中山大學
SUN YAT-SEN UNIVERSITY

Lecture 6.
Image Resizing

Pattern Recognition and Computer Vision

Guanbin Li,
School of Data and Computer Science, Sun Yat-Sen University

扫码签到

What we will learn today?

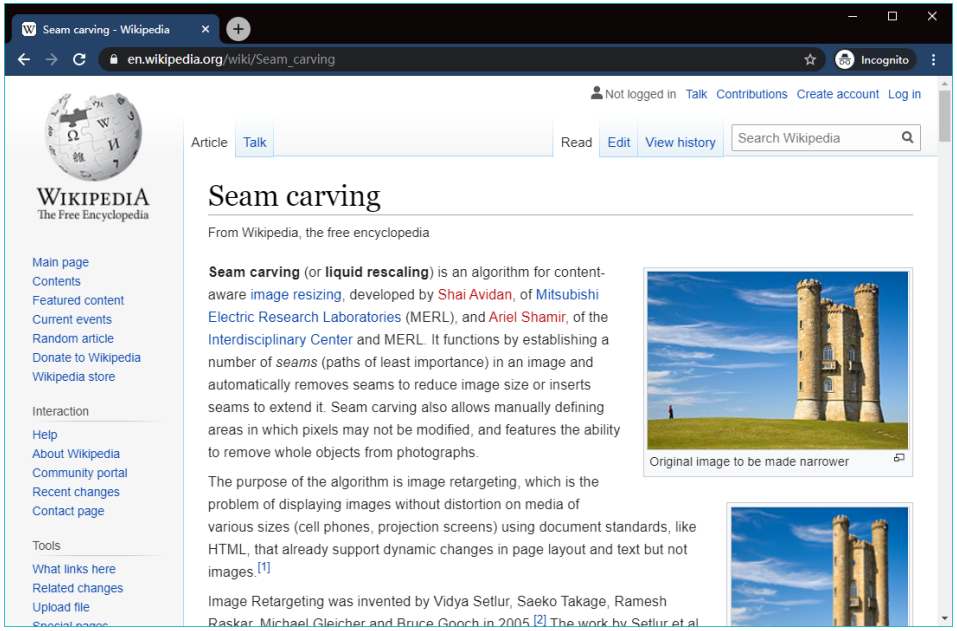
- Background
- What is image retargeting
- Seam carving
- Dynamic programming
- Applications

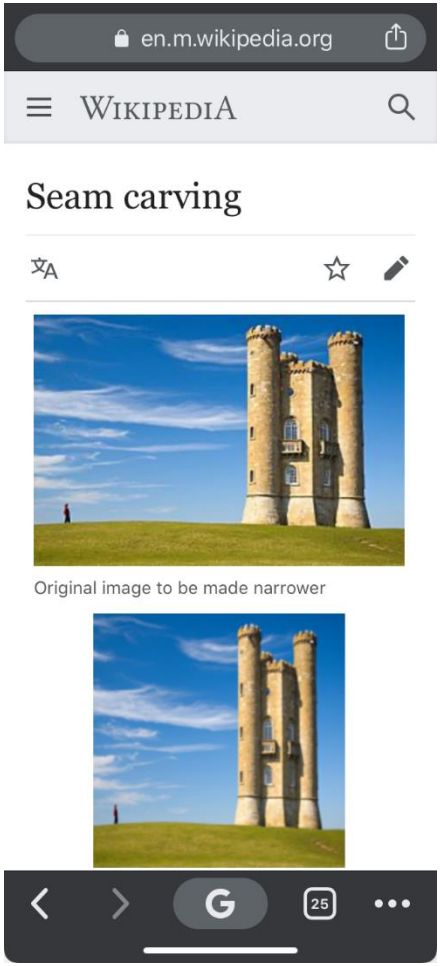
Background

- Display Devices

Background

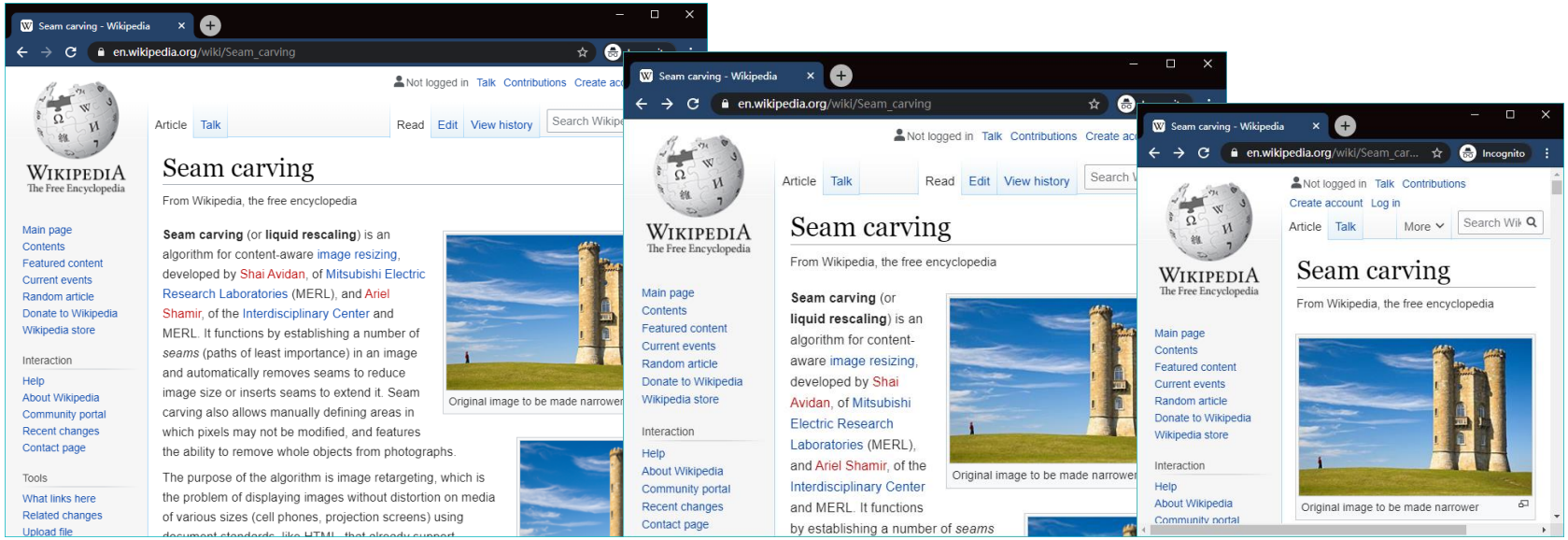
- Content Retargeting





Background

- Text layout can be easily changed



- But how about image?

Background

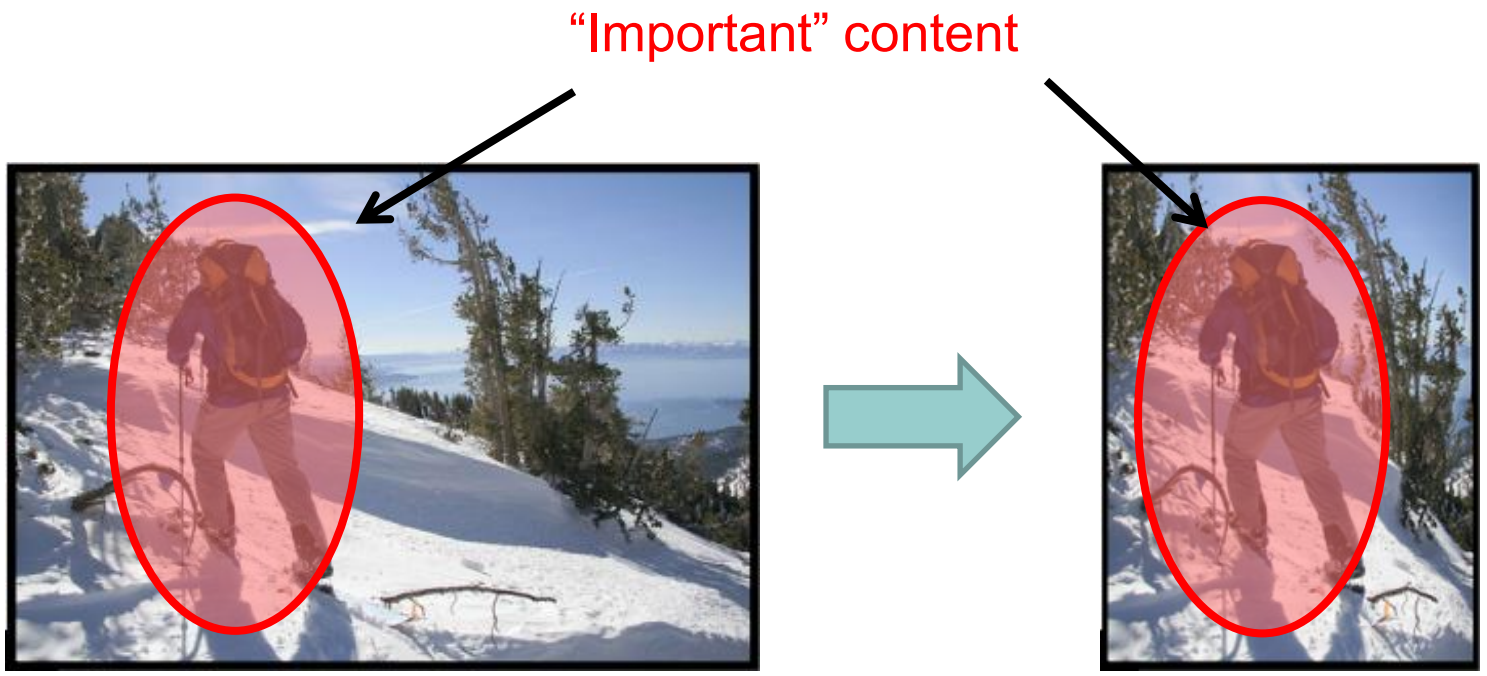
- Simple Media Retargeting Operators
- Crop

Background

- Simple Media Retargeting Operators
- Scale

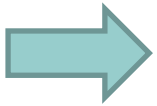
Background

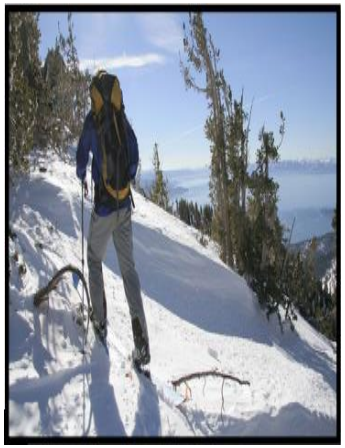
- Content-aware Retargeting Operators



Background

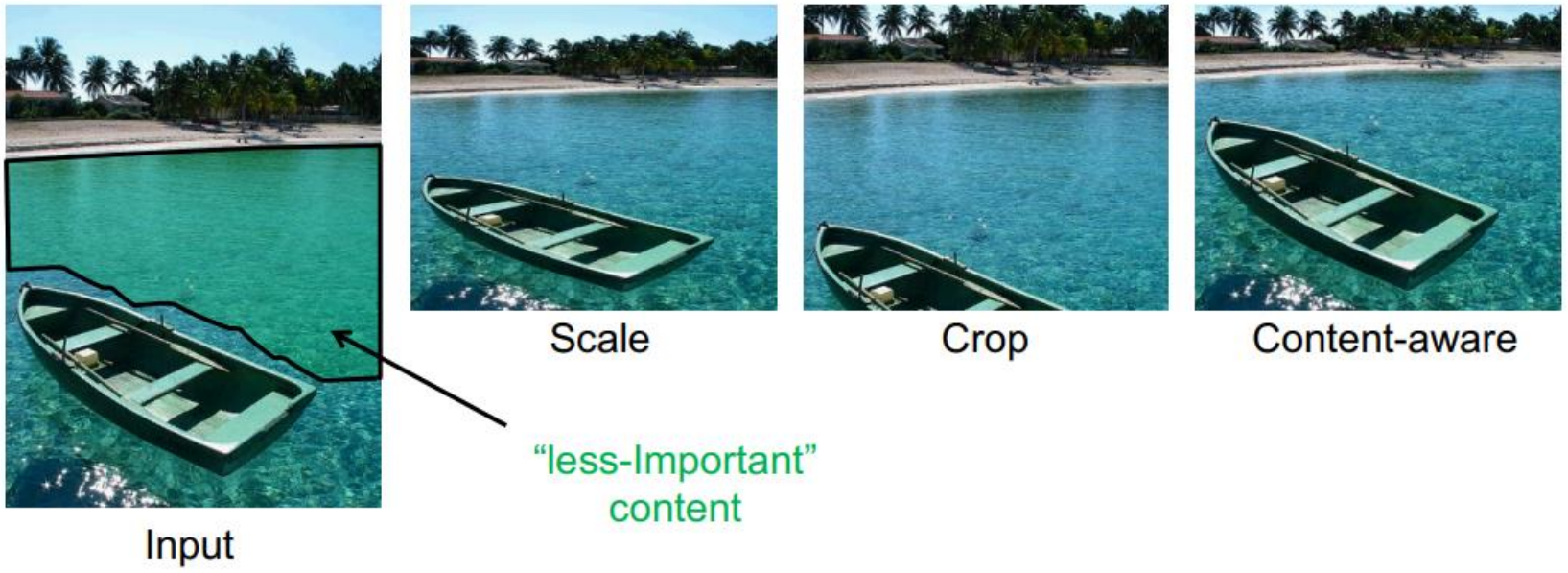
- Content-aware Retargeting Operators





Background

- Content-aware Retargeting Operators



What we will learn today?

- Background
- What is image retargeting
- Seam carving
- Dynamic programming
- Applications

What is image retargeting

- Image Retargeting
- Problem statement:
  - Input Image ***I*** (n * m), and new size (n' * m')
  - Output Image ***I'*** of size (n' * m') which will be "good representative" of the original image ***I***
- "Good representative"?
- To date, no agreed definition, or measure, as to what a good representative is in this context!

What is image retargeting

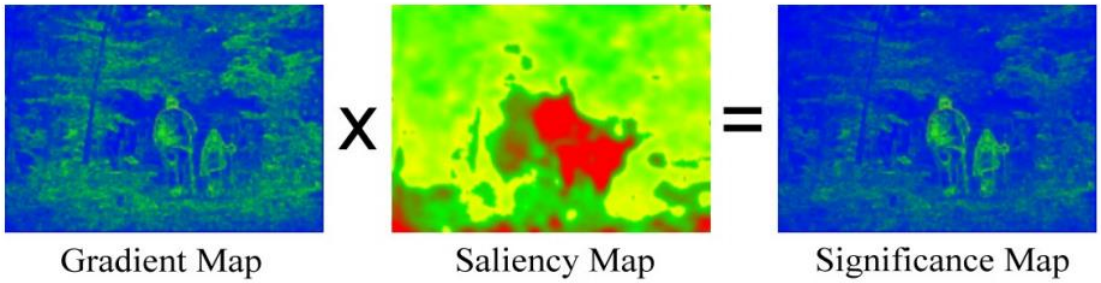
- In large, we would expect retargeting to:
  - 1. Adhere to the geometric constraints (display/aspect ratio)
  - 2. Preserve the important content and structures
  - 3. Limit artifacts

- • 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?

What is image retargeting

- Importance (Saliency) Measures
  - gradient map $W = \left(\left(\frac{\partial}{\partial x} I \right)^2 + \left(\frac{\partial}{\partial y} I \right)^2 \right)^{1/2}$
  - saliency map A function S: p -> [0,1]
  - significance map

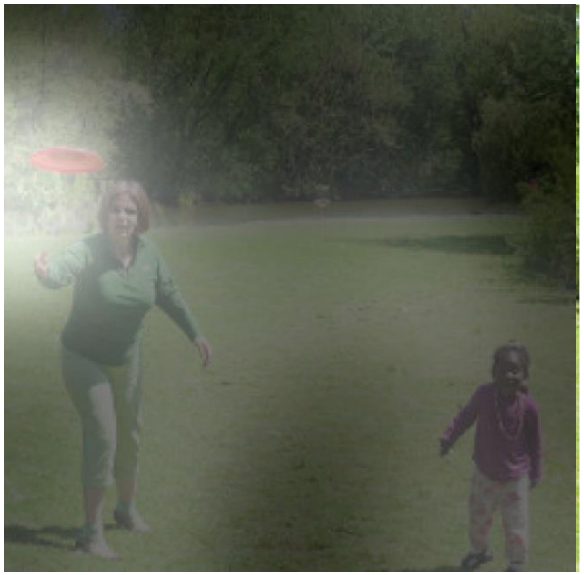
original image



Wang et al. 2008

What is image retargeting

- Importance (Saliency) Measures



What is image retargeting

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

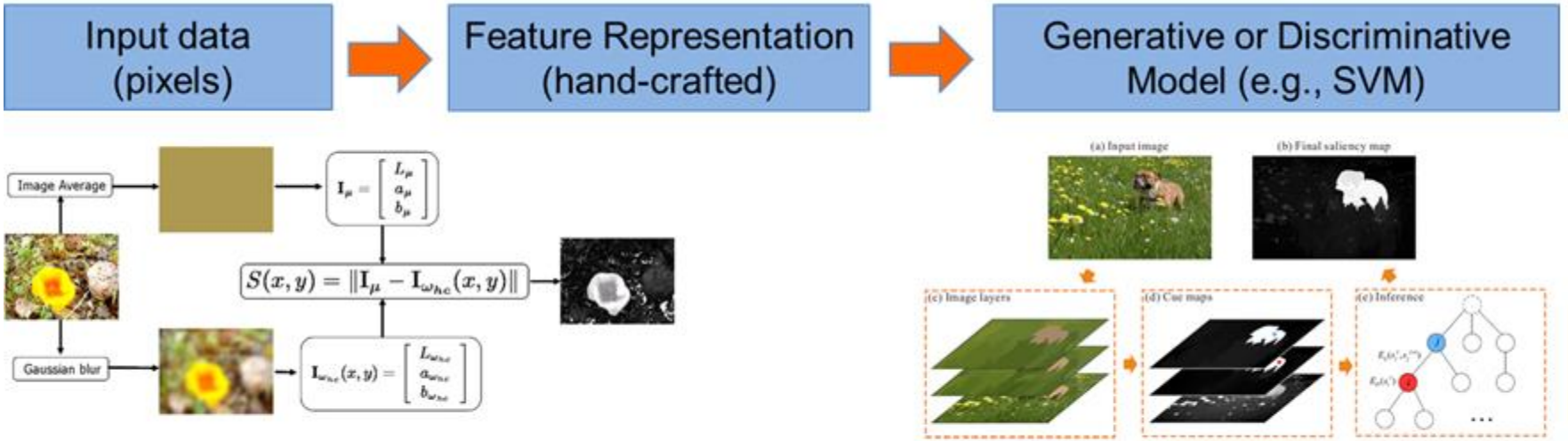
Judd et al. ICCV09 *Learning to predict where people look*

Image Saliency Definition

Salient Object

Eye Fixation

Image Saliency Calculation

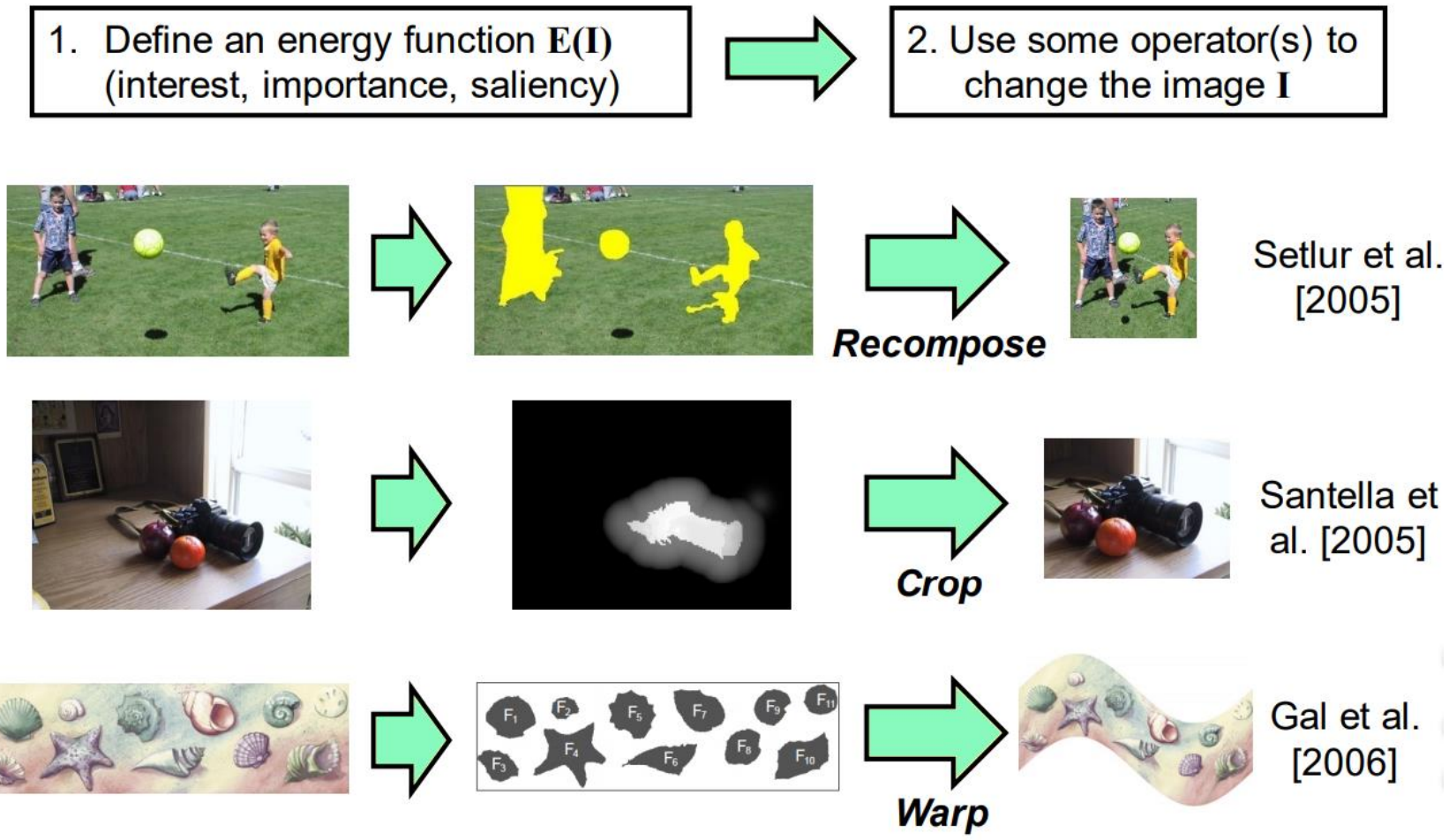


Frequency-tuned Salient Region Detection
[R. Achanta et al., CVPR2009]

Hierarchical Saliency Detection
[Q. Yan et al., CVPR2013]

What is image retargeting

- General Retargeting Framework



What we will learn today?

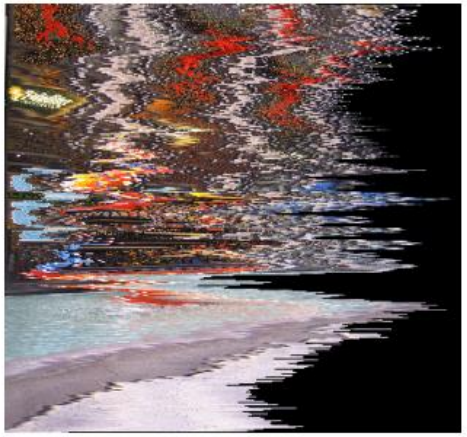
- Background
- What is image retargeting
- Seam carving（接缝裁剪算法）
- Dynamic programming
- Applications

Seam carving

- Assume m x n -> m x n', n'<n
- Basic Idea: remove unimportant pixels from the image
  - Unimportant = pixels with less "energy"
  - $E_1(I) = \left|\frac{\partial}{\partial x} I\right| + \left|\frac{\partial}{\partial y} I\right|.$
- 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

Seam carving

- Pixel Removal



Optimal

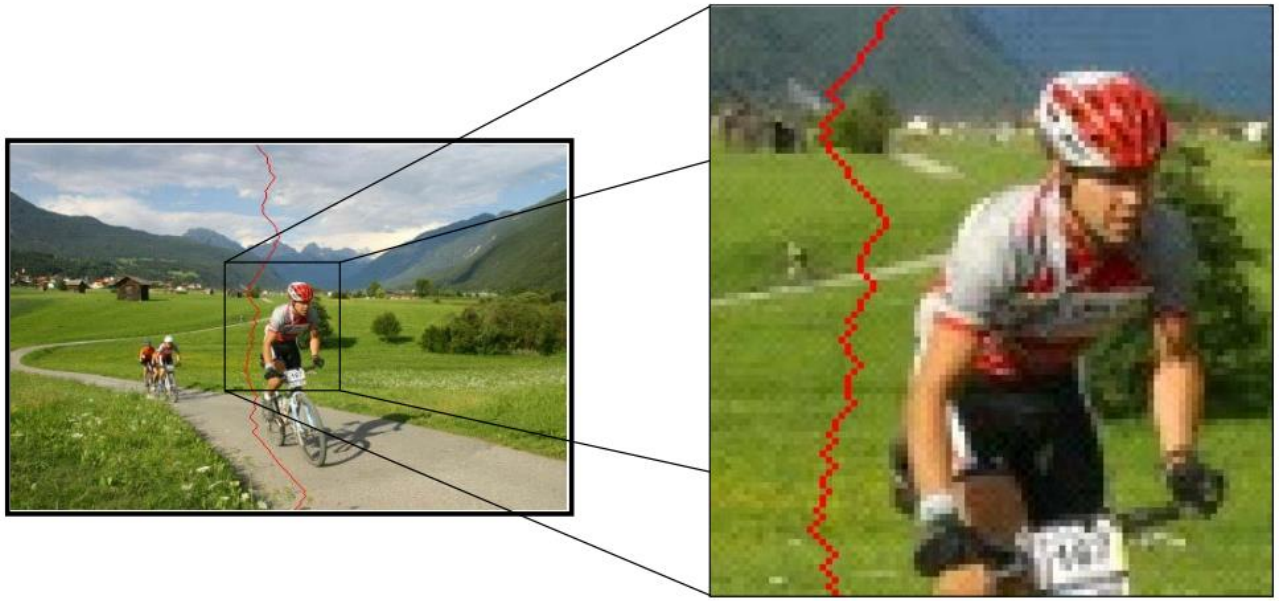
Least-energy pixels (per row)

Least-energy columns

Seam carving

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

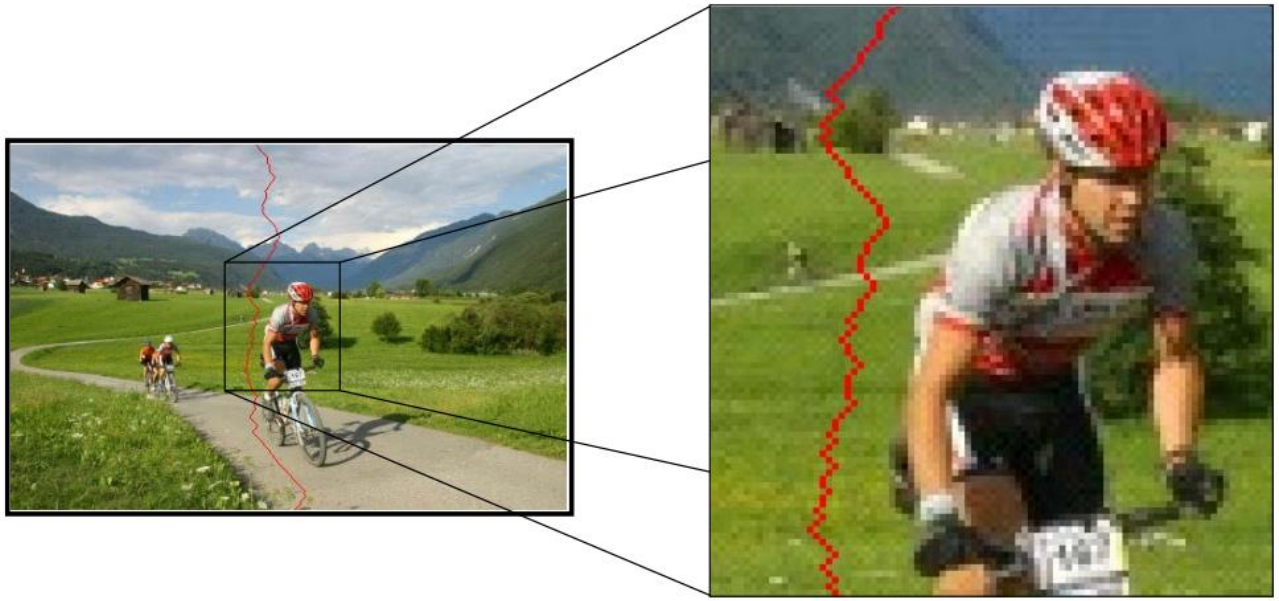
$$\mathbf{s}^{\mathbf{x}} = \{s_i^x\}_{i=1}^n = \{(x(i), i)\}_{i=1}^n, \text{ s.t. } \forall i, |x(i) - x(i-1)| \leq 1$$



Seam carving

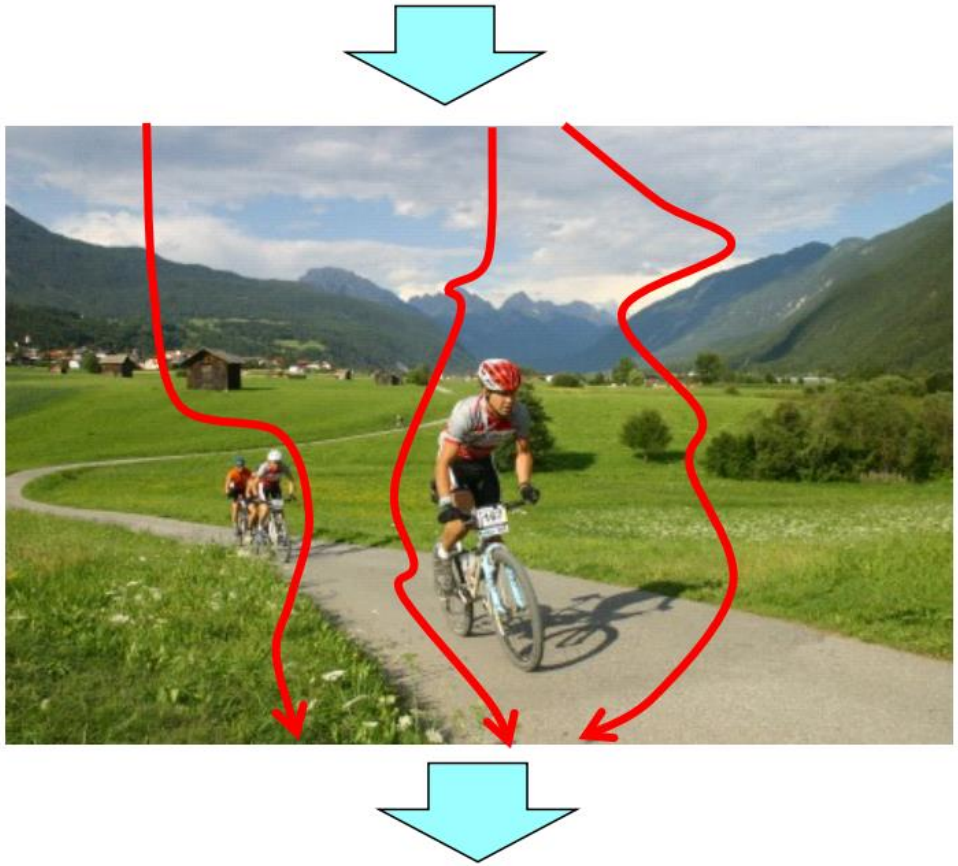
- A Seam
  - A connected path of pixels from top to bottom (or left to right). Exactly one in each row

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



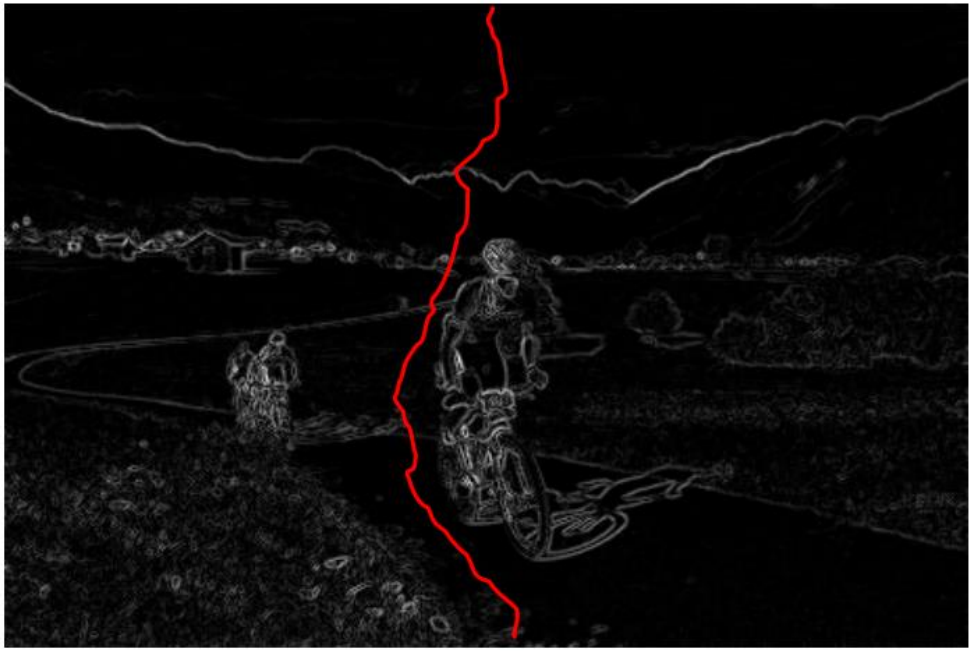
Seam carving

- Finding the Seam?



Seam carving

- The Optimal Seam



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

Seam carving

- The Optimal Seam
- The recursion relation

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

- Can be solved efficiently using dynamic programming in O(s· n ·m)

  (s=3 in the original algorithm)

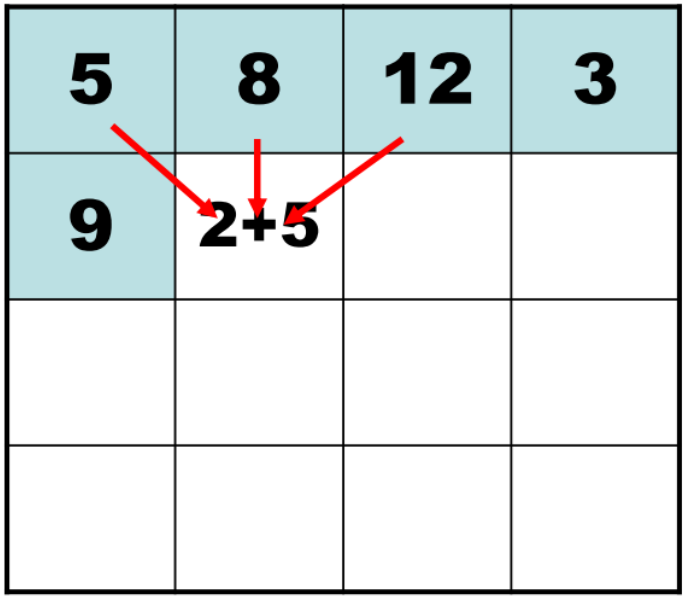
What we will learn today?

- Background
- What is image retargeting
- Seam carving
- Dynamic programming
- Applications

Dynamic programming

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

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



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

Energy - E(I,j)

Dynamic programming

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

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

5	8	12	3
9	2+5		

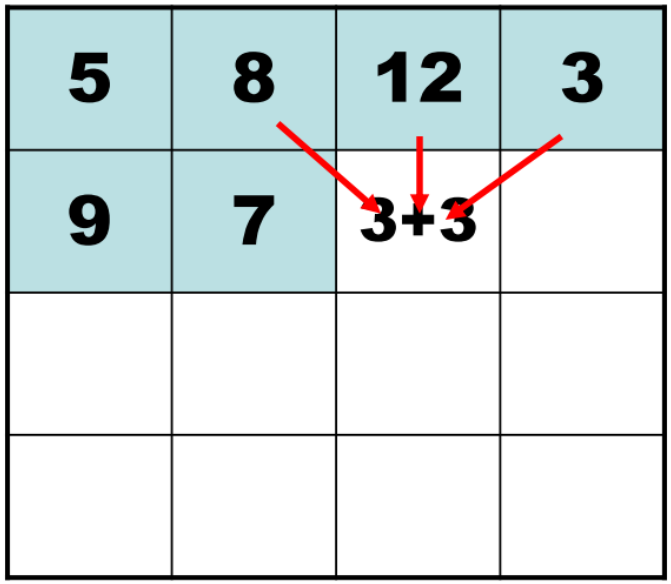
5	8	12	3
4	2	3	9
7	3	4	2
5	5	7	8

Energy - E(I,j)

Dynamic programming

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

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



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

Energy - E(I,j)

Dynamic programming

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

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

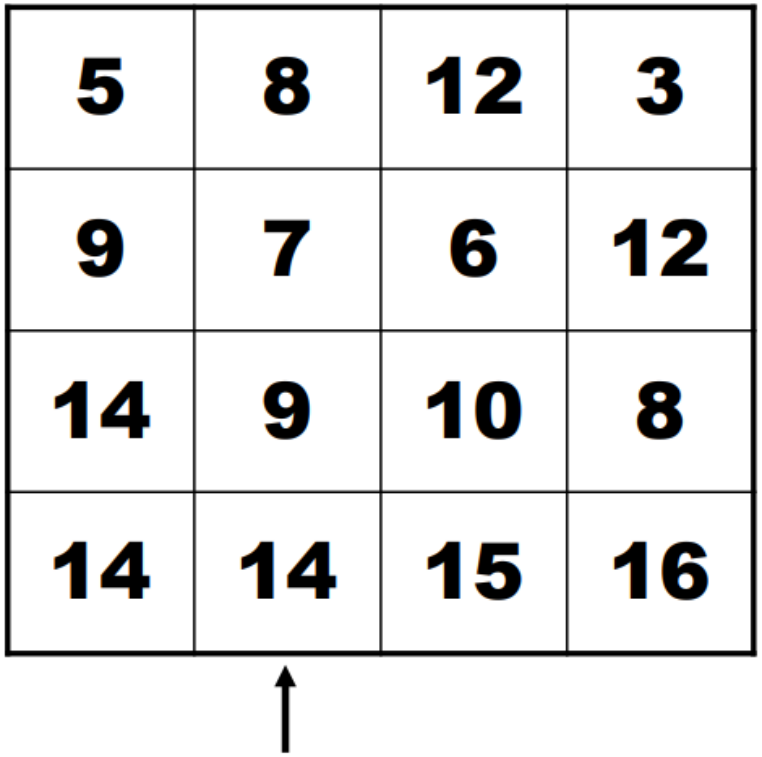
5	8	12	3
9	7	6	12
14	9	10	8
14	14	15	8+8

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

Energy - E(I,j)

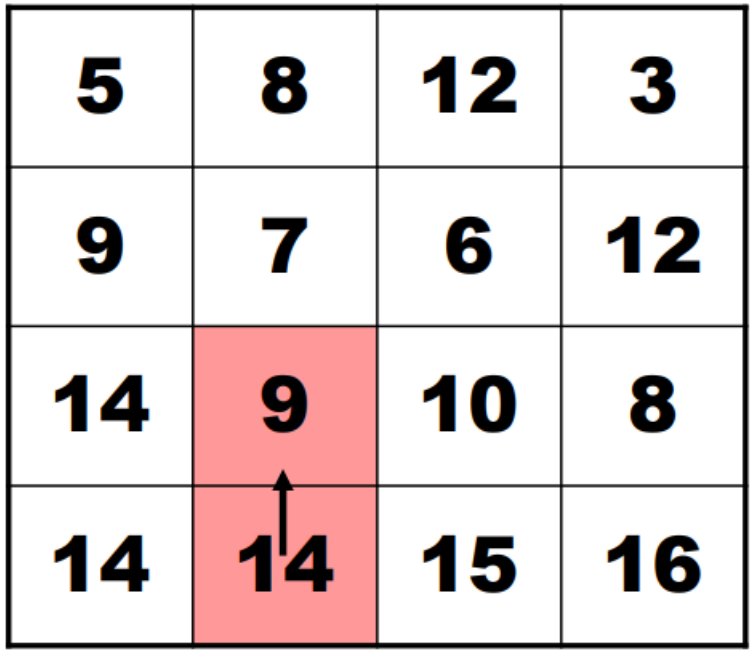
Dynamic programming

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



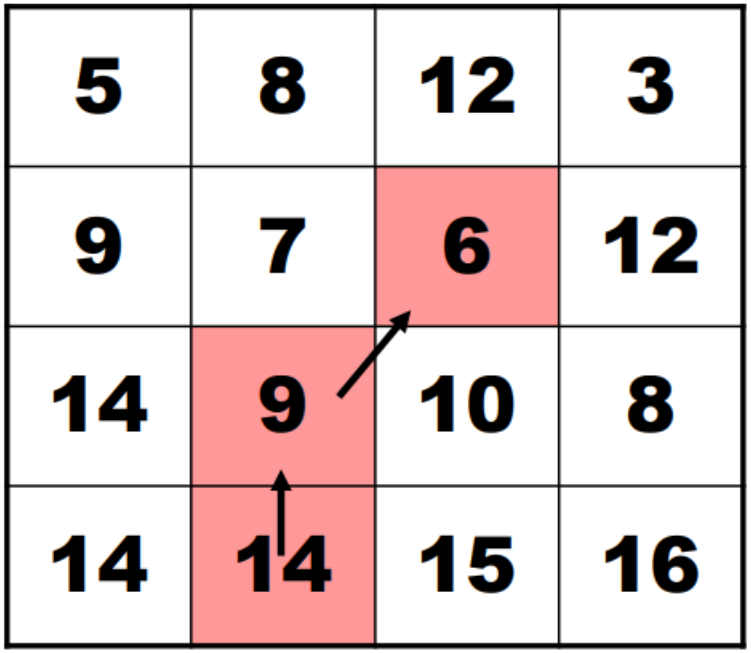
Dynamic programming

- Searching for Minimum
  - Backtracking the Seam



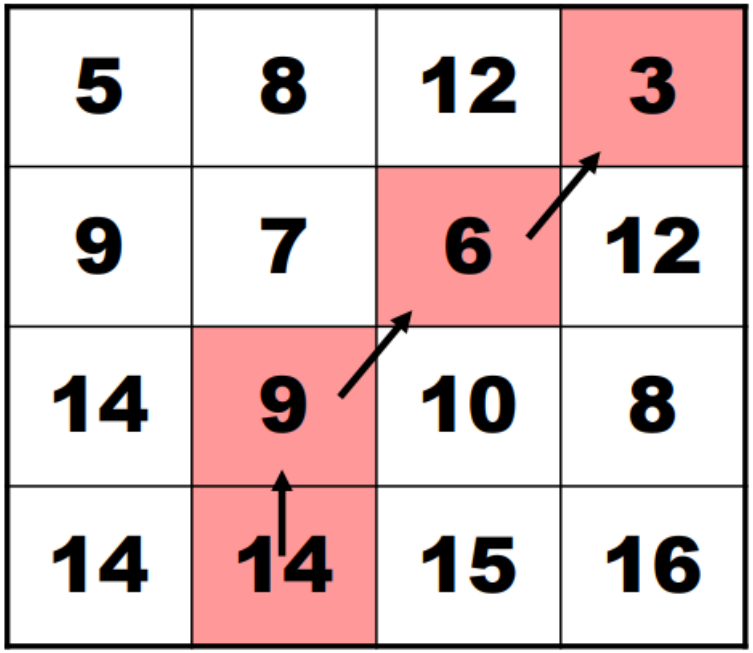
Dynamic programming

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



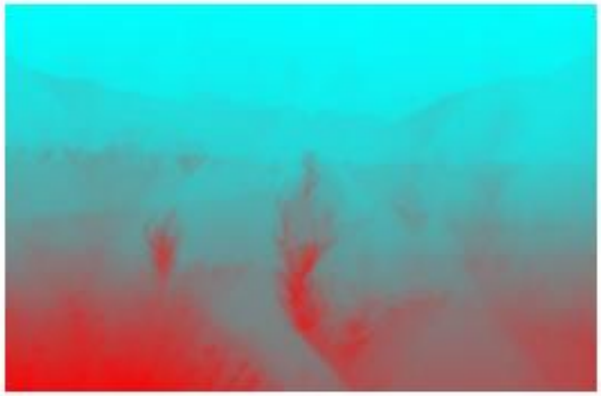
Dynamic programming

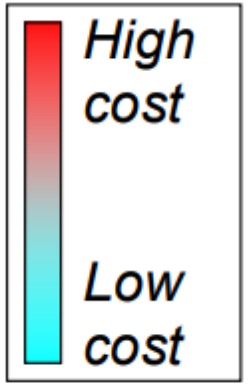
- Searching for Minimum
  - Backtrack (can store choices along the path, but do not have to)

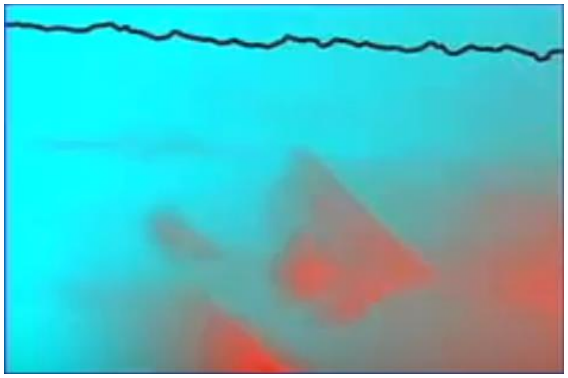


Dynamic programming

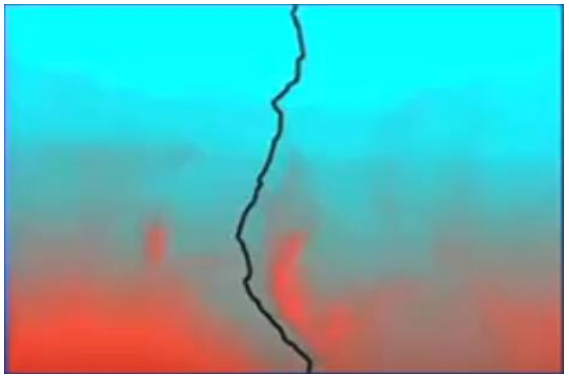
- H & V Cost Maps







Horizontal Seam



Vertical Seam

Dynamic programming

- Seam Carving (GIF)

Dynamic programming

- The Seam-Carving Algorithm

```
SEAM -CARVING(im, n') // size(im) = m x 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 image

- Running time:
  - 2.1 O(mn) 2.2 O(mn) 2.3 O(mn)

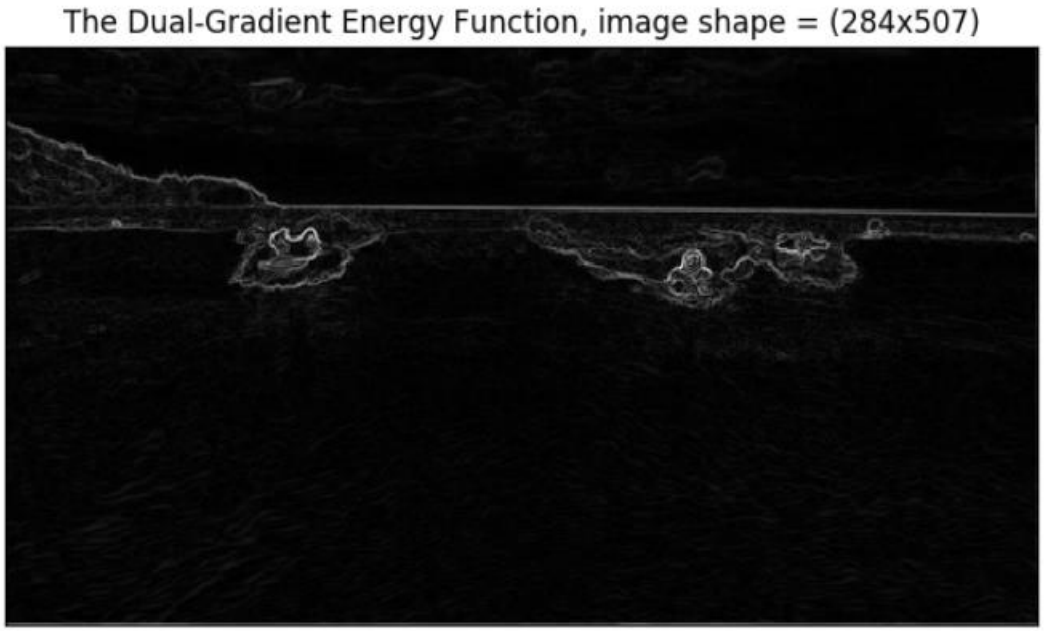
    -> O(dmn), d=n -n'

Dynamic programming

- Changing Aspect Ratio

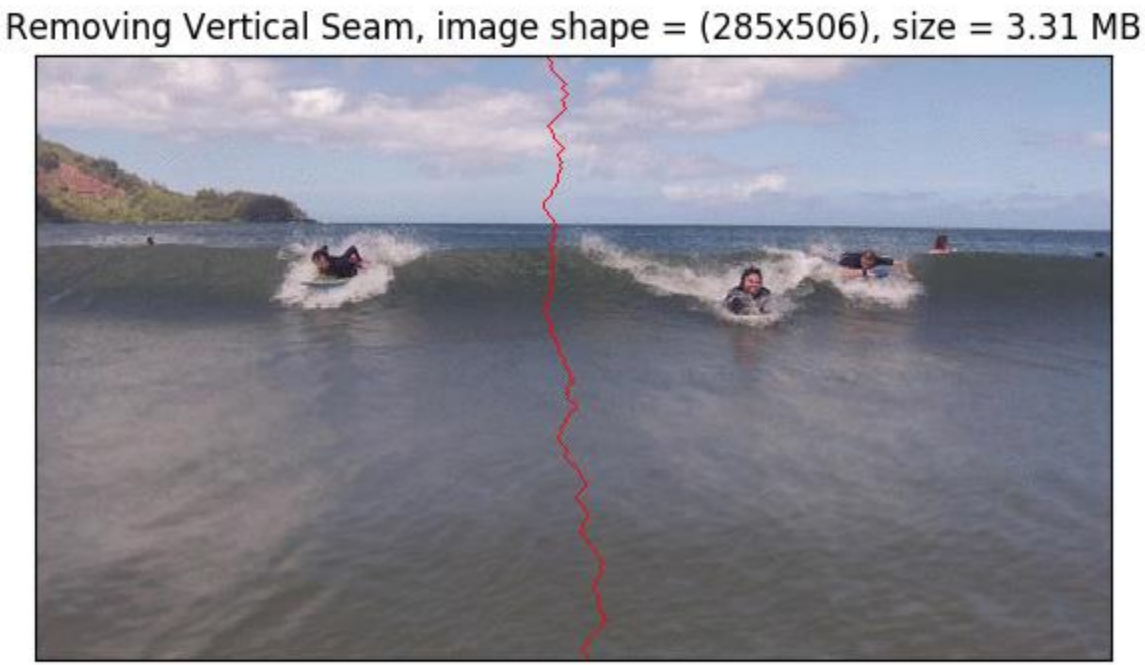
Dynamic programming

- Changing Aspect Ratio



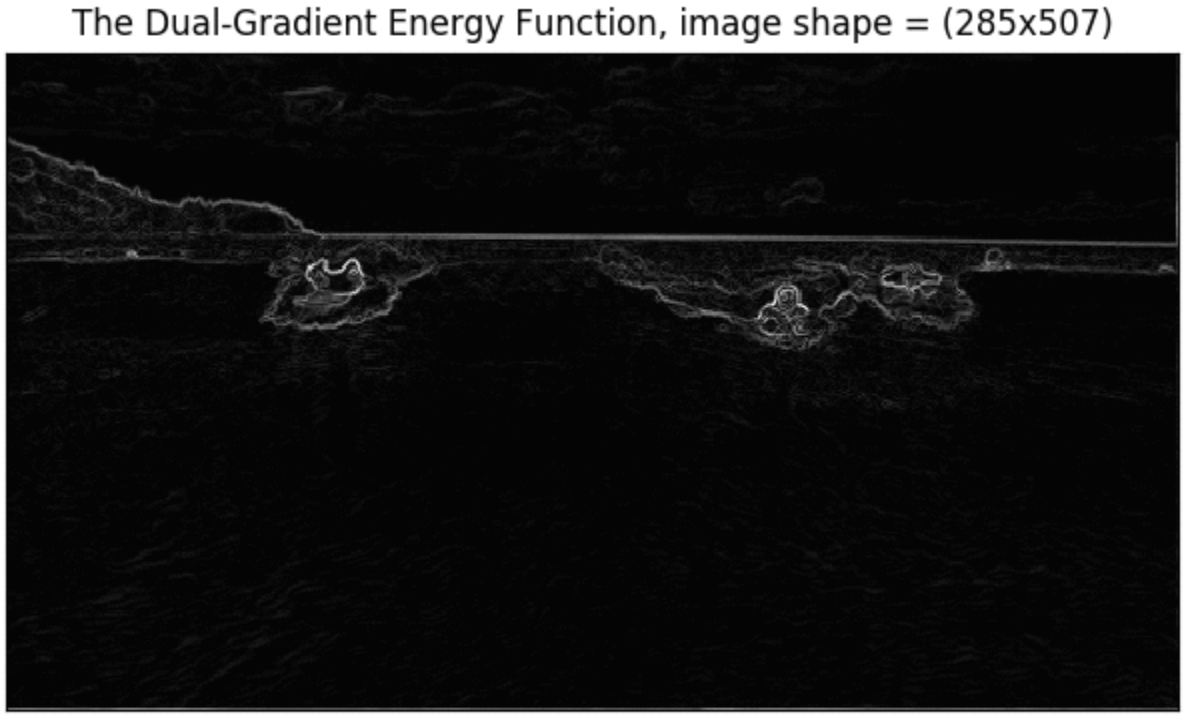
Dynamic programming

- Changing Aspect Ratio (GIF)



Dynamic programming

- Changing Aspect Ratio (GIF)



Dynamic programming

- Another example

Dynamic programming

- Changing Aspect Ratio

Original

Seam Carving

Scaling

Dynamic programming

- Changing Aspect Ratio

Cropping

Seams

Scaling

Dynamic programming

- Changing Aspect Ratio

Original

Retarget

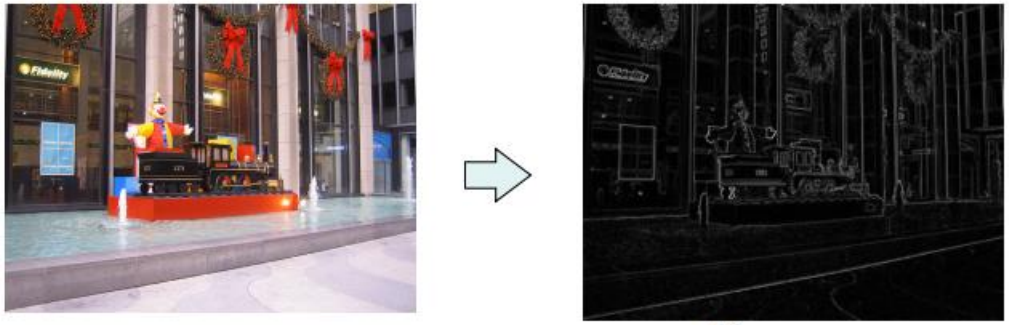
Scaling

Dynamic programming

- Content Enhancement

Dynamic programming

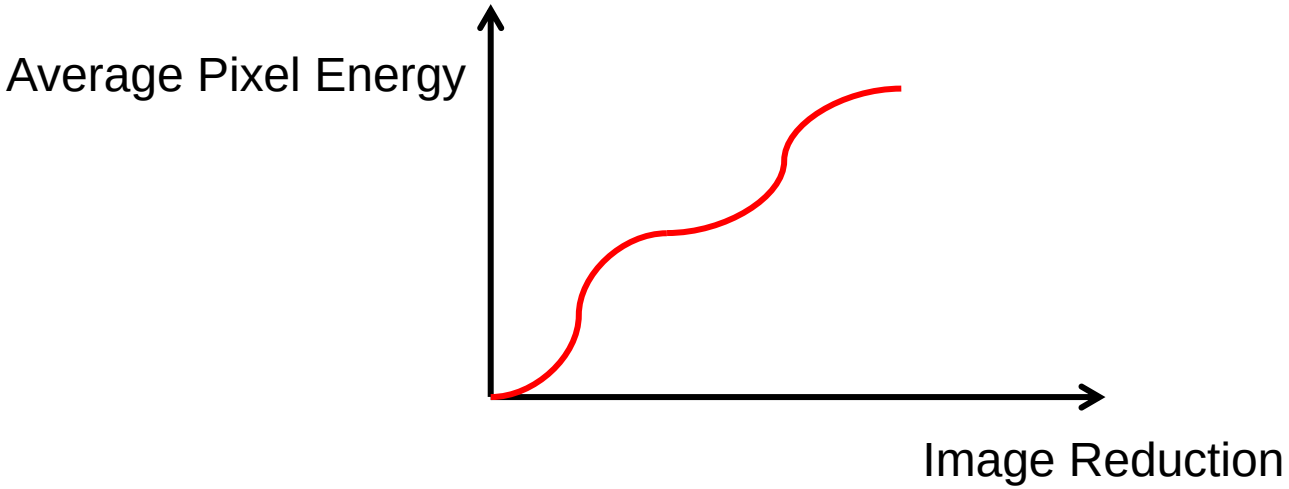
- Q: What happens to the overall energy in the image during seam carving?



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

Dynamic programming

- Preserved Energy
- While resizing: remove **as many** low energy pixels and **as few** high energy pixels!
- If we measure the average energy of pixels in the image after applying a resizing operator…
- …the average should increase!



Dynamic programming

- Preserved Energy

Average Pixel Energy

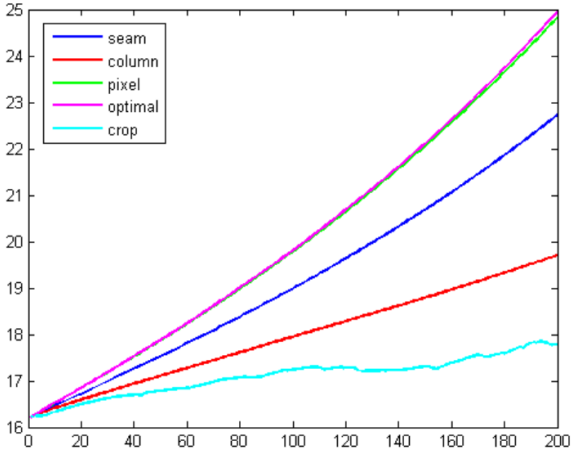


Image Reduction

optimal

pixel

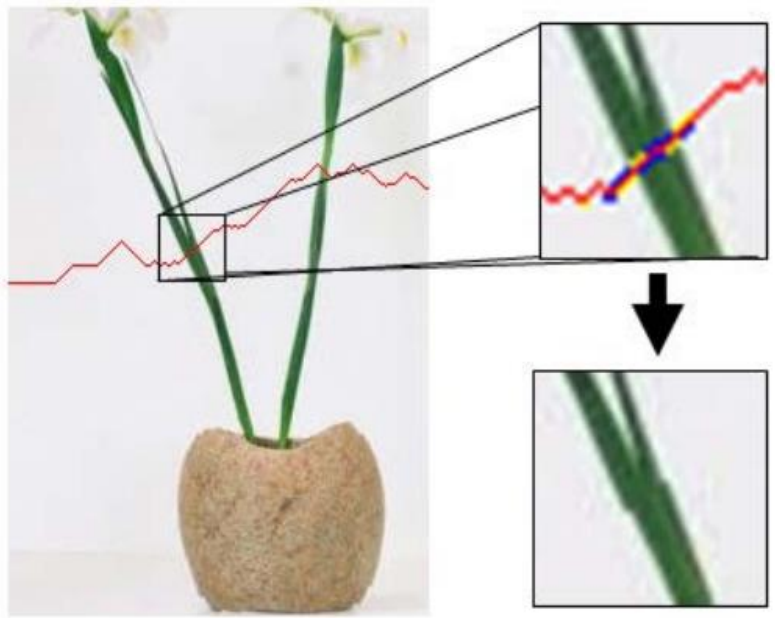
crop

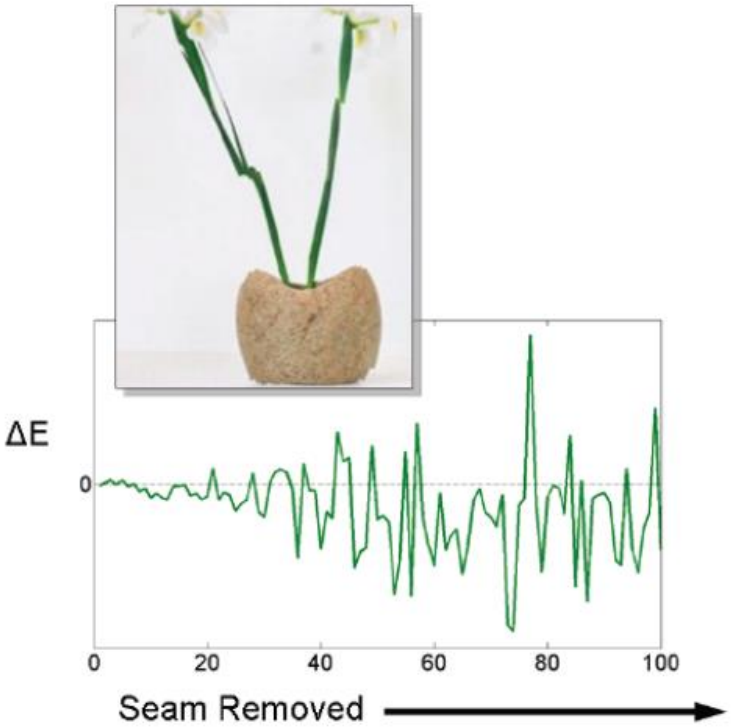
column

seam

Dynamic programming

- Inserted Energy
  - Limitation





Dynamic programming

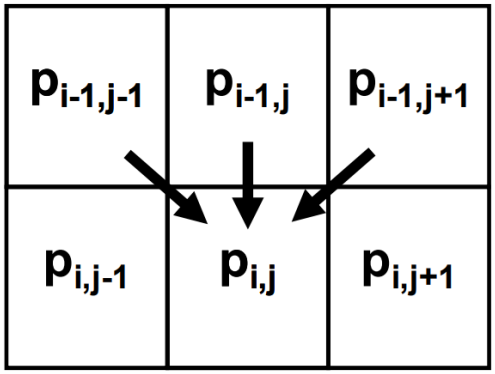
- Minimize Inserted Energy

- Instead of removing the seam of least energy, remove the seam that inserts the least energy to the image !

Dynamic programming

- Old “Backward” Energy

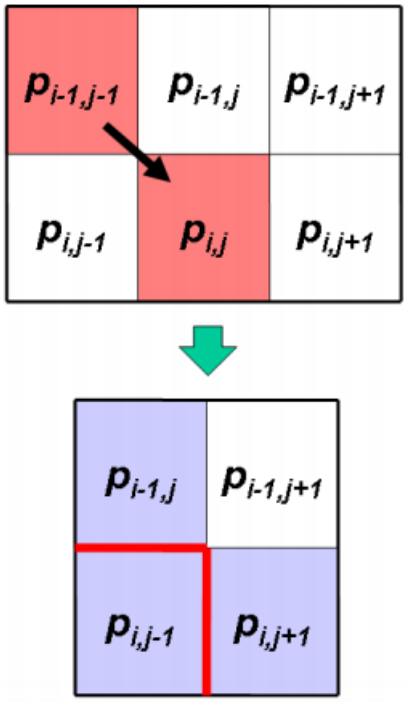
$$M(i,j) = E(i,j) + \min \begin{cases} M(i-1,j-1) \\ M(i-1,j) \\ M(i-1,j+1) \end{cases}$$



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

Dynamic programming

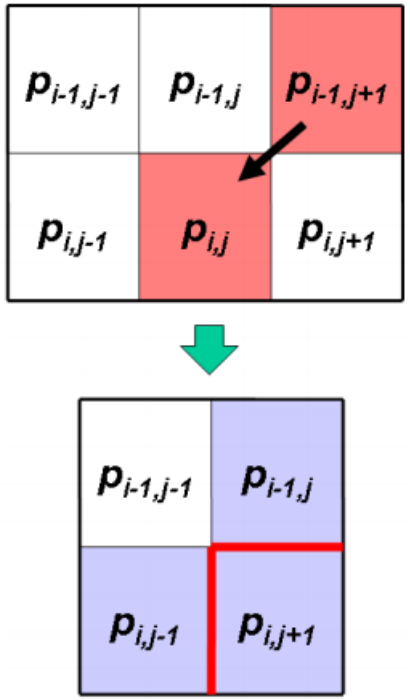
- Left Seam



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

Dynamic programming

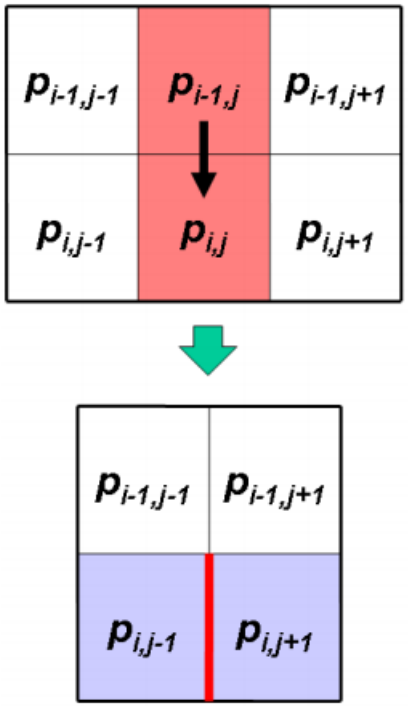
- Right Seam



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

Dynamic programming

- Vertical Seam

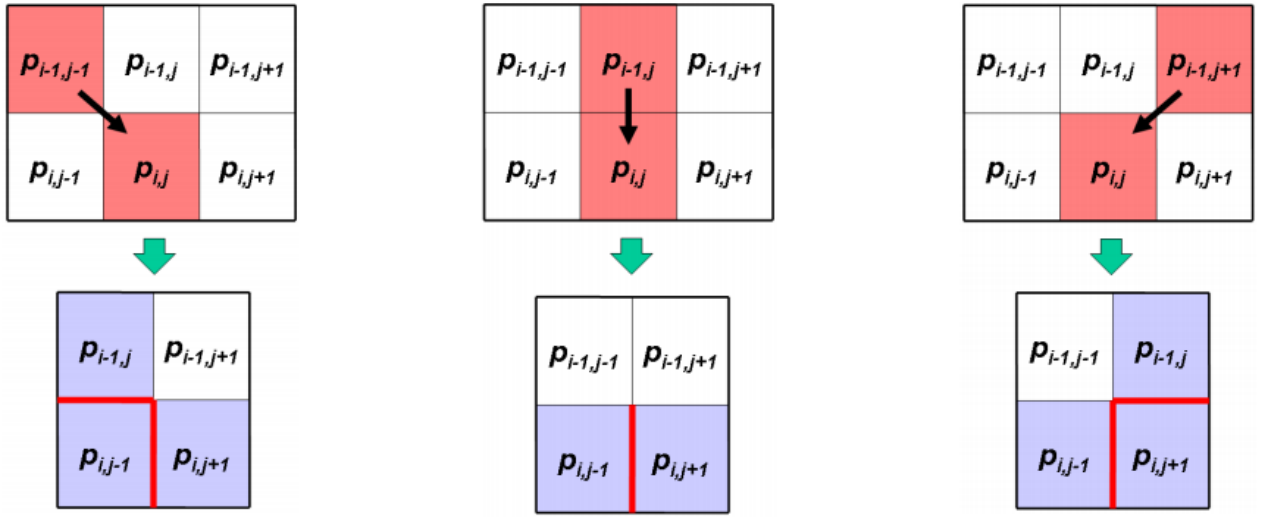


$$C_V(i,j) = |I(i,j+1) - I(i,j-1)|$$

Dynamic programming

- New “Forward” Looking Energy

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



Dynamic programming

- Backward vs. Forward
  - removing the seam of least energy

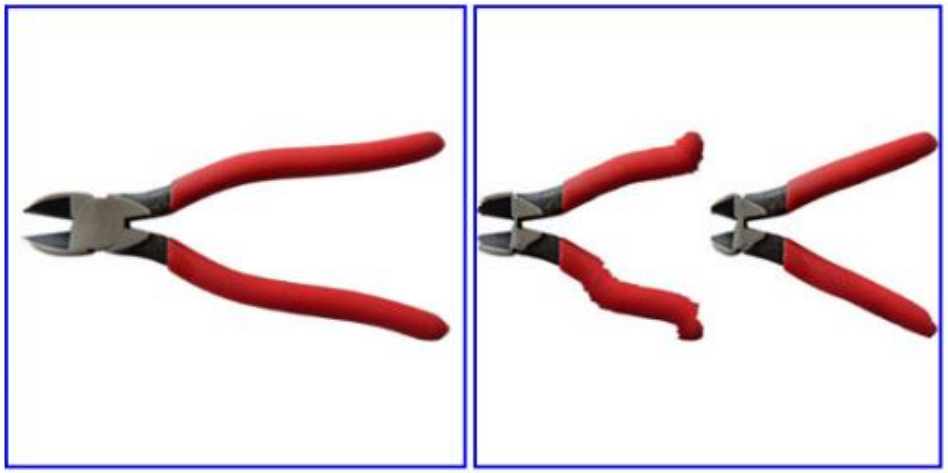
$$M(i,j) = E(i,j) + \min \begin{cases} M(i-1,j-1) \\ M(i-1,j) \\ M(i-1,j+1) \end{cases}$$

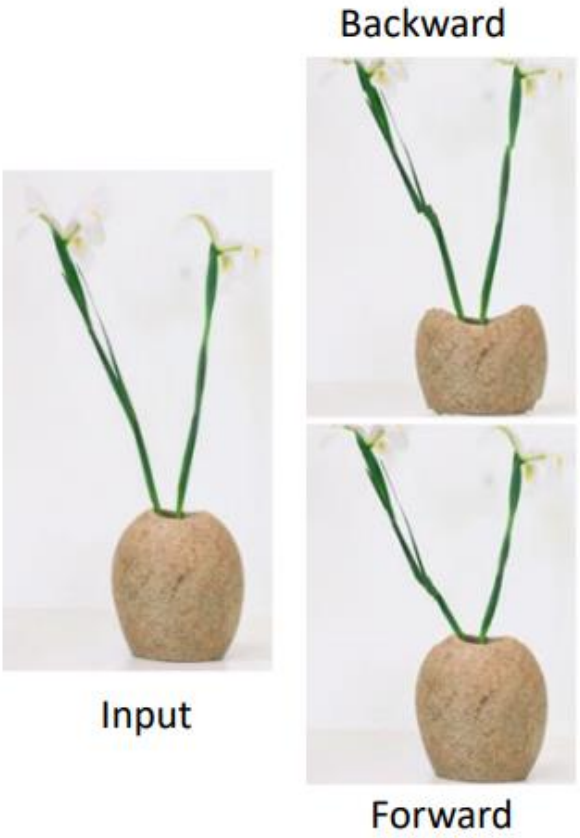
  - remove the seam that inserts the least energy to the image

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

Applications

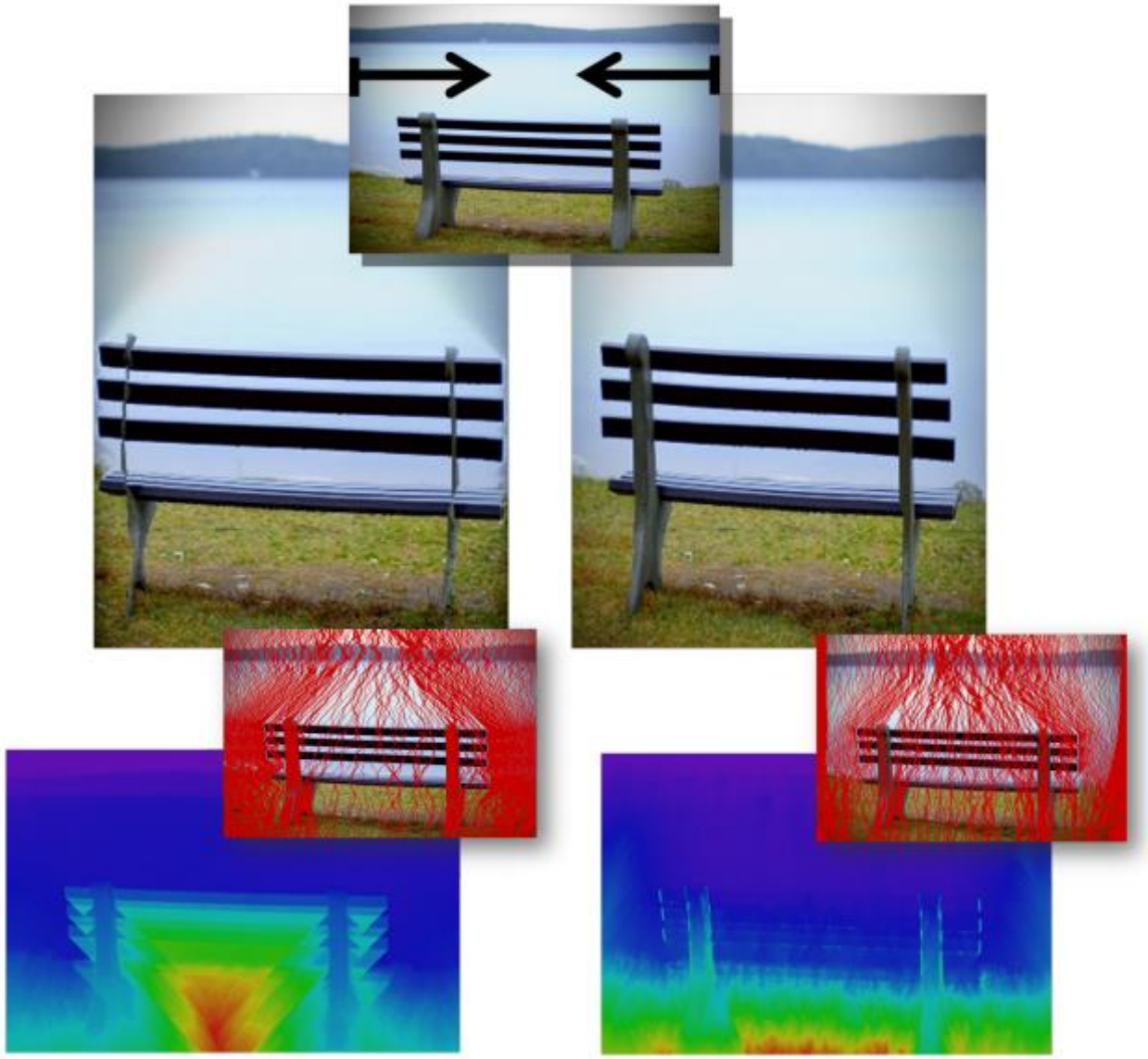
- Results





Dynamic programming

- Results



Dynamic programming

- Backward vs. Forward

(a) Original image.

(b) Backward energy seams.

(c) BE Resizing.

(d) Forward energy seams.

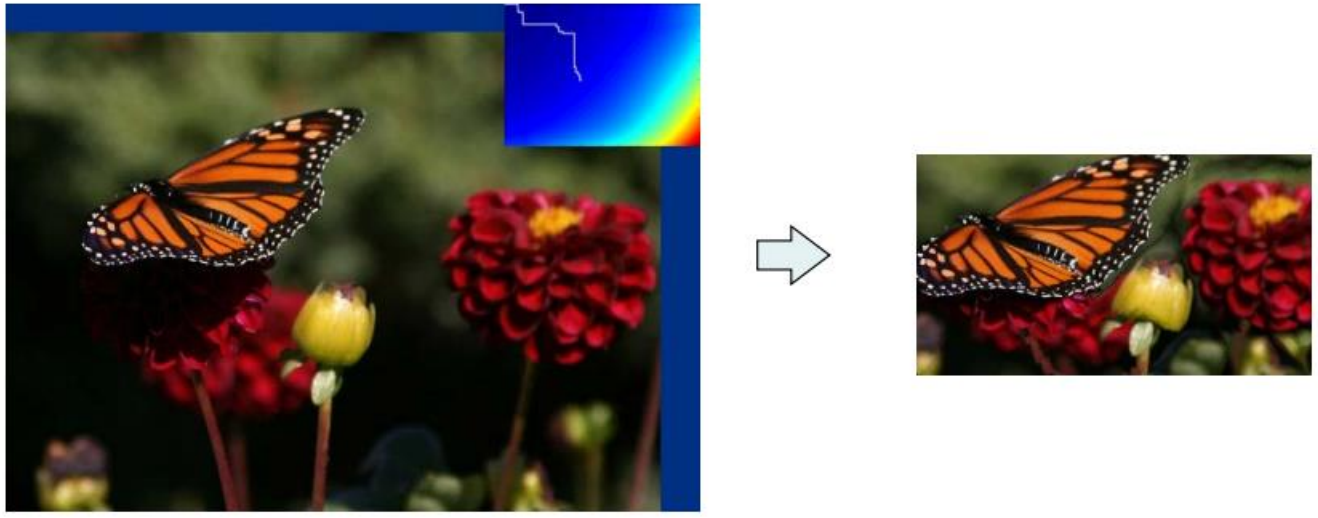
(e) FE Resizing.

Applications

- Backward vs. Forward

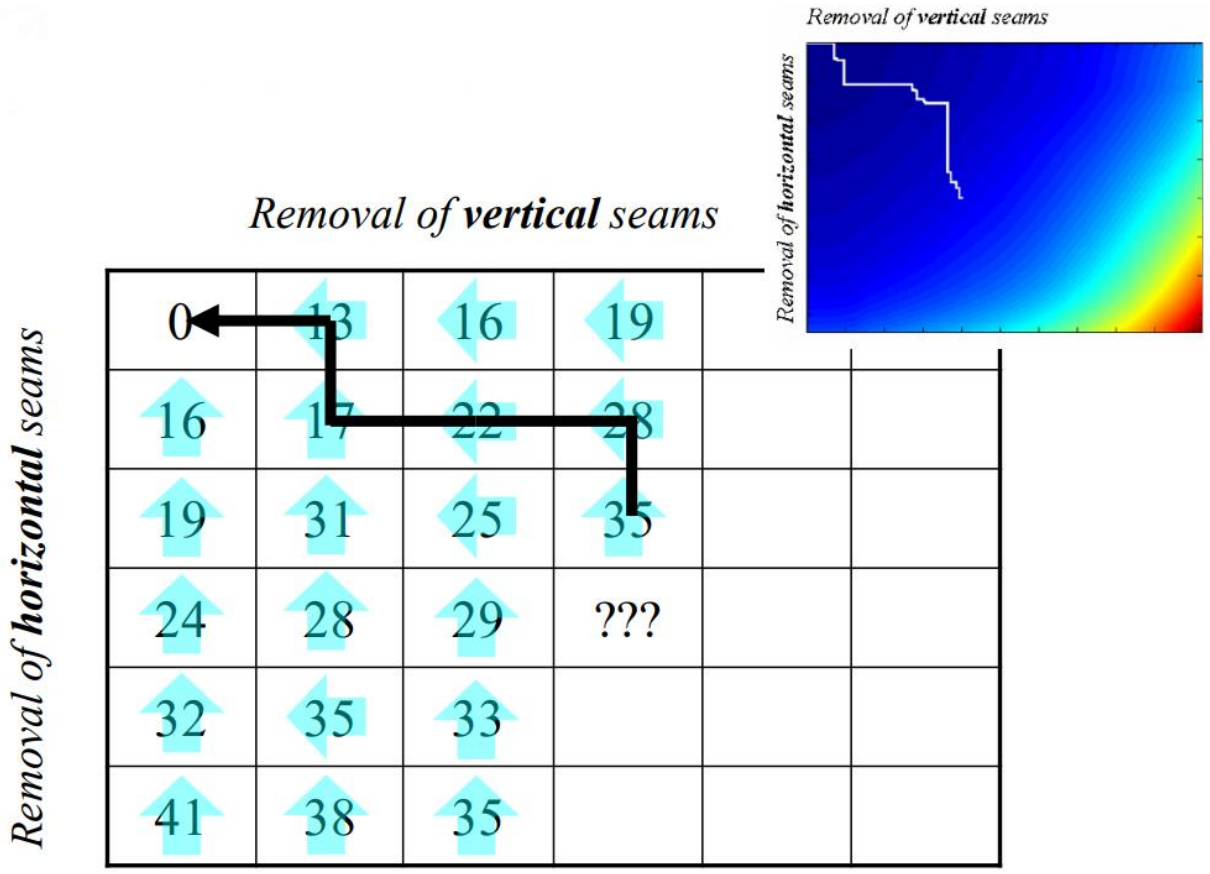
Dynamic programming

- Extension to 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)



Dynamic programming

- Extension to Both Dimensions

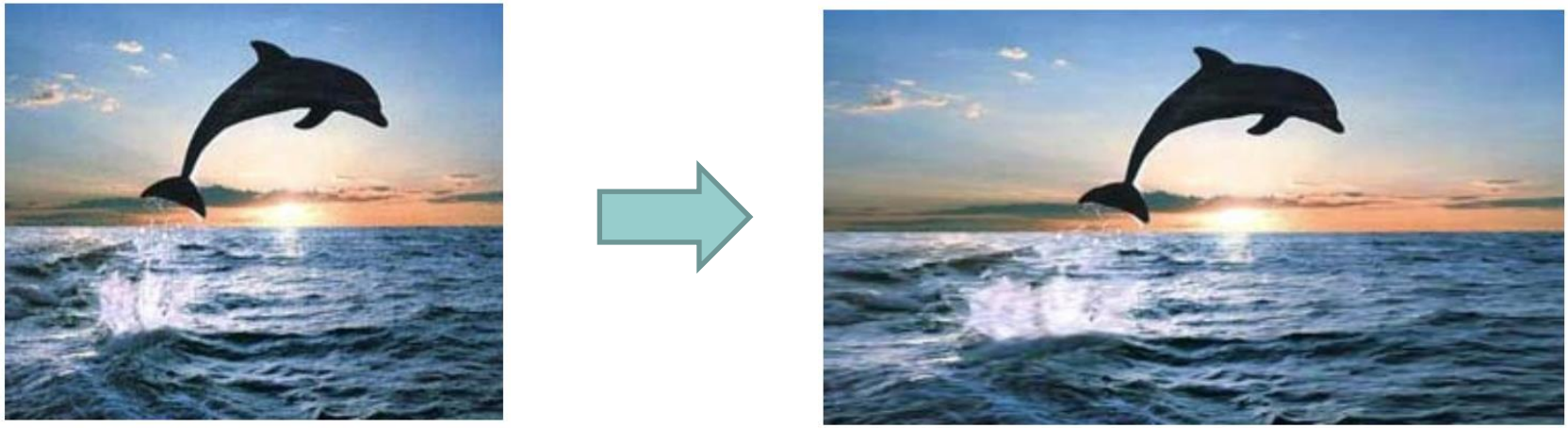


What we will learn today?

- Background
- What is image retargeting
- Seam carving
- Dynamic programming
- Applications

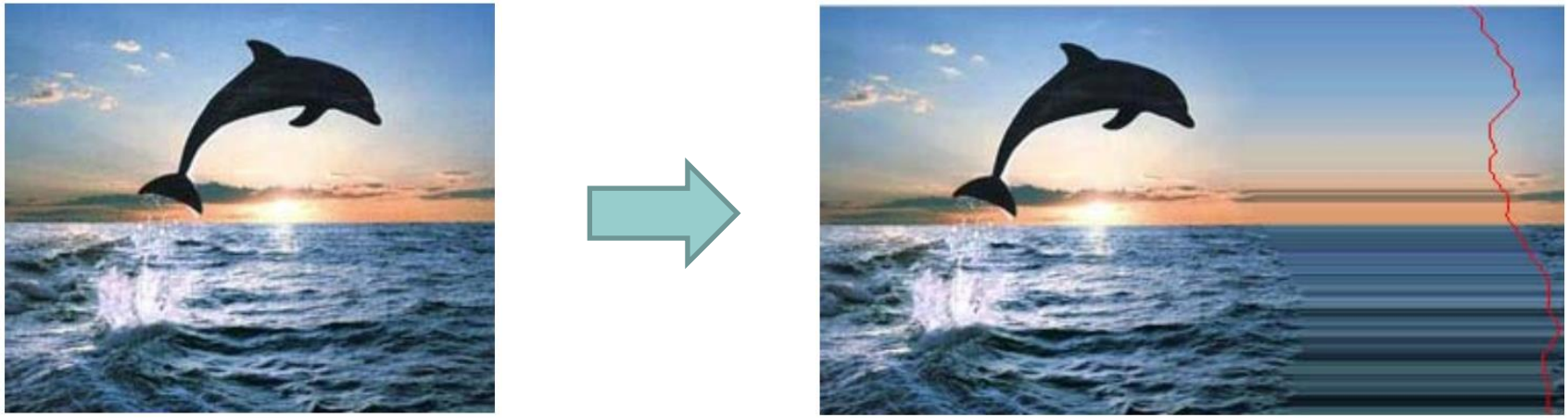
Applications

- Image Expansion (Synthesis)



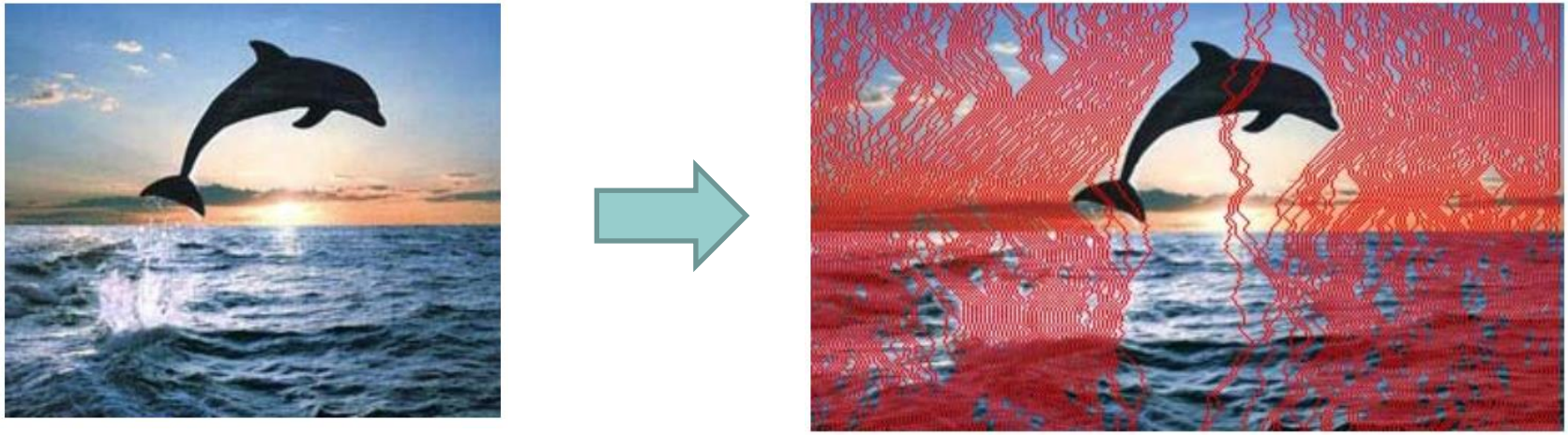
Applications

- Image Expansion



Applications

- Image Expansion (Synthesis)



Applications

- Combined Insert and Remove

Insert & remove seams

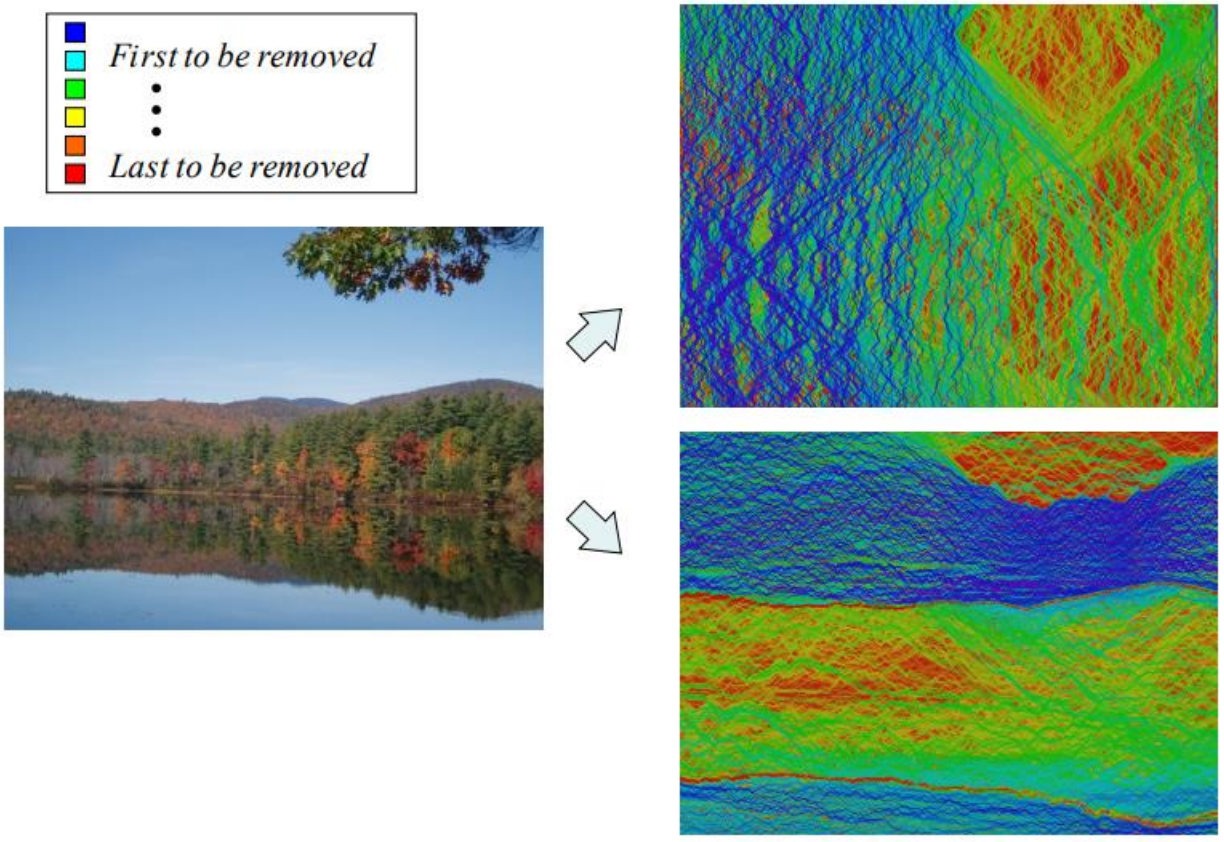
Scaling

Applications

- Multi-Size Image
  - 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

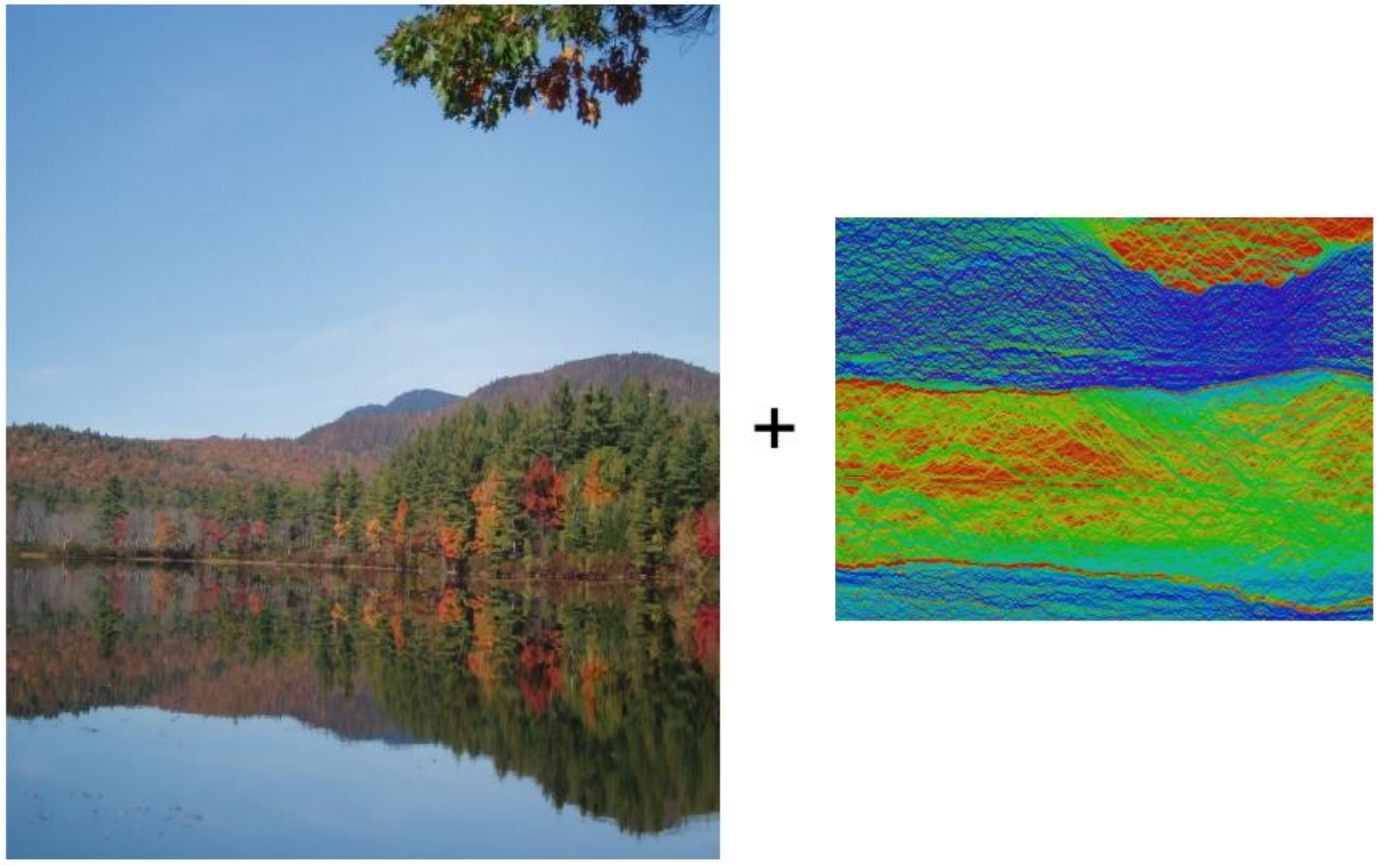
Applications

- Multi-Size Images



Applications

- Multi-Size Image Representation



Applications

- Object Removal

(a) Original image.

(b) Highlighted regions.

(c) Resized image with object removed.

Applications

- Auxiliary Energy
  - Recall our seam equation (Backward)

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

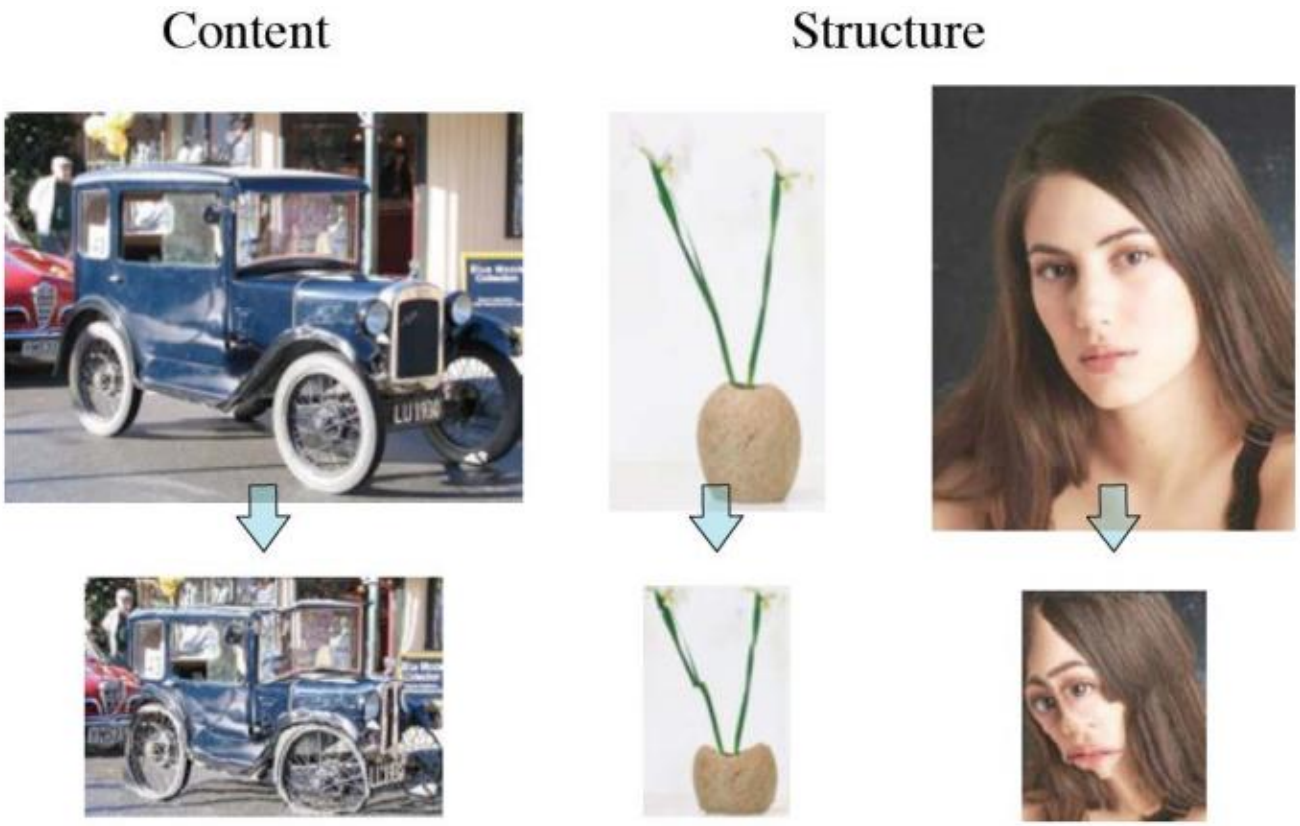
Applications

- Object Removal

Input | Retargeted | Pigeon Removed | Girl Removed

Applications

- Limitations



Applications

- With User Constraints

(a) Original image.

(b) Failed seam carved image.

(c) Highlighted original image.

(d) Successful seam carved image.

Applications

- With User Constraints

Applications

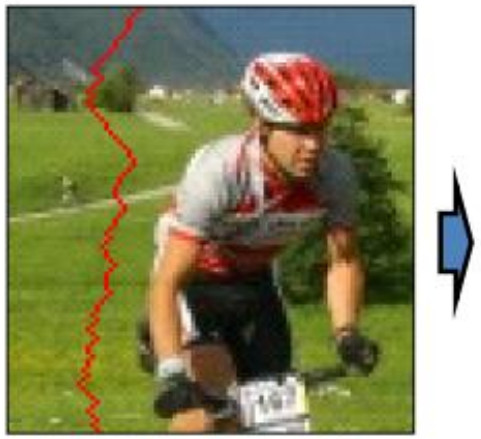
- With face detector

Applications

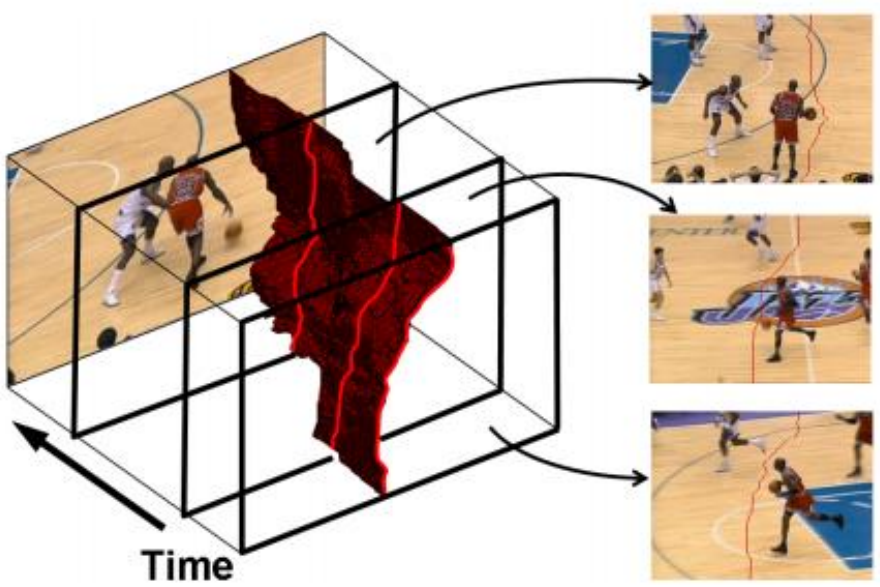
- From Images to Videos
  - In general, video processing is a much (much!) harder problem
  - 1. Cardinality
    - Suppose 1min of video x 30 fps = 1800 frames
    - Say your algorithm processes an image in 1 minute -> 30 hours !!
  - 2. Dimensionality/algorithmic
    - Temporal coherency: human visual system is highly sensitive to motion

Applications

- From 2D to 3D



1D paths in images



2D manifolds in video cubes

Seam Carving Demo

What we have learned today?

- Background
- What is image retargeting
  - ***I*** (n * m) -> ***I'***(n' * m') with "good representation"
  - 1. Define an energy function **E(I)** (interest, importance, saliency) ⇒ 2. Use some operator(s) to change the image **I**
- Seam carving
  - remove unimportant pixels from the image
    - $E_1(I) = \left|\frac{\partial}{\partial x} I\right| + \left|\frac{\partial}{\partial y} I\right|.$
  - the Optimal Seam
    - $E(\mathbf{I}) = \left|\frac{\partial}{\partial x}\mathbf{I}\right| + \left|\frac{\partial}{\partial y}\mathbf{I}\right| \Rightarrow s^* = \arg\min_s E(s)$
    - $\mathbf{M}(i,j) = E(i,j) + \min\left(\mathbf{M}(i-1,j-1), \mathbf{M}(i-1,j), \mathbf{M}(i-1,j+1)\right)$

What we have learned today?

- Dynamic programming
  - algorithm

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

  - preserved energy
  - backward vs. forward
  - Extension to Both Dimensions
- Applications
  - Image Expansion, Multi-Size Image, Object Removal, video retargeting …
  -