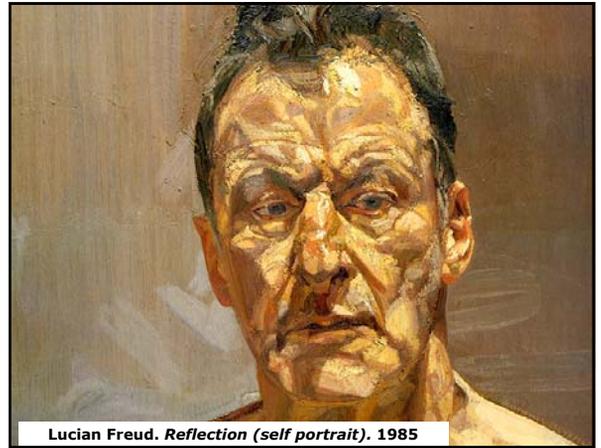
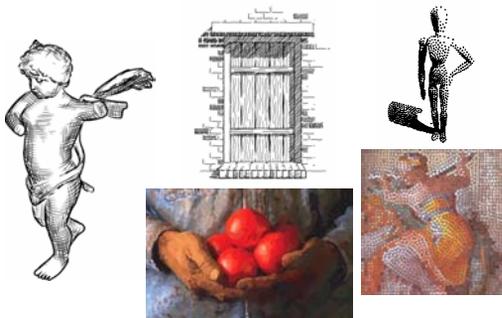


# Stroke-Based Rendering

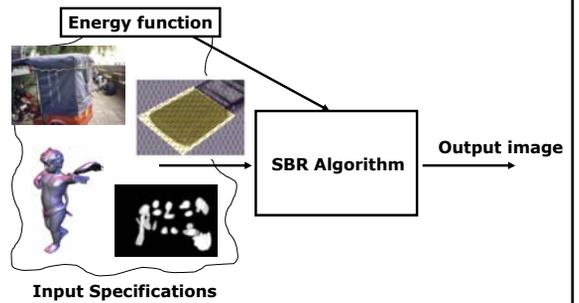
Aaron Hertzmann  
University of Washington



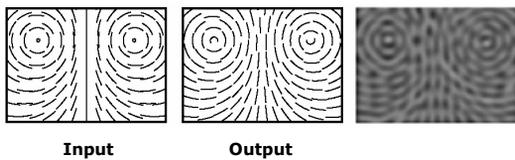
## Many SBR algorithms...



## Unified view



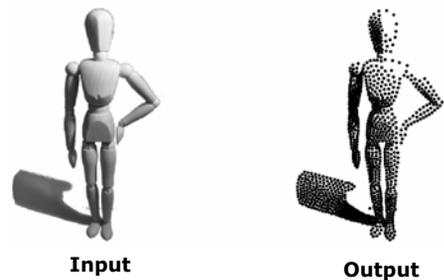
## Vector field illustration



Energy function:  $\sum \|G - B(x, y)\|^2$

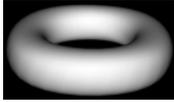
Turk and Banks, SIGGRAPH 96

## Stippling

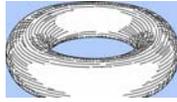


Secord, NPAR 02

## 3D illustration



3D model/  
intensity

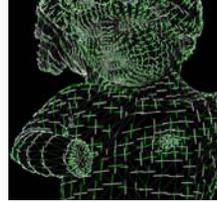


Hatching

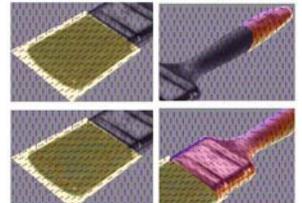


Hertzmann and Zorin, SIGGRAPH 00

## Hatching orientations



From 3D data



User input

## Emphasis variation



Source image



Weights

## Jigsaw image mosaics



Kim and Pellacini, SIGGRAPH 02 (Friday morning)

## Focus on automation

- Painting software is an artistic tool
- Computer performs repetitive tasks
  - e.g. placing brush strokes
- This talk: "High-level" paintbox

## Outline

- Greedy algorithms
- Optimization algorithms

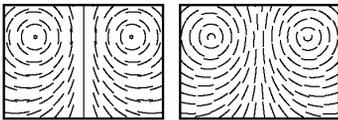
## Greedy algorithms

## Greedy algorithms

```
while not done
  pick a starting point
  create a stroke
```

## Vector field visualization

- Problem statement



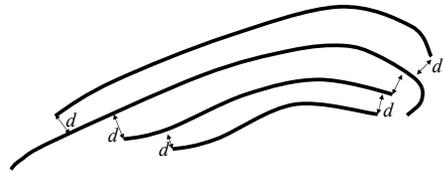
Input

Output

Turk and Banks, SIGGRAPH 96

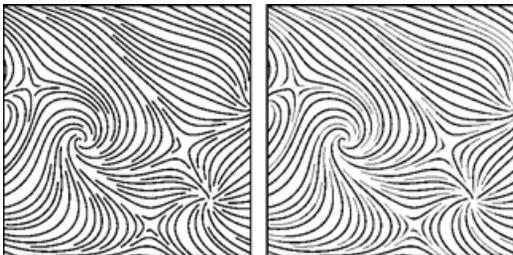
## Greedy algorithm

Goal: spacing  $d$  between strokes



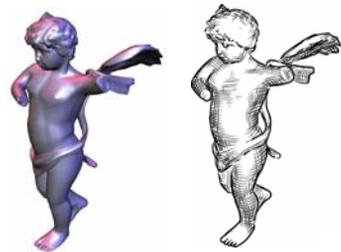
Jobard and Lefer, EVSC 97

## Vector field visualization

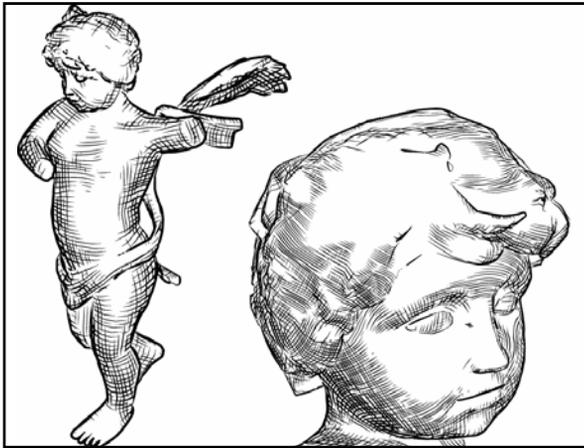


Jobard and Lefer, EVSC 97

## Illustrating smooth surfaces



Hertzmann and Zorin, SIGGRAPH 00



## Painterly rendering

Problem statement



Input image



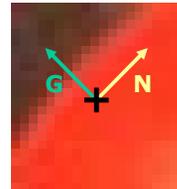
Painting

## The Impressionist



Haeberli, SIGGRAPH 90

## Stroke orientations



Source Image

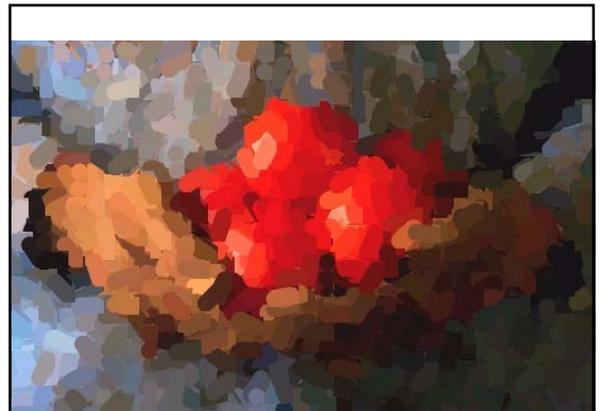


Painting

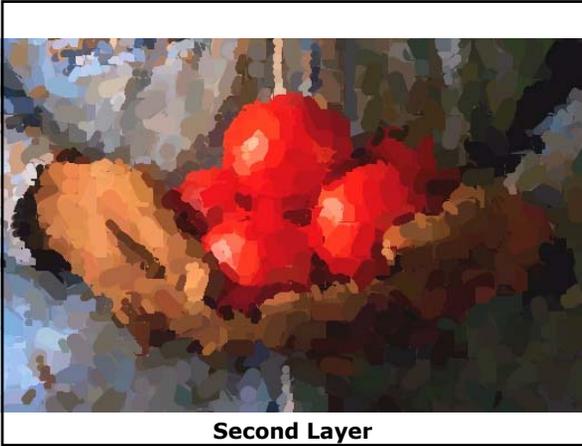
## Gallery effects



Litwinowicz, SIGGRAPH 97



First Layer



Second Layer

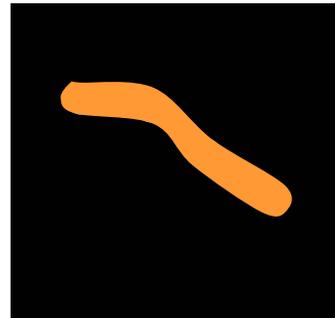


Final Painting

### Brush strokes



### Curved strokes



"Impressionist" tomatoes



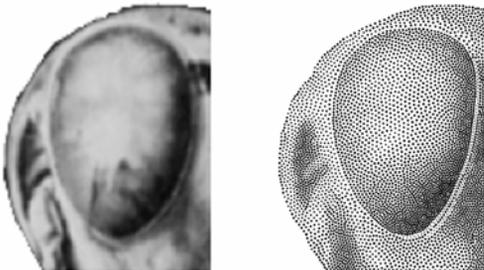


## Optimization algorithms

## Optimization algorithms

- Define formal energy and constraints
- Iteratively improve the rendering

## Stippling



Deussen et al., EG00

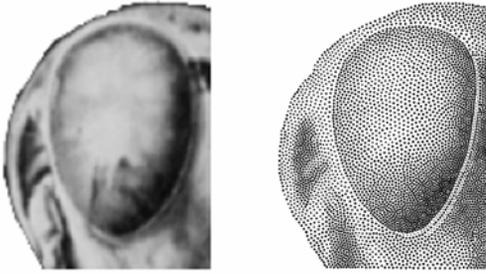
## Lloyd's algorithm



With graphics support: Hoff, SIGGRAPH 99

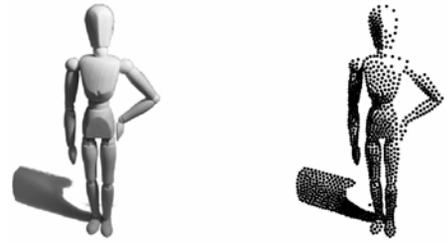
Hausner, SIGGRAPH 01

## Stippling



Deussen et al., EG00

## Weighted stippling

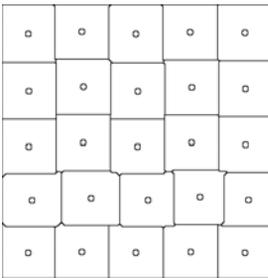


Input

Output

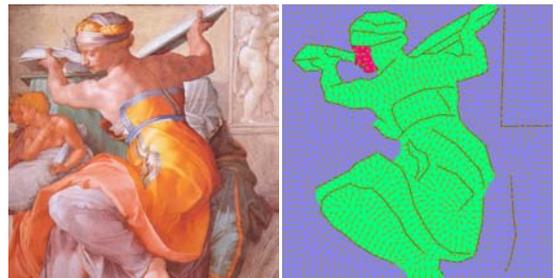
Secord, NPAR 02

## Tile mosaics



Hausner, SIGGRAPH 01

## Tile mosaics



Hausner, SIGGRAPH 01

## Tile mosaics



Hausner, SIGGRAPH 01

## Paint by relaxation



Source image

Painting

$$\sum \|I(x, y) - P(x, y)\|^2 + N$$

## Paint by relaxation



Source image



Weights

$$\sum w(x, y) \|I(x, y) - P(x, y)\|^2 + N$$



## Summary

- Stroke-based rendering:
  - Place strokes to minimize an error function
- Two algorithmic approaches:
  - **Greedy algorithms**
    - more intuitive to design
    - harder to interpret and control
  - **Optimization algorithms**
    - formal specification
    - slower



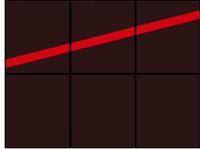
Reference Image (Blur radius = 4 pixels)



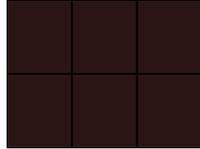
Third Layer (Blur radius = 2 pixels)

## Layering: algorithm

- Stroke placement
  - Place stroke at point of largest error (near grid point)



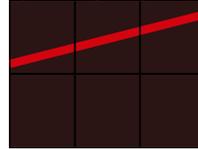
Source Image



Painting so far

## Layering: algorithm

- Stroke placement
  - Place stroke at point of largest error (near grid point)

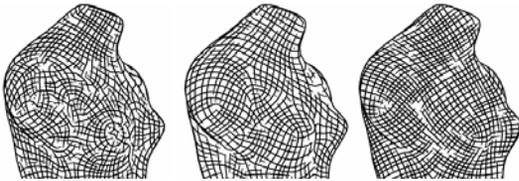


Source Image



Painting so far

## Examples of fields



Hertzmann and Zorin, SIGGRAPH 00

## Hatching densities

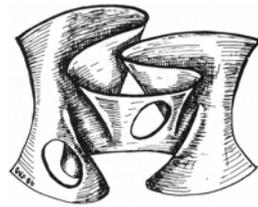
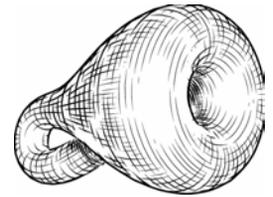


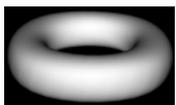
Illustration (Francis)



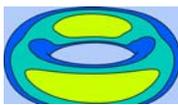
Rendering

Hertzmann and Zorin, SIGGRAPH 00

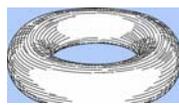
## Hatching densities



lighting

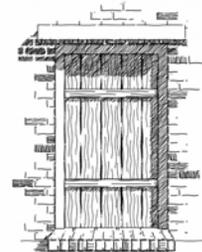


partition



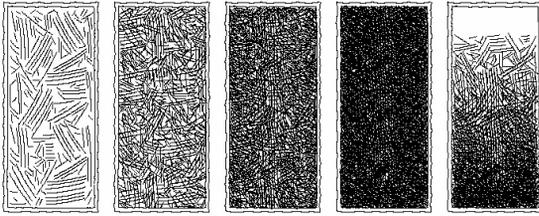
hatching

## Stroke textures



Winkenbach and Salesin, SIGGRAPH 94

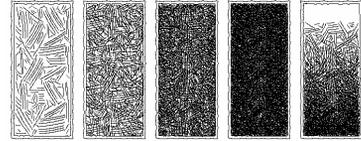
## Prioritized stroke textures



Salisbury et al., SIGGRAPH 94

## Illustration with stroke textures

### Problem statement



*To do: illustration*

## Basic algorithm

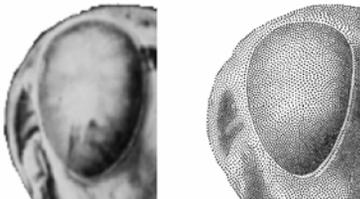
**while** hatching tone < target tone  
copy next hatch from PST

## Stroke texture algorithms

- Applied to surfaces
  - Winkenbach and Salesin, SIGGRAPH 94, 96
- Interactive
  - Salisbury et al, SIGGRAPH 94
- Scale-dependent
  - Salisbury et al, SIGGRAPH 96
- User-defined orientations
  - Salisbury et al, SIGGRAPH 97

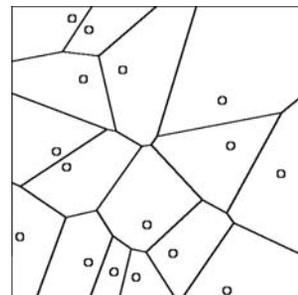
## Stippling

- Place stipples to match target tones, *or*
- Distribute stipples evenly



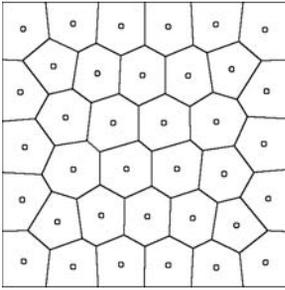
Deussen et al., EG00

## Voronoi diagram



Hausner, SIGGRAPH 01

## Centroidal voronoi diagrams



Hausner, SIGGRAPH 01

## Tile mosaics

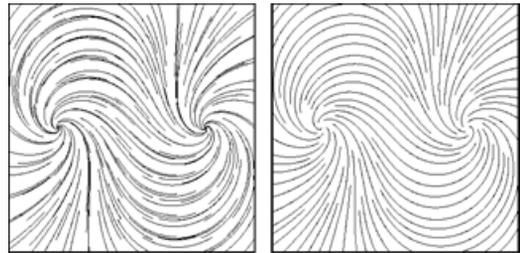


$$\sum_{L_p^i \in \{0,1\}} L_p^i \|p - C_i\|_1$$

$$\sum_{L_p^i \in \{0,1\}} L_p^i \|p - C_i\|^2$$

$$\sum_{L_p^i} w(p) \|p - C_i\|^2$$

## Vector field visualization



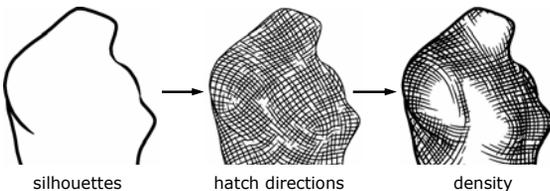
Grid-based seed points

Evenly-spaced curves

Jobard and Lefler, EVSC 97

## Hatching

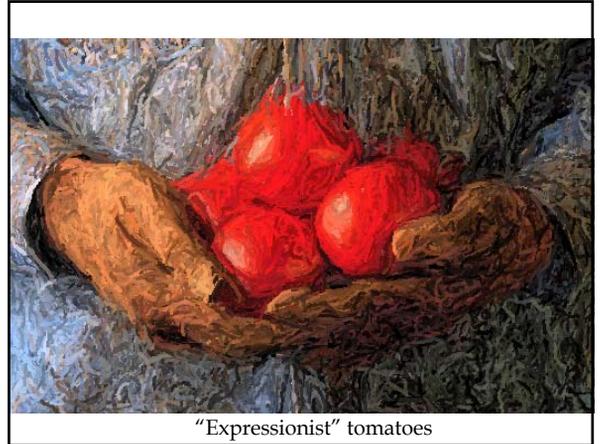
- Hatching style
  - hatch directions
  - densities



## Layering

- Coarse-to-fine painting
  - Sketch with a large brush
  - Refine with a small brush

Hertzmann, SIGGRAPH 98



"Expressionist" tomatoes