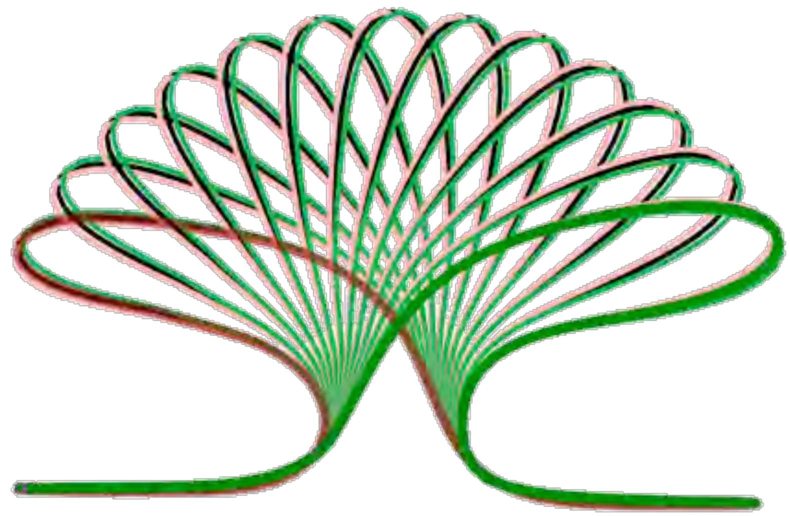


Design/analysis/transmission/simulation of shapes and animations

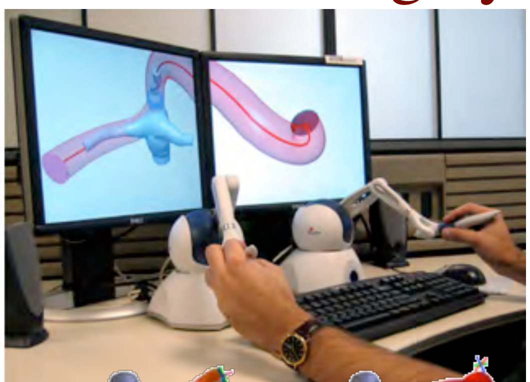
Jarek Rossignac

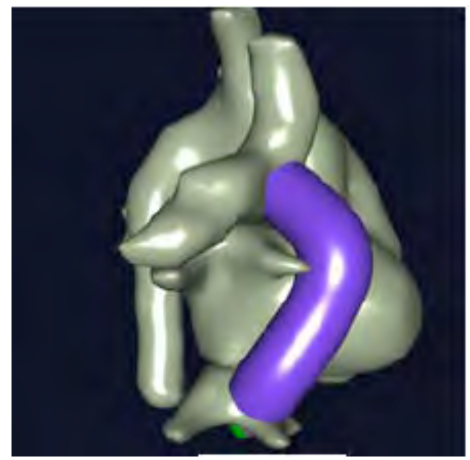
School of Interactive Computing

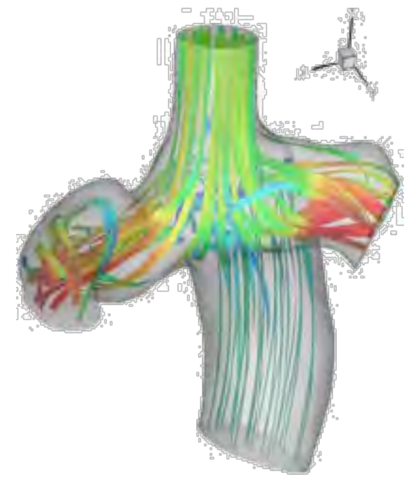
DESIGN

Plan heart surgery (BME, Emory, CMU, **HSI**)

Surgem help surgeons design anatomies of possible options for planned heart surgery and analyze resulting blood flow





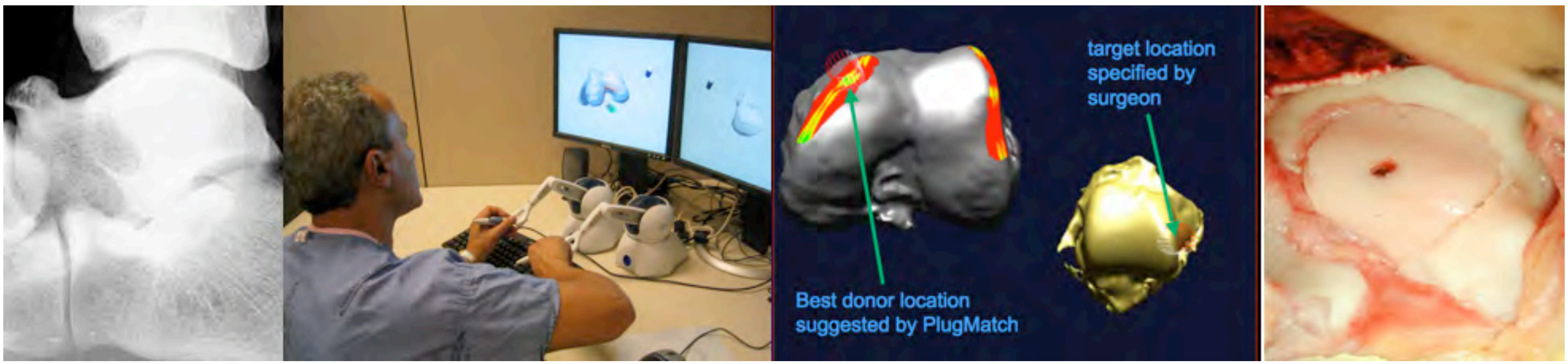


"SURGEM: Next generation CAD tools targeting anatomical complexity for patient-specific surgical planning", J. Rossignac, K. Pekkan, B. Whited, K. Kanter (Emory), A. Yoganathan. ASME 2006 Summer Bioengineering Conference (BIO2006), June 21-25, 2006.

"Patient-specific surgical planning and hemodynamic computational fluid dynamics optimization through free-form haptic anatomy editing tool (SURGEM)", K. Pekkan, B. Whited, K. Kanter, S. Sharma, D. de Zelicourt, K. Sundareswaran, D. Frakes, J. Rossignac, A. Yoganathan. Journal of Medical and Biological Engineering and Computing, Springer. 46(11):1139-1152, Nov 2008.

Orthopaedic surgery planning (Emory)

- Find best graft plug for cartilage transplant
  - Search donor site for piece with most compatible shape
  - No sharp features
- Help surgeon align tools correctly **during operation**

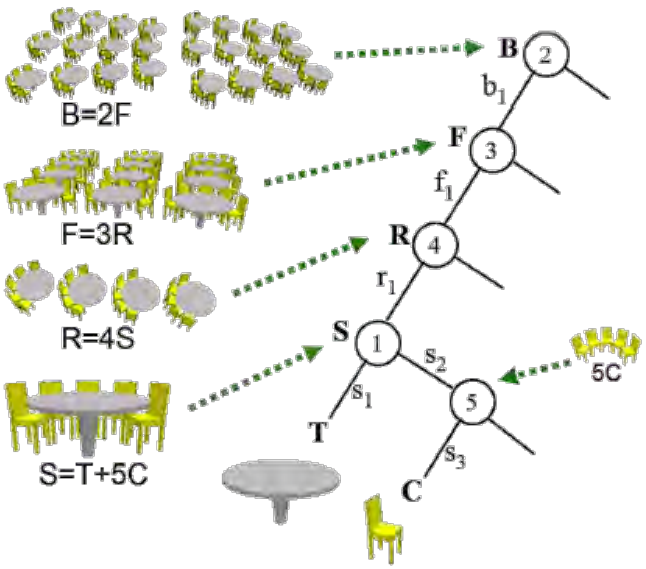


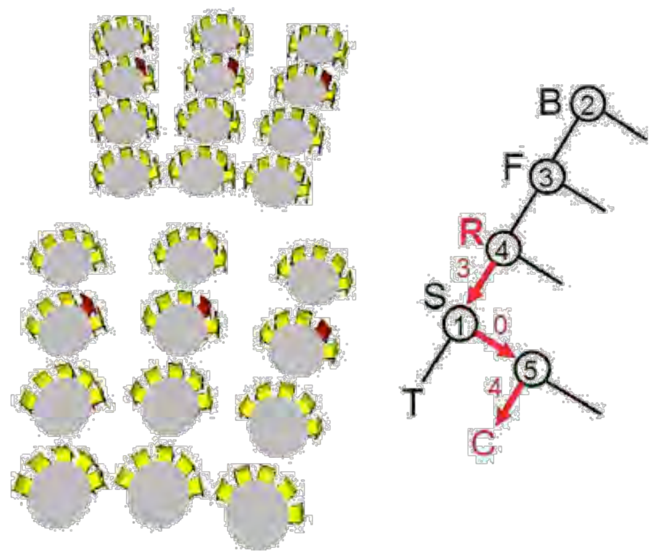
"PlugMatch: Computer-Assisted surface mapping for Talus Osteochondral Transplant", Dr. S. Labib (Emory) and Dr. B. McGehee (Emory), J. Rossignac, A. Powell, B. Whited, and J. Wiliams, 6th ICRS (International Cartilage Repair Society) Symposium, January 8-11, 2006,

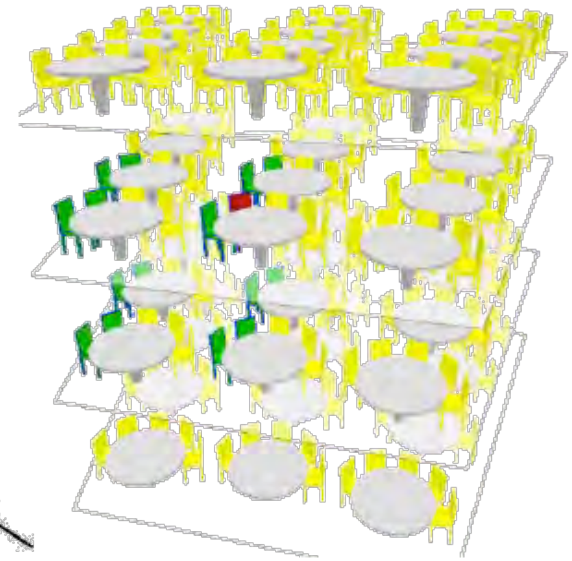
OCTOR: Exceptions in patterns

Hierarchy of (recursive) patterns

- Select sub-pattern (2 mouse clicks)
- Represent as path with wildcards





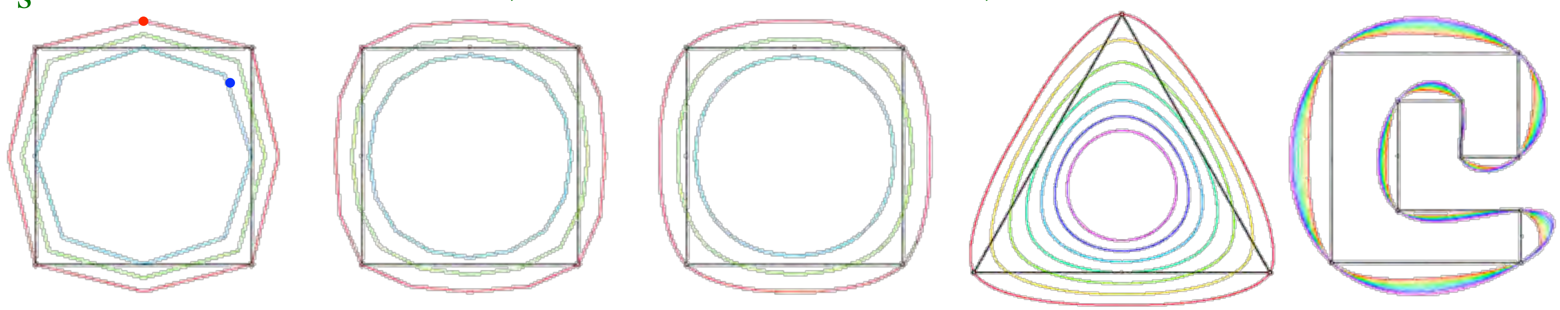


"OCTOR: OCcurrence selecTOR in pattern hierarchies", J. Jang and J. Rossignac, IEEE International Conference on Shape Modeling and Applications (SMI), 205-212, 2008.
"OCTOR: Subset selection in recursive pattern hierarchies", J. Jang and J. Rossignac, Graphical Models (GMOD), 71:92-106, 2009.

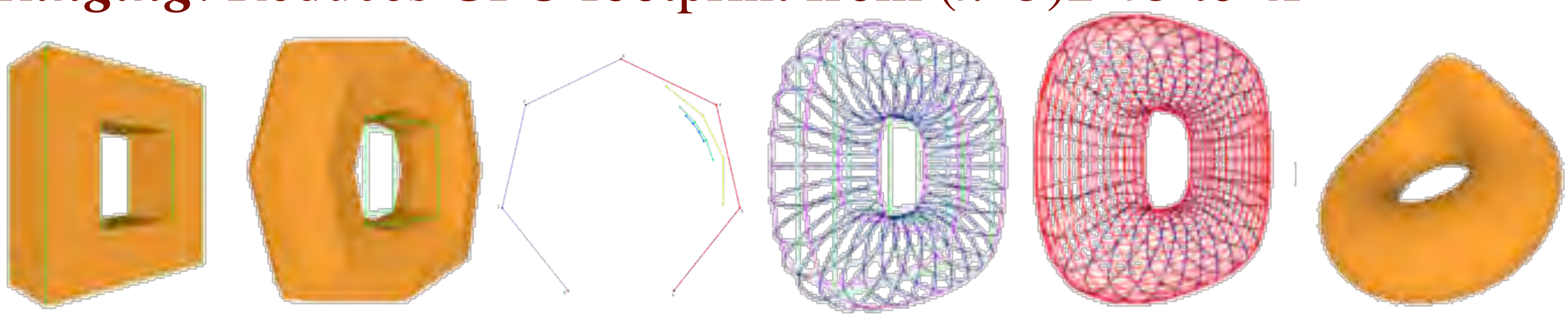
Ringing J-spline surfaces, animations (TAMU)

4-point: f_j, cubic B-spline: b_j, *J-spline:* $(1-s)f_j+sb_j$

J_s is C^2 when $0<s<4$, C^3 when $1<s\leq2.8$, and C^4 when $s=1.5$



Ringing: Reduces GPU footprint from $(n-5)2^r+5$ to $\mathbf{4r}$



"J-splines", J. Rossignac, S. Schaefer, Journal of Computer Aided-Design (JCAD). 40(10-11):1024-1032, October-November 2008.

"Ringing: Frugal subdivision of curves and surfaces", J. Rossignac, A. Venkatesh, IEEE Computer Graphics and Applications (CG&A), 2010.

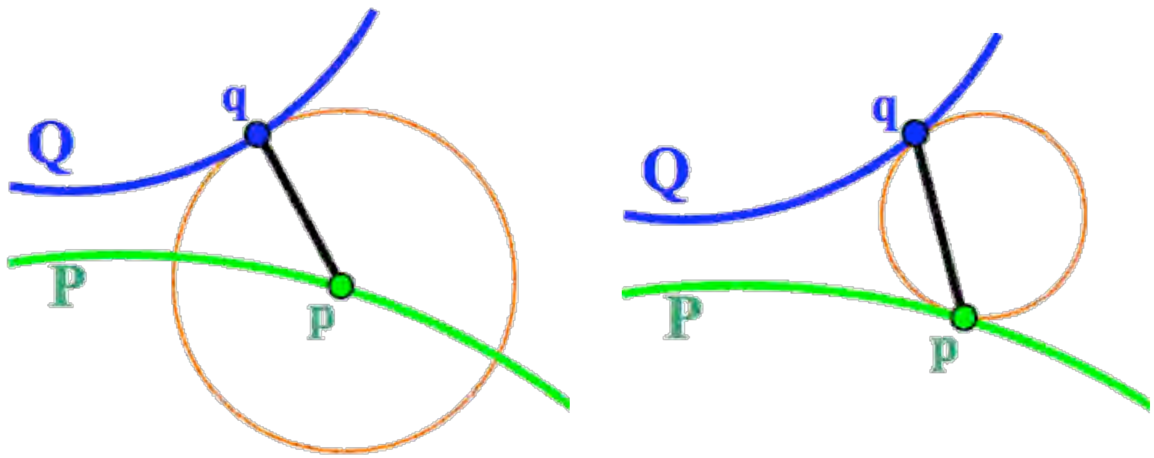
PROCESS

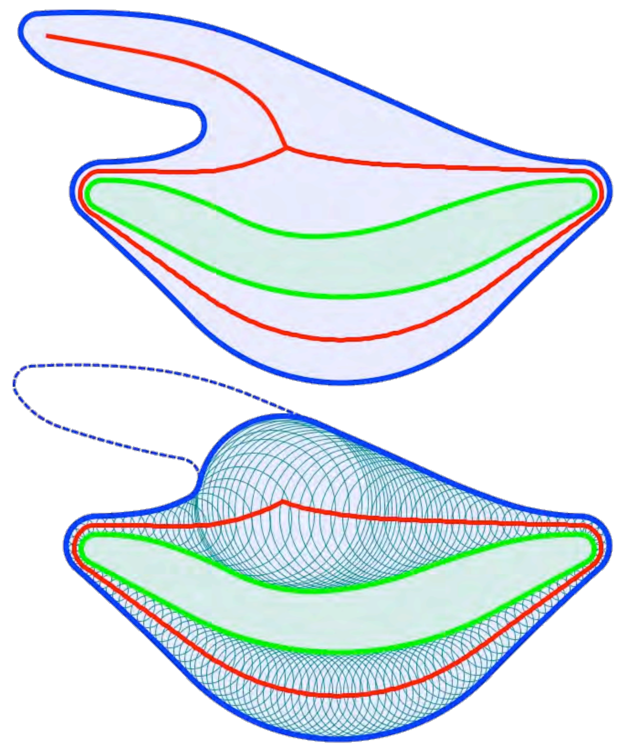
Compute correspondence (INRIA, Dassault)

Ball-map: Maps contact points of maximal balls in P xor Q

Advantages over *Closest Point map*

- Symmetric (same incidence angle)
- No distortion between symmetric features
- Shorter average travel!!





"Ball Map: Homeomorphism between compatible surfaces", F. Chazal, A. Lieutier, J. Rossignac, B. Whited. Int. Journal of Computational Geometry and Applications (IJCGA), 2009.

Test compatibility, similarity (INRIA, DS)

A and B are ***normal-compatible*** (normal offset of each other) if

- $H(A,B) < (2-\sqrt{2})\min(mfs(A),mfs(b))$, tight bound

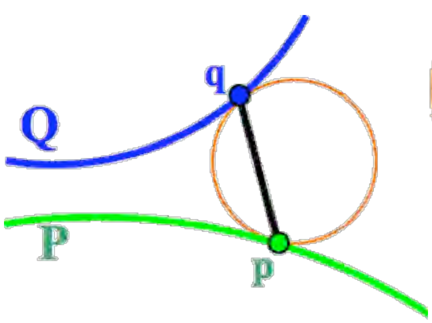
A and B are ***ball-compatible*** (***ball map*** = homeomorphism) if

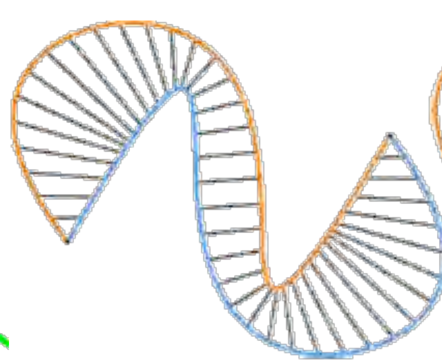
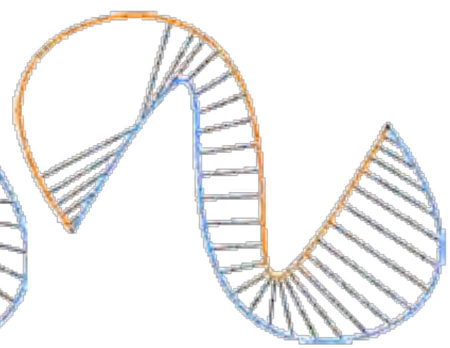
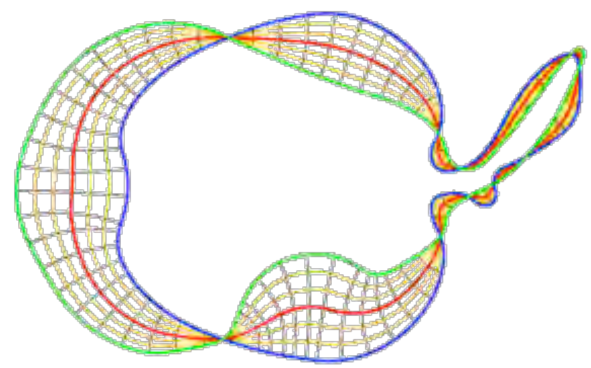
- $H(A,B) < \min(mfs(A),mfs(b))$, tight bound

Median of two C^k ball-compatible manifolds is C^k

A and B ball-compatible => H(A,B) = F(A,B)

- Frechet=Hausdorff!!!



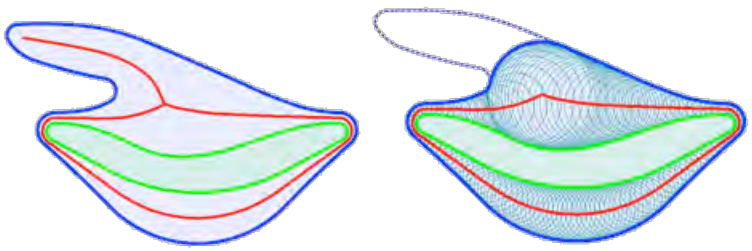
"Normal map between normal-compatible manifolds", F. Chazal, A. Lieutier, and J. Rossignac. Int. Journal of Computational Geometry & Applications (IJCGA), 17(5)403-421, Oct. 2007.

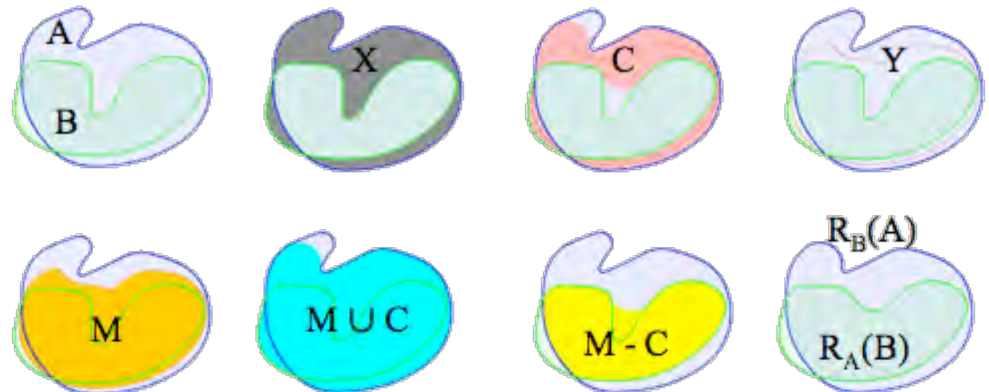
Round one shape relative to another

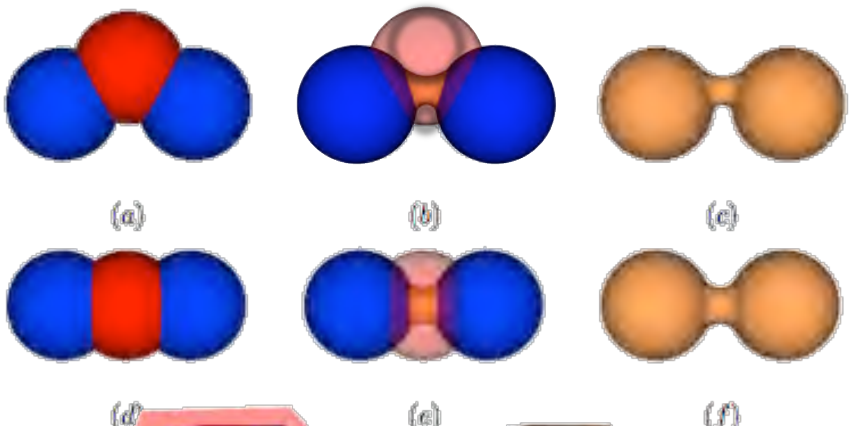
C=balls that touch both, Y=their centers

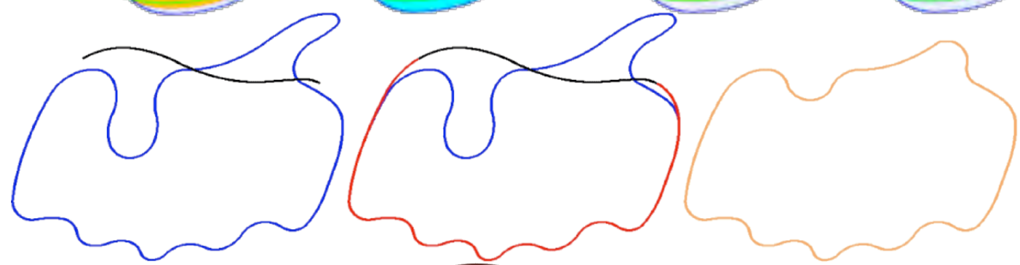
$$R_B(A) = (A \cap (M \cup C)) \cup (M - C)$$

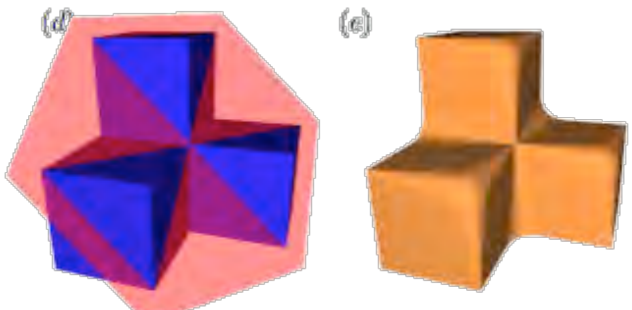
$$R_A(B) = (B \cap (M \cup C)) \cup (M - C)$$

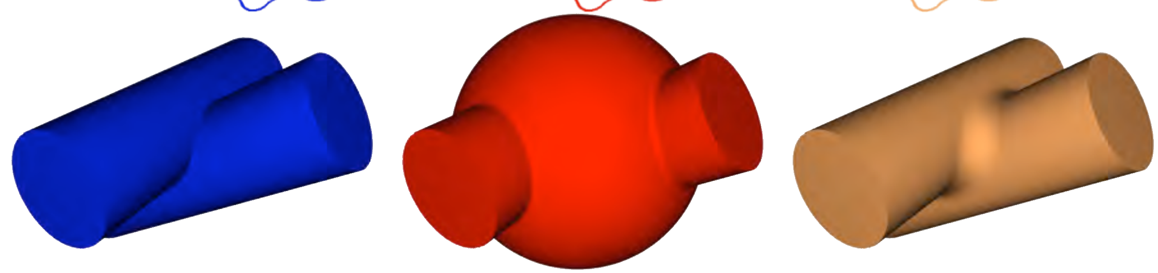












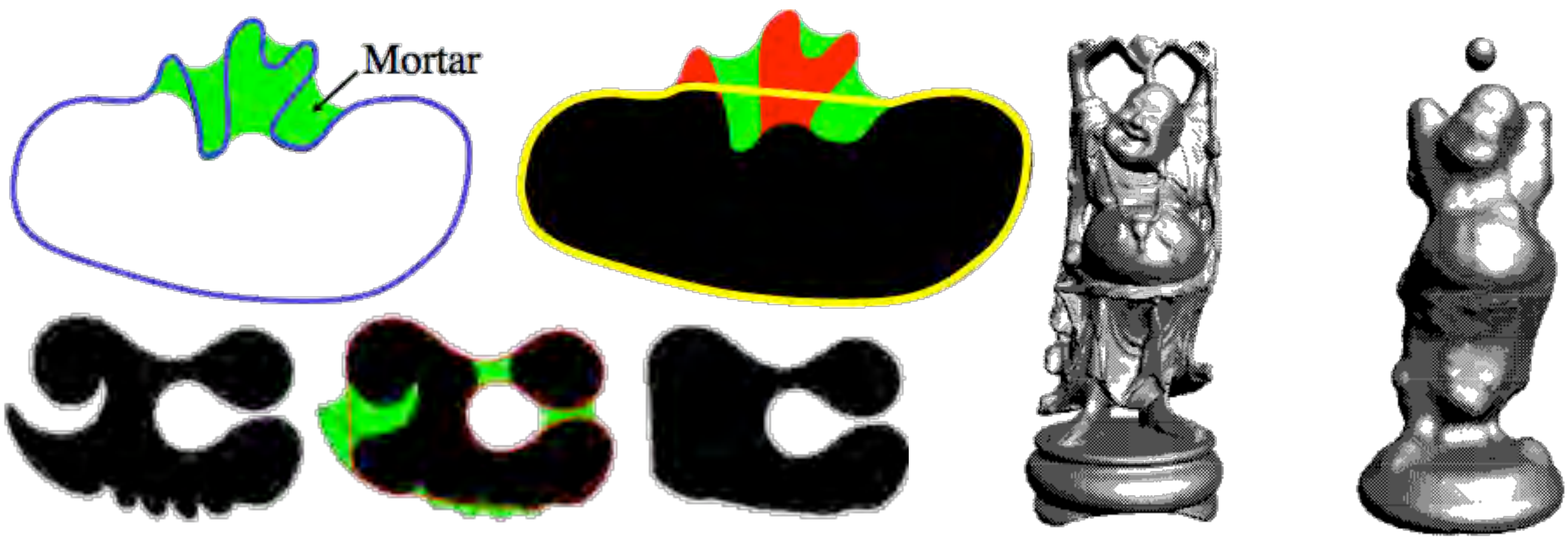
"Relative blending", B. Whited, J. Rossignac. Journal of Computer-Aided Design, 41(6)456-462, 2009.

Tighten a shape in the mortar

Tighten boundary B in r-*mortar* $(B^r)_r$.

Nature of resulting surface in 3D?

r-Mortar = places not reached by r-ball disjoint from boundary



"Tightening: Morphological Simplification", J. Williams and J. Rossignac. International Journal of Computational Geometry & Applications (IJCGA), 17(5)487-503, Oct. 2007.

SEGMENT

Surface reconstruction from slices

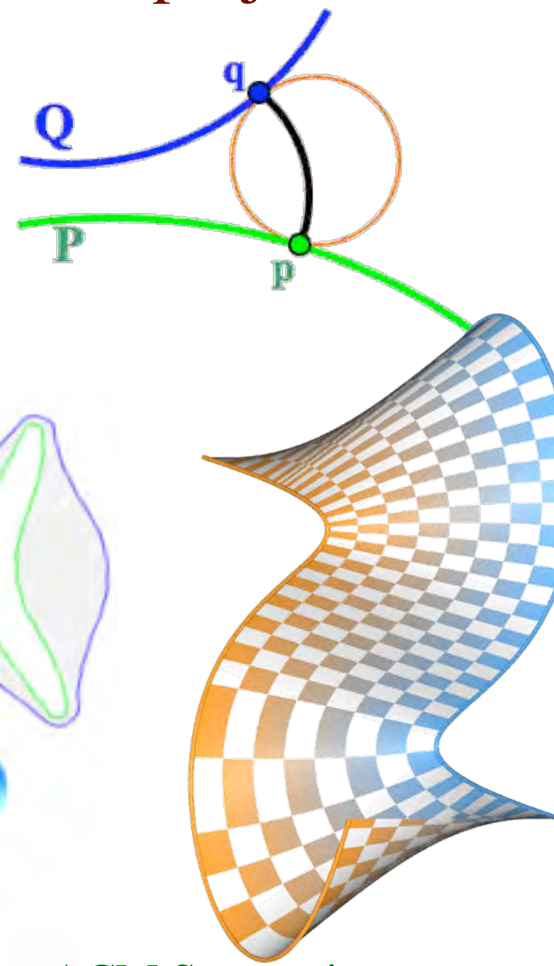
Compute circular ball-morph trajectories between projections

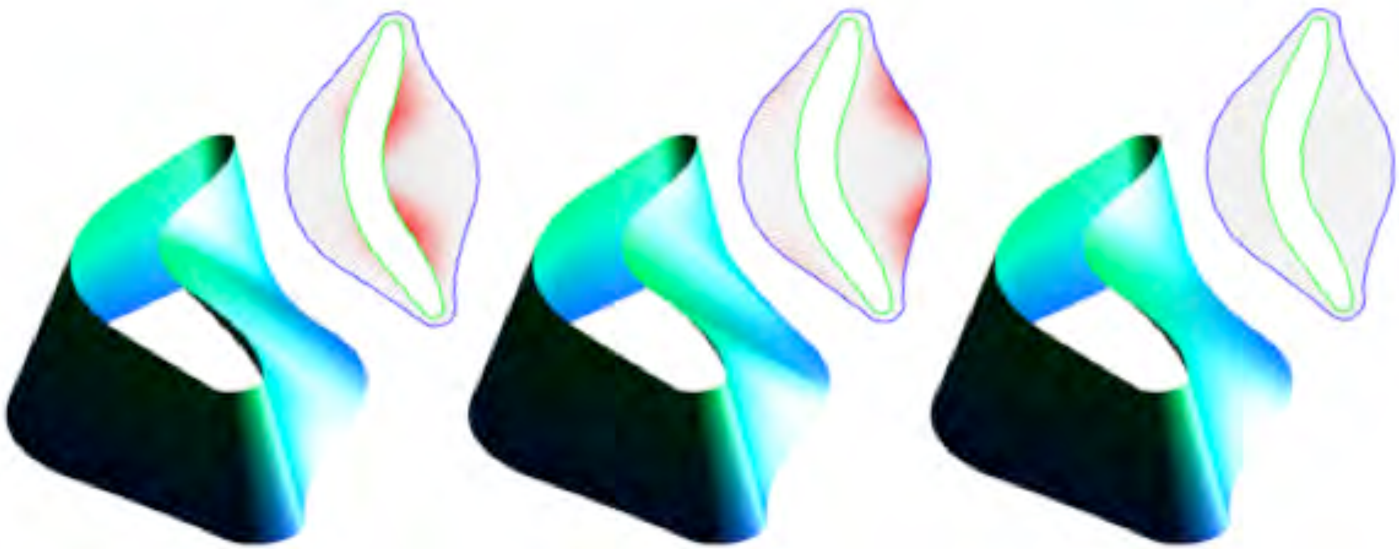
Trajectory ortogonal to both curves

Interpolating surface – pencil of helices

The construction is symmetric

Smoother than other solutions

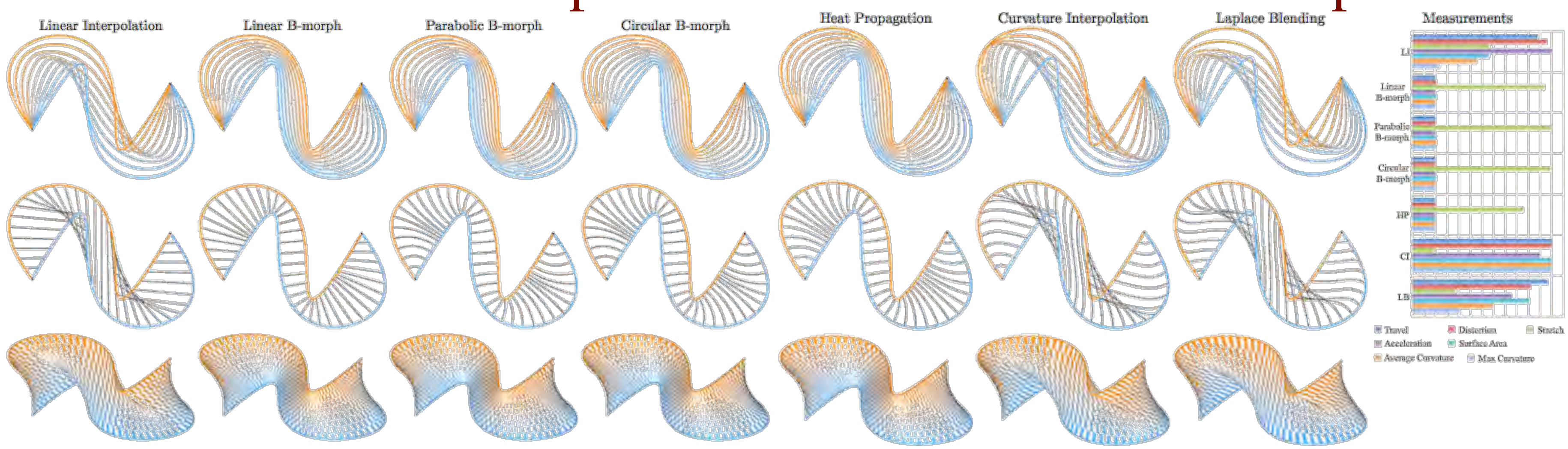


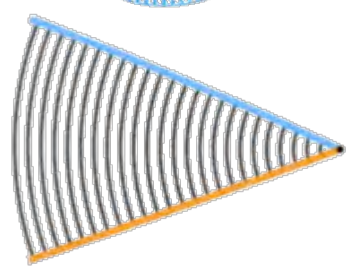


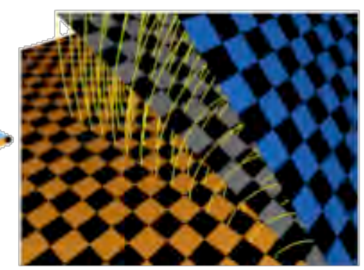
"B-morphs between b-compatible curves", B. Whited, J. Rossignac. ACM Symposium on Solid and Physical Modeling (SPM), 2009.

Compare ball-morph to other morphs

Assume two closed loops or two strokes with same endpoints







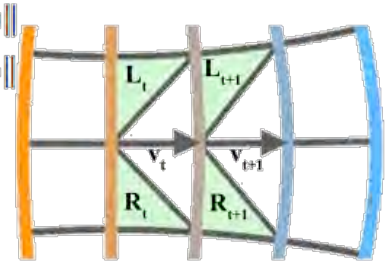
Travel distance

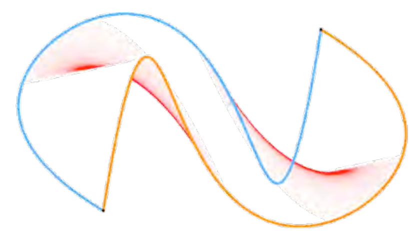
Stretch

Acceleration

$$S(P,Q) = \sum_{t\in[0,1-\epsilon]} \left(\sum_{p\in P} |L(p,t+\epsilon) - L(p,t)|\right) + \sum_{t\in[0,1-\epsilon]} \left(\sum_{q\in Q} |L(q,t+\epsilon) - L(q,t)|\right)$$

$$g_t = \tfrac{1}{2}\|B_L(p_{t-\epsilon}p_t) - B_R(p_{t-\epsilon}p_t)\| + \tfrac{1}{2}\|B_L(p_t p_{t+\epsilon}) - B_R(p_t p_{t+\epsilon})\|$$

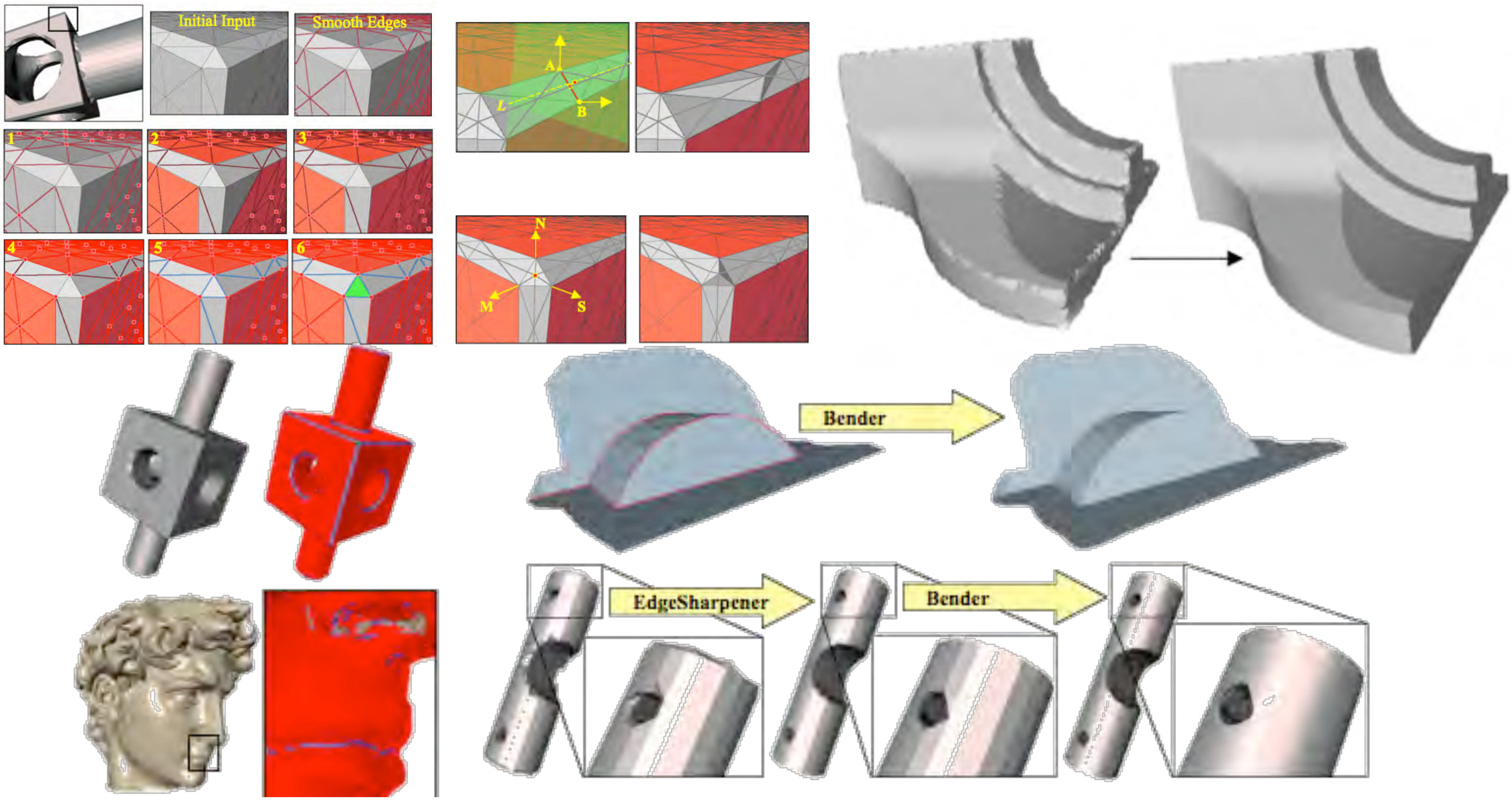




Surface area

Max square mean curvature

Sharpen&Bend triangle meshes (CNR, Italy)



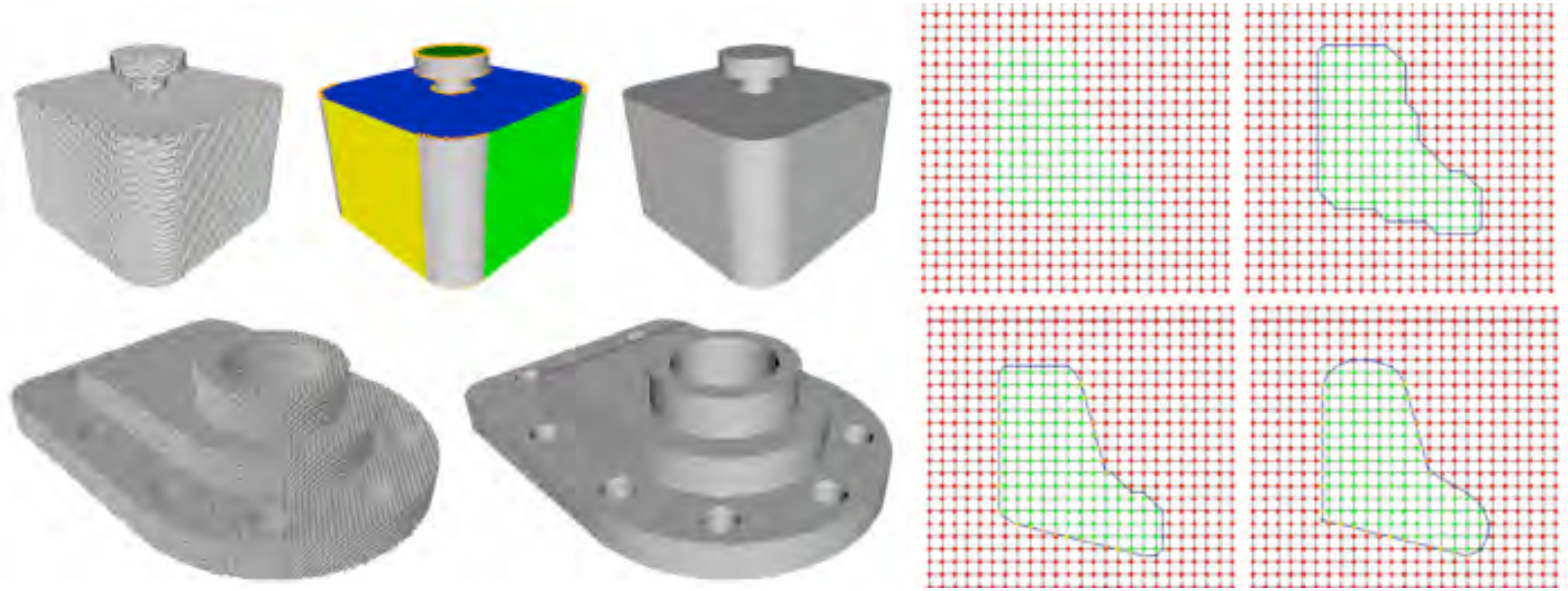
M. Attene, B. Falcidieno, J. Rossignac and M. Spagnuolo “Edge-Sharpener: A geometric filter for recovering sharp features in uniform triangulations,” Eurographics Symposium on Geometry Processing 2003.

M. Attene, B. Falcidino, M. Spagnuolo, J. Rossignac, “Sharpen&Bend: Recovering curved edges in triangle meshes produced by feature-insensitive sampling”, IEEE Transactions on Visualization and Computer Graphics, vol 11, no 2, pp 181-192, 2005.

Press and blend isosurfaces (UPC, Spain)

Identify **flats**, **blends**, and **sharp edges** in binary volumes

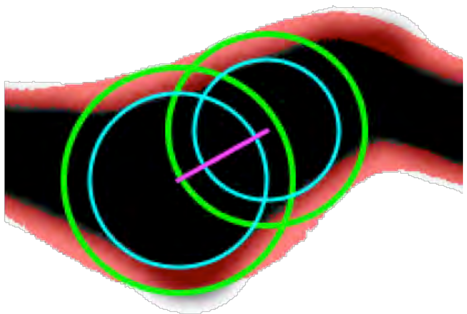
- grow maximal hyperplanes through red-green edges
- perform constrained smoothing of blends



"Pressing: Smooth Isosurfaces with Flats from Binary Grids", A. Chica J. Williams, C. Andujar, P. Brunet, I.Navazo, J.Rossignac, A.Vinacua. Computer Graphics Forum, 2008.

Fill arteries with pearl strings (**Siemens**)

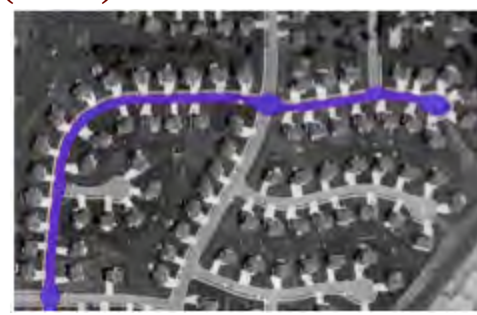
Trace/segment strokes (2D or tubes (3D) in realtime

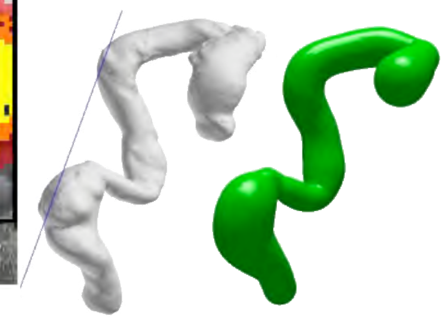


$$F(c_i, r_i) = \frac{9}{\pi r_i^3} \int_{x \in P_i} \Phi(x)(c_i - x)\left(1 - \frac{\|c_i - x\|^2}{r_i^2}\right) dx$$

$$G = \frac{\int_{x \in P_i} \Phi(x) dx}{\int_{x \in P_i} dx}$$

$$\Phi(x) = \begin{cases} 1, \text{ if } p_b(I(x)) > p_g(I(x)) \\ 0, \text{ otherwise} \end{cases}$$



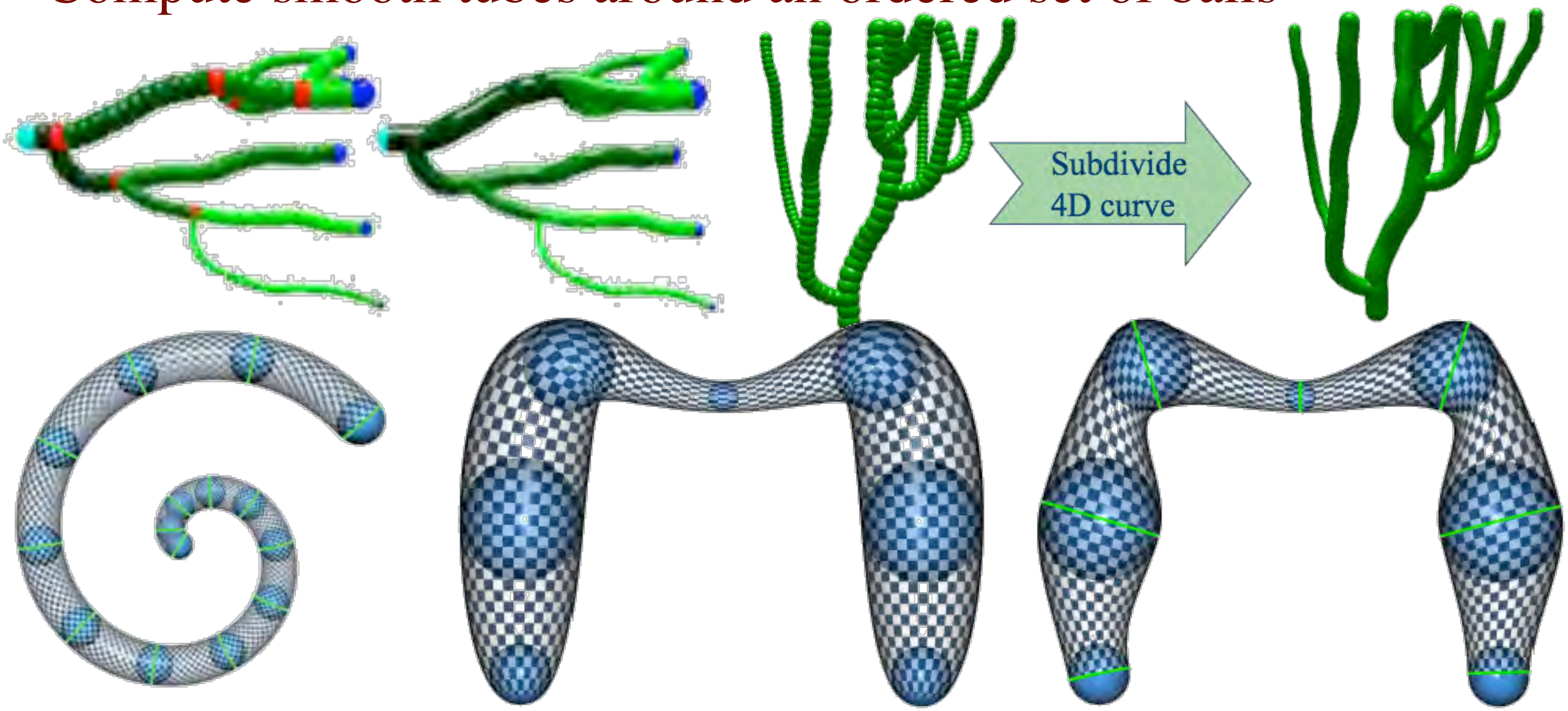


"Pearling: 3D interactive extraction of tubular structures from volumetric images", J. Rossignac, B. Whited, G. Slabaugh, T. Fang, G. Unal. International Conference on Medical Image Computing and Computer Assisted Intervention (MICCAI), Workshop on Interaction in Medical Image Analysis and Visualization. November 2, 2007.

"Pearling: Stroke segmentation with crusted pearl strings", B. Whited, J. Rossignac, G. Slabaugh, T. Fang, G. Unal. Journal of Pattern Recognition and Image Analysis (PRIA), 2(19), 2009.

Put a skin on these pearl strings (**Siemens**)

Compute smooth tubes around an ordered set of balls



"Variational Skinning of an Ordered Set of Discrete 2D Balls", G. Slabaugh, G. Unal, T. Fang, J. Rossignac, B. Whited. Geometric Modeling and Processing (GMP), pp. 450-461, 2008.
"3D Ball Skinning using PDEs for Generation of Smooth Tubular Surfaces", G. Slabaugh, J. Rossignac, B. Whited, T. Fang, G. Unal. Journal of Computer Aided-Design (JCAD). 2009.

COMPRESS

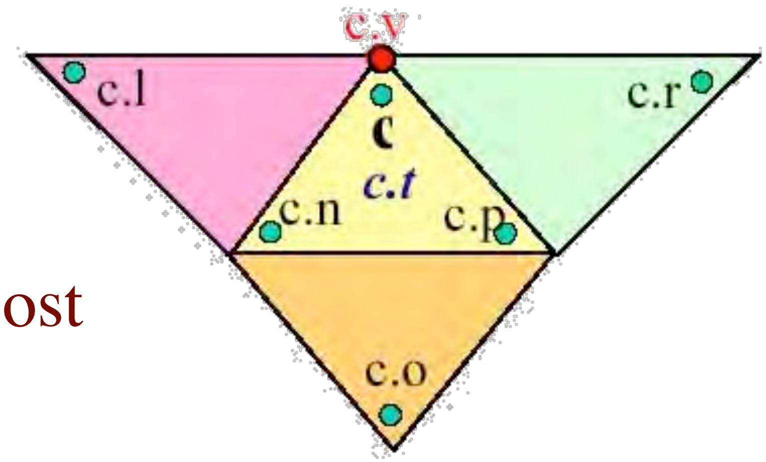
Corner Table: Connectivity of triangle meshes

Store two integers per corner c (each triangle has 3 corners)

- **V[c]** int index of vertex of corner c
- **O[c]** int index of opposite corner

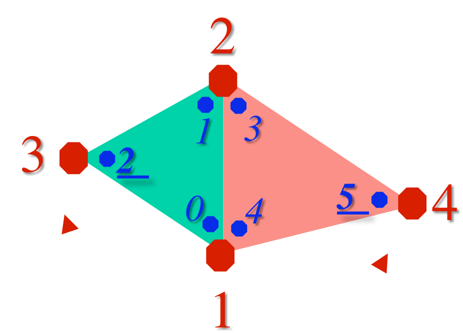
Storage: 6 references per triangle

Other operators derived at constant cost



vertex 1	**x**	**y**	**z**
vertex 2	**x**	**y**	**z**
vertex 3	**x**	**y**	**z**
vertex 4	**x**	**y**	**z**

	V	**O**
Triangle 0 corner 0	**1**	**7**
Triangle 0 corner 1	**2**	**8**
Triangle 0 corner 2	**3**	**5**
Triangle 1 corner 3	**2**	**9**
Triangle 1 corner 4	**1**	**6**
Triangle 1 corner 5	**4**	**2**



SOT: Extension to tetrahedral meshes

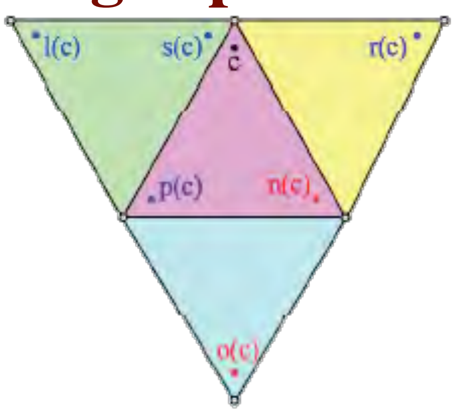
Trivial Corner Table extension: 8 rpt [Lage05]

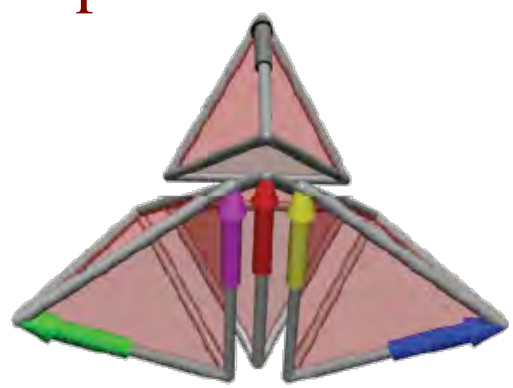
- Store vertex V[c] and opposite O[c] indices for reach corner c

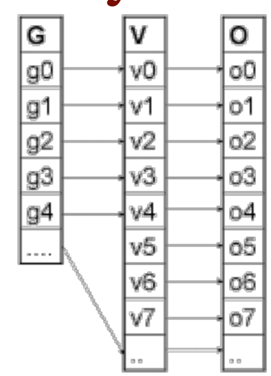
SOT: only 4 rpt !!!

- V-table is not represented at all! Only the ***Sorted O Table*** (+ 9 bpt)
- Offers **vertex-star references at no additional storage cost** !!!
- Linear construction and traversal cost

Wedge operators: mimic corner operators on star boundary

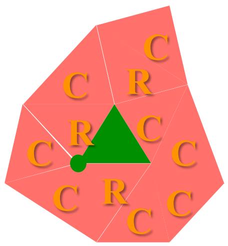






"*SOT*: Compact representation for Tetrahedral Meshes", T. Gurung and J. Rossignac. ACM Symposium on Solid and Physical Modeling (SPM), 2009.

Edgebreaker: **The** triangle-mesh compression



clers=CCCCRCCRCRC…

clers=…CRSRLECRRRLE

Guaranted 1.8T bit
Entropy: **1T** bit

```
void compress (corner c) {
repeat {c.t.m:=1;                         # mark the triangle as visited
    if c.v.m == 0                         # test whether tip vertex was visited
      then {    write(vertices, c.v);     # append vertex index to "vertices"
                write(clers, C);          # append encoding of C to "clers"
                c.v.m:= 1;                # mark tip vertex as visited
                c:=c.r }                  # continue with the right neighbor
    else if c.r.t.m==1                    # test whether right triangle was visited
        then if c.l.t.m== 1               # test whether left triangle was visited
             then {write(clers, E);       # append encoding of E to clers string
                   return }               # exit (or return from recursive call)
             else {write(clers, R);       # append encoding of R to clers string
                   c:=c.l }               # move to left triangle
        else if c.l.t.m == 1              # test whether left triangle was visited
             then {write(clers, L);       # append encoding of L to clers string
                   c:=c.r }               # move to right triangle
             else {write(clers, S);       # append encoding of S to clers string
                   compress(c.r);         # recursive call to visit right branch first
                   c:=c.l } }}            # move to left triangle
```

"Edgebreaker: Connectivity compression for triangle meshes", J. Rossignac. IEEE Transactions on Visualization and Computer Graphics, Vol. 5, No. 1, pp. 47-61, January - March 1999.

PRM: Resample mesh using X, Y, Z grids

"Piecewise Regular Meshes: Construction and Compression". A. Szymczak, J. Rossignac, and D. King. Graphics Models, Special Issue on Processing of Large Polygonal Meshes, 2002.

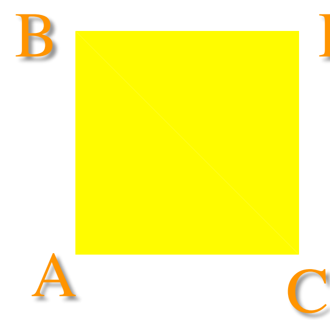
Split surface in 3 sets by orientation

Resample each set on a regular grid

Merge sets and fill topological cracks

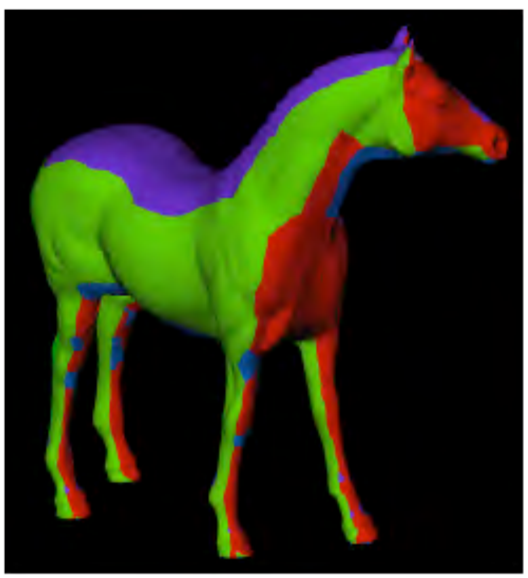
Encode with ***Edgebreaker***

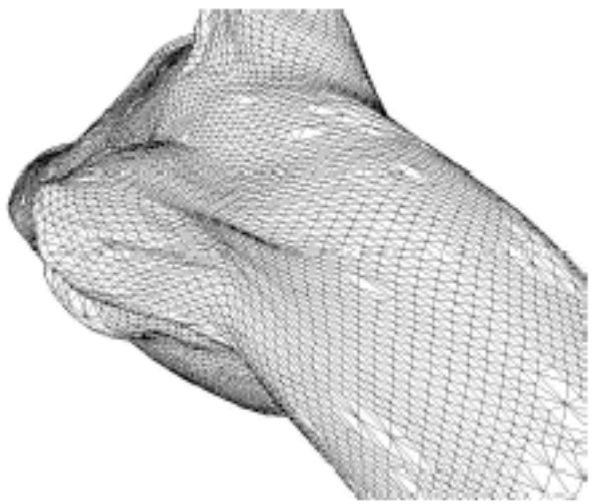
1T bits (geometry=89%)

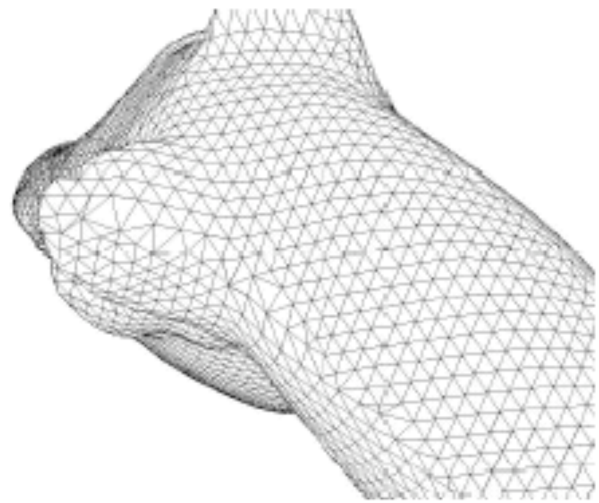


$D^* = B + C - A$

parallelogram prediction







SwingWrapper: triangular retiling (CNR, Italy)

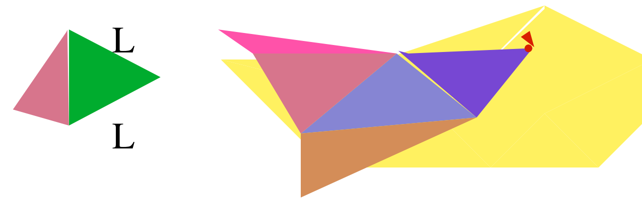
M. Attene, B. Falcidieno, M. Spagnuolo and J. Rossignac "SwingWrapper: Retiling Triangle Meshes for Better Compression," ACM Transactions in Graphics vol. 22, no. 4, pp. 982-996, 2003.

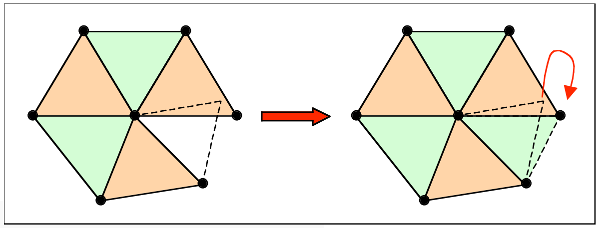
Retile the surface with mostly isosceles triangles

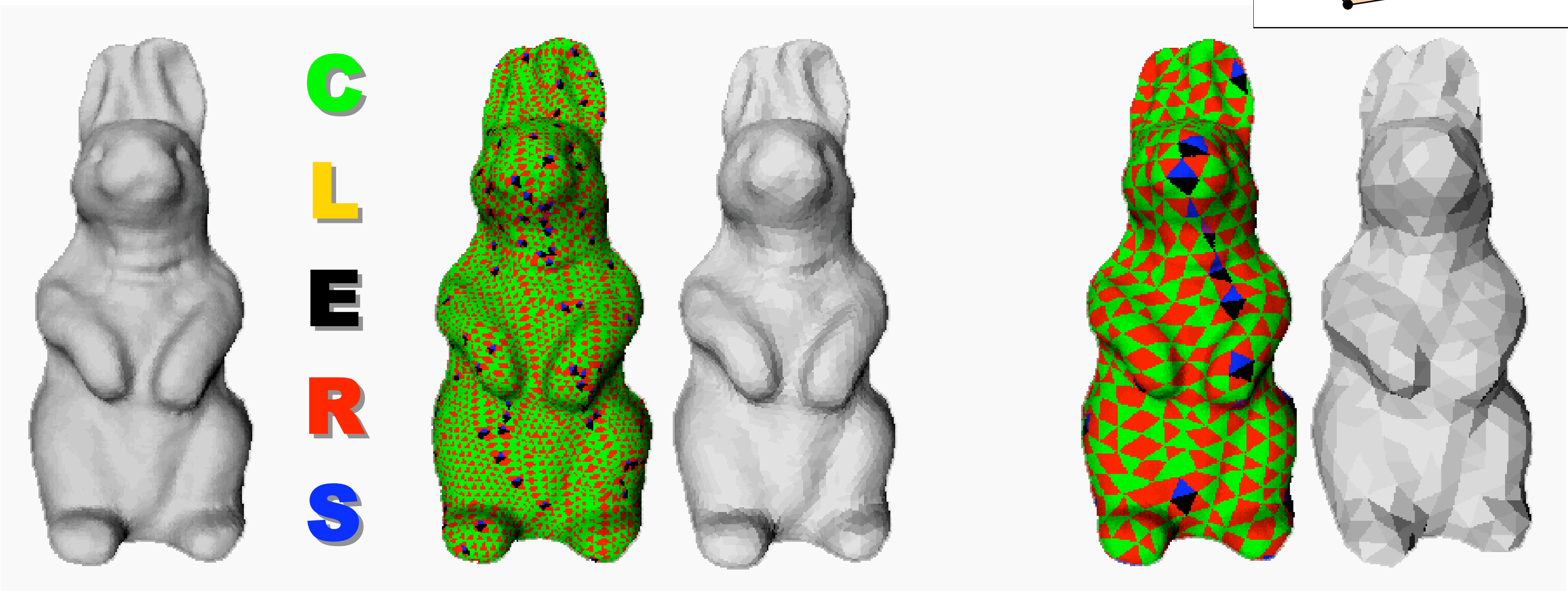
2/3 edges have length L (prescribed by user)

4000-to-1 compression (…when it works)

Option to adjust L locally

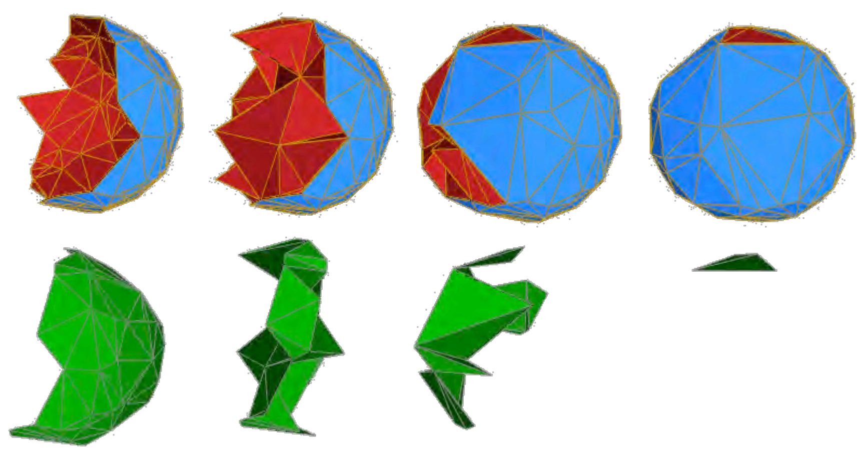






Stream compressed tet meshes back-to-front

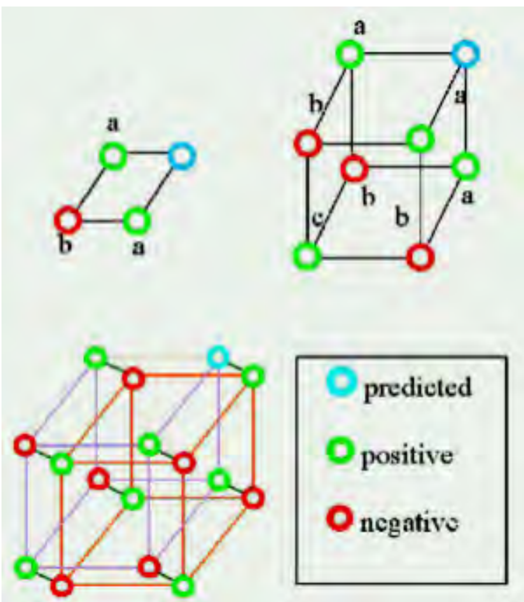
- Encode a tetrahedral mesh in back-to-front order
- Stream it in a compressed format (connectivity: **2 bits per tet**)
- Compression with SOT wedge operators is simple and efficient
- Decompression is suited for **out-of-core** processing:
  - The decoder maintains only a triangle mesh representation of a slice (red) and evolves it through vertex insertion, vertex deletions, and edge flips.

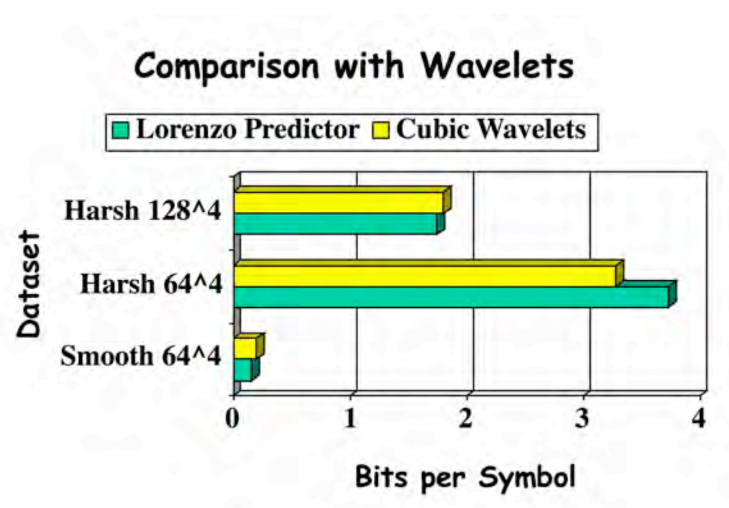


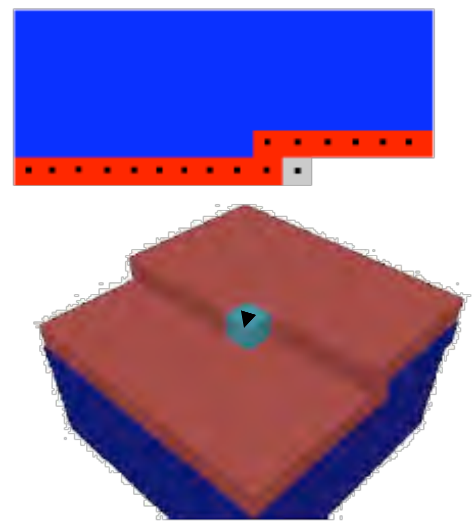
"TetStreamer: Compressed Back-to-Front Transmission of Delaunay Tetrahedra Meshes", Urs Bischoff and Jarek Rossignac. *Data Compression Conference (DCC), 93-102, 2005*.

Lorenzo predictor in 4D (**LLNL**)

- Function F(x,y,z,t) sampled over a regular 4D grid
- Predict F(x+1, y+1, z+1, t+1) as sum of values at other corners
  - Change their sign if reached via even number of edges
- **Perfect** (zero residues) for fields that are **cubic** polynomials







L. Ibarria, P. Lindstrom, J. Rossignac, A. Szymczak, Out-of-core compression and decompression of large n-dimensional scalar fields, Eurographics 2003

Spectral compression (**LLNL**)

Predict value from the known values in a 3×3 neighborhood

Fit lowest degree polynomial, resolve ambiguities

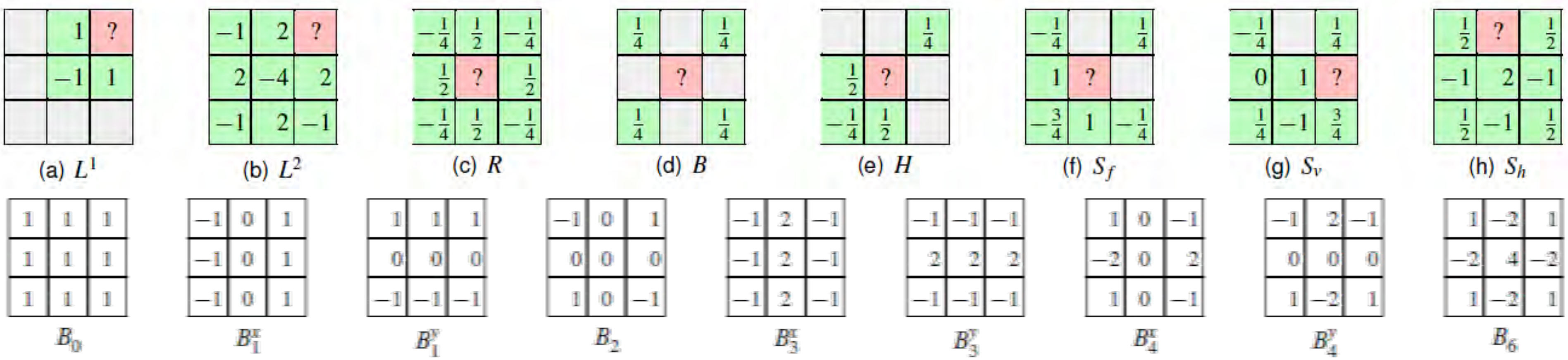
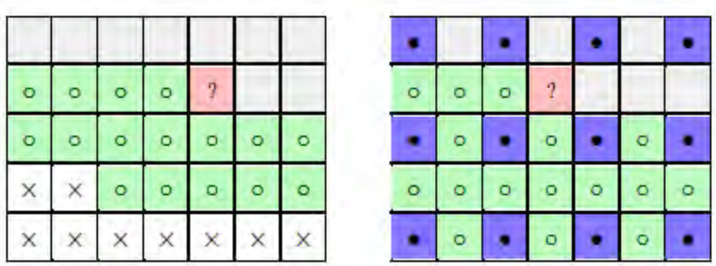
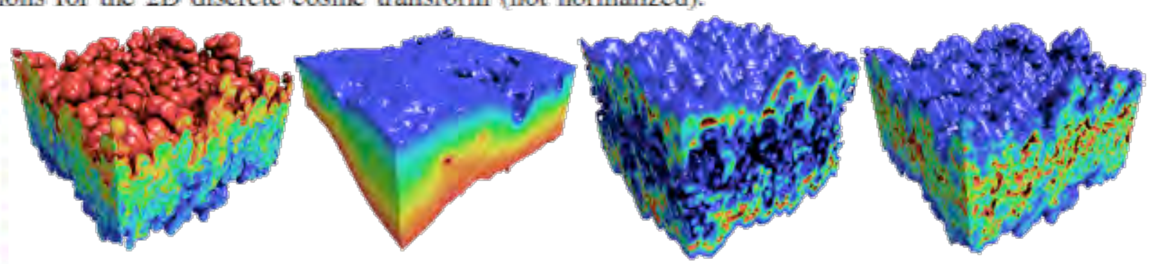


Figure 2. Basis functions for the 2D discrete cosine transform (not normalized).





(a) Density (b) Pressure (c) Diffusivity (d) Viscocity

Spectral Interpolation on 3x3 Stencils for Prediction and Compression L. Ibarria, P. Lindstron, J. Rossignac. Journal of Computers, 2(8)53-63, 2007.

ANIMATE

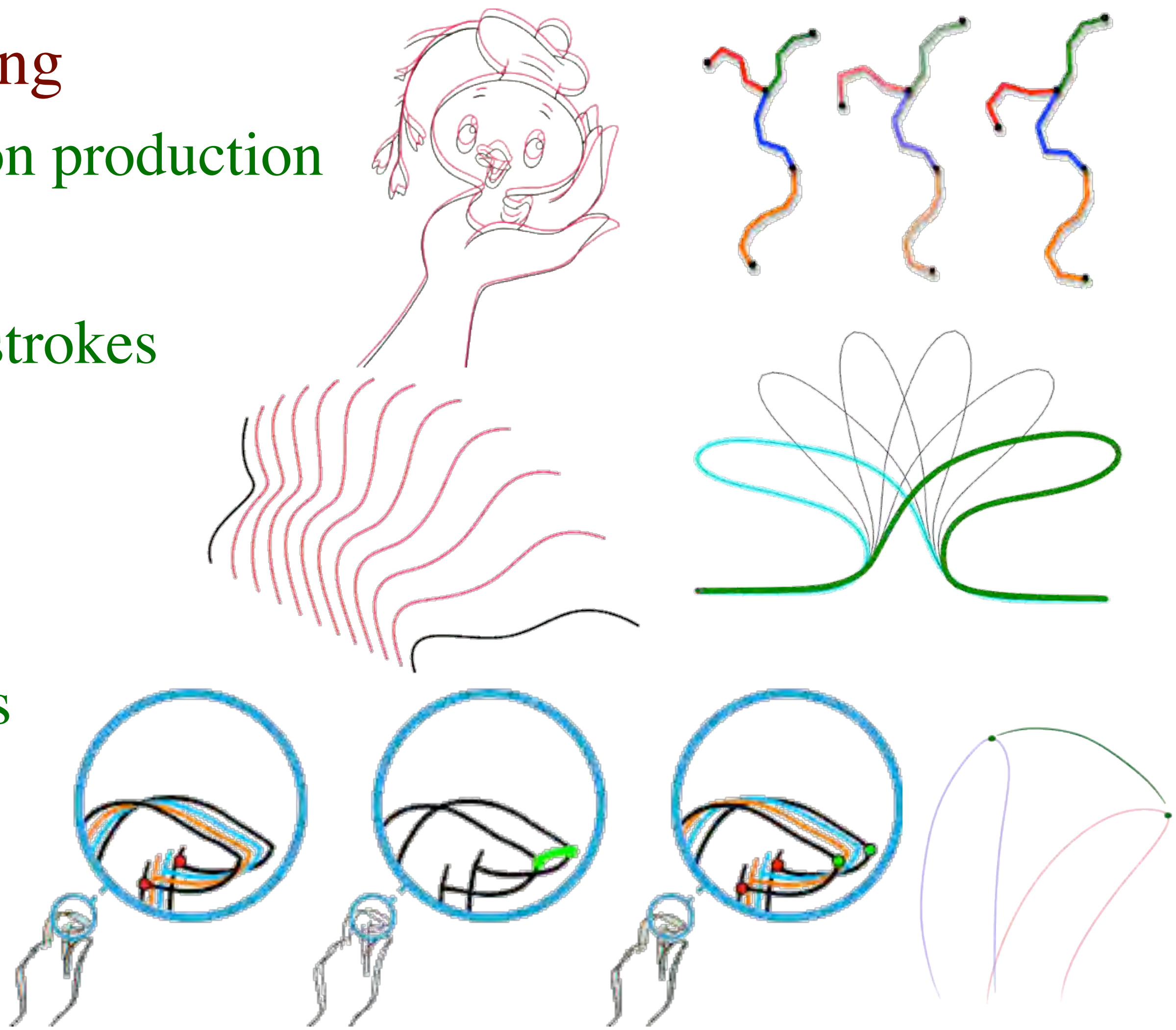
In-betweening (**Disney**, ETH)

Automate inbetweening

- for feature animation production

Issues:

- Segmentation into strokes
- Correspondence
- Morphing strokes
- Occlusion
- Enable artist tweaks

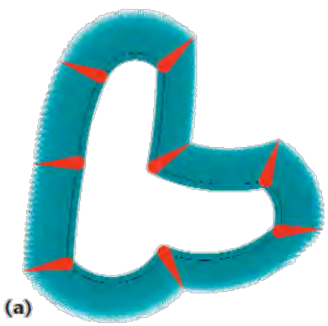


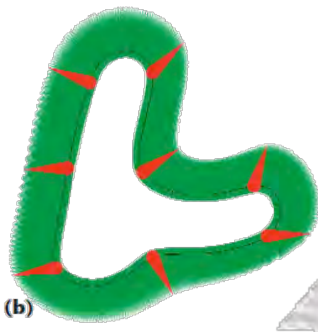
"*BetweenIT: An Interactive Tool for Tight Inbetweening*", B. Whited, G. Noris, M. Simmons, R. Sumner, M. Gros, J. Rossignac. 2009.

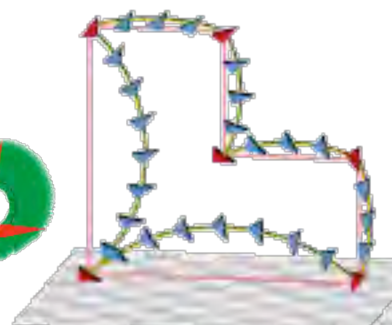
Bend&sweep screws (with Hangyang, Korea)

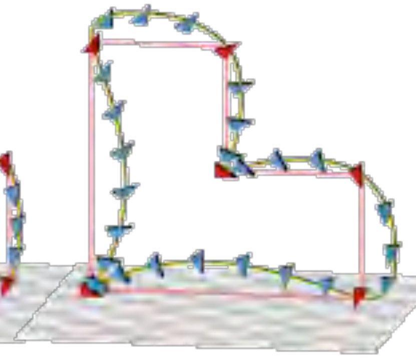
ScrewBender: J-spline subdivision of piecewise-helical motions

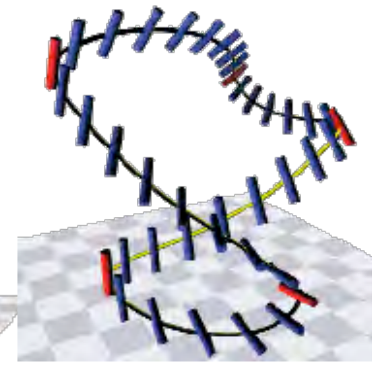
Sweeps: Grazing points are fixed under screw motion

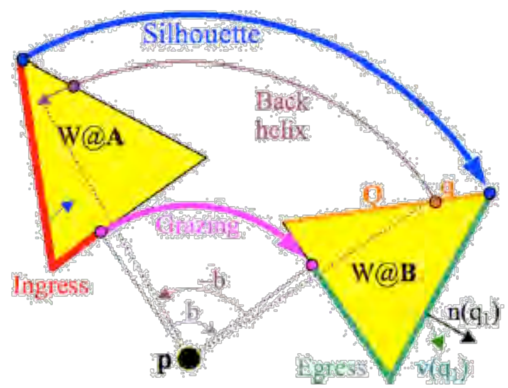

(a)

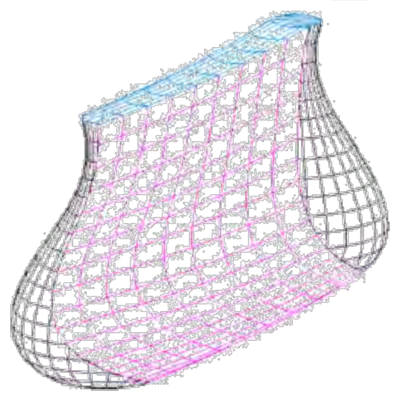

(b)

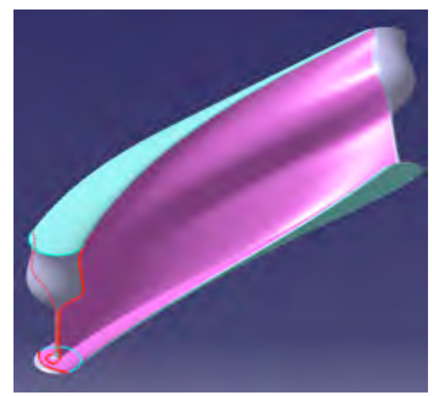












"Boundaries of volumes swept by free-form solids in screw motion", J. Rossignac, J. Kim, S. Song, K. Suh, C. Joung. Journal of Computer-Aided Design (JCAD), 39(9):745-755, Sep. 2007.
"ScrewBender: Smoothing Piecewise Helical Motions", A. Powell and J. Rossignac, January 2007. IEEE Computer Graphics and Applications, 28(1):56-63 Jan/Feb 2008.

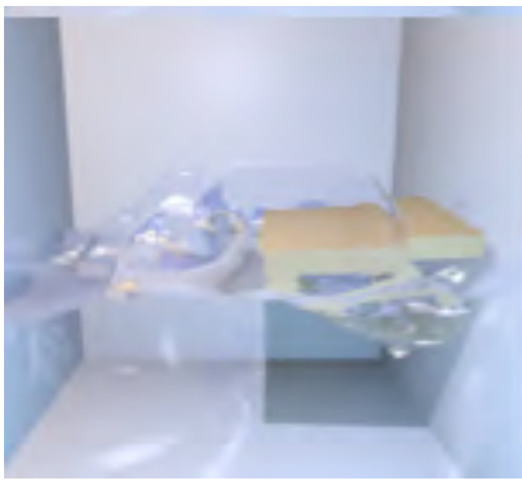
SIMULATE

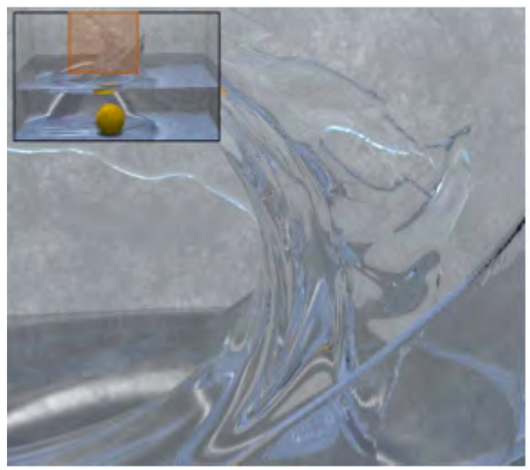
Solids and bubbles in water (Math, Stanford)

Increase accuracy & performance (BFECC, MacCormack)

Avoid volume loss of bubbles and fluid

Preserve foam bubbles (surface tension, thin membranes)





"FlowFixer: Using BFECC for Fluid Simulation", BM. Kim, Y. Liu, I. Llamas, J. Rossignac. Eurographics Workshop on Natural Phenomena, pp 51-56. September 2005

"Simulation of bubbles in foam with the volume control method", BM. Kim, Y. Liu, I. Llamas, X. Jiao, J. Rossignac. ACM Transactions on Graphics, 26(3):98, Proc. ACM SIGGRAPH, July 2007.

"Advections with Significantly Reduced Dissipation and Diffusion", BM. Kim, Y. Liu, I. Llamas, J. Rossignac. IEEE Transactions on Visualization and Computer Graphics, 13(1)135-144, Jan/Feb 2007.

"An Unconditionally Stable MacCormack Method", A. Sell, R. Fedkiw, BM. Kim, Y. Liu, J. Rossignac. Journal of Scientific Computing. 2008.

Aquatic Propulsion Lab (USC, Nvidia, **NSF**)

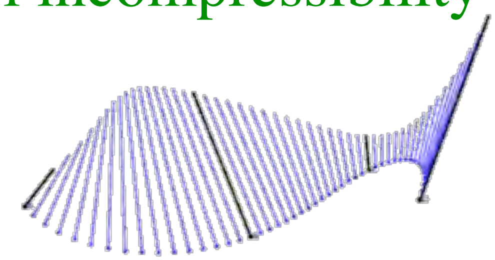
with G. Turk & K. Liu (and E. Kanso, Aero-ME USC)

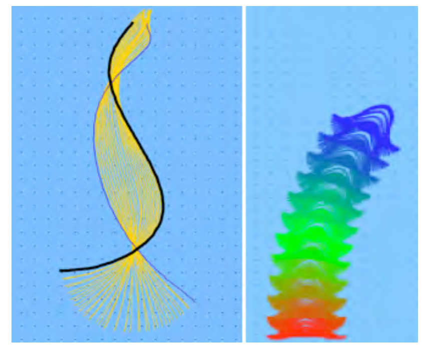
Provide interactive design tools for swimming motions

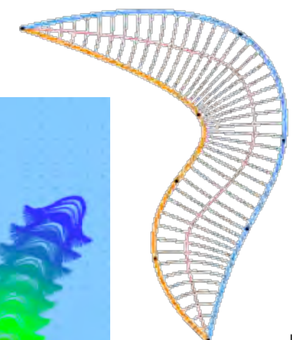
- Constant length spine, constant area

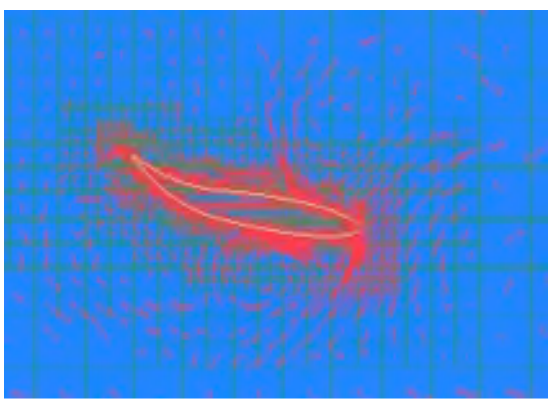
Evaluate/compare/optimize their performance

- CFD: Particles, Voronoi incompressibility
- Smart controllers

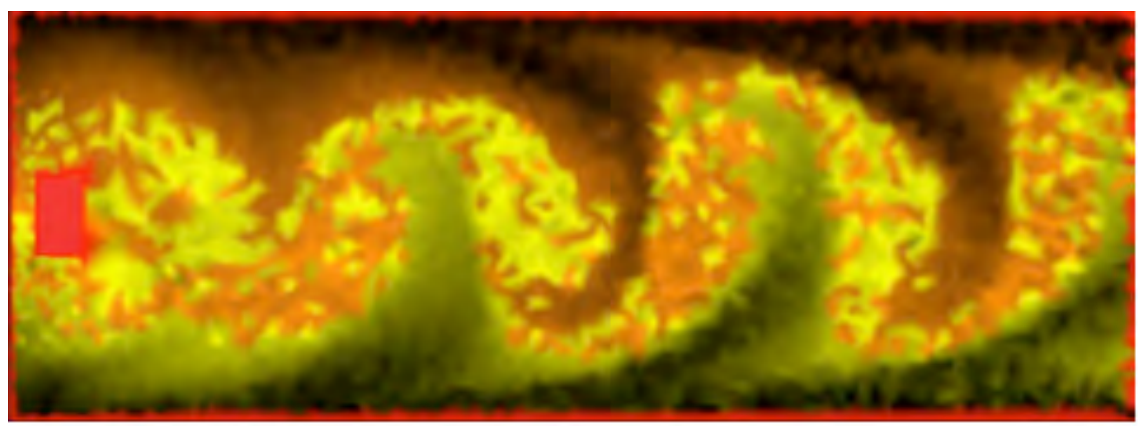








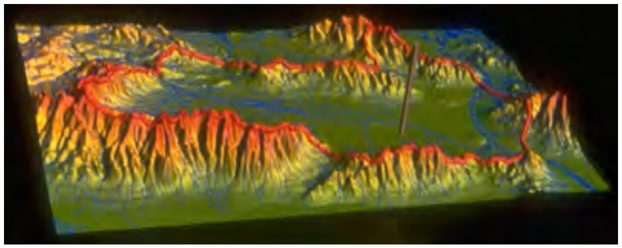
BM Kim Nvidia

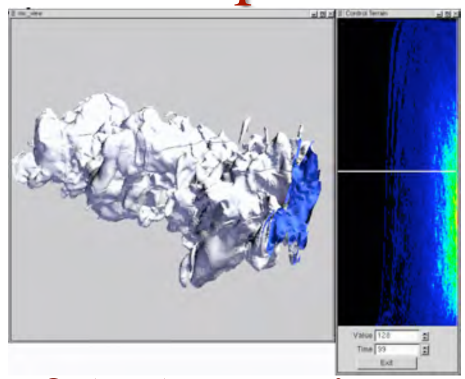


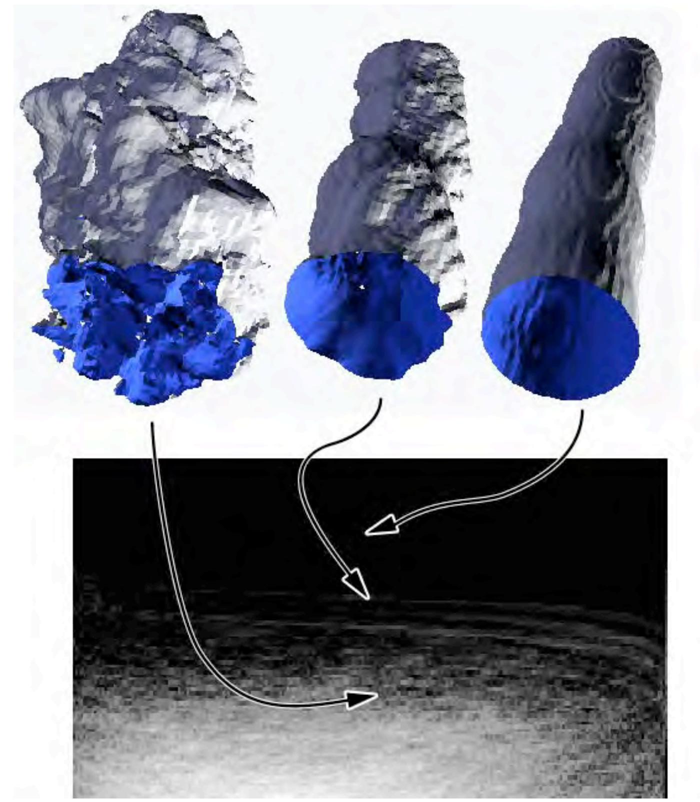
VISUALIZE

SAFARI: 4D VIZ (UNC & **LLNL**)

Interactive isosurface-based inspection of 4D structured data







S(t,s) = {P: F(P,t)=s}

Compute color/height of (t,s) terrain

from filters designed by scientist

User traces path on it

We animate isosurface accordingly

quick extraction

L. Kettner, J. Rossignac, J. Snoeyink, The Safari Interface for Visualizing Time-dependent Volume Data Using Iso-Surfaces and a Control Plane, CGTA 25:1-2(2003), pages 97-116

A. Mascarenhas, J. Snoeyink, Seed Set Computation for Isosurface Extraction in Time-varying Volumetric Data

Constructive Solid Trimming (CST)

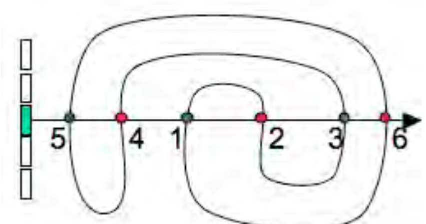
Define faces as intersection of surface with trimming volume

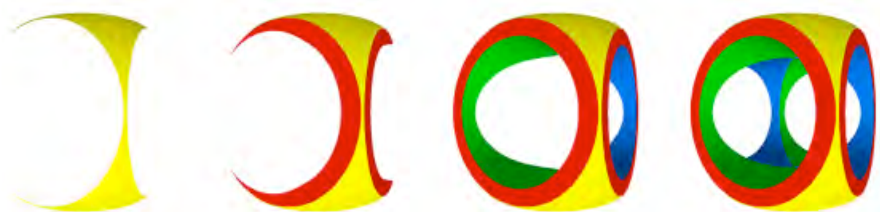
Define trimming volume as CSG of subdivision primitives

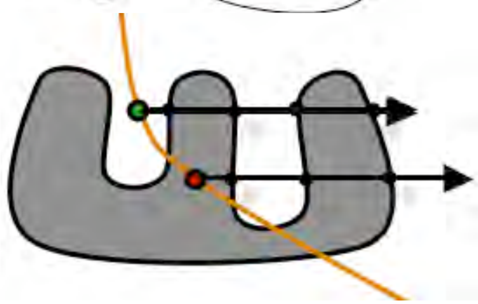
Use Optimized Blist Form (OFB) to trim and render on GPU

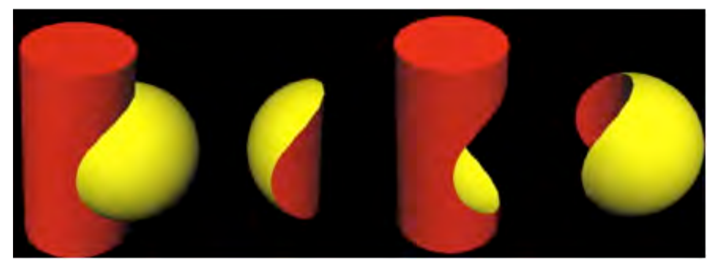
- Avoid expensive and delicate surface/surface intersection computation

Plans to combine J-spline surface/animation ringing and CST on the GPU









"Blister: GPU-based rendering of Boolean combinations of free-form triangulated shapes", Hable & Rossignac. ACM Transactions on Graphics, Proceedings of *SIGGRAPH 2005*

"CST: Constructive Solid Trimming for rendering BReps and CSG", Hable & Rossignac. IEEE Transactions on Visualization & Computer Graphics, 2007

www.cc.gatech.edu/**~jarek**

Surgery planning: Surgem, Plugmatch

Patterns & exceptions: Octor

Curves & surfaces & animations: J-splines, Ringing

Ball map: Rounding, morphing, slice interpolation

Reverse engineering: Sharpen&Bend, Pressing

Vessel segmentation: Pearling, skinning

Triangles: Corner Table, EdgeBreaker, PRM, SwingWrapper

Tetrahedra: SOT, TetStreamer

Field compression: Lorenzo, Spectral

Animation: InBetweening, ScrewBender, Sweeps, swimmers

Fluid: BFECC, volume, foam, particles

Visualization: Safari, CST