Image Vectorization

What is Vectorization?

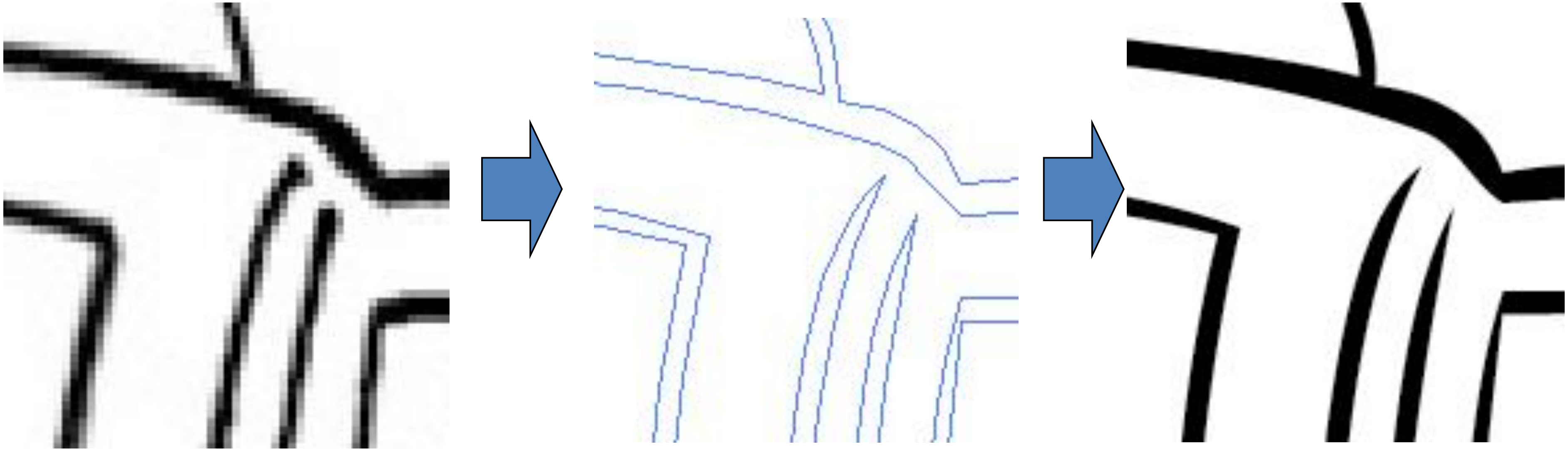


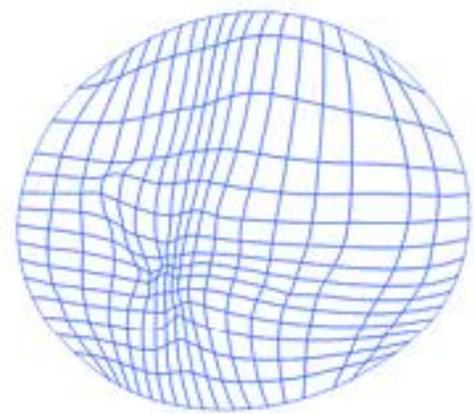
Image Vectorization

- Goal
  - Convert a raster image into a vector graphics
  - Vector graphics include
    - points
    - lines
    - curves
    - paths
    - polygons
    - regions
    - …

Why Vector Graphics

- Compact
- Scalable
- Editable
- Easy to animate

Compact



input raster image

37.5KB

optimized gradient mesh

7.7KB

Why Vector Graphics

- Compact
- Scalable
- Editable
- Easy to animate

Scalable

original image

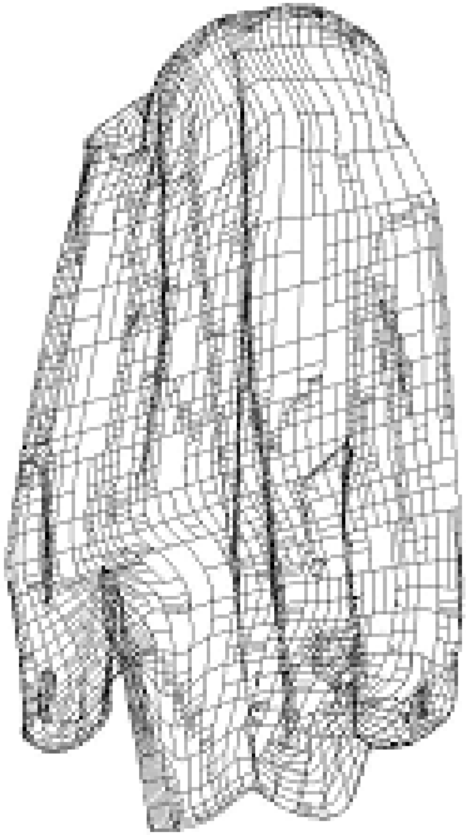
vector form

bicubic interpolation

Why Vector Graphics

- Compact
- Scalable
- Editable
- Easy to animate

Editable



Why Vector Graphics

- Compact
- Scalable
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- Easy to animate

Easy to Animate

Related Work

- Cartoon drawing vectorization
  - Skeletonization, tracing, and approximation
- Triangulation-based method
- Object-based vectorization
  - Bezier patch
  - Subdivision

Image Vectorization using Optimized Gradient Meshes

Jian Sun, Lin Liang, Fang Wen, Heung-Yeung Shum

Siggraph 2007

Surface Representation

- A tensor-product patch is defined as

$$m(u,v) = F(u)QF^T(v)$$

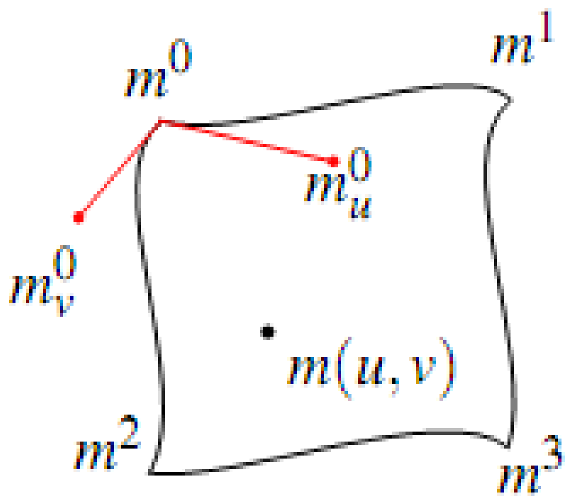
- Bezier bicubic, rational biquadratic, B-splines…
  - Control points lying outside the surface

Ferguson Patch

$$m(u,v) = UCQC^T V^T$$

$$Q = \begin{bmatrix} m^0 & m^2 & m_v^0 & m_v^2 \\ m^1 & m^3 & m_v^1 & m_v^3 \\ m_u^0 & m_u^2 & m_{uv}^0 & m_{uv}^2 \\ m_u^1 & m_u^3 & m_{uv}^1 & m_{uv}^3 \end{bmatrix}$$

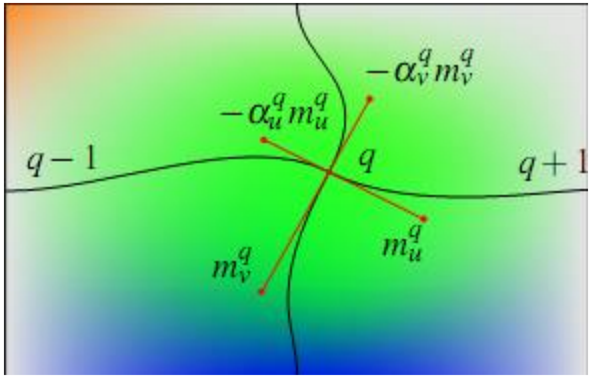
$$C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -3 & 3 & -2 & -1 \\ 2 & -2 & 1 & 1 \end{bmatrix}$$



$$U = \begin{bmatrix} 1 & u & u^2 & u^3 \end{bmatrix} \qquad V = \begin{bmatrix} 1 & v & v^2 & v^3 \end{bmatrix}$$

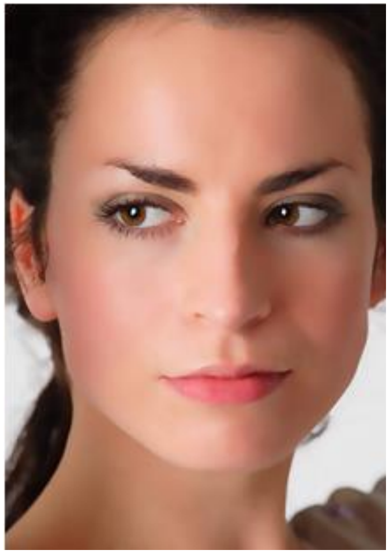
Gradient Mesh

- Control point attributes:
  - 2D position
  - Geometry derivatives
  - RGB color
  - Color derivatives

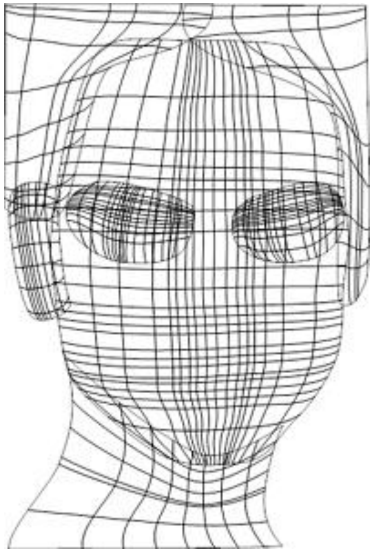


$$f(u,v) = UCQ^f C^T V^T$$

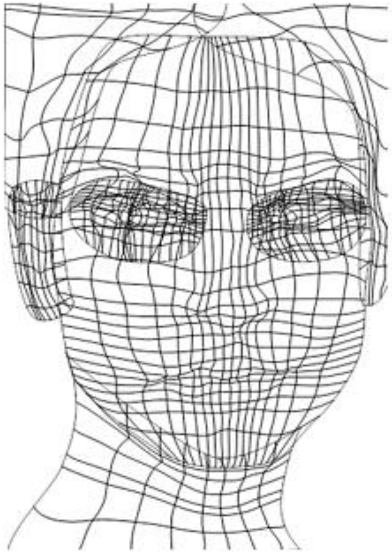
Flow Chart



Original



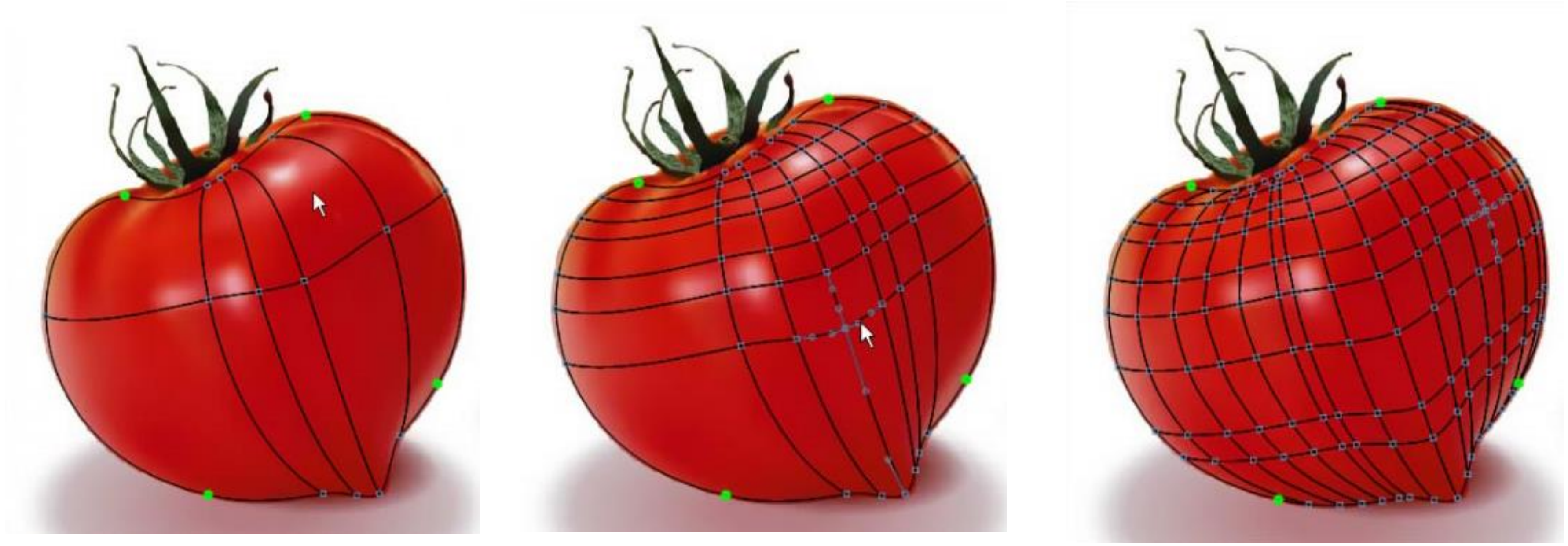
Initial Mesh



Optimized Mesh

Final Rendering

Mesh Initialization



Mesh Initialization

- Decompose image into sub-objects
- Divide the boundary into four segments
- Fitting segments by cubic Bezier splines
- Refine the mesh-lines
  - Evenly distributed
  - Interactive placement

Mesh Optimization

Input image

Initial rendering

Final rendering

Mesh Optimization

- To minimize the energy function

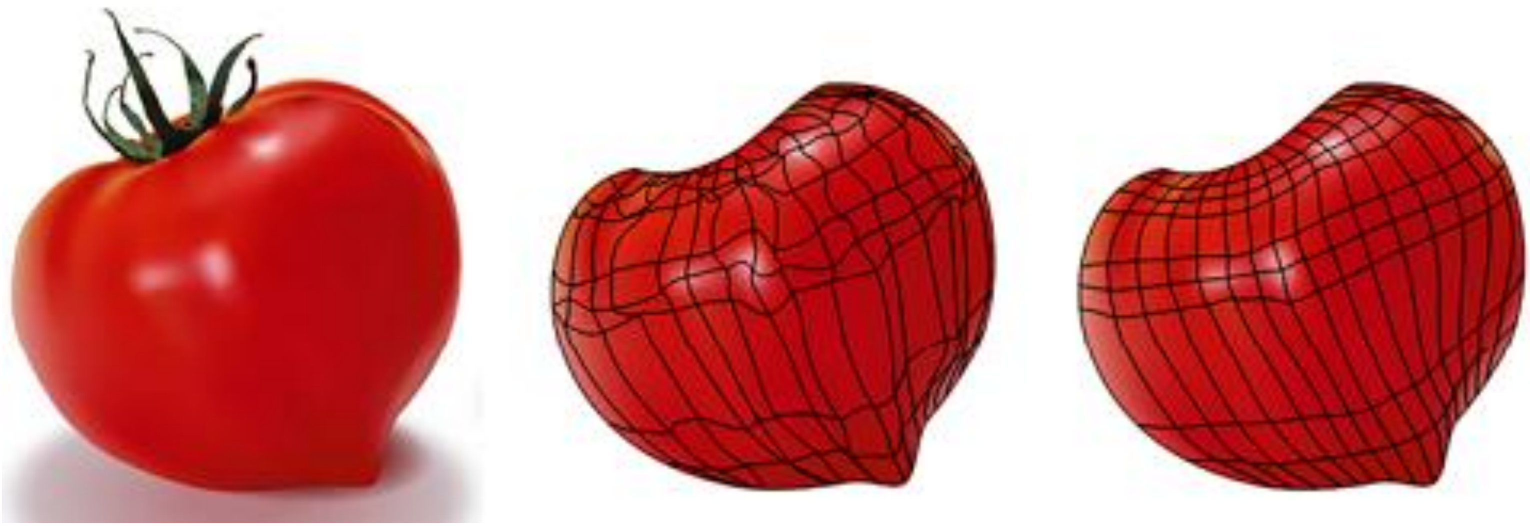
$$E(M) = \sum_{p=1}^{P} \sum_{u,v} \left\| I_p(m(u,v)) - f_p(u,v) \right\|^2$$

P: number of patches

Levenberg-Marquardt Algorithm

- Most widely used algorithm for Nonlinear Least Squares Minimization.
- First proposed by Levenberg, then improved by Marquardt
- A blend of Gradient descent and Gauss-Newton iteration

Smoothness



Smoothness Constraint

- Add a smoothness term into the energy

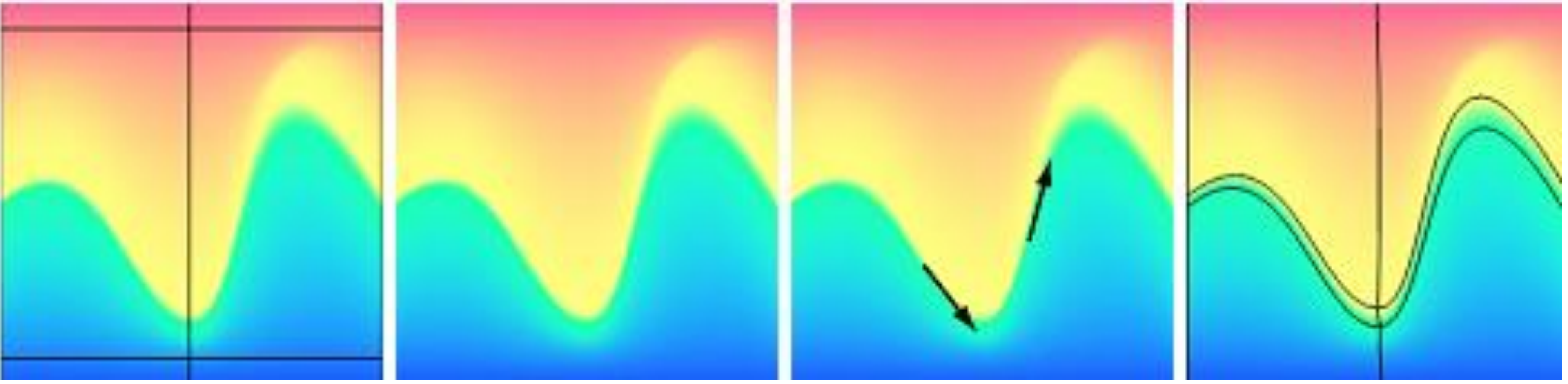
$$E^{'}(M) = E(M)$$

$$+\lambda \sum_{p=1}^{P} \sum_{s,t} \{ \left\| m(s-\Delta s,t) - 2m(s,t) + m(s+\Delta s,t) \right\|^2$$

$$+ \left\| m(s,t-\Delta t) - 2m(s,t) + m(s,t+\Delta t) \right\|^2 \}$$

which minimizes the second-order finite difference.

Optimized Gradient Mesh guided by Vector Line/Fields

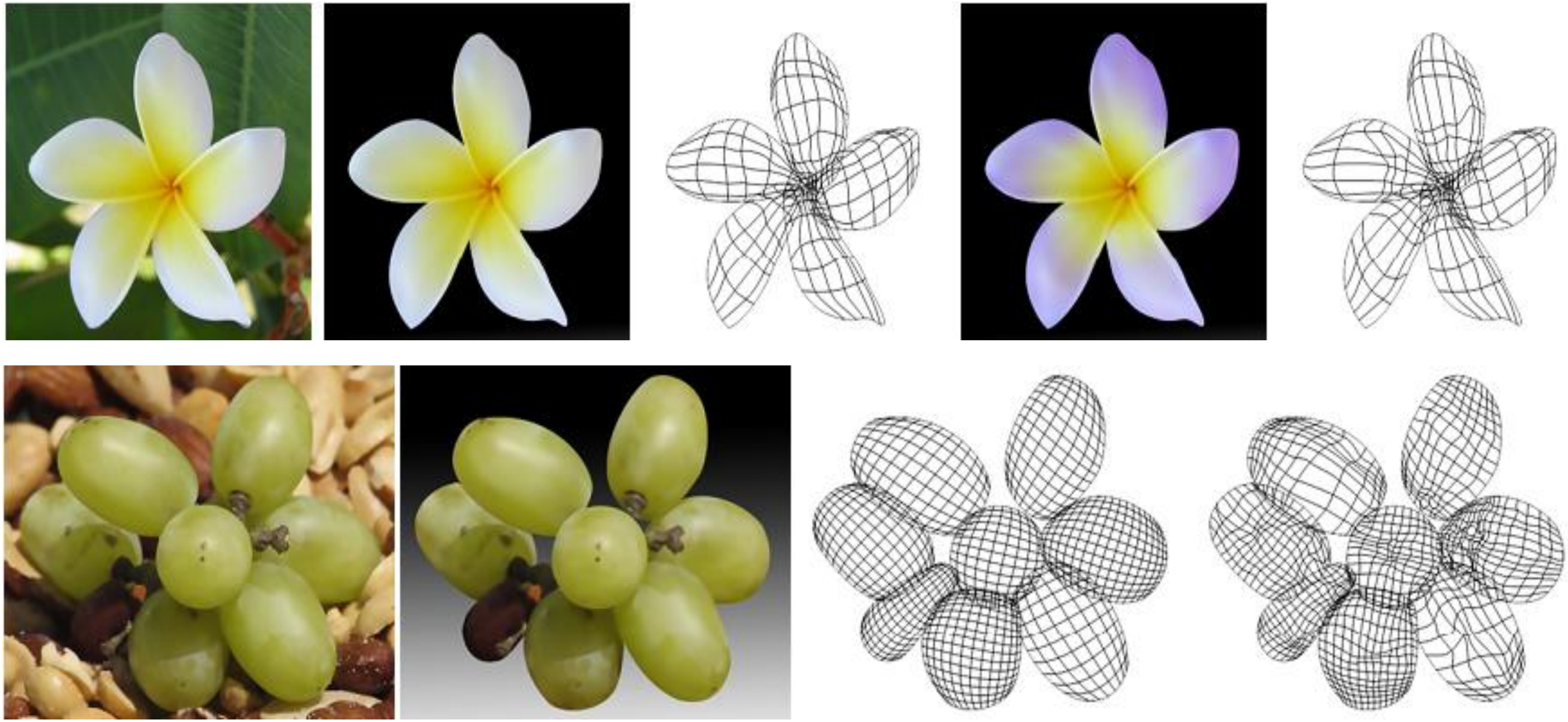


Optimized Gradient Meshes guided by Vector Line/Field

- Given vector fields V_u and V_v, we optimize

$$E^{''}(M) = E^{'}(M) + \beta \sum_{p=1}^{P} \sum_{u,v} \{ w_u(m(u,v)) \left\langle \frac{\partial m(u,v)}{\partial u}, \perp V_u(m(u,v)) \right\rangle^2 + w_v(m(u,v)) \left\langle \frac{\partial m(u,v)}{\partial v}, \perp V_v(m(u,v)) \right\rangle^2$$

More Results



More Results