

Lecture 9

Saliency and Retargeting

CSE 455 Roadmap

Pixels

Video

Camera

Segment

ML

Convolutions
Edges
Descriptors

Motion
Tracking

Camera
3D Geometry

Segmentation
Clustering
Detection

Linear Models
(Conv) Neural networks

Today's agenda

- Image retargeting
- Seam carving
- Applications
- Forward algorithm

Content Retargeting

Home News Sport Business Innovation Culture Arts Travel Earth Video Live

US judge temporarily blocks Trump's freeze on federal grants and loans
The order is in response to a lawsuit that says the freezing of billions of dollars in already approved funding violates the law.
3 hrs ago | US & Canada

US judge temporarily blocks Trump's freeze on federal grants and loans
The order is in response to a lawsuit that says the freezing of billions of dollars in already approved funding violates the law.
3 hrs ago | US & Canada

Life sentence for hitman who killed suspect in 1985 Air India bombings
Tanner Fox is one of two hitmen who killed Ripudaman Singh Malik in Canada in 2022. It is still unknown who hired them.
3 hrs ago | US & Canada

Worshippers feared killed in crowd crush at India's huge Kumbh Mela festival
There are no official numbers yet on how many people may have been injured or killed at the festival.
• In pictures: Kumbh Mela crowd crush
▶ 'Ambulances zipping past': BBC reporter at site of crowd surge in India

Lunar New Year: Millions worldwide welcome the Year of the Snake
The Year of the Snake is here - and millions across Asia and the world are welcoming it, with family, friends, prayers and plenty of food.

Trump offers millions of federal workers eight months' pay to resign
The buyout offer to those who do not want to return to the office is part of the president's plan to shrink the US government.
32 mins ago | US & Canada

Australian sect members guilty of causing girl's death
The defendants had denied the diabetic girl her insulin, believing God would save her, a court heard.
48 mins ago | Australia

Mona Lisa to be moved as part of major Louvre overhaul
France's president says a second museum entrance will be built, while non-EU residents will also pay more to visit.
10 hrs ago | Europe

Only from the BBC

11 of the best TV shows to watch this February
From the return of HBO's holiday-resort satire to a political thriller starring Robert De Niro and the latest violent period drama from Peaky Blinders creator Stephen Knight.
17 hrs ago | Culture

Inside the race for Greenland's mineral wealth
The territory's untapped mineral wealth has caught the eye of both mining firms and Donald Trump.
2 days ago | Business

More news >

How China's 'AI heroes' overcame US curbs to stun Silicon Valley
15 hrs ago | Asia

South Korea plane fire causes mass evacuation
12 hrs ago | Asia

Italy's PM investigated over release of Libyan war crimes suspect
10 hrs ago | Europe

Danish PM in whirlwind EU trip as Greenland unease grows
9 hrs ago | Europe

'Half our house is gone': Palestinians face worst fears in north Gaza
12 hrs ago

PC



Worshippers feared killed in crowd crush at India's huge Kumbh Mela festival

There are no official numbers yet on how many people may have been injured or killed at the festival.

- In pictures: Kumbh Mela crowd crush
- ▶ 'Ambulances zipping past': BBC reporter at site of crowd surge in India

US judge temporarily blocks Trump's freeze on federal grants and loans
3 hrs ago | US & Canada

Life sentence for hitman who killed suspect in 1985 Air India bombings
3 hrs ago | US & Canada

Lunar New Year: Millions worldwide welcome the Year of the Snake

The Year of the Snake is here - and millions across Asia and the world are welcoming it, with family, friends, prayers and plenty of food.

Trump offers millions of federal workers eight months' pay to resign

The buyout offer to those who do not want to return to the office is part of the president's plan to shrink the US government.

32 mins ago | US & Canada

Australian sect members guilty of causing girl's death

The defendants had denied the diabetic girl her insulin, believing God would save her, a court heard.

48 mins ago | Australia

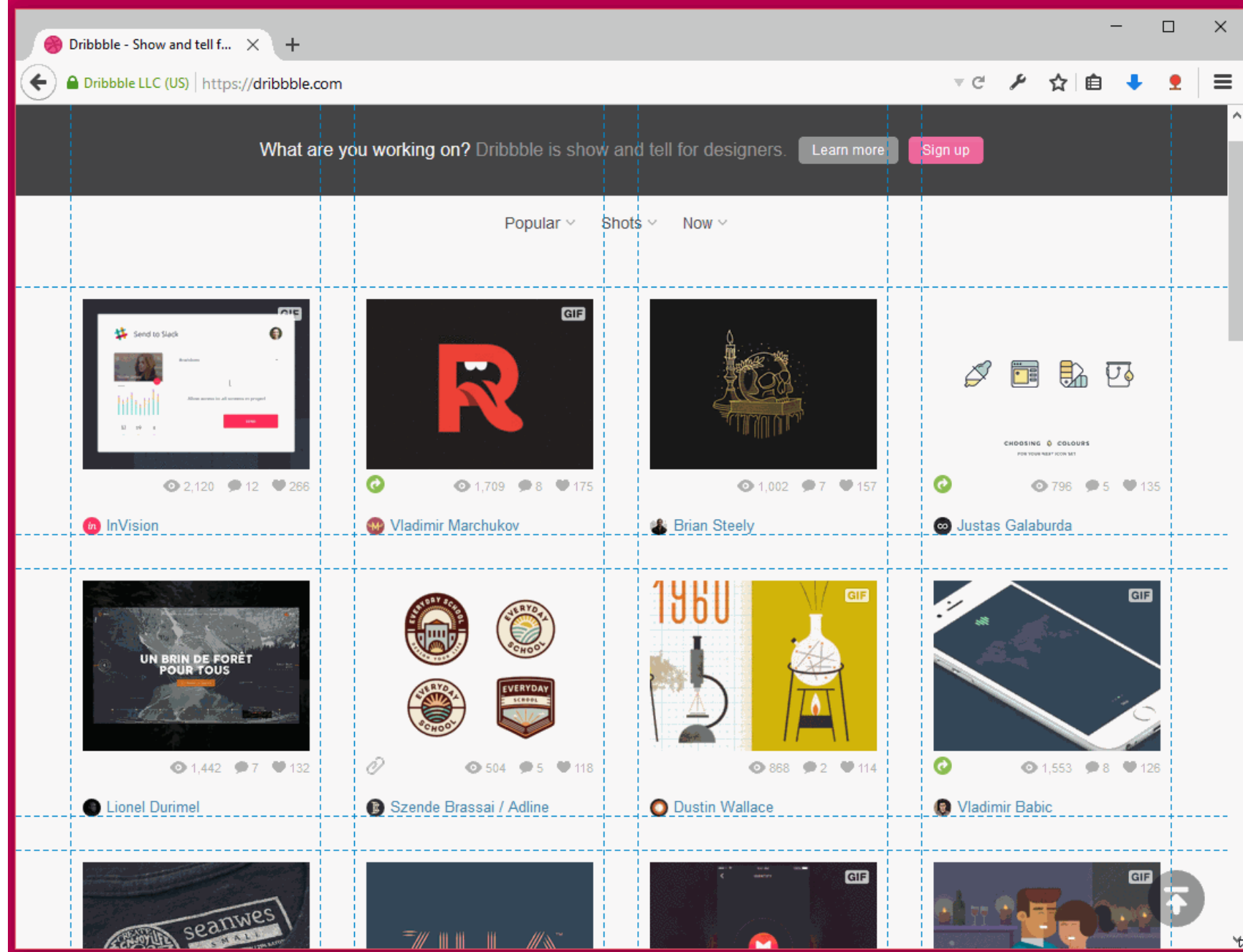
Mona Lisa to be moved as part of major Louvre overhaul

France's president says a second museum entrance will be built, while non-EU residents will also pay more to visit.

10 hrs ago | Europe

iPhone

Page Layout



Display Devices



Have you ever seen this?

**The following film has been modified
from its original version. It has been
formatted to fit this screen.**



Simple Media Retargeting Operators

Letterboxing



Content-aware Retargeting Operators

Content-
aware



“Important”
content



Content-
oblivious



Content-aware Retargeting

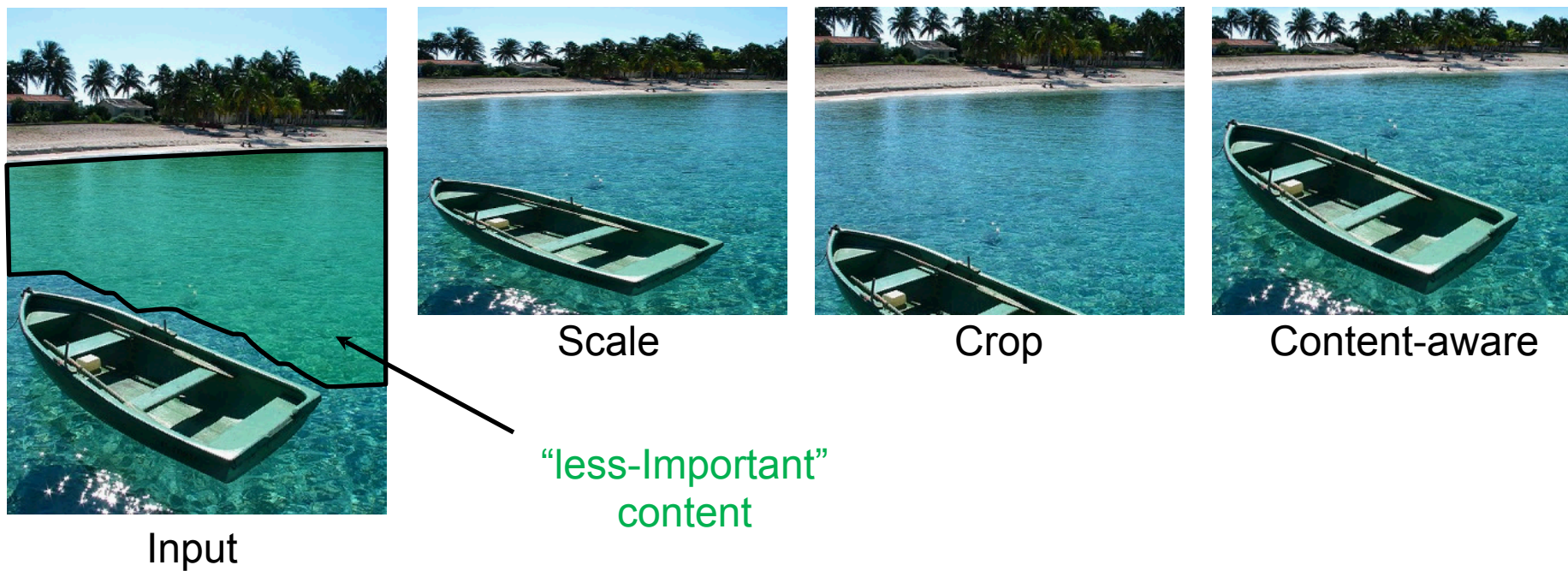


Image Retargeting (“More” Formally)

Problem statement

- Input image I of size $n \times m$
- Output image I' of size $n' \times m'$

Output image should be **geometrically** and **semantically** consistent with input image

How can we define consistency?

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**

How can we define consistency?

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 what is important?
 - Is there a universal important vs unimportant?
- Would different people find different image regions more or less important?
- What about artistic impression in the original content?

Importance (Saliency) Measures

- A function $\mathcal{S} : n \times m \rightarrow [0, 1]$
- More sophisticated: attention models, eye tracking (gazing studies), face detectors, ...

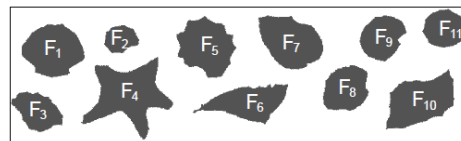
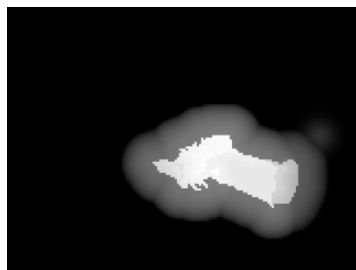
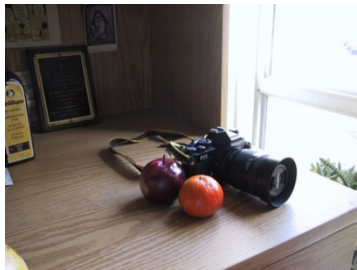
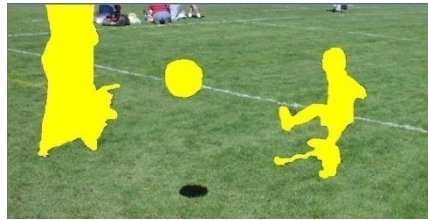


General Retargeting Framework



General Retargeting Framework

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

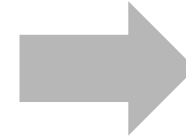
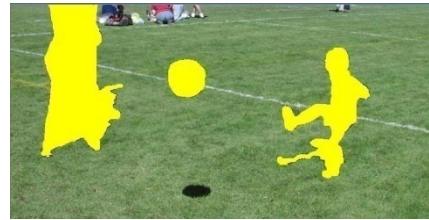


General Retargeting Framework

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



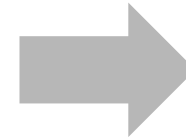
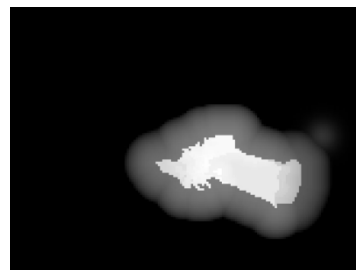
Step 2. Use some operator(s) to change the image \mathbf{I}



Recompose



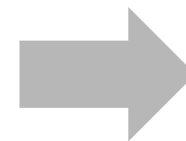
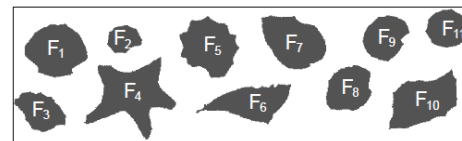
Setlur et al.
[2005]



Crop



Santella et al.
[2005]



Warp



Gal et al.
[2006]

Potential Retargeting Approaches

- Done manually in the movie industry for many years



Today's agenda

- Image retargeting
- **Seam carving**
- Applications
- Forward algorithm

Seam Carving

- Assume input I is size $m \times n$
- Output I is $m \times n'$,
 - where $n' < n$
- Basic Idea: remove unimportant pixels from the image
 - Unimportant = pixels with less “energy”

Seam Carving

- Assume input I is size $m \times n$
- Output I is $m \times n'$,
 - where $n' < n$
- Basic Idea: remove unimportant pixels from the image
 - Unimportant = pixels with less “energy”

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

$$E(I) = \sqrt{\left(\frac{\partial I}{\partial x}\right)^2 + \left(\frac{\partial I}{\partial y}\right)^2}$$

- Intuition for gradient-based energy:
 - Preserve edges – we are sensitive to edges
 - Try remove content from smoother areas
 - Simple enough for producing some nice results

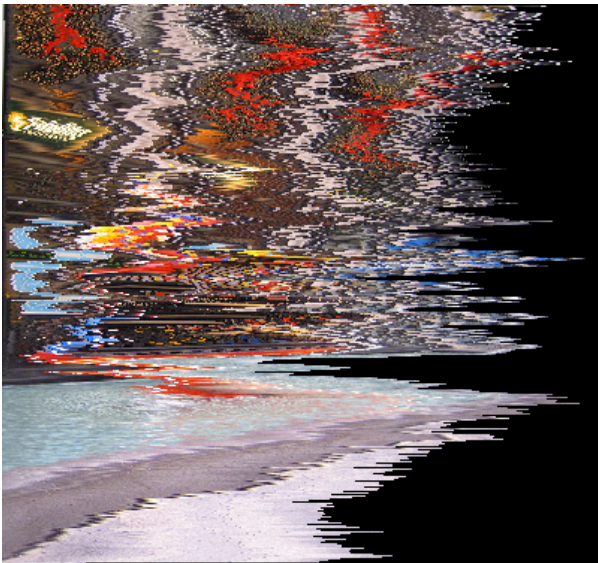
Let's do an experiment

We calculate the energy for this image.



Q1. Can we just remove the **K pixels** with the lowest energy?

Pixel Removal



Optimal

Let's do an experiment

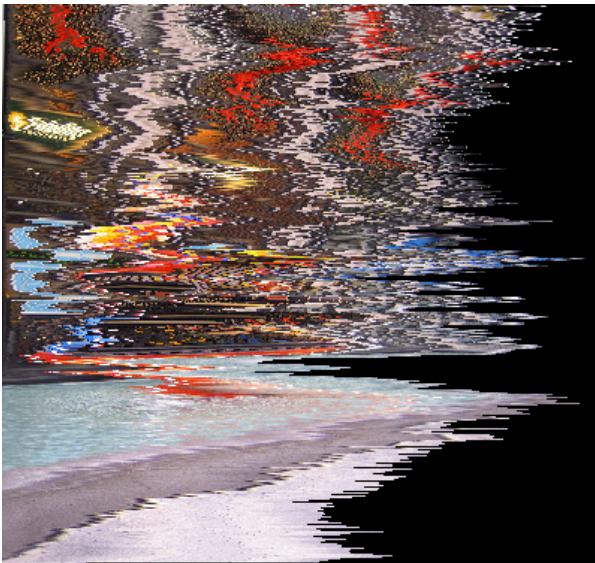
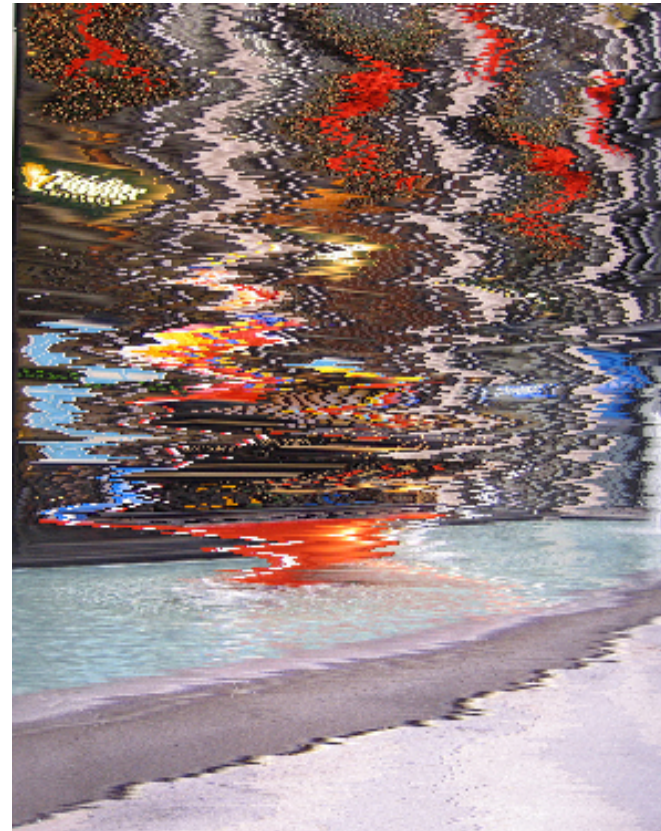


We calculate the energy for this image.

Q1. Can we just remove the K **pixels** with the lowest energy?

Q2. Can we remove the K **pixels** with the lowest energy **per rows**?

Pixel Removal



Optimal

Least-energy pixels
(per row)

Let's do an experiment



We calculate the energy for this image.

Q1. Can we just remove the K **pixels** with the lowest energy?

Q2. Can we remove the K **pixels** with the lowest energy **per column**?

Q3. Can we remove the K **columns** with the lowest energies?

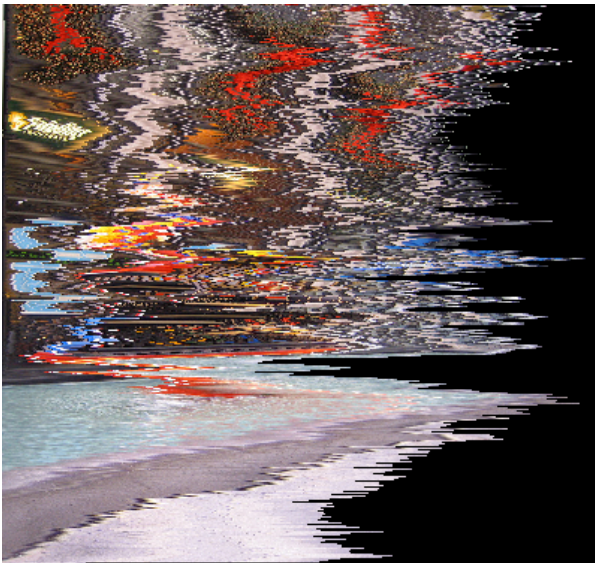
Pixel Removal



Least-energy pixels
(per row)



Least-energy
columns



Optimal

Solution: A Seam

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

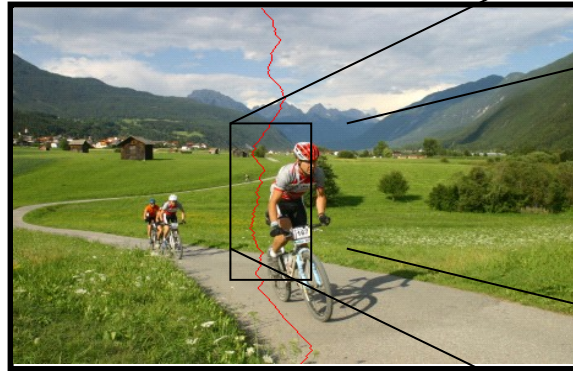
$$s^x = \{s_i^x\}_{i=1}^n$$

$$s^x = \{x(i), i\}_{i=1}^n$$

for every row i

$$\text{s.t. } \forall i, |x(i) - x(i - 1)| \leq 1$$

Ensure that seam is “connected”.
Columns can only change by a
maximum of 1 column

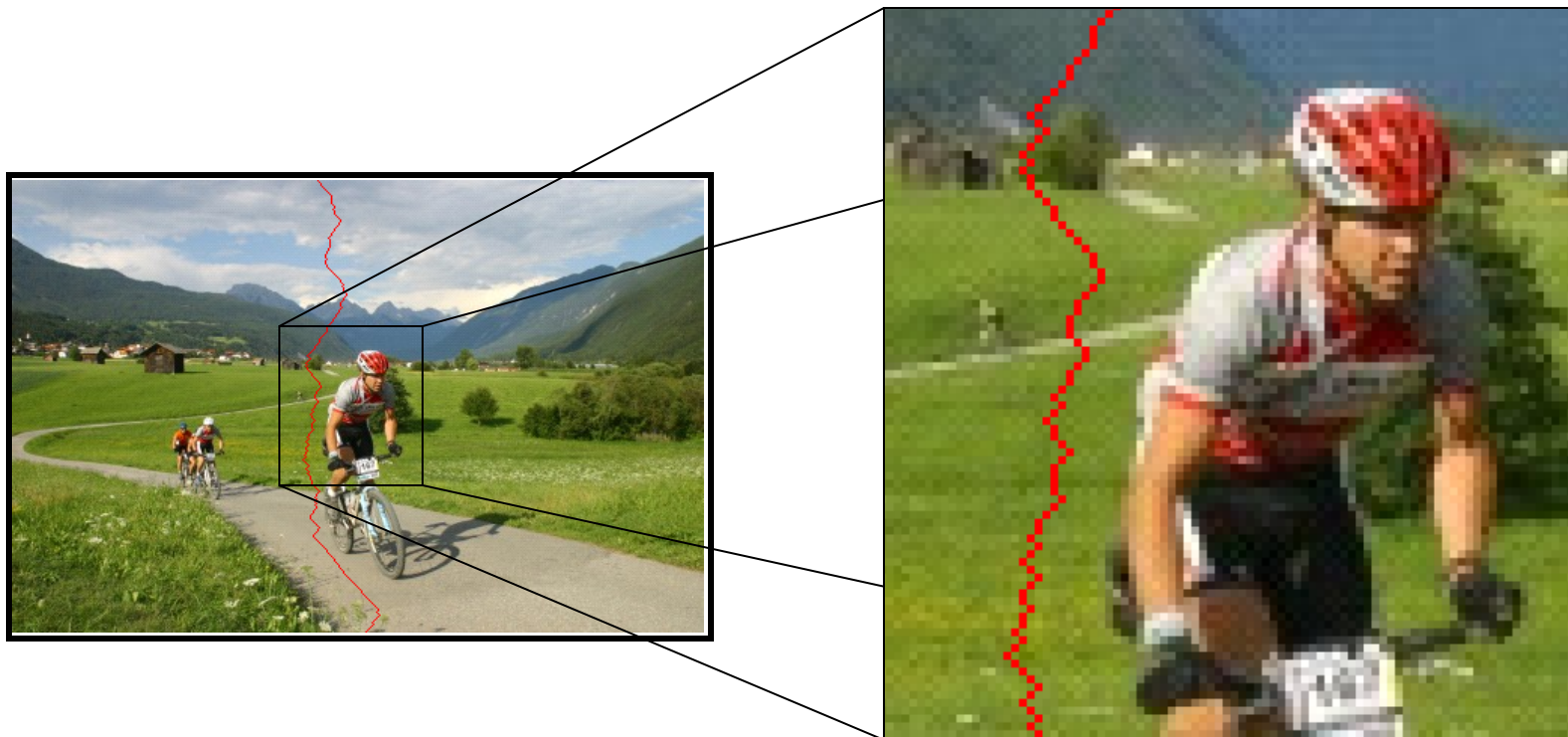


A Seam

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

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

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



How do we find the optimal Seam?

Q: How many seam do we have for an image? $O(???)$



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

Brute force is not practical, but you must have seen this

An example here, and there are many more

746. Min Cost Climbing Stairs

Easy

Topics

Companies

Hint

You are given an integer array `cost` where `cost[i]` is the cost of i^{th} step on a staircase. Once you pay the cost, you can either climb one or two steps.

You can either start from the step with index `0`, or the step with index `1`.

Return the *minimum cost to reach the top of the floor*.

$$\mathbf{A:} \text{ sol}[i] = \text{cost}[i] + \min(\text{sol}[i-1], \text{sol}[i-2])$$

Dynamic Programming

Input: Given an energy $E(i, j)$

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

Energy - $E(i, j)$

Dynamic Programming

- Create a **cost matrix M** with the following property:
 - **$M(i, j)$ = minimal cost** of a seam going through pixel (i, j)
 - starting from $j=0$

$M(i, j)$

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

Energy - $E(i, j)$

Dynamic Programming

$M(i, 0) = E(i, 0)$ of a seam going through pixel (i, j)

$M(i, j)$

5	8	12	3

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

Energy - $E(i, j)$

Dynamic Programming

Q. What do you think should be this value?

$M(i, j)$

5	8	12	3
	?		

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

Energy - $E(i, j)$

Dynamic Programming

$M(i, j)$ = total energy of seam going through pixel (i, j) from $j=0$

$M(i, j)$

5	8	12	3
	2+5		

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

Energy - $E(i, j)$

Dynamic Programming

The recurrence formula

$$M(i, j) = E(i, j) + \min(M(i-1, j-1), M(i-1, j), M(i-1, j+1))$$

5	8	12	3
	2+5		

$M(i, j)$

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

Energy - $E(i, j)$

Dynamic Programming

5	8	12	3
	7		

$M(i, j)$

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

Energy - $E(i, j)$

Dynamic Programming

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

5	8	12	3
	7	?	

$\mathbf{M}(i, j)$

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

Energy - $E(i, j)$

Dynamic Programming

$$M(i, j) = E(i, j) + \min(M(i-1, j-1), M(i-1, j), M(i-1, j+1))$$

5	8	12	3
	7	3+3	

$M(i, j)$

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

Energy - $E(i, j)$

Dynamic Programming

$$M(i, j) = E(i, j) + \min(M(i-1, j-1), M(i-1, j), M(i-1, j+1))$$

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

M(i, j)

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

Energy - E(i, j)

Searching for minimum seam

Backtrack: Find the minimum $M(i, j=m)$

	5	8	12	3
	9	7	6	12
	14	9	10	8
$M(i, j)$	14	14	15	16

This is the minimum in the last row

Backtrack

After finding minimum $M(i, j)$ at row j ,

find minimum $M(i, j-1)$ but only be looking at neighboring locations: $i-1, i, i+1$

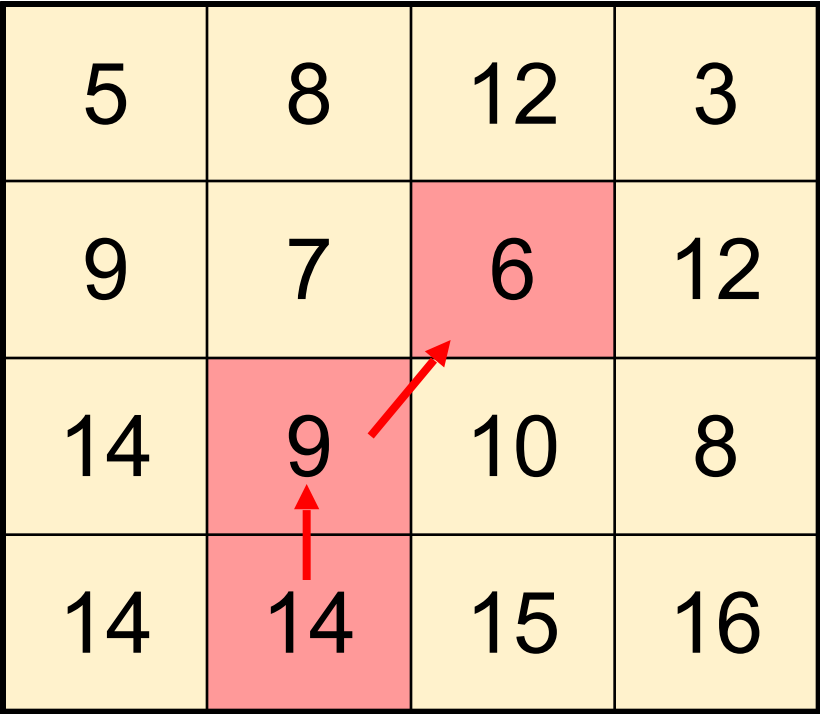
	5	8	12	3
	9	7	6	12
	14	9	10	8
$M(i, j)$	14	14	15	16

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

Energy - $E(i, j)$

Searching for Minimum

	5	8	12	3
	9	7	6	12
	14	9	10	8
$M(i, j)$	14	14	15	16



Searching for Minimum

$M(i, j)$

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

The Optimal Seam - **dynamic programming**

- The recursion relation

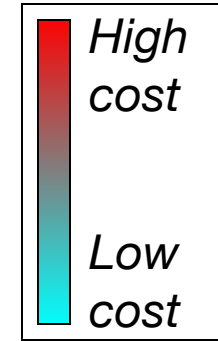
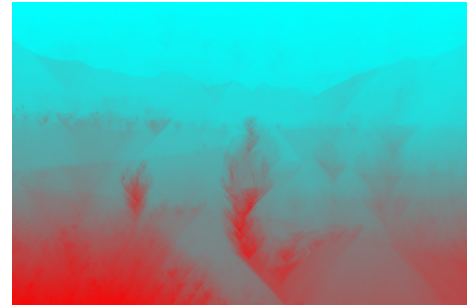
$$\mathbf{M}(i, j) = E(i, j) + \min(\mathbf{M}(i - 1, j - 1), \mathbf{M}(i - 1, j), \mathbf{M}(i - 1, j + 1))$$

- **Q: What is the time complexity?**

$$O(s \cdot n \cdot m)$$

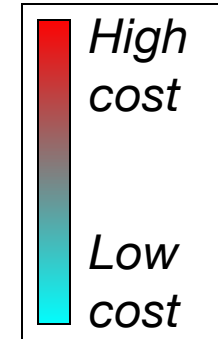
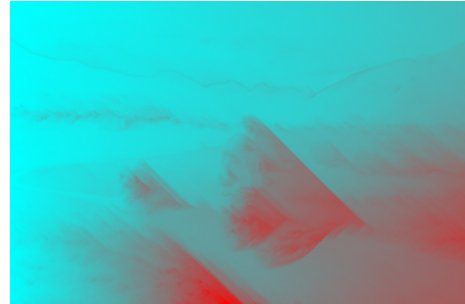
(s=3 in the original algorithm)

Vertical cost maps



Vertical Cost

Horizontal cost maps



Horizontal Cost

The Seam-Carving Algorithm

Algorithm: Seam carving

Input: Image I of size $m \times n$

Output: Image I' of size $m \times n'$ where $n' < n$

$I' = I$

Do $d=(n-n')$ times

 Compute energy map on I'

 Find optimal seam in E

 Remove s from im

Return I'

For vertical resize: transpose the image

Running time: $O(dmn)$ or $O(dsmn)$

Changing Aspect Ratio



Another example



Example seam carving



Example seam carving



Changing Aspect Ratio



Original



Retargeting



Scaling

Changing Aspect ratio



Cropping



Retarget



Scaling

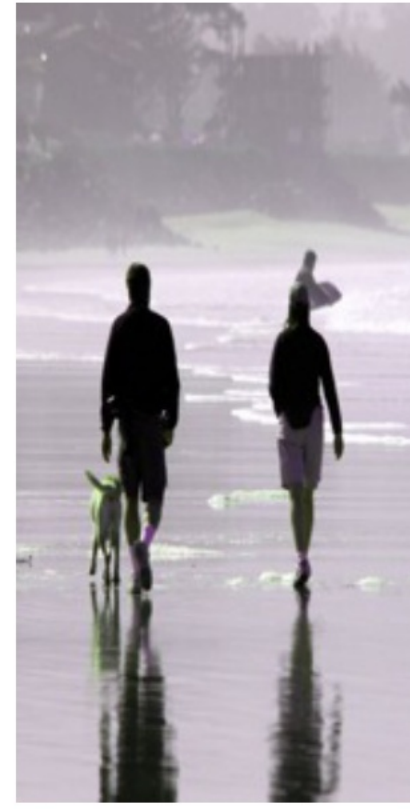
Changing Aspect Ratio



Original



Retarget

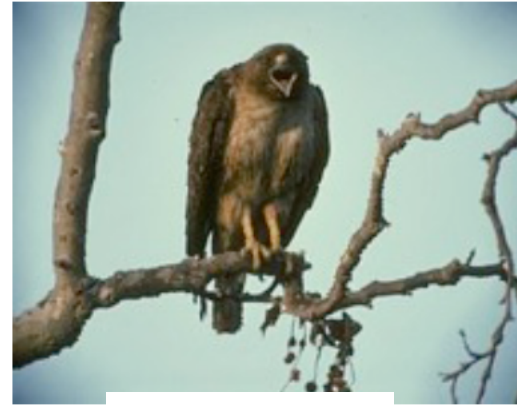


Scaling

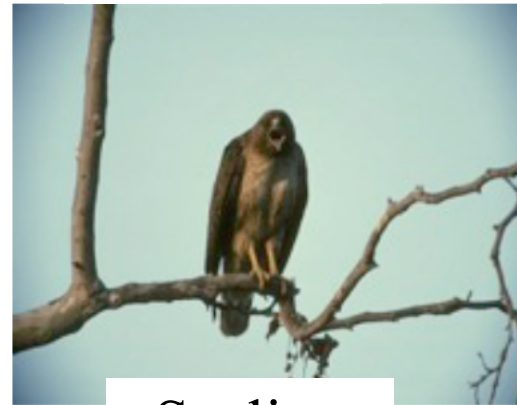
Changing Aspect Ratio



Original



Retarget



Scaling

Questions

- Q: Will the result be the same if the image is flipped upside down?

Q. What if we simultaneously want to reduce both width and height?

$m \times n \rightarrow m' \times n'$

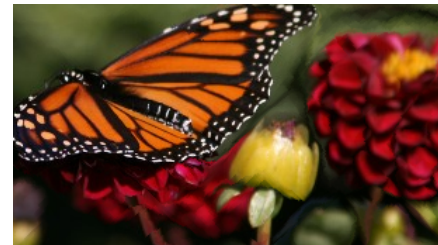
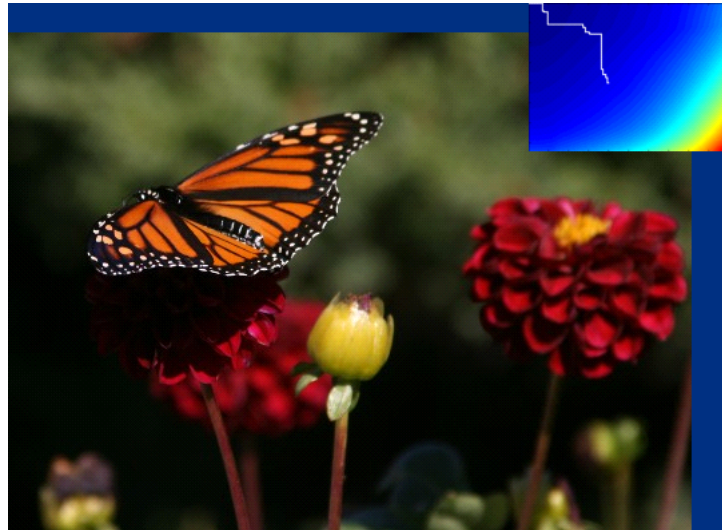
1. Should we remove horizontal seam first?
2. Should we remove vertical seams first?
3. Alternate between the two?
4. Any other ideas?

What if we simultaneously want to reduce both width and height?

$m \times n \rightarrow m' \times n'$

1. Should we remove horizontal seam first?
2. Should we remove vertical seams first?
3. Alternate between the two?
4. Any other ideas?

Exercise: the optimal order can be found! Dynamic Prog (again! but this is not easy)



Today's agenda

- Image retargeting
- Seam carving
- Dynamic programming
- **More Applications**
- Forward algorithm

Image expansion - Repeat the lowest energy seam?

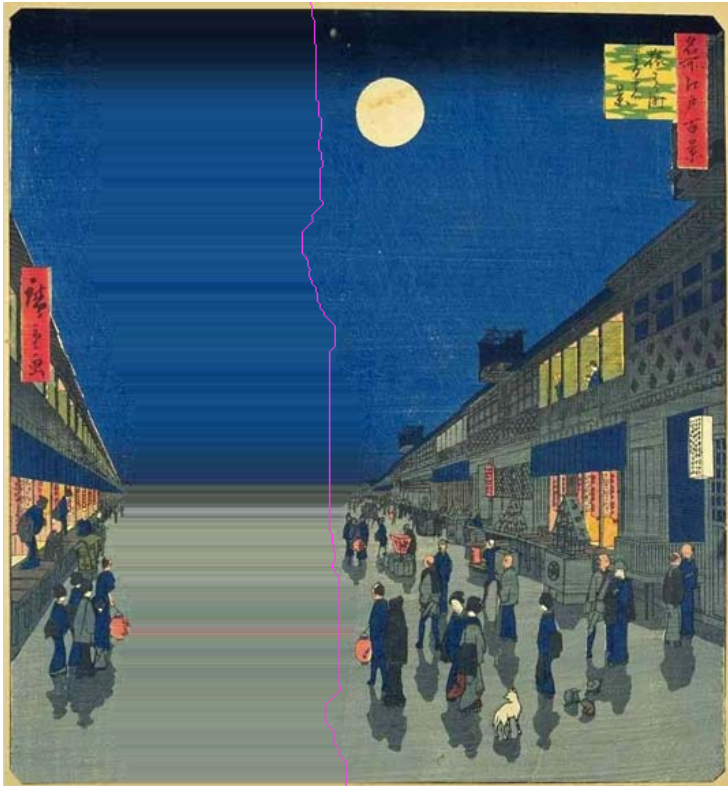
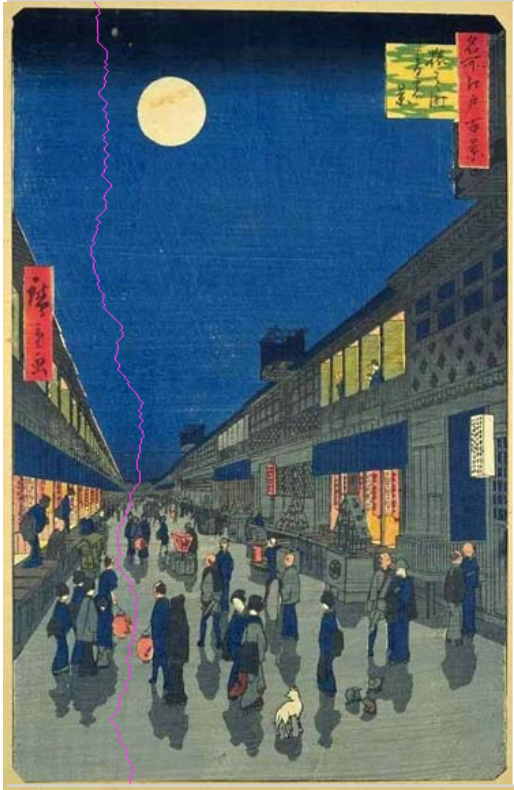
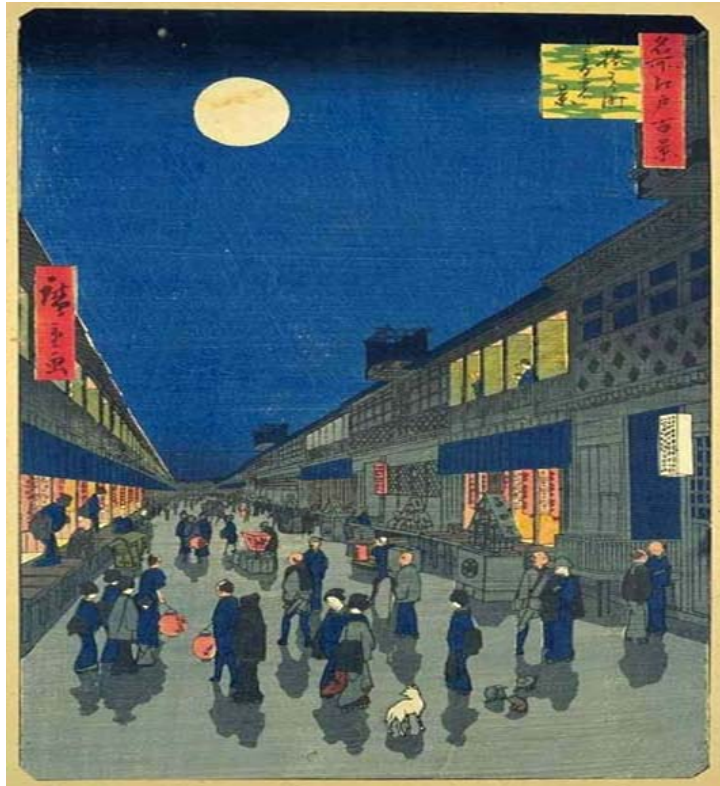


Image Expansion – Repeat the K lowest energy seams



Scaling



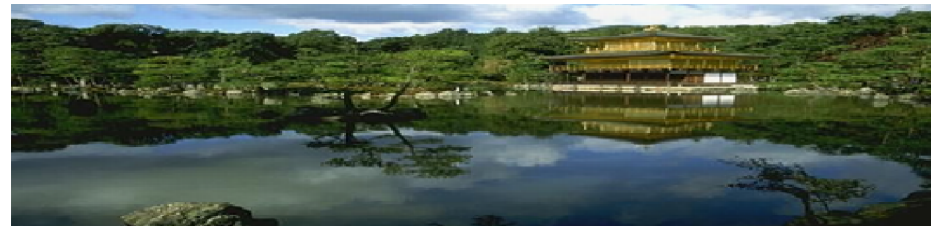
Can you tell if this image has been **enlarged** or **reduced**?



Combined Insert and Remove



Insert & remove seams



Scaling

Content Enhancement



Q. How to not touch objects when using seam carving?

Replace $E(i, j)$ with user defined energies

Recall our seam equation

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

Set $E(i, j)$ to be infinity if a user wants to keep this pixel

Set $E(i, j)$ to be negative number if a user wants to get rid of it.

Object Removal



Object Removal



Input



Retargeted



Pigeon Removed



Girl Removed

Let's delete a shoe from this image



Find the missing Shoe in the left image!



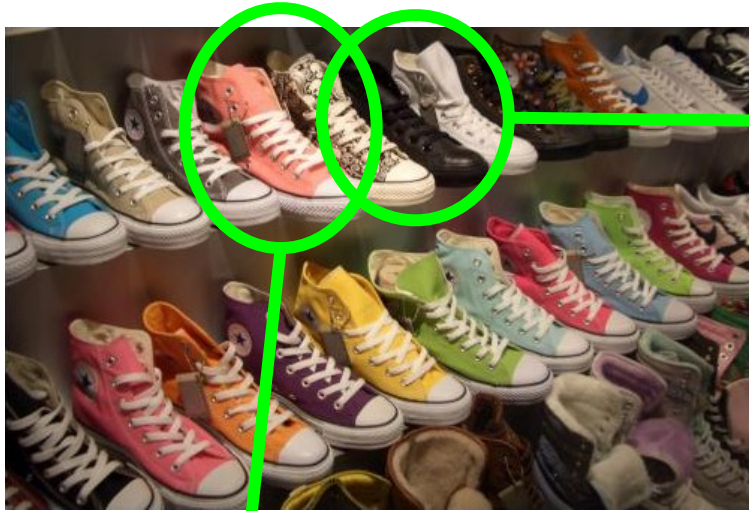
Solution: black shoe is gone



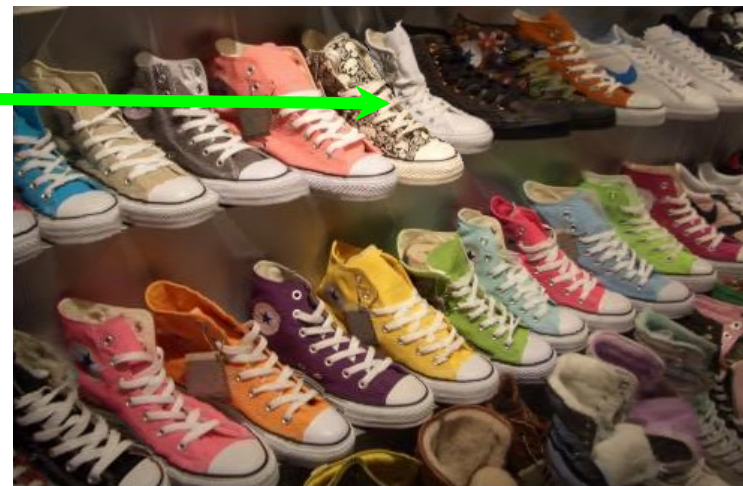
Let's delete another shoe. Find the new missing shoe!



Solution



We can stack these edits. Find the missing show from the **bottom right** image by **deleteing from the upper right**



Solution



Use face detector to set energies of faces high



Energy with gradients



Energy with face detectors

Today's agenda

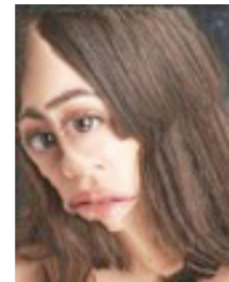
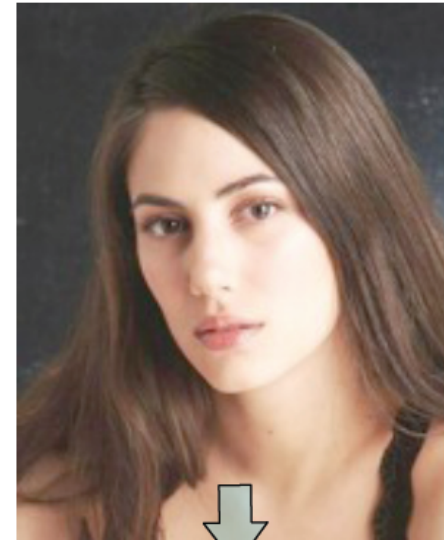
- Image retargeting
- Seam carving
- More Applications
- **Forward algorithm**

Limitations

Content



Structure



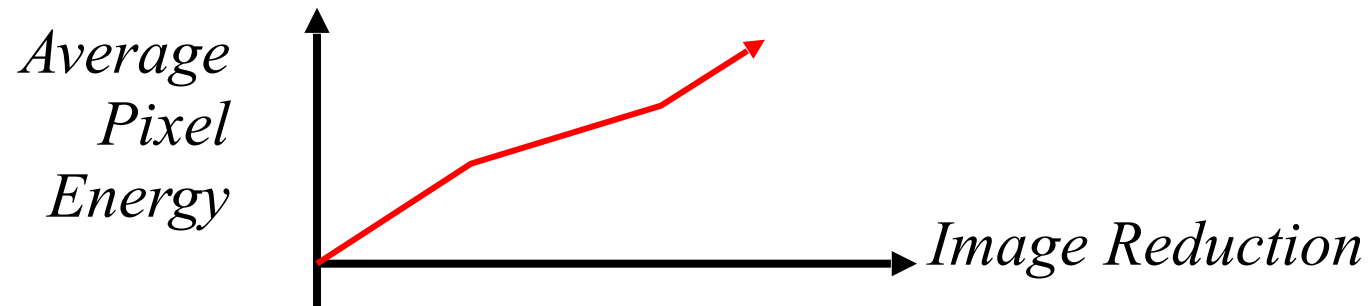
Questions

Q: What happens to the avg pixel energy in the image during seam carving?

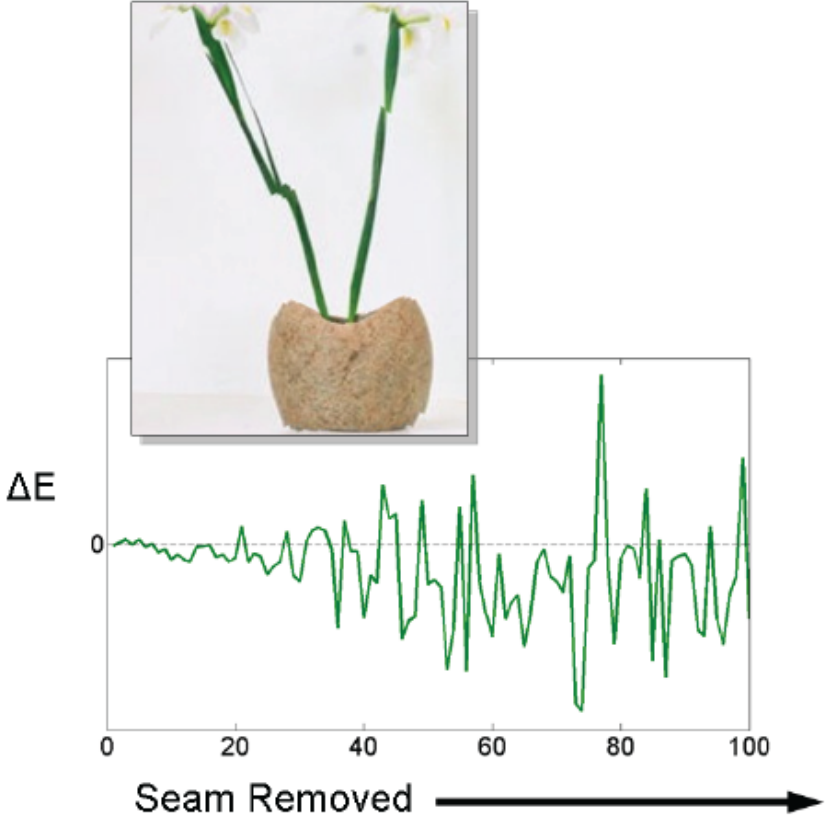
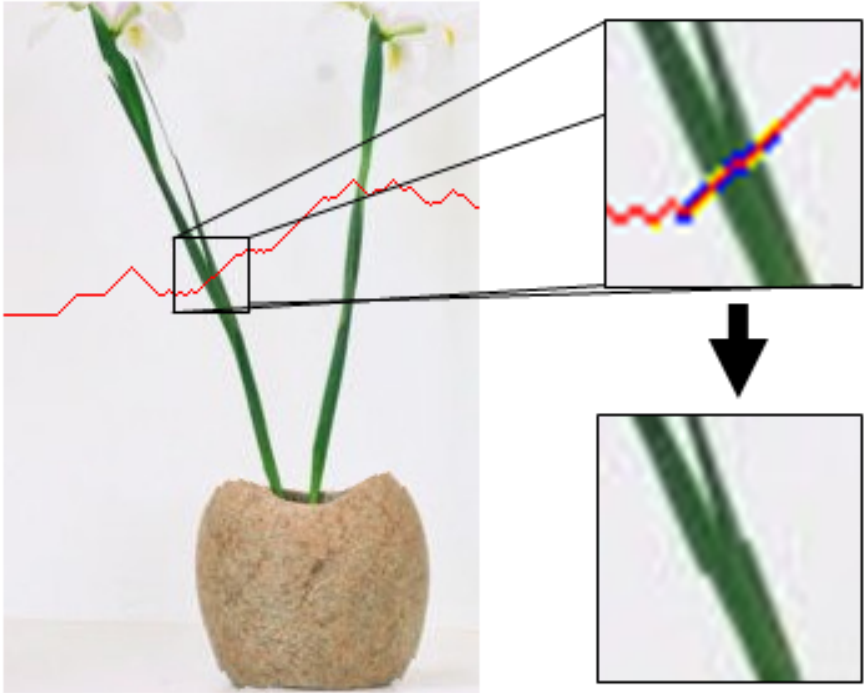
Preserved Energy

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

...the average should increase!



Inserted Energy

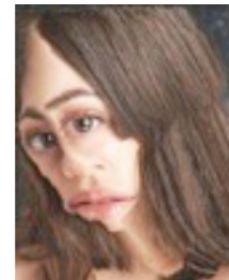
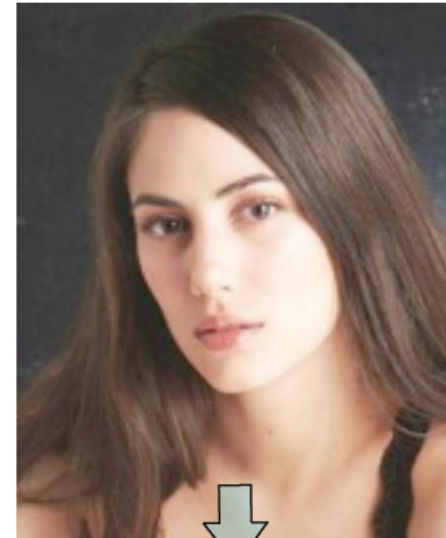


Limitations

Content



Structure



Preserved Energy



Average
Pixel
Energy

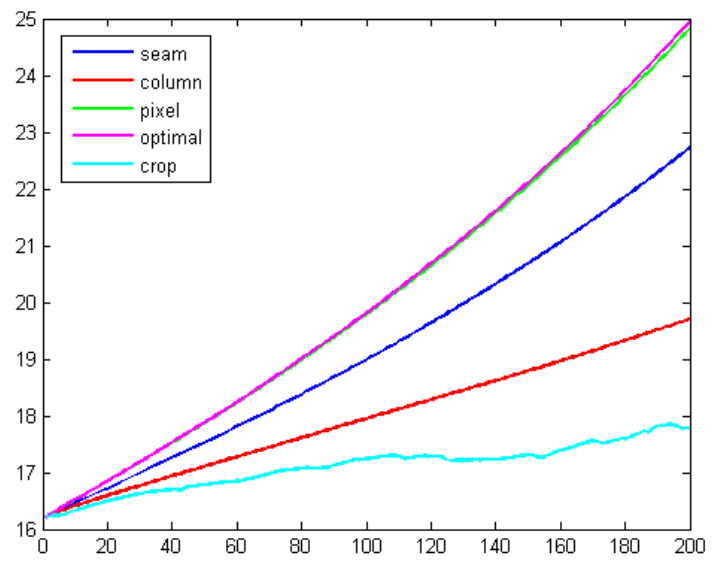


Image Reduction



crop



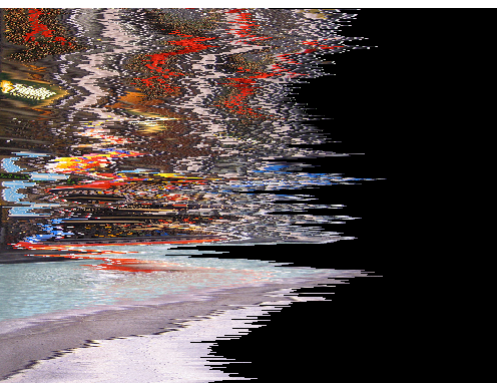
column



seam



pixel

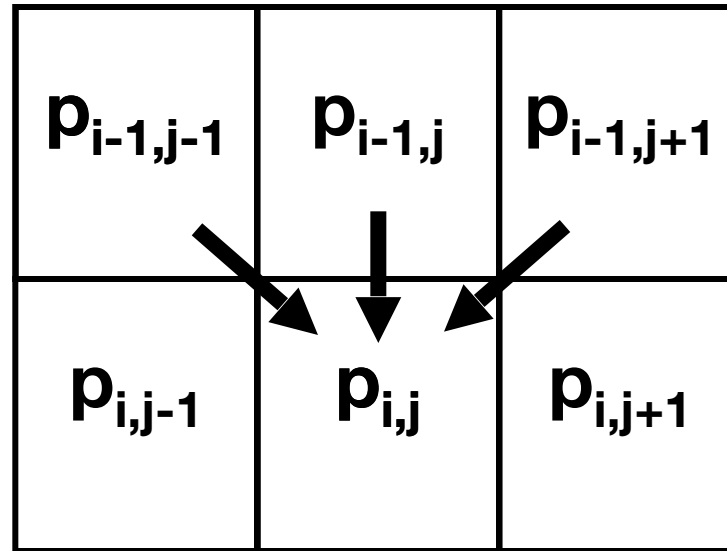


optimal

Minimize Inserted Energy

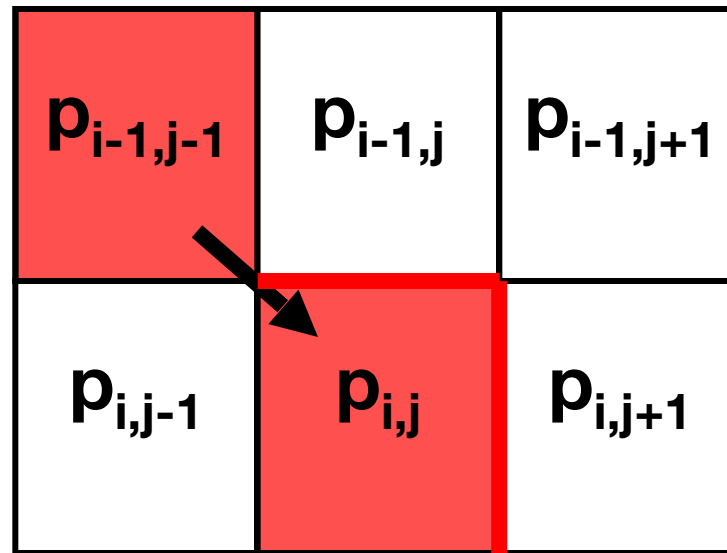
- Instead of removing the seam of least energy, remove the seam that inserts the least energy to the image (forward looking) !

Tracking Inserted Energy



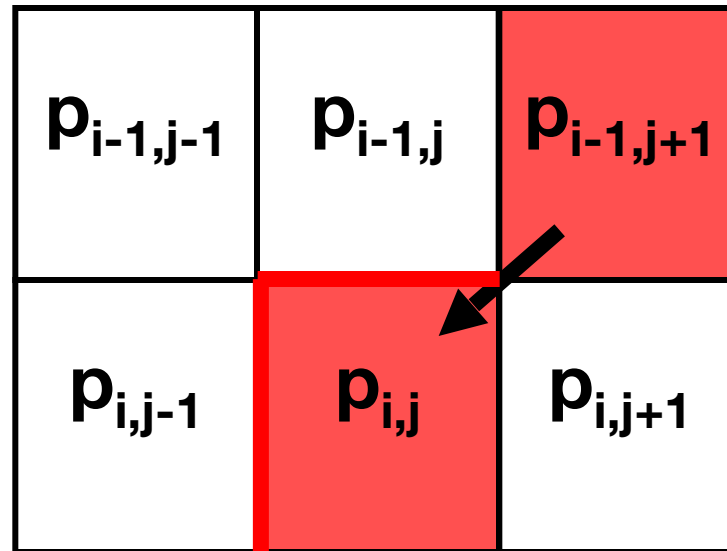
- Three possibilities when removing pixel $P_{i,j}$

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



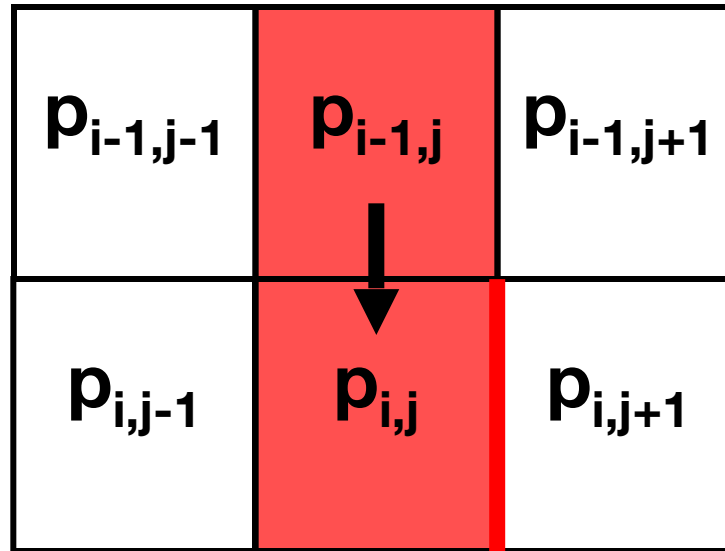
$$C_L(i, j) = |I(i, j + 1) - I(i, j - 1)| + |I(i - 1, j) - I(i, j - 1)|$$

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



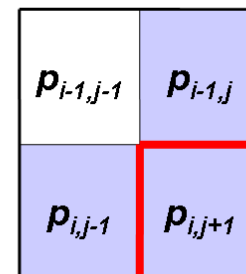
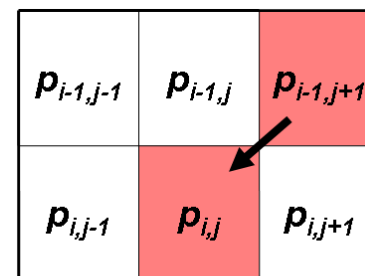
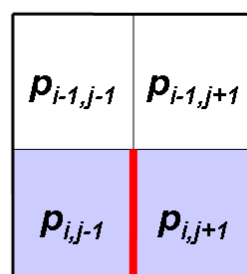
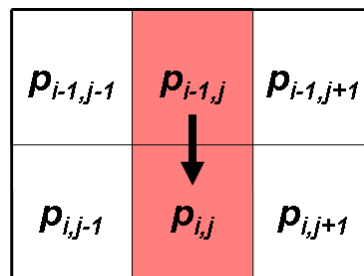
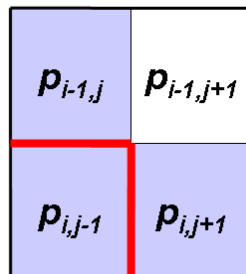
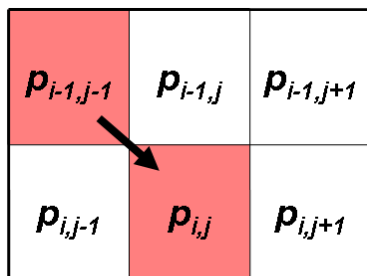
$$C_V(i, j) = |I(i, j + 1) - I(i, j - 1)|$$

Old Backward Cost Matrix

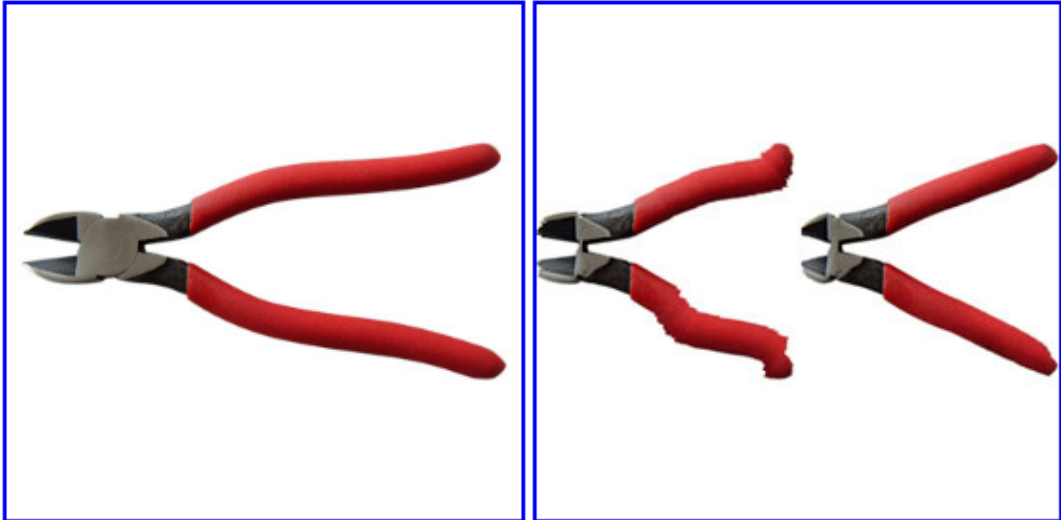
$$M(i, j) = E_{i,j} + \min \begin{cases} M(i-1, j-1) \\ M(i-1, j) \\ M(i-1, j+1) \end{cases}$$

New Forward Looking Cost Matrix

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



Results



Input

Backward

Forward



Input



Forward

Backward vs. Forward

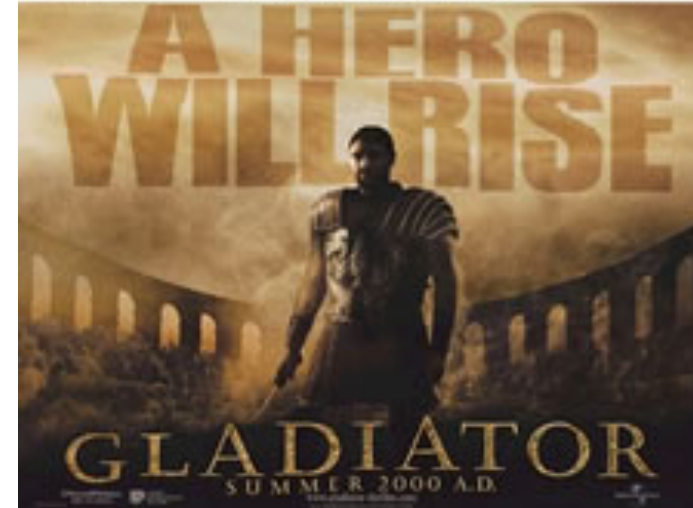
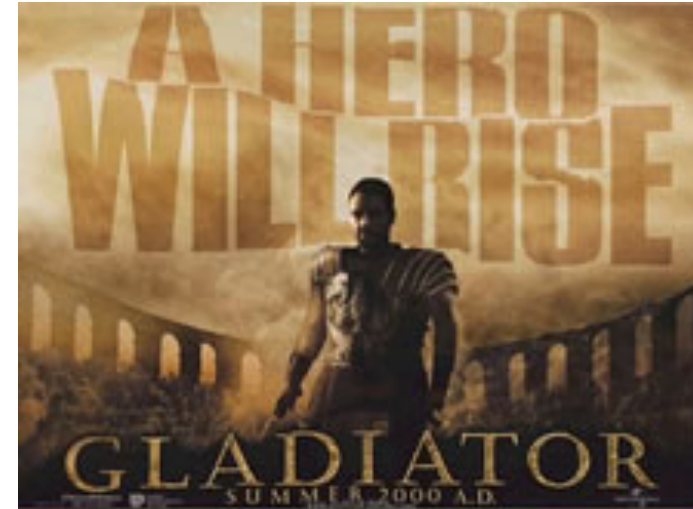


Backward



Forward

Results



From Images to Videos

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

1. Cardinality

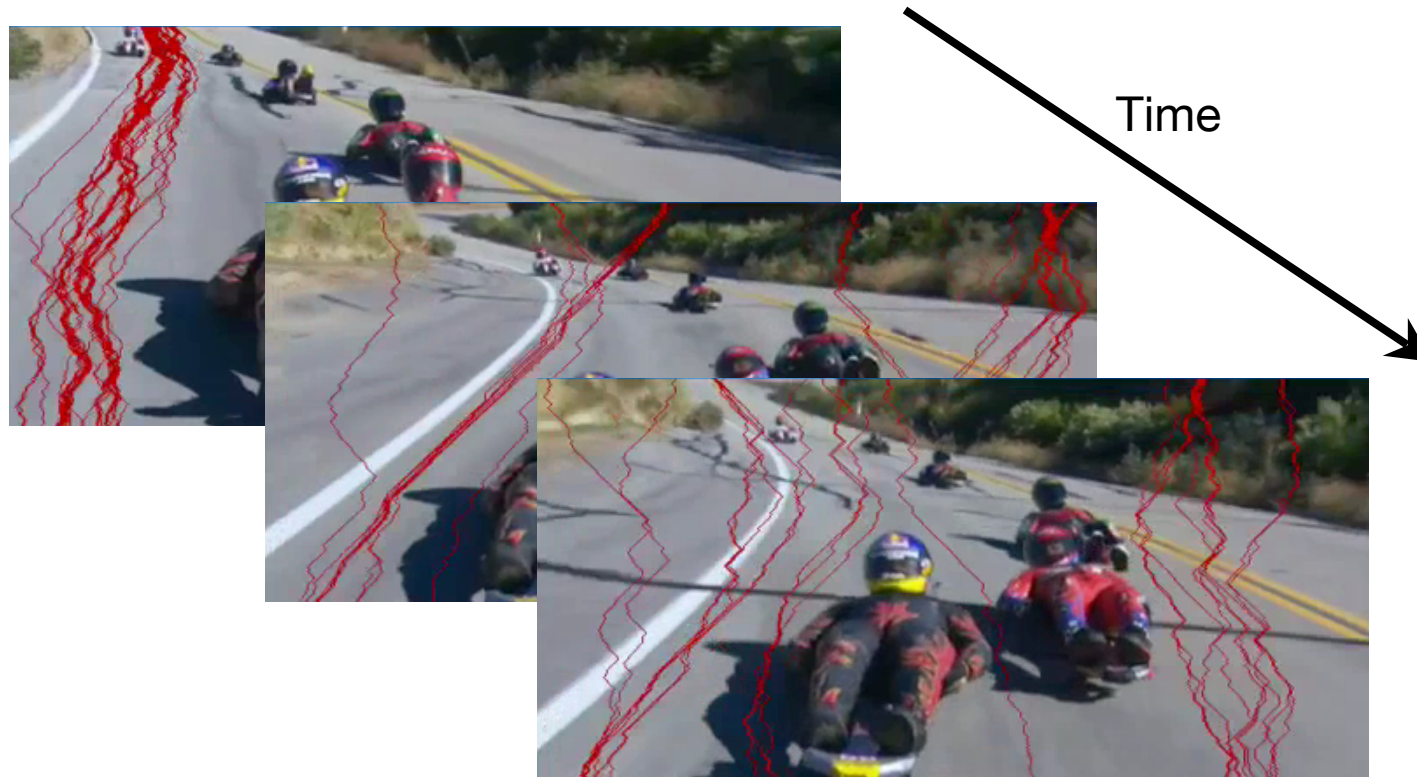
- Suppose 1min of video x 30 fps = 1800 frames
- Say your algorithm processes an image in 1 minute
 - 1 video would take **30 hours !!**

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



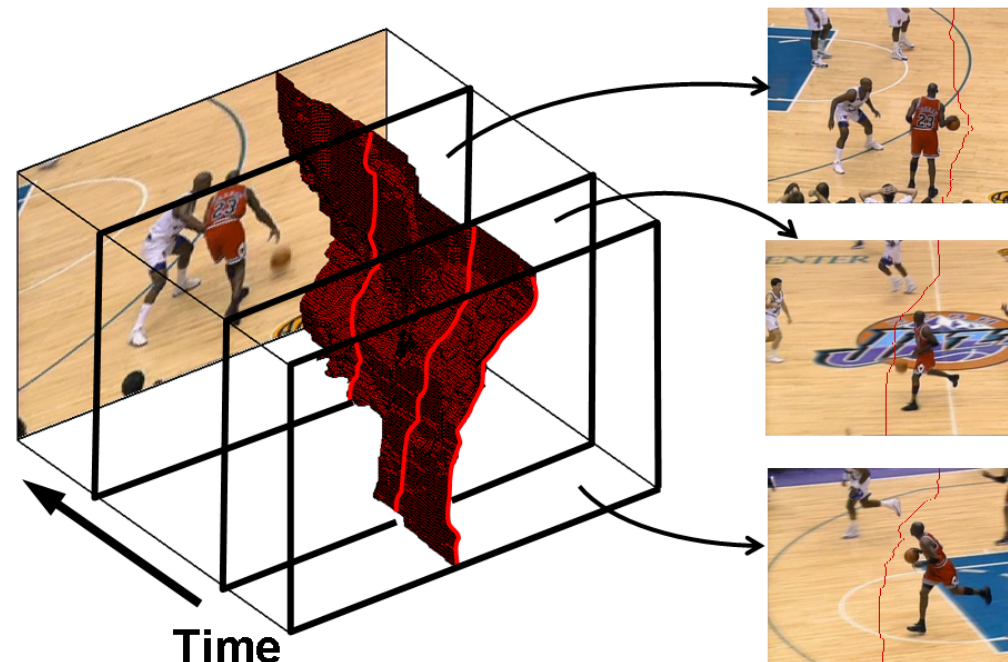
[Let's check out
this video](#)

Backward Energy

From 2D to 3D



1D paths in images



Time

2D manifolds in video cubes

Example video retargeting



Backward Energy

Object
detection +
seam
carving



Backward Energy

Today's agenda

- Image retargeting
- Seam carving
- Dynamic programming
- Applications
- Forward algorithm

Next lecture

Motion & Camera

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