

Smoothing



Paolo Cignoni

3D GEOMETRIC MODELING & PROCESSING



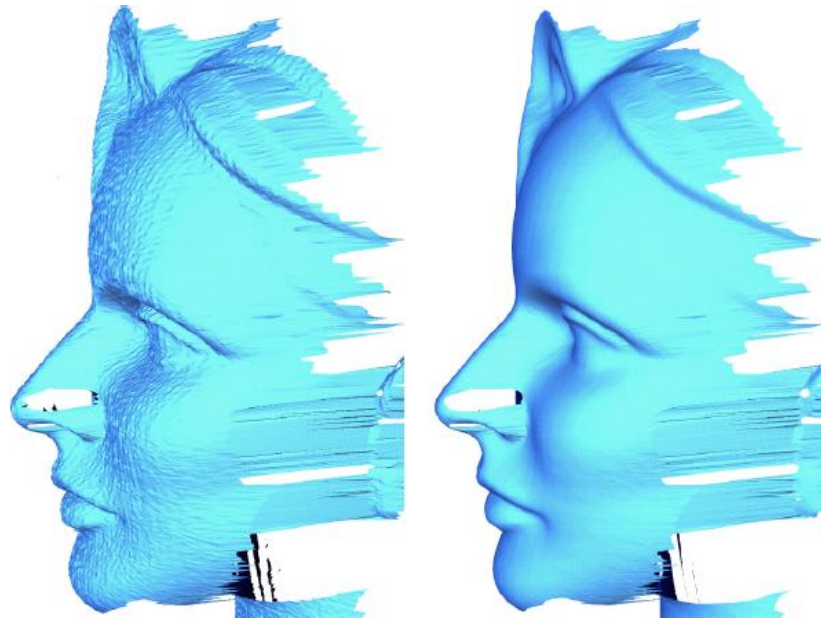
Smoothing

- ▣ Filtering out Noise from a mesh
- ▣ As in image processing



Motivations

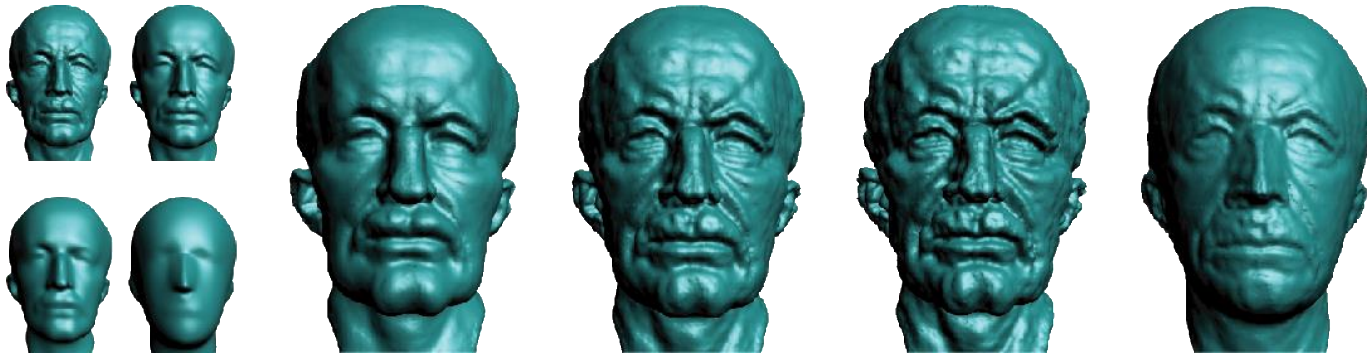
- Filter out high frequency components for noise removal



Desbrun, Meyer, Schroeder, Barr: *Implicit Fairing of Irregular Meshes using Diffusion and Curvature Flow*, SIGGRAPH 99

Motivations

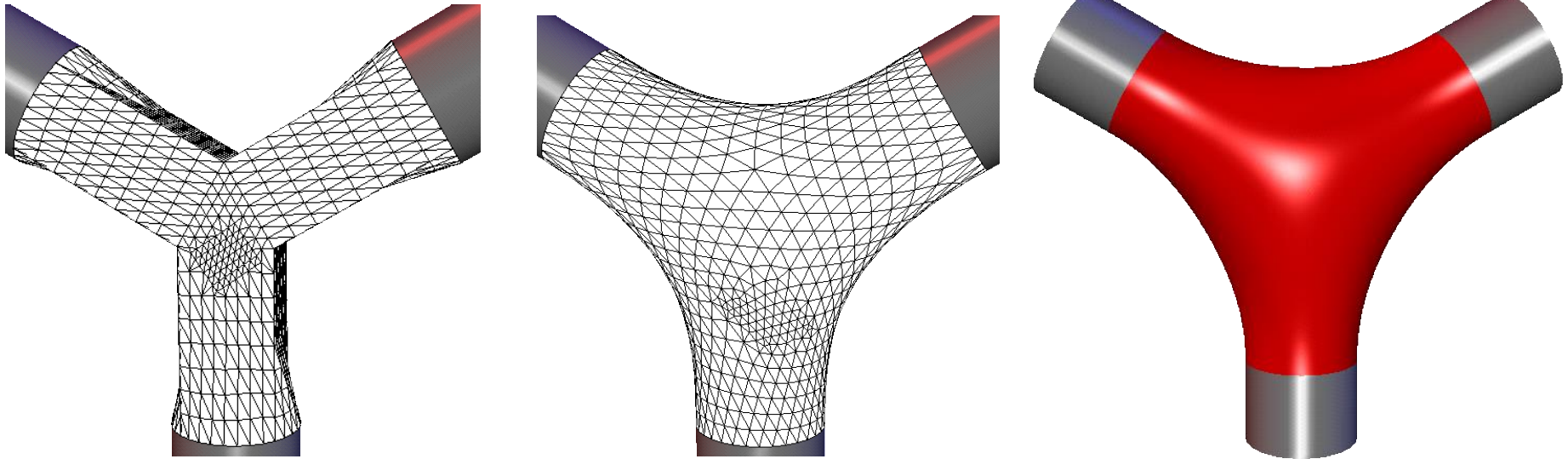
■ Advanced Filtering / Signal Processing, Multiscale



Pauly, Kobbelt, Gross: *Point-Based Multi-Scale Surface Representation*,
ACM TOG 2006

Motivations

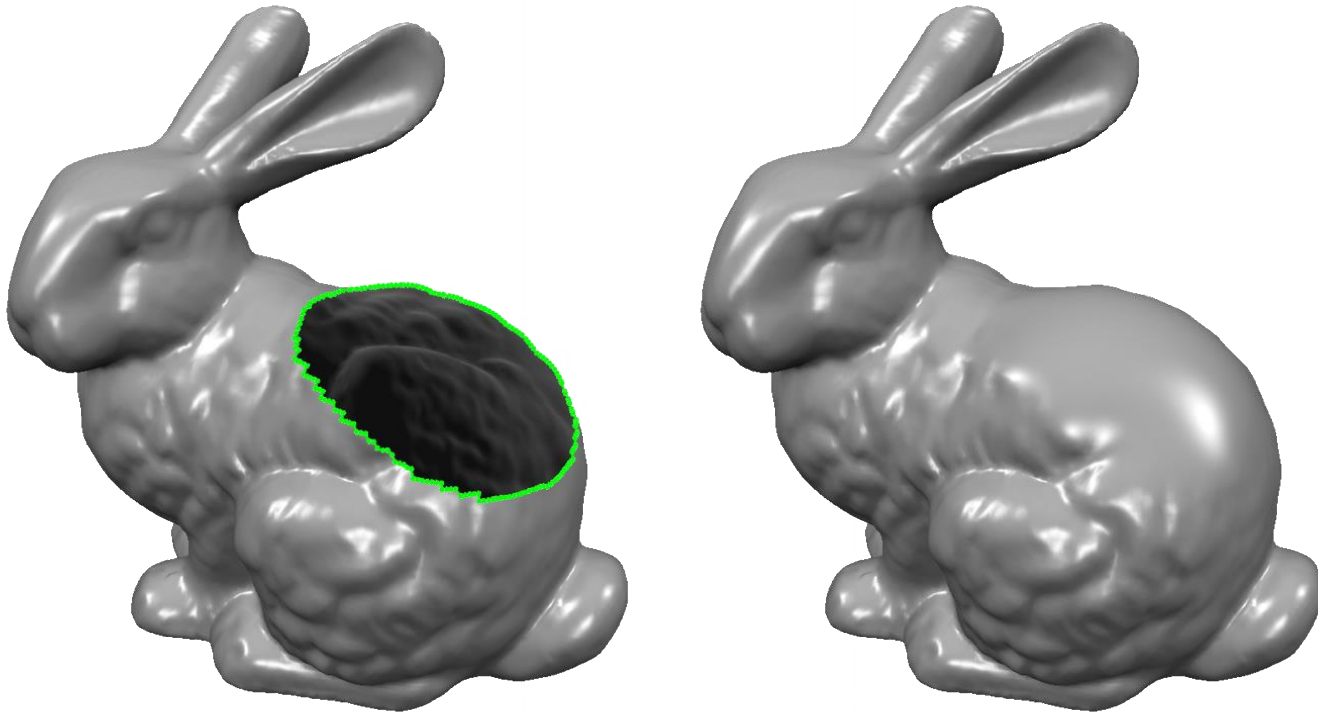
□ Smooth surface design



Desbrun, Meyer, Schroeder, Barr: *Implicit Fairing of Irregular Meshes using Diffusion and Curvature Flow*, SIGGRAPH 99

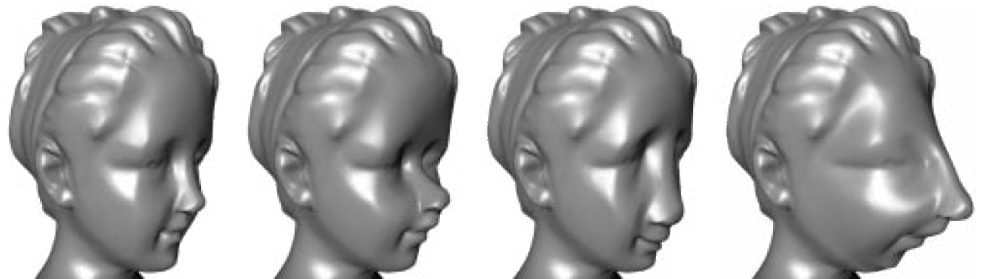
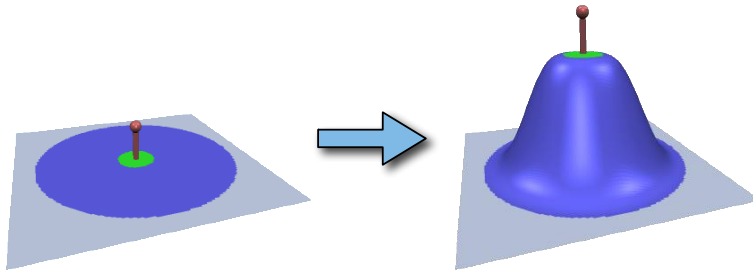
Motivations

- Hole-filling with energy-minimizing patches



Motivations

- Mesh deformation
 - Smoothing terms are often needed to obtain nice deformations



noise and smoothing

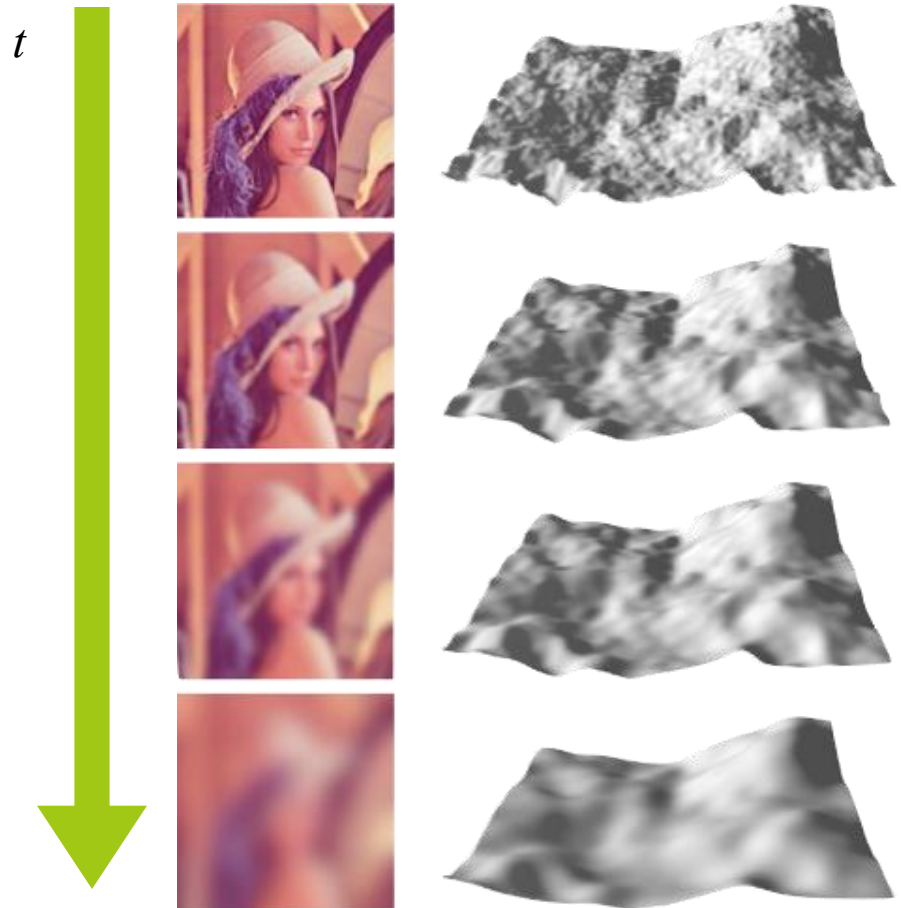
- The mesh can be viewed as a two-dimensional vector signal defined over a manifold:

$$f : M \longrightarrow \mathbb{R}^3 \quad f(v_i) = \mathbf{x}_i$$

- where $\mathbf{x}_i$ denotes the position of vertex v_i in space and f is extended by linear interpolation to the rest of the mesh
- Under a signal-processing point of view, smoothing can be viewed as a **filtering process of the signal f**

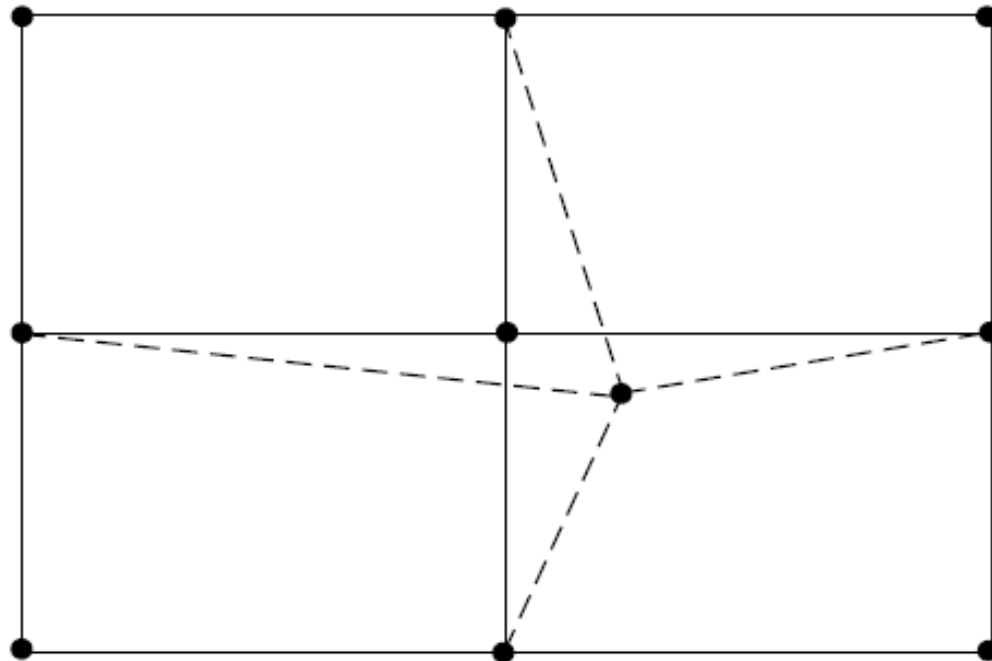
diffusion flow

- widely used to blur images and smooth terrain surfaces
- build a *scale space* describing the evolution of data through time under the blurring/smoothing process



Laplacian Smooth: Explicit

- For each vertex, compute the displacement vector towards the average of its neighbors (Laplacian Operator). Then move each vertex by a fraction of its displacement vector (diffusion over time)



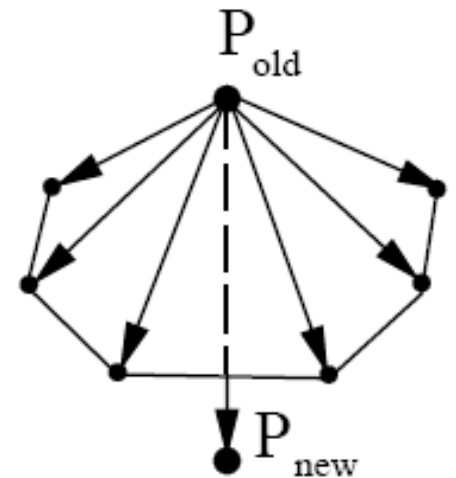
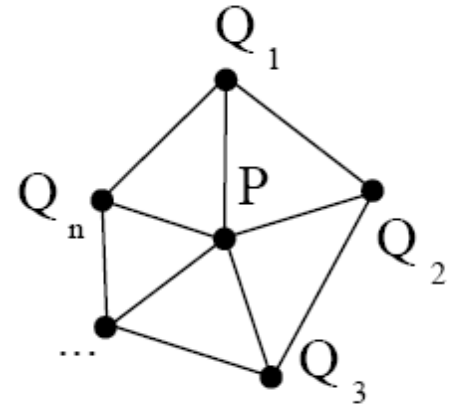
Umbrella Operator

- For each vertex of the mesh:

$$P_{new} = P_{old} + \lambda U(P_{old})$$

- Where **U** is the Umbrella operator

$$U(P) = \frac{1}{\sum_i w_i} \left(\sum_i w_i Q_i - P \right)$$



Code

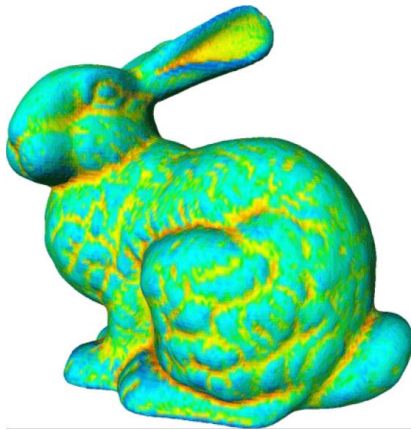
■ vcg/complex/algorithms/smooth.h

```
static void VertexCoordLaplacianBlend(MeshType &m, int step, float alpha, bool
SmoothSelected=false)
{
    VertexIterator vi;
    LaplacianInfo lpz(CoordType(0,0,0),0);
    assert (alpha<= 1.0);
    SimpleTempData<typename MeshType::VertContainer,LaplacianInfo > TD(m.vert);

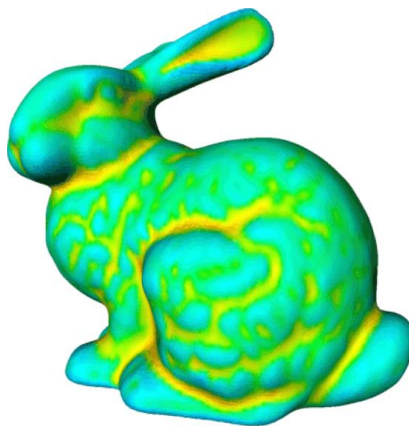
    for(int i=0;i<step;++i)
    {
        TD.Init(lpz);
        AccumulateLaplacianInfo(m,TD);
        for(vi=m.vert.begin();vi!=m.vert.end();++vi)
            if(!(*vi).IsD() && TD[*vi].cnt>0 )
            {
                if(!SmoothSelected || (*vi).IsS())
                {
                    CoordType Delta = TD[*vi].sum/TD[*vi].cnt - (*vi).P();
                    (*vi).P() = (*vi).P() + Delta*alpha;
                }
            }
    }
}
```

Example...

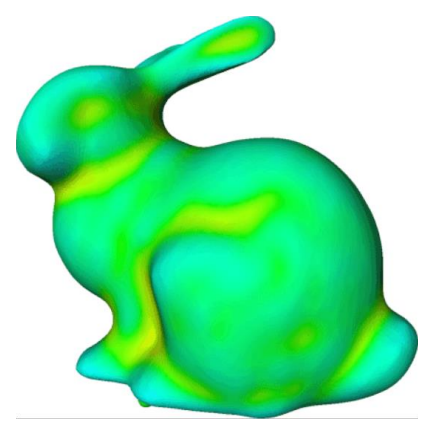
▣ Shrinking



0 Iterations



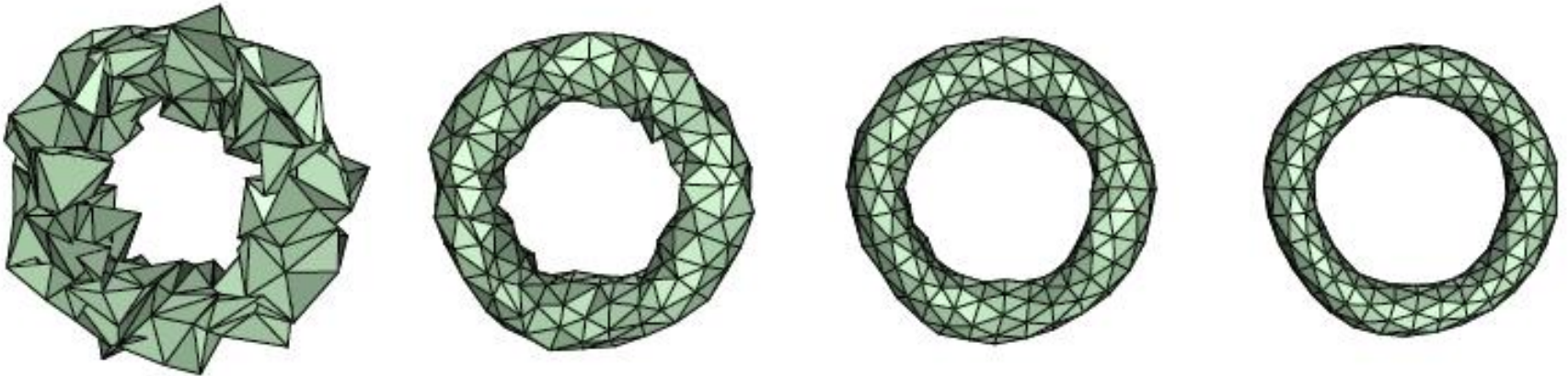
5 Iterations



20 Iterations

Problems...

▣ Shrinking



Taubin Smoothing

- (2 constants $\lambda > 0$ $\mu < 0$)

- For each iteration performs 2 steps:

1. compute the laplacian displacement for each vertex and moves the vertices by λ times this displacement.
2. Then compute again the laplacian and moves back each vertex by μ times the displacement.

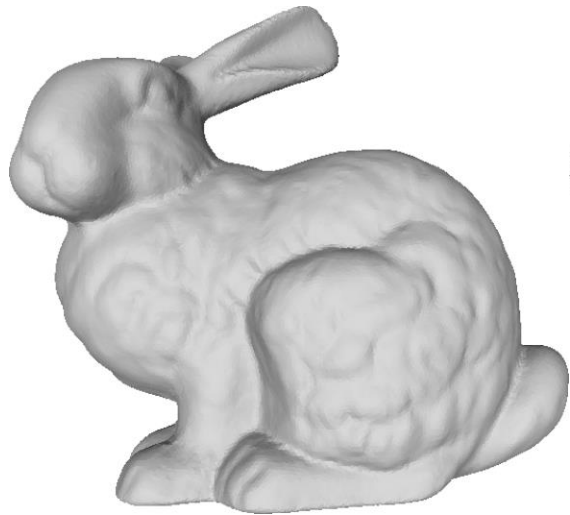
- λ and μ must be tuned to filter noise at a certain frequency

Code

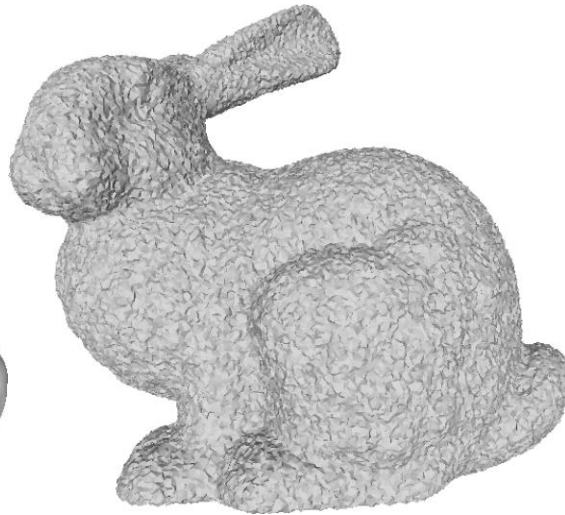
vcg/complex/algorithms/smooth.h

```
static void VertexCoordTaubin(MeshType &m, int step, float lambda, float mu...)
{
    LaplacianInfo lpz(CoordType(0,0,0),0);
    SimpleTempData<typename MeshType::VertContainer,LaplacianInfo > TD(m.vert,lpz);
    VertexIterator vi;
    for(int i=0;i<step;++i)
    {
        if(cb) cb(100*i/step, "Taubin Smoothing");
        TD.Init(lpz);
        AccumulateLaplacianInfo(m,TD);
        for(vi=m.vert.begin();vi!=m.vert.end();++vi)
            if(!(*vi).IsD() && TD[*vi].cnt>0 )
            {
                if(!SmoothSelected || (*vi).IsS())
                {
                    CoordType Delta = TD[*vi].sum/TD[*vi].cnt - (*vi).P();
                    (*vi).P() = (*vi).P() + Delta*lambda ;
                }
            }
        TD.Init(lpz);
        AccumulateLaplacianInfo(m,TD);
        for(vi=m.vert.begin();vi!=m.vert.end();++vi)
            if(!(*vi).IsD() && TD[*vi].cnt>0 )
            {
                if(!SmoothSelected || (*vi).IsS())
                {
                    CoordType Delta = TD[*vi].sum/TD[*vi].cnt - (*vi).P();
                    (*vi).P() = (*vi).P() + Delta*mu ;
                }
            }
        } // end for step
    }
```

Results



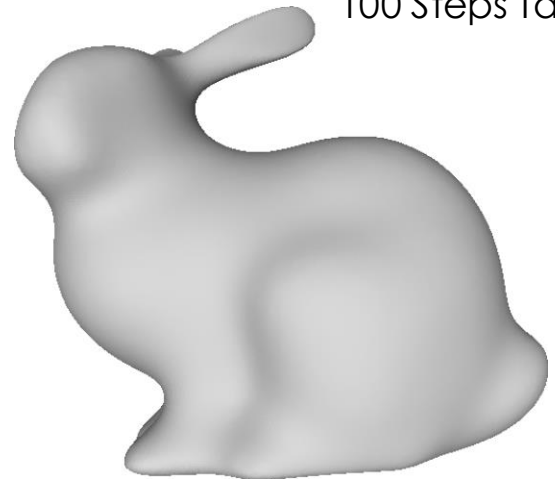
Original



Noise Added



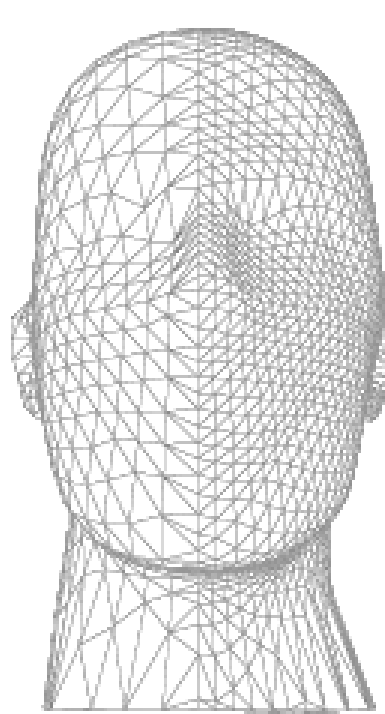
100 Steps Taubin



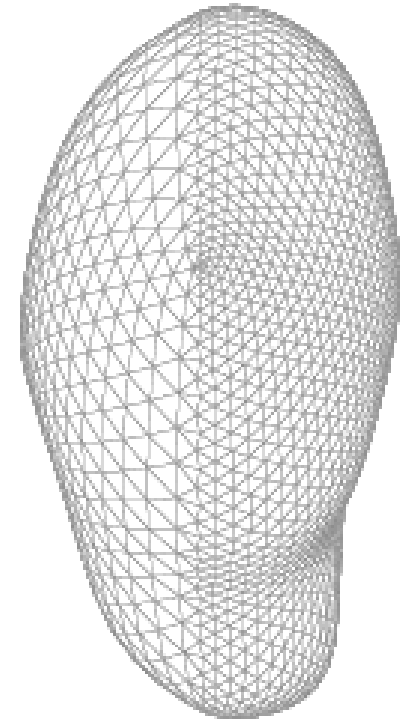
100 Steps Laplacian

Issues: Dependence on Tassellation

- Denser tassellations.. Needs more iterations to converge
- Left part converge faster



Original



Laplacian

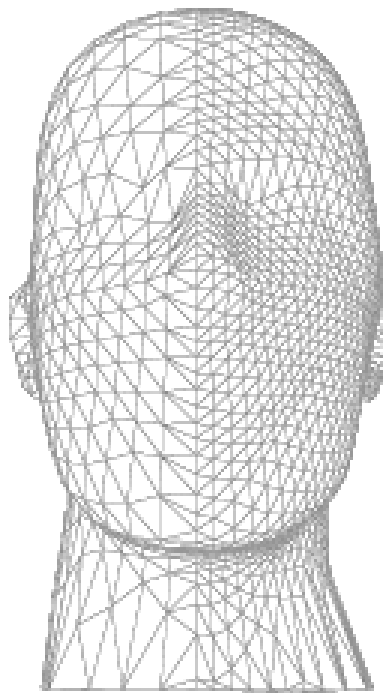
Issues: Dependence on Tassellation

- Substitute Laplacian Operator (that average vertices)
- Use another operator that weights vertices by considering involved edges

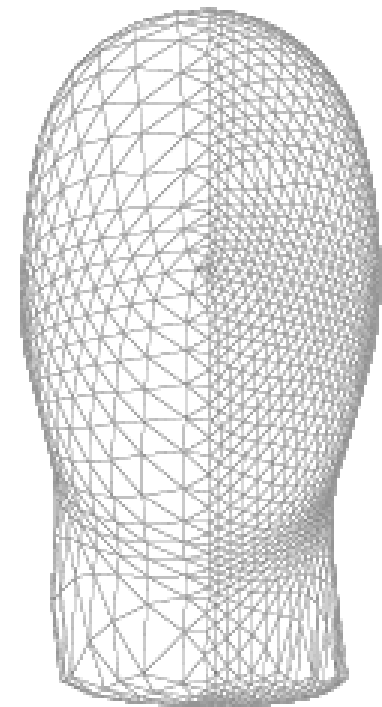
$$U(P) = \frac{2}{E} \sum_i \frac{Q_i}{|e_{ij}|} - P$$

■ Where

$$E = \sum_i e_{ij}$$



Original



Scala Dependent

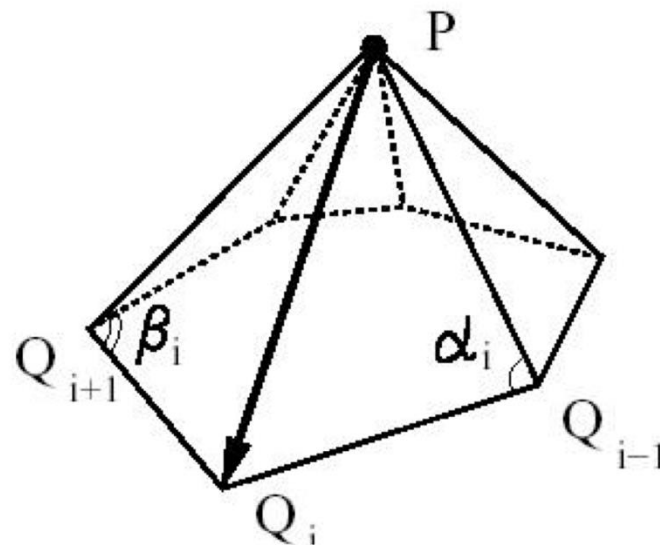
Mean Curvature Flow

- Weight differently considering the different mean curvature
- Use mean curvature in the differential form

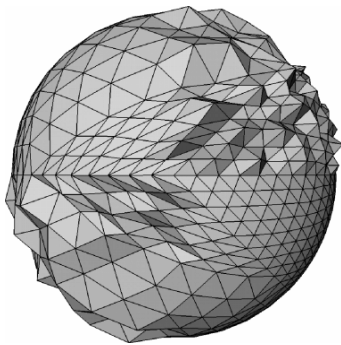
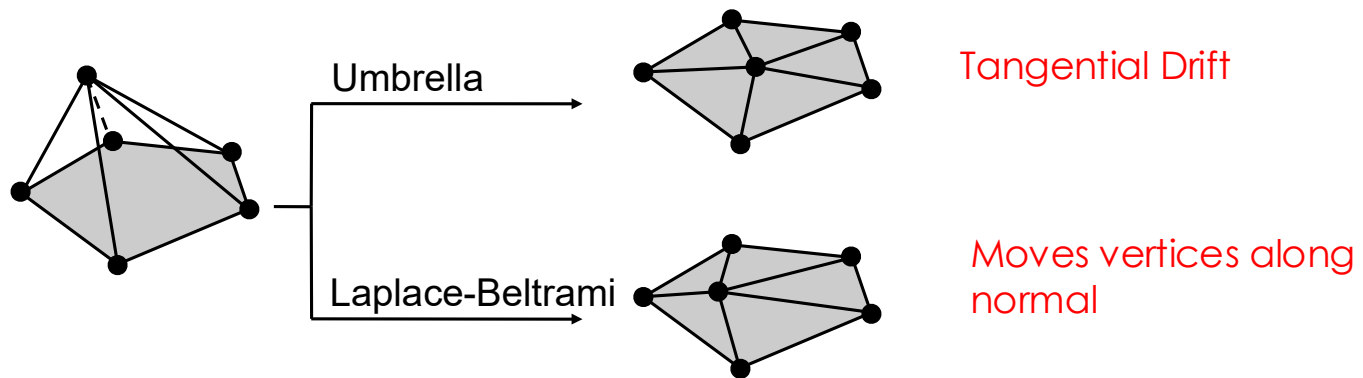
$$P_{new} = P_{old} + \lambda H n(P_{old})$$

- Laplace beltrami-operator

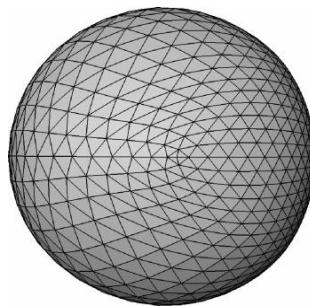
$$Hn(P) = \frac{1}{4A} \sum_i (\cot \alpha_i + \cot \beta_i)(Q_i - P)$$



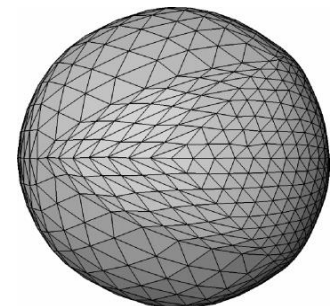
Mean Curvature Flow



Original

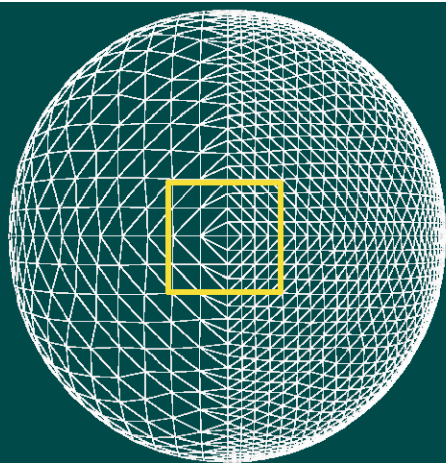


Umbrella

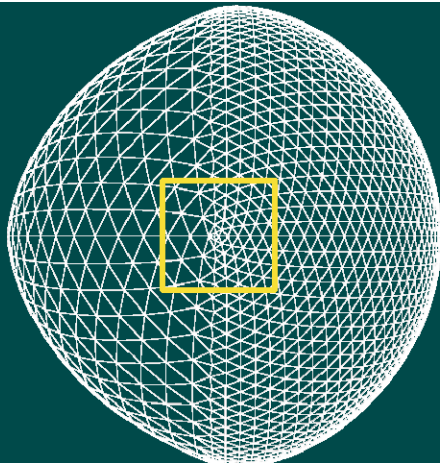


Laplace-Beltrami

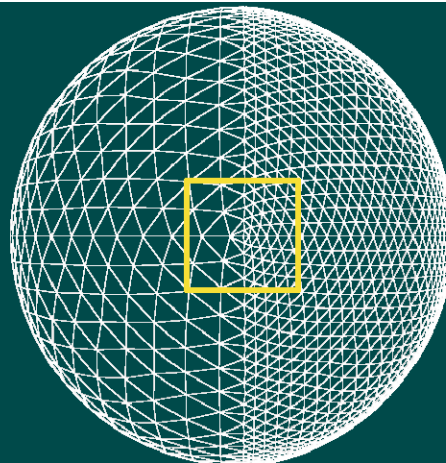
Mean Curvature Flow



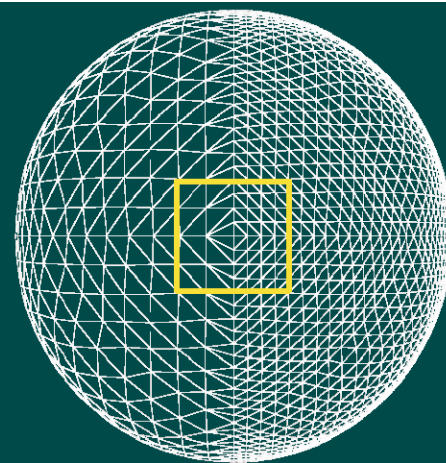
Initial
Mesh



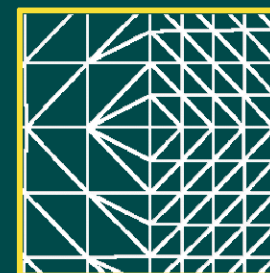
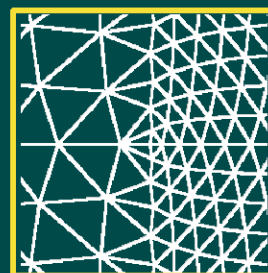
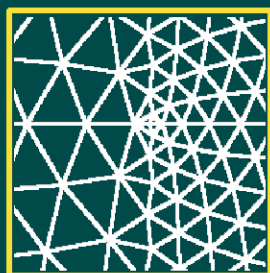
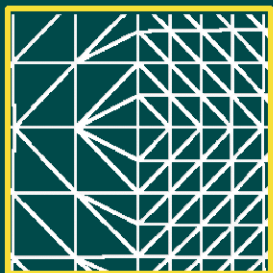
Regular
Diffusion



Improved
Diffusion



Curvature
Flow



Smoothing.. Continuous setting

- Minimize the energy dell'energia on a membrane surface
- Find **the minimal area surface**
- The gradient of the energy is the Laplacian (considering a parametrization of M on uv) is given by second partial derivatives...

$$L(M) = \frac{\partial^2(M)}{\partial u^2} + \frac{\partial^2(M)}{\partial v^2}$$

- Discrete of Laplacian (Umbrella operator)

$$L(M) = \frac{1}{n} \sum_j (Q_j - P)$$

Implicit explicit

- ▣ **Explicit Euler integration:** resolve the system by iterative substitution for small time step h

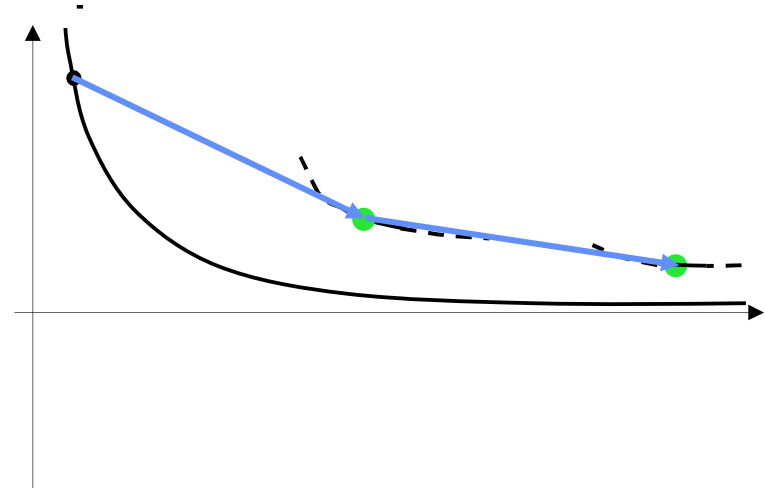
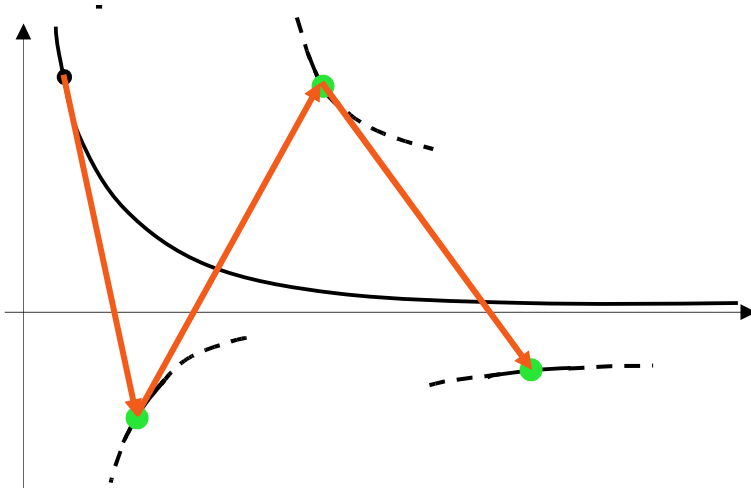
$$\mathbf{f}(t + h) = \mathbf{f}(t) + h\lambda\mathbf{L}\mathbf{f}(t)$$

- ▣ **Implicit Euler integration:** resolve the following linear system

$$(\mathbf{I} - h\lambda\mathbf{L})\mathbf{f}(t + h) = \mathbf{f}(t)$$

- ▣ the system is very large but sparse

Implicit explicit



explicit	implicit
Easy to code	More difficult to code
Easy to tune	More difficult to tune
Need several iter to converge	Instant convergence
Need to tune time step	Stable!