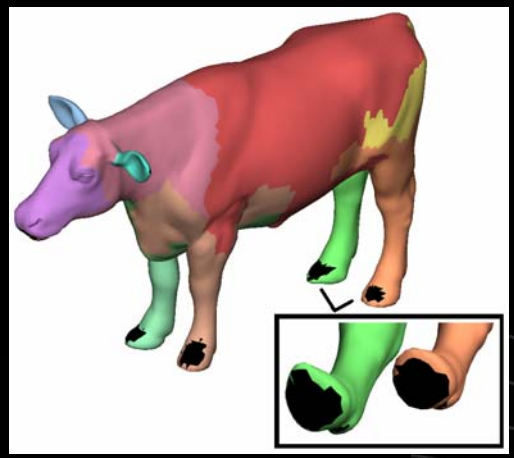
- Broaden set of captured developable surfaces
- Reduce number of charts



Algorithm overview



Bounded Lloyd iterations



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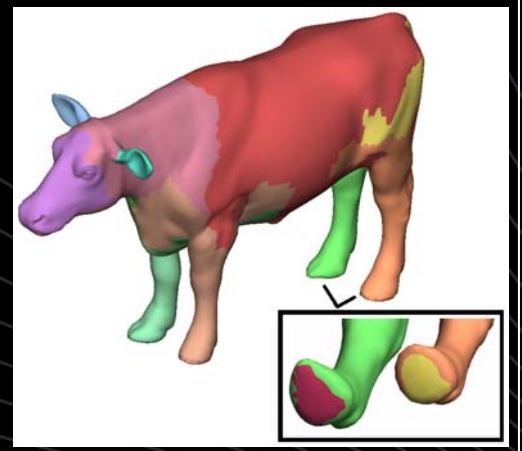
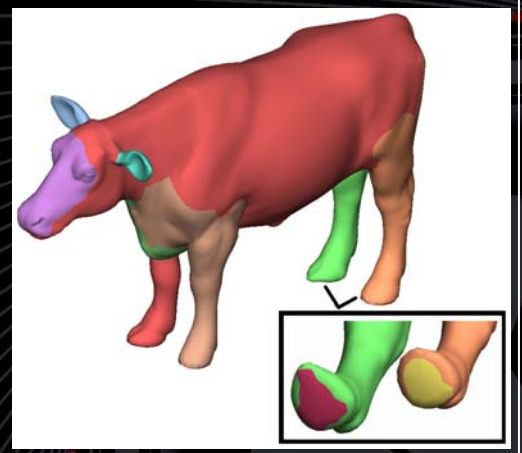
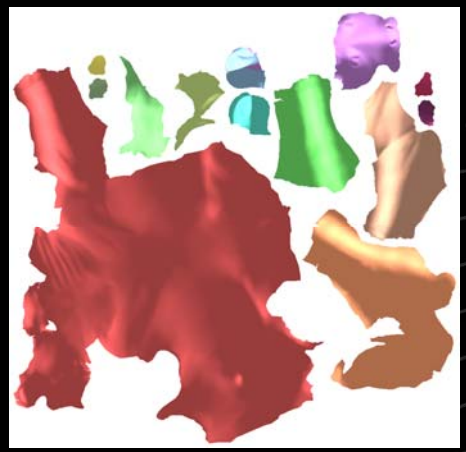
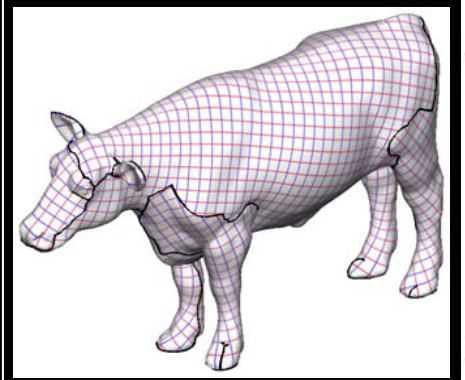


Merging



Post-Processing & Parameterization

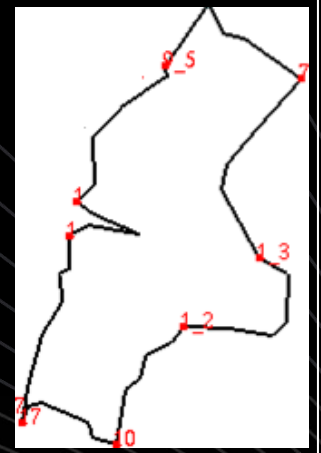


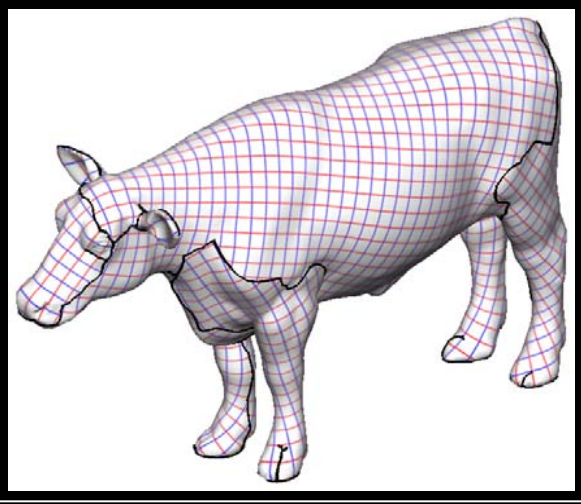


Post processing

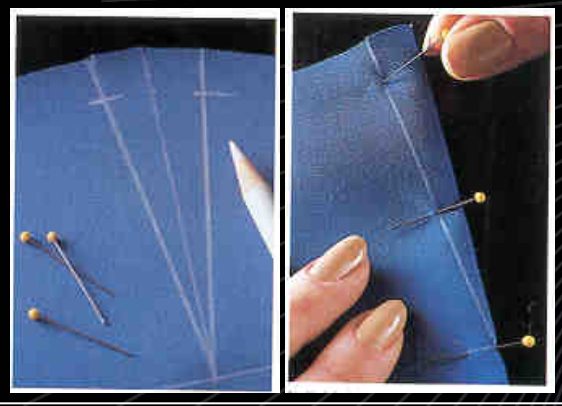
- Straighten boundaries
- Darts/Gussets relax stress
  - Add seams toward high error regions
- Verify disc topology
- Parameterization

[Sander et al. ’02] [Sheffer et al. ’05]



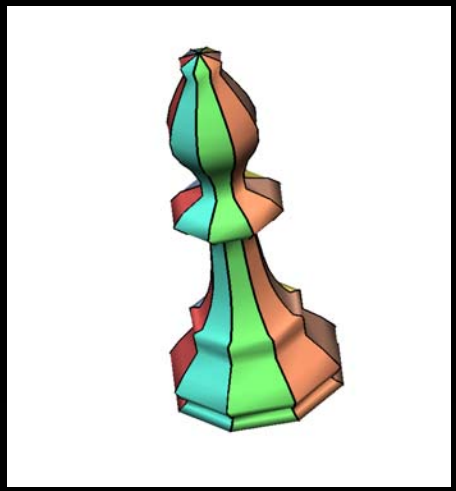


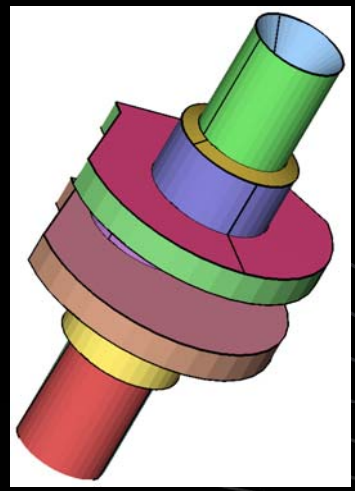
Dart

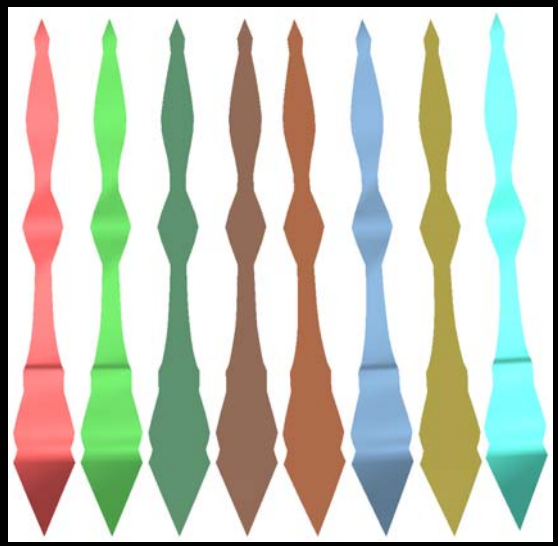


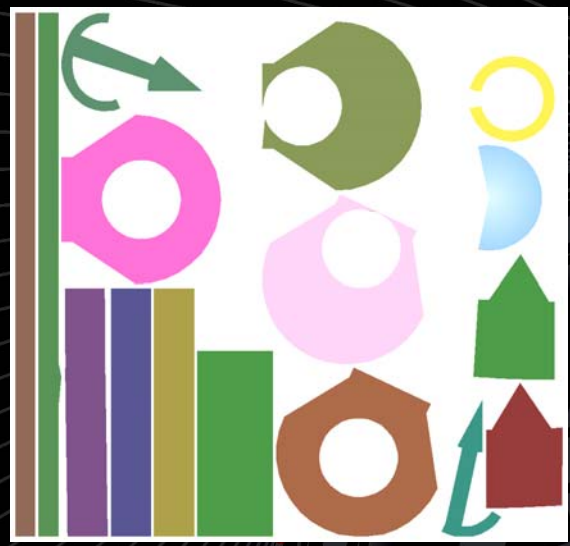
Gusset

Example results – CAD

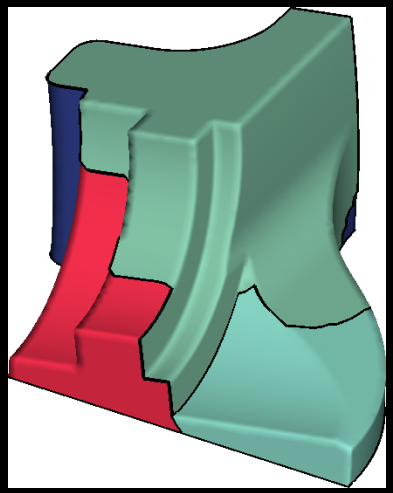






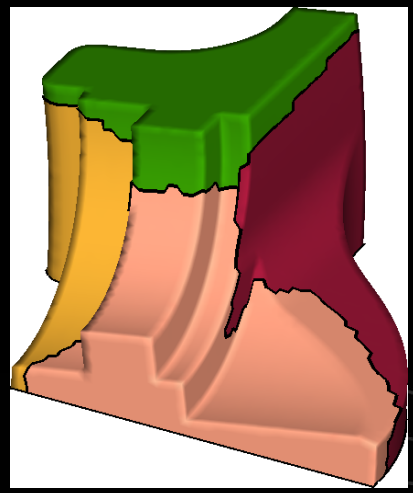


Example results – Fandisk



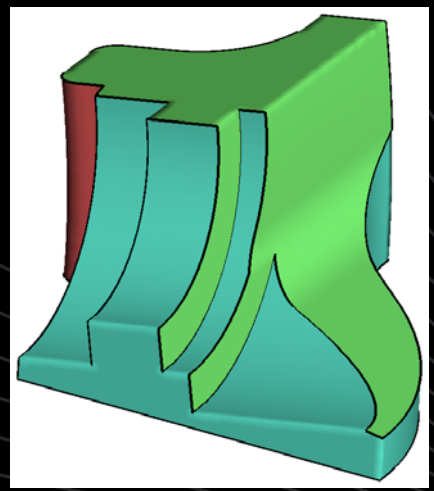
Iso-Charts,

[Zhou et al. ’04]



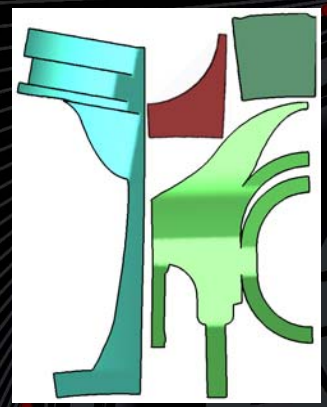
MCGIM,

[Sander et al. ’03]

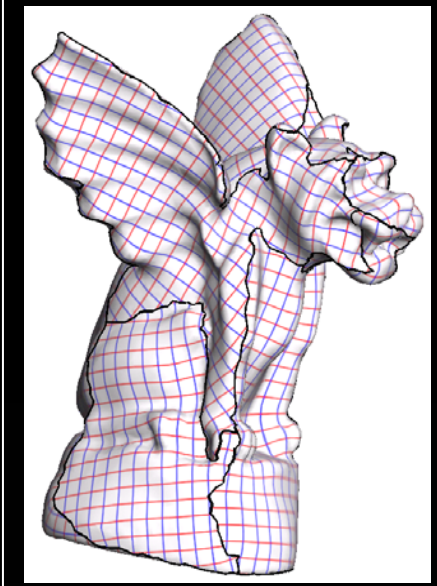


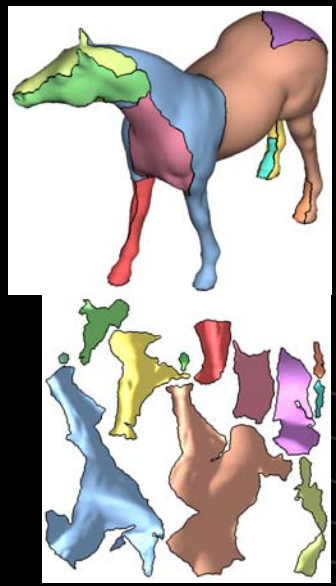
D-Charts

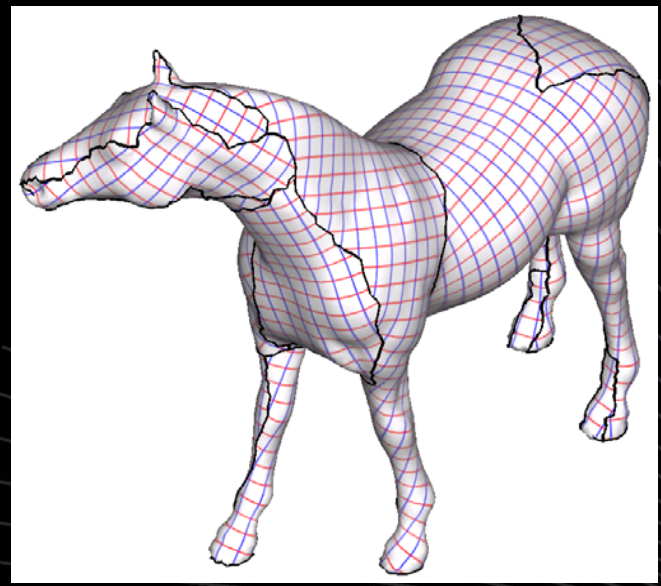
Fandisk	Iso-Charts	MCGIM	D-Charts
#Charts	4	5	4
$L_2^{Stretch}$	1.021	1.008	1.000
$L_\infty^{Stretch}$	2.272	2.092	1.017
L_2^{Shear}	0.018	0.012	0.000



Example results – irregular meshes



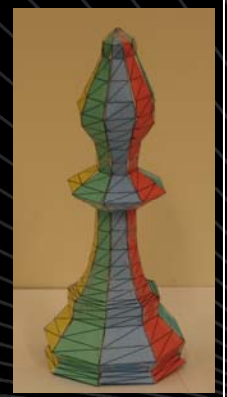




Gargoyle	MCGIM	Iso-Charts	D-Charts
#Charts	10	11	10
$L_2^{Stretch}$	1.009	1.019	1.006
$L_\infty^{Stretch}$	2.221	2.153	1.645
L_2^{Shear}	0.011	0.022	0.008

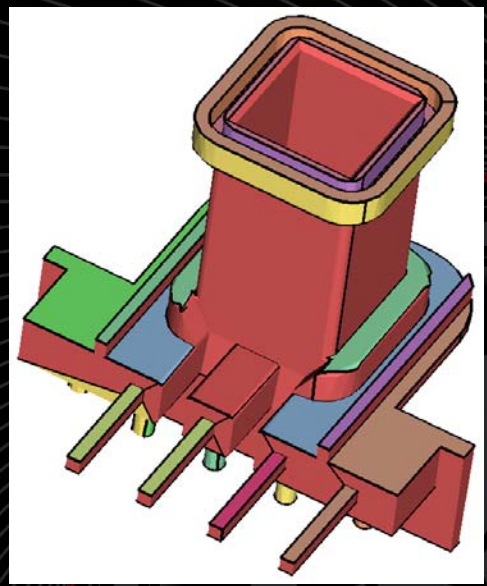
Horse	MCGIM	Iso-Charts	D-Charts
#Charts	15	13	12
$L_2^{Stretch}$	1.014	1.035	1.01
$L_\infty^{Stretch}$	2.803	2.766	2.315
L_2^{Shear}	0.014	0.038	0.001

Soft and paper-craft toys

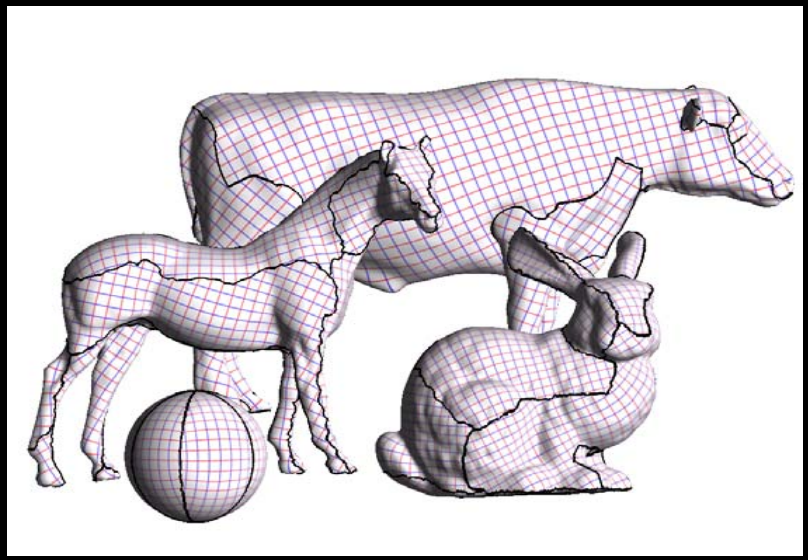


Summary

- Segment mesh into nearly developable charts
- A simple metric of developability for surface charts – *The Fitting Error*
- Use bounded Lloyd iterations
- Use Holes / Merging to correct no. of charts



Thank you



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