# Artistic Stylization of Images and Video

## Part II – Vision for Stylisation

Eurographics 2011

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# Higher Level Visual Analysis

- **Artistic Stylization pre-2000**
  - **Dependent on low-level image processing (e.g. Sobel) to drive preservation of local edge and high frequency content.**
- **An Artist does not paint a stroke by looking only at the image content under that stroke**
- **A higher level of visual analysis is needed:**

**Consider more than local edge information**

**Global analysis vs. greedy placement**

- **Computer Vision and Optimisation are solutions**

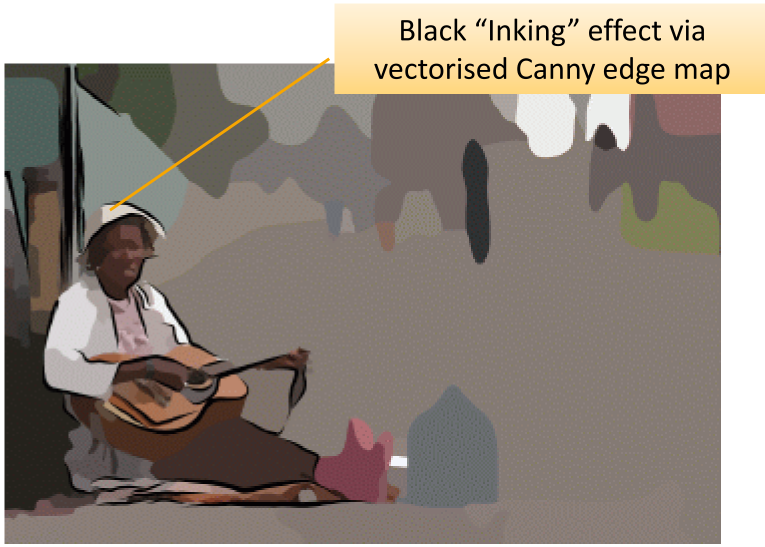
**Region-based discrimination**

Around the Cake (Thiebaud'62). Markup (Kolliopoulos '06)

# Stylization and Abstraction of Photographs

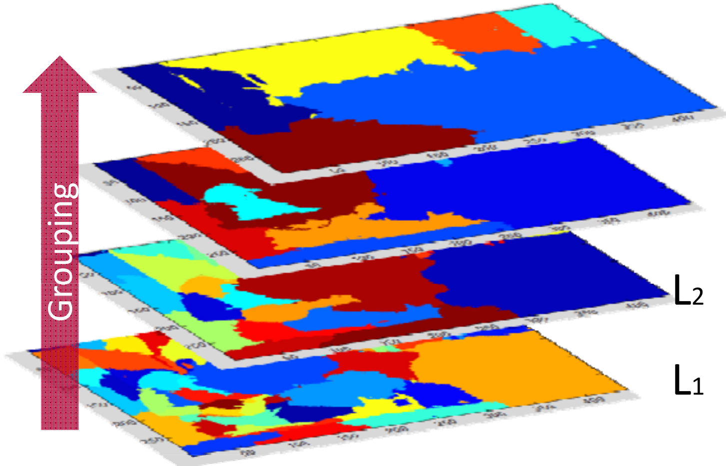
Decarlo and Santella. (2002)

- **Segmentation (EDISON / Mean-Shift)** [Christoudias et al, ICPR 2002]
  - **Create a spatial hierarchy of regions**
    - **Strokes painted in a region have same prominence**
    - **Or render regions flat with black edges to create ‘toon effect**
  - **Determine prominence of regions interactively**
    - **…using an eye tracker**

# Stylization and Abstraction of Photographs
## Implementation Steps

- **Segment levels of low-pass (Gaussian) pyramid**
  - **DeCarlo uses factor of $\sqrt{2}\sigma$ between layers**
  - **Discard regions < 500 pixels (on 640x480 image)**
- **Segments grouped into hierarchy from fine to coarse based on overlap and common colour**




1. For each* region A at the current level e.g. $L_1$
   2. Find the region $B_i$ in level above e.g. $L_2$ maximising:

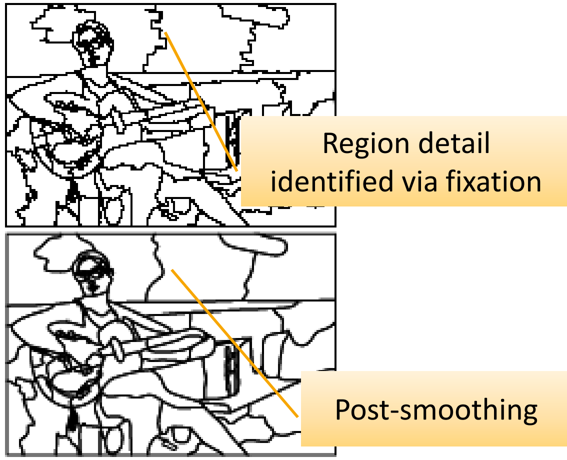
$$\text{overlap}(A, B_i) = \frac{\text{area}(A \cap B_i)}{\|\text{color}(A) - \text{color}(B_i)\| + 1}$$

   3. Assign A's parent to Bi, providing $A \cap B_i$ is contiguous+


*At step 1, iterate through regions in order of increasing area.
+ After all levels are processed, any orphan regions become children of root note.

# Stylization and Abstraction of Photographs

Decarlo and Santella. (2002)

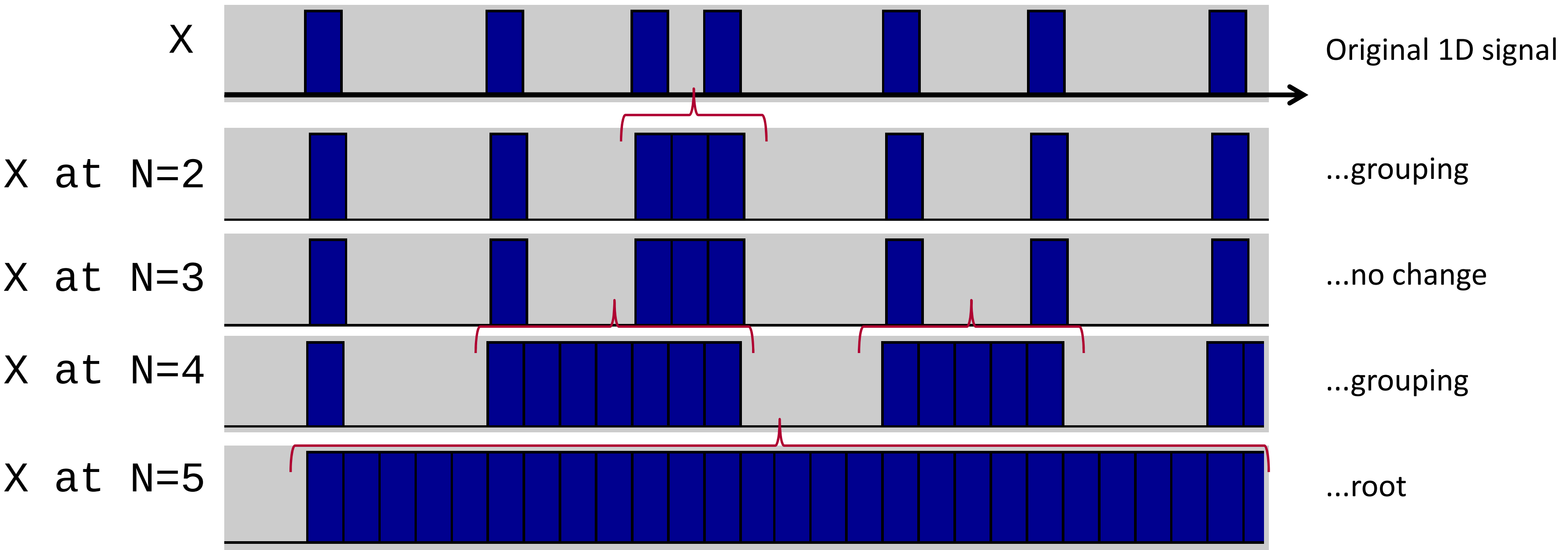



- **Painting starts at the coarsest level of region detail**
- **A region is split if more than half its children are fixated upon**
- **The resulting region map is noisy, but aesthetics improve after smoothing and vectorisation**

# Sieves
Bangham et al. (2003)

- **Alternative scale-space hierarchy using <u>sieves</u>**
  - **Morphological operations (closure followed by opening)**

```
X=imerode(imdilate(X,ones(1,N)),ones(1,N));
```



# The Art of Scale Space (Sieves)

Bangham et al. (2003)

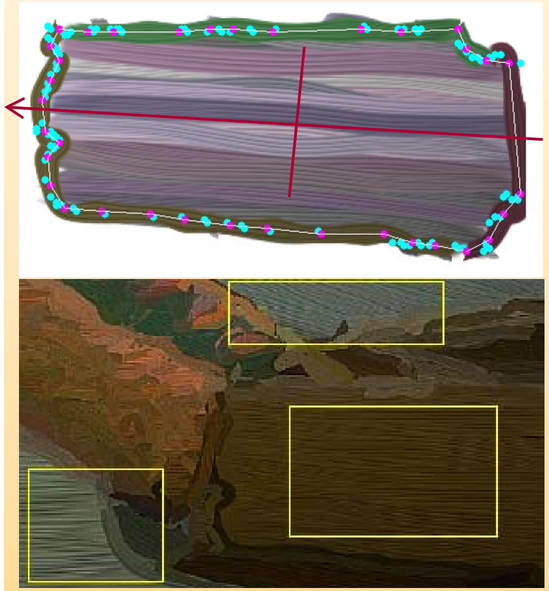
- **Sieves better preserve edges/corners vs. Gaussian**
  - Extended to 2D in [Bangham ‘99], NPR application [Bangham ’03]. Colour sieves (Harvey ‘04)

- Similar level of detail strategy to Decarlo/Santella can be applied to scale-space tree

# Region based Painting

- **Painting the regions**

**Paint via 3rd party algorithm e.g. Hertzmann with constant stroke size [Santella /DeCarlo NPAR'02]**



**Fill region with strokes in direction of principal axis [Shugrina et al, NPAR '06]**

**Fill with strokes in directions derived from region exterior contour [Wang et al, NPAR '10]**

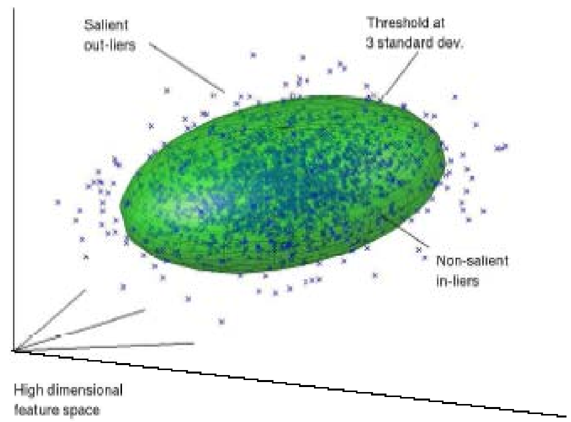
c.f. video painting...

# Genetic Paint: Search for Salient Paintings

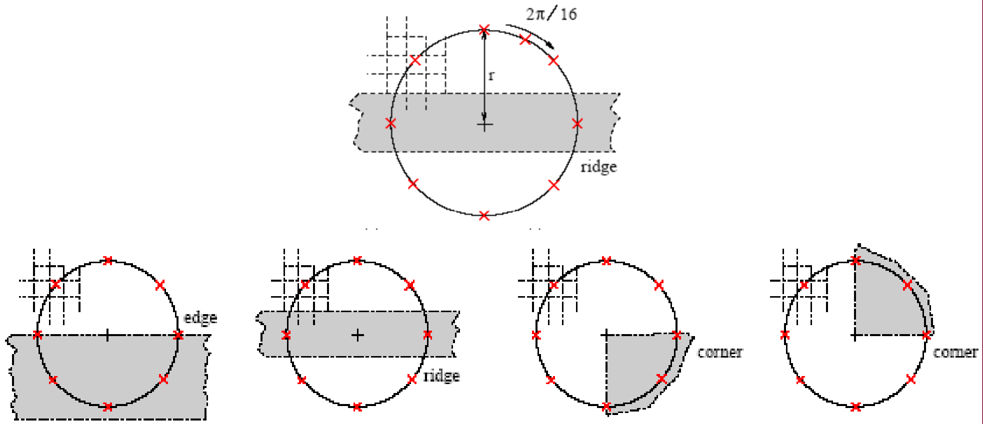
Collomosse et al. 2005.

- **Automated Differential Emphasis in Painting**
  - **Prescriptive salience measures [Itti & Koch]**
    - **Not closely correlated to human behaviour [Santella/DeCarlo NPAR'04]**
    - **Salience is subjective and task dependent**
  - **Trainable measure of salience (GMM of radial features)**

**Rarity & Visibility**



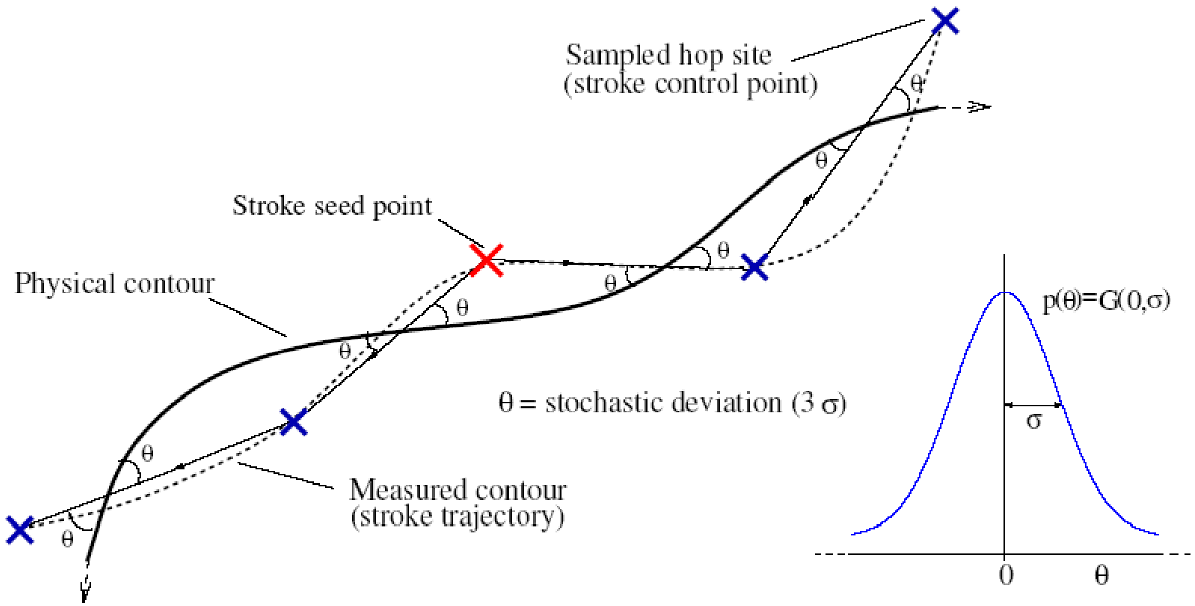

**Radial Features**

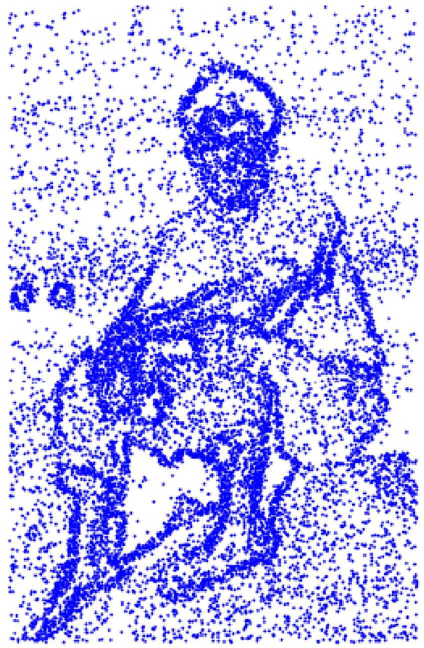


# Genetic Paint: Search for Salient Paintings

Collomosse et al. 2005.

- **Genetic Optimizaton to find “best” painting**
  - **<u>The optimal painting preserves detail in salient areas, and removes non-salient detail</u>**
  - **MSE between salience map and Sobel edge detail in the painting (c.f. Hertzmann ‘01)**

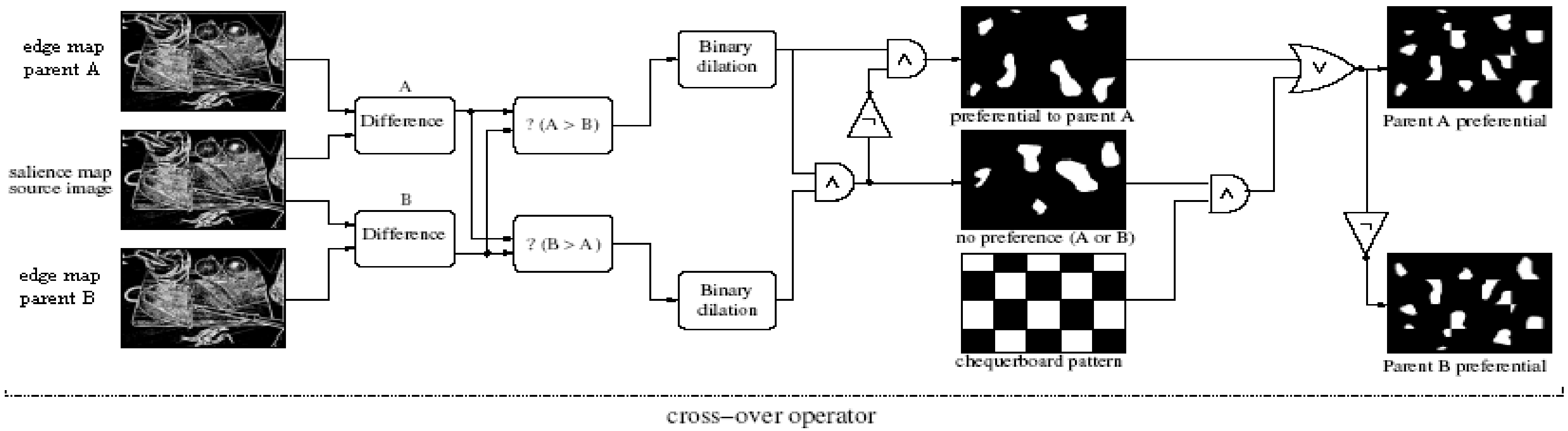


# Genetic Paint: Search for Salient Paintings

Collomosse et al. 2005.

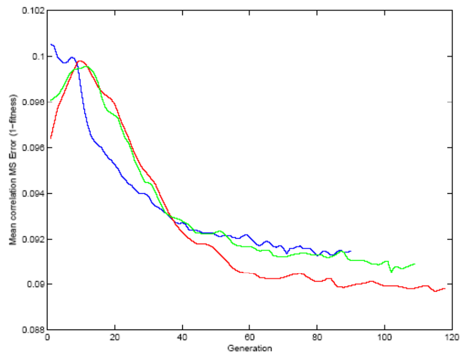
- Paintings are bred by cloning strokes from two individuals
- (Two parent cross-over)
  - fitness proportionate selection with replacement
- Promotion of rapid convergence
  - Top 10% carried over to next gen. automatically
  - Bottom 10% culled



# Genetic Paint: Search for Salient Paintings

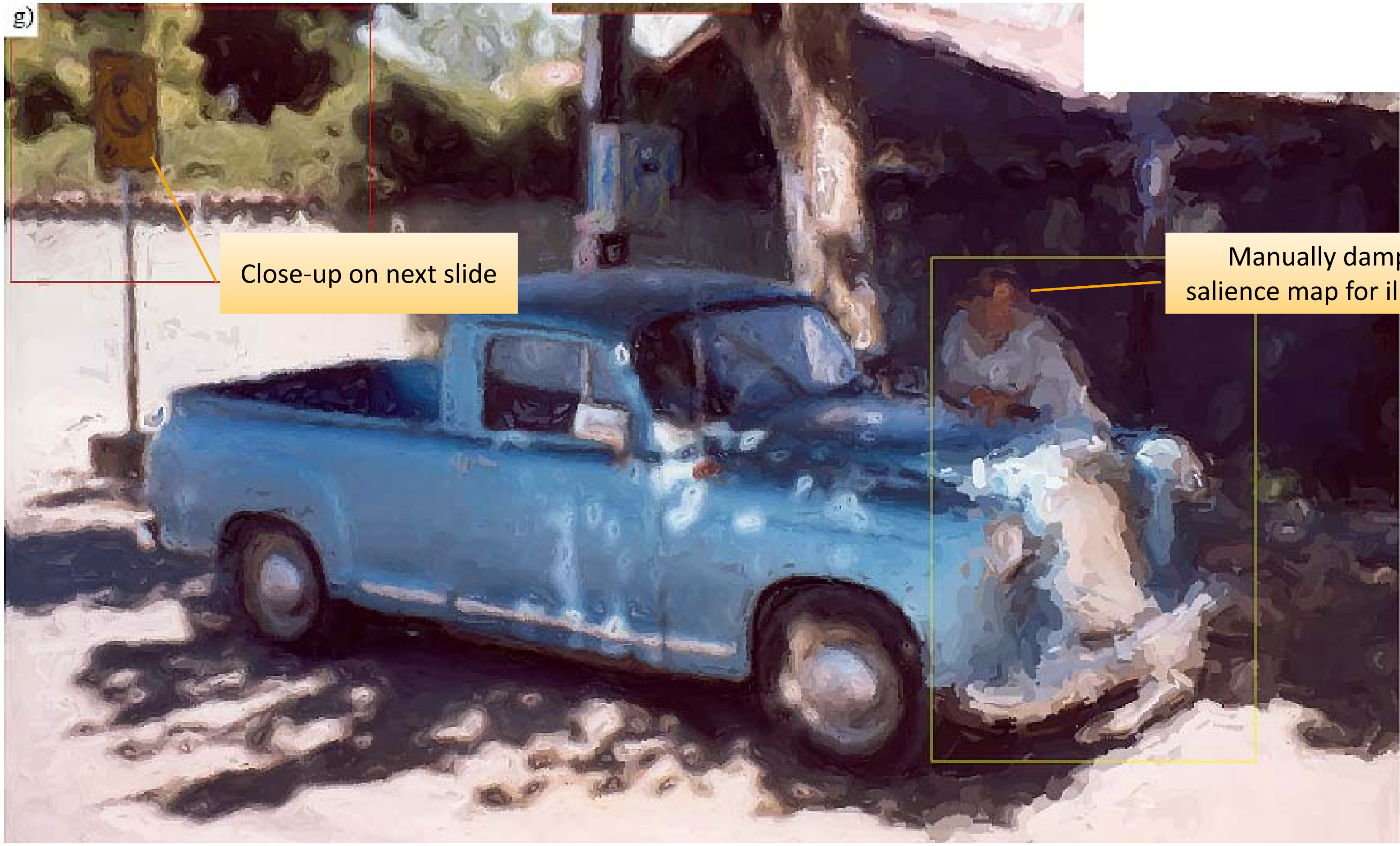
Collomosse et al. 2005.

- **Iterative optimization improves detail in salient regions**
  - **Population of ~50 paintings**
  - **Convergence in ~200 iterations**
  - **Stochastic variation in stroke attributes creates diversity**
  - **GA combines favourable regions of parent paintings**




# Genetic Paint: Search for Salient Paintings

Collomosse et al. 2005.



# Comparison of Salience vs. Edge based Painting

- **Comparison of Sobel-driven and Salience-driven painting**
  - **Detail on the sign is preferentially retained (wrt. Leaves of the tree)**
  - **Not all edges / high frequency texture are salient**

Original

Litwinowicz ‘97

Salience driven

# Painting Code

- **Painting research code available**
  - **http://www.collomosse.com/EG2011tut/summerschool.zip**

- **MATLAB based (experiment with different salience maps)**
- **Code adapted from Collomosse et al. 2005 – single iteration, spline strokes.**
- **Previously released as lab exercise at EPSRC VVG Summer School (2007)**

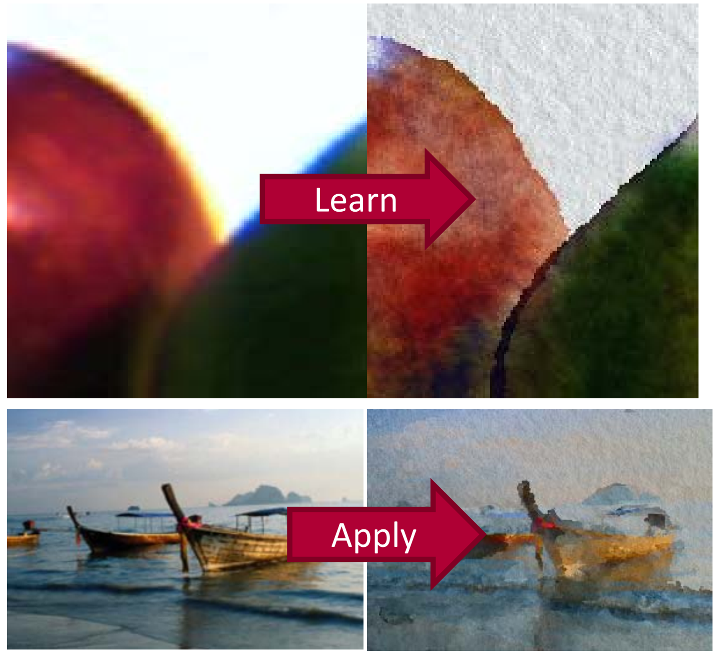
# Image Analogies

Hertzmann et al. (2001)

- **Style Transfer**
  - **Learning vs Heuristic approach to stylise photos**
  - **Patch based lookup (luminance only)**

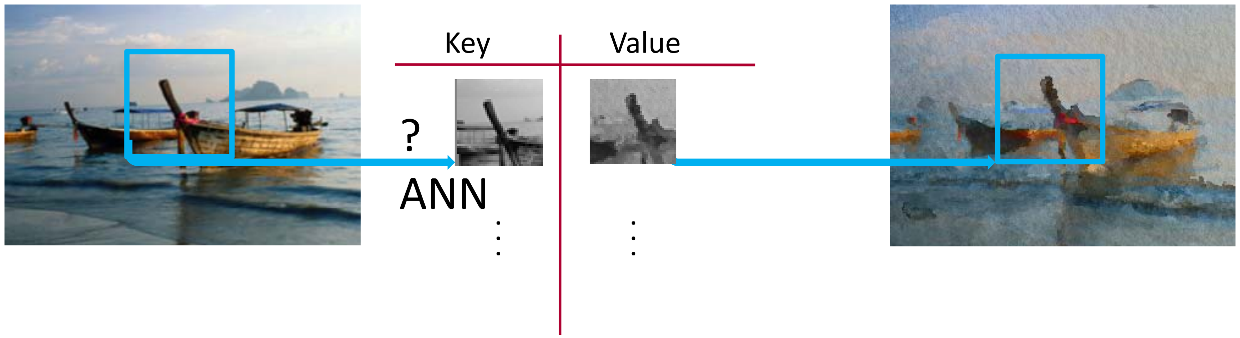
$$Y(p) \leftarrow \frac{\sigma_B}{\sigma_A}(Y(p) - \mu_A) + \mu_B$$

    - **Similar to Freeman texture synthesis but using external collection of patches**
    - **Learned as lookup table**




# Image Analogies
Hertzmann et al. (2001)

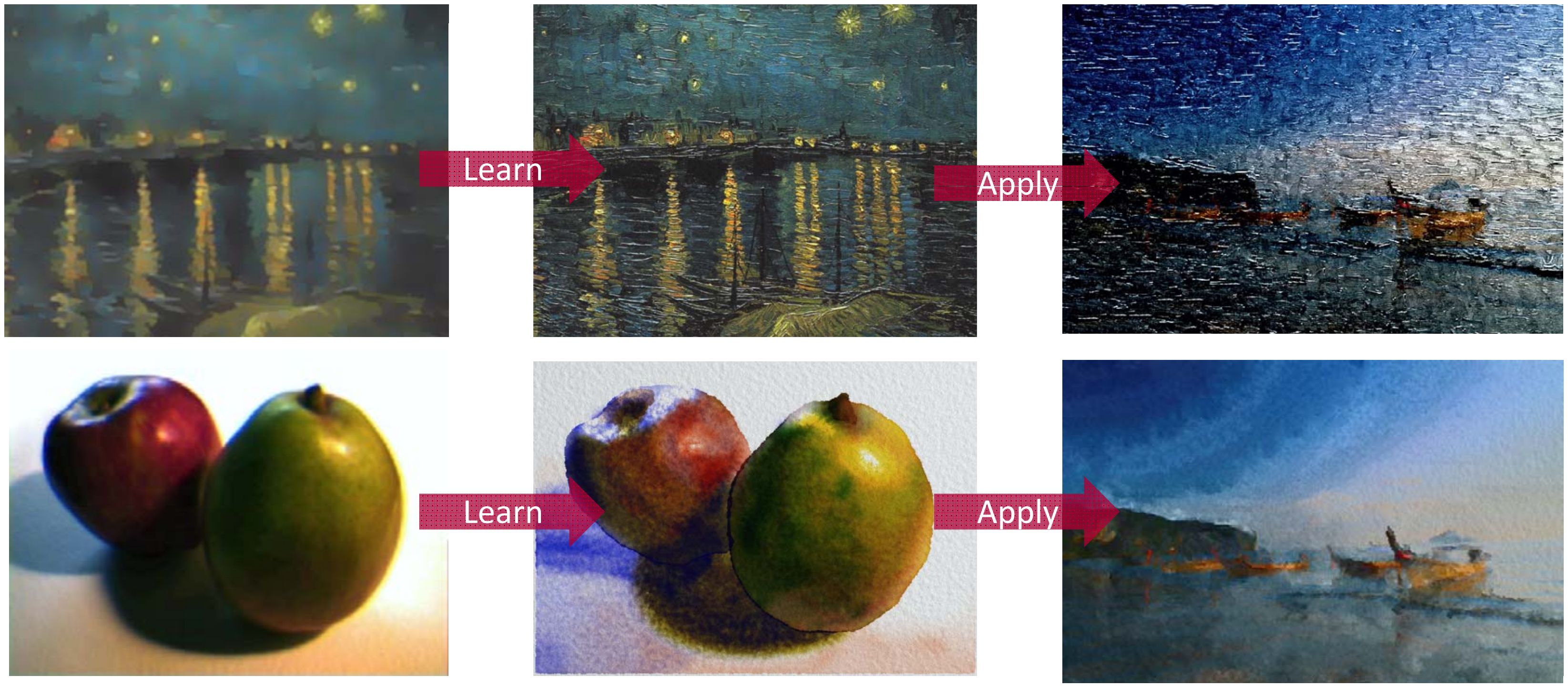
- **Style Transfer**
  - **Synthesis has ‘data’ and ‘smoothness’ terms**
    - **Data (patch lookup)**
      - **Pixel-wise luminance comparison (after PCA)**
    - **Smoothness (derived from Ashikhmin)**
      - **Minimise MSE between proposed patch and existing neighbours**
      - **Gaussian weighted distance function (avoids discontinuity)**



# Image Analogies

Hertzmann et al. (2001)

- **Style Transfer Examples**




- **Other extensions to video [Hors & Essa '02] and to take orientation into account [Lee et al. '10]**

# Video Painting

- **Video Stylisation**
  - **Techniques to create painterly animations or cartoons from video**
  - **Enabled by automated techniques for image stylization**

**Stylised Appearance**

**Stylised Motion**

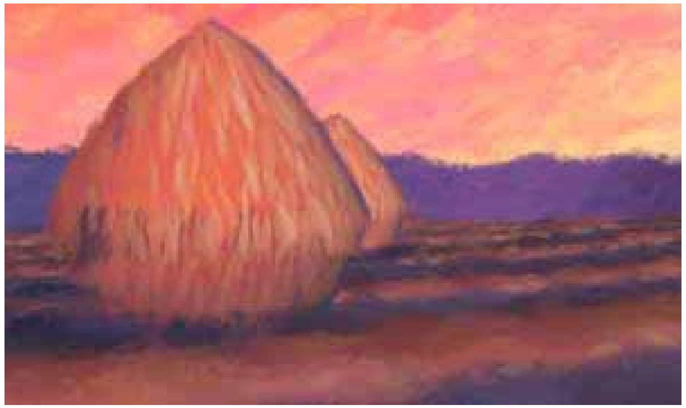
# Temporal Coherence

- **Goal of video stylization**
  - **Create the desired aesthetic exhibiting good <u>temporal coherence</u>**
- **Temporal coherence is here defined as:**
  1. **Absence of distracting flicker**
  2. **Motion of brush strokes (or other component marks) is in agreement with the motion of content**
- **Naïve approaches**
  - **Repaint every frame independently**

    **= *Flicker (violates 1.)***
  - **Fix strokes in place and change attributes e.g. colour according to video content**

    **= *Motion unmatched (violates 2.)***

    ***"the shower door effect" – Barb Meier***



Meier '96

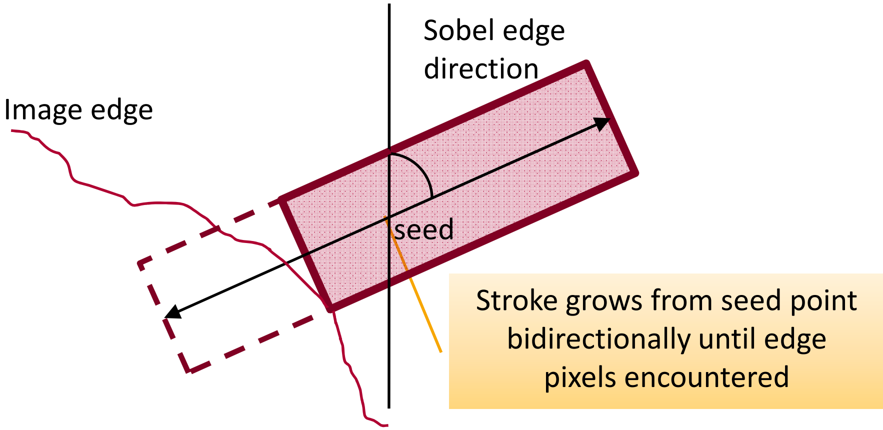
# Processing Images & Video for Impressionist Effect

Litwinowicz (1997)

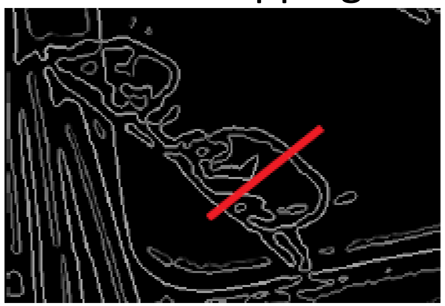
- **Painterly animation using Optical Flow**
  - **Brush strokes are pushed from frame to frame using flow estimate**
  - **Oscar winning visual effects in movie "What Dreams May Come" (1998)**
    - **Manual correction of flow estimate (~1000 person-hours [Green'99])**

# Processing Images & Video for Impressionist Effect

Litwinowicz (1997)




No clipping



Clipping

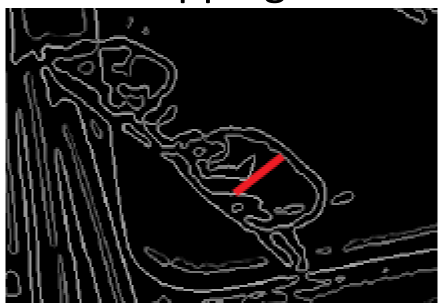




Photo credit: Litwinowicz '97

# Processing Images & Video for Impressionist Effect

Litwinowicz (1997)

- **Initialisation as per single image (regular seeding)**
  - Randomise rendering order of strokes
- **Strokes translated to next frame via flow field**
- **Greedy approximation to avoid irregular coverage**
  - Delaunay triangulation of seeds (and image corners)
  - **Death.** Seeds too close together are deleted
    - Tested in random order
  - **Birth.** Triangles with area > threshold are subdivided
    - New seeds are randomly place rendering order

Photo credit: Litwinowicz '97

# Processing Images & Video for Impressionist Effect

Litwinowicz (1997)

- **Stroke Birth**

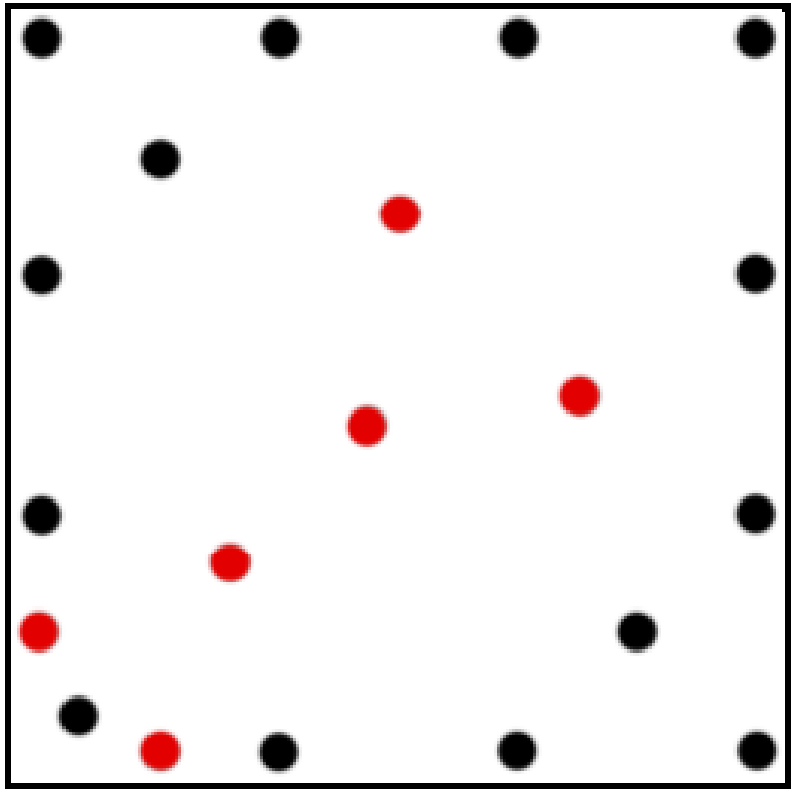




Photo credit: Litwinowicz '97

# Processing Images & Video for Impressionist Effect

Litwinowicz (1997)

- **Tips on reducing flicker**
  - **Detect your own scene cuts and reinitialise**
  - **Use a robust Optical Flow algorithm (!)**
    - **e.g. SIFTFlow or Brox**
  - **Pre-filter heavily (Gaussian).  Care with interlaced content.**
  - **Interpolate orientations from strong edges only**
    - **Smooths out codec noise**
    - **Litwinowicz uses thin-plate spline (expensive) but can use Poisson filling (fast on GPU) to good effect**

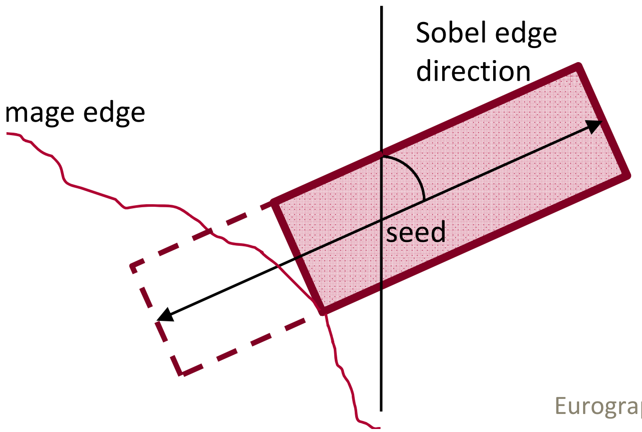








Photo credit: Litwinowicz ‘97

# Processing Images & Video for Impressionist Effect

Litwinowicz (1997)

- **Main sources of temporal incoherence**
- **Motion matching**
  - **Optical Flow = visual correspondence problem**
  - **Inevitable inaccuracies in estimate are cumulative**
  - **Content appears to slip below strokes = shower door effect**
    - **Manual correction of OF mitigates this but is expensive**
- **Flicker**
  - **Random order of new strokes disguises regularity**
    - **…but the noise generates flicker**
  - **Sudden disappearance of strokes exposes others = popping**
  - **Sobel edges are noisy at moderate scales**
    - **Strokes are clipped against flicking edge map**

# Improving the Coherence of Flow-based Schemes

- **Main sources of temporal incoherence**
- **Motion matching**
  - **Optical Flow = visual correspondence problem**
  - **Inevitable inaccuracies in estimate are cumulative**
  - **Content appears to slip below strokes = shower door effect**
    - **Manual correction of OF mitigates this but is expensive**
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    - **Strokes are clipped against flicking edge map**

<u>Addressed by</u>

Hertzmann and Perlin
NPAR 2000

Hays and Essa
NPAR 2004

# Painterly Rendering for Video and Interaction

Hertzmann and Perlin (2000)

- **Repaint only the areas that change significantly**
  - **Fast – enables realtime interaction**
  - **Limits shower-door by repainting limited regions of canvas ("paint-over")**
- **RGB Difference to detect regions**
  - **Optical flow *optionally* used to translate strokes**

$$\frac{1}{|M|}\sum_{(i,j)\in M}||I_{t+1}(i,j)-I_t(i,j)||>T_V$$

- **Control points shifted under flow**

# Paint-Over

Hertzmann '00

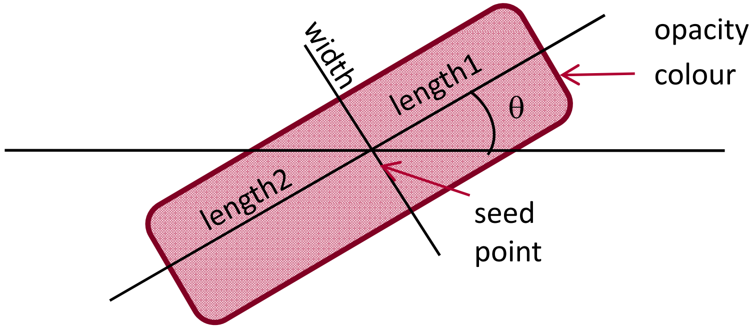
# Paint-Over and Optical Flow

Hertzmann '00

# Image and Video-based Painterly Animation

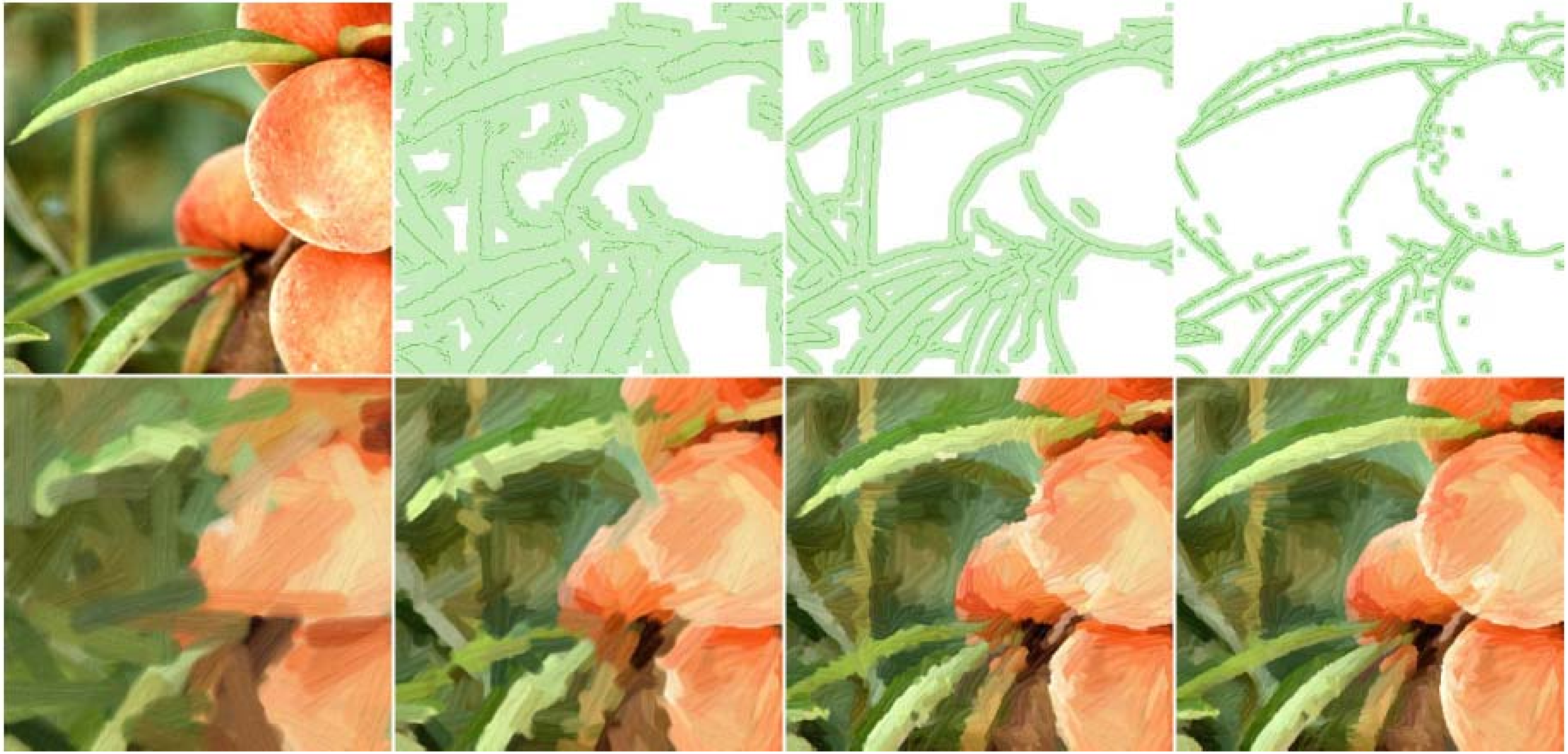
Hayes & Essa (2004)

- **Key Innovation**
  - **Temporal smoothing of stroke attributes**
- **Stroke Opacity for birth/death**
- **Orientation**
  - **RBF interpolated field (similar to Litwinowicz)**
  - **But interpolated from strokes marked "strong"** ***not from per-frame orientation field***
    - **Strokes born on strong edges**
- **Length and orientation are also smoothed**




# Image and Video-based Painterly Animation

Hayes & Essa (2004)



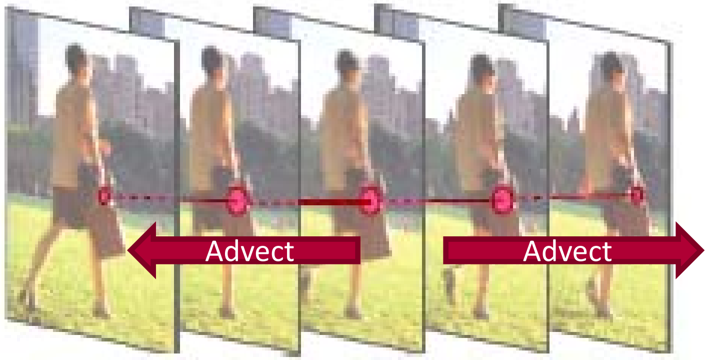
# Image and Video-based Painterly Animation

Hayes & Essa (2004)

# Video Watercolorization by bi-directional advecation

Boisseau et al. (2007)

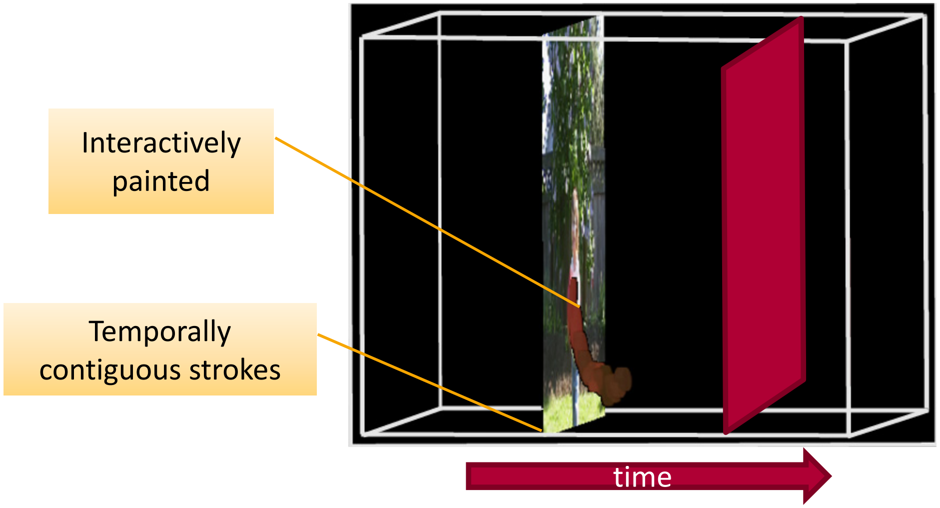
- **Bi-Directional Flow (of textures vs. strokes)**
  - **Adaptation of “Texture advection” from flow visualisation**
  - **Frequent occlusions in video motivated bi-directional flow**
    - **Two textures seeded – one flows forward, one back**



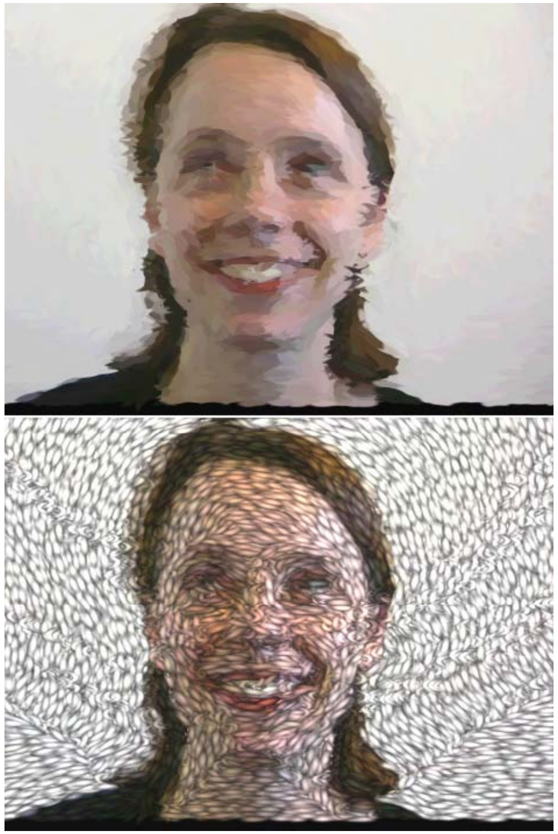

- **Trend towards more global temporal analysis**

# Video Cubism
Klein et al. (2002)

- **Temporally local (inter-frame) approaches**
  - No long-view of video structure
    - necessitates averaging of past information
    - Averaging mitigates flicker but exaggerates the shower door effect
- **Spatio-temporal primitives**




timeslice



# Space-time Segmentation for Video Stylisation

- **Automated Space-time Analysis**
  - **Goal is coherent segmentation of video into semantic regions**
  - **Coherent space-time regions are smoothed then do not flicker**

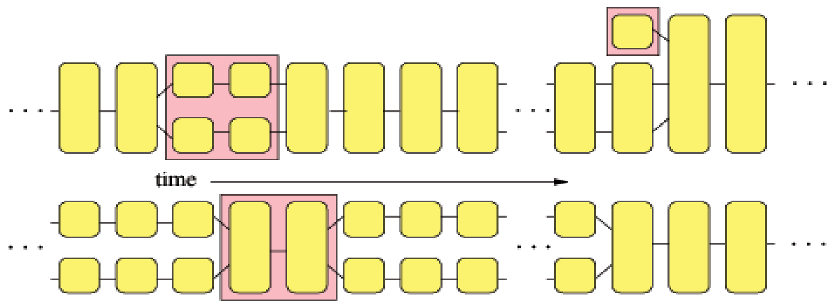
**Extending Mean-shift to Space-time (3D)**

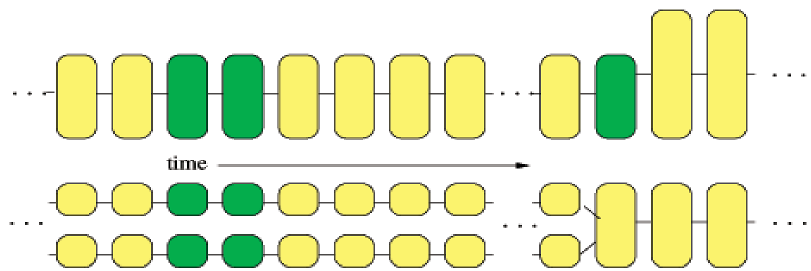
**EDISON segment frames and associate (2D+t)**

# Stroke Surfaces: Coherent Artistic Animations from Video

Collomosse et al. (2005)

- **Region association (2D+t)**
  - **Based on a weighted blend of heuristics**
    - **Shape (Fourier Descriptors)**
    - **Colour**
    - **Overlap (as DeCarlo/Santella)**
  - **Associations are filtered by locating**
    - **Short-time branches**
    - **Short-time cycles**
  - **Surface voxels between volumes are identified**
  - **Surfaces fragmented into "stroke surfaces" that abut only two volumes**

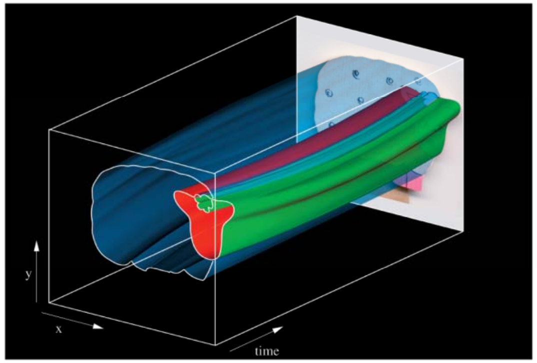


# Stroke Surfaces: Coherent Artistic Animations from Video

Collomosse et al. (2005)

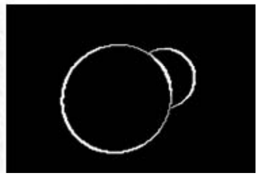
- **"Stroke Surfaces" separate volumes**
  - **Winged edge structure**
  - **Smoothing the surface smoothes the volumes**
    - **Generalisation of snakes to 2D surfaces**
    - **Separate terms for spatial and temporal constraint**




$$E = \int_0^1 \int_0^1 (E_{int}[\underline{Q}(s,t)] + E_{ext}[\underline{Q}(s,t)])\mathrm{d}s\mathrm{d}t.$$

$$E_{int} = \alpha\left|\frac{\partial \underline{Q}(s,t)}{\partial s}\right|^2 + \beta\left|\frac{\partial \underline{Q}(s,t)}{\partial t}\right|^2 + \gamma\left|\frac{\partial^2 \underline{Q}(s,t)}{\partial s^2}\right|^2 + \delta\left|\frac{\partial^2 \underline{Q}(s,t)}{\partial t^2}\right|^2$$

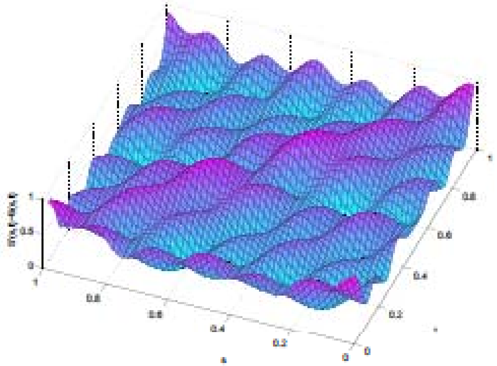
$$E_{ext} = \eta f(\underline{Q}(s,t)).$$

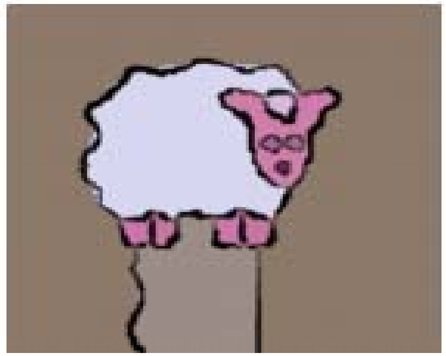


# Stroke Surfaces: Coherent Artistic Animations from Video

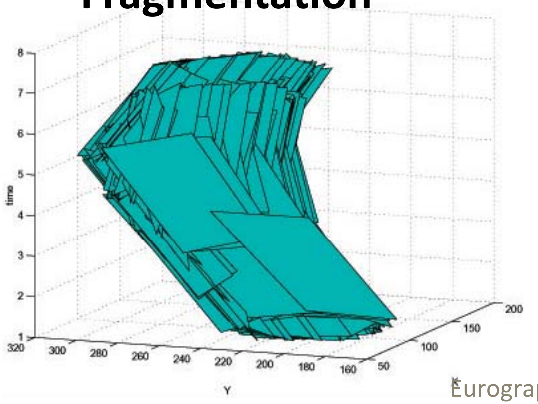
Collomosse et al. (2005)

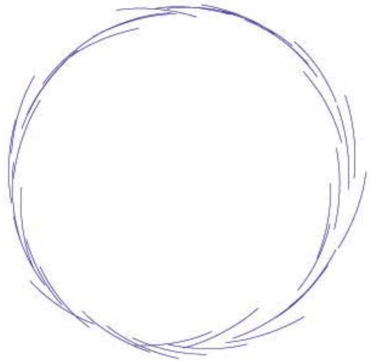
- **Surface Manipulation**
  - **Undulation**

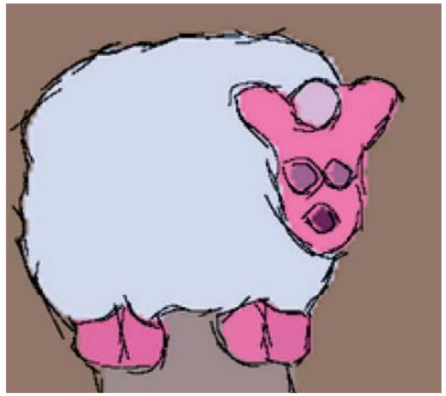




  - **Fragmentation**

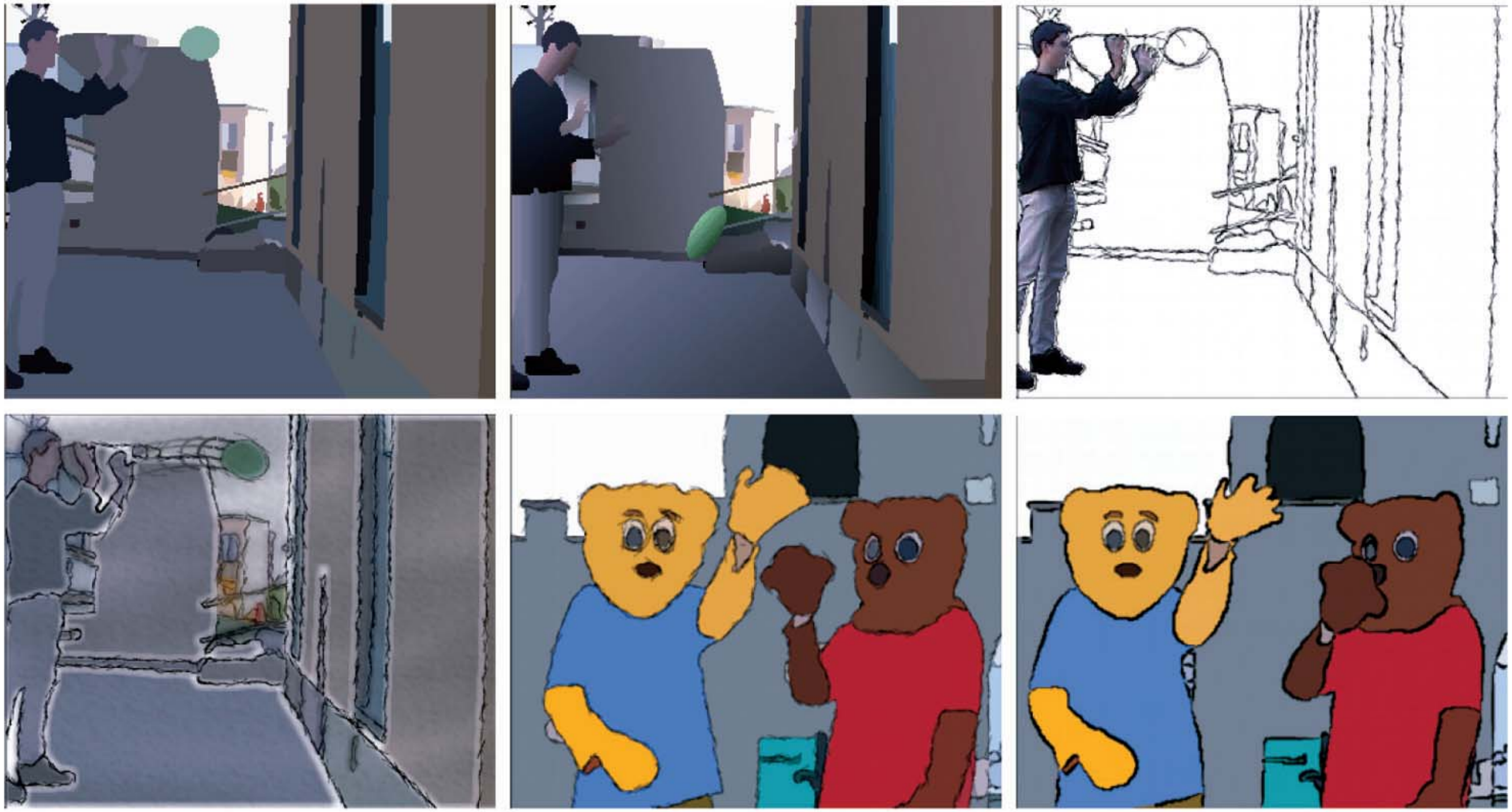






# Stroke Surfaces: Coherent Artistic Animations from Video

Collomosse et al. (2005)



# Stroke Surfaces: Coherent Artistic Animations from Video

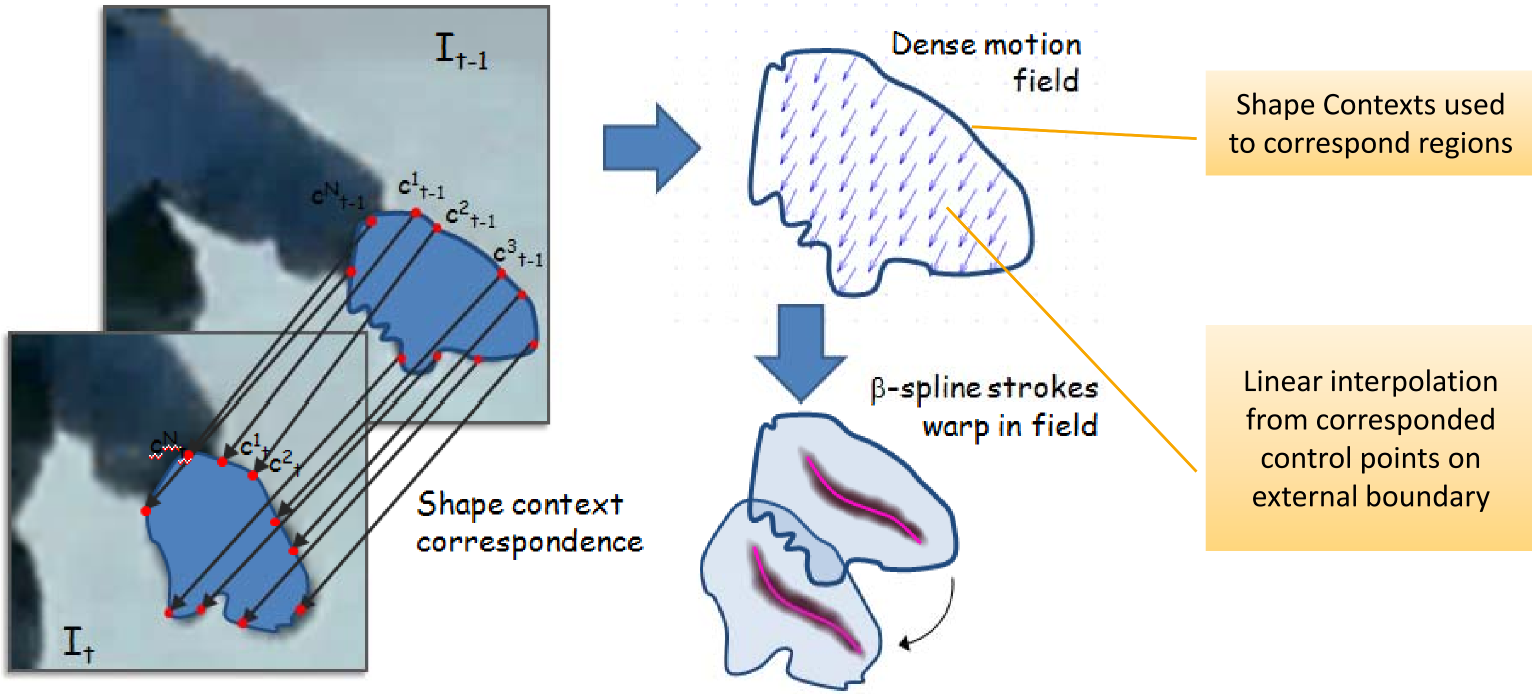
Collomosse et al. (2005)

- **Coherent Segmentation**

# Rotoscoping for Painterly Rendering

Agarwala et al. (2004)

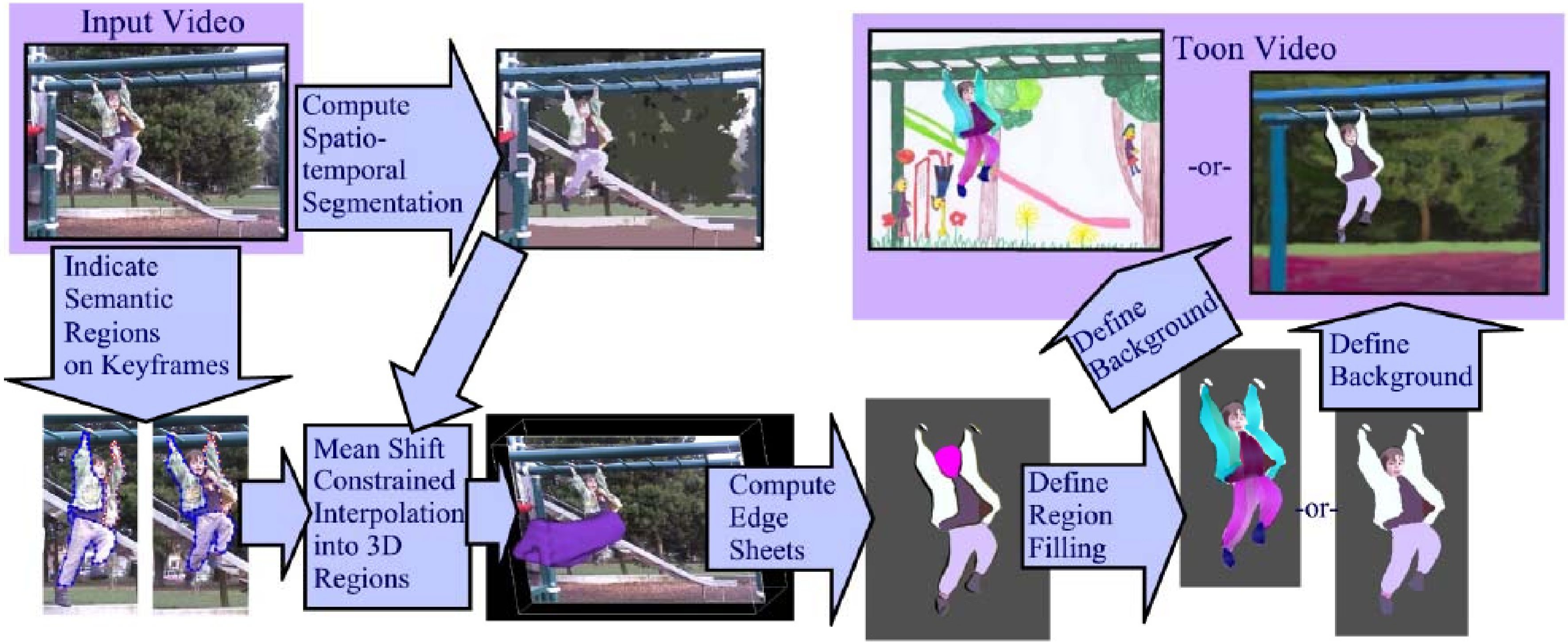
- **Rotoscoping**
  - **Coherent motion of (groups of) regions can be exploited to paint coherently**
  - **Interpolate internal points (e.g. stroke seeds) from region boundary**



# Video Tooning

Wang et al. (2004)

- **Rotoscoping**



# Video Tooning
Wang et al. (2004)

- **Rotoscoping**
  - **Coherent motion of (groups of) regions can be exploited to paint coherently**

# Cartoon Style Rendering of Motion

Collomosse et al. (2003)

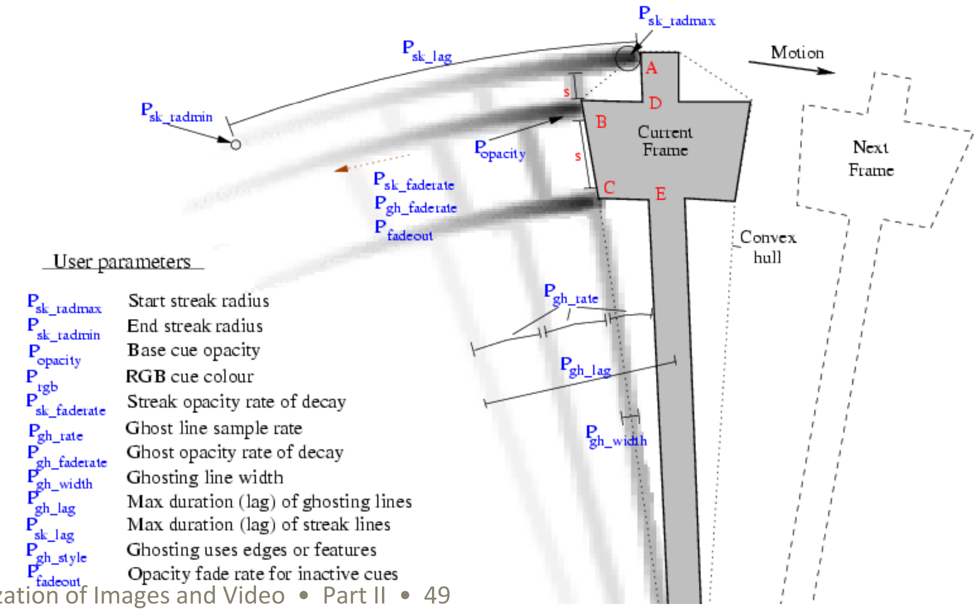
- **Motion Emphasis**
  - **Augmentation cue (Speed-lines, ghosting)**
  - **Deformation (Squash and stretch, general deformation)**
  - **Time warping (Anticipation/snap)**

- **Augmentation Cues**
  - **Segment trails of corresponded control points into smooth sections.**
  - **Iteratively select  smooth sections to maximising:**

$$
\begin{aligned}
H(0) &= 0 \\
H(i+1) &= H(i) + (\alpha v(x) + \beta L(x) - \\
&\quad \gamma D(x) - \delta\omega(x,\sigma;w) + \zeta\rho(x))
\end{aligned}
$$

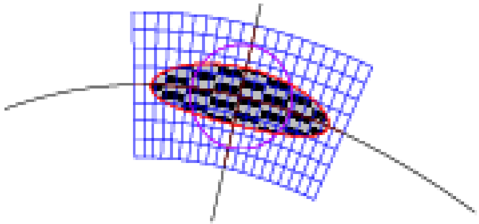
$\alpha, \beta, \gamma, \delta, \zeta$: user weights
$\sigma$ selected sections

$v(x)$ mean velocity over x
$\rho(x)$ mean curvature at x
$L(x)$ temporal extent of x
$D(x)$ dist from convex hull at x
$\omega(x,\sigma;w)$ overlap of x and $\sigma$



# Squash and Stretch

- **Deformation Cues**
  - A motion dependent curvilinear basis is formed using the trajectory of the region centroid, and its normal.



$$\underline{x} = \underline{G}_c(s) + r\underline{n}(s)$$

U(.) as the transformation from curvilinear space, keep the inverse as a lookup table.

$$\underline{x} = U(\underline{r}) \qquad \underline{r} = (s, r)^T$$

$$\underline{x} \leftarrow U(\begin{bmatrix} k & \mathbf{0} \\ \mathbf{0} & \frac{1}{k} \end{bmatrix} U^{-1}(\underline{x}))$$

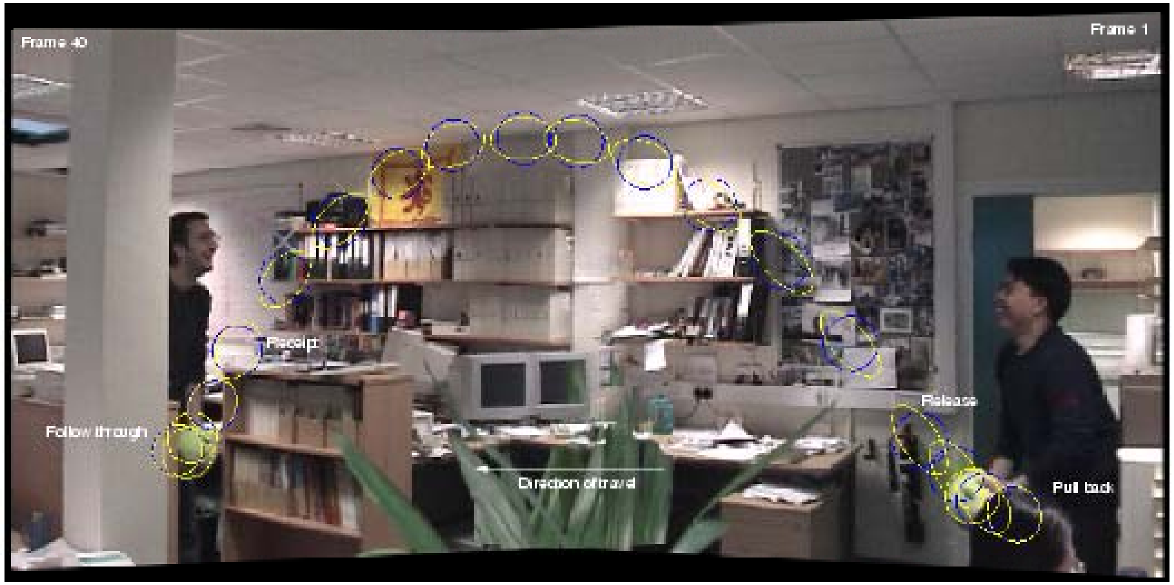
$$k = 1 + \frac{K}{2}(1 - cos(\pi \frac{v^2 + 1}{2}))$$

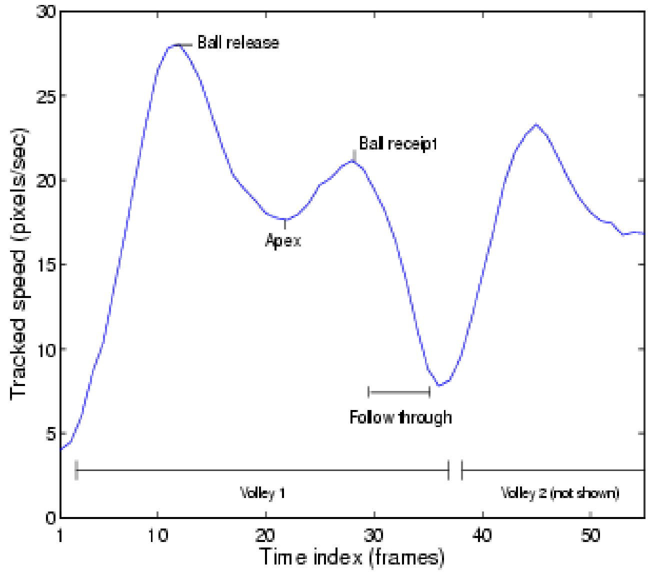
$$v = \begin{cases} 0 \text{ if } |\underline{\dot{\mu}}| < V_{min} \\ 1 \text{ if } |\underline{\dot{\mu}}| >= V_{max} \\ (|\dot{\mu}| - V_{min})/(V_{max} - V_{min}) \text{ otherwise} \end{cases}$$

Squash and stretch
(after Chenney et al '02)

# Squash and Stretch

- **Deformation Cues**
  - **Squash and stretch in a camera motion compensated frame**



# General Deformation

- **Deformation Cues**
  - **More general motion deformations can be created by specifying a transfer function dependent on a point's local acceleration and position, as well as its speed.**

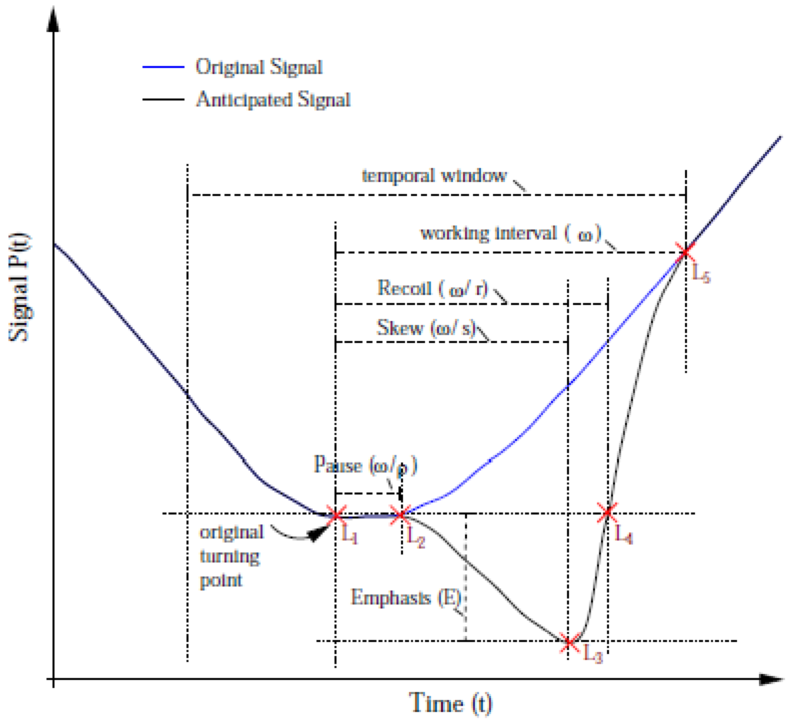
$$x' = U(T(U^{-1}(\underline{x}), \underline{\dot{x}}, \underline{\ddot{x}}))$$

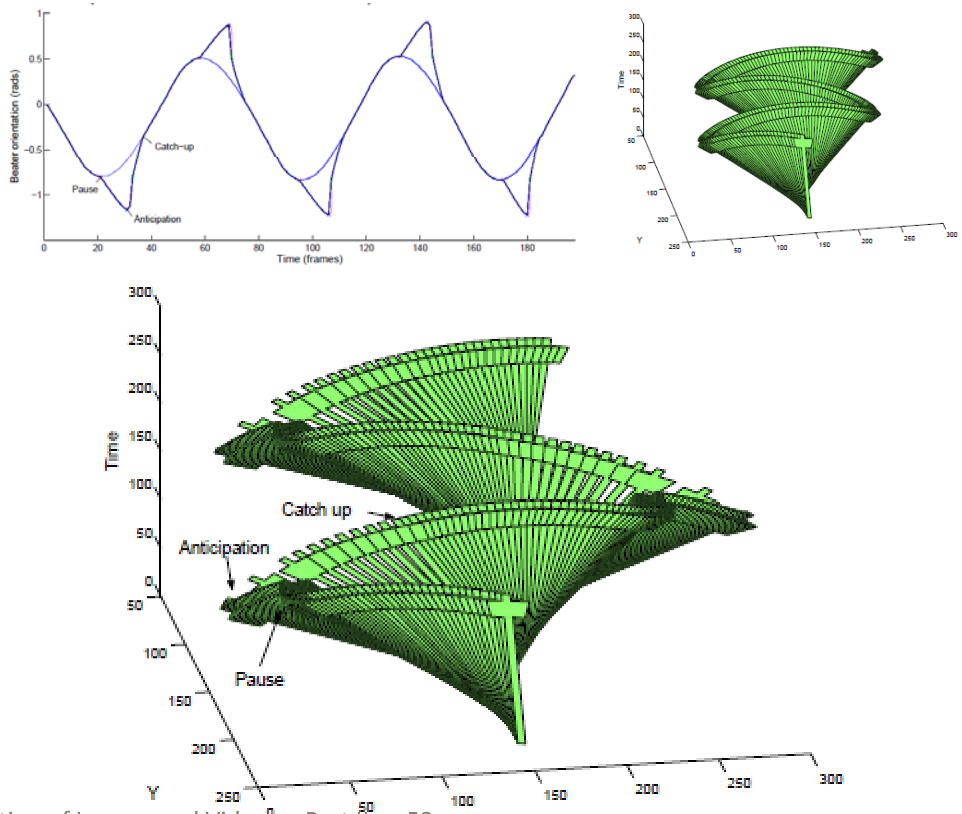
A function can operate on each component of $\underline{r} = (r_1, r_2)$ independently, to create effects suggesting drag we use...

$$r_1 = r_1 - F(\frac{2}{\pi} atan(|\underline{\dot{x}}_i|))^P sign(\underline{\dot{x}}_i)$$

# Video Analysis for Dynamic Cues
Collomosse and Hall (2005)

- **Anticipation (Snap)**
  - **Alter motion timing to introduce a lag then "catch up" prior to changes of motion**



# Video Paintbox: The Fine Art of Video Painting

Collomosse and Hall (2006)

- **A Complete Video Paintbox**

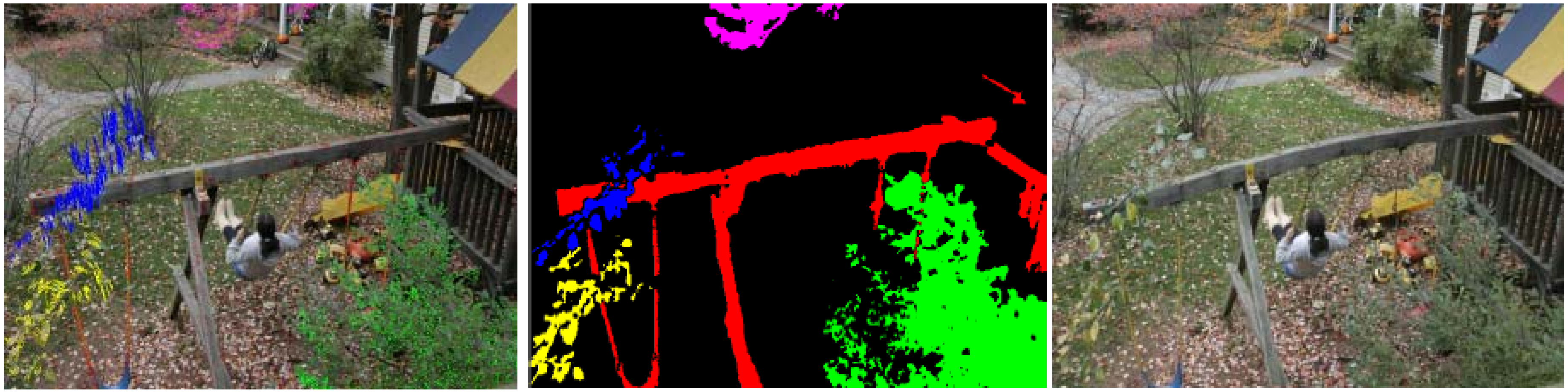
**Segmentation + augmentation + deformation**

**Anticipation + deformation**

# Motion Magnification

Liu et al. (2005)

- **Deformation Cues**
  - **General deformation technique using motion vector clustering to layer video**
    - **User intervention needed to fix noisy segmentation maps**
  - **Per-pixel flow vector pushes pixels to exaggerate existing motion**
  - **Texture filling compensates for holes**

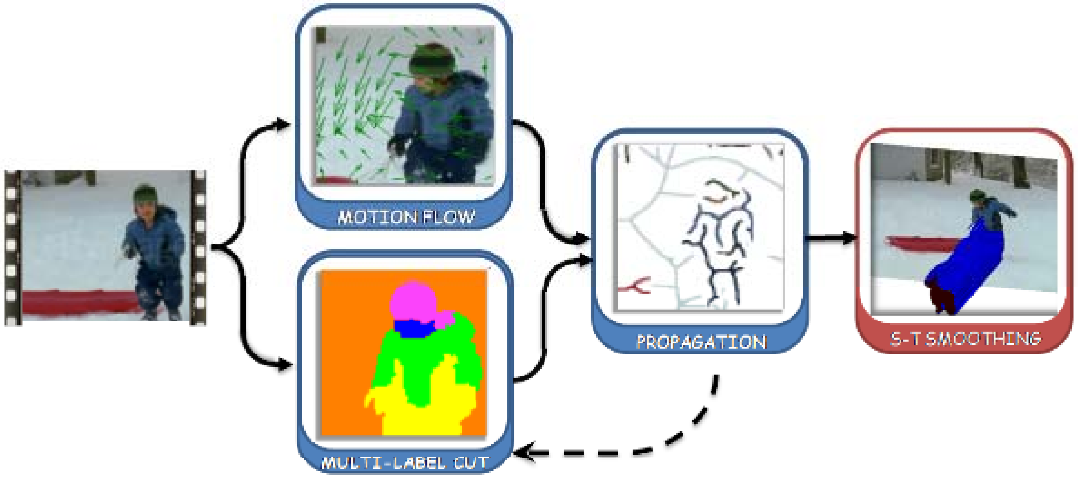


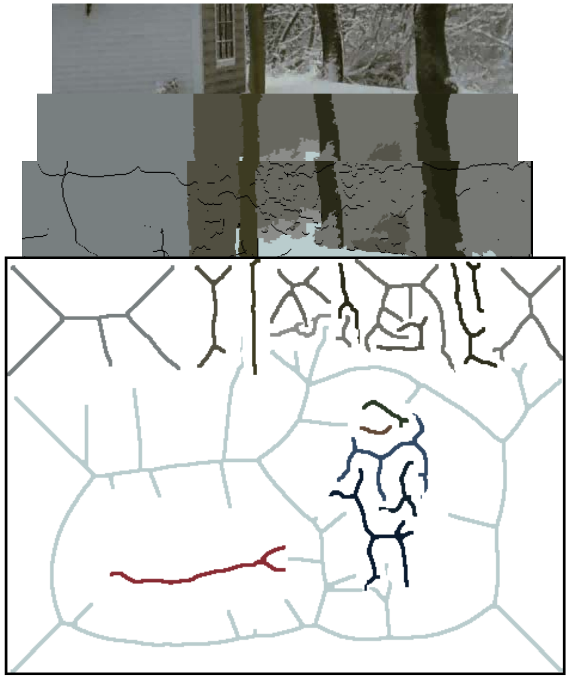


Liu et al. '05

# Motion Magnification

- **Combining Segmentation and Optical Flow**
  - **Multi-label graph-cut segmentation with label prior propagated forward from previous frames**
  - **Region colour models are learned incrementally**



propagation to next...



Wang et al. '10

# Motion Magnification

- **Combining Segmentation and Optical Flow**
  - **For each pixel** $p \in \mathcal{P}$ **within frame** $I_t(p)$
    - **Find best mapping** $l : \mathcal{P} \rightarrow \mathcal{L}$
      $\mathcal{L} = (l(1), \ldots, l(p), \ldots, l(|\mathcal{P}|))$
    - **Subset of** $\mathcal{L}$ **are carried from** t-1 **by flow**

$$E(\mathcal{L}, \Theta, \mathcal{P}) = U(\mathcal{L}, \Theta, \mathcal{P}) + V(\mathcal{L}, \mathcal{P}).$$

Learned colour model

$$U(\mathcal{L}, \Theta, \mathcal{P}) = \sum_{p \in \mathcal{P}} -\log P_g(I_t(p) | l(p); \Theta).$$

Contrast adaptive

$$P_g(I(p) | l(p) = l_i; \Theta) = \sum_{k=1}^{n_l} w_{ik} \mathcal{N}(I(p); \mu_{ik}, \Sigma_{ik})$$

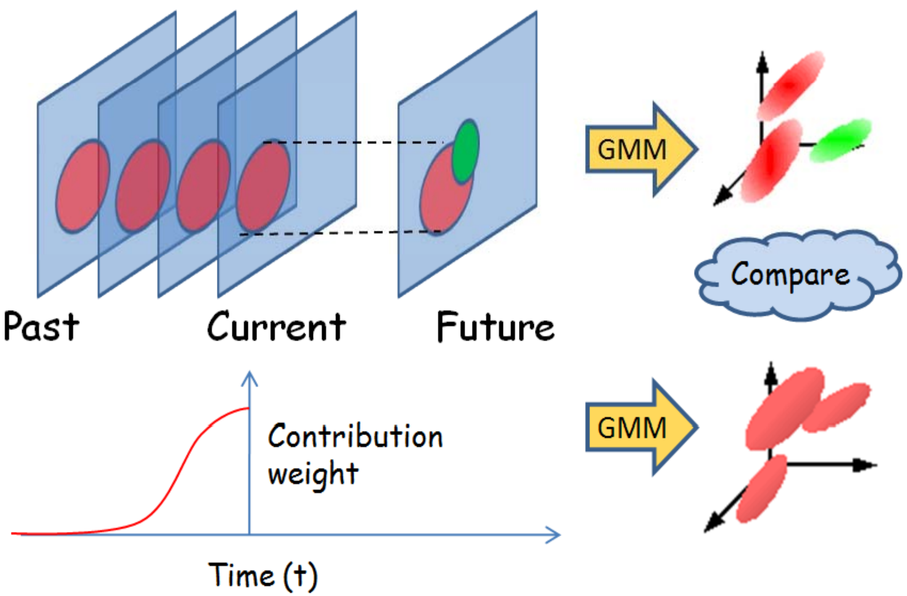
$$V(\mathcal{L}, \mathcal{P}) = \gamma \sum_{(m,n) \in N} [l(m) \neq l(n)] e^{-\beta \|I(m) - I(n)\|^2}.$$

  - **Colour models are learned over time incrementally via Gaussian Mixtures**

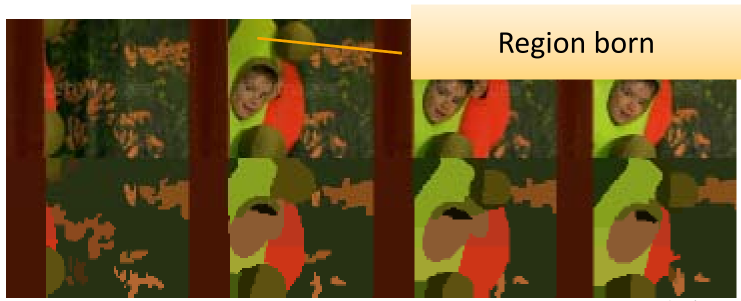
Wang et al. '10

# Motion Magnification

- **Region colour distribution (GMM) updated with temporal weight**
  - **Comparison with historic model (Chi^2) can detect region birth**



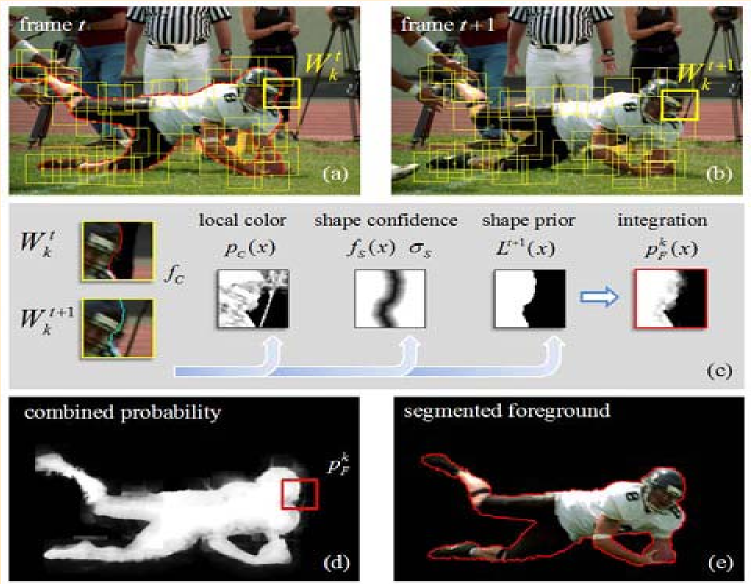





Wang et al. '10

# Motion Magnification

- **Trends from automatic 'Tooning to interactive tools**
  - **The necessity of interaction to solve the general segmentation problem**




**Video Snap-Cut**

Bai et al. '09


**Complex Interactive Painting Systems**

Liang et al. '10

**Yet many applications demand automation or real-time. Part III discusses solutions.**

# Coffee Q & A

- **After the break!**
  - **Part III - Anisotropy and Diffusion**
  - **Part IV - Future Challenges in NPR**



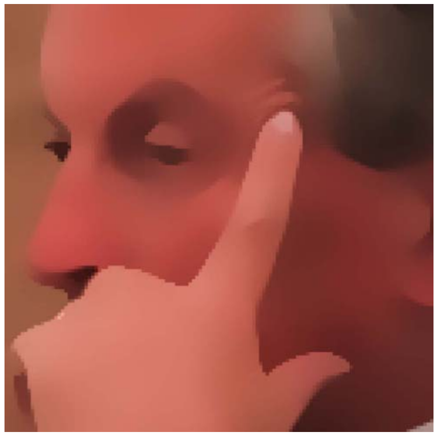



Photo credits as noted in Part III