Seam-Carving

and Content-driven Retargeting of Images (and Video)

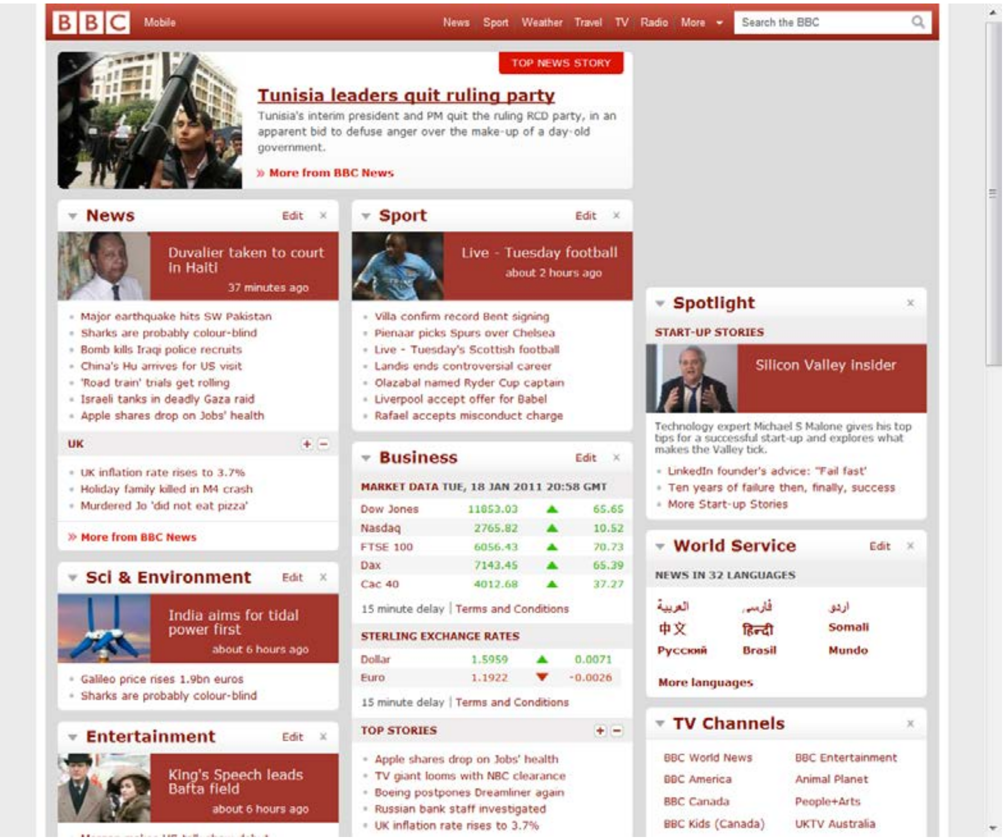
Michael Rubinstein

MIT

Some slides borrowed from Ariel Shamir and Shai Avidan

Display Devices

Content Retargeting



PC

iPhone

Page Layout

Page layout - Wikipedia, the free encyclopedia - Mozilla Firefox

File Edit View History Bookmarks Tools Help

http://en.wikipedia.org/wiki/Page_layout

Page Layout

Page layout - Wikipedia, the ...

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Page layout

From Wikipedia, the free encyclopedia

For the Wikipedia guideline on an articles' layout, see Wikipedia:Manual of Style (layout).

This article **does not cite any references or sources.**
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Page layout is the part of graphic design that deals in the arrangement and style treatment of elements (content) on a page.

Contents [hide]
1 History and development
2 Grids versus templates
3 Front-end versus back-end
4 See also

Consumer magazine sponsored advertisements and covers rely heavily on professional page layout skills to compete for visual attention.

History and development [edit]

Beginning from early illuminated pages in hand-copied books of the Middle Ages and proceeding down to intricate modern magazine and catalog layouts, proper page design has long been a consideration in printed material. With print media, elements usually consist of type (text), images (pictures), and occasionally place-holder graphics for elements that are not printed with ink such as die/laser cutting, foil stamping or blind embossing.

Since the advent of personal computing, page layout skills have expanded to electronic media as well as print media. The electronic page is better known as a graphical user interface (GUI) when interactive elements are included. Page layout for interactive media overlaps with (and is often called) interface design. This usually includes interactive elements and multimedia in addition to text and still images. Interactivity takes page layout skills from planning attraction and eye flow to the next level of planning user experience in collaboration with software engineers and creative directors.[citation needed]

A page layout may be designed in a rough paper and pencil sketch before producing, or produced during the design process to the final form. Both design and production may be achieved using hand tools or page layout software. Producing a web page may require knowledge of markup languages along with WYSIWYG editors to compensate for incompatibility between platforms. Special considerations must be made for how the layout of an HTML page will change (reflow) when resized by the end-user. Cascading style sheets are often required to keep the page layout consistent between web browsers.

Grids versus templates [edit]

Grids and templates are page layout design patterns used in advertising campaigns and multiple-page publications, including websites.

Done F110%

Simple Media Retargeting Operators

Letterboxing
Scaling

Content-aware Retargeting Operators

“Important” content

Content-*aware*

Content-*oblivious*

Content-aware Retargeting

Input

Scale

Crop

Content-aware

"less-Important" content

Image Retargeting

- **Problem statement:**
  - Input Image I nxm, and new size n'xm'
  - Output Image I' of size n'xm' which will be "good representative" of the original image I

- **To date, no agreed definition, or measure, as to what a good representative is in this context!**

Image/Video Retargeting

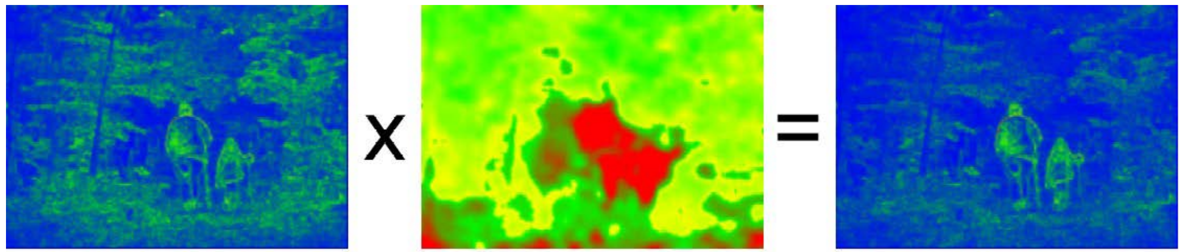
- **In large, we would expect:**

1. Adhere to the **geometric constraints** (display/aspect ratio)
2. Preserve the **important *content*** and *structures*
3. **Limit *artifacts***
4. **Perhaps a new representation that will support different sizes?**

- **Very Ill-posed!**
  - How do we define important? Is there a universal ground truth?
  - Would different viewers think the same about a retargeted image?
  - What about artistic impression in the original content?

Importance (Saliency) Measures

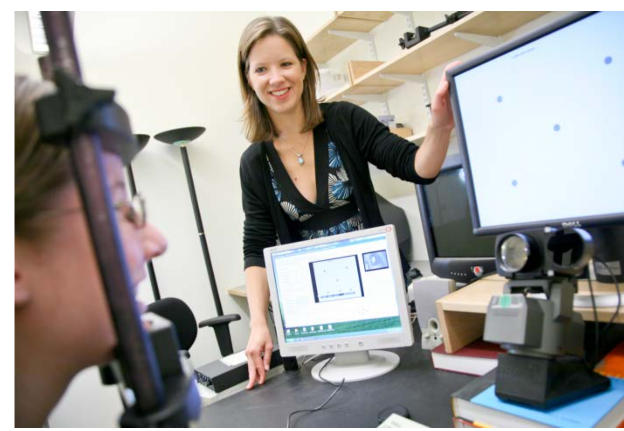
- **A function S: p → [0,1]**



Wang et al. 2008

- **More sophisticated: attention models, eye tracking (gazing studies), face detectors, …**

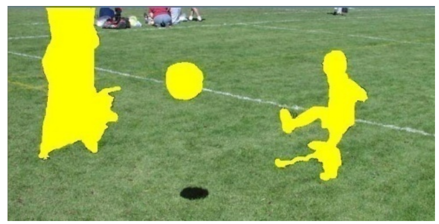
Judd et al. ICCV09 *Learning to predict where people look*



General Retargeting Framework

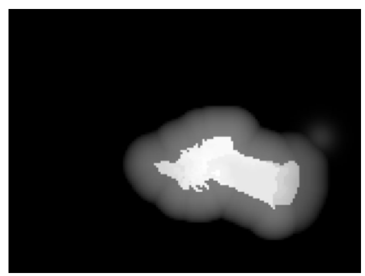
1. Define an energy function $\mathbf{E(I)}$ (interest, importance, saliency)

2. Use some operator(s) to change the image $\mathbf{I}$



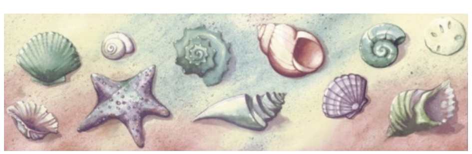
Recompose

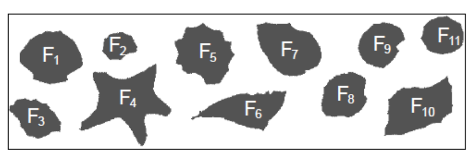
Setlur et al. [2005]



Crop

Santella et al. [2005]



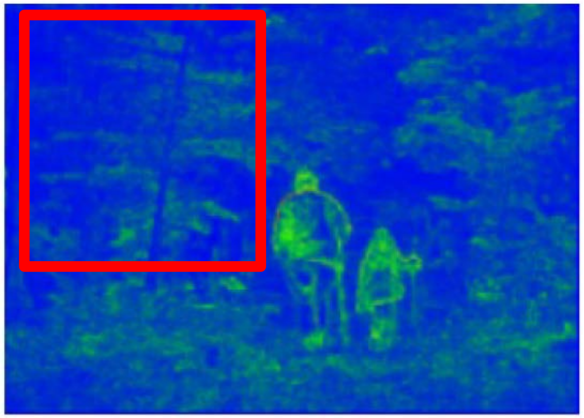


Warp

Gal et al. [2006]

Previous Retargeting Approaches

- **Optimal Cropping Window**



- **For videos: “Pan and scan”**

  Still done manually in the movie industry

Liu and Gleicher, **Video Retargeting: Automating Pan and Scan (2006)**

Cropping

Seam Carving

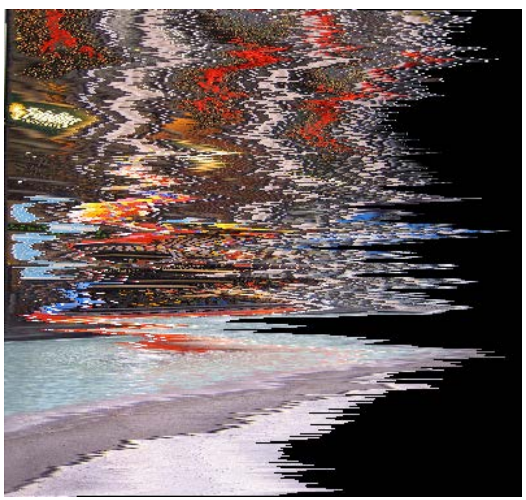
- **Assume m x n → m x n', n'<n (summarization)**

- **Basic Idea: remove unimportant pixels from the image**
  - Unimportant = pixels with less "energy"

$$E_1(\mathbf{I}) = |\frac{\partial}{\partial x}\mathbf{I}| + |\frac{\partial}{\partial y}\mathbf{I}|.$$

- **Intuition for gradient-based energy:**
  - Preserve strong contours
  - Human vision more sensitive to edges – so try remove content from smoother areas
  - Simple, enough for producing some nice results
  - See their paper for more measures they have used

Pixel Removal



Optimal

Least-energy pixels (per row)

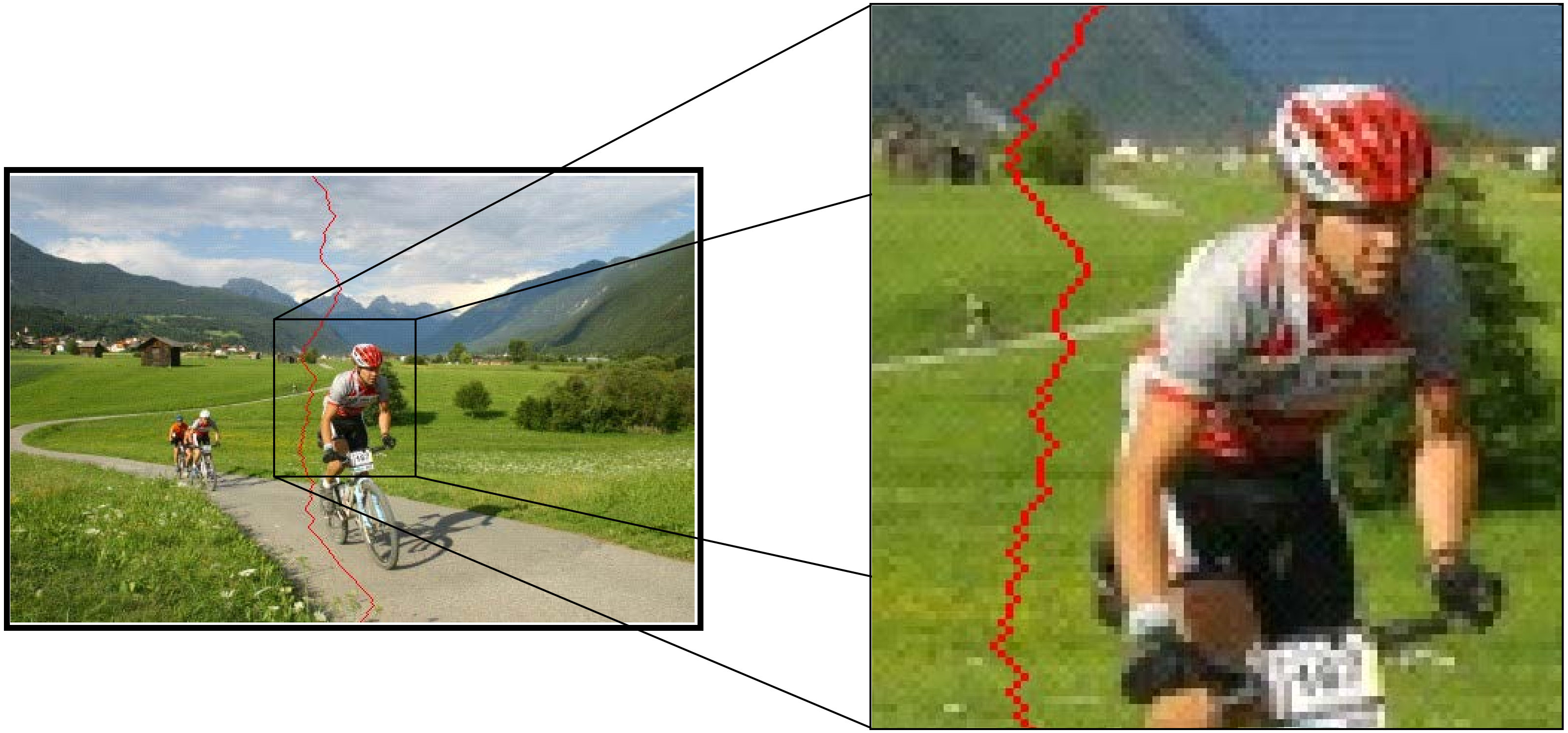
Least-energy columns

A Seam

- **A connected path of pixels from top to bottom (or left to right). Exactly one in each row**

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

$$\mathbf{s}^{\mathbf{y}} = \{s_j^y\}_{j=1}^m = \{(j, y(j))\}_{j=1}^m, \text{ s.t. } \forall j |y(j) - y(j-1)| \leq 1$$



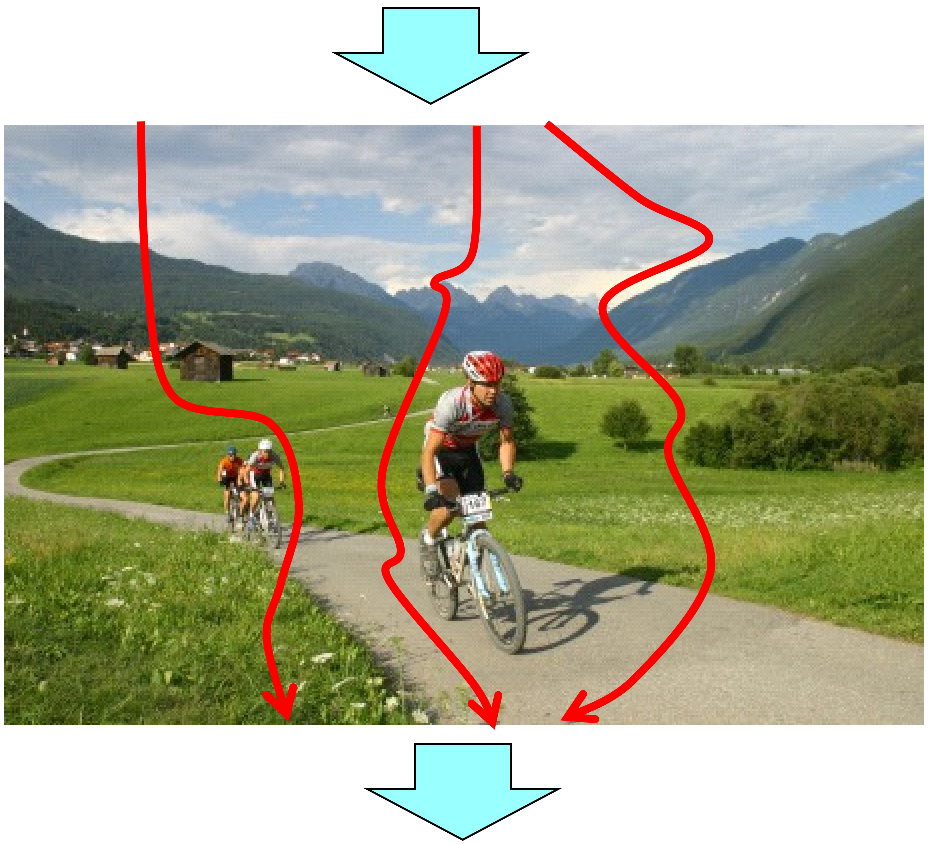
Seams in Images

- **Efros & Freeman [2001] – Texture synthesis**
- **Kwatra et al. [2003] – Image and video synthesis**
- **Agarwala et al. [2004] – Digital Photomontage**
- **Perez et**
- **Jia et al.**
- **Rother e**
- **Wang and Cohen [2006] – simultaneous matting and compositing**

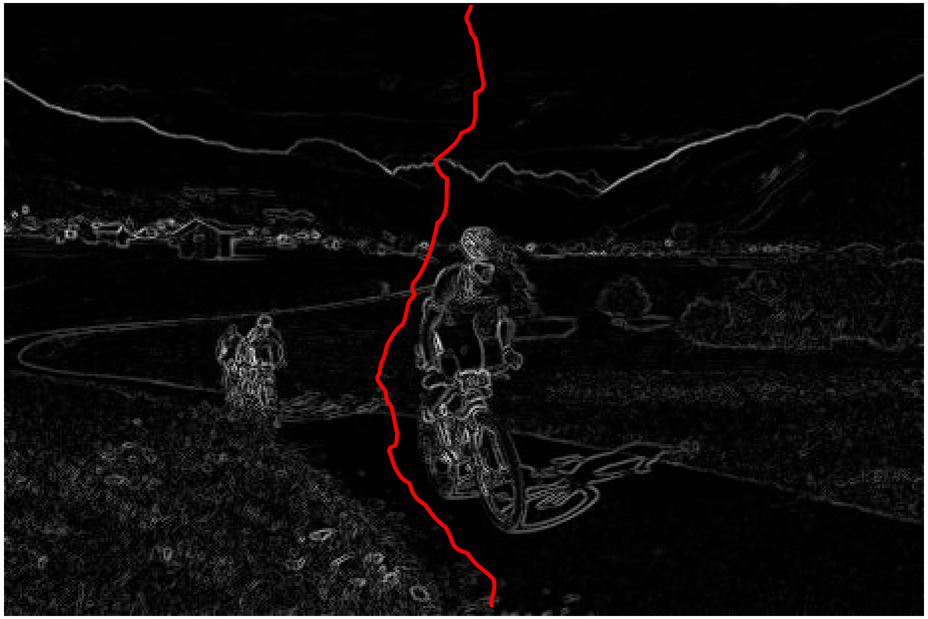
Mostly used for composition of two (or more) images or patches…

Agarwala et al., *Interactive Digital Photomontage*

Finding the Seam?



The Optimal Seam



$$E(\mathbf{I}) = \left|\frac{\partial}{\partial x}\mathbf{I}\right| + \left|\frac{\partial}{\partial y}\mathbf{I}\right| \Rightarrow s^* = \arg\min_s E(s)$$

The Optimal Seam

- **The recursion relation**

$$\mathbf{M}(i,j) = E(i,j) + \min\big(\mathbf{M}(i-1,j-1), \mathbf{M}(i-1,j), \mathbf{M}(i-1,j+1)\big)$$

- **Can be solved efficiently using dynamic programming in** $O(s \cdot n \cdot m)$

  (s=3 in the original algorithm)

Dynamic Programming

- **Invariant property:**
  - M(i,j) = minimal cost of a seam going through (i,j) (satisfying the seam properties)

5	8	12	3
9	2	3	9
7	3	4	2
4	5	7	8

Dynamic Programming

$$\mathbf{M}(i,j) = E(i,j) + \min\big(\mathbf{M}(i-1,j-1), \mathbf{M}(i-1,j), \mathbf{M}(i-1,j+1)\big)$$

5	8	12	3
9	2+5	3	9
7	3	4	2
4	5	7	8

Dynamic Programming

$$\mathbf{M}(i,j) = E(i,j) + \min\big(\mathbf{M}(i-1,j-1), \mathbf{M}(i-1,j), \mathbf{M}(i-1,j+1)\big)$$

5	8	12	3
9	7	3+3	9
7	3	4	2
4	5	7	8

Dynamic Programming

$$\mathbf{M}(i,j) = E(i,j) + \min\left(\mathbf{M}(i-1,j-1), \mathbf{M}(i-1,j), \mathbf{M}(i-1,j+1)\right)$$

5	8	12	3
9	7	6	12
14	9	10	8
14	14	15	8+8

Searching for Minimum

- **Backtrack (can store choices along the path, but do not have to)**

5	8	12	3
9	7	6	12
14	9	10	8
14	14	15	16

Backtracking the Seam

5	8	12	3
9	7	6	12
14	9	10	8
14	14	15	16

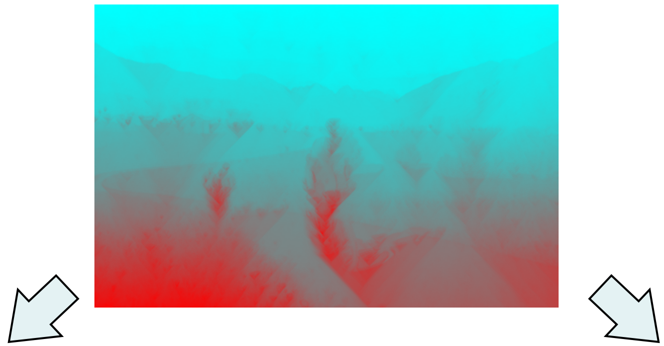
Backtracking the Seam

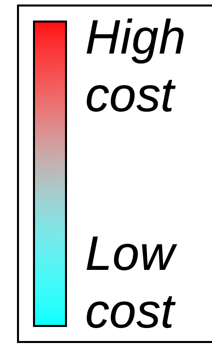
5	8	12	3
9	7	6	12
14	9	10	8
14	14	15	16

Backtracking the Seam

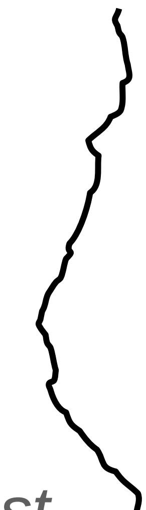
5	8	12	3
9	7	6	12
14	9	10	8
14	14	15	16

H & V Cost Maps





Horizontal Cost



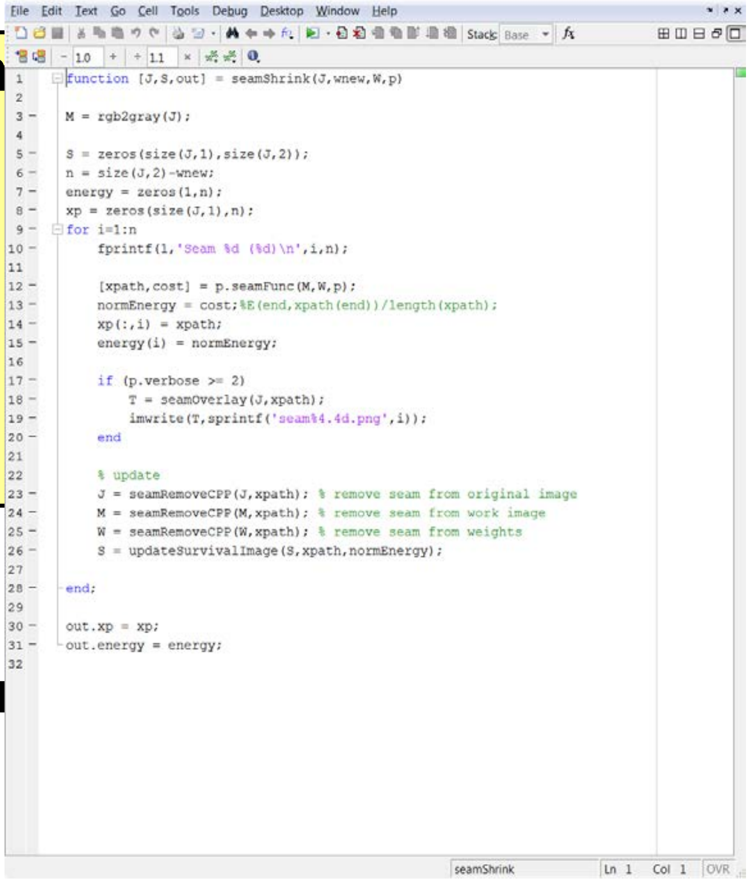
Vertical Cost

Seam Carving

The Seam-Carving Algorithm

SEAM-CARVING(im,n') // size(im) = n

1. **Do (n-n') times**
   - 2.1. E ← Compute energy map on im
   - 2.2. s ← Find optimal seam in E
   - 2.3. im ← Remove s from im
2. **Return im**



- **For vertical resize: transpose the i**
- **Running time:**

  2.1 O(mn) 2.2 O(mn) 2.3 O(mn)

  ➔O(dmn)   d=n-n'

Changing Aspect Ratio

Changing Aspect Ratio

Original

Seam Carving

Scaling

Changing Aspect ratio

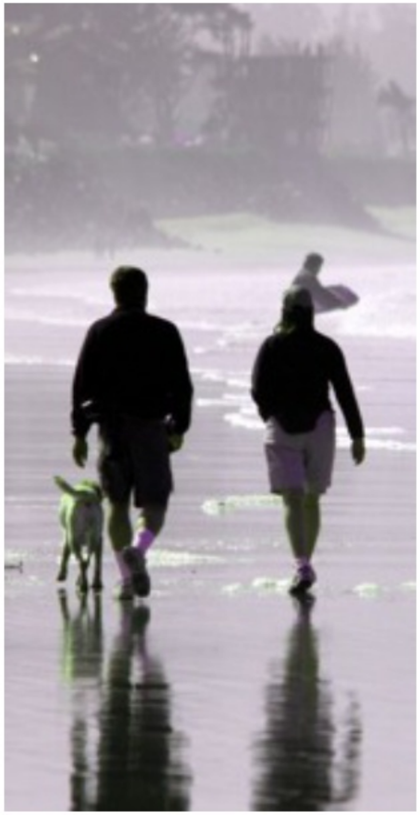
Cropping

Seams

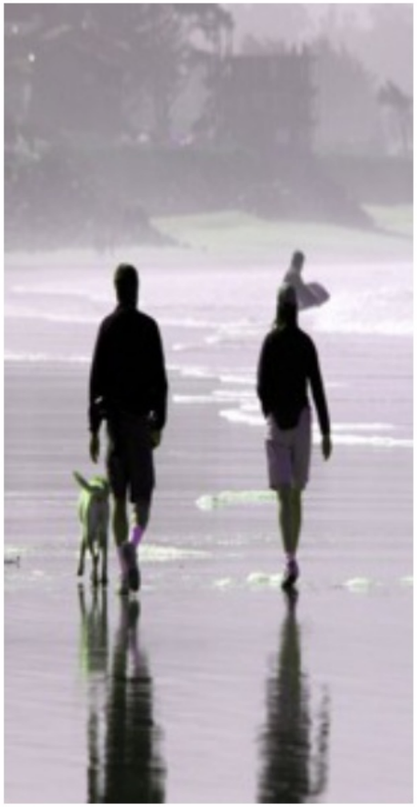
Scaling

Changing Aspect Ratio

Original



Retarget



Scaling

Changing Aspect Ratio

Original

Retarget

Scaling

Content Enhancement

Seam Carving in the Gradient Domain

Questions?

- **Q: Will the result be the same if the image is flipped upside down?**
- **A: Yes (up to numerical stability)**

- **Q: Can we improve the running time?**
- **A: Yes. by factor (account for locality of operations)**

A Local Operator

Questions?

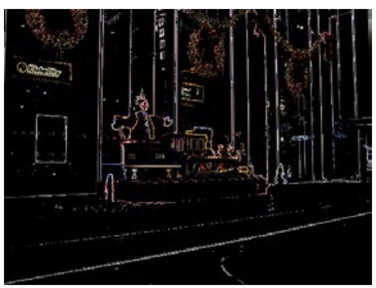
- **Q: Will the result be the same if the image is flipped upside down?**
- **A: Yes (up to numerical stability)**

- **Q: Can we improve the running time?**
- **A: By factor (local operations)**

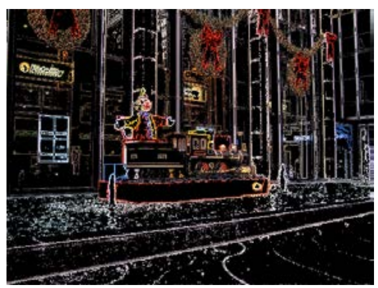
- **Q: What happens to the overall energy in the image during seam carving?**

Preserved Energy

Energy



10%



30%

40%

75%

While resizing: remove ***as many*** low energy pixels and ***as few*** high energy pixels!

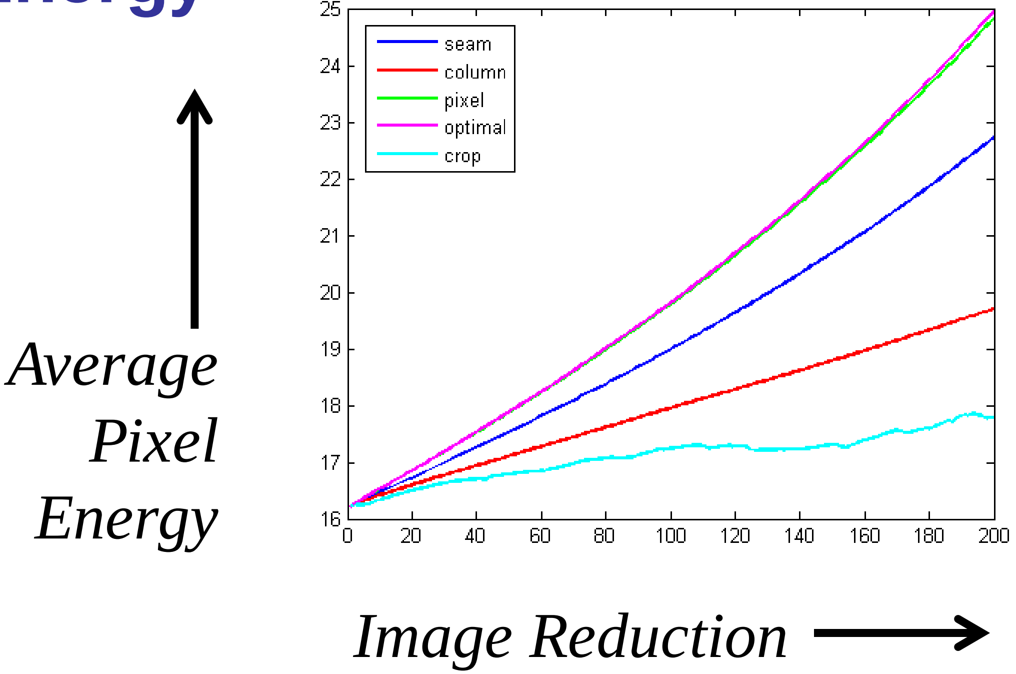
Preserved Energy

If we measure the average energy of pixels in the image after applying a resizing operator…

…the average should increase!

While resizing: remove ***as many*** low energy pixels and ***as few*** high energy pixels!

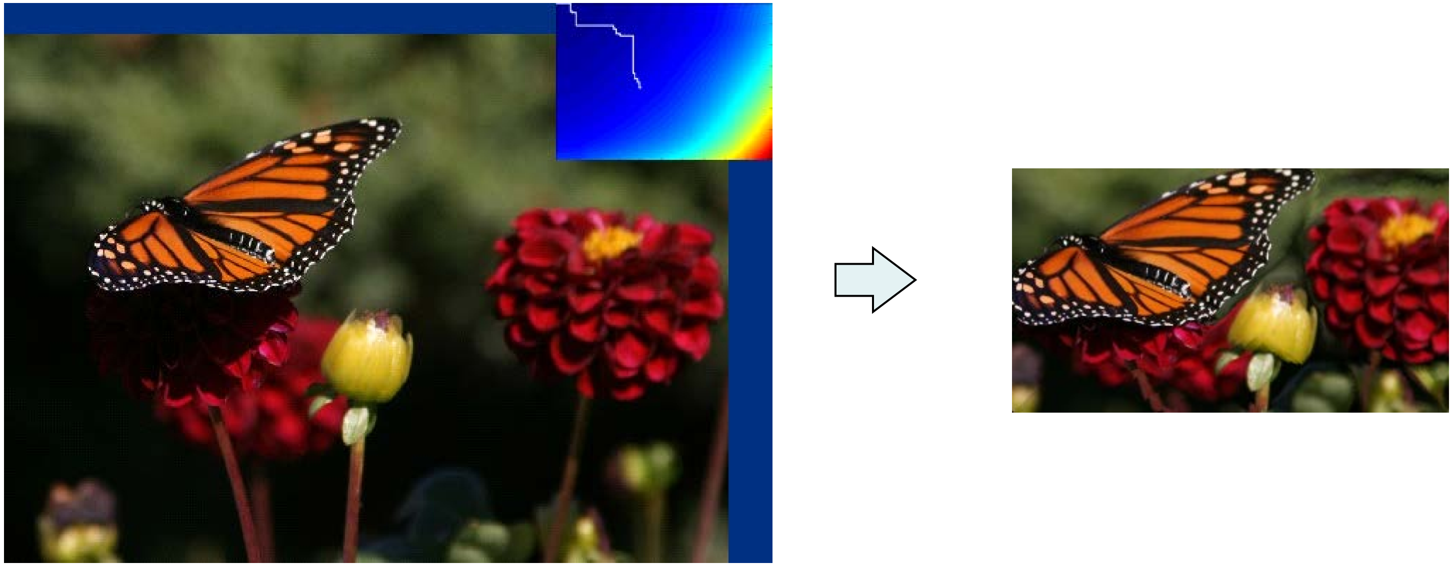
Preserved Energy



Both Dimensions?

- **m x n → m' x n'**

- **Remove horizontal seam first?**
- **Remove vertical seams first?**
- **Alternate between the two?**
- **The optimal order can be found! → Dynamic Prog (again)**

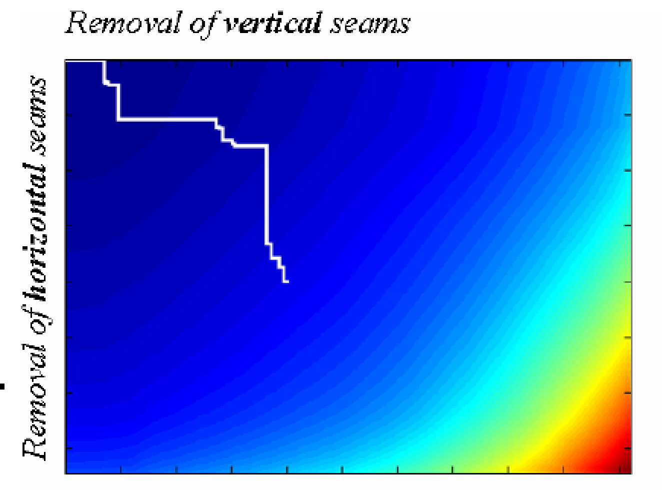


Retargeting in Both Dimensions

- **The recursion relation:**

$$\begin{aligned}\mathbf{T}(r,c) \quad = \quad & min(\mathbf{T}(r-1,c) + E(\mathbf{s^x}(\mathbf{I_{n-r-1\times m-c}})),\\ & \mathbf{T}(r,c-1) + E(\mathbf{s^y}(\mathbf{I_{n-r\times m-c-1}})))\end{aligned}$$

Optimal Order Map



Removal of ***vertical*** *seams*

Removal of ***horizontal*** *seams*

0	13	16	19		
16	17	22	28		
19	31	25	35		
24	28	29	???		
32	35	33			
41	38	35			

Optimal?

- **In a greedy sense…**

- **Seam costs are not absolute**
  - Consider HVV (how many possibly orderings?)
  - Cost(V) on HV not necessarily equal Cost(V) on VH
  - But we keep track of only one: min(HV,VH)…

Vertical Seams

Horizontal Seams

0	V	VV
H	min(HV,VH)	?

Image Expansion (Synthesis)

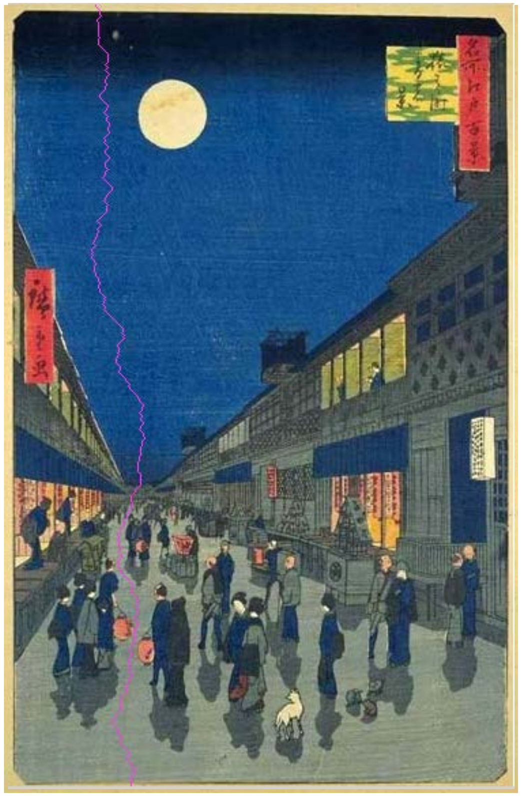


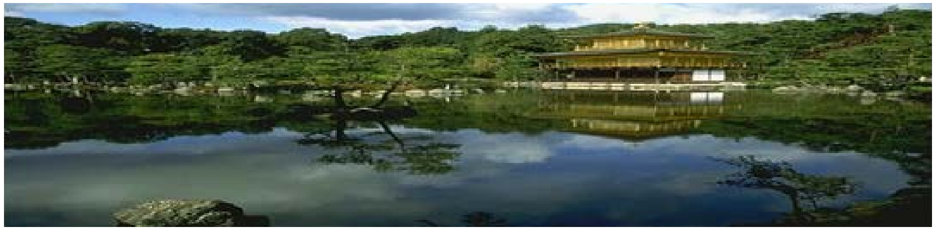
Image Expansion – take 2

Scaling

Enlarged or Reduced?

Combined Insert and Remove

Insert & remove seams



Scaling

Questions?

Multi-Size Images

- **We can create a new *representation* of an image that will allow adapting it to different sizes!**

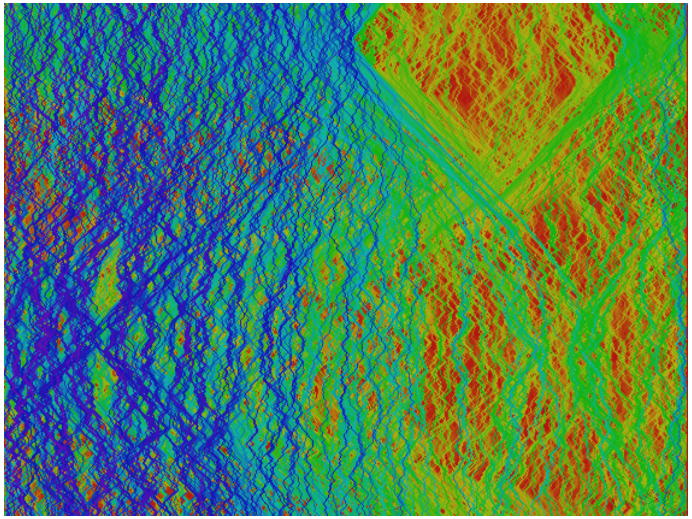
1. Precompute all seams once
2. Realtime resizing / transmit with content

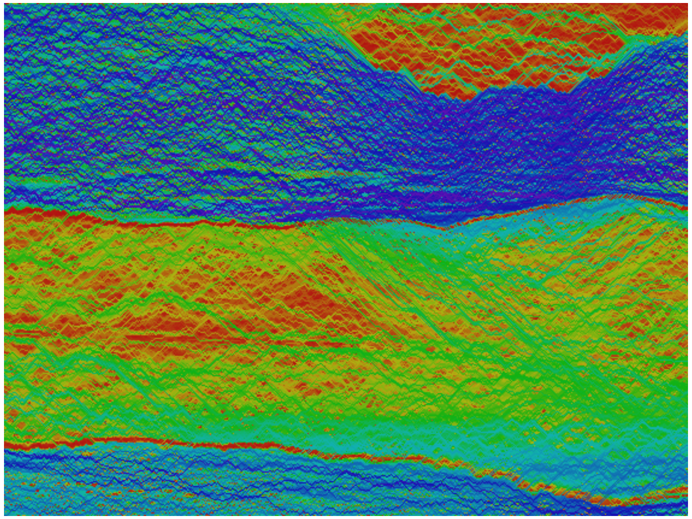
Multi-Size Images

First to be removed

•
•
•

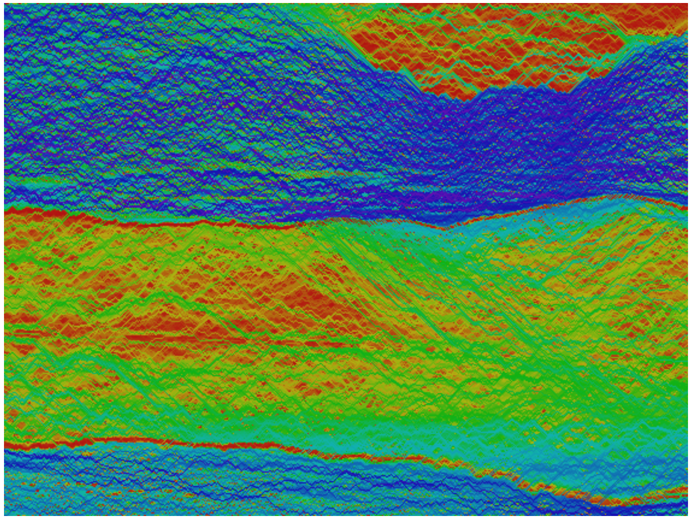
Last to be removed



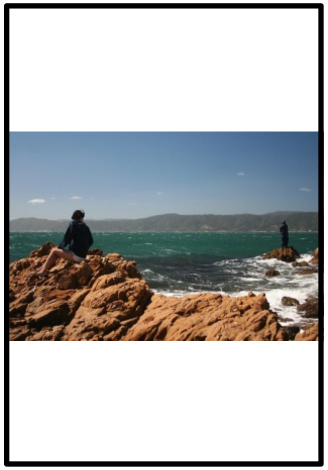


Multi-Size Image Representation

+



Multi-Size Image Representation



2D Multi-Size Representation?

- **Consistent index maps (see appendix in their paper)**

- **Alternatives**
  – Use seams in one direction, row/column seams in the other direction
  – Compute seams in one direction and use them to constrain seams in the other direction
    - If you can do that you'll have a nice publication ☺

Auxiliary Energy

- **Recall our seam equation**

$$\mathbf{M}(i,j) = E(i,j) + \min\left(\mathbf{M}(i-1,j-1), \mathbf{M}(i-1,j), \mathbf{M}(i-1,j+1)\right)$$

With face detector

With User Constraints

Object Removal

Object Removal

Input | Retargeted | Pigeon Removed | Girl Removed

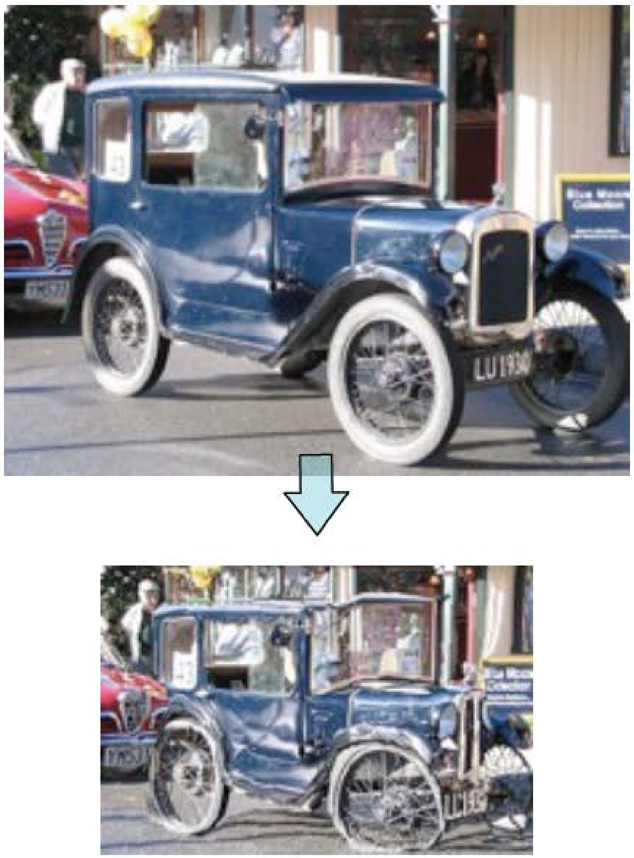
Find the Missing Shoe!



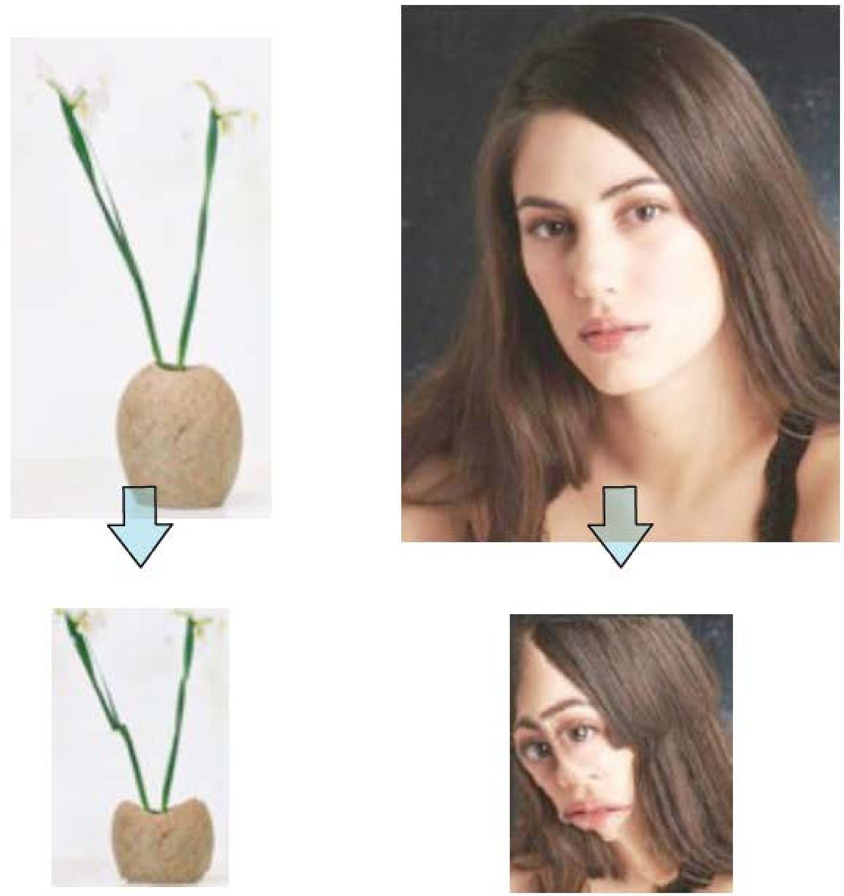

Solution

Limitations

Content



Structure



Preserved Energy - Revisited

Average Pixel Energy

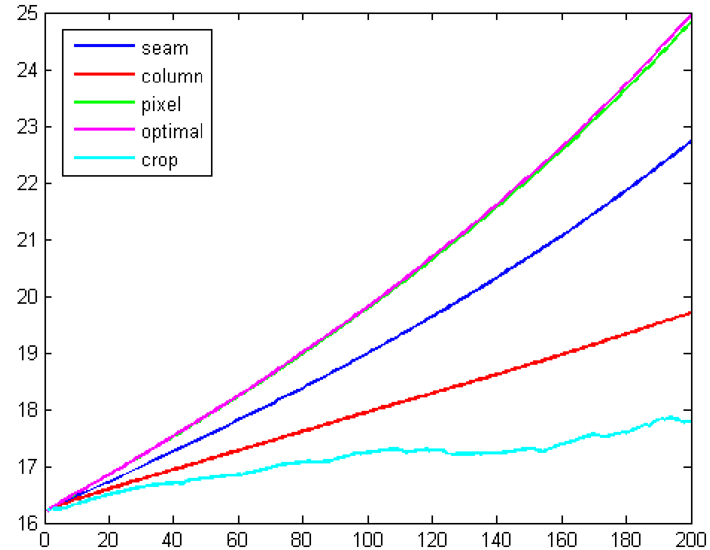


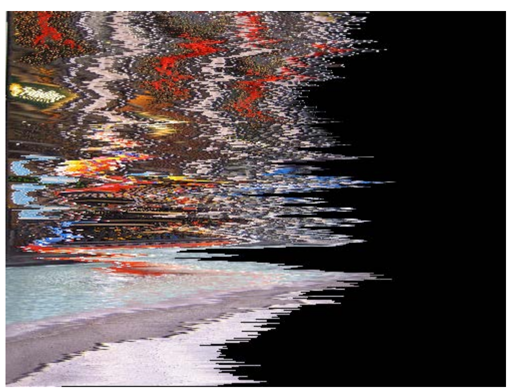
Image Reduction

crop

column

seam

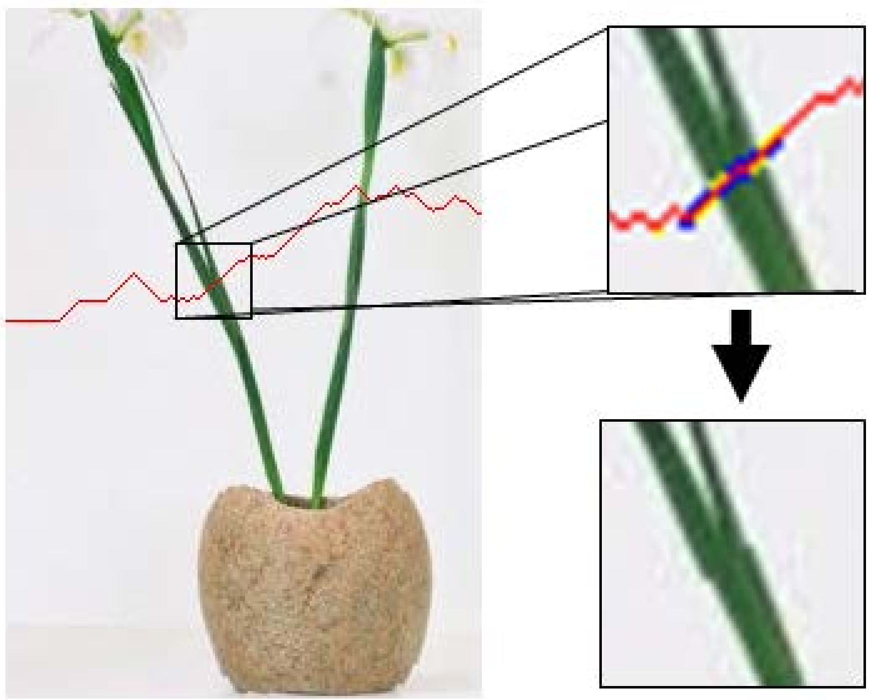
pixel

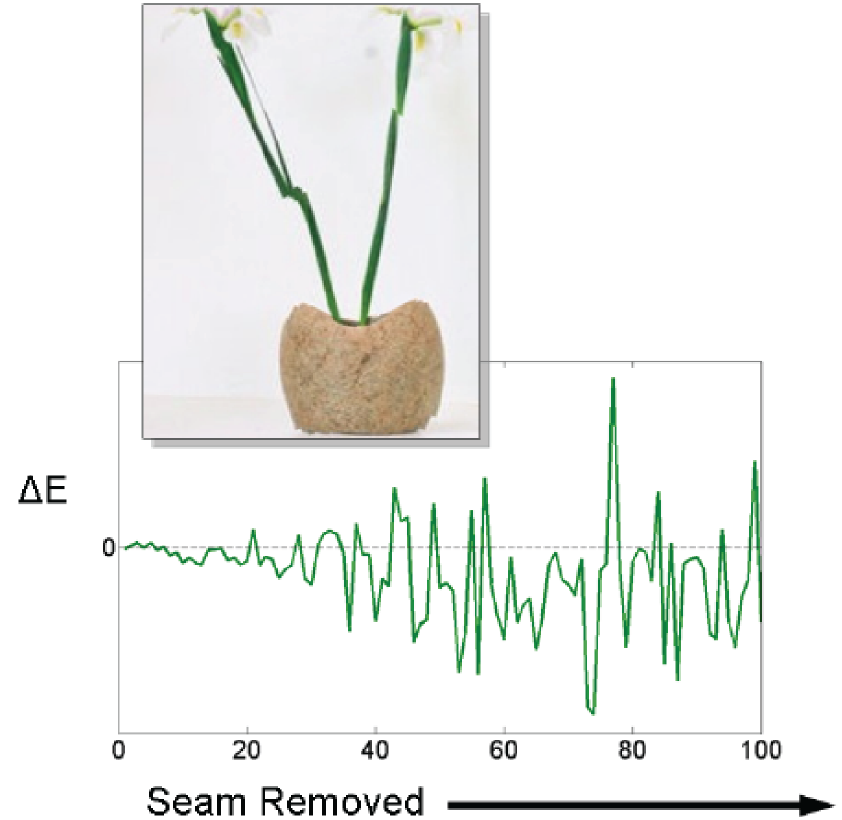


optimal

Michael Rubinstein — MIT CSAIL – mrub@mit.edu

Inserted Energy

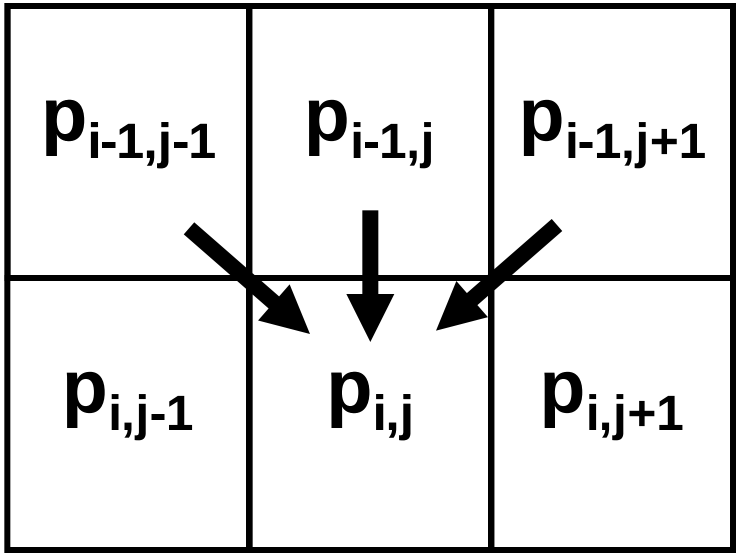




Minimize Inserted Energy

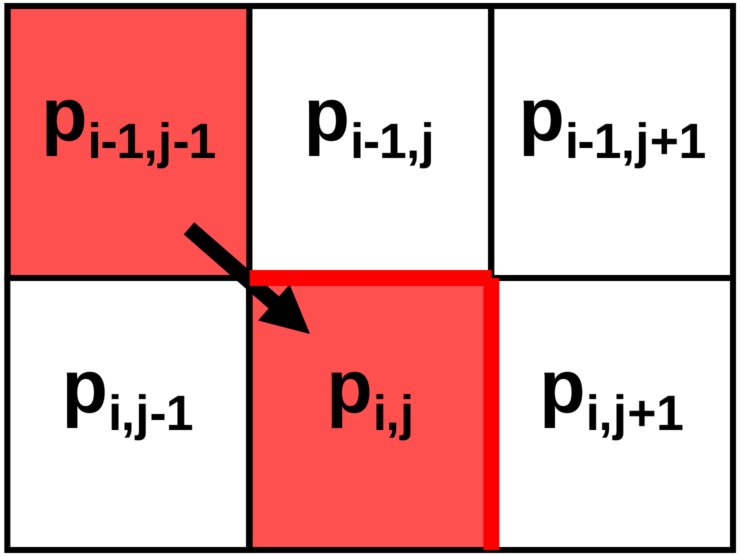
- **Instead of removing the seam of least energy, remove the seam that *<u>inserts the least energy</u>* to the image !**

Tracking Inserted Energy



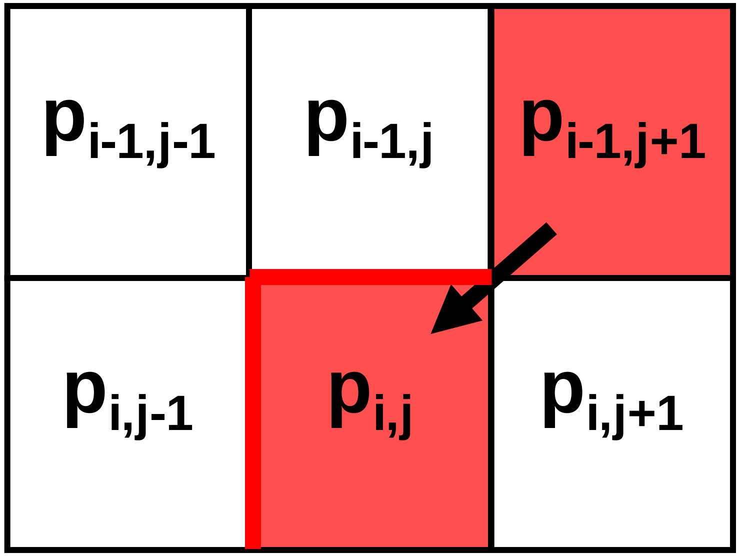
- **Three possibilities when removing pixel $P_{i,j}$**

Pixel $P_{i,j}$: Left Seam



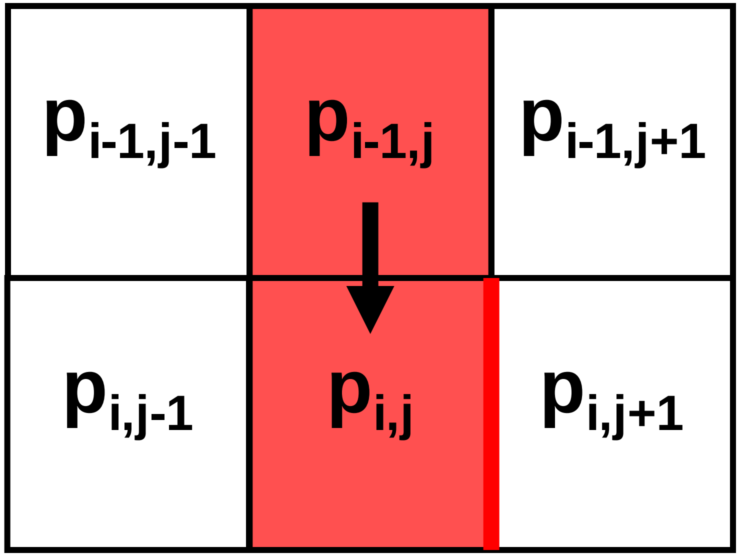
$$C_L(i,j) = |I(i,j+1) - I(i,j-1)| + |I(i-1,j) - I(i,j-1)|$$

Pixel $P_{i,j}$: Right Seam



$$C_R(i,j) = |I(i,j+1) - I(i,j-1)| + |I(i-1,j) - I(i,j+1)|$$

Pixel $P_{i,j}$: Vertical Seam



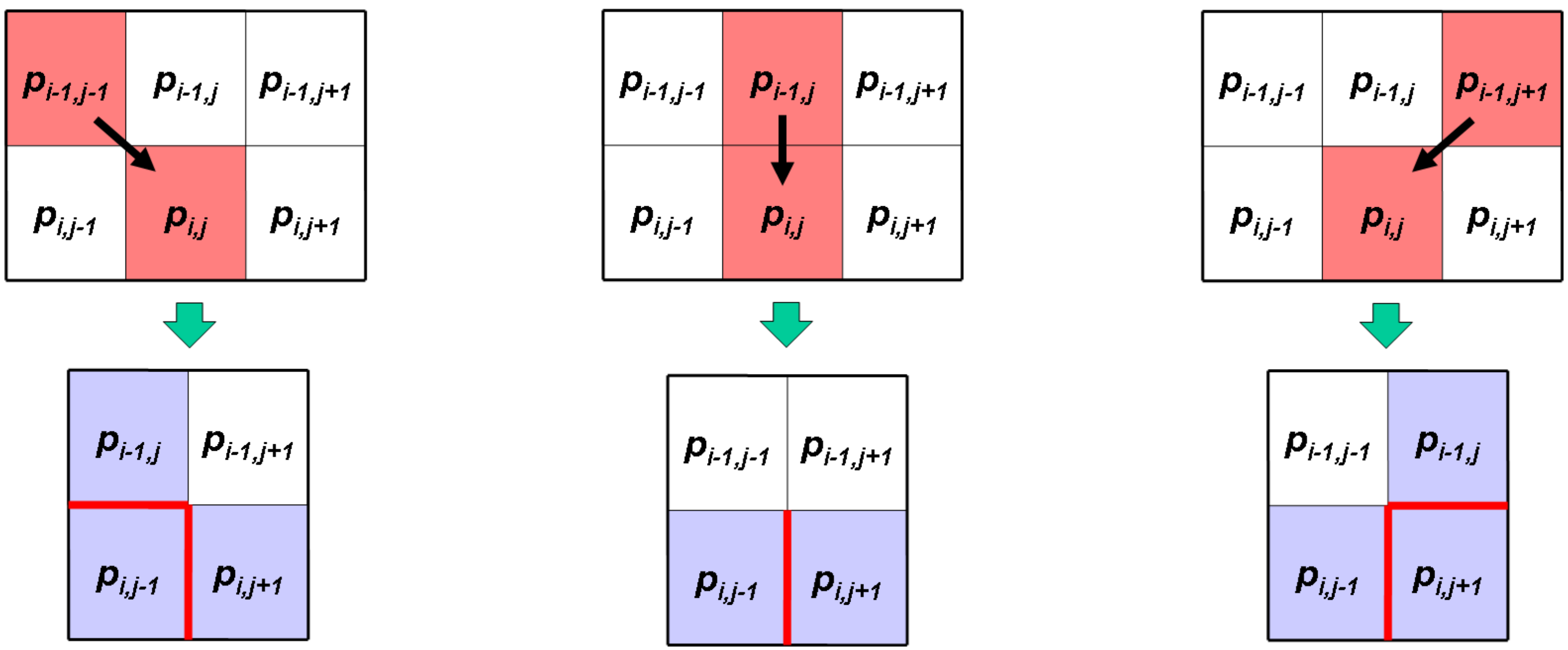
$$C_V(i,j) = |I(i,j+1) - I(i,j-1)|$$

Old "Backward" Energy

$$M(i,j) = E(i,j) + \min \begin{cases} M(i-1, j-1) \\ M(i-1, j) \\ M(i-1, j+1) \end{cases}$$

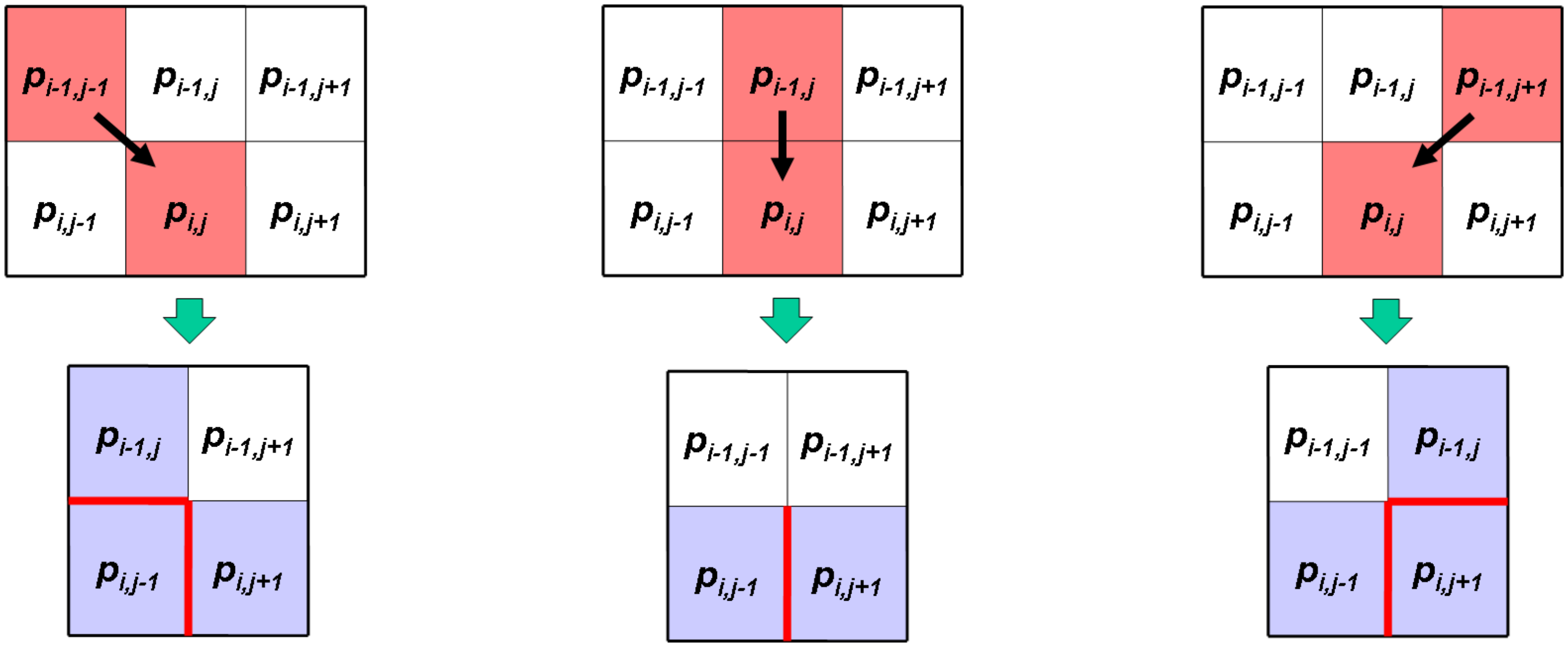
New Forward Looking Energy

$$M(i,j) = \min \begin{cases} M(i-1,j-1) + C_L(i,j) \\ M(i-1,j) + C_U(i,j), \\ M(i-1,j+1) + C_R(i,j) \end{cases}$$

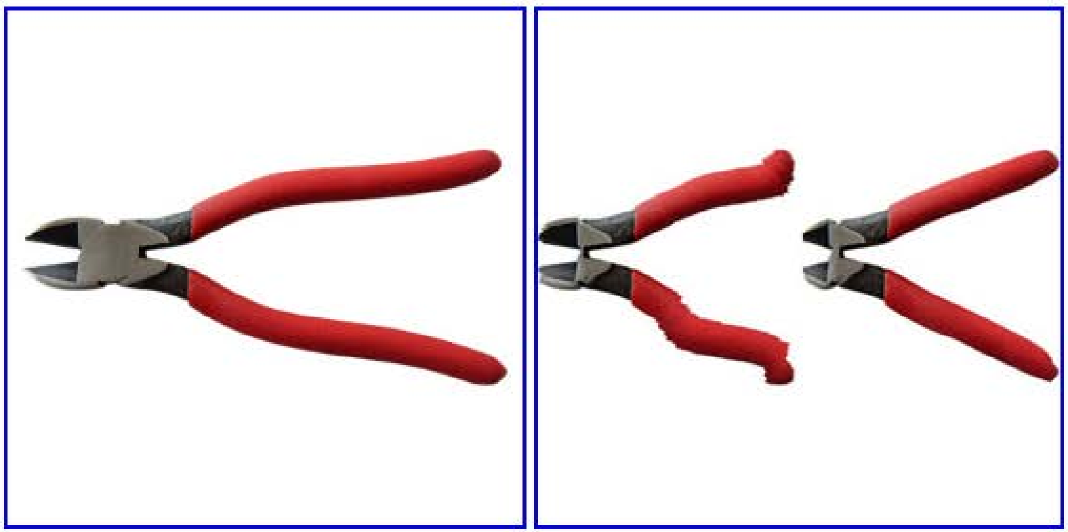


Adding “Pixel Energy”

$$M(i,j) = P(i,j) + \min \begin{cases} M(i-1,j-1) + C_L(i,j) \\ M(i-1,j) + C_U(i,j), \\ M(i-1,j+1) + C_R(i,j) \end{cases}$$

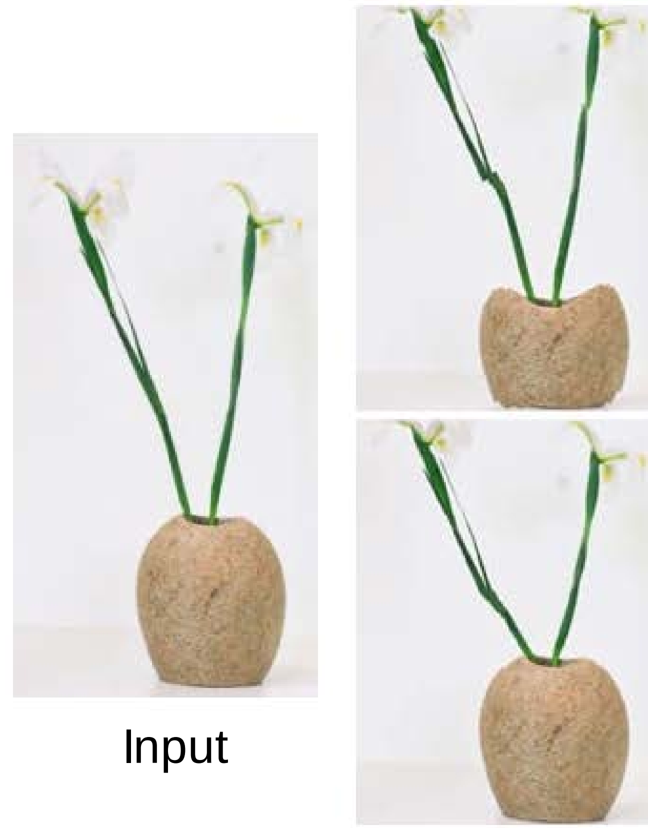


Results



Input   Backward   Forward

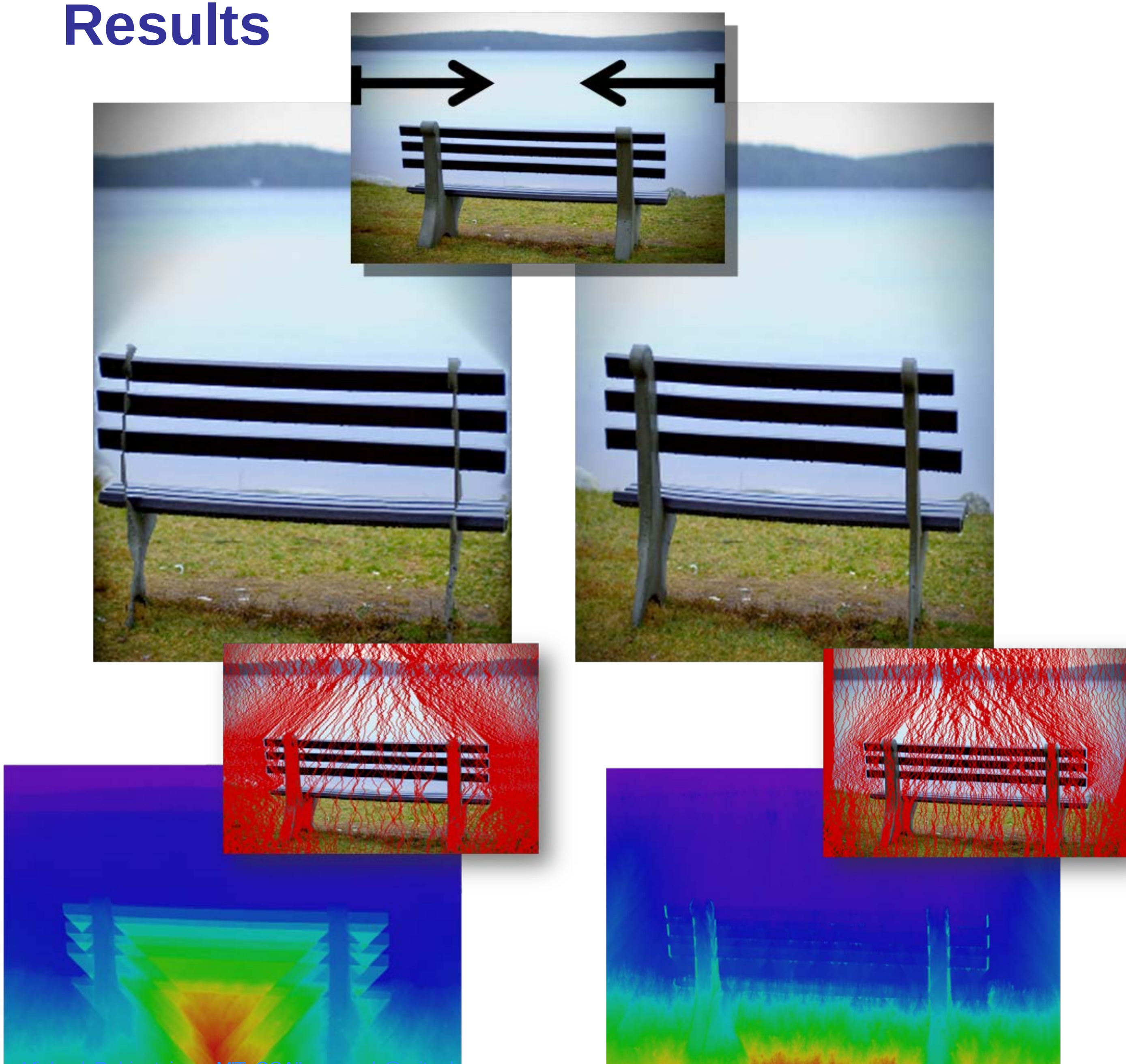
Backward



Input

Forward

Results

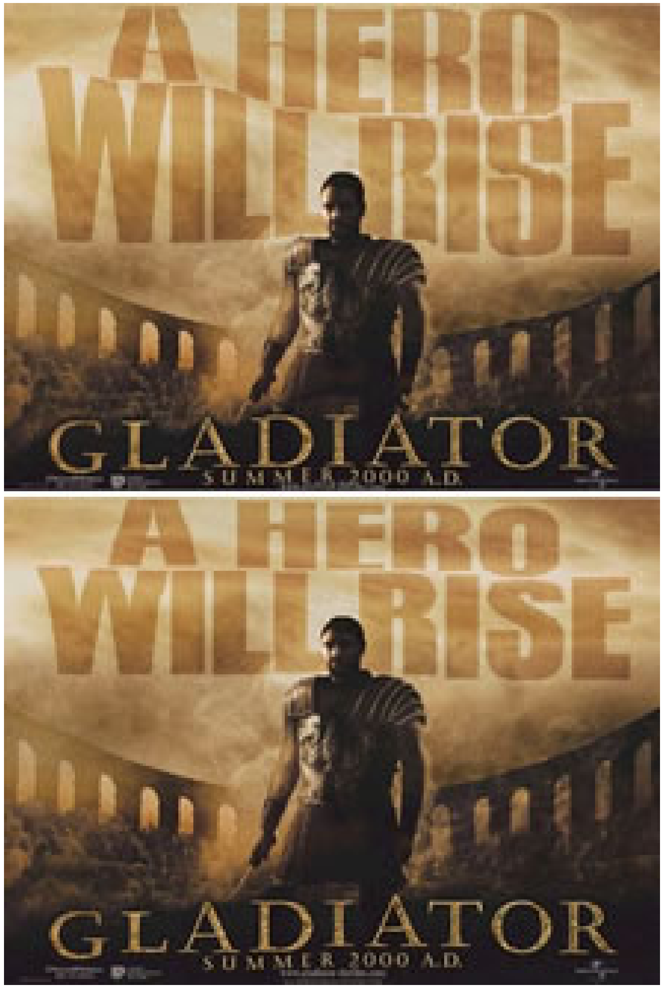


Backward vs. Forward

Backward

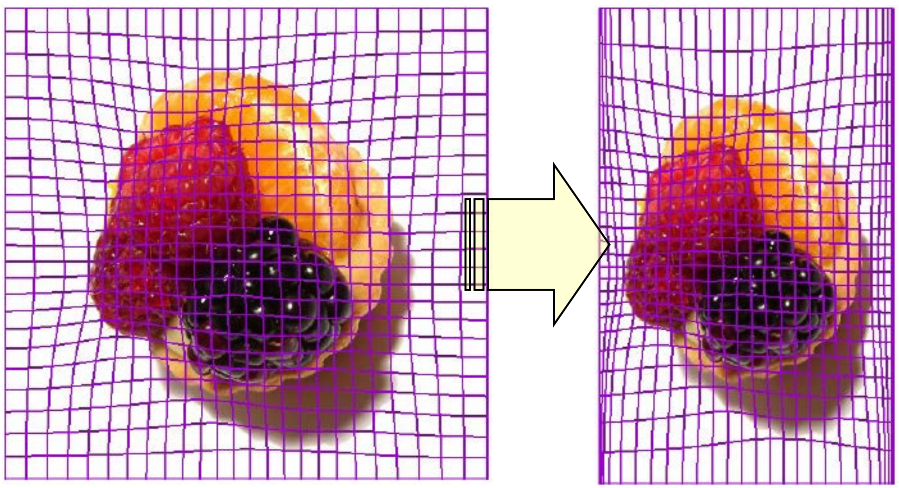
Forward

Results


A HERO
WILL RISE
GLADIATOR
SUMMER 2000 A.D.
A HERO
WILL RISE
GLADIATOR
SUMMER 2000 A.D.

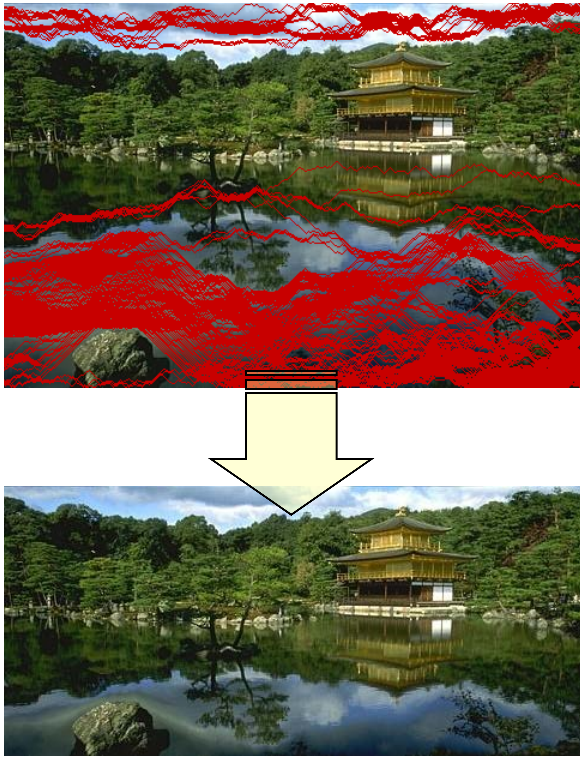
Discrete vs. Continuous

[Wang et al 2008]



Continuous

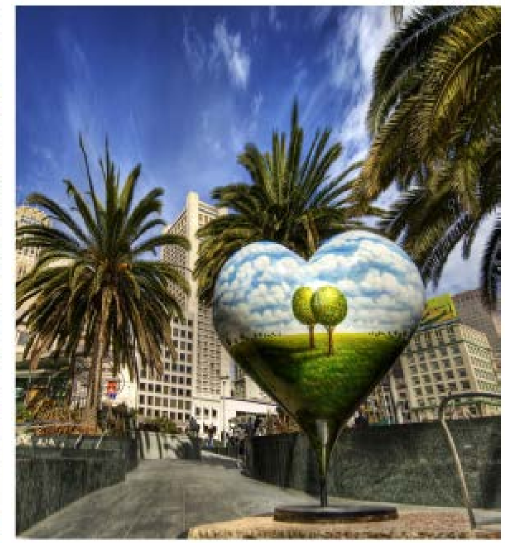
[Avidan and Shamir 2007]



Discrete

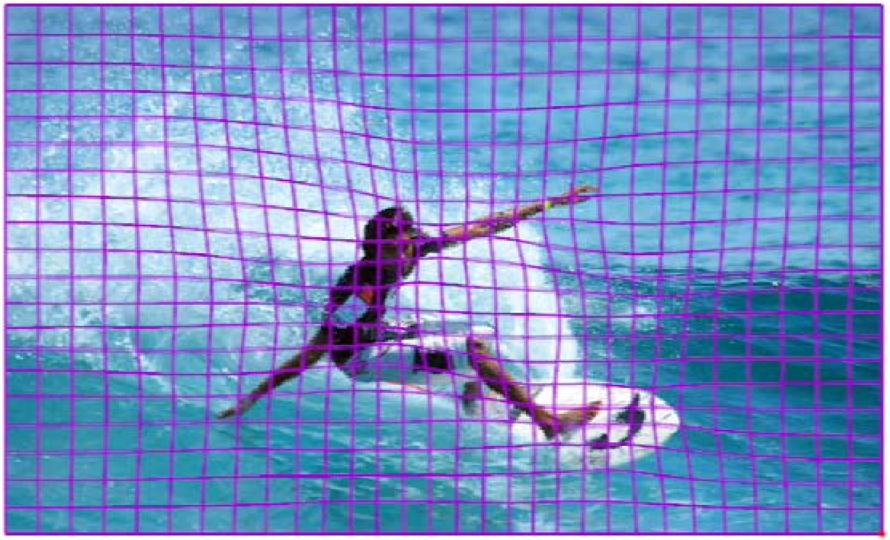
Non-homogeneous Scaling

Seam Carving



Scale-and-Stretch

Non-homogeneous Scaling



[Wang et al 2008]

Bidirectional Similarity [Simakov et al. CVPR 08]

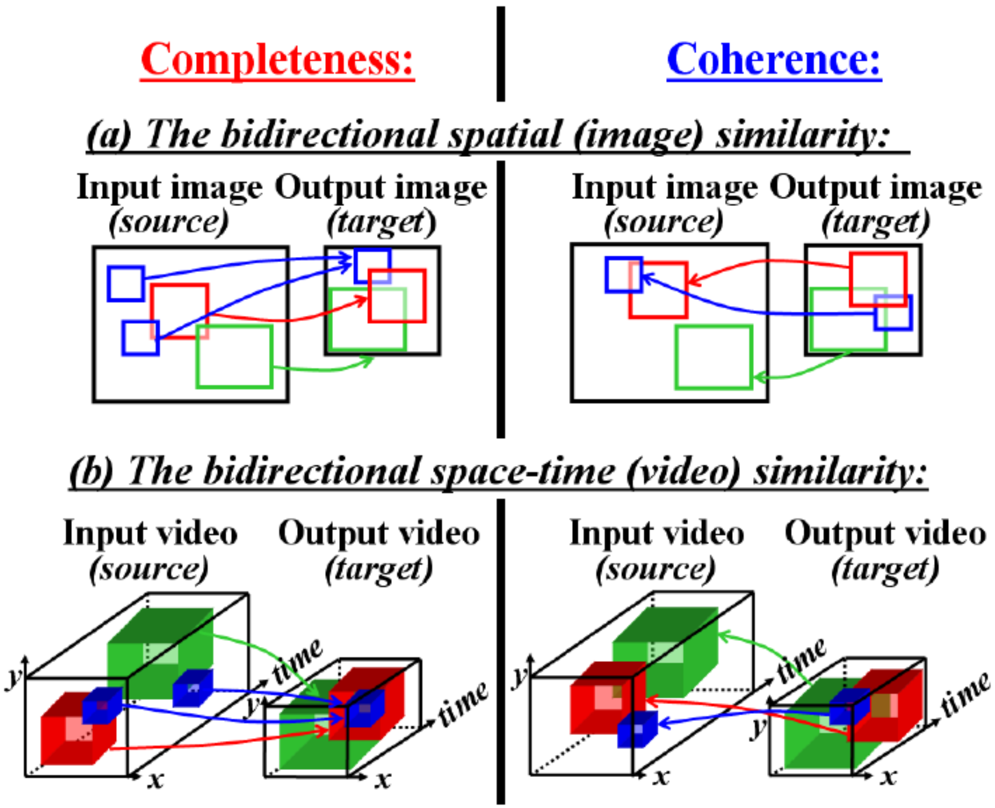
$$d(S,T) = \overbrace{\frac{1}{N_S}\sum_{P\subset S}\min_{Q\subset T} D(P,Q)}^{d_{\text{complete}}(S,T)} + \overbrace{\frac{1}{N_T}\sum_{Q\subset T}\min_{P\subset S} D(Q,P)}^{d_{\text{cohere}}(S,T)}$$

Source

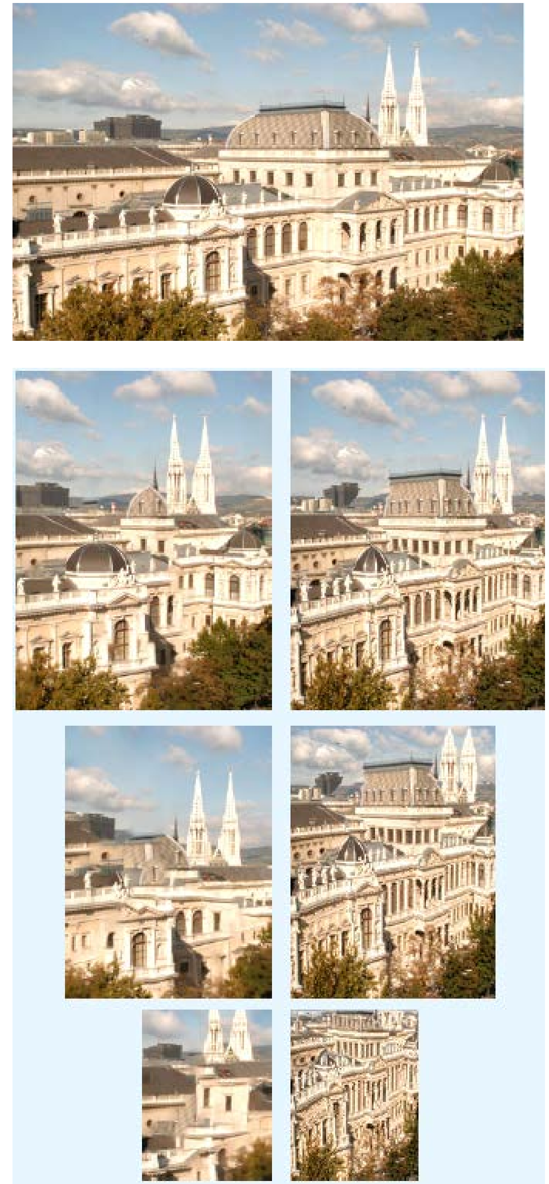
complete *and* coherent

~~**complete**~~ **coherent**

complete ~~**coherent**~~



Bidirectional Similarity



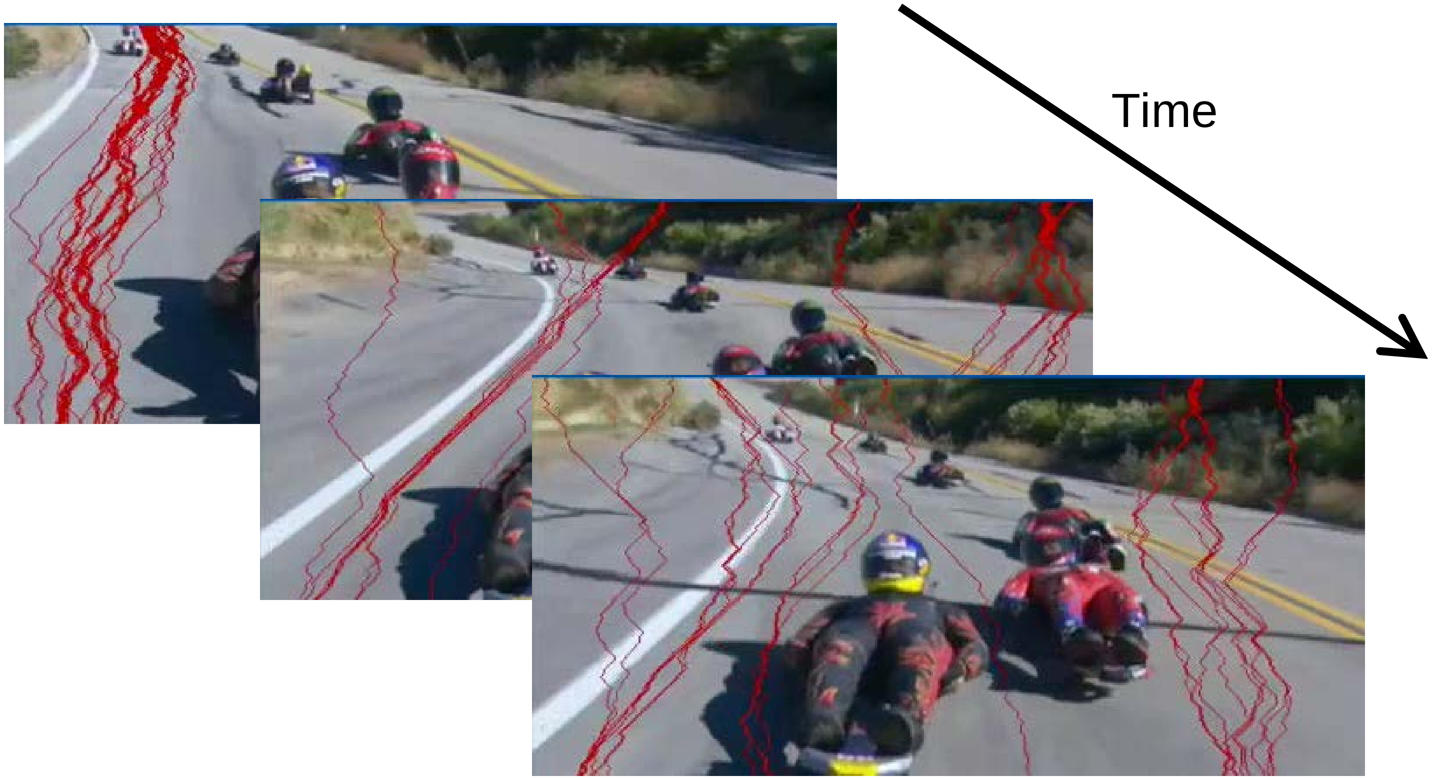
From Images to Videos

- **In general, video processing is a much (much!) harder problem**

1. **Cardinality**
   – Suppose 1min of video x 30 fps = 1800 frames
   – Say your algorithm processes an image in 1 minute → **30 hours !!**
2. **Dimensionality/algorithmic**
   – Temporal coherency: human visual system is highly sensitive to motion!

Seam-Carving Video?

- **Naive… frame by frame independently**

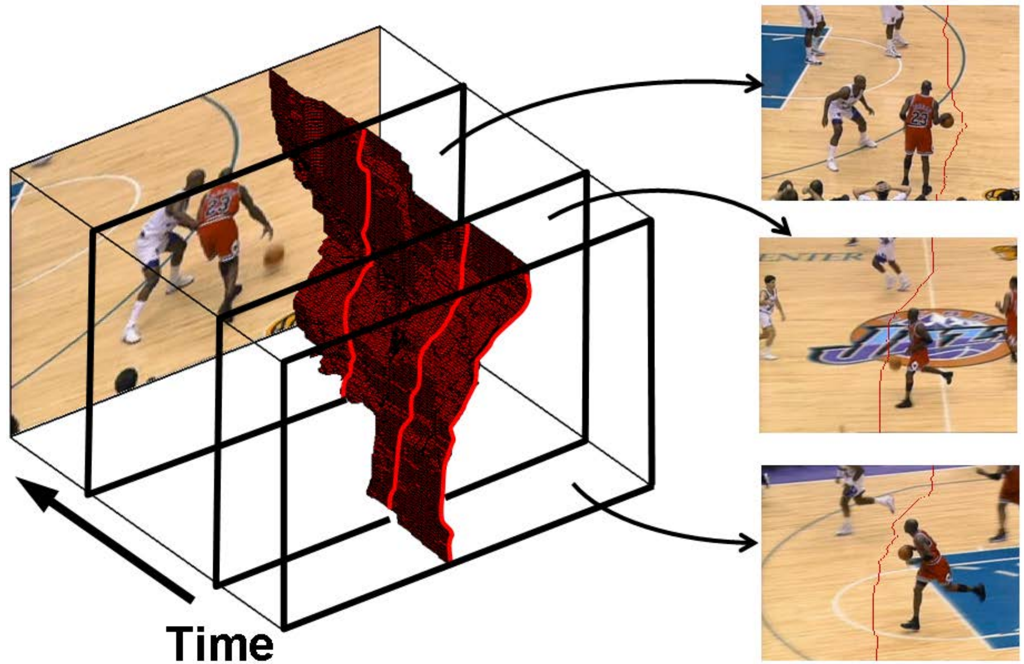


Frame-by-frame Seam-Carving

*Representative seams

From 2D to 3D

1D paths in images



2D manifolds in video cubes

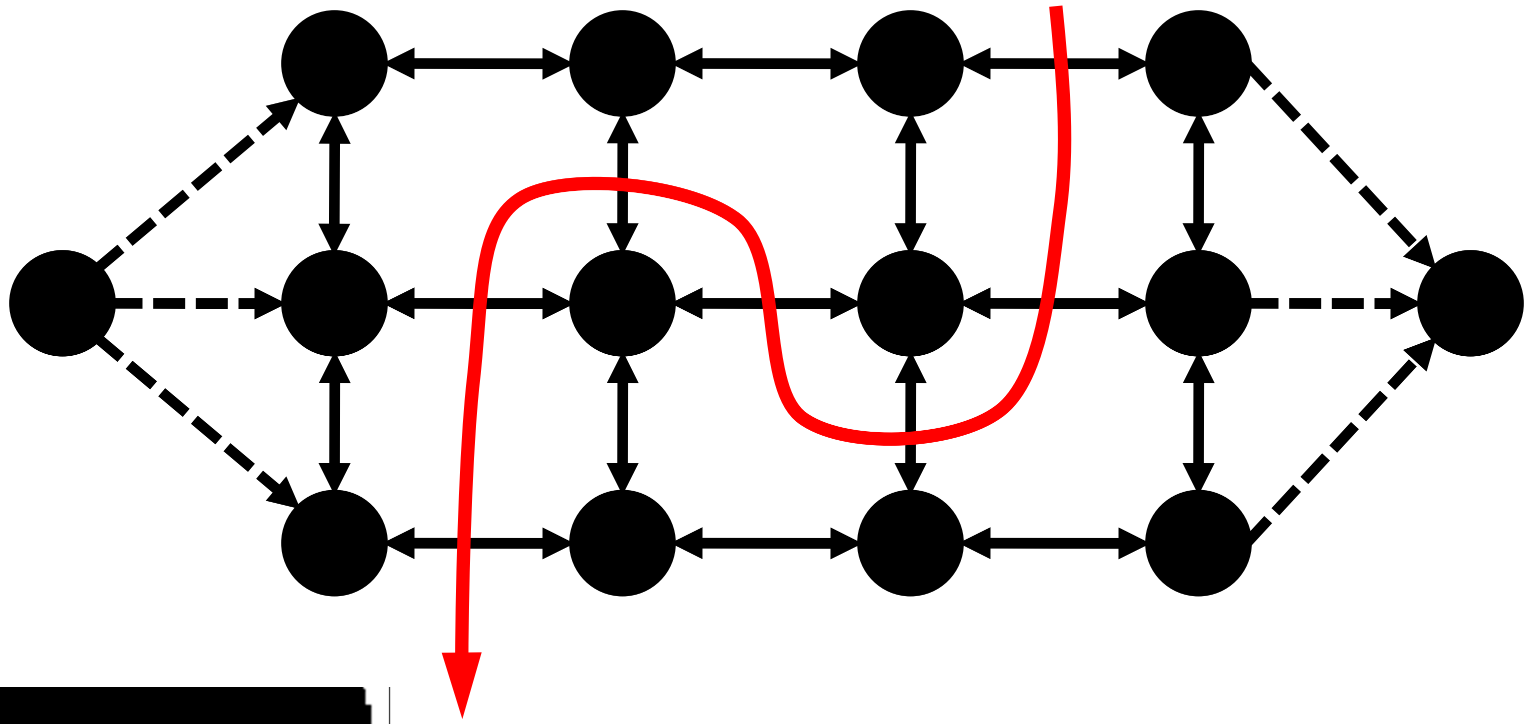
Challenges

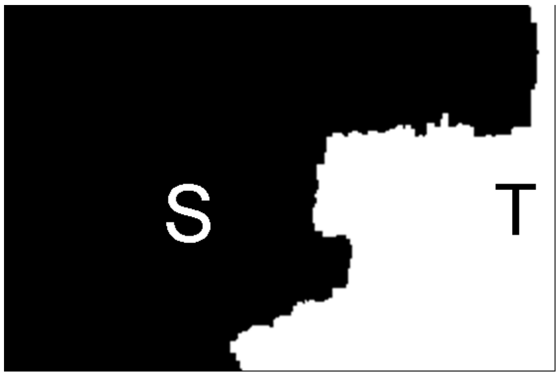
- **Dynamic Programming no longer applicable**
  - Reduction to min-cut graph problem

- **Cut must fulfill seam constraints**
  1. *Monotonic* (cut each row exactly once)
  2. Connected

Cut should be a function!

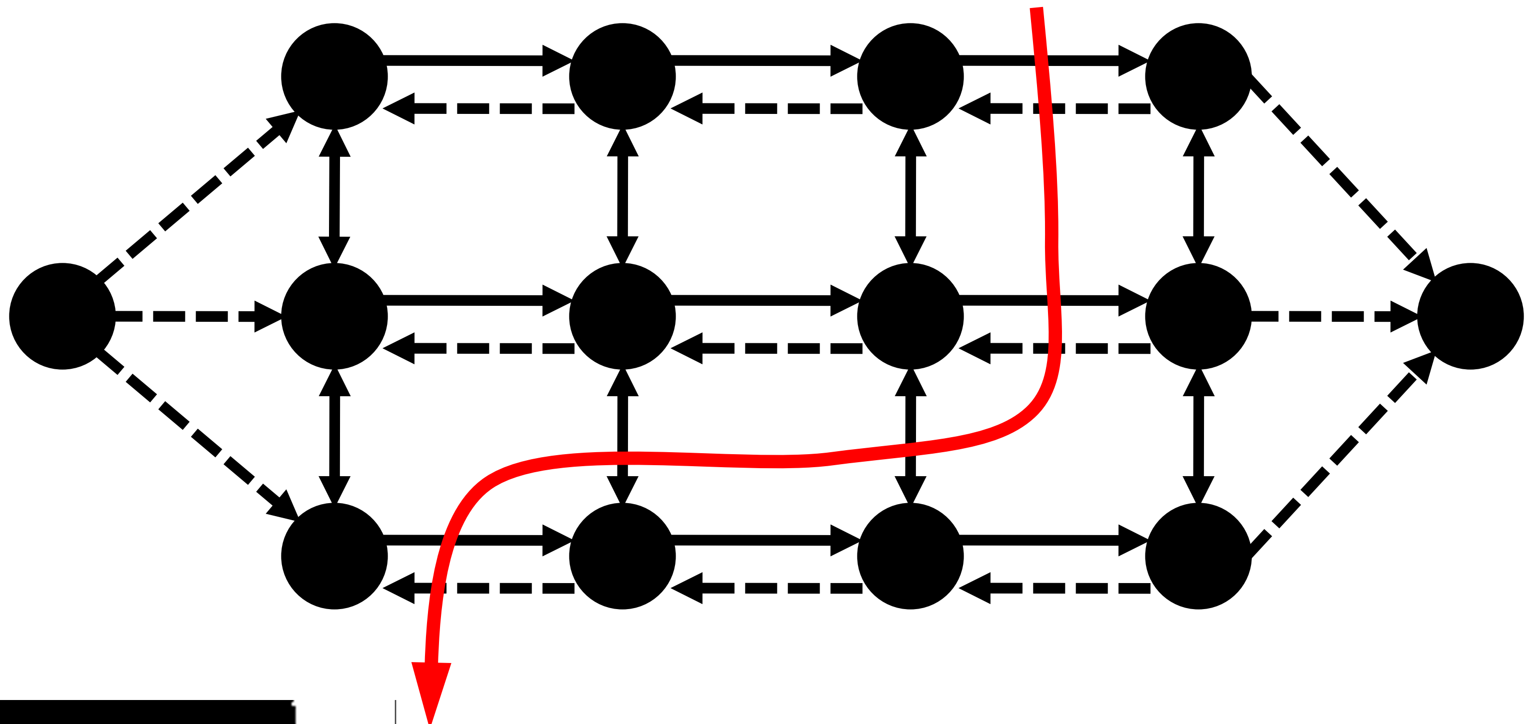
Graph Construction

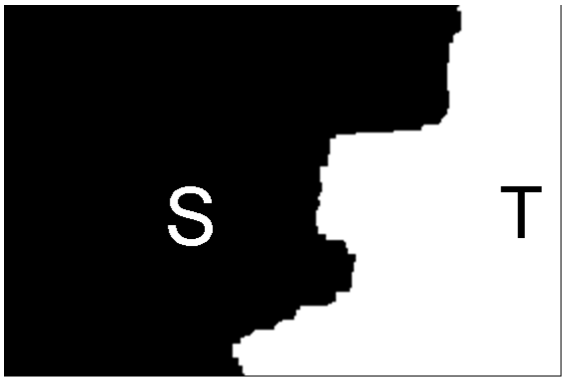




Not monotonic

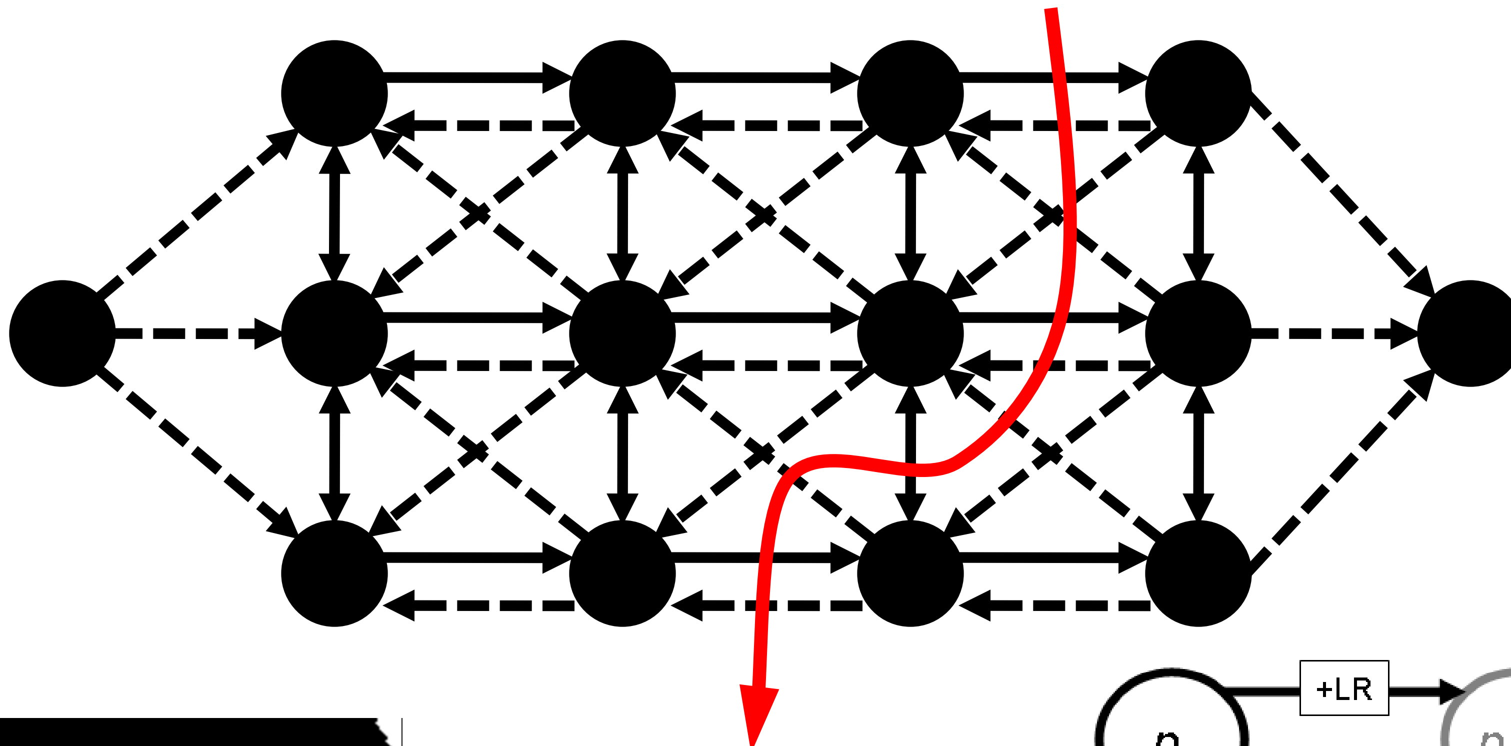
Graph Construction





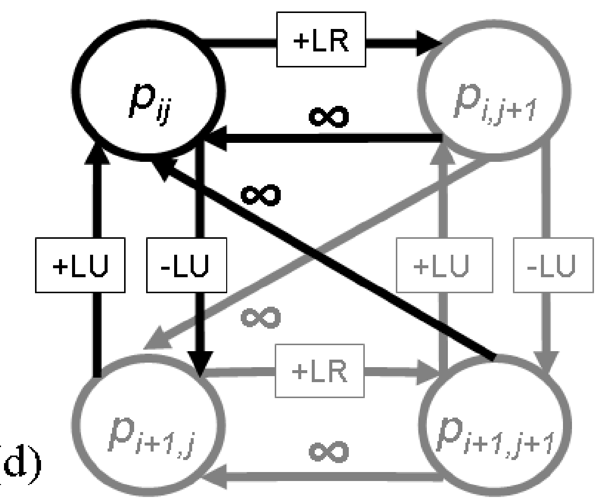
Monotonic, not connected

Graph Construction



Backward Energy

Forward Energy



(d)

Multiresolution Graph Cut

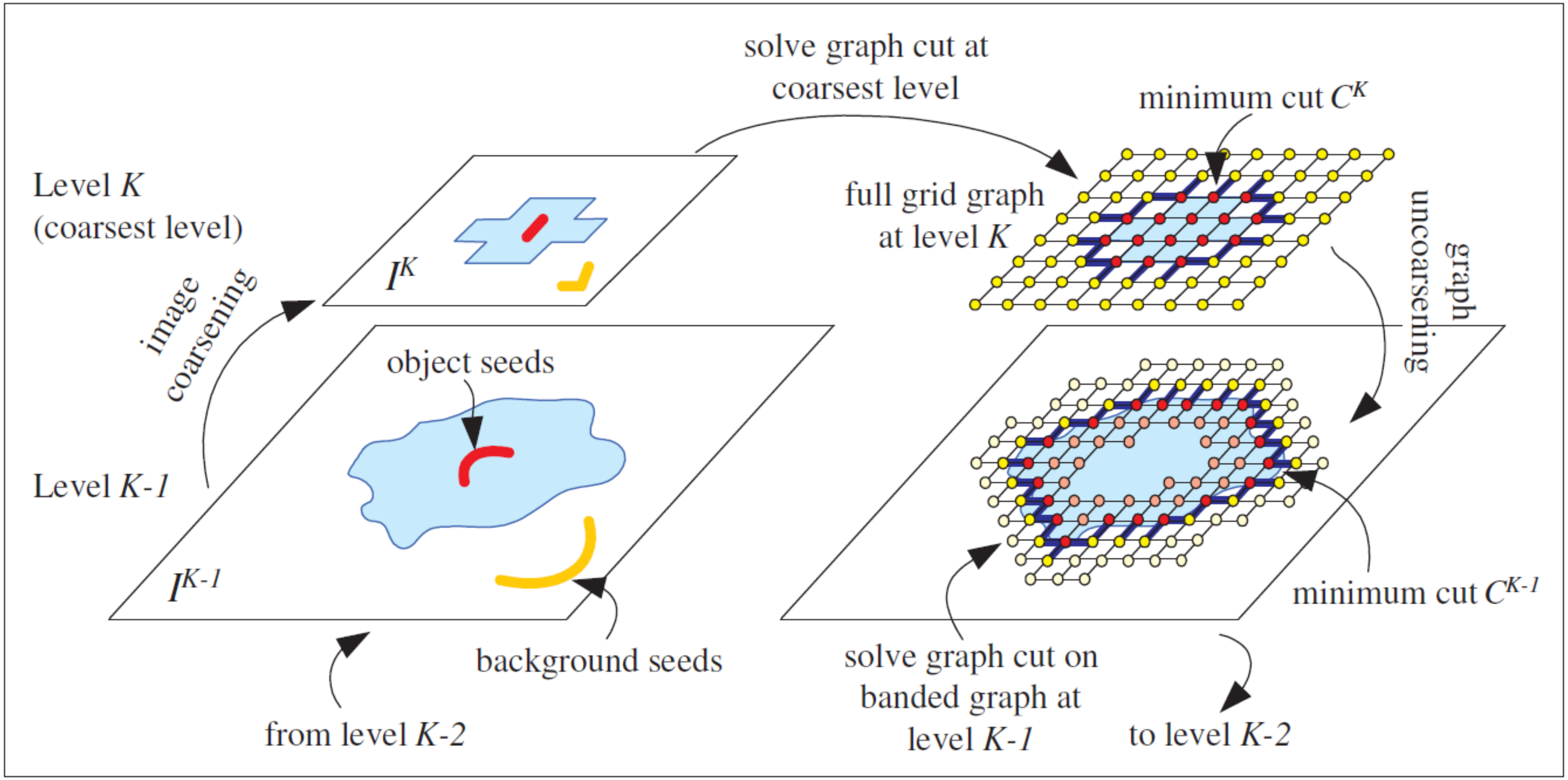


Figure 1. Multilevel banded graph cuts algorithm

Lombaert et al. [2005]

Results

Rescale

Retarget

Results

Seams

Backward

Forward

Multi-size Video

Object Removal…

References

- **Seam Carving for Content-Aware Image Resizing – Avidan and Shamir 2007**
- **Content-driven Video Retargeting – Wolf et al. 2007**
- **Improved Seam Carving for Video Retargeting – Rubinstein et al. 2008**
- ***Optimized Scale*-and-*Stretch* for Image Resizing – Wang et al. 2008**
- **Summarizing Visual Data Using Bidirectional Similarity – Simakov et al. 2008**
- **Multi-operator Media Retargeting – Rubinstein et al. 2009**
- **Shift-Map Image Editing – Pritch et al. 2009**
- **Energy-Based Image Deformation – Karni et al. 2009**

- **Seam carving in Photoshop CS4: http://help.adobe.com/en_US/Photoshop/11.0/WS6F81C45F-2AC0-4685-8FFD-DBA374BF21CD.html**

References

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The Interdisciplinary Center