Image Morphing, Warping, and Resizing

CS535

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Topics

- Image morphing (2D)
  - A “hack”
- View morphing (2D+)
  - Planar warp using homography
- Image warping (3D)
  - Full 3D warp

Motivation – Rendering from Images

- Given
  - left image
  - right image
- Create intermediate images
  - simulates camera movement

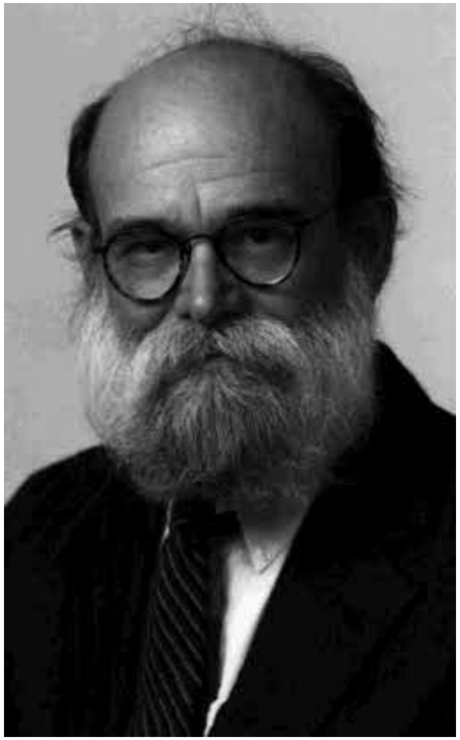
Related Work

- Panoramas ([Chen95/QuicktimeVR], etc)
  - user can look in any direction at few given locations but camera translations are ***not*** allowed…

Topics

- Image morphing (2D)
- View morphing (2D+)
- Image warping (3D)

Image Morphing



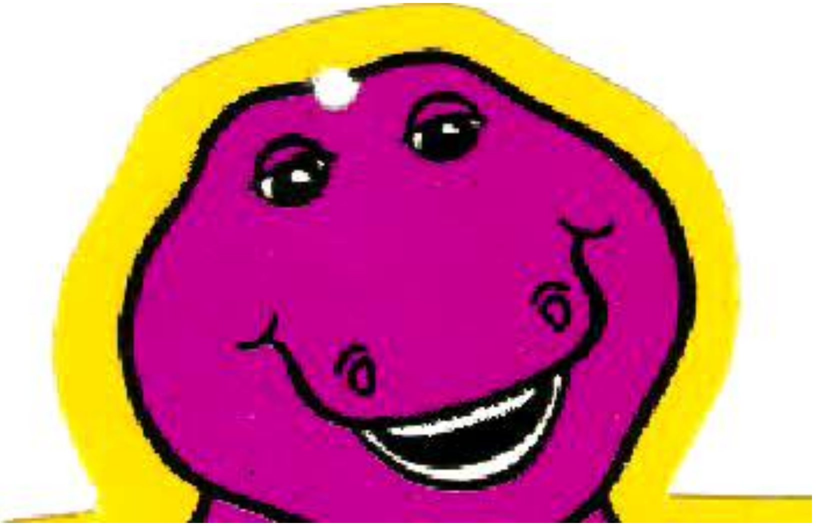


Image Morphing

- Identify correspondences between input/output image
- Produce a sequence of images that allow a smooth transition from the input image to the output image

Image Morphing

1. Correspondences

Image Morphing

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Image Morphing

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Image Morphing

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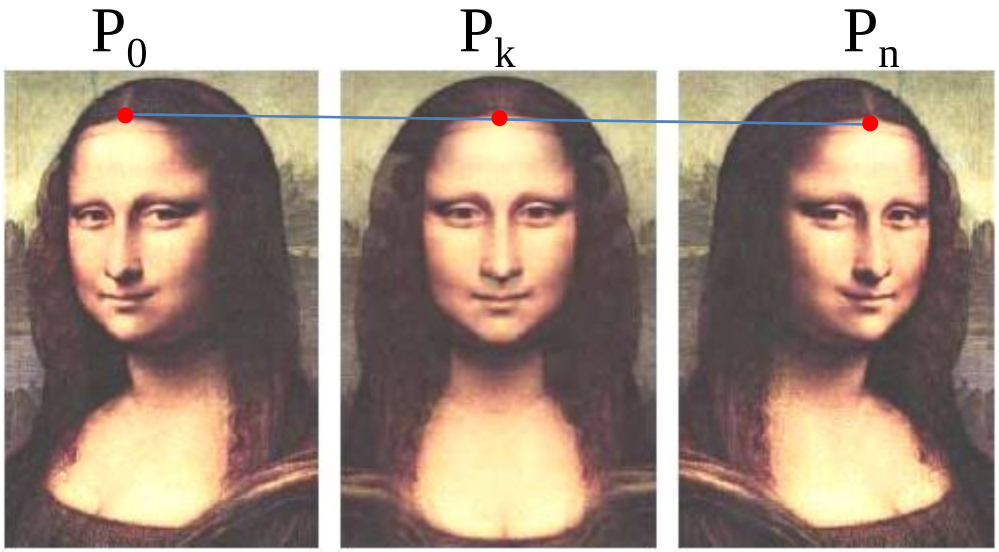
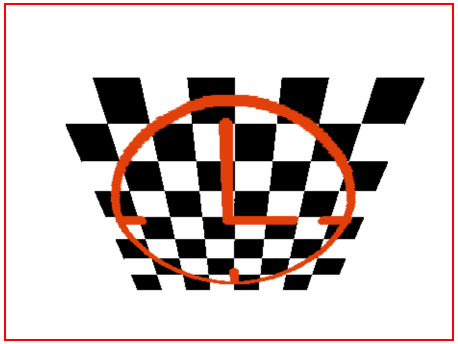
Image Morphing



1. Correspondences
2. Linear interpolation

$$P_k = (1 - \frac{k}{n})P_0 + \frac{k}{n}P_n$$

Image Morphing



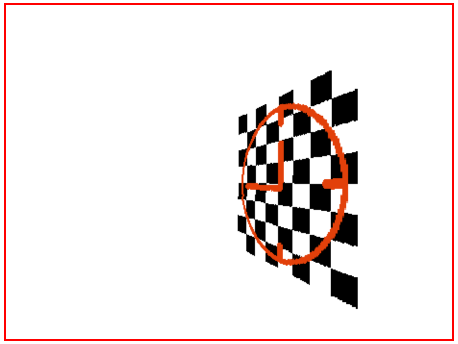


Image Morphing

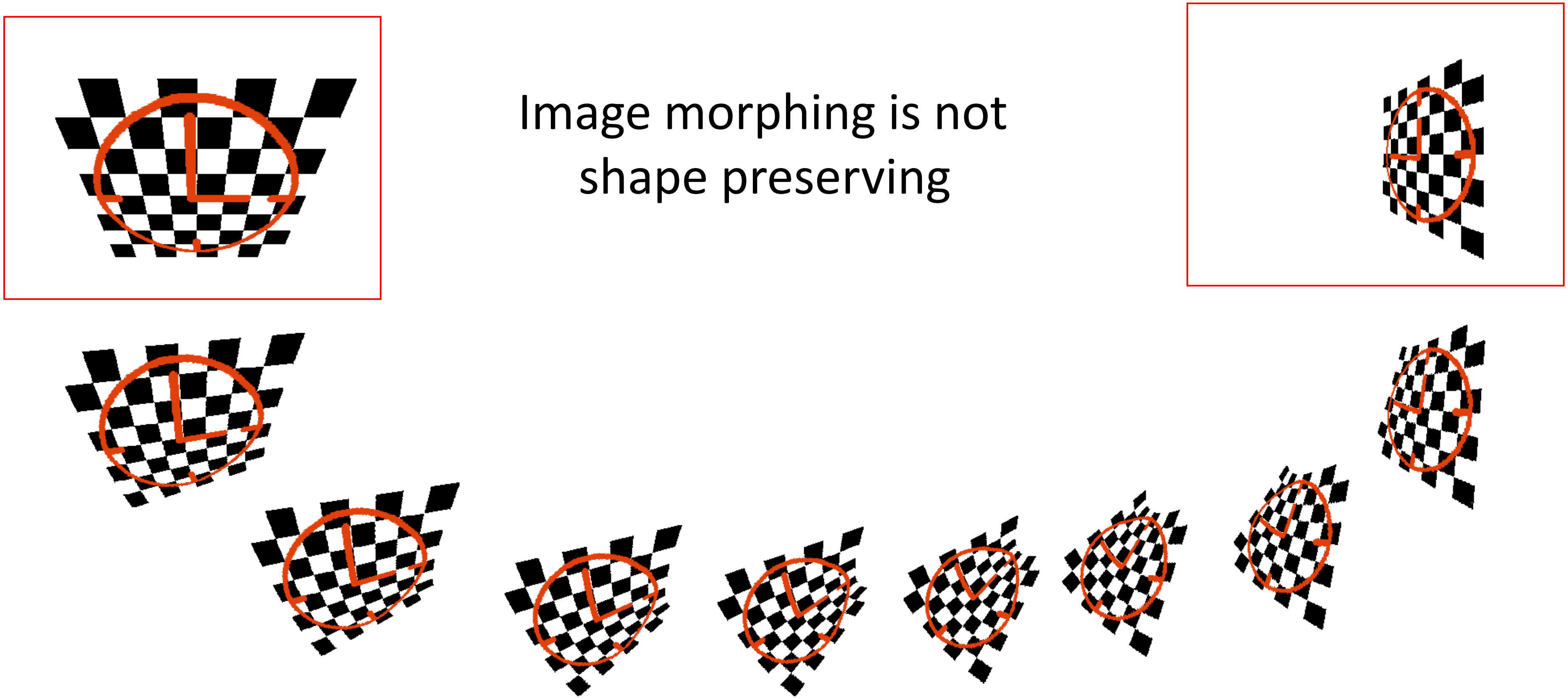
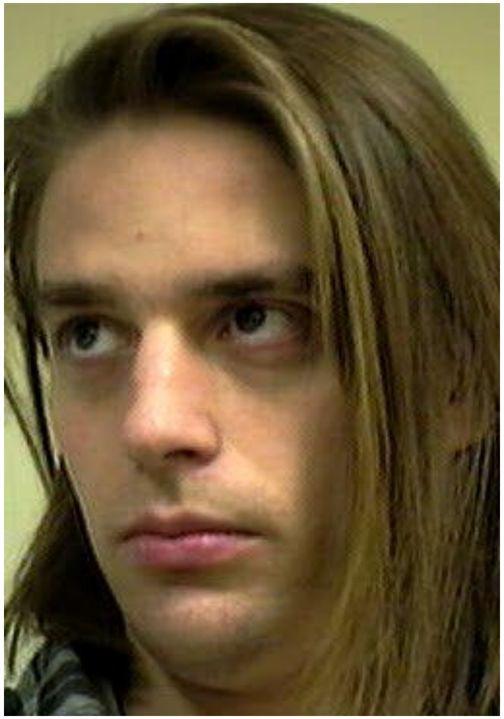


Image morphing is not shape preserving

Topics

- Image morphing (2D)
- View morphing (2D+)
- Image warping (3D)

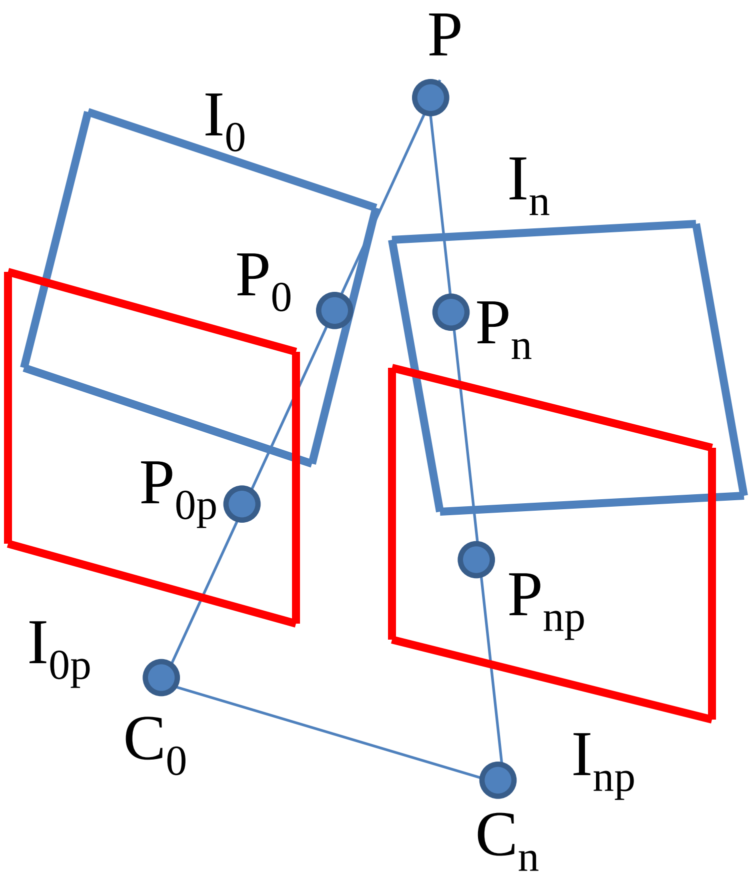
View Morphing



View Morphing

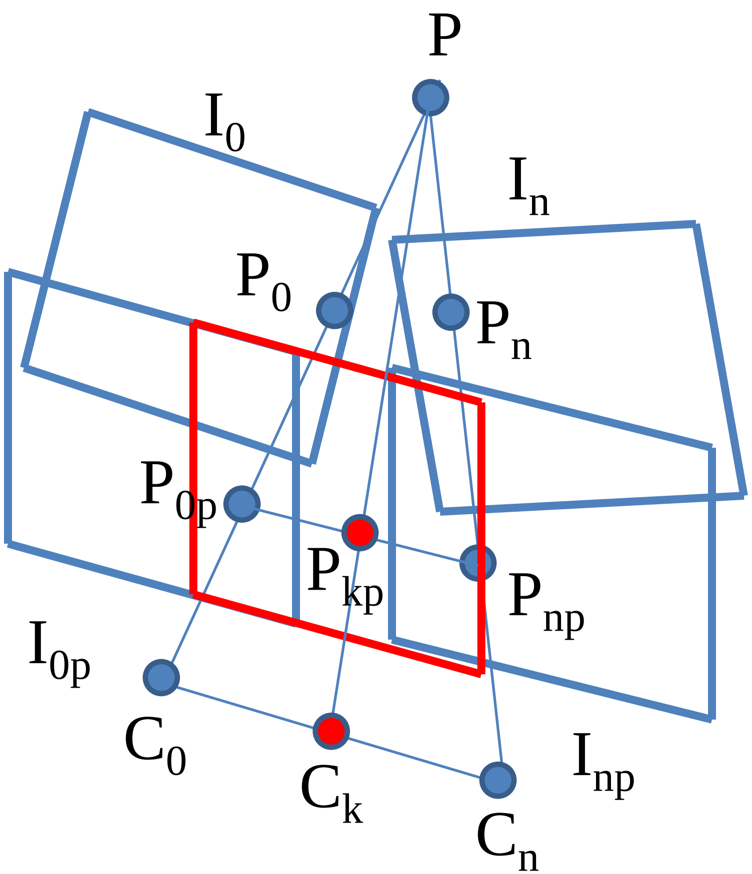
- Shape preserving morph
- Three step algorithm
  - Prewarp first and last images to parallel views
  - Image morph between prewarped images
  - Postwarp to interpolated view

Step 1: prewarp to parallel views



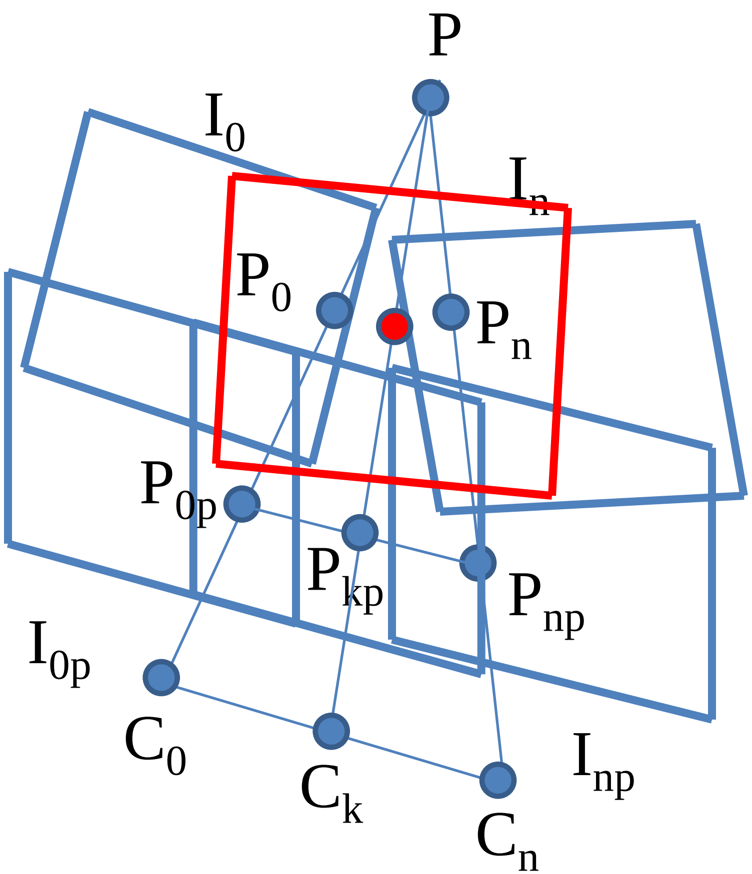
- Parallel views
  - same image plane
  - image plane parallel to segment connecting the two centers of projection
- Prewarp
  - compute parallel views I_{0p}, I_{np}
  - rotate I_0 and I_n to parallel views
  - prewarp correspondence is $(P_0, P_n) \rightarrow (P_{op}, P_{np})$

Step 2: morph parallel images



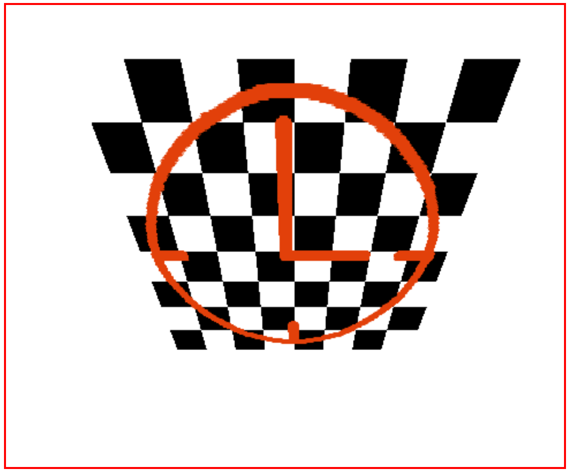
- Shape preserving
- Use prewarped correspondences
- Interpolate C_k from C_0 C_n

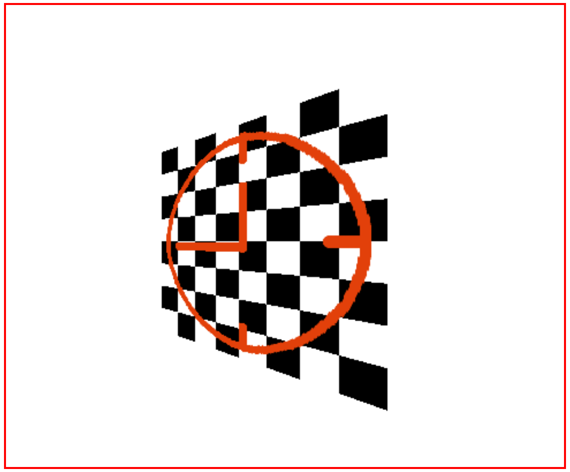
Step 3: postwarp image



- Postwarp morphed image
  - create intermediate view
    - C_k is known
    - interpolate view direction and tilt
  - rotate morphed image to intermediate view

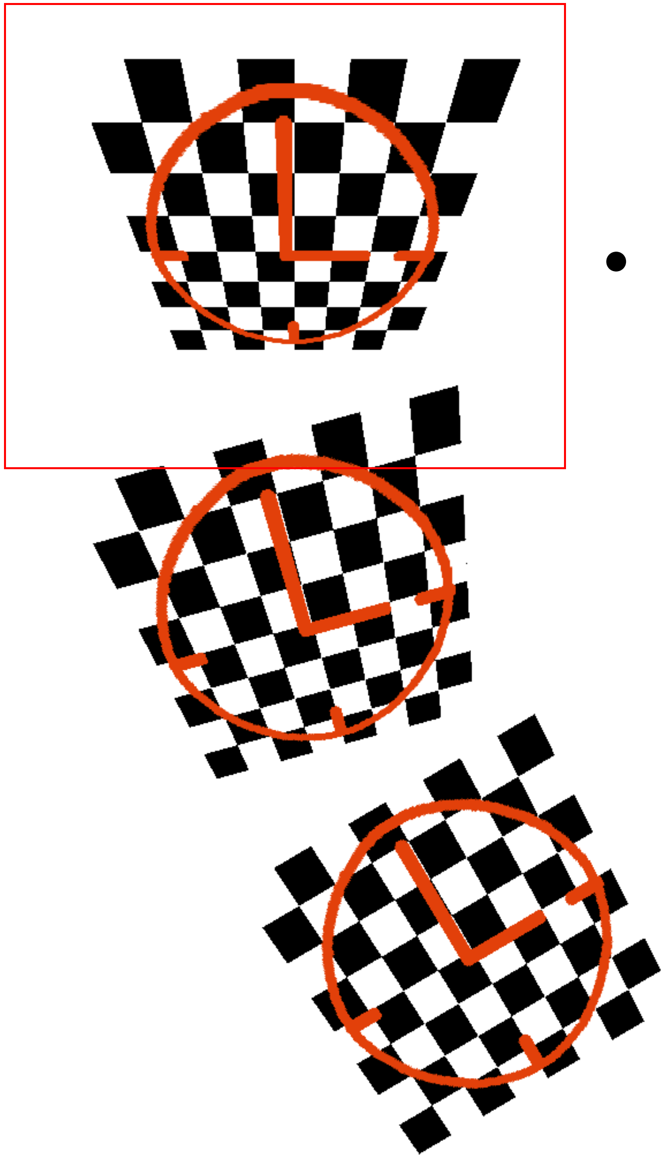
View morphing

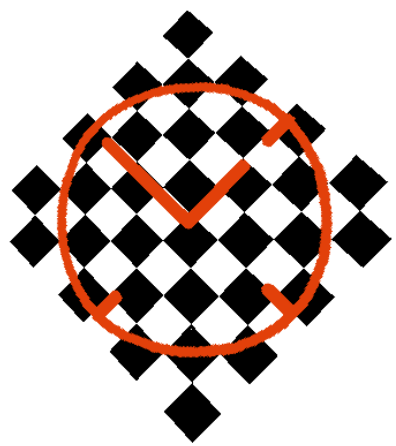


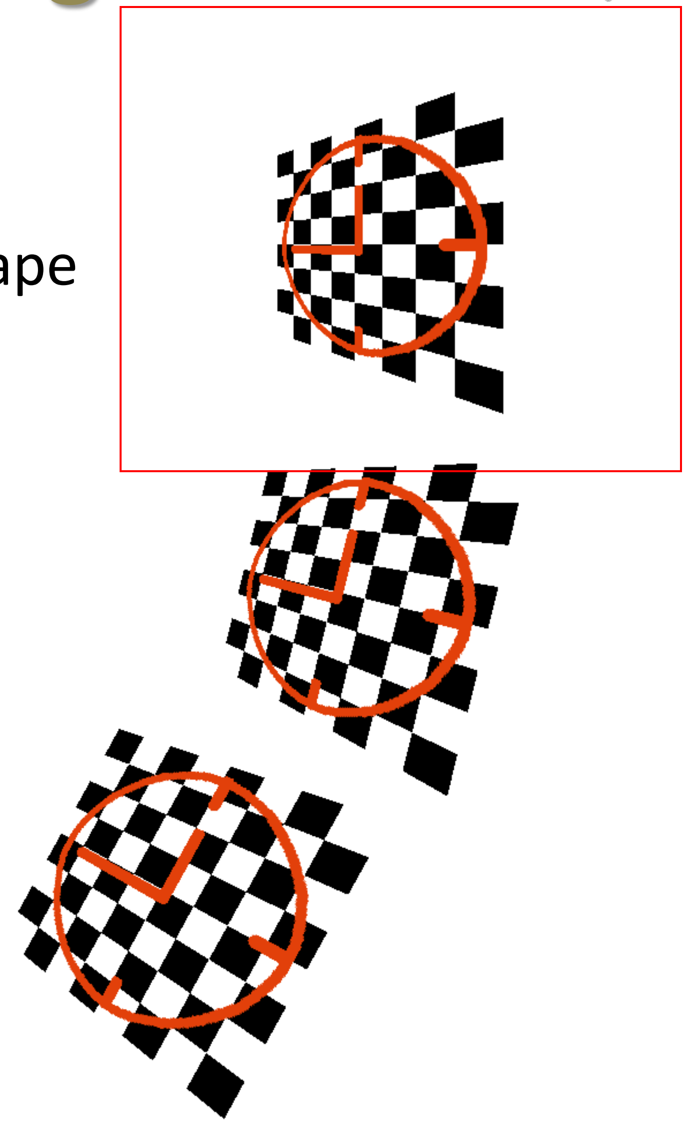


View morphing

- View morphing is shape preserving

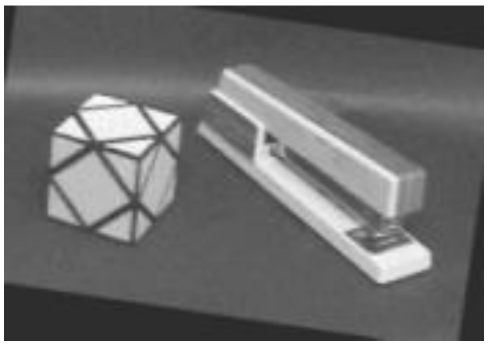
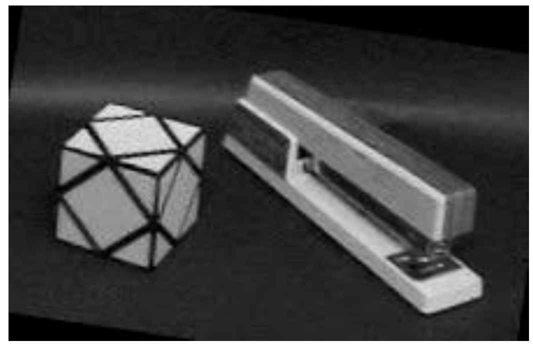
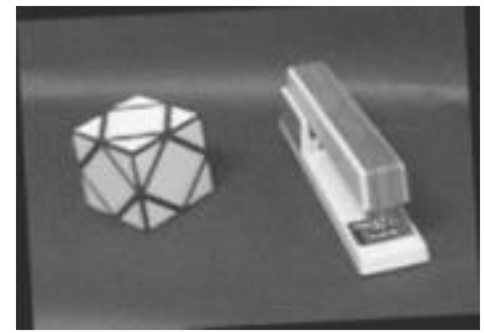






View Morphing Examples

- Using computer vision/stereo reconstruction techniques

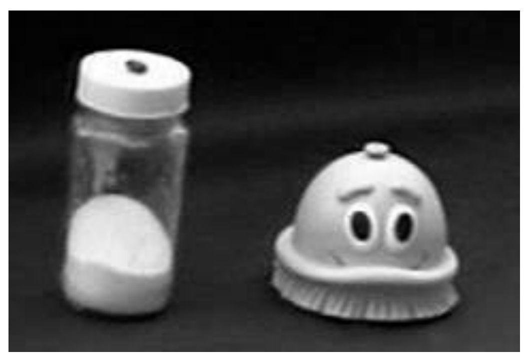
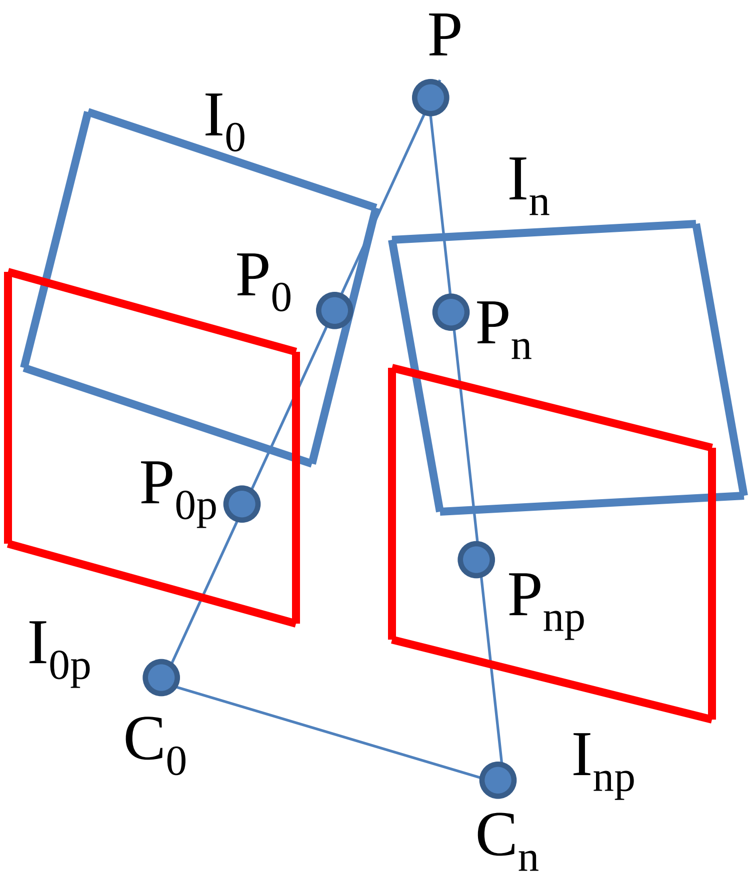




Image Transformations



- Intuitively, how do you compute the matrix M by which to transform P_0 to P_{0p}?

Image Transformations

- A geometric relationship between input (u,v) and output pixels (x,y)
  - Forward mapping:

    $(x,y) = (X(u,v), Y(u,v))$

  - Inverse mapping:

    $(u,v) = (U(x,y), V(x,y))$

Image Transformations

- General matrix form is

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} u \\ v \\ w \end{bmatrix} = \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

and operates in the “homogeneous coordinate system”.

Affine Transformations

- Matrix form is

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} u \\ v \\ w \end{bmatrix} = \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

and accommodates translations, rotations, scale, and shear.

- How many unknowns? How to create matrix?

Affine Transformations

- Transformation can be inferred from correspondences; e.g.,

$$\begin{bmatrix} u_i \\ v_i \\ w_i \end{bmatrix} \Leftrightarrow \begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix}$$

- Given ≥3 correspondences can solve for T

Perspective/Projective Transformations

- Matrix form is

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & 1 \end{bmatrix} \begin{bmatrix} u \\ v \\ w \end{bmatrix} = \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

and it accommodates foreshortening of distant line and convergence of lines to a vanishing point;

also, straight lines are maintained but not their mutual angular relationships, and

only parallel lines parallel to the projection plane remain parallel

Perspective/Projective Transformations

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & 1 \end{bmatrix} \begin{bmatrix} u \\ v \\ w \end{bmatrix} = \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

- How many unknowns?
- How many correspondences are needed?

Perspective/Projective Transformations

- Solve

$$\begin{pmatrix} u_0 & v_0 & 1 & 0 & 0 & 0 & -u_0 x_0 & -v_0 x_0 \\ u_1 & v_1 & 1 & 0 & 0 & 0 & -u_1 x_1 & -v_1 x_1 \\ u_2 & v_2 & 1 & 0 & 0 & 0 & -u_2 x_2 & -v_2 x_2 \\ u_3 & v_3 & 1 & 0 & 0 & 0 & -u_3 x_3 & -v_3 x_3 \\ 0 & 0 & 0 & u_0 & v_0 & 1 & -u_0 y_0 & -v_0 y_0 \\ 0 & 0 & 0 & u_1 & v_1 & 1 & -u_1 y_1 & -v_1 y_1 \\ 0 & 0 & 0 & u_2 & v_2 & 1 & -u_2 y_2 & -v_2 y_2 \\ 0 & 0 & 0 & u_3 & v_3 & 1 & -u_3 y_3 & -v_3 y_3 \end{pmatrix} A = b$$

where A is the vector of unknown coefficients a_{ij}

Topics

- Image morphing (2D)
- View morphing (2D+)
- Image warping (3D)

3D Image Warping

- Goal: "warp" the pixels of the image so that they appear in the correct place for a new viewpoint
- Advantage:
  - Don't need a geometric model of the object/environment
  - Can be done in time proportional to screen size and (mostly) independent of object/environment complexity
- Disadvantage:
  - Limited resolution
  - Excessive warping reveals several visual artifacts

    (see examples)

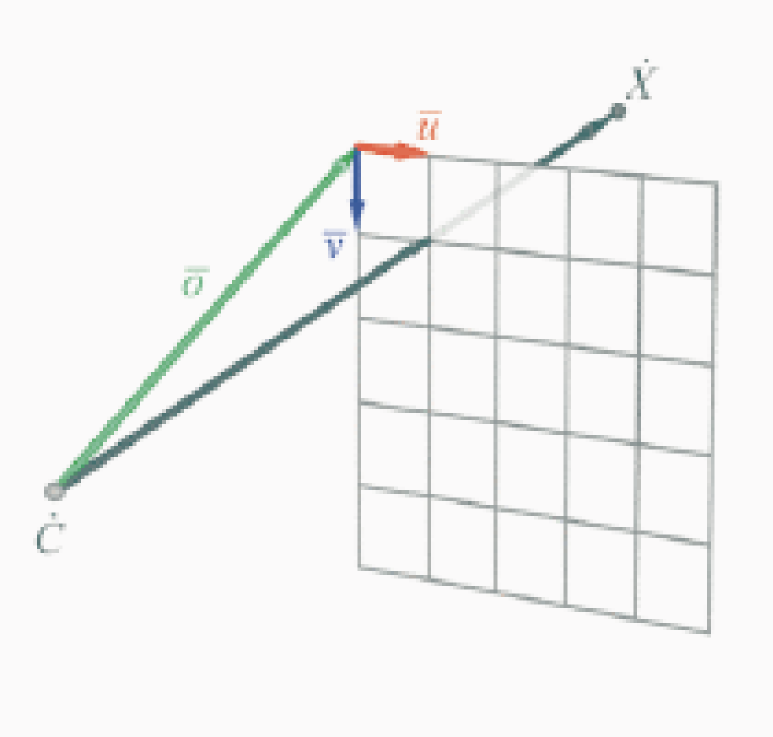
3D Image Warping Equations

McMillan & Bishop Warping Equation:

$$x_2 = \underbrace{\delta(x_1)\, P_2^{-1} (c_1 - c_2)}_{\text{Move pixels based on distance to eye}} + \underbrace{P_2^{-1} P_1\, x_1}_{\text{\textasciitilde Texture mapping}}$$

- Per-pixel distance values are used to warp pixels to their correct location for the current eye position

3D Image Warping Equations

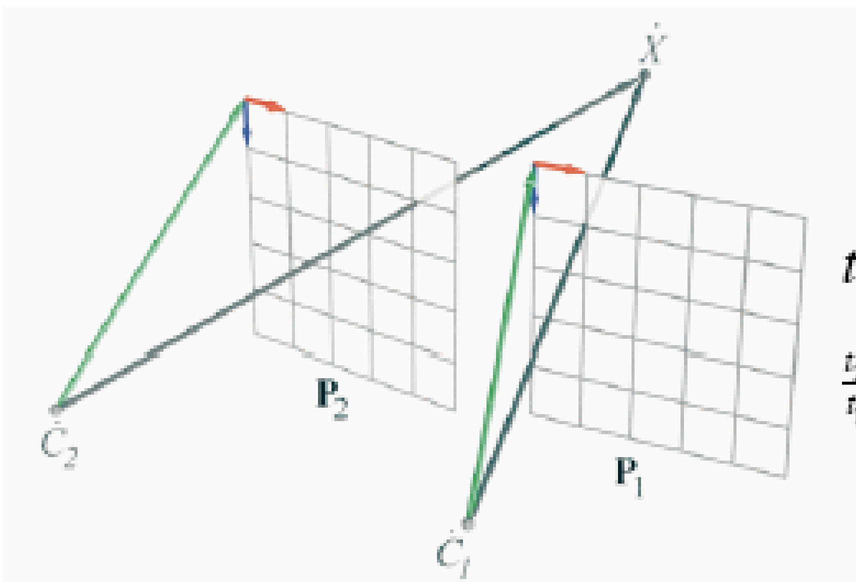


$$P = \begin{bmatrix} u_x & v_x & o_x \\ u_y & v_y & o_y \\ u_z & v_z & o_z \end{bmatrix}$$

$$\dot{X} = \dot{C} + t\,P\,\vec{x}$$

Some pictures courtesy of SIGGRAPH '99 course notes
(Leonard McMillan)

3D Image Warping Equations



$$\dot{C}_2 + t_2 P_2 \vec{x}_2 = \dot{C}_1 + t_1 P_1 \vec{x}_1$$

$$t_2 P_2 \vec{x}_2 = \dot{C}_1 - \dot{C}_2 + t_1 P_1 \vec{x}_1$$

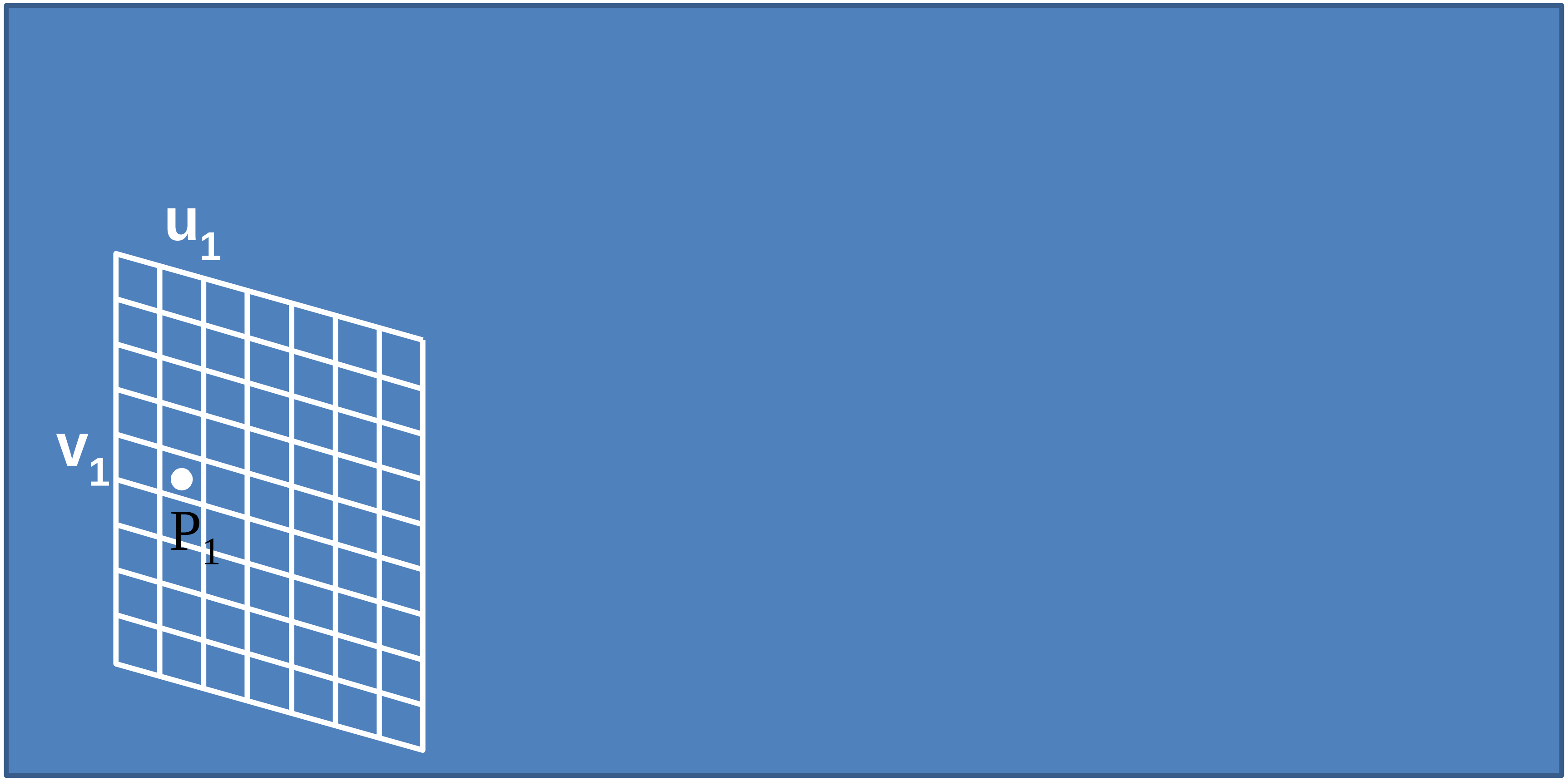
$$t_2 \vec{x}_2 = P_2^{-1}\left(\dot{C}_1 - \dot{C}_2\right) + t_1 P_2^{-1} P_1 \vec{x}_1$$

$$\tfrac{t_2}{t_1} \vec{x}_2 = \tfrac{1}{t_1} P_2^{-1}\left(\dot{C}_1 - \dot{C}_2\right) + P_2^{-1} P_1 \vec{x}_1$$

$$\vec{x}_2 \doteq \underbrace{\tfrac{1}{t_1}}_{\delta} \underbrace{P_2^{-1}\left(\dot{C}_1 - \dot{C}_2\right)}_{e_{21}} + \underbrace{P_2^{-1} P_1}_{H_{21}} \vec{x}_1$$

3D Image Warping Equations

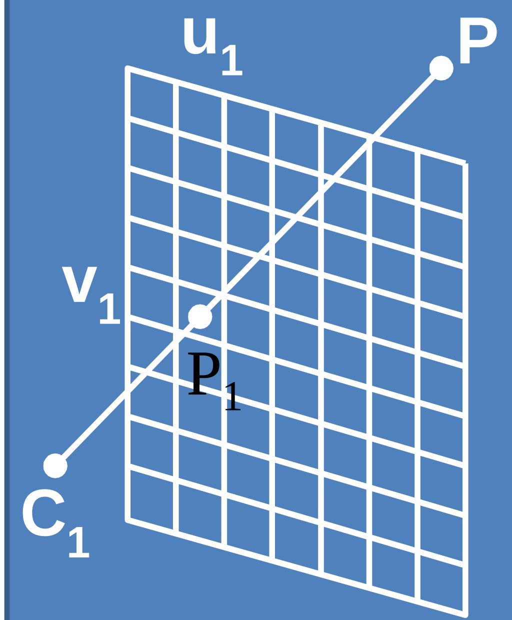
- Images enhanced with per-pixel depth [McMillan95]



3D Image Warping Equations

$$\dot{P} = \dot{C}_1 + (\bar{c}_1 + u_1 \bar{a}_1 + v_1 \bar{b}_1) w_1$$

$$w_1 = \frac{C_1 P}{C_1 P_1}$$

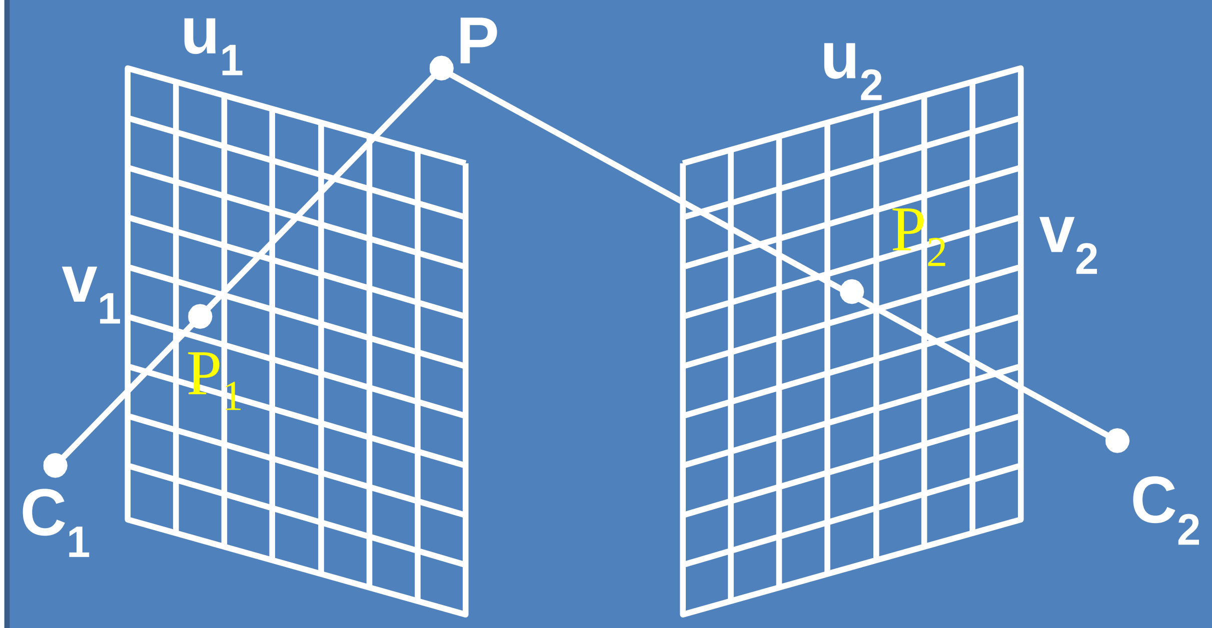


- $1/w_1$ also called generalized disparity
- another notation $\delta(u_1, v_1)$

3D Image Warping Equations

$$\dot{P} = \dot{C}_1 + (\bar{c}_1 + u_1 \bar{a}_1 + v_1 \bar{b}_1) w_1$$

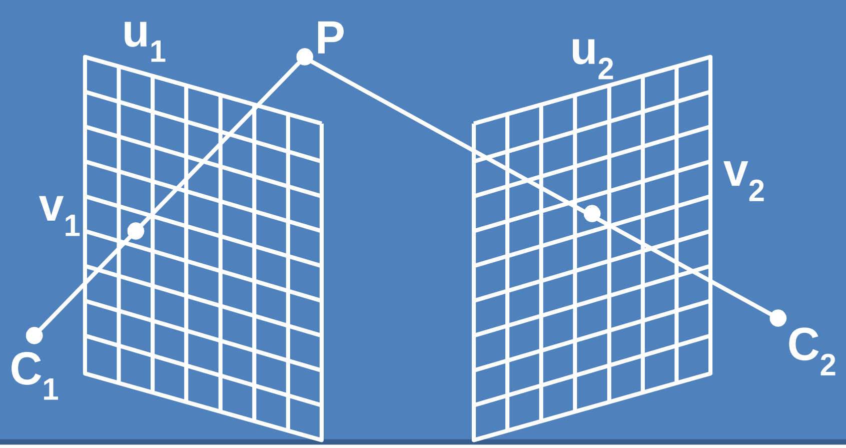
$$\dot{P} = \dot{C}_2 + (\bar{c}_2 + u_2 \bar{a}_2 + v_2 \bar{b}_2) w_2$$



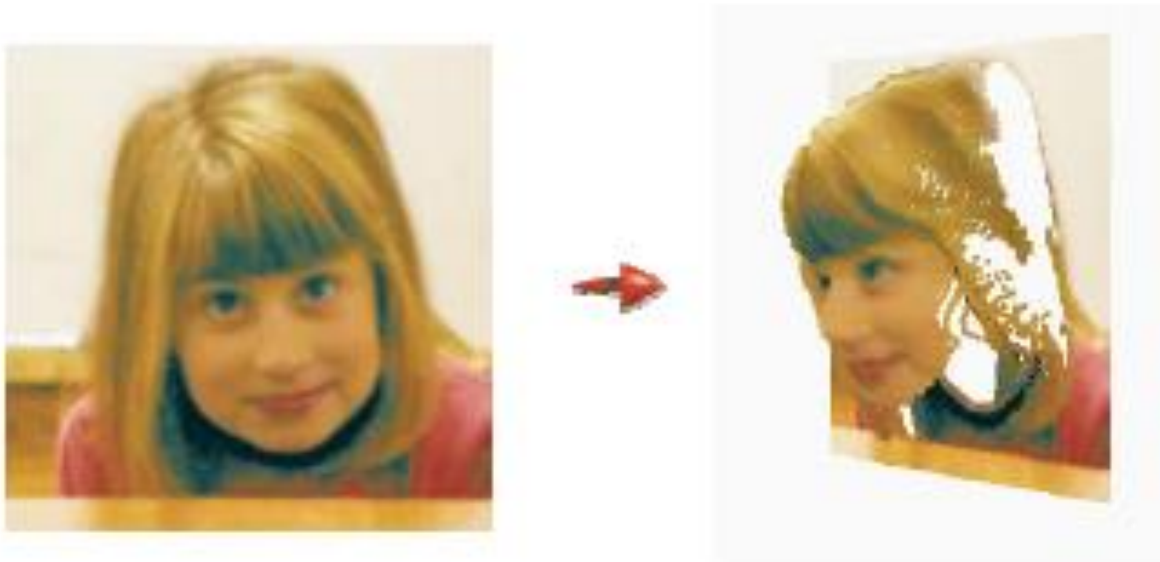
3D Image Warping Equations

$$u_2 = \frac{w_{11} + w_{12} \cdot u_1 + w_{13} \cdot v_1 + w_{14} \cdot \delta(u_1, v_1)}{w_{31} + w_{32} \cdot u_1 + w_{33} \cdot v_1 + w_{34} \cdot \delta(u_1, v_1)}$$

$$v_2 = \frac{w_{21} + w_{22} \cdot u_1 + w_{23} \cdot v_1 + w_{24} \cdot \delta(u_1, v_1)}{w_{31} + w_{32} \cdot u_1 + w_{33} \cdot v_1 + w_{34} \cdot \delta(u_1, v_1)}$$



3D Image Warping Example



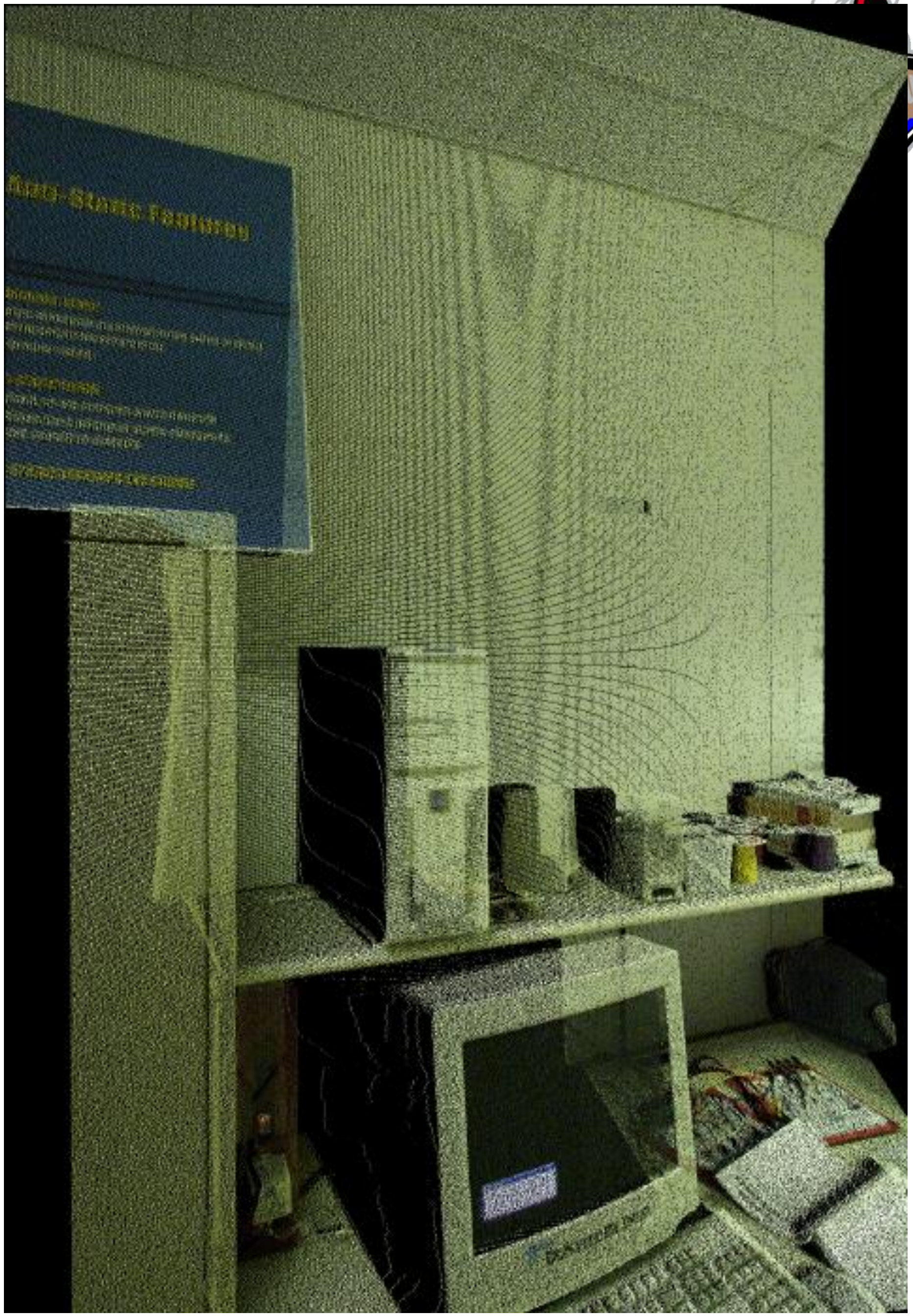
3D Image Warping Example

- DeltaSphere
  - Lars Nyland *et al.*

3D Image Warping Example

3D Image Warping Example

3D Image Warping Example



3D Image Warping Example

Disocclusions

- Disocclusions (or exposure events) occur when unsampled surfaces become visible…

What can we do?

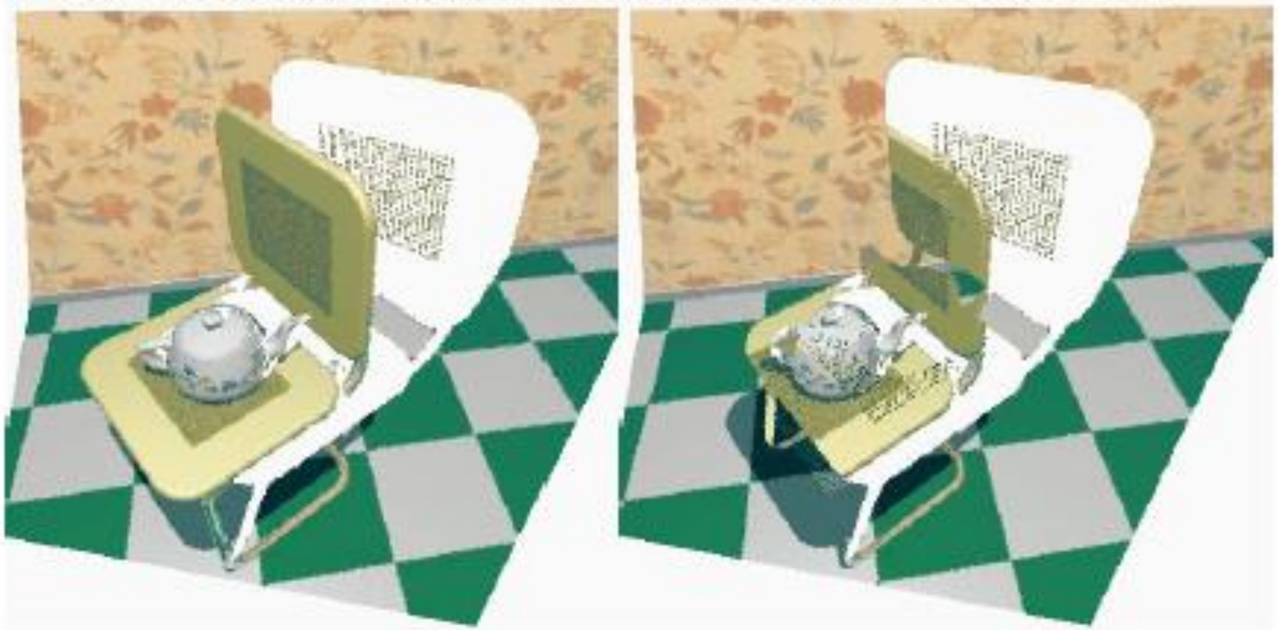
Disocclusions

- Bilinear patches: fill in the areas

What else?

Rendering Order

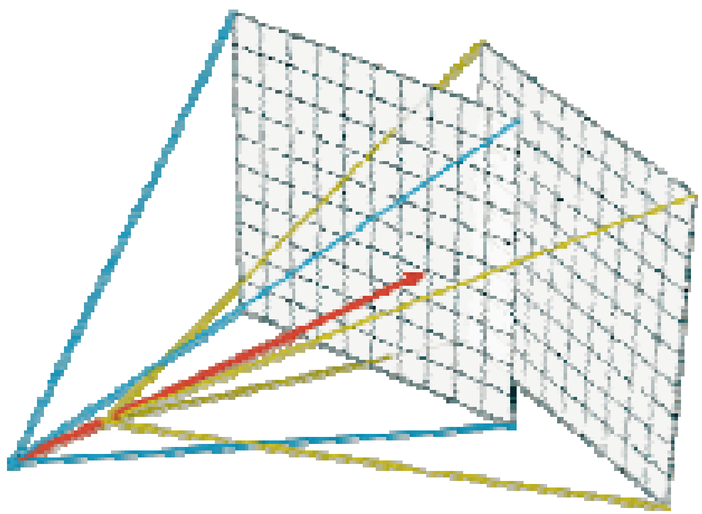
- The warping equation determines where points go…

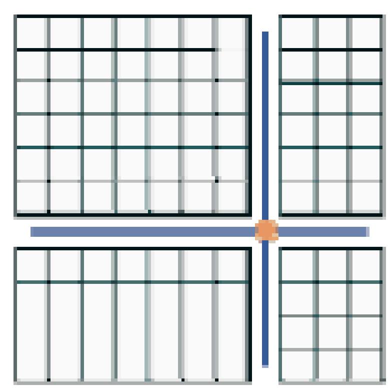


… but that is not sufficient

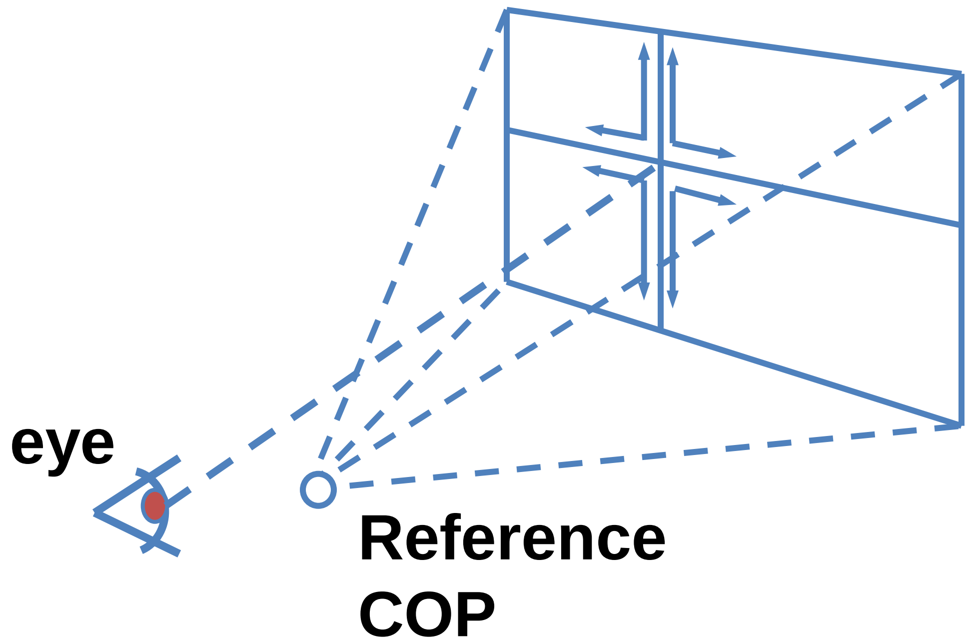
Occlusion Compatible Rendering Order

- Remember epipolar geometry?
- Project the new viewpoint onto the original image and divide the image into 1, 2 or 4 "sheets"





Occlusion Compatible Rendering Order



- A raster scan of each sheet produces a back-to-front ordering of warped pixels

The Image Resizing/Retargeting Problem

Image Retargeting Objectives

1. Change size

2. Preserve the important ***content*** and ***structures***
3. Limit ***artifacts*** created

Traditional Methods

Scaling

Cropping

- Scaling introduces distortions
- Cropping removes important parts

Many Existing Resizing Methods

Seam Carving Method

- "Seam Carving for Content-Aware Image Resizing," S. Avidan and A. Shamir
- In Photoshop called "content aware scaling"
- Main idea: **Remove the least noticeable pixels**
  - How? Define an "energy function" that measures how perceptually noticeable each pixel is
- **Remove the pixels with "low energy" and avoid removing pixels with "high energy"**
  - How? Define a criterion for picking which pixels to remove

Possible Energy Functions

- Edgeness
  - Gradient magnitude

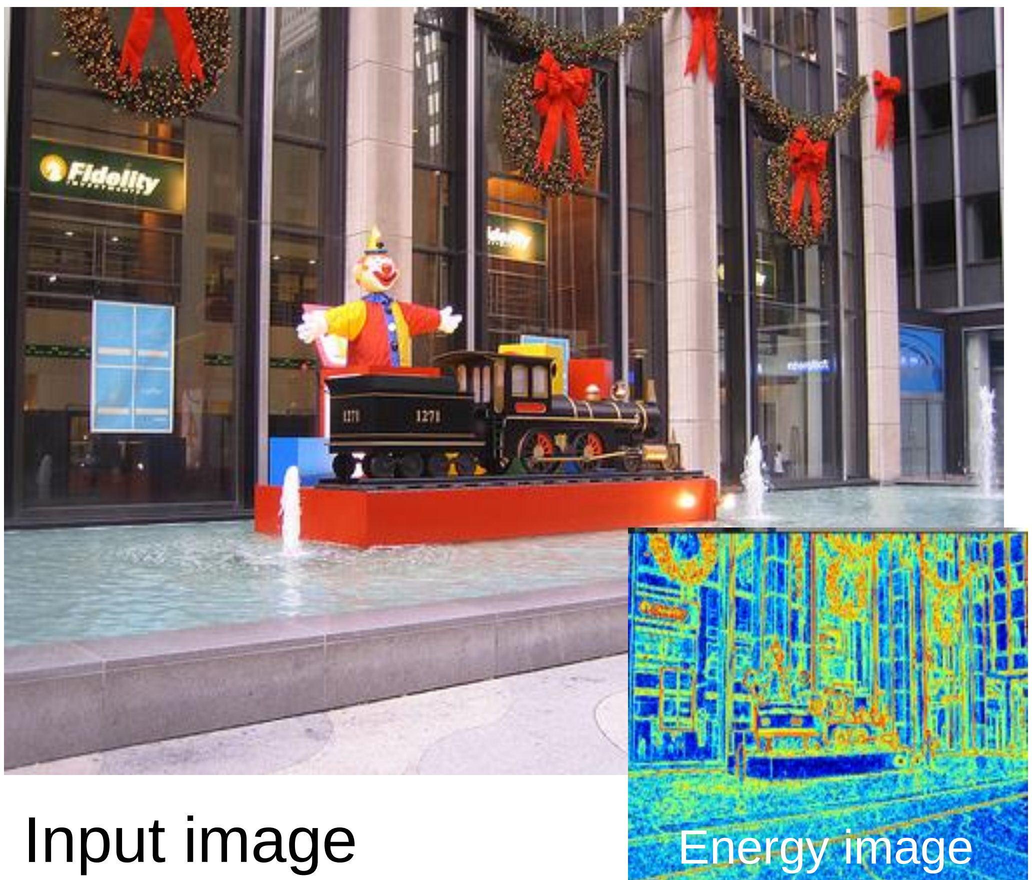
$$e_1(\mathbf{I}) = |\frac{\partial}{\partial x}\mathbf{I}| + |\frac{\partial}{\partial y}\mathbf{I}|$$

- Entropy
- HOG (Histogram of Gradient)
- Saliency
- …

Caviet: No single energy function performs well on ***all*** images

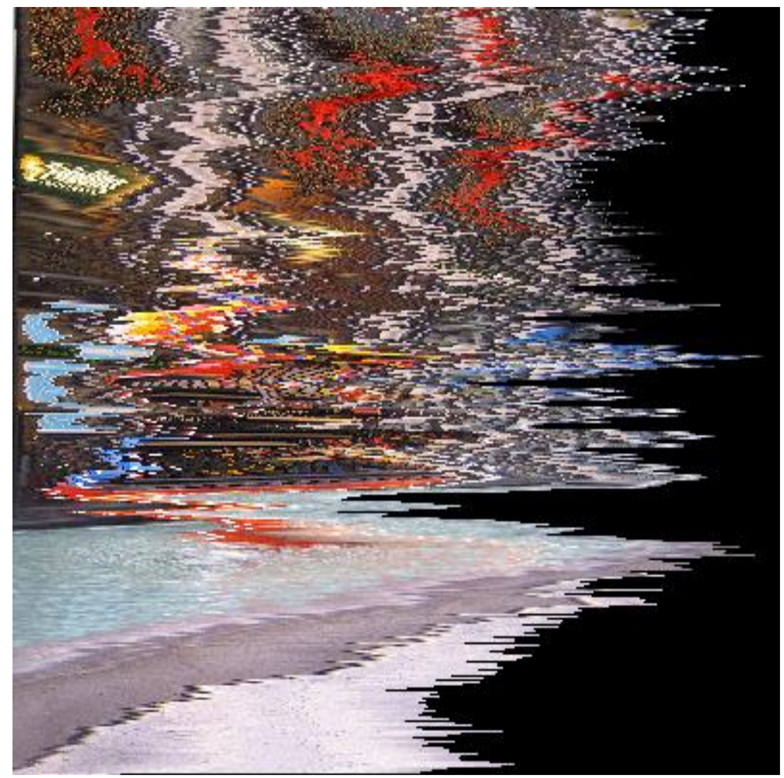
Pixel Removal Criteria

- **Optimal**: remove the *k* pixels with lowest energy
- Output image no longer rectangular



Input image

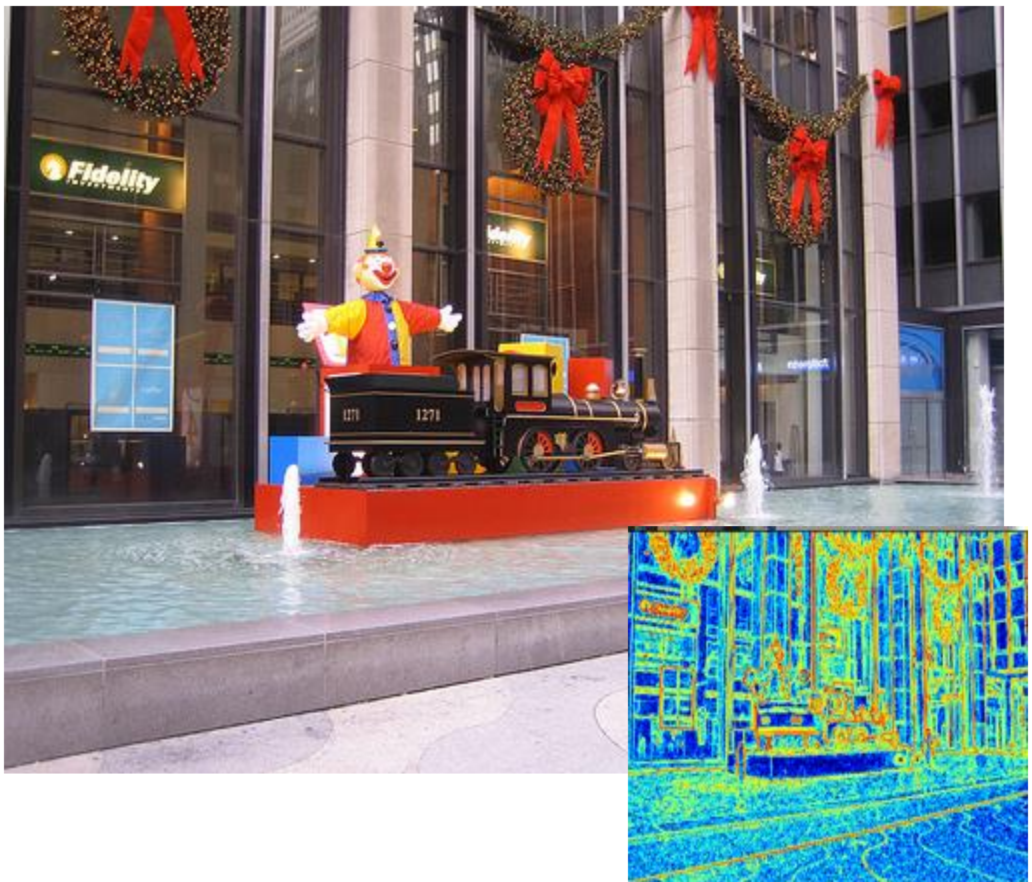
Energy image



Output image

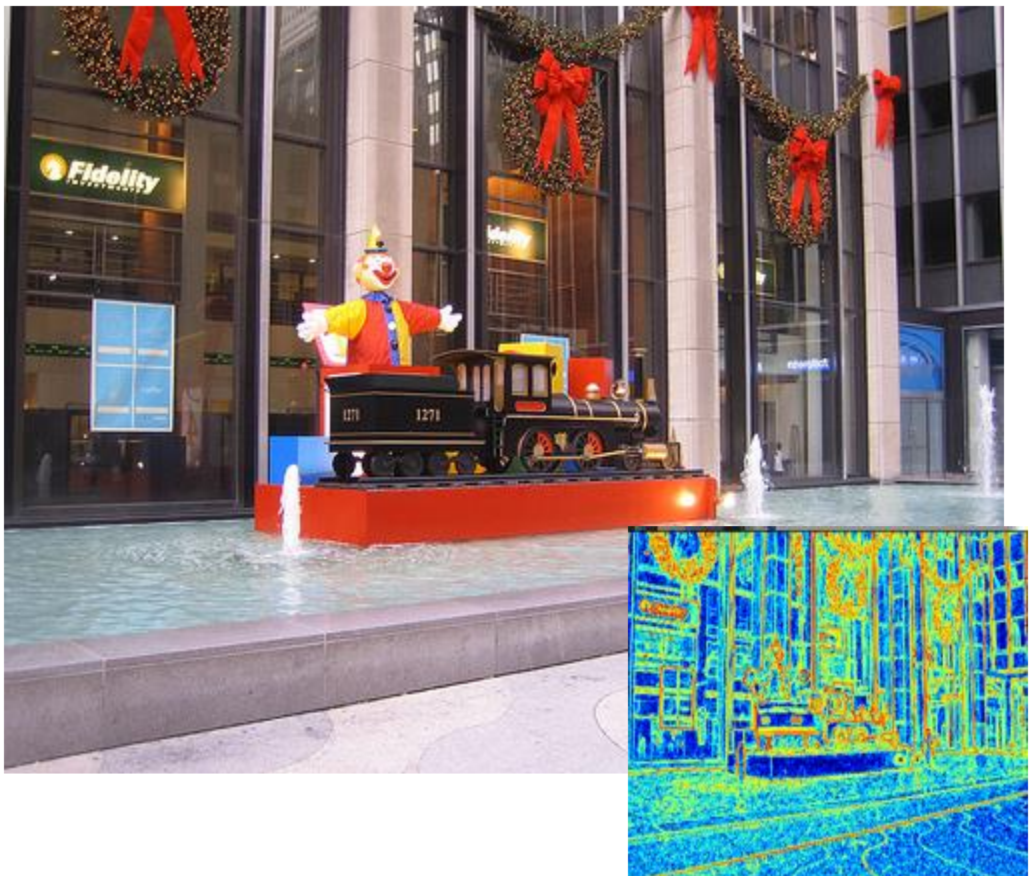
Pixel Removal Criteria

- **Pixel**: Remove *k* pixels with lowest energy in *each* row
- No visual coherence between adjacent rows



Pixel Removal Criteria

- **Column**: Remove whole column with lowest energy
- Frequently introduces artifacts



Seam Definition

- Vertical Seam

  is an 8-connected path of pixels in an *n* x *m* image from top to bottom, containing one, and only one, pixel in each row of the image:

$$\mathbf{s}^{\mathbf{x}} = \{s_i^x\}_{i=1}^{n} = \{(x(i), i)\}_{i=1}^{n}, \text{ s.t. } \forall i, |x(i) - x(i-1)| \leq 1$$

Seam Energy

- Energy of a Seam

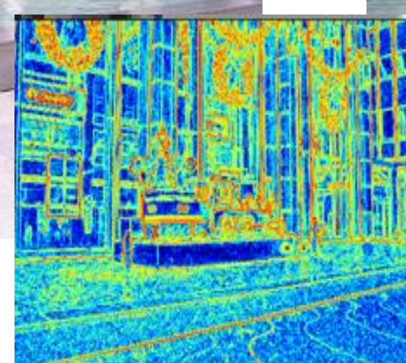
$$E(\mathbf{s}) = E(\mathbf{I_s}) = \sum_{i=1}^{n} e(\mathbf{I}(s_i))$$

- Minimum Energy Seam

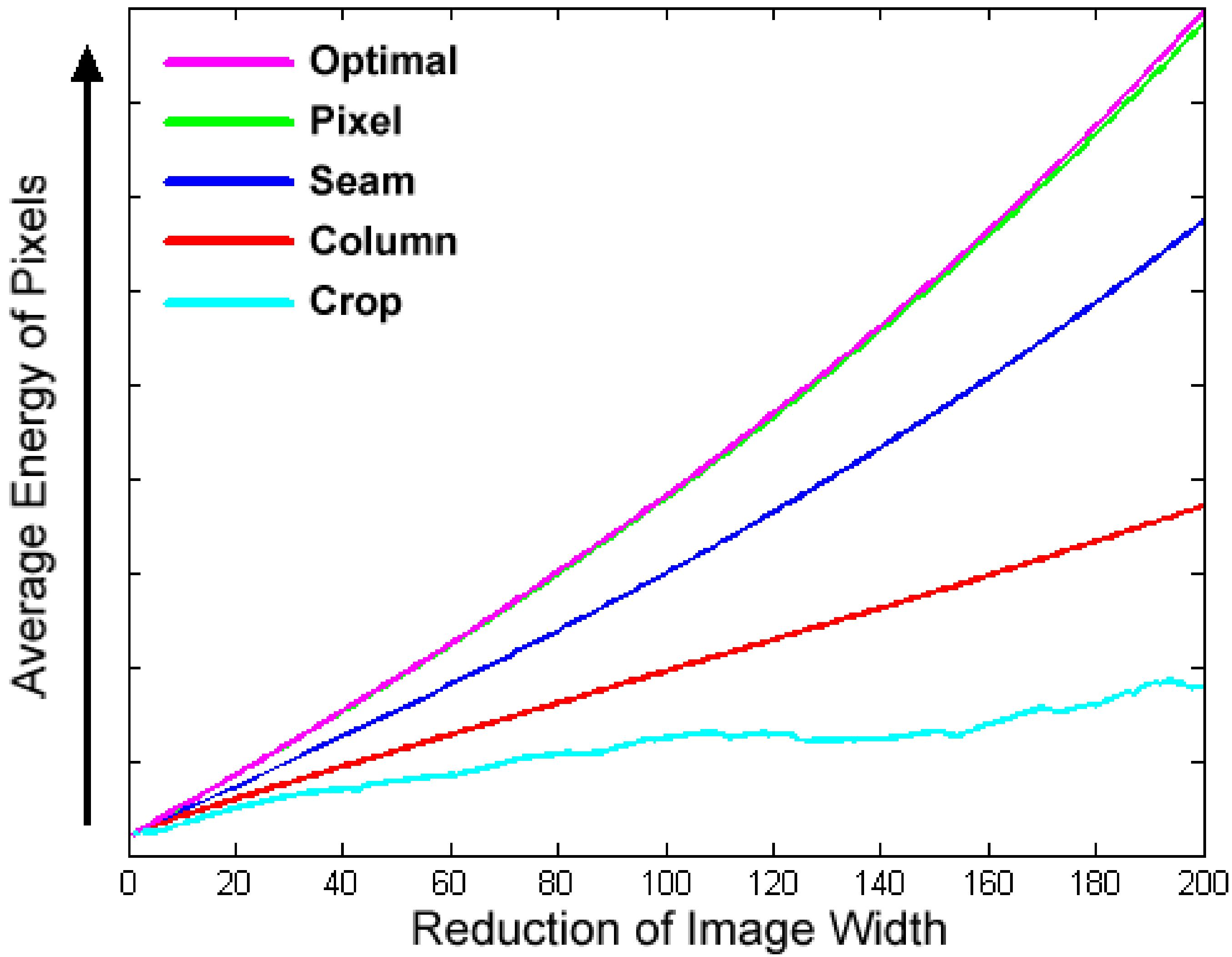
$$s^* = \min_{\mathbf{s}} E(\mathbf{s}) = \min_{\mathbf{s}} \sum_{i=1}^{n} e(\mathbf{I}(s_i))$$

Pixel Removal Criteria

- **Seam**: Remove the vertical curve of lowest energy



Pixel Removal Effectiveness

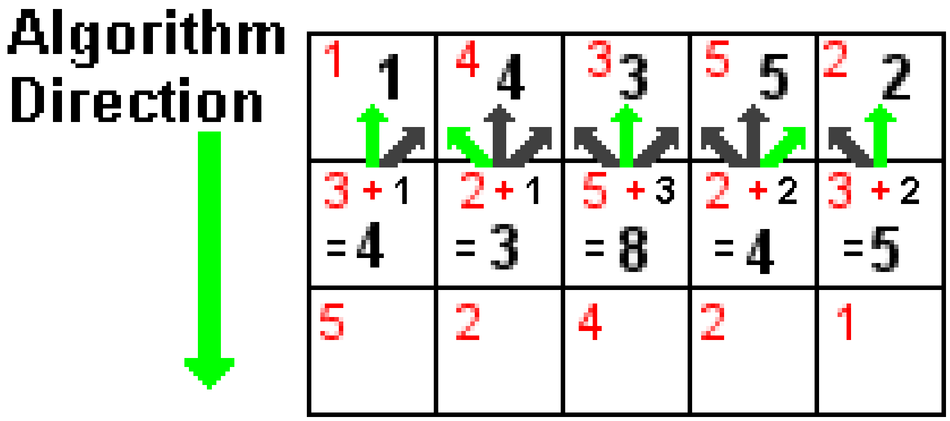


How to Efficiently Compute Best Seam?

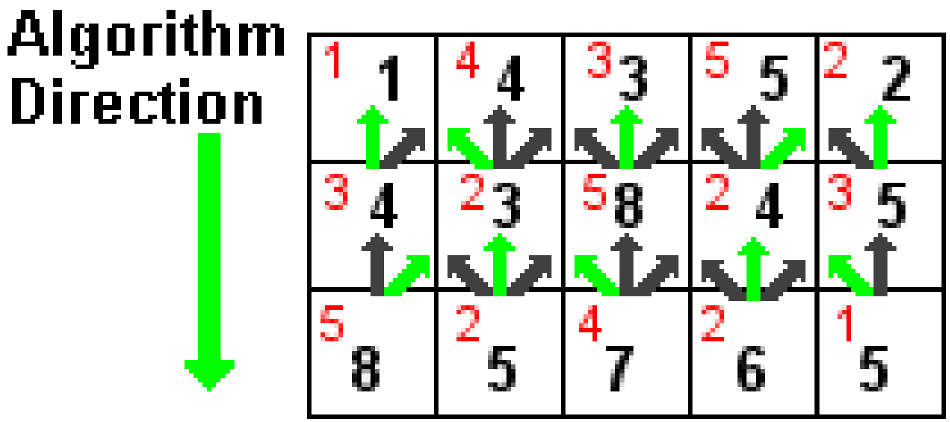
- Use **Dynamic Programming** to find lowest energy seam in linear time

1. **Forward Pass** (top row to bottom row for finding vertical seam)
   - Define $M(i, j)$ = total energy of path ending at (i, j)
   - $M(1, j) = e(1, j)$
   - $M(i, j) = e(i, j) + \min(M(i\text{-}1, j\text{-}1), M(i\text{-}1, j), M(i\text{-}1, j\text{+}1))$
   - $B(i, j) = \mathrm{argmin}_{k=j-1,\, j,\, j+1}\ M(i\text{-}1, k)$
   - Find minimum value in last row: $\min_j M(n, j)$
2. **Backward Pass** (bottom row to top row)
   - Trace back path from pixel in bottom row with min value to top row using B

Forward Pass

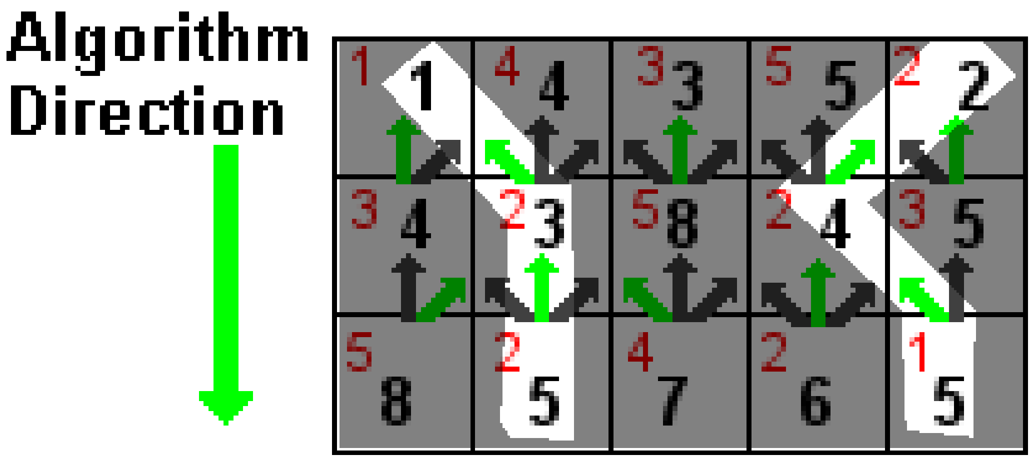


e = red numbe
M = black num
B = green arro



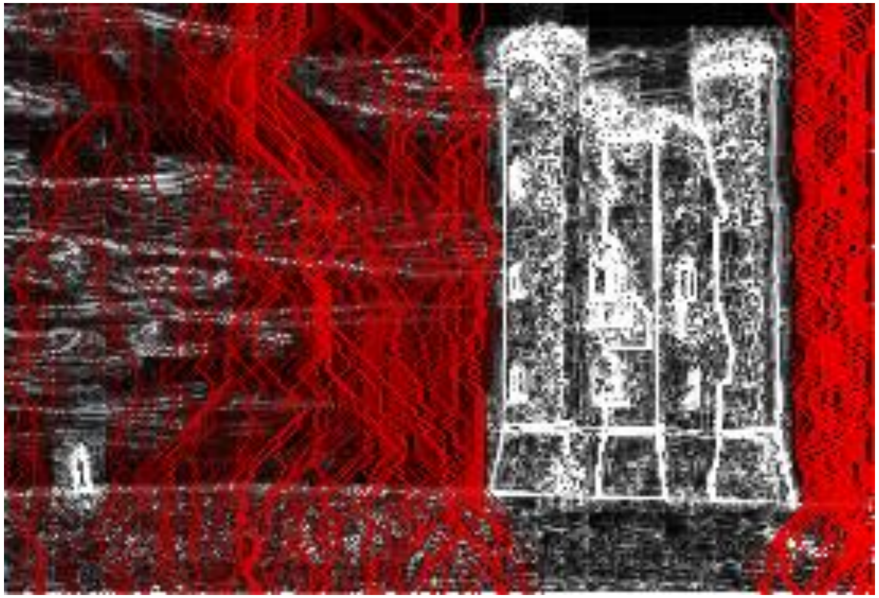
Credit: Wikipedia

Backward Pass



Credit: Wikipedia

Seams



Seams over energy image

Seams over input image

Shrink Image in 1 Dimension

- Change the image from size $n \times m$ to $n \times m'$
  - assume $m' < m$
- Remove $m\text{-}m' = c$ seams successively

Seam Carving

Shrink Image in 1 Dimension

- Change the image from size $n \times m$ to $n \times m'$
  - assume $m' < m$
- Remove $m\text{-}m' = c$ seams successively

Scaling

Shrink Image in Both Dimensions: Optimal Seam Ordering

- Change the image from size $n \times m$ to $n' \times m'$
  - assume $m' < m$ and $n' < n$
- What is the best order for seam carving?
  - Remove vertical seams first?
  - Horizontal seams first?
  - Alternate between the two?

Optimal Seam Ordering

- Solve optimization problem:

$$\min_{\mathbf{s^x},\mathbf{s^y},\alpha} \sum_{i=1}^{k} E(\alpha_i \mathbf{s_i^x} + (1-\alpha_i)\mathbf{s_i^y})$$

where $k = r+c$, $r = (m-m')$, $c = (n-n')$ and α_i is a parameter that determines if at step i we remove a horizontal or vertical seam: $\alpha \in \{0,1\}$

Enlarging Images

- Method 1: Compute the optimal vertical (horizontal) seam *s* in image and duplicate the pixels in *s* by averaging them with their left and right neighbors (top and bottom in the horizontal case)
- Often will choose the *same* seam at each iteration, producing noticeable stretching artifact

Enlarging Images

- Method 2: To enlarge width by *k*, compute top *k* vertical seams (for removal) and duplicate *each* of them

Content Amplification

- Scale the image; this will scale everything, “content” as well as “non-content”
- Shrink the scaled-image using seam carving, which will (hopefully) carve out the non-content part

Object Removal

- User marks the target object to be removed
- Force seams to pass through marked pixels
- Seams are removed from the image until all marked pixels are gone
- To obtain the original image size, use seam insertion

Object Removal

- One shoe removed (and image enlarged to original size)

input

Object Removal

- Object marking to prevent unwanted results: mark regions where seams must ***not*** pass

Multi-Size Images

- Methods mentioned so far are not real-time
- We calculate best seam, remove it, calculate the next seam based on new image, etc.
- For real-time resizing
  - Pre-compute removal order for every pixel in image
  - Compute Index map, V, of size $n \times m$ that encodes, for each pixel, the index of the seam that removed it, i.e., $V(i, j) = t$ means pixel (i, j) was removed by the t^{th} seam removal iteration

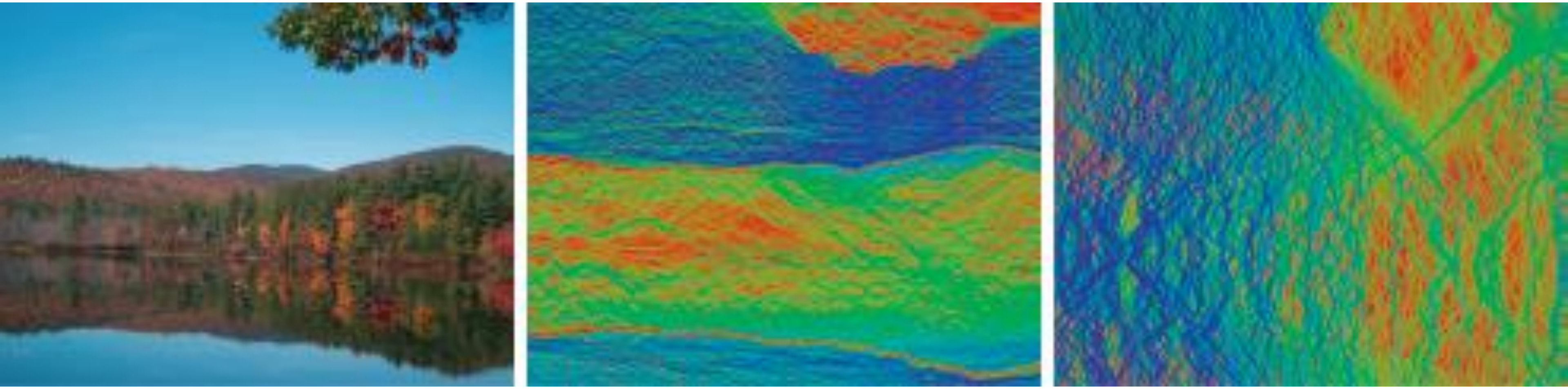
Multi-Size Images

- Horizontal Index map (H)
- Vertical Index map (V)

- To get an image of width m'
  - need to remove m-m' pixels from each row
  - concatenate, in each row, all pixels with seam index greater than or equal to $m-m'$

- Same for changing the height

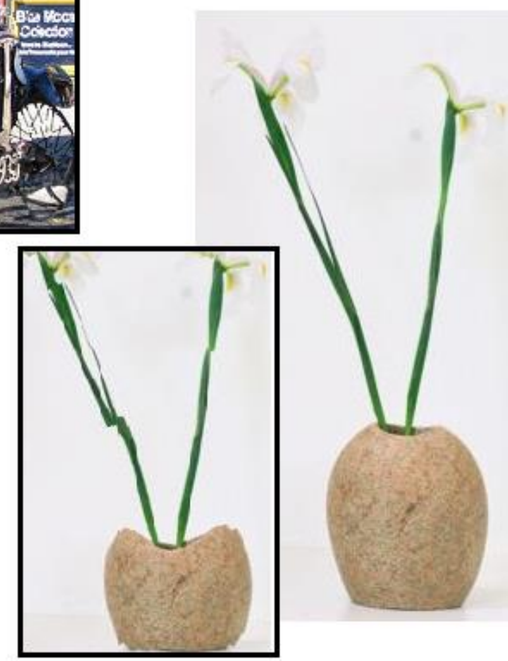
Seam Index Maps



Input H V

Blue seams are removed first, red seams removed last

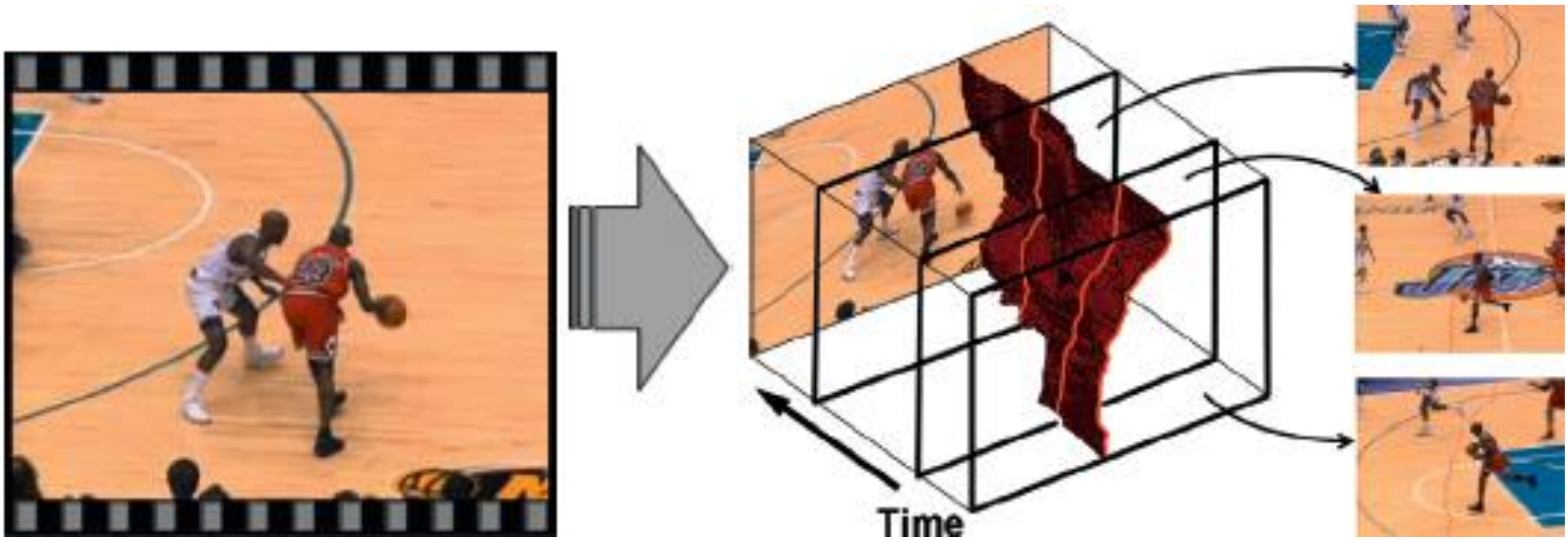
Failures



- Too much content
- No space for seam to avoid content

Video Resizing

- Resizing each frame independently is bad
- Instead, find 2D surface in 3D *x-y-t* video volume



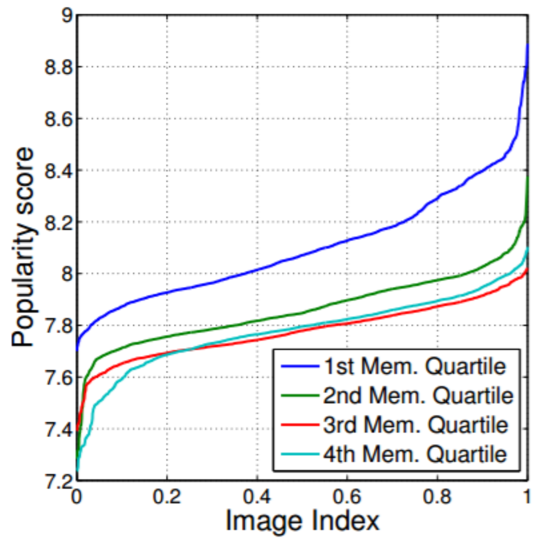
What next?

What makes a picture memorable?

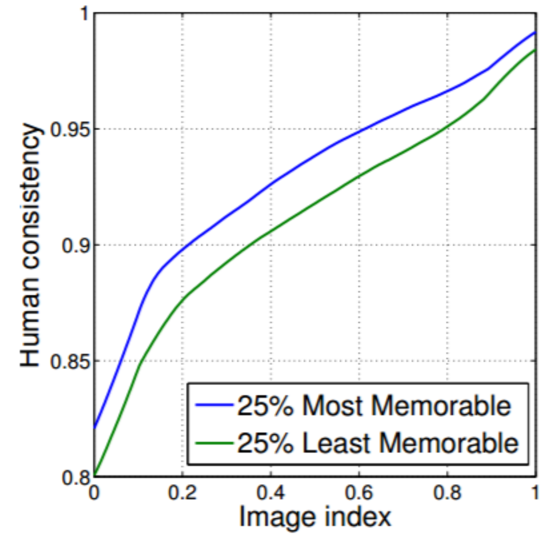
Most memorable images:
(top-left is most memorable…)

[Khosla et al. 2015]

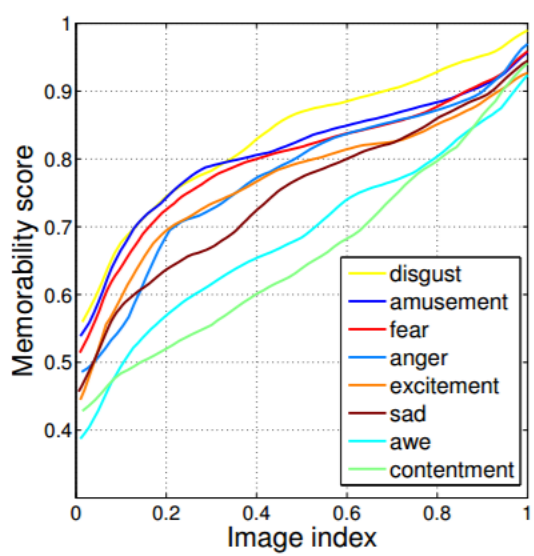
http://memorability.csail.mit.edu/



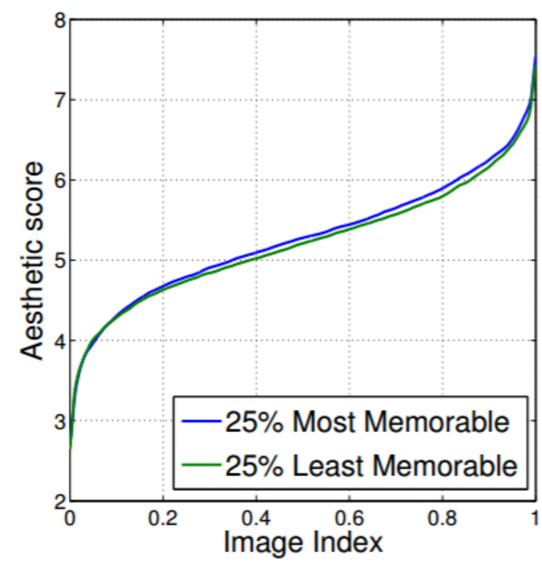
(a) Memorability vs popularity



(b) Memorability vs saliency



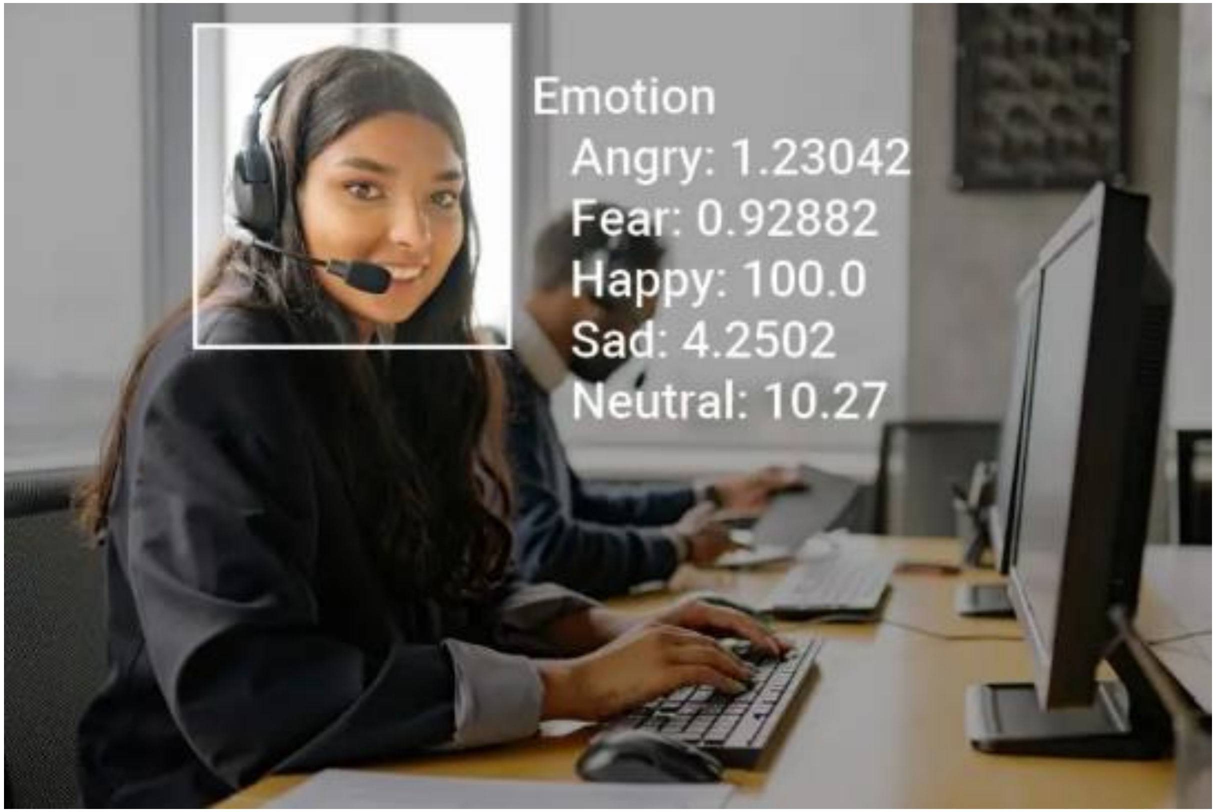
(c) Memorability vs emotions



(d) Memorability vs aesthetics

AI-Based Emotion Recognition

- https://viso.ai/deep-learning/visual-emotion-ai-recognition/
- https://openaccess.thecvf.com/content/CVPR2023W/LatinX/papers/de_Lima_Costa_High-Level_Context_Representation_for_Emotion_Recognition_in_Images_CVPRW_2023_paper.pdf



EmoGen: Emotional Image Content **Generation** with Text-to-Image Diffusion Models

- https://openaccess.thecvf.com/content/CVPR2024/papers/Yang_EmoGen_Emotional_Image_Content_Generation_with_Text-to-Image_Diffusion_Models_CVPR_2024_paper.pdf

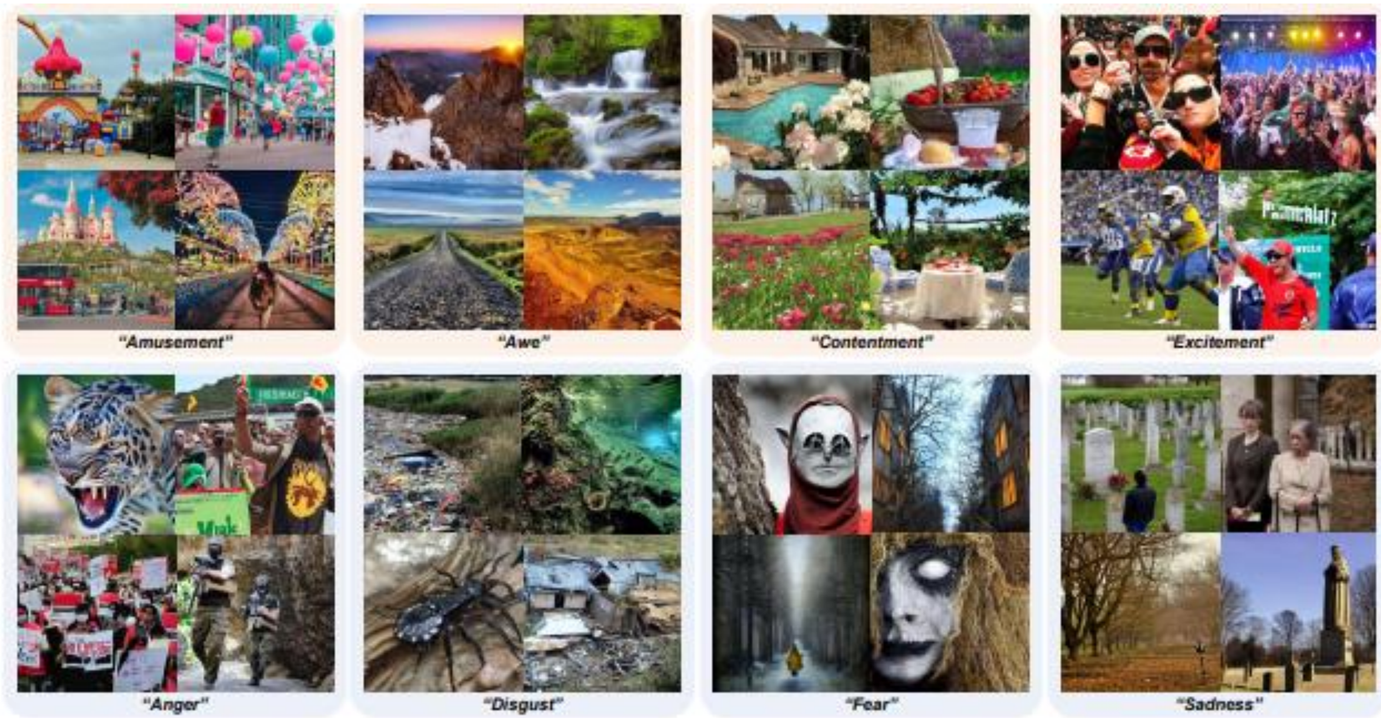


Figure 1. Emotional Image Content Generation (EICG). Given an emotion category, our network produces images that exhibit unambiguous meanings (*semantic-clear*), reflect the intended emotion (*emotion-faithful*) and incorporate varied semantics (*semantic-diverse*).

and More…

Mood Determination: urgency, emergency?