Artistic Stylization of Images and Video

Eurographics 2011

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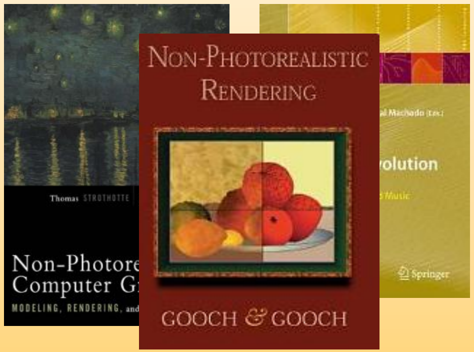
http://kahlan.eps.surrey.ac.uk/EG2011

Artistic Stylization Resources

▪ Texts



Strothotte & Schlechtweg
ISBN: 1558607870

Gooch & Gooch
ISBN: 1568811330

Romero & Machado
ISBN: 3540728767

▪ Web Bibliographies

http://video3d.ims.tuwien.ac.at/~stathis/nprlib/index.php

http://isgwww.cs.uni-magdeburg.de/~stefans/npr/nprpapers.html

http://www.red3d.com/cwr/npr/ (dated)

▪ Tutorials

SIGGRAPH 99 (Green et al.) – 2D/3D NPR
SIGGRAPH 02 (Hertzmann) – 2D NPR
SIGGRAPH 03 (Sousa et al.) – 2D/3D NPR
Eurographics 05,06 and...
SIGGRAPH 06 (Sousa et al) – 3D NPR
SIGGRAPH 10 (McGuire) – 3D NPR for Games

▪ Main Publication Forums

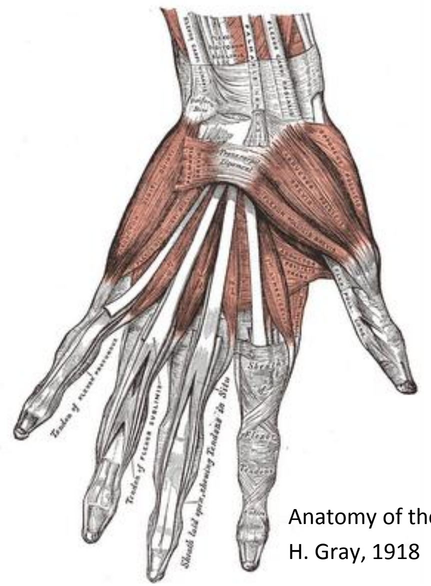
NPAR (Symposium on Non-photorealistic Animation)
Held in Annecy even years, at SIGGRAPH odd years.

IEEE Trans Visualization and Comp. Graphics (**TVCG**)
IEEE Computer Graphics and Applications (**CG&A**)
Eurographics and **Computer Graphics Forum**
SIGGRAPH, SIGGRAPH Asia and **ACM ToG**
EG Symposium on Rendering (**EGSR**)
ACM/EG Symposium on Computer Animation (**EGSA**)

Artistic Stylization

Non-Photorealistic Rendering (NPR)
Coined by Salesin et al., 1994

- **Stylized Rendering**
- **Aesthetic Rendering**
- **Artistic Stylization**
- **Artistic Rendering**



Anatomy of the Human Body
H. Gray, 1918

Motivation

Artistic Stylization

- **Why?**

Comprehension

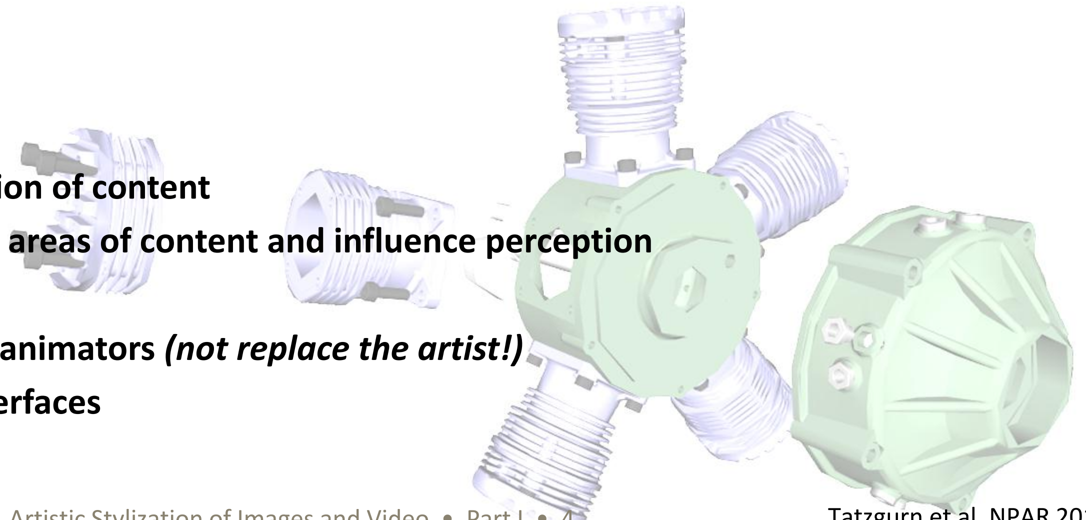
Communication

Visualization

Aesthetics

Animation

- **Artistic Stylization can**
  - **Simplify and structure the presentation of content**
  - **Selectively guide attention to salient areas of content and influence perception**
  - **Learn and emulate artistic styles**
  - **Provide assistive tools to artists and animators *(not replace the artist!)***
  - **Help us to design effective visual interfaces**

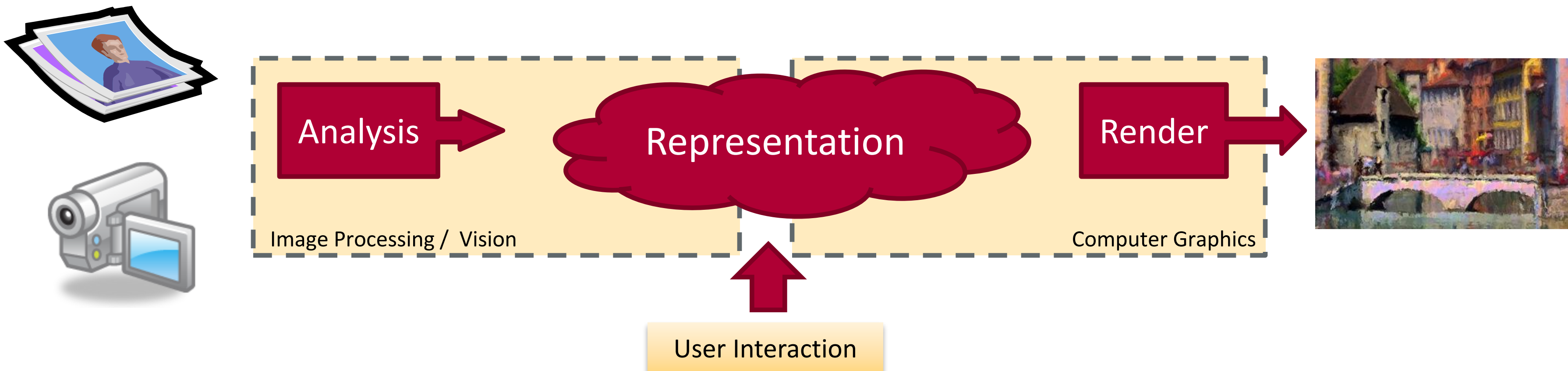


Tatzgurn et al. NPAR 2010

Motivation

Artistic Stylization

- **Rendering real images/video footage in to pseudo-artistic styles**
- **Convergence of Computer Vision, Graphics (and HCI)**



- **Visual analysis enables new graphics. Graphical needs motivate new vision.**

Chronology

Late 1980s
Advances in media emulation

D. Strassman (SIGGRAPH 86)

Video painting

P. Litwinowicz (SIGGRAPH 97)

Perceptual UI & segmentation

D. Decarlo [SIGGRAPH 02]

Space-time video

J. Wang [SIGGRAPH 04]
J. Collomosse [TVCG 05]

Anisotropy / filters

H. Winnemoeller [SIGGRAPH 06]
J. Kyprianidis [TPCG 08]

1990 1997 1998 2000 2002 2005 2006 2010

Semi-automatic painting systems

P. Haeberli (SIGGRAPH 90)

Fully automatic painting

A. Hertzmann (SIGGRAPH 98)
Treveatt/Chen [EGUK 97]
P. Litwinowicz [SIGGRAPH 97]

Automatic perceptual

J. Collomosse [EvoMUSART 05]

User evaluation

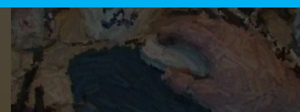
T. Isenberg [NPAR 06]

NPAR 2010
Grand challenges

Interactions with Vision

Rendering process is guided by...

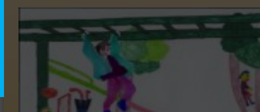
emulation



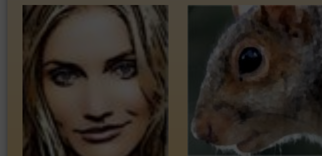
Perceptual UI &

User subconscious interaction

Space-time video



Anisotropy / filters



User concious interaction

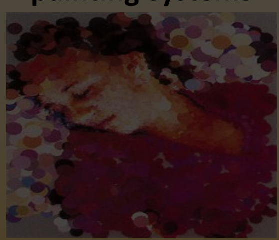
Low-level image processing

Higher level computer vision

Direct Anisotropic filtering

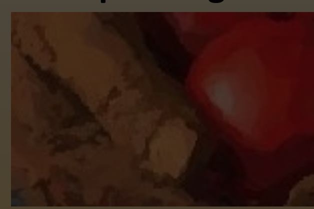
1990 1997 1998 2000 2002 2005 2006 2010

Semi-automatic painting systems



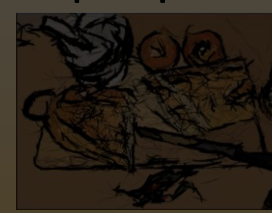
P. Haeberli (SIGGRAPH 90)

Fully automatic painting



A. Hertzmann (SIGGRAPH 98)
Treveatt/Chen [EGUK 97]
P. Litwinowicz [SIGGRAPH 97]

Automatic perceptual



J. Collomosse [EvoMUSART 05]

NPAR 2010
Grand challenges

User evaluation

T. Isenberg [NPAR 06]

Tutorial Structure

Rendering process is guided by…

emulation

Perceptual UI & seg

User subconscious interaction

Part III: Anisotropy and Filtering (70 min)

User concious interaction

Low-level image processing

Higher level compute vision

pic filtering

BREAK!

1990 1997 1998 2000 2002 2010

Part I: Classical algorithms (30 min)

Part IV: Future Challenges (20 min)

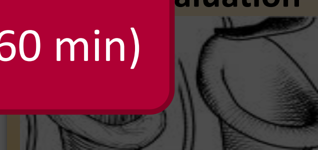
Part II: Vision for Stylisation (60 min)

aluation

P. Haeberli (SIGGRAPH 90)

A. Hertzmann (SIGGRAPH 98)
Treveatt/Chen [EGUK 97]
P. Litwinowicz [SIGGRAPH 97]

J. Collomosse [EvoMUSART 05]



T. Isenberg [NPAR 06]

Artistic Stylization of Images and Video

Part I – Classical Algorithms / Stroke Based Rendering

Eurographics 2011

John Collomosse

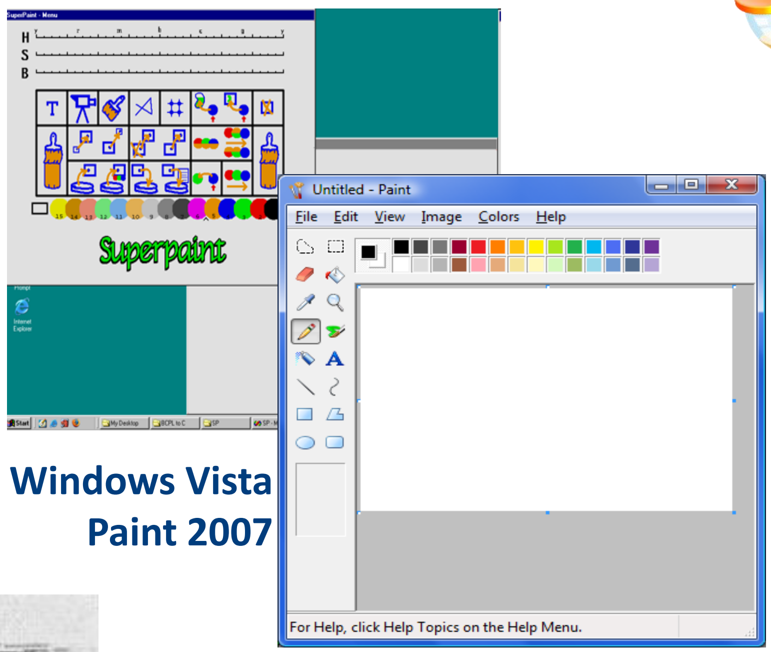
Centre for Vision Speech and Signal Processing (CVSSP),
University of Surrey, United Kingdom

References

- **Paint by numbers: Abstract image representations**
  P. Haeberli, SIGGRAPH 1990
- **Almost Automatic Computer Painting**
  P. Haggerty, IEEE CG & A 1991
- **Orientable Textures for Image based Pen-and-Ink Illustration**
  D. Salisbury et al., SIGGRAPH 1997
- **Processing images and video for an impressionist effect**
  P. Litwinowicz, SIGGRAPH 1997
- **Statistical techniques for the automated synthesis of non-photorealistic images**
  S. Treavett and M. Chen, Eurographics UK 1997.
- **Automatic Painting based on Local Source Image Approximation**
  Shiraishi and Yamaguchi, NPAR 2000.
- **Painterly Rendering with Curved Strokes of Multiple Sizes**
  A. Hertzmann, SIGGRAPH 1998.
- **Paint by Relaxation**
  A. Hertzmann, CGI 2001
- **Fast Paint Texture**
  A. Hertzmann, NPAR 2002

- **Early painting systems lacked appropriate UI for rich digital painting**

Xerox superpaint (1980s)

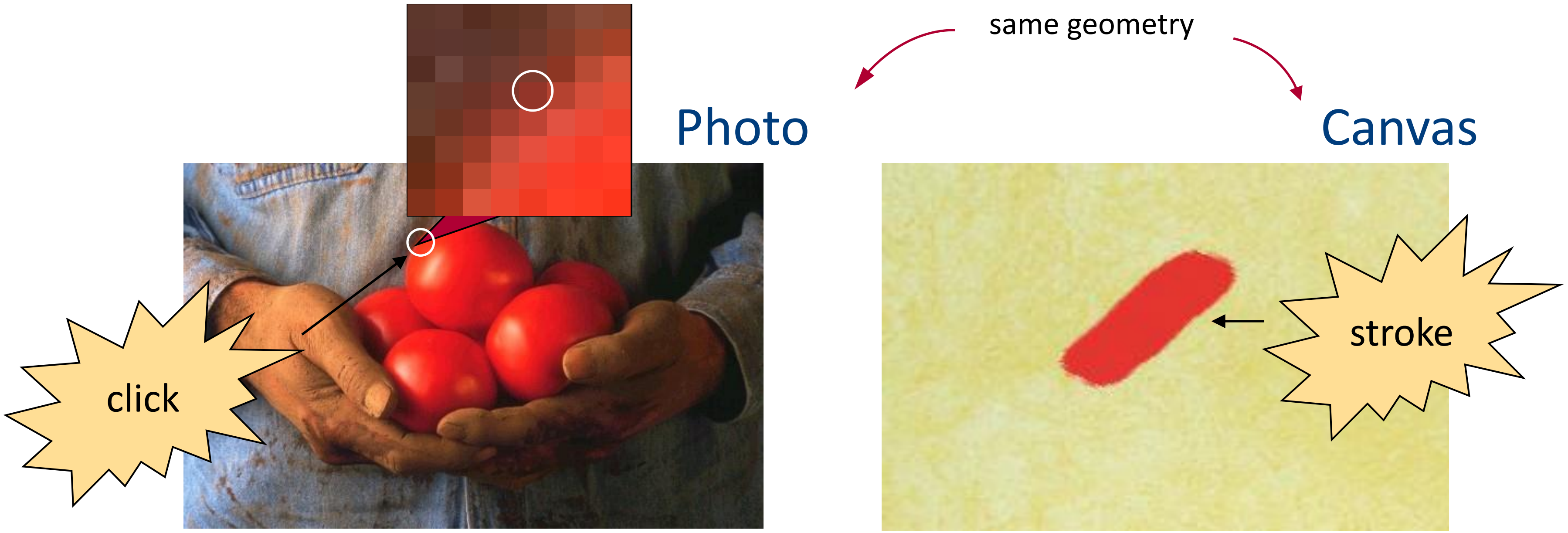


Windows Vista Paint 2007

Paint by numbers: Abstract Image Representations

Haeberli. (1990)

- **Stroke based rendering (SBR)**
- **Painting is a manually ordered list of strokes, placed interactively.**
- **Stroke attributes sampled from the photo.**



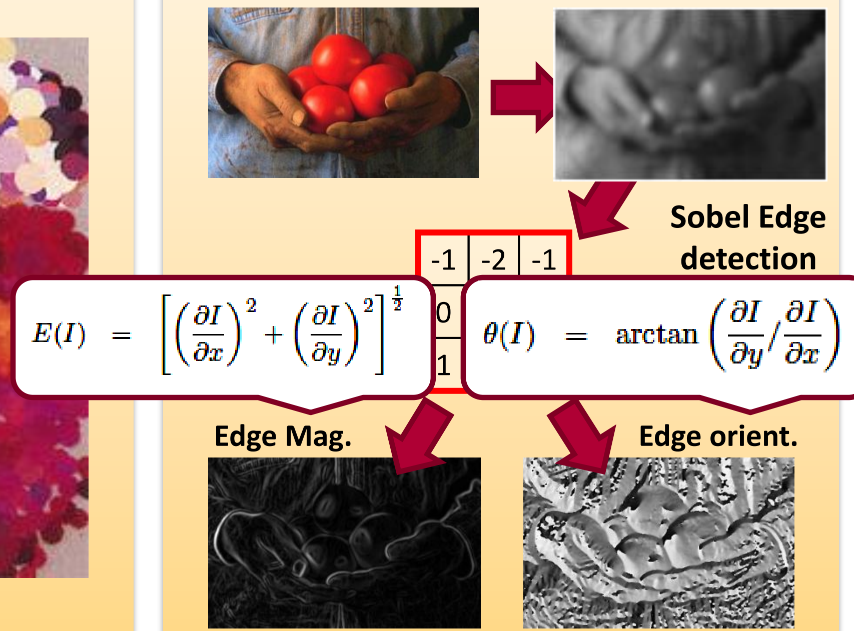
Paint by numbers: Abstract Image Representations

Haeberli. (1990)

- **Stroke colour and orientation are sampled from the source image**
- **Stroke order and scale are user-selected**
- **Addition of RGB noise generates an impressionist effect**

Photo credit: Haeberli '90.

Paintings with / without orientable strokes



Orientation

Paint by numbers: Abstract Image Representations

Haeberli. (1990)

- **More stylised orientation effects with a manually defined orientation field**

Orientation field

Painterly Rendering

Photo credit: Haeberl '90.

Paint by numbers: Abstract Image Representations

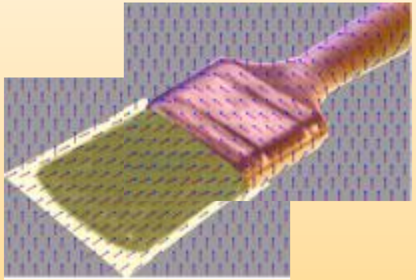
Haeberli. (1990)

All tutorial code at http://kahlan.eps.surrey.ac.uk/EG2011

Orientable Textures for Image-based Pen-and-Ink Illustration

Salisbury et al. (1997)

- Very similar system for pen-and-ink rendering of photos
- User defined orientation field.
  - Regions manually drawn and marked up with orientation
- Stroke (line) placement automatic. Strokes clipped to keep within regions.



Manually defining regions of the orientation field

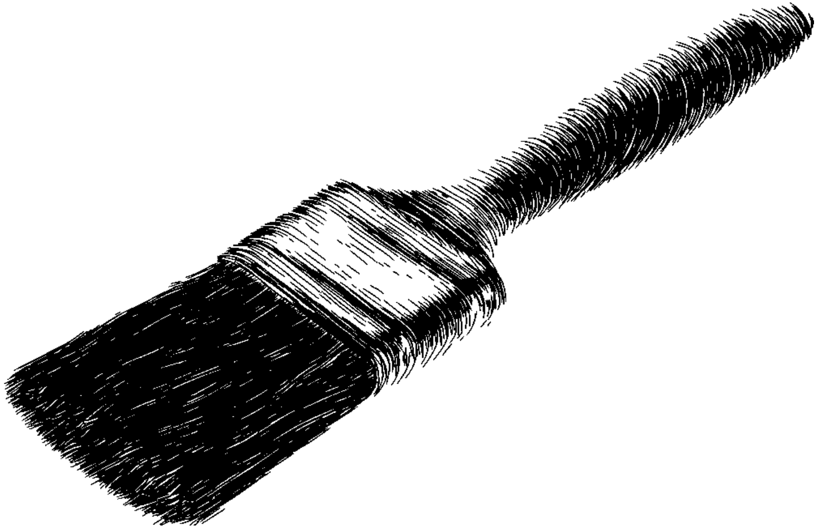


Photo credit: Salisbury'97.

Almost automatic computer painting

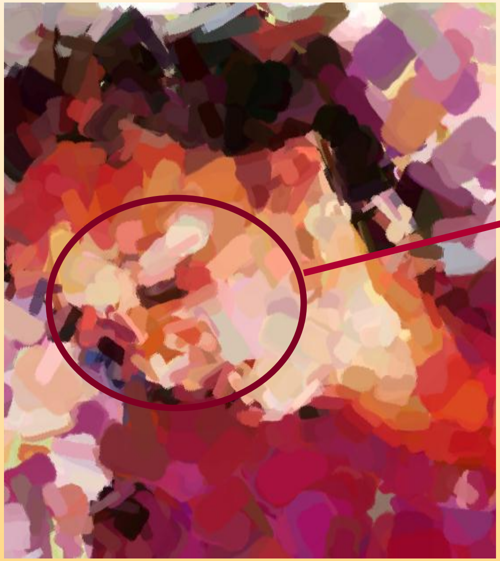
Haggerty (1991)

- **Stroke colour and orientation are sampled from the source image**
- **Stroke order and scale ~~are user selected~~**
- **Scale sampled from Sobel edge magnitude**
- **Regularly place strokes. Order of strokes randomly generated**

Fully automated

Photo credit: Haeberli '90.

Interactive (Haeberli)

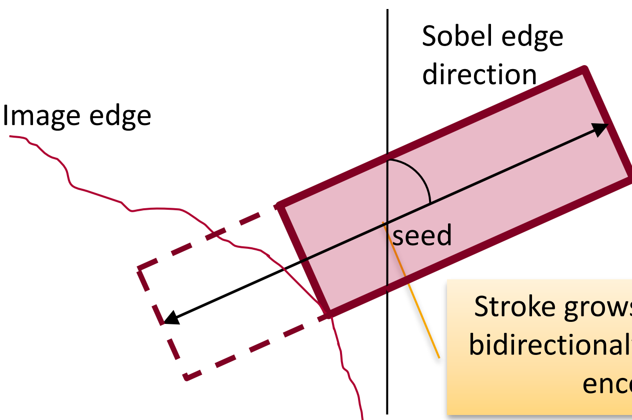


Pseudo-random (as Haggerty)

Loss of detail in important regions

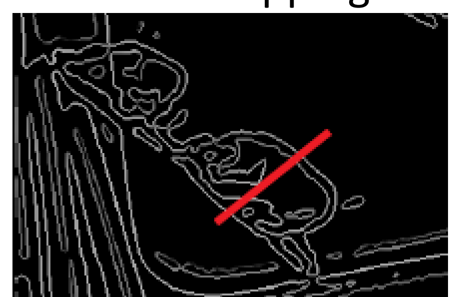
Processing Images & Video for Impressionist Effect

Litwinowicz (1997)



Stroke grows from seed point bidirectionaly until edge pixels encountered

No clipping



Clipping

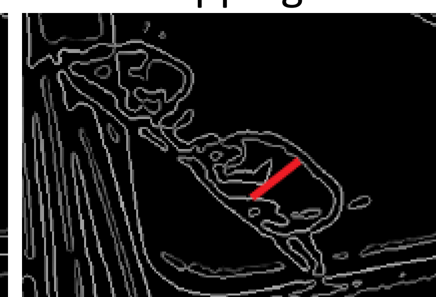


Photo credit: Litwinowicz '97

Statistical techniques for automated synthesis of NPR

Treavett and Chen (1997)

- **Common recipe for SBR in the 1990s**
  - Sobel edge detection on blurred image
  - Regular seeding of strokes on canvas
  - Scale strokes inverse to edge magnitude
  - Orient strokes along edge tangent
  - Place strokes in a specific way using this data

- **An interesting alternative uses 2nd order moments within local window to orient strokes.**
  - Extended to multi-scale strokes by Shiraishi and Yamaguchi (NPAR 2000)

Photo credit: Shiraishi / Yamaguchi '00

Automatic Painting based on Local Source Image Approximation

Shiraishi and Yamaguchi (2000)

- **2D zero-moments for greyscale image I(x,y)**

$$M_{lm} = \sum \sum x^l y^m I(x,y).$$

Automatic Painting based on Local Source Image Approximation

Shiraishi and Yamaguchi (2000)

- The canvas is built up in layers from coarse to fine
  - Analysis window scale, and stroke scale are varied in proportion

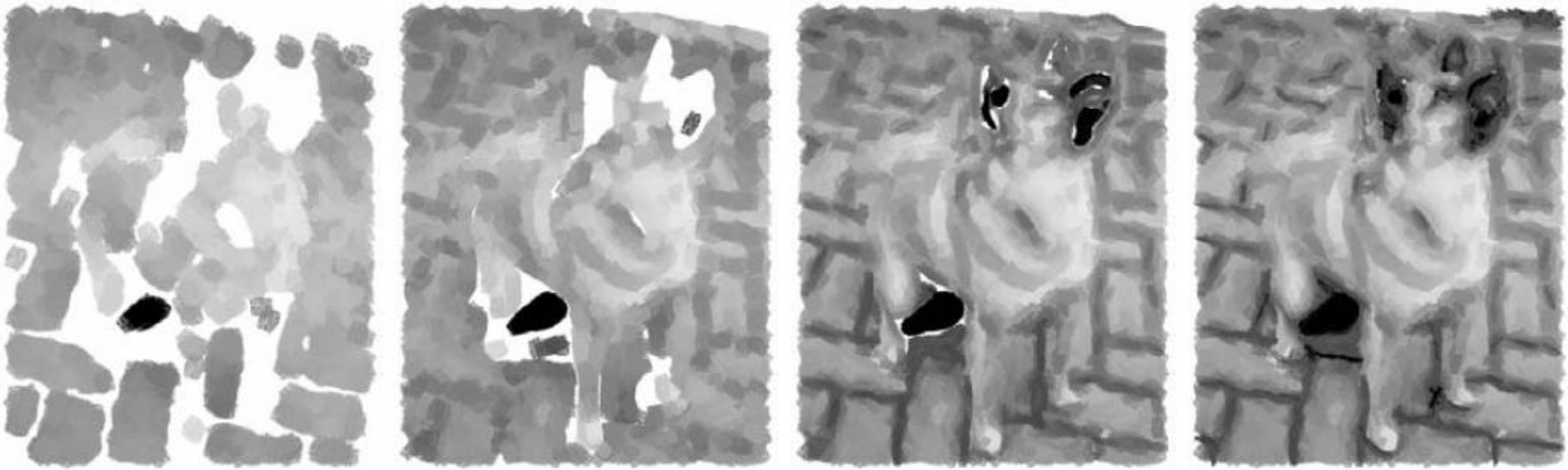
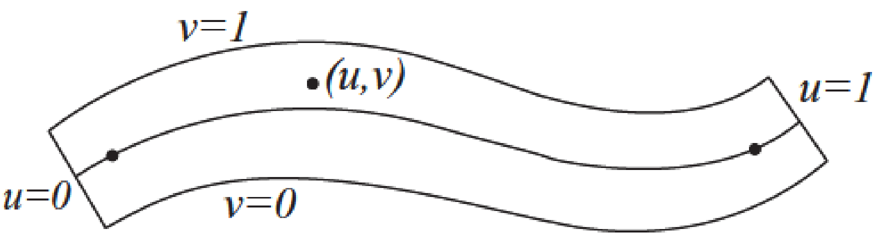


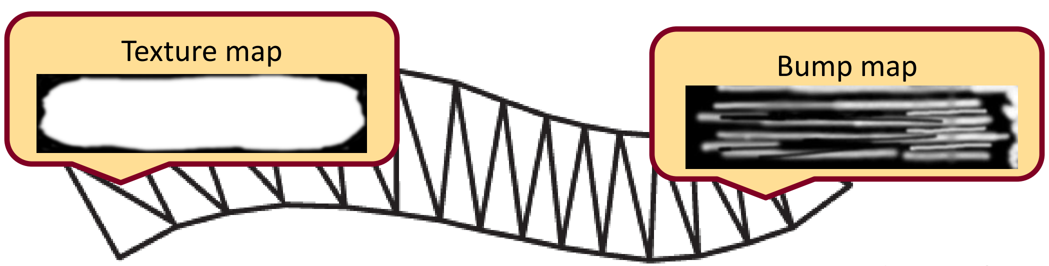
Photo credit: Shiraishi / Yamaguchi '00

Painterly Rendering With Curved Brush Strokes

Hertzmann (1998)

- Artists do not paint with uniformly shaped short strokes (pointillism excepted!)
- Two key contributions (1998)
  - Multi-layer (coarse to fine) painting
  - Painting using β-spline strokes
- Spline strokes can be bump mapped for an improved painterly look (NPAR 2002)





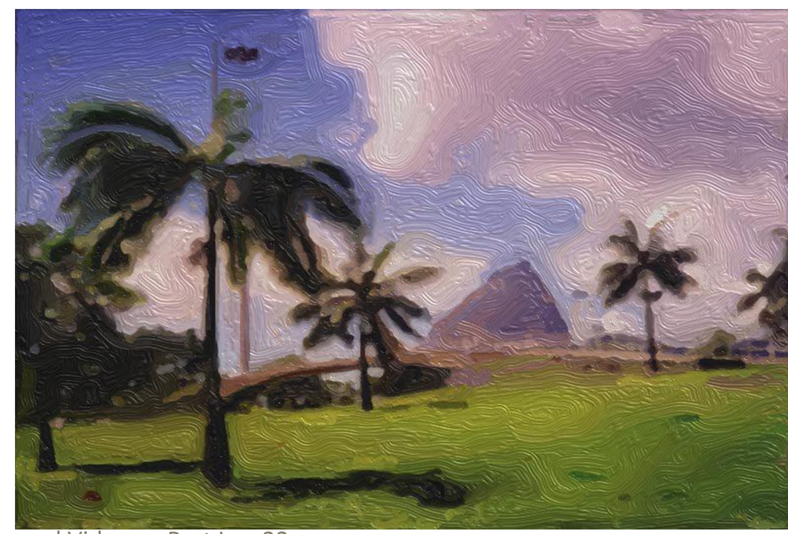


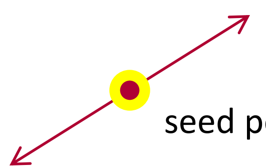
Photo credit: Hertzman '02

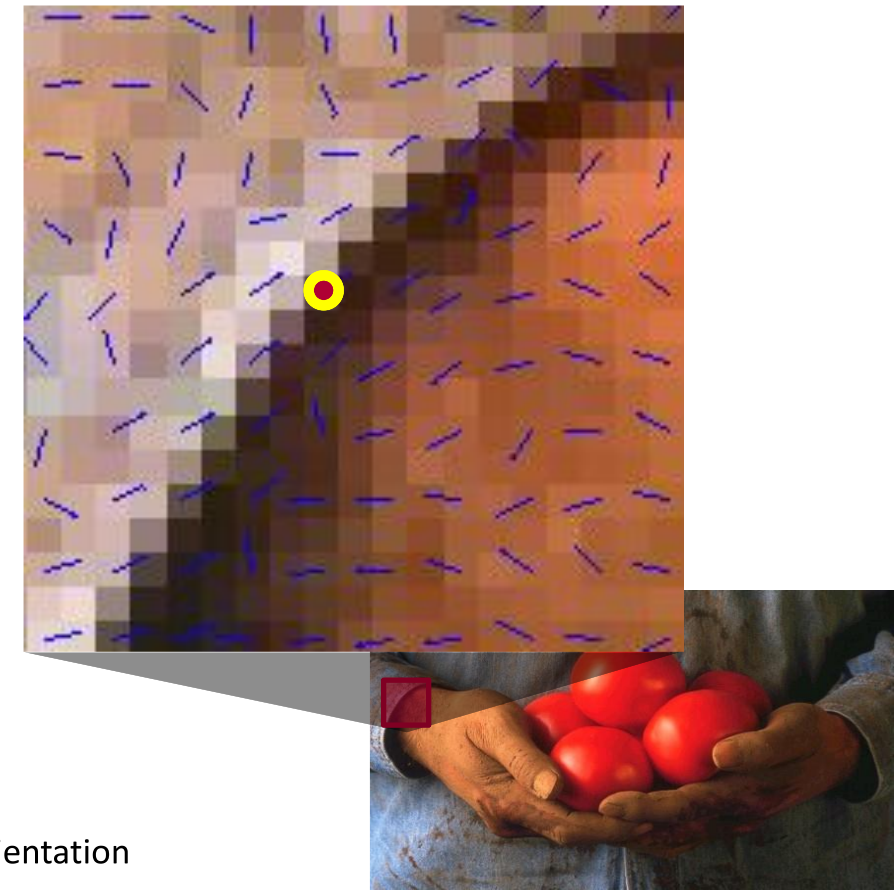
Painterly Rendering With Curved Brush Strokes

Hertzmann (1998)

- Greedy algorithm for stroke placement
- Regularly sample the canvas to seed strokes
- Build a list of control points for each stroke by “hopping” between pixels*

1) Pick a direction arbitrarily
   (some implementations explore both)





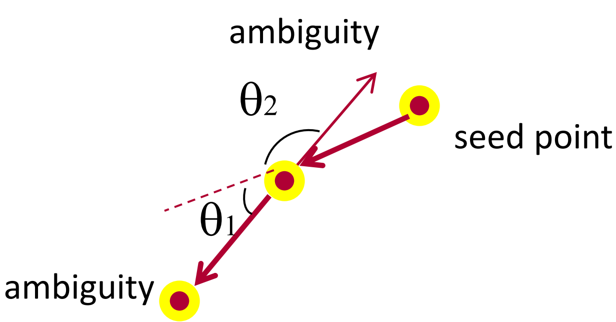
* In practice, best to use float coordinates and interpolate edge orientation

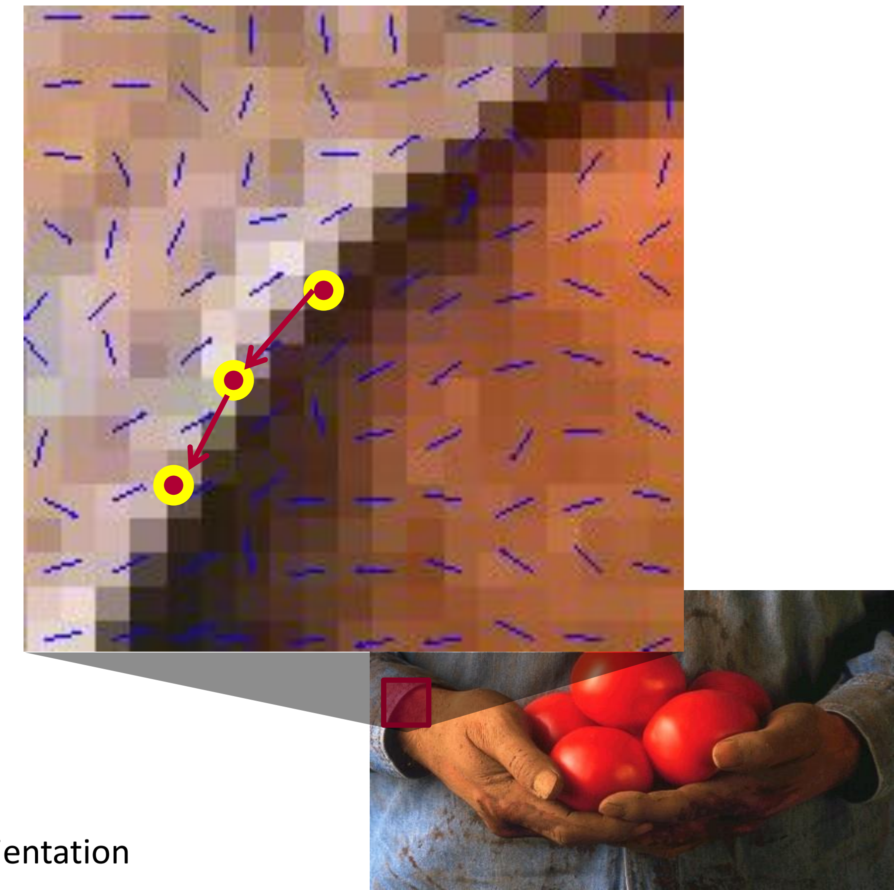
Painterly Rendering With Curved Brush Strokes

Hertzmann (1998)

- Greedy algorithm for stroke placement
- Regularly sample the canvas to seed strokes
- Build a list of control points for each stroke by “hopping” between pixels*

2) Make another hop, resolving directional ambiguity by hopping in the direction of min θ





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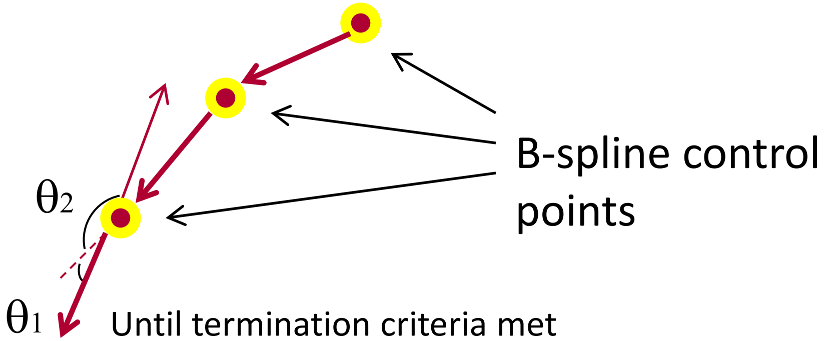
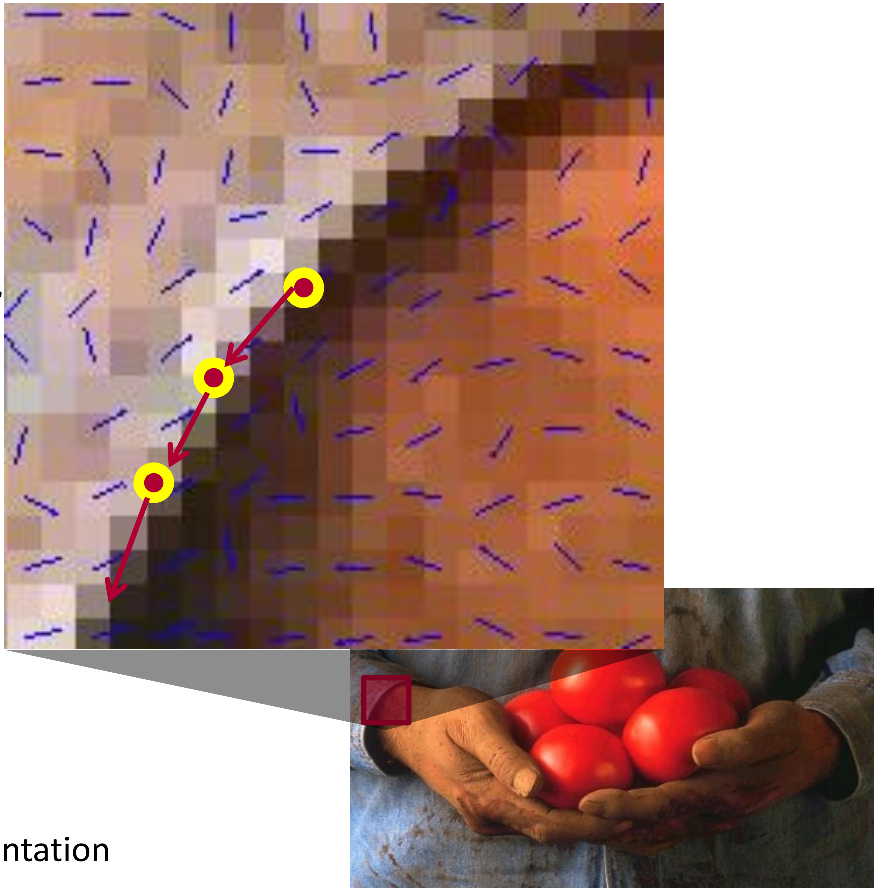
Painterly Rendering With Curved Brush Strokes

Hertzmann (1998)

- Greedy algorithm for stroke placement
- Regularly sample the canvas to seed strokes
- Build a list of control points for each stroke by “hopping” between pixels*

3) Keep hopping until end land on a pixel whose RGB colour differs (> threshold) from mean colour of stroke, or the stroke length is > a second threshold.





* In practice, best to use float coordinates and interpolate edge orientation

Painterly Rendering With Curved Brush Strokes

Hertzmann (1998)

- Painting is laid down in multiple layers (coarse to fine)
- Band-pass pyramid (= differenced layers of low-pass)
- Strokes from early layers are visible in final layer

- Paint coarsest layer with large strokes
- Paint next layer with smaller strokes
  - Only paint regions that differ between the layers
  - Use RGB difference

Painterly Rendering With Curved Brush Strokes

Hertzmann (1998)

- Tips and tricks
  - Non-linear diffusion* instead of Gaussian blur sharpens the painting – preserves edges and accuracy of edge orientation.
  - Build Gaussian pyramid at octave intervals, σ=(1,2,4,8). 4 layers sufficient.
  - Stroke thickness also at octave intervals
  - Low-pass filter the hop direction θ

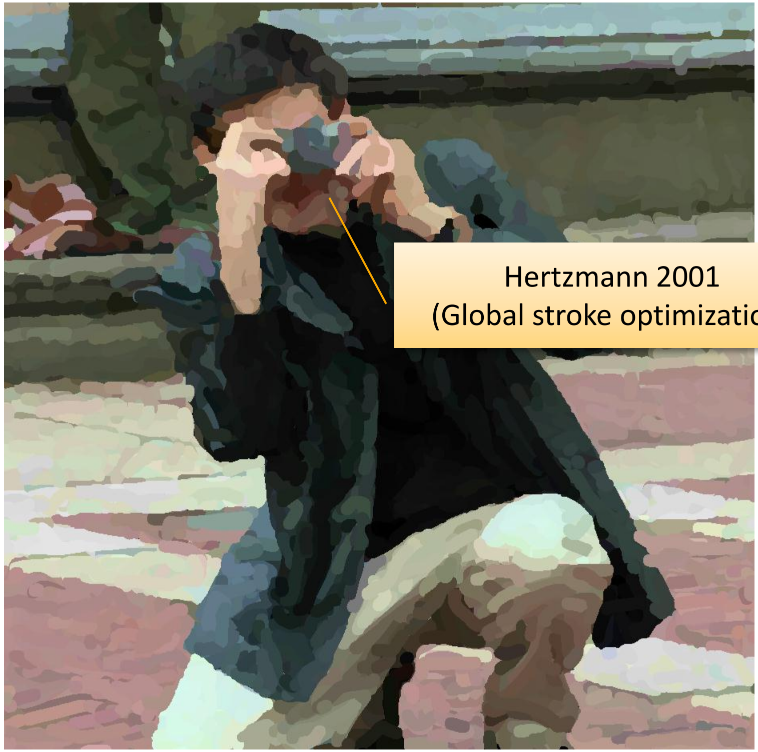
* "Scale-Space and Edge Detection using Anisotropic Diffusion". P. Perona and J. Malik. *PAMI 12:629–639.* 1990.

Paint by Relaxation

Hertzmann. (2001)

- Global Optimization to Iteratively Produce "Better" Paintings

Hertzmann 1998
(Greedy stroke placement)



Hertzmann 2001
(Global stroke optimization)

Photo credit: Hertzman '01

Paint by Relaxation

Hertzmann. (2001)

- How to define the optimality of a painting 'P' derived from a photo 'G'

$$
\begin{aligned}
E(P) &= E_{app}(P) + E_{area}(P) + E_{nstr}(P) + E_{cov}(P) \\
E_{app}(P) &= \sum_{(x,y)\in I} w_{app}(x,y)\|P(x,y) - G(x,y)\| \\
E_{area}(P) &= w_{area} \sum_{S\in P} \text{Area}(S) \\
E_{nstr}(P) &= w_{nstr} \cdot (\text{number of strokes in } P) \\
E_{cov}(P) &= w_{cov} \cdot (\text{number of empty pixels in } P)
\end{aligned}
$$

Weighted sum of Heuristics

Painting similar to photo - weighted

Stroke area ("paint used by artist")

Number of strokes

Fraction of canvas covered by strokes

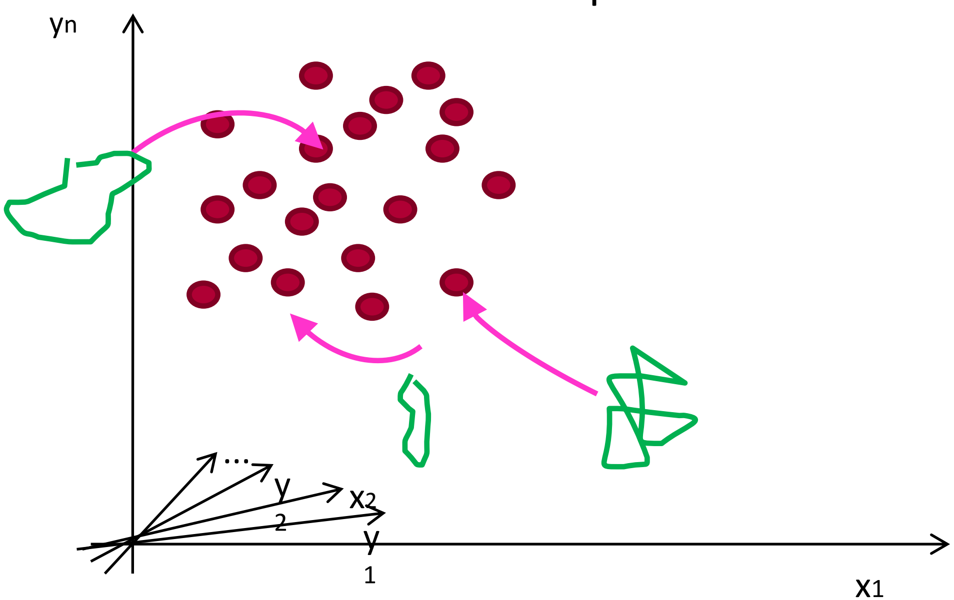
- Weighting ω_{app} is derived from a Sobel edge magnitude (or user defined)
- The right strokes in the right place will minimize the energy function E(P)

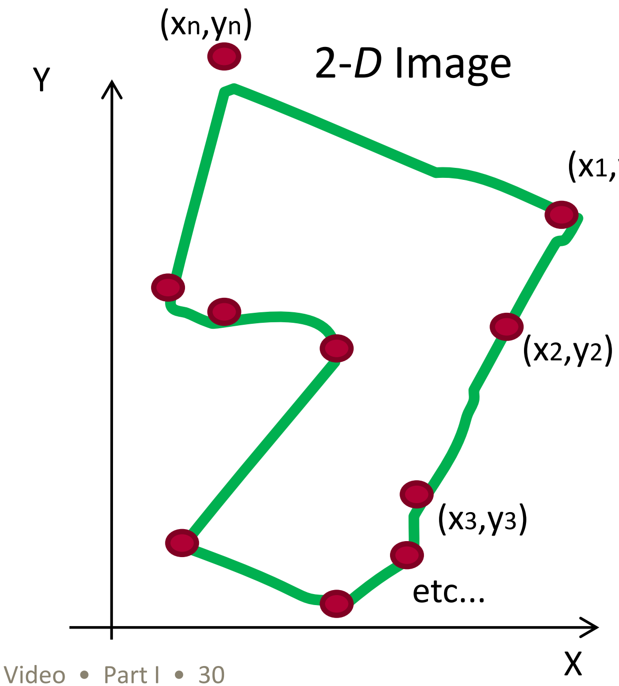
Active Contours (Snakes)

Kass et al. (1987)

$$E = \int_{s=0}^{s=1} \underbrace{\alpha \frac{dP(s)}{ds} + \beta \frac{dP^2(s)}{ds^2}}_{\text{Internal energy}} + \underbrace{\gamma\, \mathrm{I}(P(s))}_{\text{External energy}}$$

2n-*D* Solution space

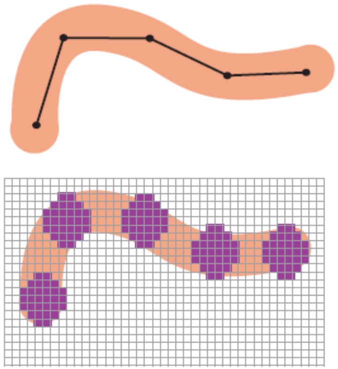




Paint by Relaxation

Hertzmann. (2001)

- Strokes selected at random and modified by local optimization to minimize **E(P)**
- Strokes modelled as active contours ("snakes")
  - … but energy has no 1st/2nd order derivative terms
  - **E(P)** is approximated under control points



$$E(P) = E_{app}(P) + E_{area}(P) + E_{nstr}(P) + E_{cov}(P)$$

$$E_{app}(P) = \sum_{(x,y)\in I} w_{app}(x,y)||P(x,y) - G(x,y)||$$

$$E_{area}(P) = w_{area} \sum_{S\in P} \text{Area}(S)$$

$$E_{nstr}(P) = w_{nstr} \cdot (\text{number of strokes in } P)$$

$$E_{cov}(P) = w_{cov} \cdot (\text{number of empty pixels in } P)$$

Weighted sum of Heuristics

Painting similar to photo - weighted

Stroke area ("paint used by artist")

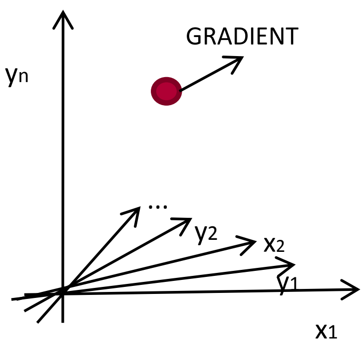
Number of strokes

Fraction of canvas covered by strokes

Paint by Relaxation

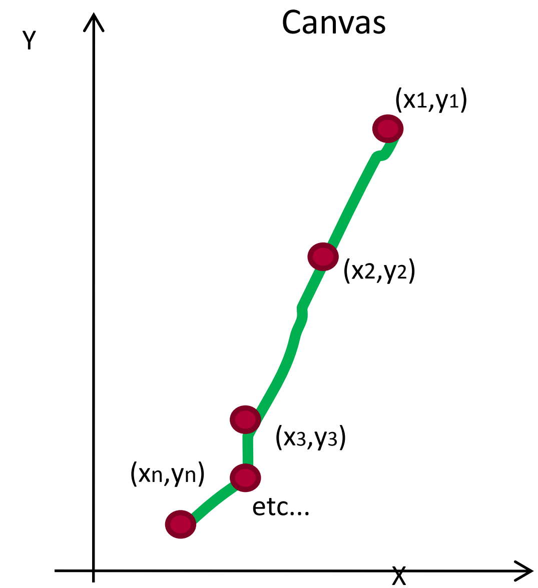
Hertzmann. (2001)

- Simplest solution (gradient descent)
  - Can be unstable for this weighted heuristic function



$$\begin{pmatrix} \delta E(x_1) / \delta x_1 \\ \delta E(y_1) / \delta y_1 \\ \delta E(x_2) / \delta x_2 \\ \delta E(y_2) / \delta y_2 \\ \delta E(x_3) / \delta x_3 \\ \delta E(y_3) / \delta y_3 \\ \delta E(x_4) / \delta x_4 \\ \delta E(y_4) / \delta y_4 \\ \ldots \\ \delta E(x_n) / \delta x_n \\ \delta E(y_n) / \delta y_n \end{pmatrix}$$

GRADIENT

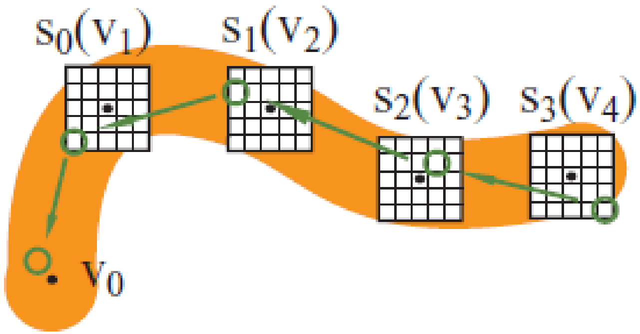


Paint by Relaxation

Hertzmann. (2001)

- Dynamic programming solution (Amini et al. '90)
  - Move each control point to obtain locally optimal position (5x5)
  - E(P) at control point dependent only on current v_i and previous v_{i-1}

$$
\begin{aligned}
s_0(v_1) &= \min_{v_0} e_0(v_0) + e_0(v_1) + e_1(v_0, v_1) \\
s_1(v_2) &= \min_{v_1} s_0(v_1) + e_0(v_2) + e_1(v_1, v_2) \\
&\vdots \\
s_{i-1}(v_i) &= \min_{v_{i-1}} s_{i-2}(v_{i-1}) + e_0(v_i) + e_1(v_{i-1}, v_i)
\end{aligned}
$$



Paint by Relaxation

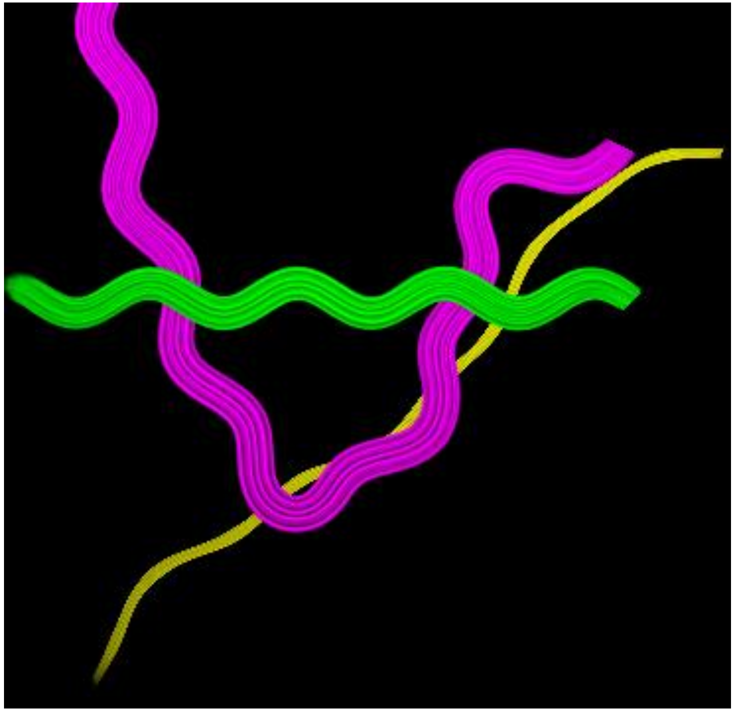
Hertzmann. (2001)

- Sobel magnitude can be replaced with a manually sketched mask to alter emphasis

Photo credit: Hertzman '01

Stroke Rendering Library (C/C++)

- Quick Start: OpenGL **research code** for bump-mapped paint strokes
  - Strokes as Catmull-Rom (interpolating) splines
  - Bump mapping via Multi-texturing (can be disabled)
  - Dependency on OpenCV to load images (can substitute this trivially)
  - Code used in “Empathic Painting” Collomosse et al. NPAR 2006



http://kahlan.eps.surrey.ac.uk/EG2011