Non-Photorealistic Rendering (NPR)

Christian Richardt, Rainbow Group

Structure in six parts

1. Definition of “non-photorealistic rendering” (NPR)
2. History of computer graphics: from 1970s to 1995
3. Overview of NPR techniques
4. Example 1: toon shading
5. Example 2: painterly rendering
6. Example 3: video abstraction

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Rend·er·ing |'rɛnd(ə)rɪŋ|

- The conversion of a high-level object-based description into a graphical image for display. (FOLDOC)
- The process of generating an image from a model, by means of computer programs. (Wikipedia)

Photorealism

Telephone Booths (Richard Estes, 1968)

Non-Photorealism (1886)

A Sunday Afternoon on the Island of La Grande Jatte (Georges Seurat, 1884–1886)

Photorealism (2006)

http://www.flickr.com/photos/oldonliner/182839989/

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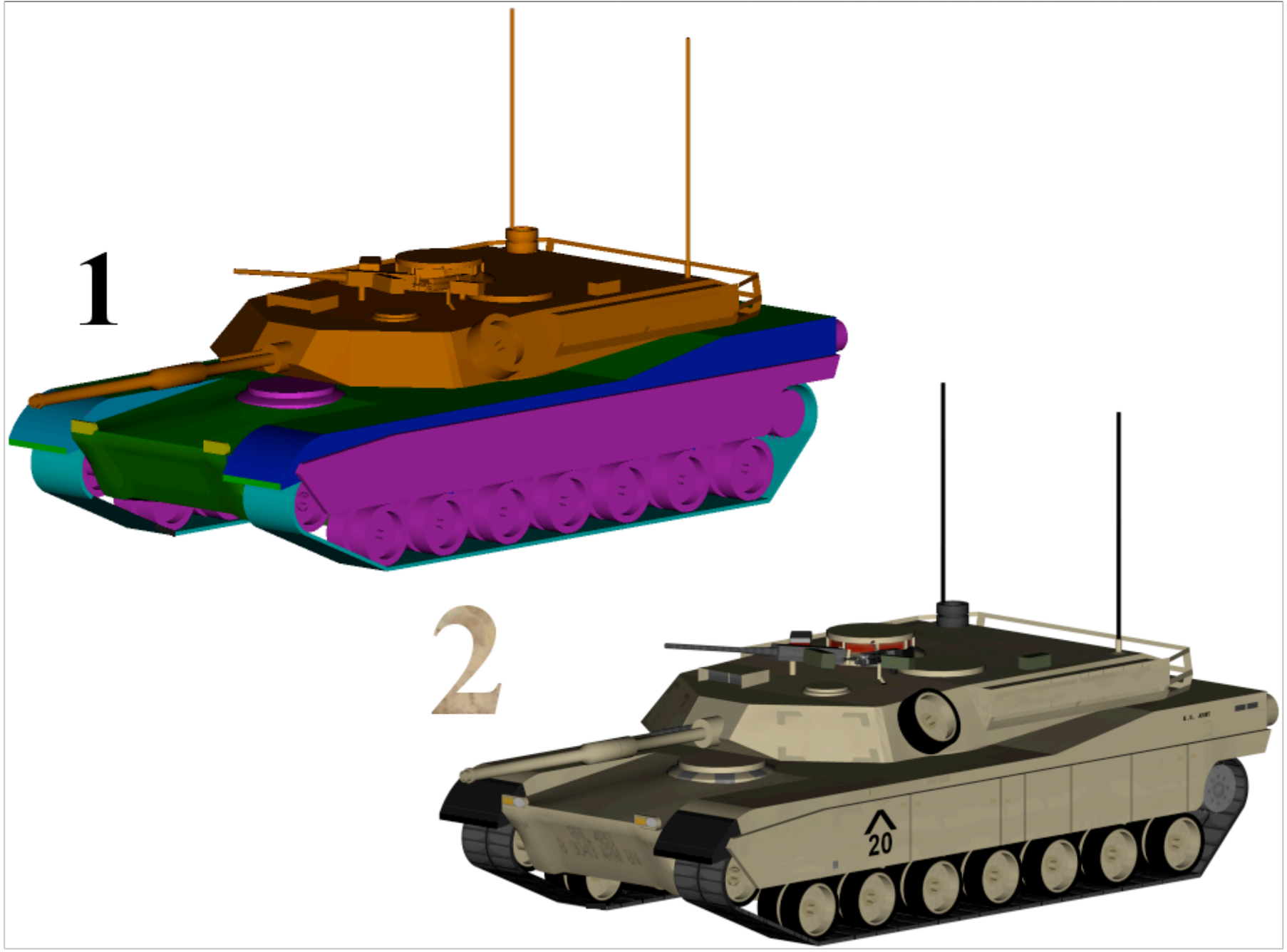
History of computer graphics

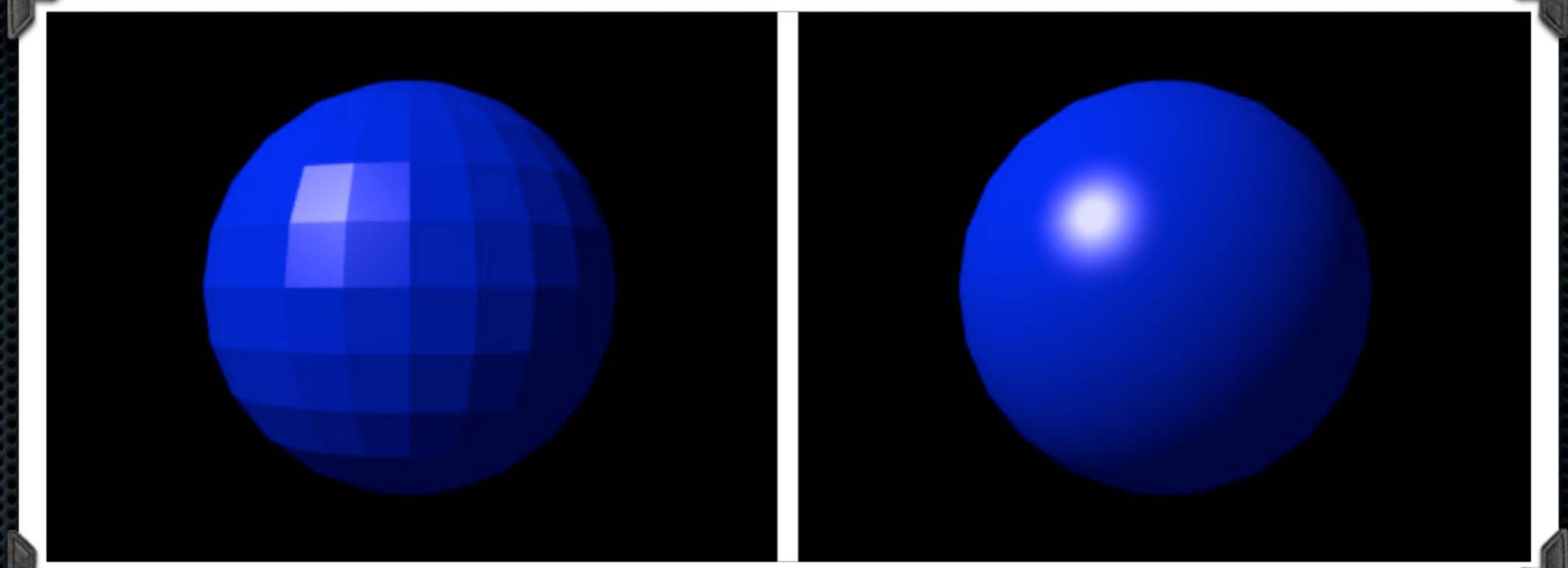
- term “computer graphics” coined in 1960
  - synonymous with graphics hardware
- tremendous increase in computation power
  - stand-alone GPUs from mid-1990s
  - driven by 3D computer games
- primary aim is to achieve photorealism

Texture mapping



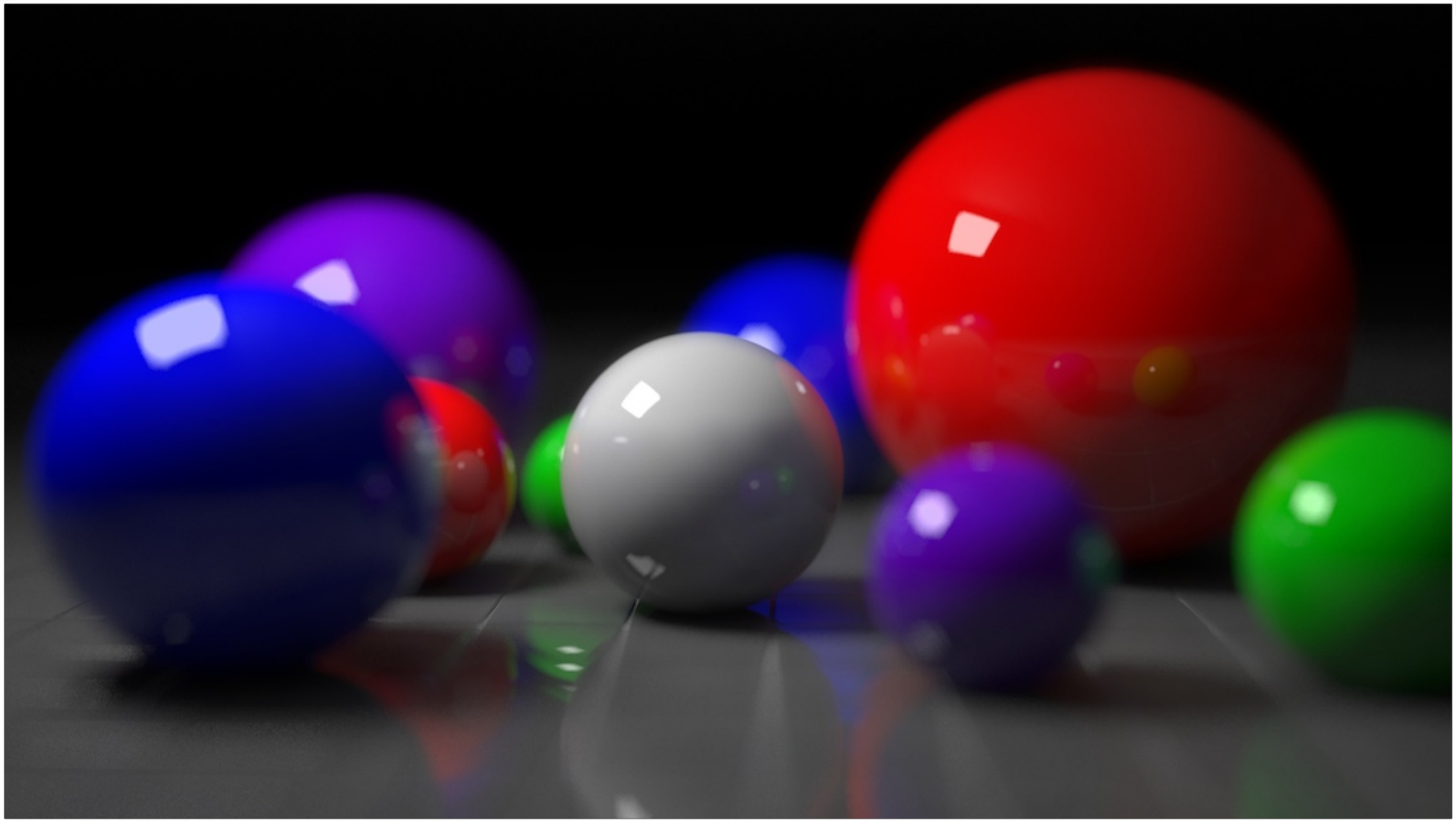
Catmull 1974

Phong shading



Phong 1975

Ray tracing



Whitted 1980

Radiosity

Goral et al. 1984

Tone mapping

Tumblin & Rushmeier 1993

Photon mapping

Jensen & Christensen 1995

Also 1995: Toy Story

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Survey of NPR techniques

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stylisation 

Survey of NPR techniques

	stylisation 	abstraction 

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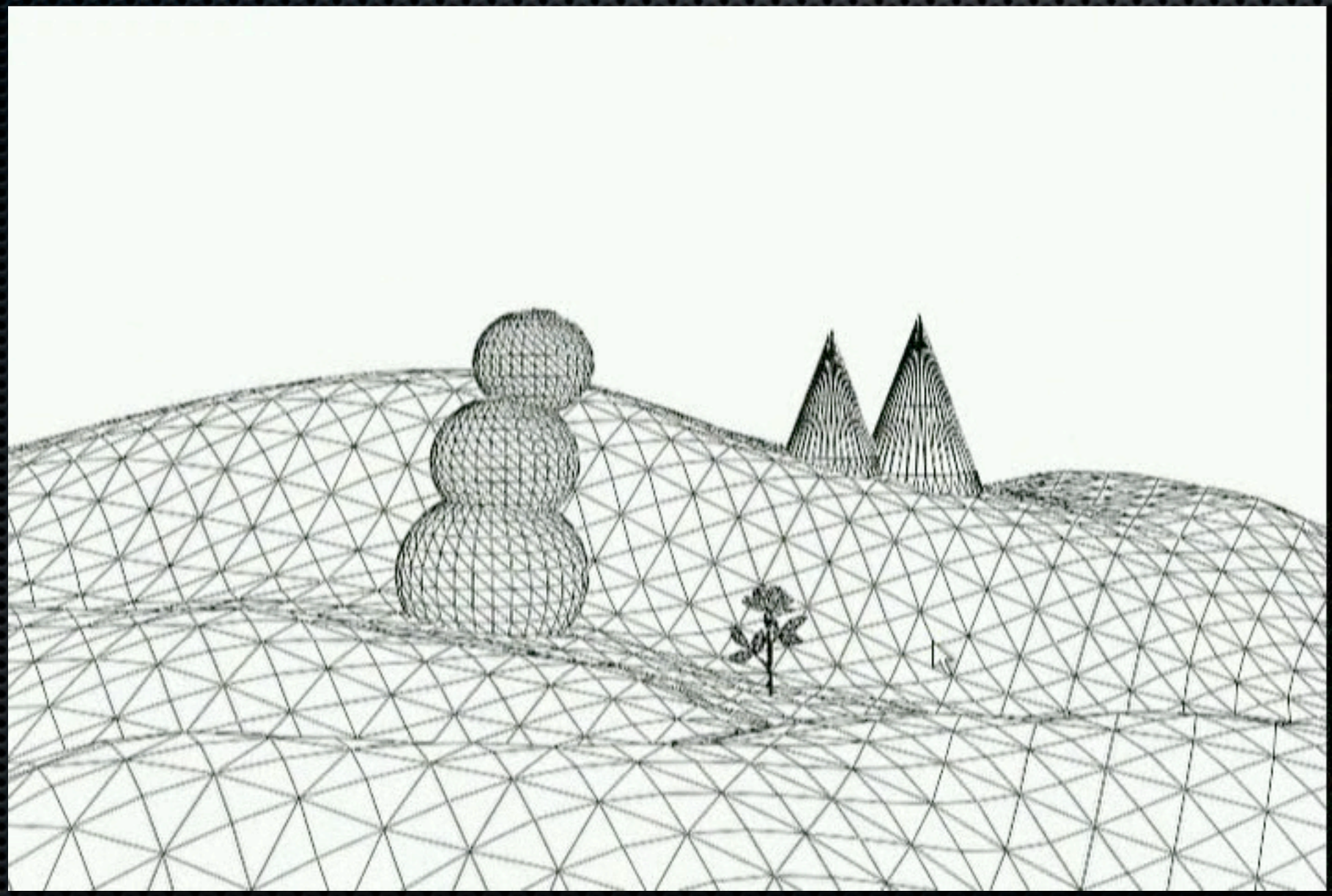
WYSIWYG NPR:
Drawing Strokes Directly on 3D Models



Kalnins et al. 2002

	Styl.	Abs.
Geom.		
Image		
Video		

Processing Images and Video for an Impressionist Effect

Litwinowicz 1997

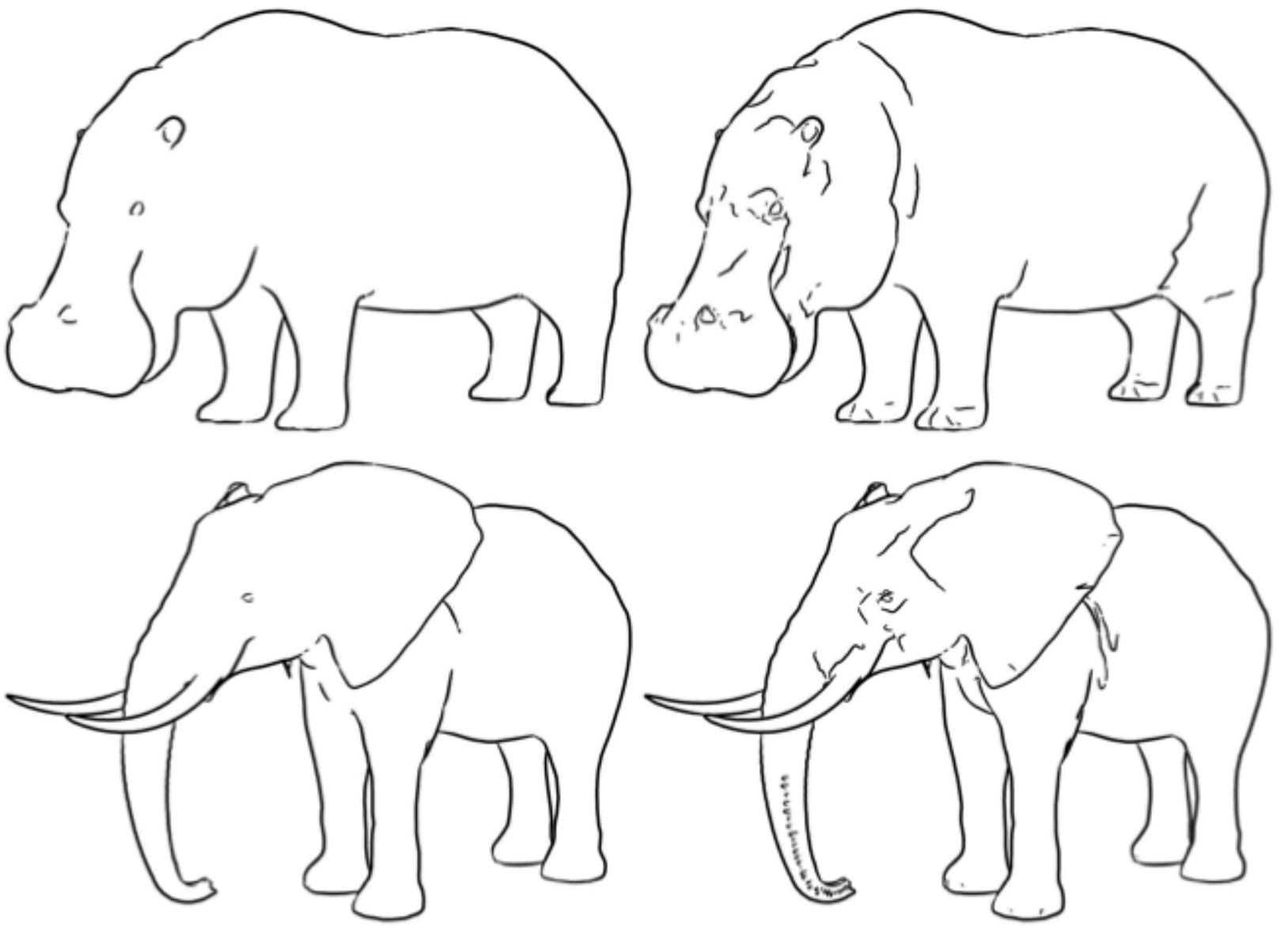
	Styl.	Abs.
Geom.		
Image		
Video		

Video Watercolorization using Bidirectional Texture Advection

Bousseau et al. 2007

	Styl.	Abs.
Geom.		
Image		
Video		

Suggestive Contours for Conveying Shape



DeCarlo et al. 2003

	Styl.	Abs.
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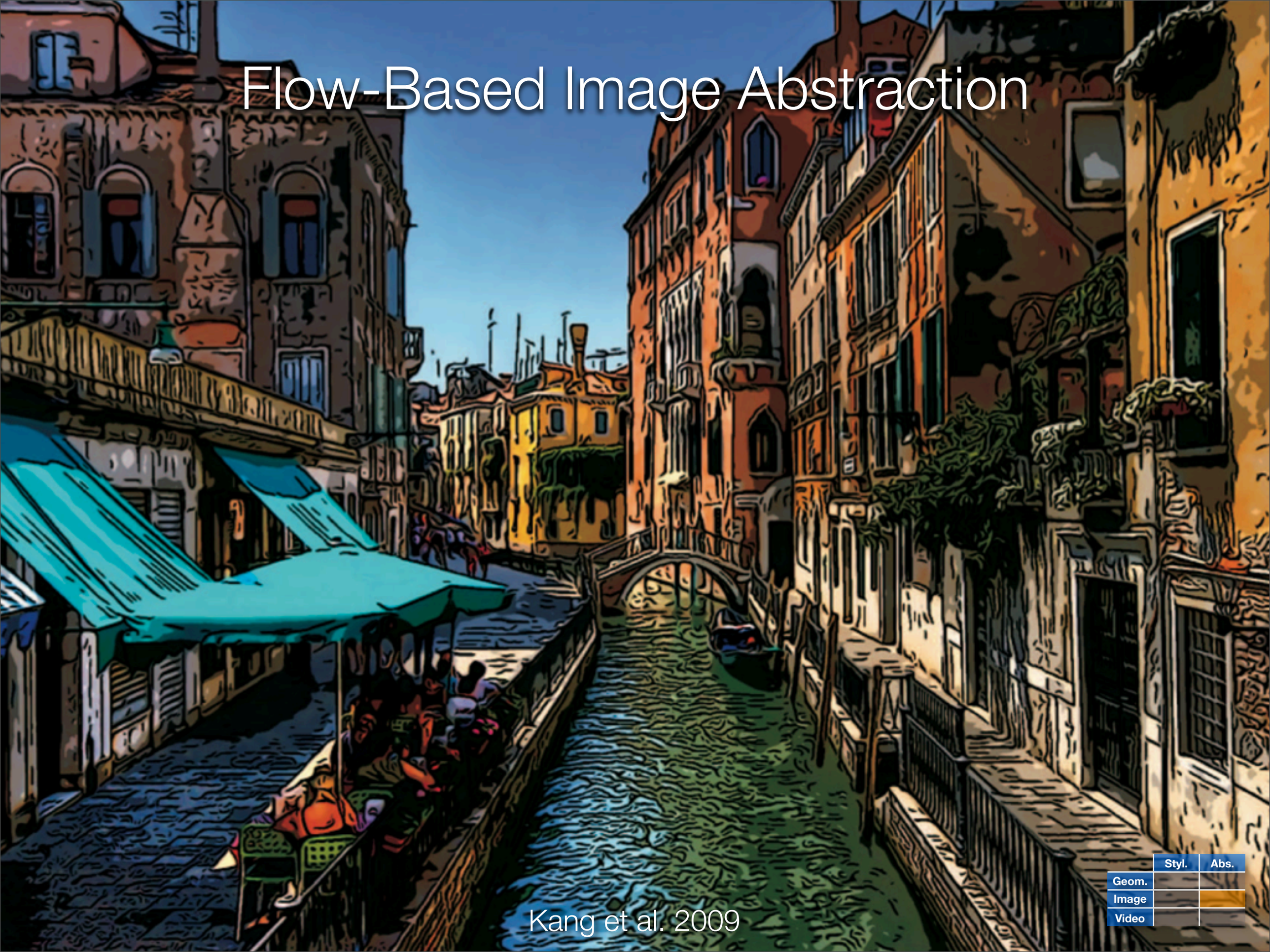
Video		

Flow-Based Image Abstraction



Kang et al. 2009

Image and Video Abstraction by Anisotropic Kuwahara Filtering

Kyprianidis et al. 2009

	Styl.	Abs.
Geom.		
Image		
Video		

Recap of NPR techniques

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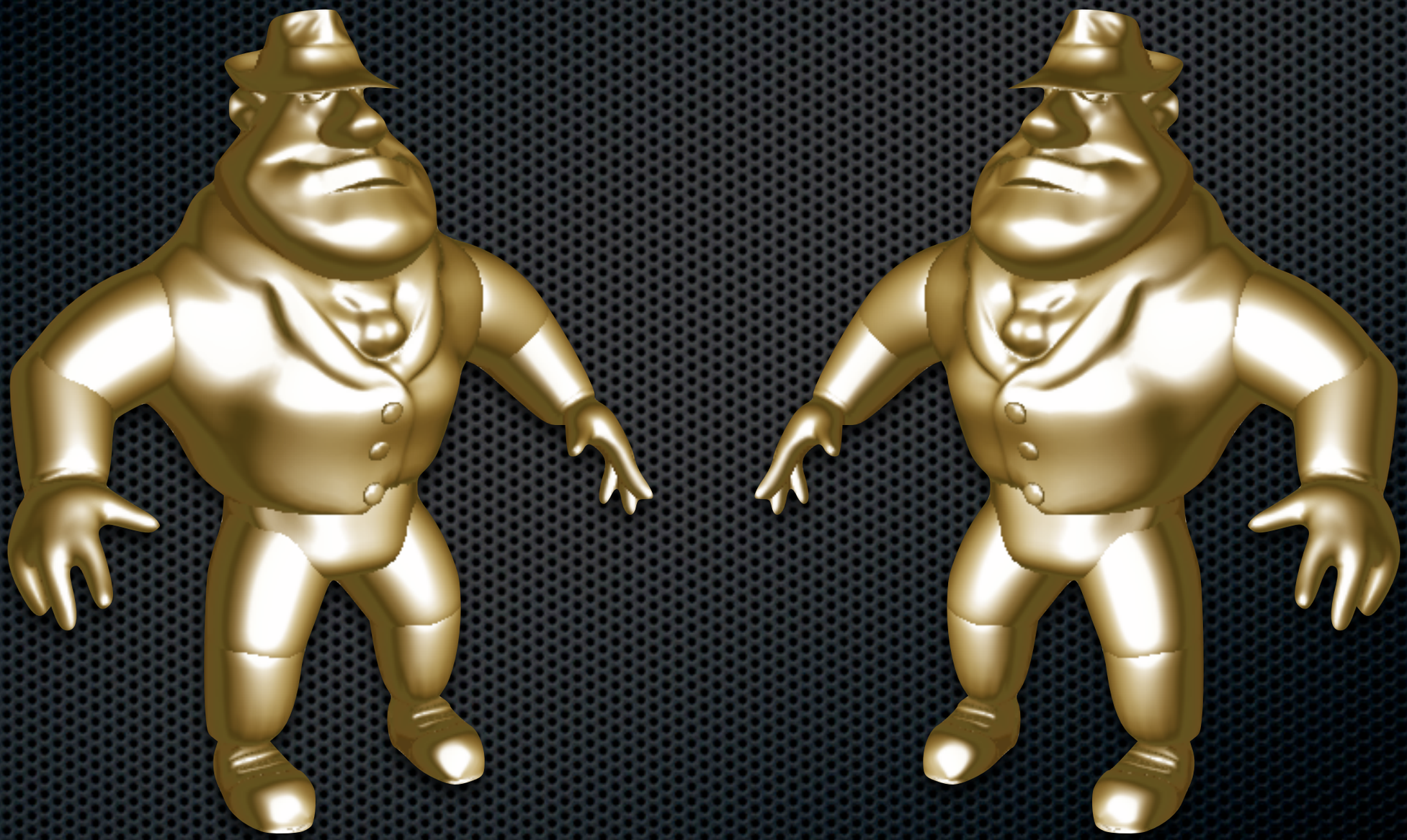
X-Toon: An Extended Toon Shader



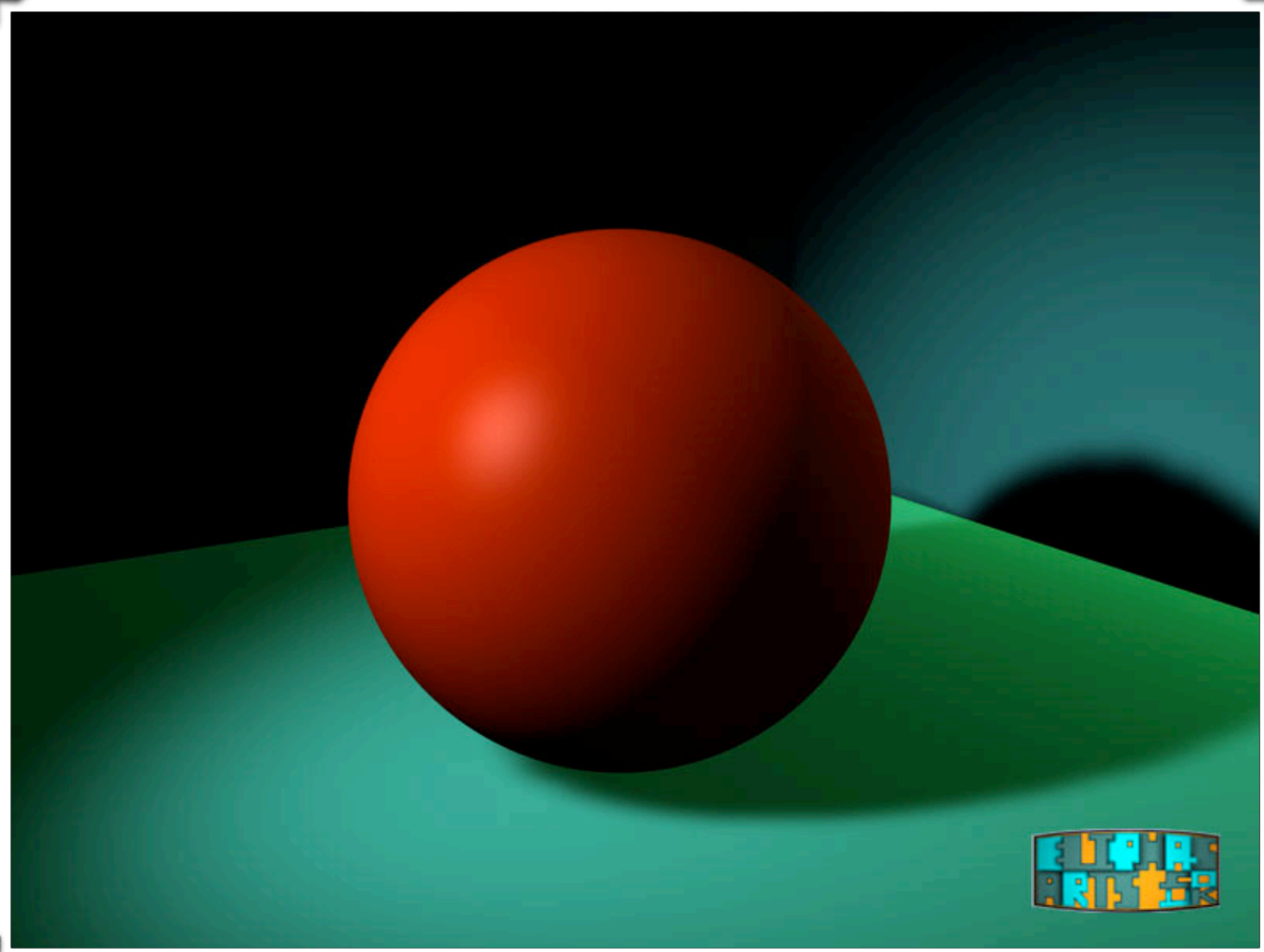
Barla, Thollot & Markosian 2006

Toon shading

- cartoon style a.k.a. cel shading (from cel = celluloid)
- dominated by large areas of flat colour
- often stylised highlights and shadows

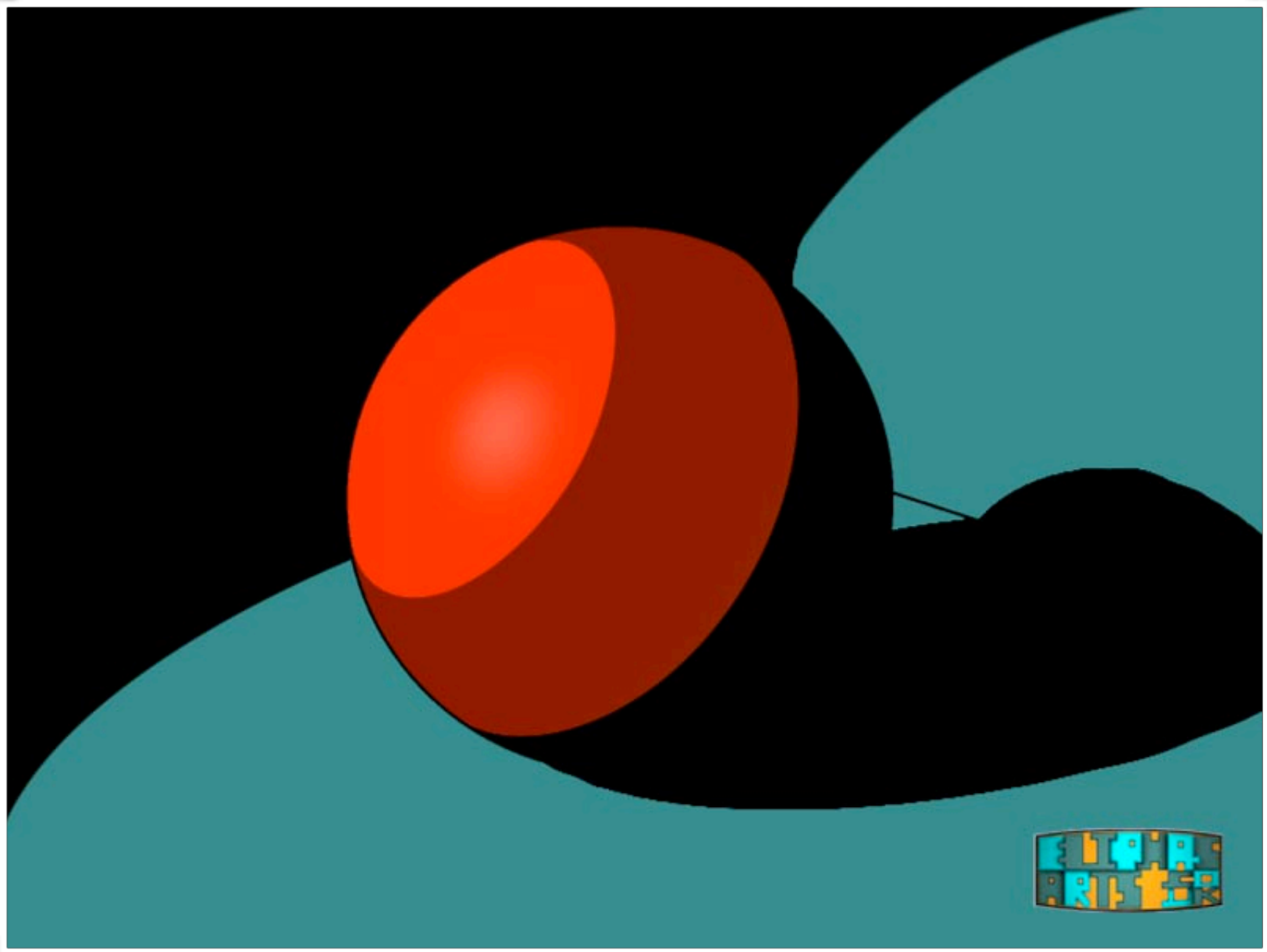
Snow White and the Seven Dwarfs (Walt Disney 1937)

Basic toon shading



http://www.eliphas-arts.co.uk/tutorials/intro%20to%203d/rendering.html

Basic toon shading



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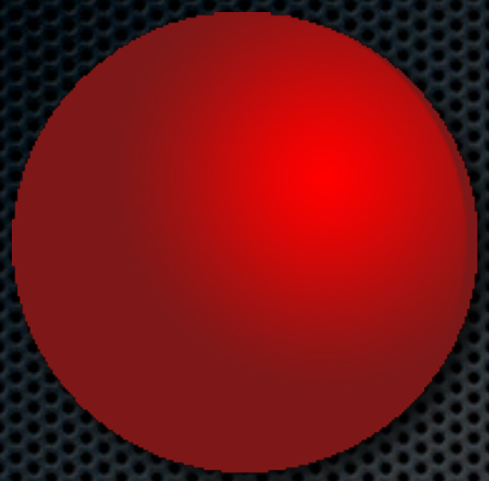


- diffuse shading: $d = \mathbf{n} \cdot \mathbf{l}$
  - unit surface normal **n**
  - direction to the light **l**

- basic toon shading:
  - compute diffuse shading
  - quantise into discrete steps

http://www.plaidcreature.com/2009/06/11/

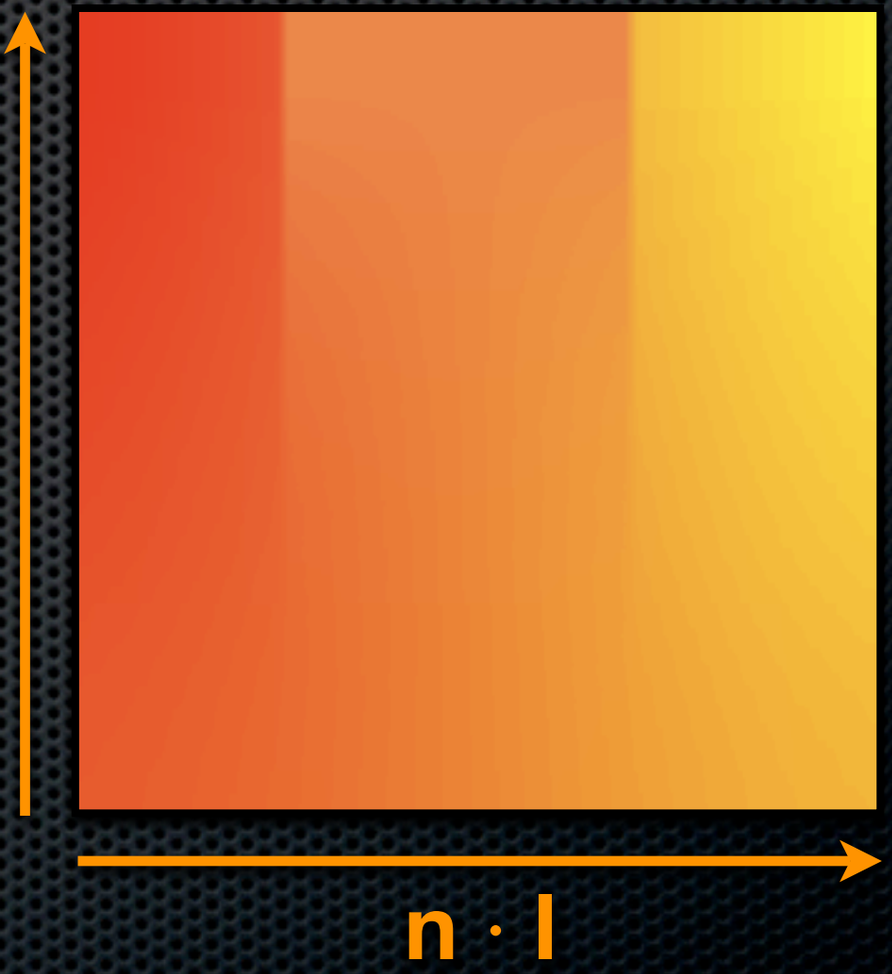
Basic toon shading

- typically use a 1D texture
- more flexible than hard-coded thresholds
- artists can modify shading for each object

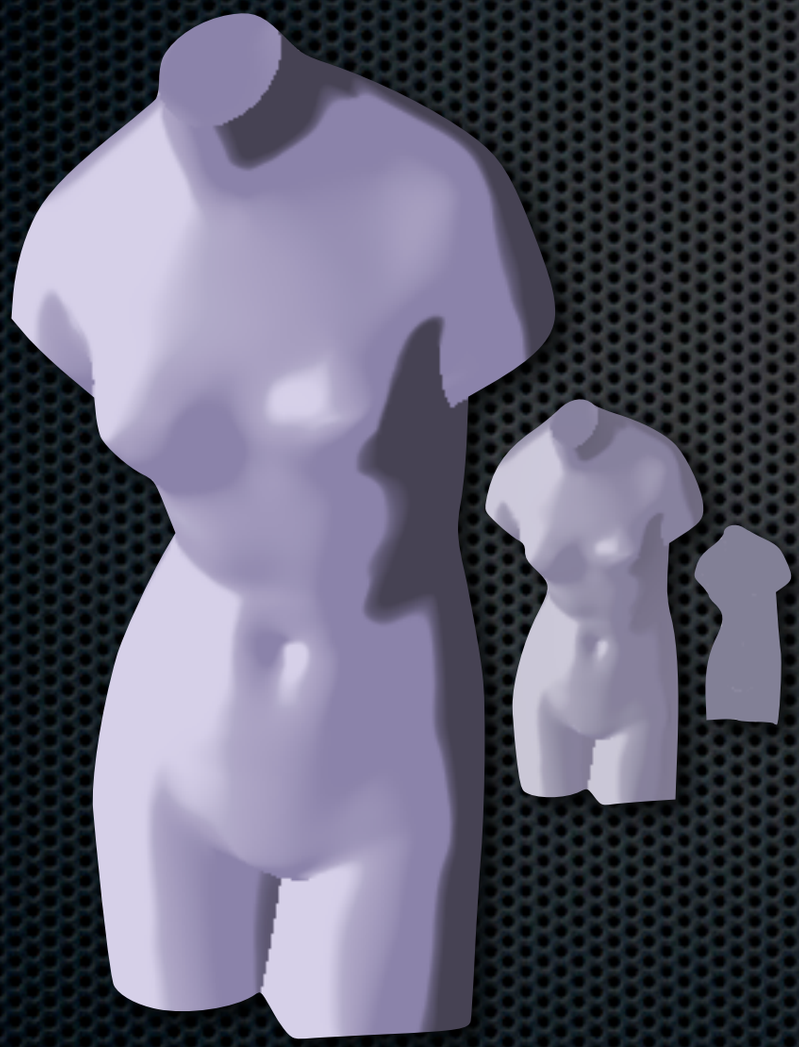
http://www.plaidcreature.com/2009/06/11/

Tone detail

- extend 1D toon texture by a second dimension (D for level of detail), e.g.
  - depth
  - highlights
  - near-silhouette



Depth-based tone detail



Highlight tone detail

Near-silhouette tone detail

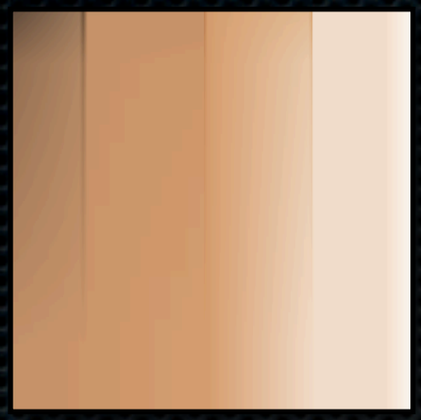


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Image and Video Based Painterly Animation

Hays & Essa 2004

Brush stroke properties

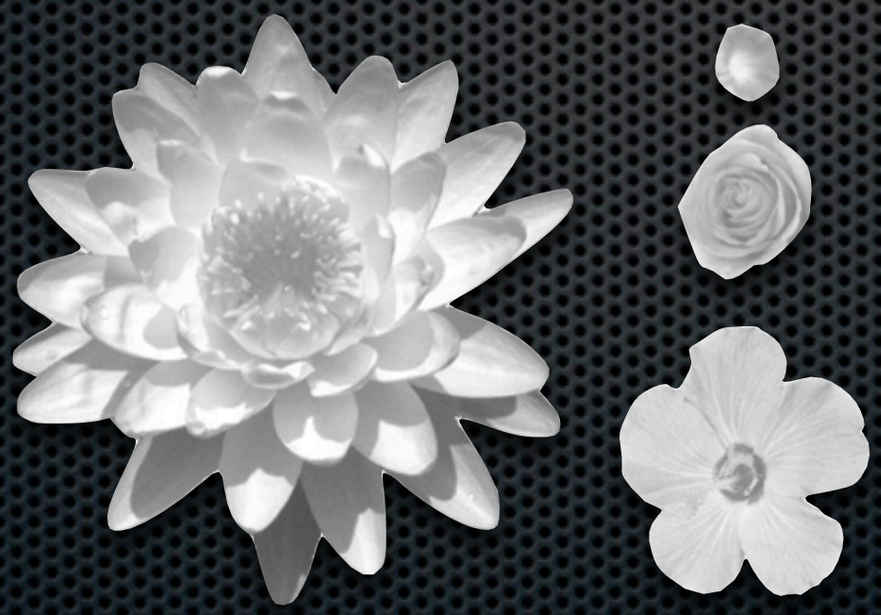
- colour
- opacity
- anchor
- lengths
- width
- angle

Brush stroke textures

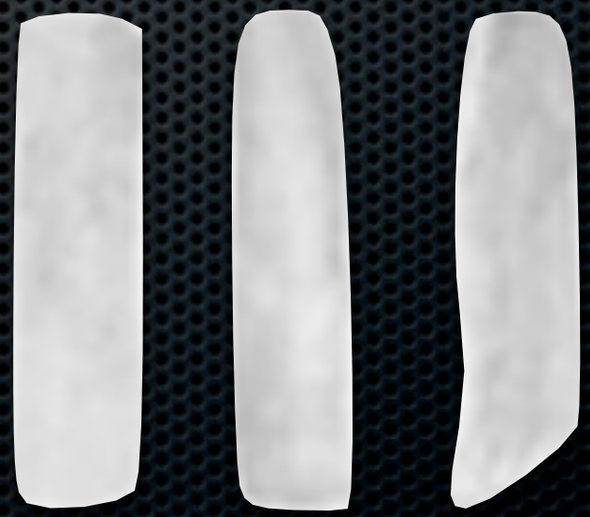
impressionism

pointillism

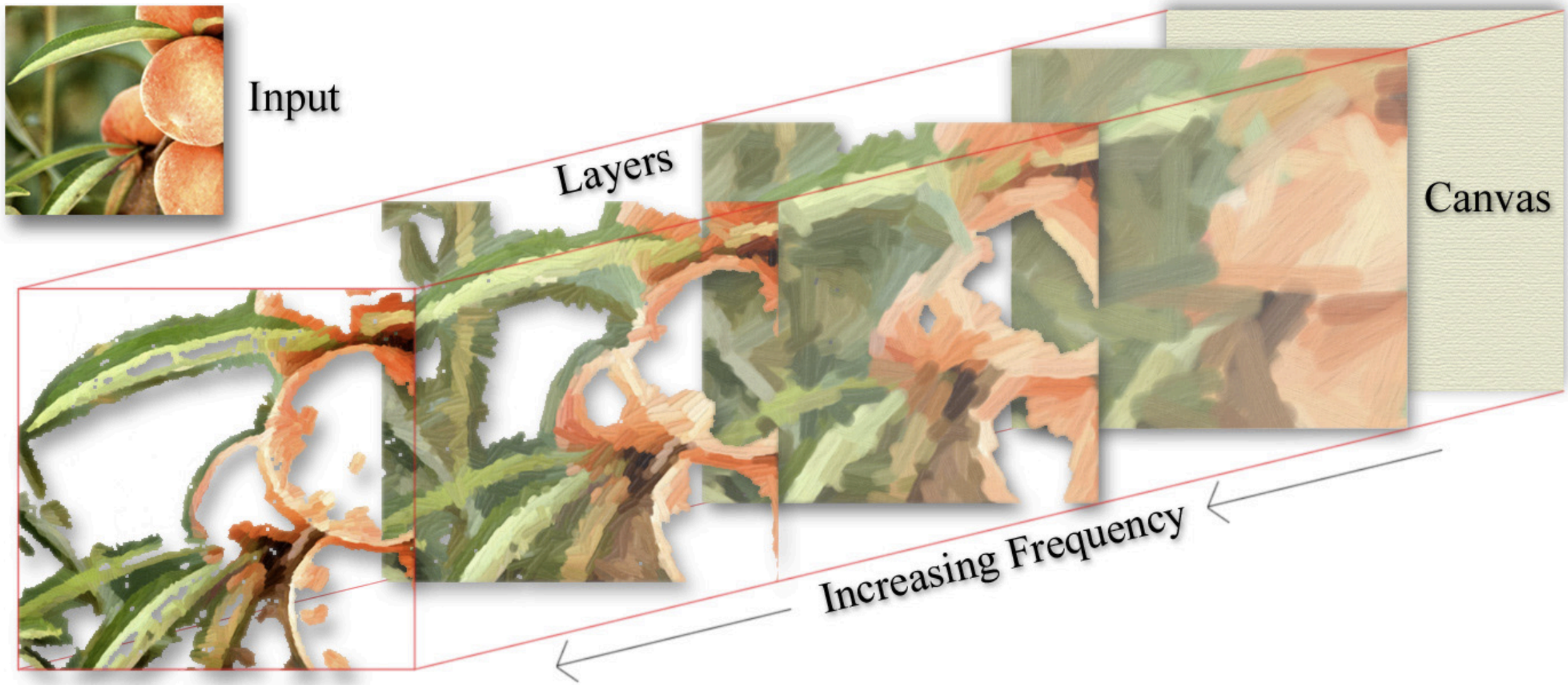
“flower” style



van Gogh style



Brush stroke layers



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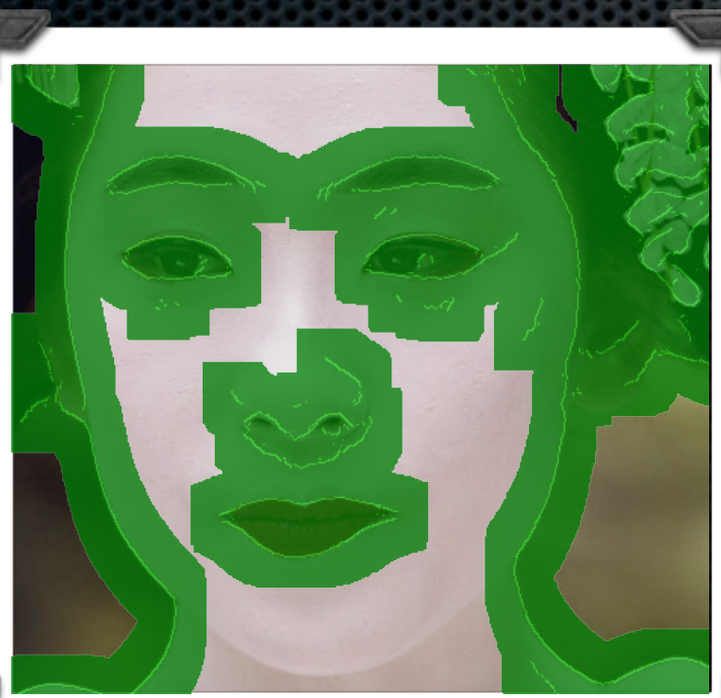

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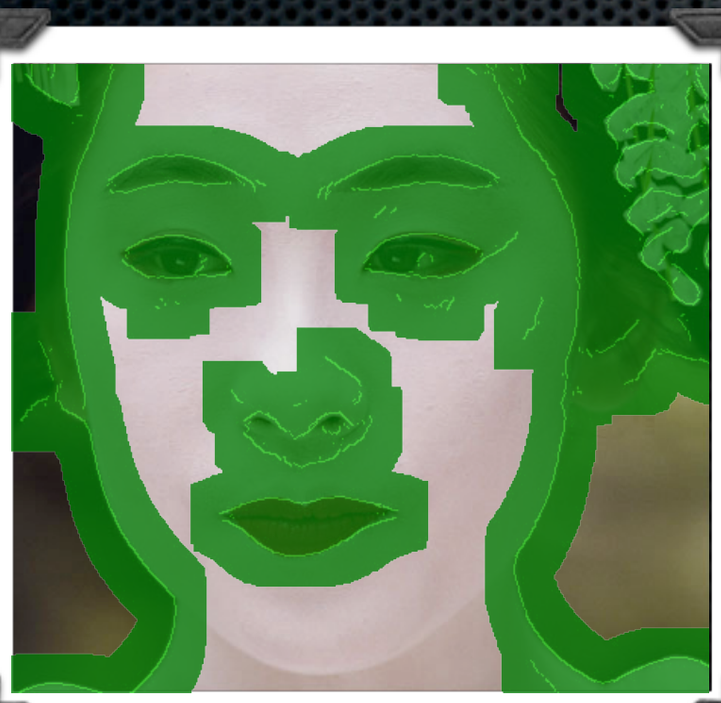


Brush stroke layers

Brush stroke layers

Brush stroke layers

Brush stroke layers

Brush stroke orientation

Brush stroke orientation

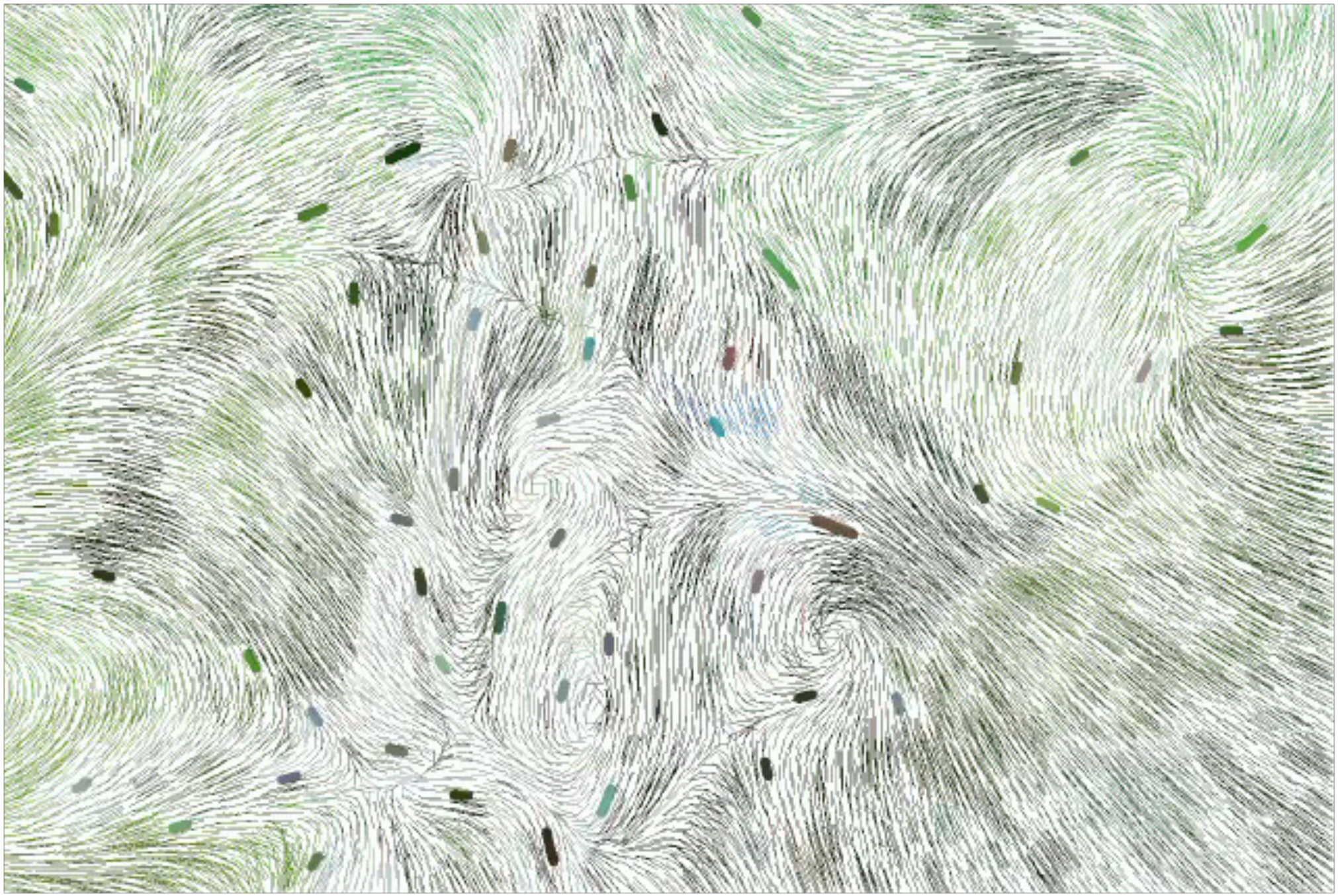
Brush stroke orientation

Brush stroke orientation

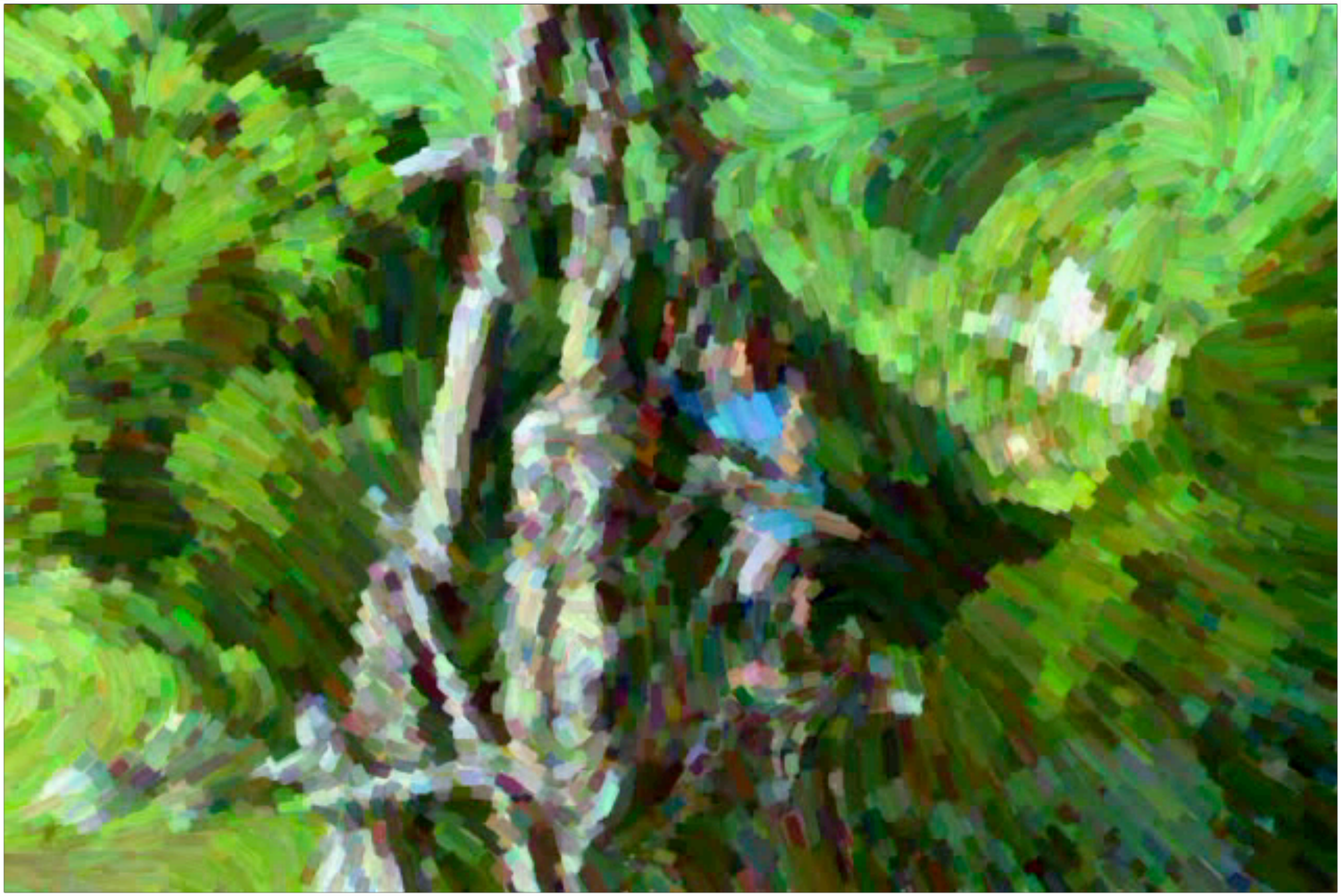
Brush stroke orientation

Brush stroke motion

Brush stroke motion



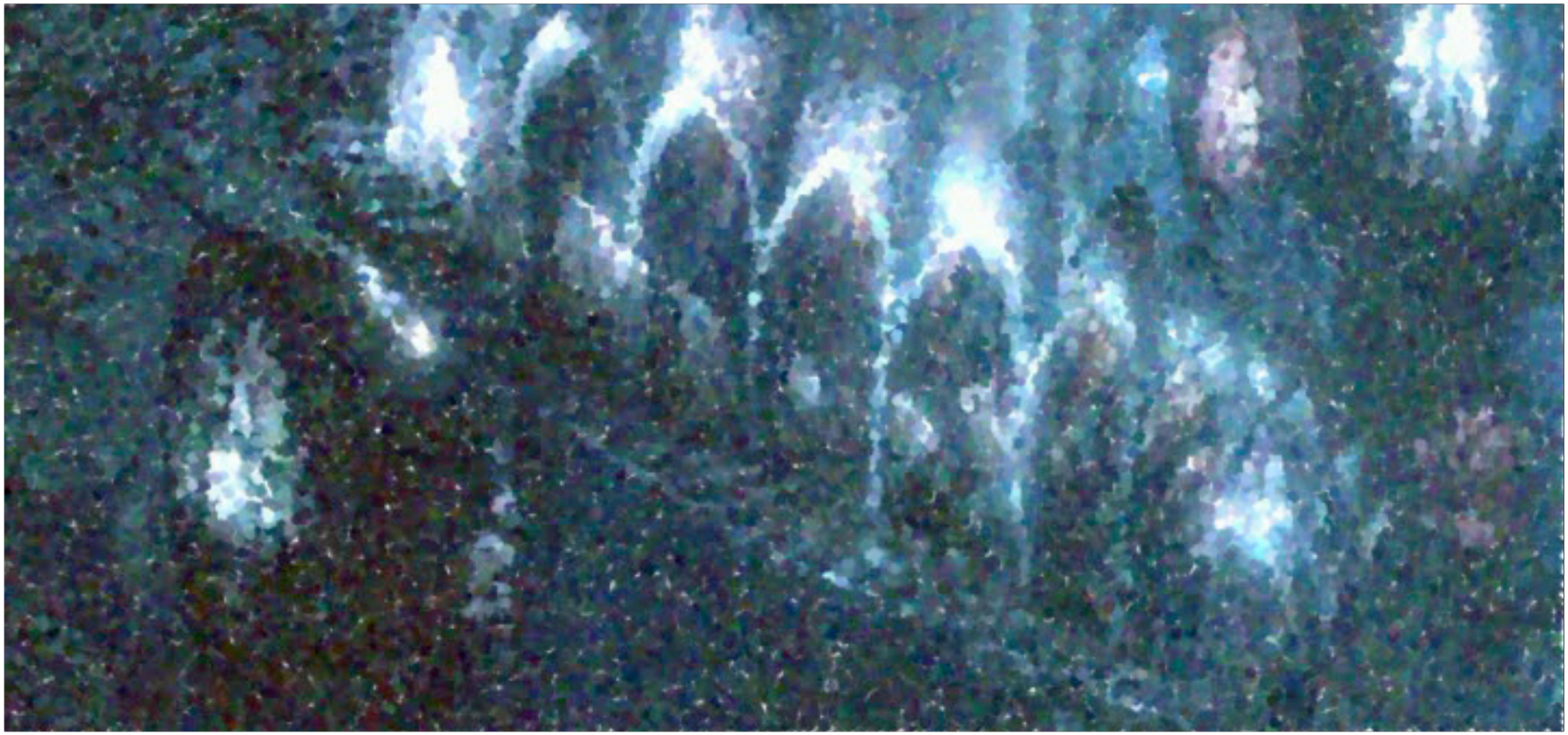
Brush stroke motion



Brush stroke regeneration

Brush stroke regeneration

Extra result: pointillism



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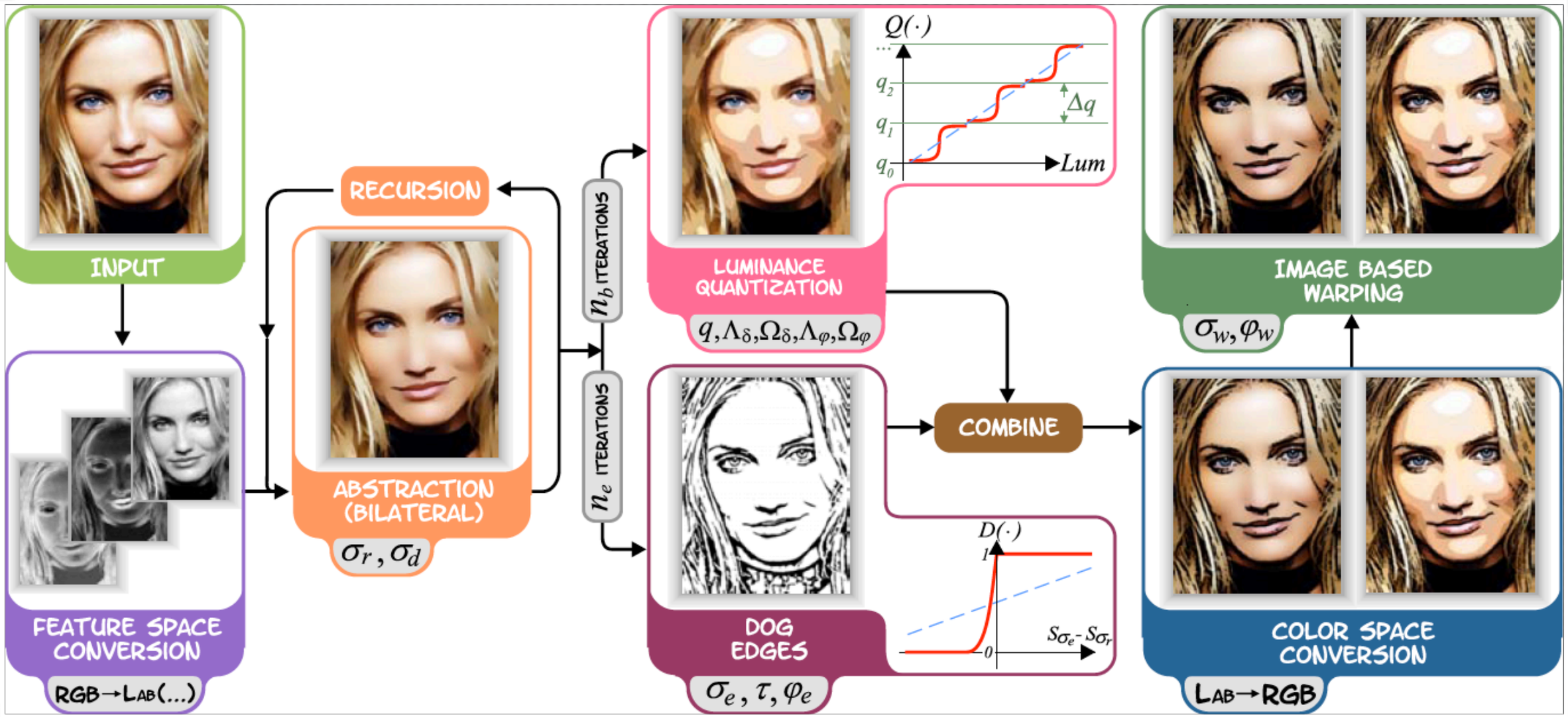
Real-Time Video Abstraction



Winnemöller, Olsen & Gooch 2006

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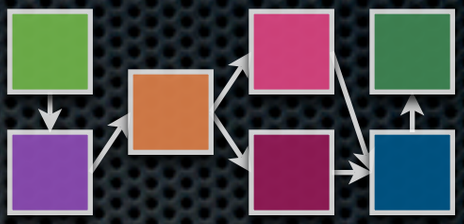

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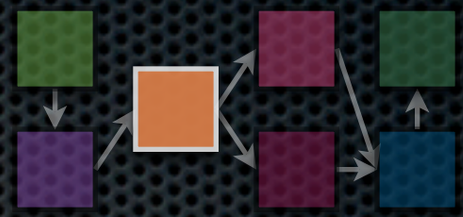
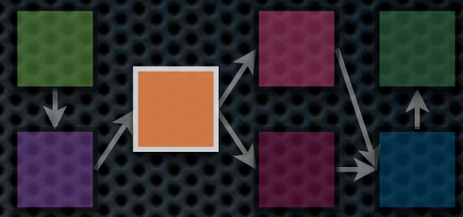
Bilateral filter



- edge preserving filter [Tomasi & Manduchi 1998]
- weight pixel contributions by
  - spatial distance between pixels
  - colour difference between pixels

Bilateral filter



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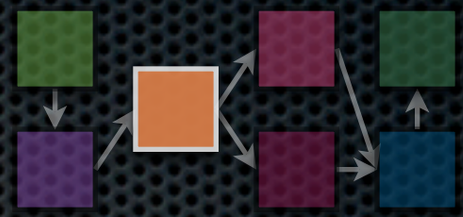
Bilateral filter



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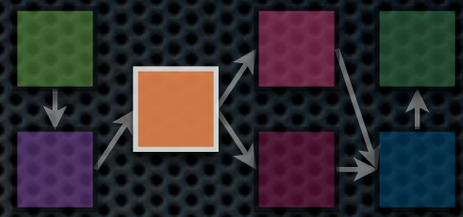
filtered pixel colour at $\mathbf{x}$

Bilateral filter



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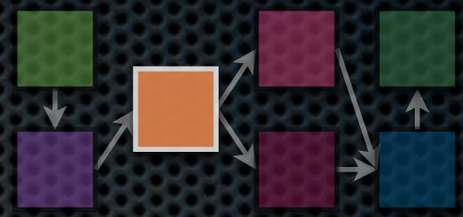
$I'(\mathbf{x})$: filtered pixel colour at **x**

$y \in N_x$: all pixels near **x**

Bilateral filter



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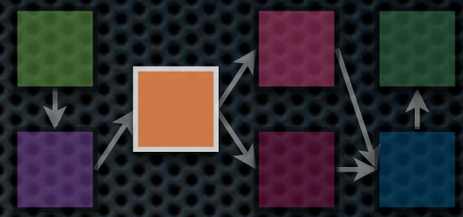
$I'(\mathbf{x})$: filtered pixel colour at **x**

$y \in N_x$: all pixels near **x**

$I(\mathbf{y})$: colour of pixel **y**

Bilateral filter



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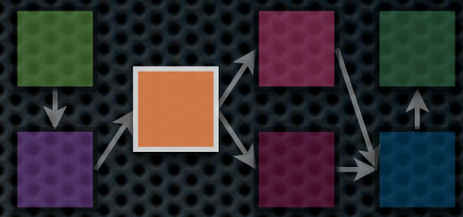
- $I'(\mathbf{x})$: filtered pixel colour at **x**
- $\mathbf{y} \in N_{\mathbf{x}}$: all pixels near **x**
- $G_{\sigma_s}(\|\mathbf{x} - \mathbf{y}\|)$: spatial distance
- $I(\mathbf{y})$: colour of pixel **y**

Bilateral filter



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filtered pixel colour at **x**

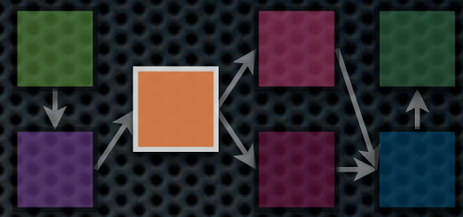
all pixels near **x**

colour distance

spatial distance

colour of pixel **y**

Bilateral filter



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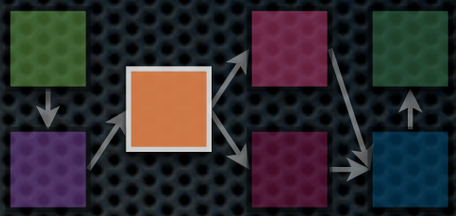
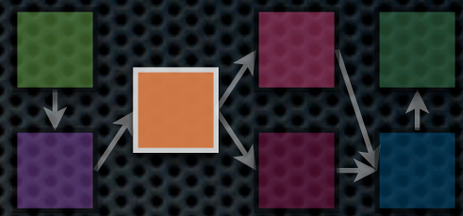
- $I'(\mathbf{x})$: filtered pixel colour at $\mathbf{x}$
- $\frac{1}{k}$: normalisation constant
- $\mathbf{y} \in N_\mathbf{x}$: all pixels near $\mathbf{x}$
- $G_{\sigma_r}(\Delta E(\mathbf{x}, \mathbf{y}))$: colour distance
- $G_{\sigma_s}(\|\mathbf{x} - \mathbf{y}\|)$: spatial distance
- $I(\mathbf{y})$: colour of pixel $\mathbf{y}$

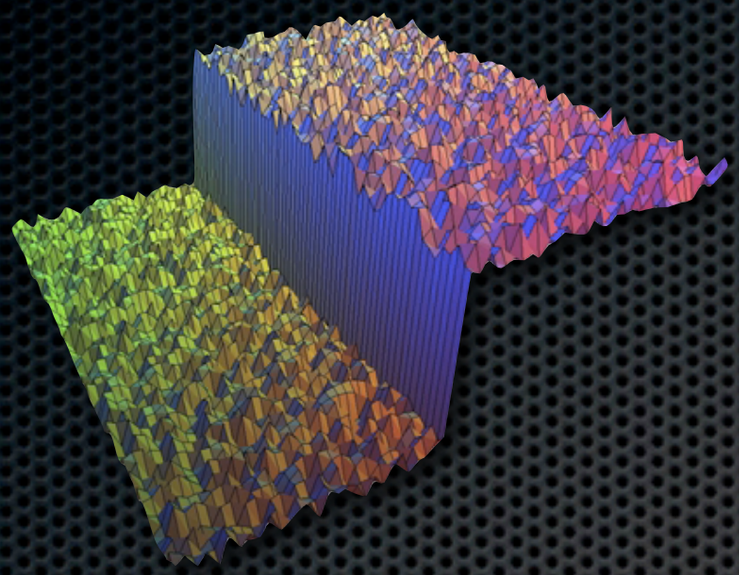
$$k = \sum_{\mathbf{y} \in N_\mathbf{x}} G_{\sigma_r}(\Delta E(\mathbf{x}, \mathbf{y})) \cdot G_{\sigma_s}(\|\mathbf{x} - \mathbf{y}\|)$$

Bilateral filter



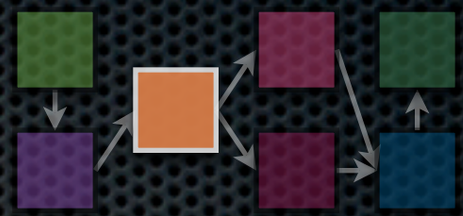
Bilateral filter

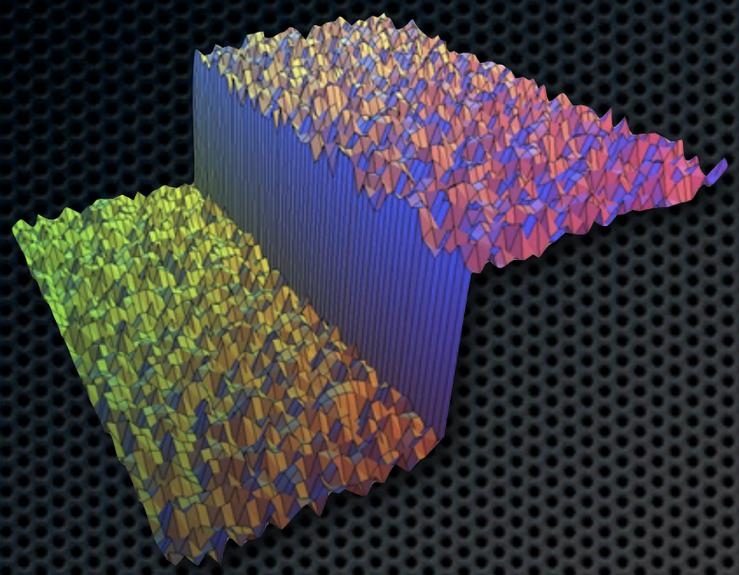




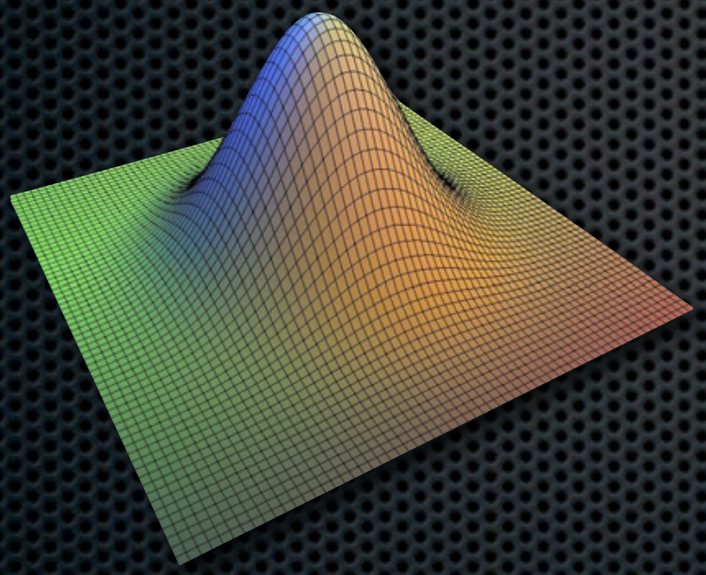
input image

Bilateral filter



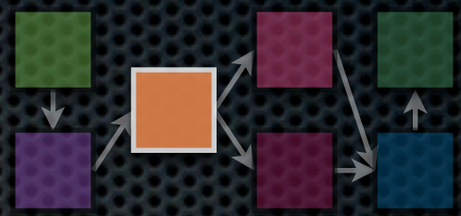


input image

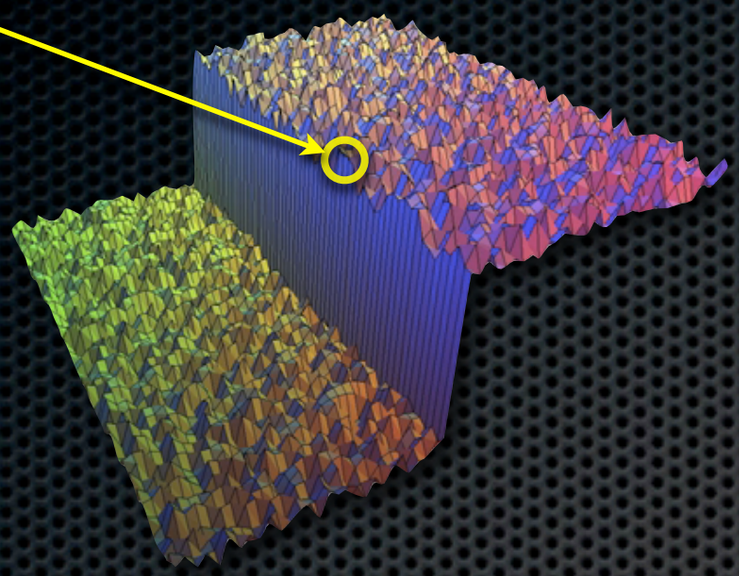


spatial filter

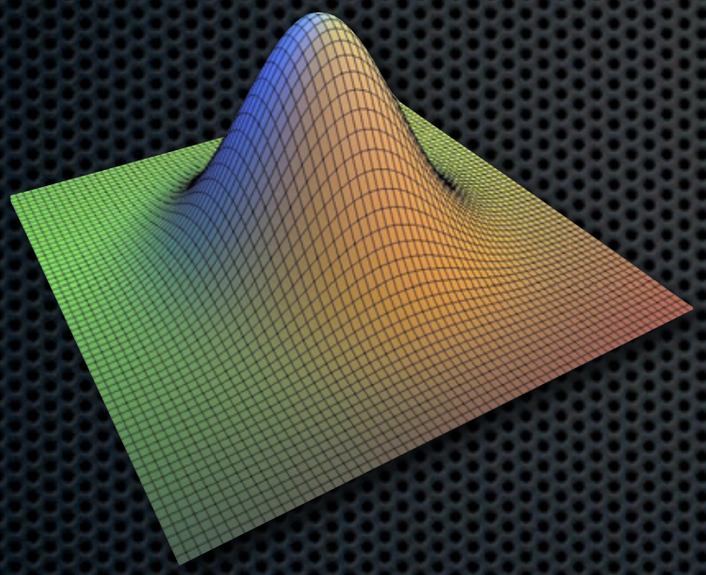
Bilateral filter



central pixel

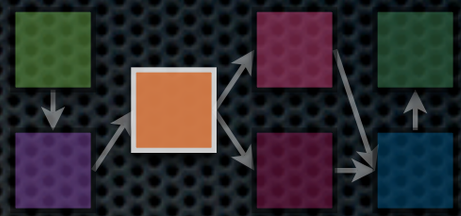


input image

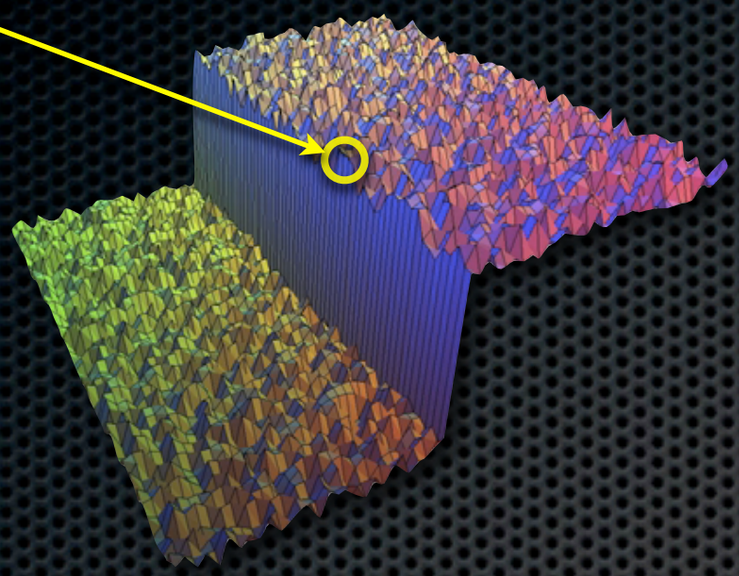


spatial filter

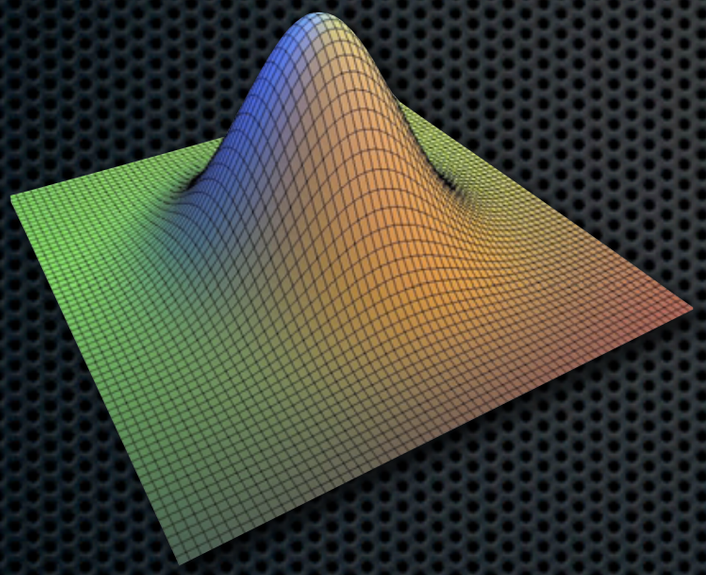
Bilateral filter



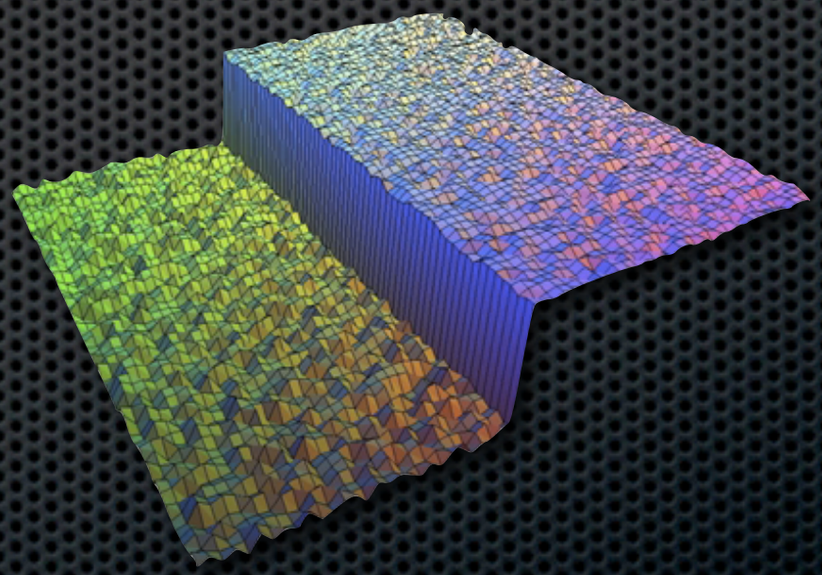
central pixel



input image

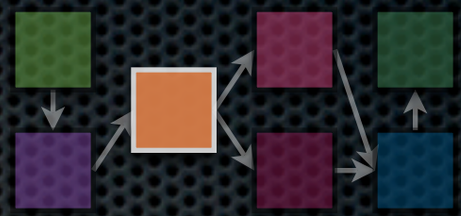


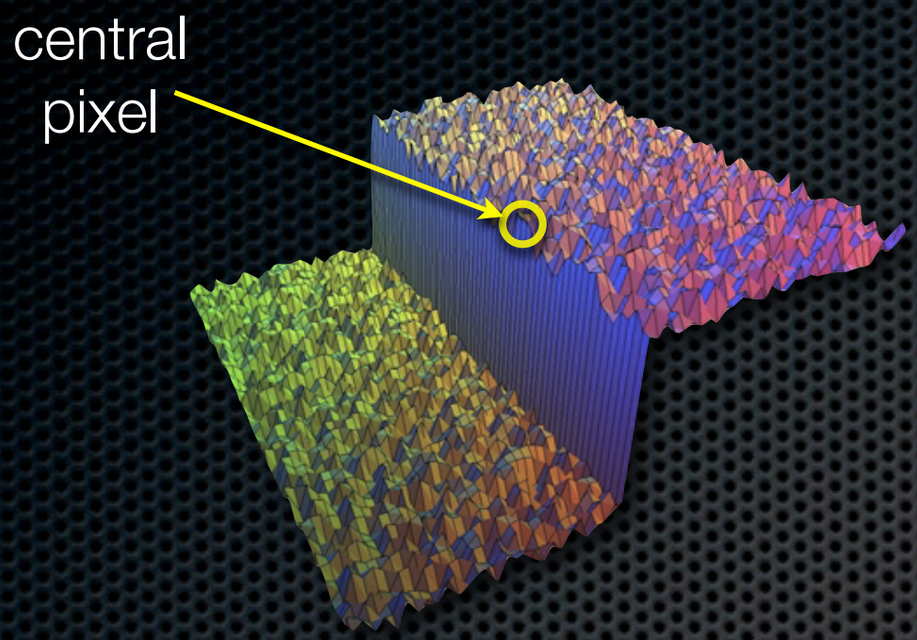
spatial filter

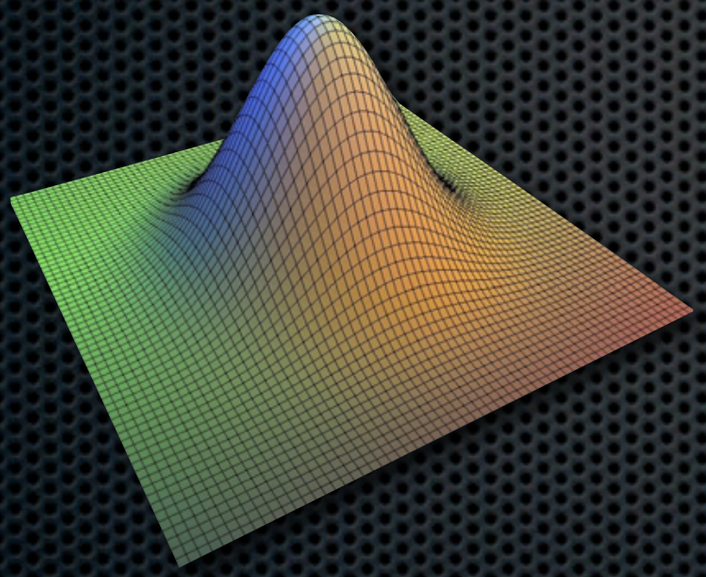


range weights
(for central pixel)

Bilateral filter

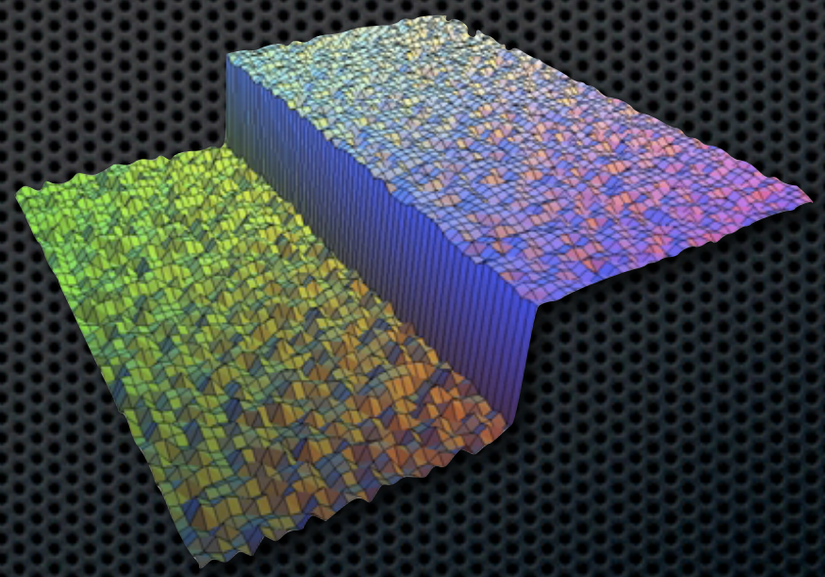






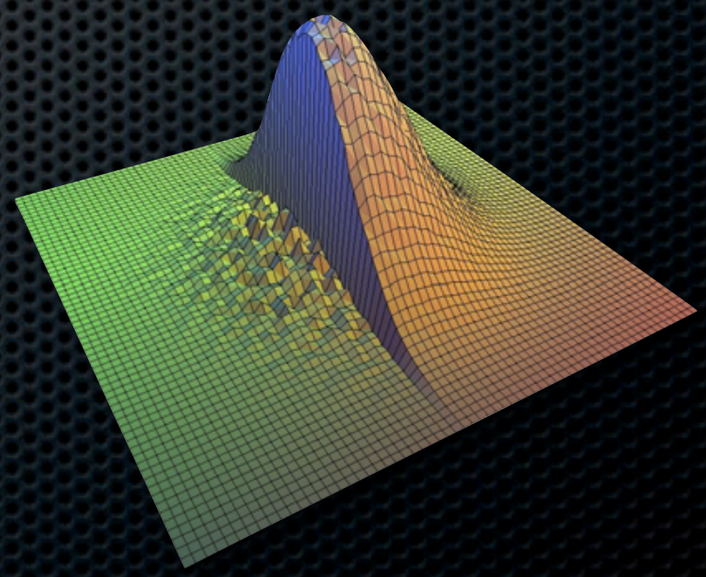
spatial filter

•



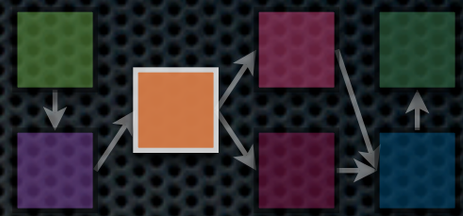
range weights
(for central pixel)

=



bilateral weights
(for central pixel)

Bilateral filter



central pixel

input image

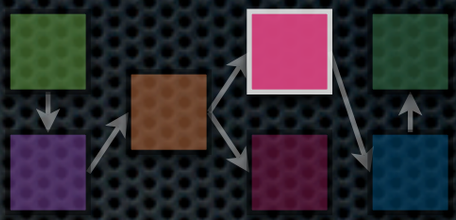
filtered image

spatial filter

range weights (for central pixel)

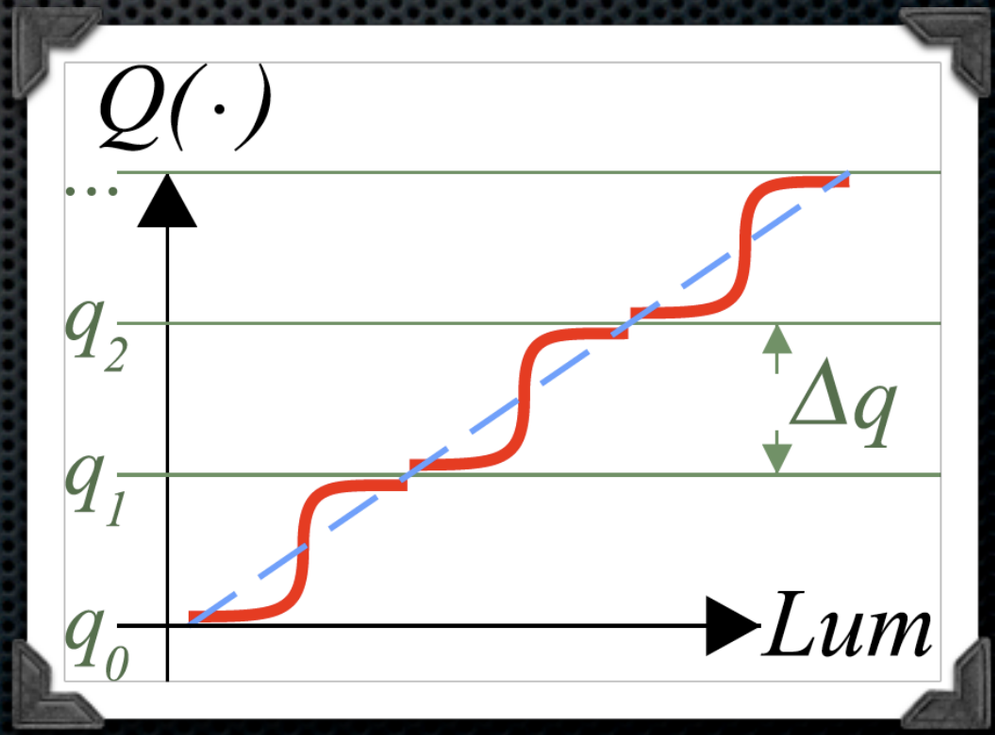
bilateral weights (for central pixel)

Luminance quantisation

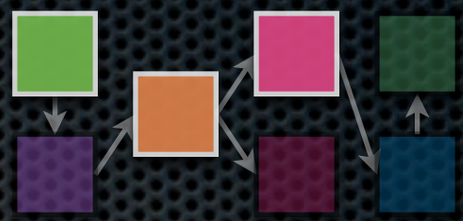


- colour quantisation for a cartoon-like effect
- but small changes in input can cause large changes in output: causes flickering, particularly in noisy videos

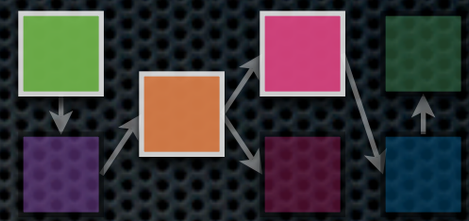
- solution: use soft quantisation
- can adapt sharpness according to luminance gradient in image
- hard boundaries only near strong gradients



Results so far

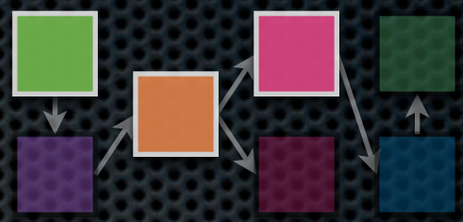


Results so far



input image

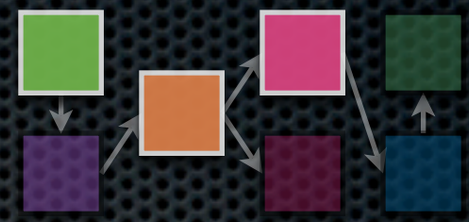
Results so far



input image

abstracted

Results so far

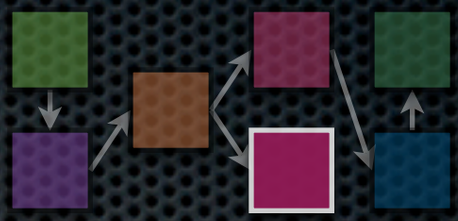


input image

abstracted

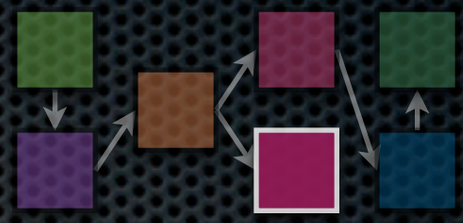
quantised

DoG edges



- DoG: difference of Gaussians
- approximation to human edge detection [Marr & Hildreth 1980]

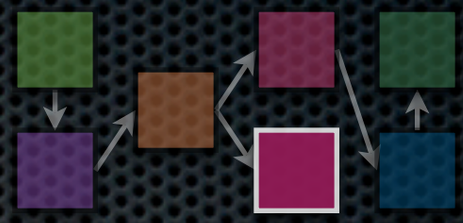
DoG edges



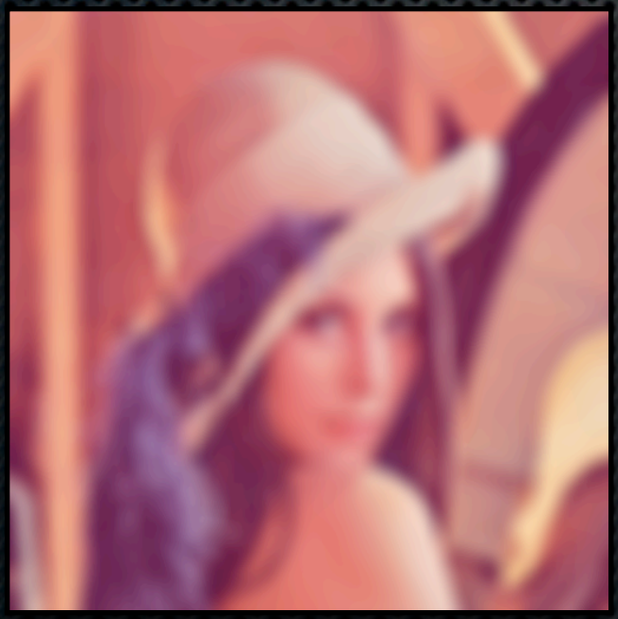
- DoG: difference of Gaussians
- approximation to human edge detection [Marr & Hildreth 1980]

input image

DoG edges



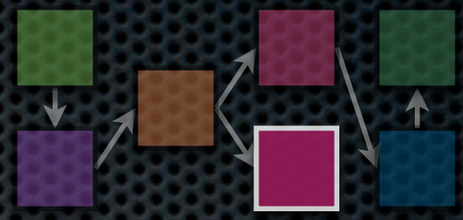
input image



Gaussian blur (σ=8)

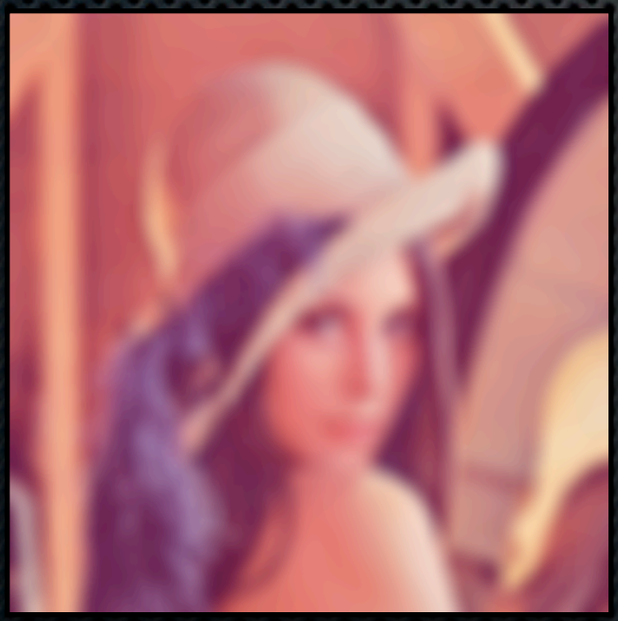
- DoG: difference of Gaussians
- approximation to human edge detection [Marr & Hildreth 1980]

DoG edges

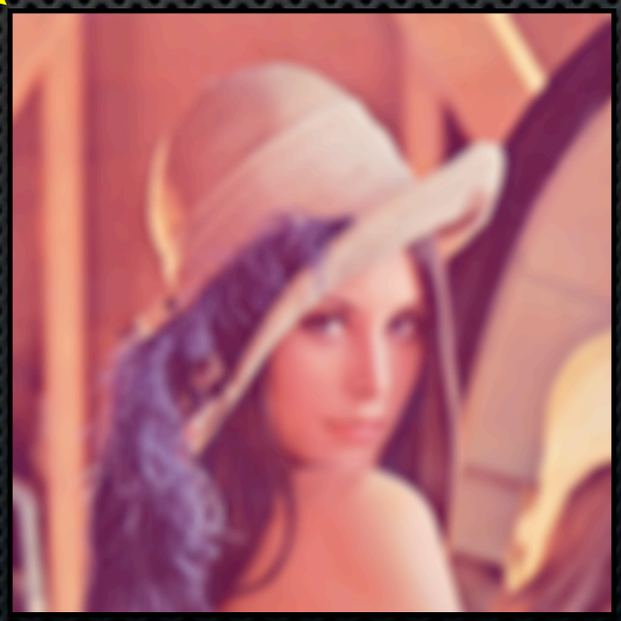


- DoG: difference of Gaussians
- approximation to human edge detection [Marr & Hildreth 1980]

input image

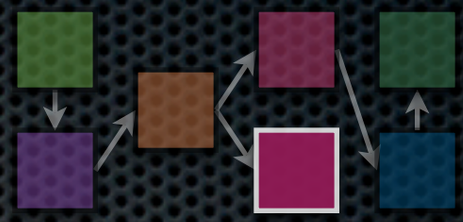


Gaussian blur (σ=8)



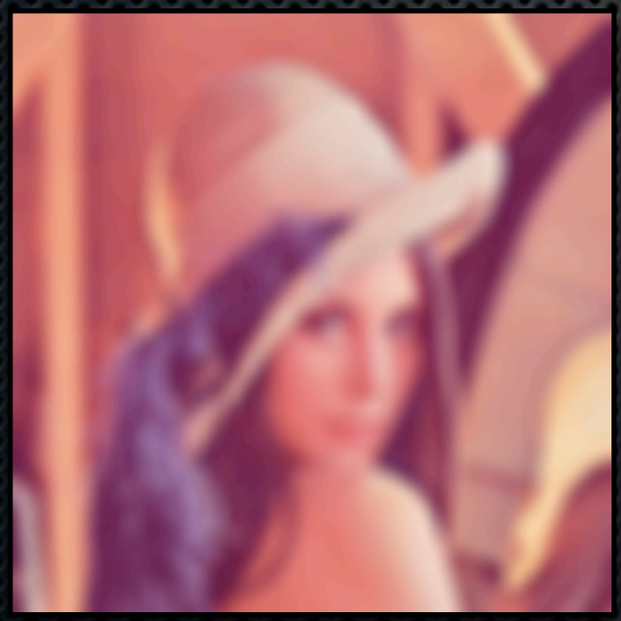
Gaussian blur (σ=5)

DoG edges



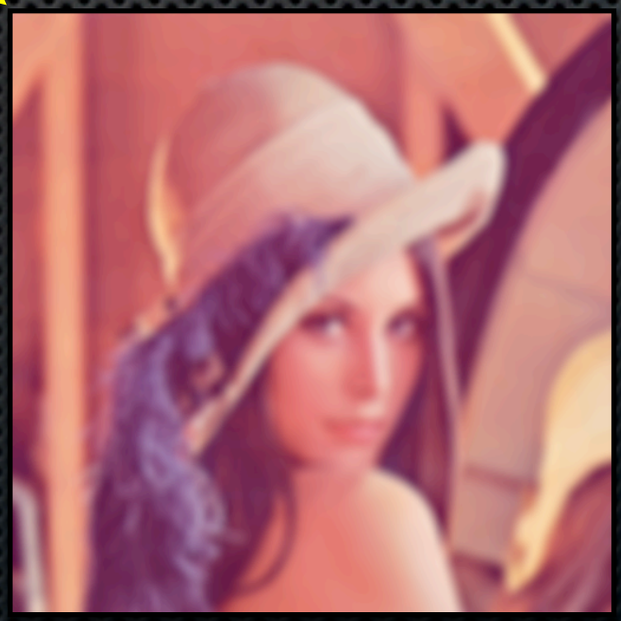
- DoG: difference of Gaussians
- approximation to human edge detection [Marr & Hildreth 1980]

input image



Gaussian blur (σ=8)

−

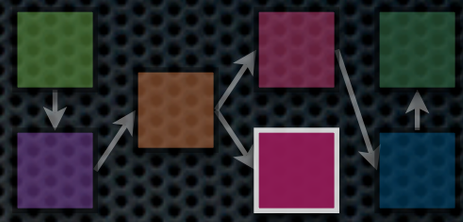


Gaussian blur (σ=5)

=

difference of Gaussians

DoG edges

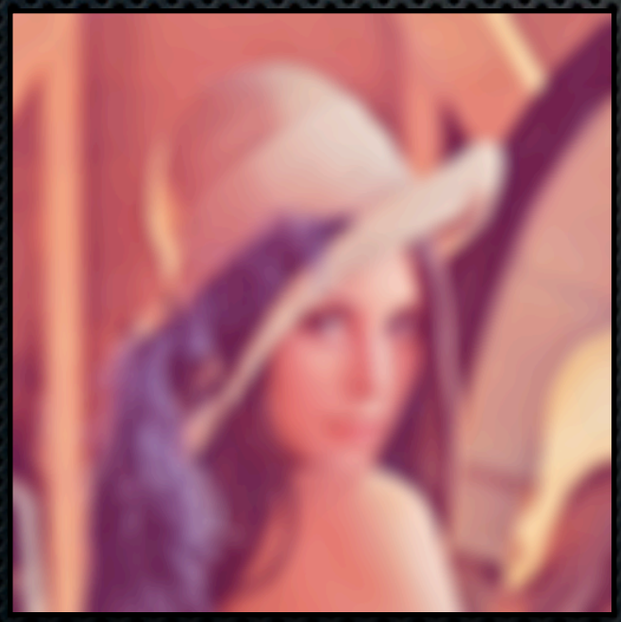


- DoG: difference of Gaussians
- approximation to human edge detection [Marr & Hildreth 1980]

input image

DoG edges

thresholding



Gaussian blur (σ=8)

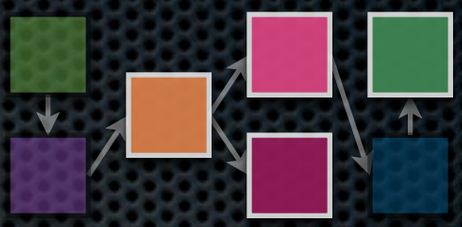
−

Gaussian blur (σ=5)

=

difference of Gaussians

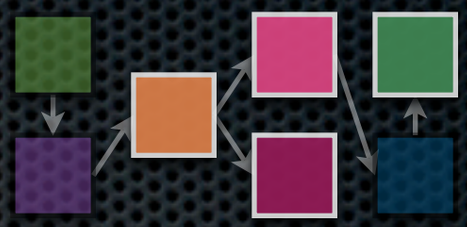
Final result

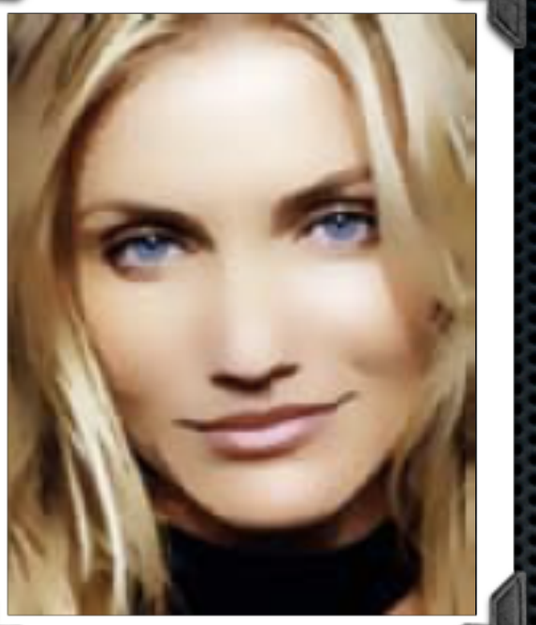


abstracted

abstracted + quantised

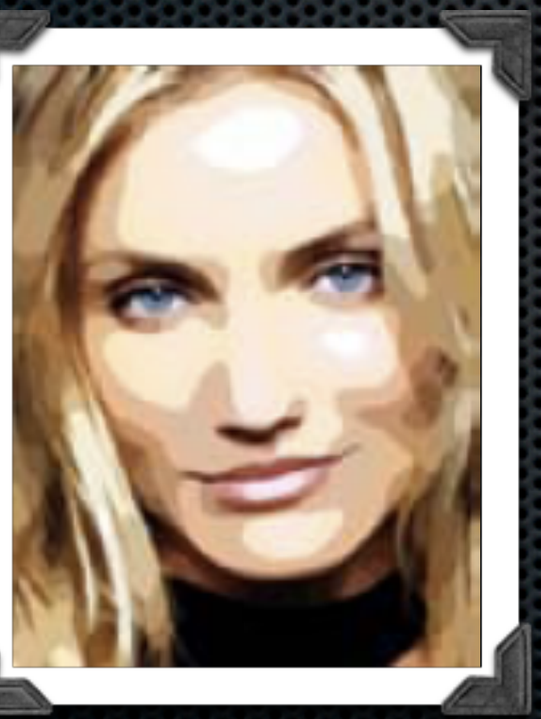
Final result





abstracted

DoG edges



abstracted + quantised

Final result

abstracted

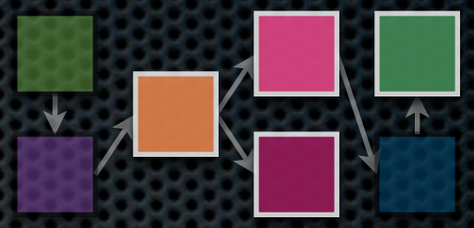
×

DoG edges

=

abstracted + quantised

Final result



abstracted

×

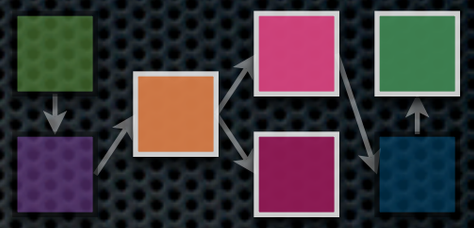
DoG edges

=

result (without quantisation)

abstracted + quantised

Final result



abstracted

×

DoG edges

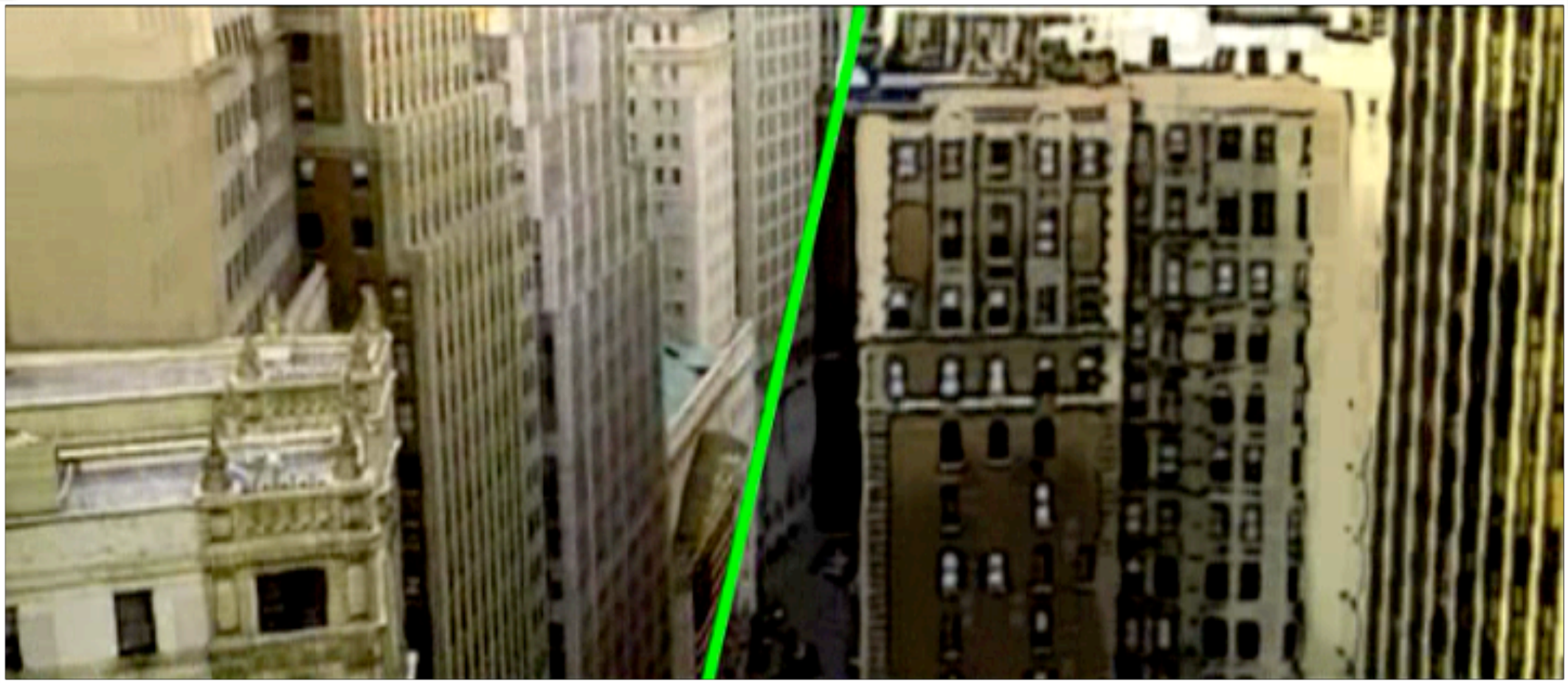
=

result (without quantisation)

abstracted + quantised

result (with quantisation)

Real-Time Video Abstraction



Winnemöller, Olsen & Gooch 2006

Summary

- Non-photorealistic rendering is an alternative to conventional, photorealistic computer graphics
- aims to make visual communication more effective
- also strives to (semi-)automatically create aesthetic results resembling a variety existing art styles
- main venue: annual symposion on Non-Photorealistic Animation and Rendering (NPAR)

Questions?