Lecture 9

Saliency and Retargeting

Ruta Desai, Chun-Liang Li



Administrative

- A2 is due May 2nd





Administrative

Recitation

- Geometric transformations
- May cover some exam practice questions if time allows as last time

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CSE 455 Roadmap

Pixels	Video	Camera	Segment	ML
Convolutions Edges Descriptors	Motion Tracking	Camera 3D Geometry	Segmentation Clustering Detection	Linear Models (Conv) Neural networks

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Today's agenda

- Image retargeting
- Seam carving
- Applications
- Forward algorithm

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Content Retargeting

ВВС

Innovation Culture Arts Travel Earth Video Live





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

●LIVE Lunar New Year: Millions

Snake

worldwide welcome the Year of the

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 on to shrink the US government

ins ago US & Canada Australian sect members guilty of

causing girl's death The defendants had denied the diabetic girl here are no official numbers yet on how many people may have been injured or killed at her insulin, believing God would save her, court heard.

Mona Lisa to be moved as part of

In pictures: Kumbh Mela crowd crush

crush at India's huge Kumbh Mela festival

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 & Canad

3 hrs ago | US & Canada

Only from the BBC

'Ambulances zipping past': BBC reporter at site of crowd surge in India

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

48 mins ago Australia

major Louvre overhaul



11 of the best TV shows to watch this February Inside the race for Greenland's mineral wealth From the return of HBO's holiday-resort satire to a political thriller starring Robert De Niro The territory's untapped mineral wealth has caught the eye of both mining firms and and the latest violent period drama from Peaky Blinders creator Stephen Knigh Donald Trump

2 days ago Business

17 hrs ago Culture More news >

How China's 'AI heroes' South Korea plane fire overcame US curbs to stun causes mass evacuation Silicon Valley 15 hrs ago | Asia

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

EU trip as Greenland unease grows 9 hrs ago | Europe

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

PC



 LIVE 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



the Year of the Snake



LIVE Lunar New Year: Millions worldwide welcome

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.

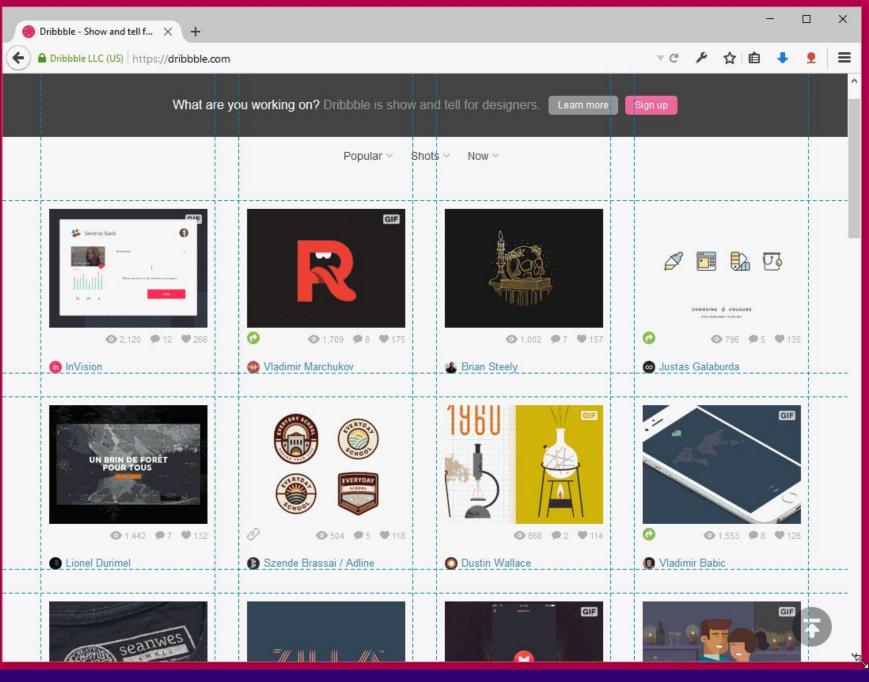
10 hrs ago | Europe

iPhone

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Page Layout



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Display Devices



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Lecture 9 - 8

Have you ever seen this?

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

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Simple Media Retargeting Operators



Le Sectorizing





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Content-aware Retargeting Operators

Contentaware



content







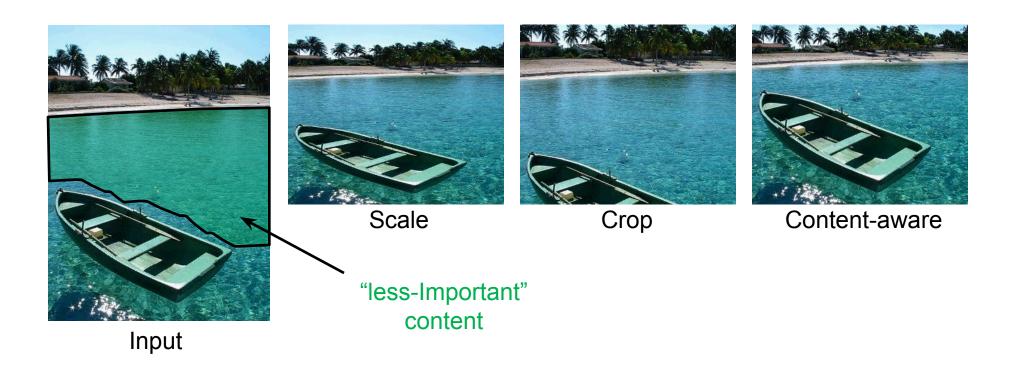




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Content-aware Retargeting



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Image Retargeting ("More" Formally)

Problem statement

- Input image I of size n x m
- Output image I' of size n' x m'

Output image should be geometrically and semantically consistent with input image

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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

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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!

- \circ 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?
- \circ What about artistic impression in the original content?

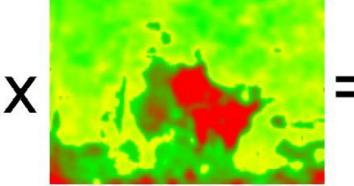
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Importance (Saliency) Measures

- A function $\mathcal{S}: n \times m \rightarrow [0, 1]$
- Ideas from human perception







First stage: coarse scan over entire image Second stage: more focused attention on specific region

Wang et al. A Two-stage approach to saliency detection in images 2008

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Importance (Saliency) Measures

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



Judd et al. Learning to predict where people look ICCV 2009

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General Retargeting Framework







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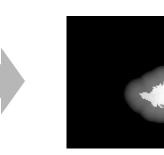
General Retargeting Framework

Step 1. Define an energy function **E(I)** (interest, importance, saliency)

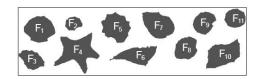












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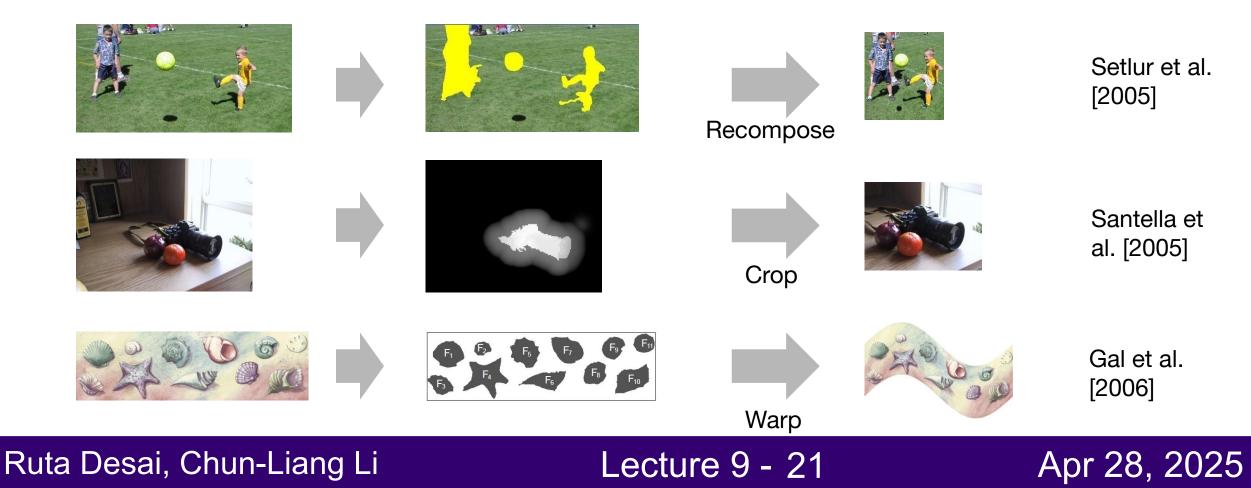


General Retargeting Framework

Step 1. Define an energy function **E(I)** (interest, importance, saliency)

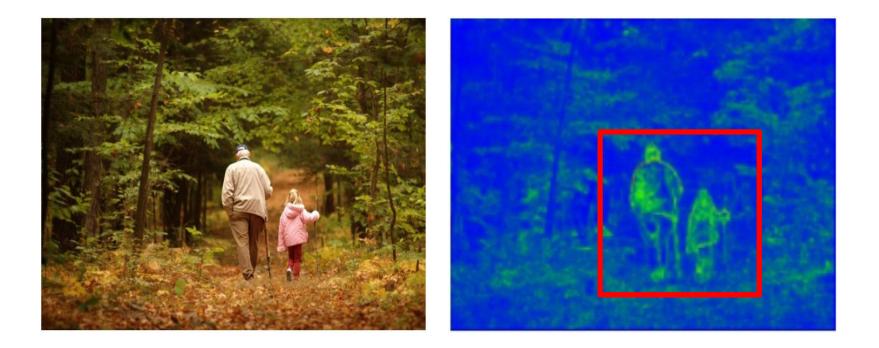


Step 2. Use some operator(s) to change the image I



Potential Retargeting Approaches

• Optimal Cropping Window



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Potential Retargeting Approaches

 Done manually in the movie industry for many years







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Today's agenda

- Image retargeting
- Seam carving
- Applications
- Forward algorithm

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Seam Carving

- Assume input I is size m x n
- Output I is m x n',
 - where n'<n
- Basic Idea: remove unimportant pixels from the image
 Onimportant = pixels with less "energy"



Seam Carving

- Assume input I is size m x n
- Output I is m x n',
 - o where n'<n</p>
- Basic Idea: remove unimportant pixels from the image
 Onimportant = pixels with less "energy"

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

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

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Let's do an experiment



We calculate the energy for this image.

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

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Pixel Removal

Optimal

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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**?

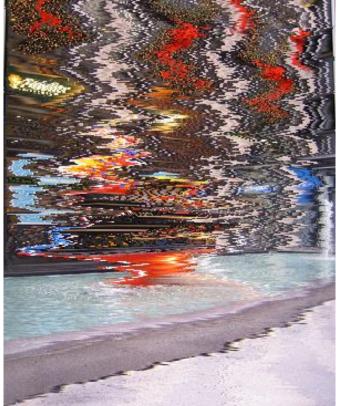
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Pixel Removal



Least-energy pixels (per row)

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Lecture 9 - 30

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**?

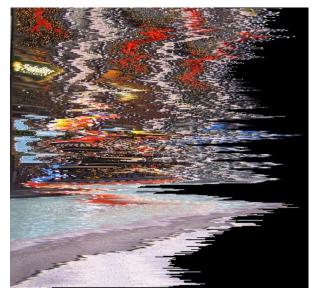
Q3. Can we remove the K **columns** with the lowest energies?

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Optimal



Pixel Removal



Least-energy pixels (per row)

Least-energy columns

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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)

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

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

s.t.
$$\forall i, |x(i) - x(i-1)| \le 1$$

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

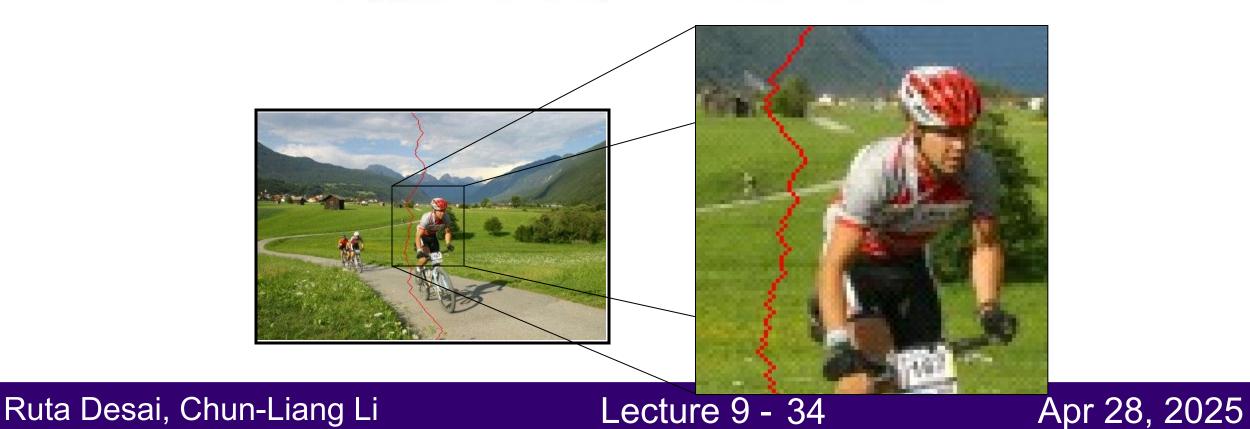
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A Seam

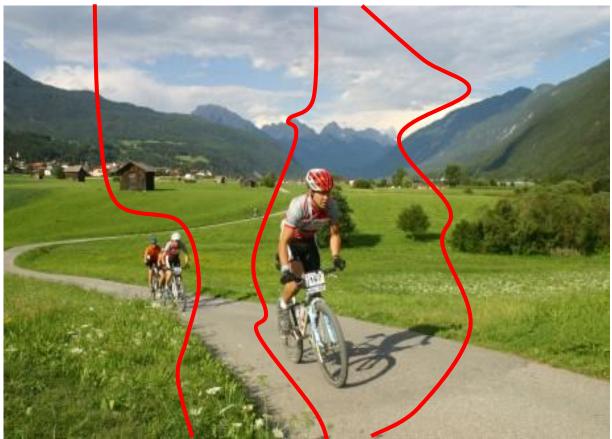
• A connected path of pixels from top to bottom (or left to right). Exactly one in each row

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



How do we find the optimal Seam?

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



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

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Lecture 9 - 35

The Optimal Seam



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

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

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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 ith 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.

A: sol[i] = cost[i] + min(sol[i-1], sol[i-2])

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Input: Given an energy E(i, j)

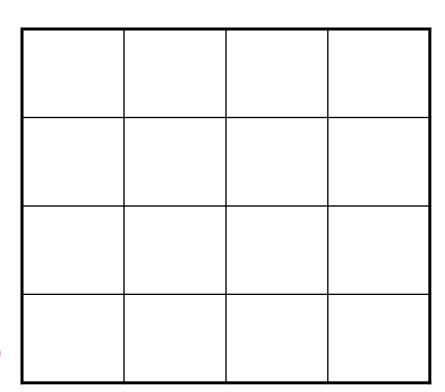
5	8	12	3
4	2	3	9
7	3	4	2
5	5	7	8

Energy - E(i, j)

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



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

Energy - E(i, j)

M(i, j)

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

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M(i, j)

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Q. What do you think should be this value?

5	8	12	3
	?		

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

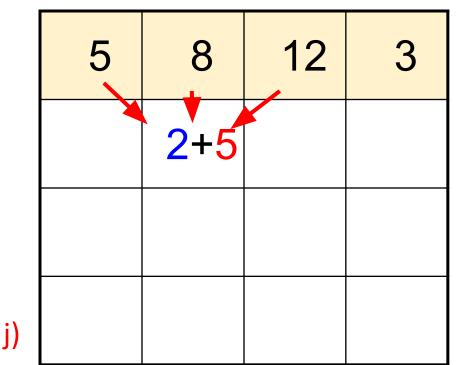
Energy - E(i, j)

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M(i, j)

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



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

Energy - E(i, j)

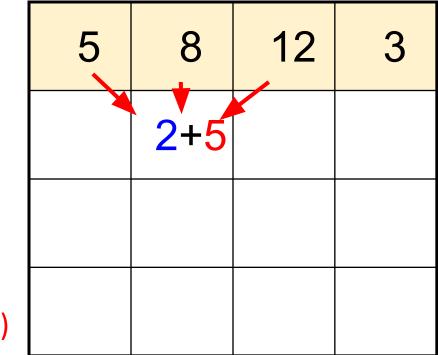
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M(i, j)

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The recurrence formula

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



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

Energy - E(i, j)

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M(i, j)

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5	8	12	3
	7		

5	8	12	3
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5	5	7	8

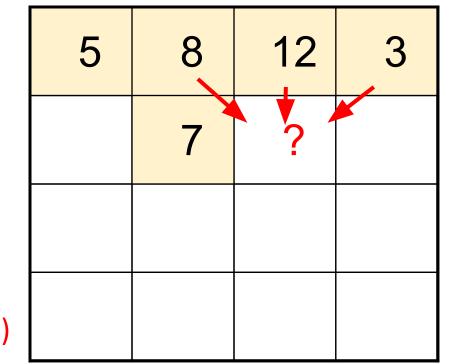
Energy - E(i, j)

M(i, j)

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



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

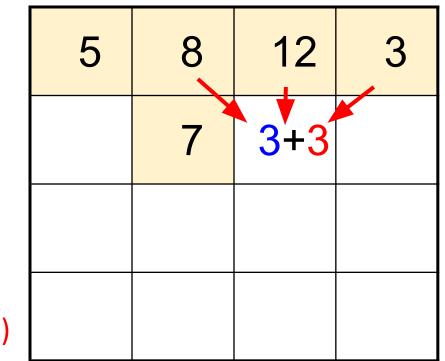
Energy - E(i, j)

M(i, j)

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



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

Energy - E(i, j)

M(i, j)

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$$\mathbf{M}(i, j) = \underbrace{E(i, j)}_{+} + \min(\mathbf{M}(i-1, j-1), \underbrace{\mathbf{M}(i-1, j)}_{+}, \underbrace{\mathbf{M}(i-1, j+1)}_{+}) \\ \hline 5 & 8 & 12 & 3 \\ \hline 9 & 7 & 6 & 12 \\ \hline 14 & 9 & 10 & 8 \\ \hline 14 & 14 & 15 & 8+8 \\ \hline \end{array}$$

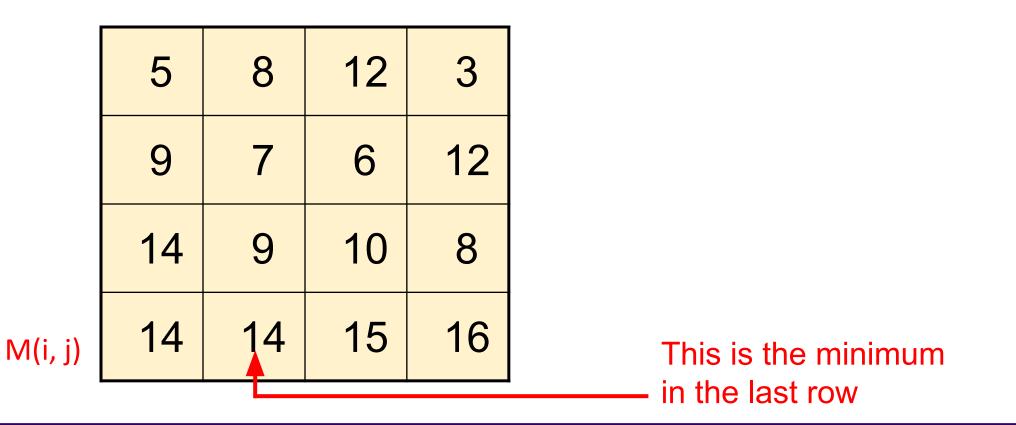
M(i, j)

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Searching for minimum seam

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



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Lecture 9 - 48

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
)	14	14	15	16

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

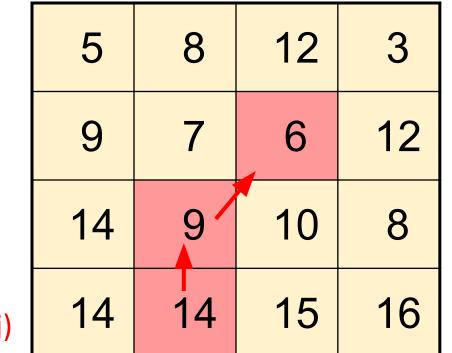
Energy - E(i, j)

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M(i, j)

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Searching for Minimum

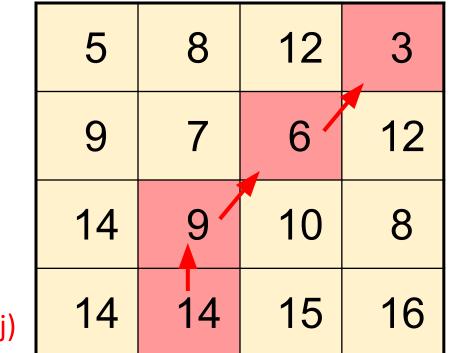


M(i, j)

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Searching for Minimum



M(i, j)

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The Optimal Seam - dynamic programming

• The recursion relation

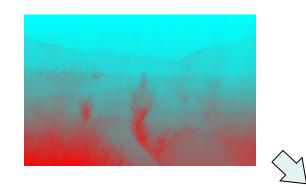
$$\mathbf{M}(i, j) = E(i, j) + \min(\mathbf{M}(i-1, j-1), \mathbf{M}(i-1, j), \mathbf{M}(i-1, j+1))$$

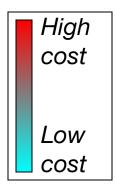
• Q: What is the time complexity?

 $O(s \cdot n \cdot m)$ (s=3 in the original algorithm)



Vertical cost maps



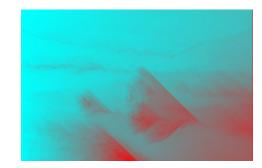


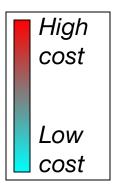


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Horizontal cost maps







Horizontal Cost

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Seam Carving





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The Seam-Carving Algorithm

```
Algorithm: Seam carving
Input: Image I of size m x n
Output: Image I' of size m x 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)

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Changing Aspect Ratio





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Another example



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Example seam carving



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Example seam carving



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Changing Aspect Ratio



Original



Retargeting



Scaling

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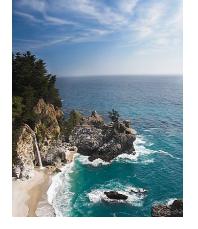
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Changing Aspect ratio













Scaling

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Changing Aspect Ratio



Original

Retarget

Scaling

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Changing Aspect Ratio



Original



Retarget



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Lecture 9 - 64

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 x n -> m' x n'

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

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

m x n -> m' x 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)





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Retargeting in Both Dimensions

• Let T(r,c) denote a new cost matrix of obtaining an image of size (n-r)x(m-c).

$$\mathbf{T}(r,c) = \min(\mathbf{T}(r-1,c) + E(\mathbf{s}^{\mathbf{x}}(\mathbf{I}_{n-r-1\times m-c})), \mathbf{T}(r,c-1) + E(\mathbf{s}^{\mathbf{y}}(\mathbf{I}_{n-r\times m-c-1})))$$

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Retargeting in Both Dimensions

• Let T(r,c) denote a new cost matrix of obtaining an image of size (n-r)x(m-c).

$$\mathbf{T}(r,c) = \min(\mathbf{T}(r-1,c) + E(\mathbf{s}^{\mathbf{x}}(\mathbf{I}_{\mathbf{n}-\mathbf{r}-\mathbf{1}\times\mathbf{m}-\mathbf{c}})), \mathbf{T}(r,c-1) + E(\mathbf{s}^{\mathbf{y}}(\mathbf{I}_{\mathbf{n}-\mathbf{r}\times\mathbf{m}-\mathbf{c}-\mathbf{1}})))$$

where $E(\mathbf{s}^{\mathbf{x}}(\mathbf{I}_{n-r-1\times m-c}))$ is the cost of removing a horizontal seam from the image $\mathbf{I}_{n-r-1\times m-c}$

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Optimal Order Map

Removal of horizontal seams ???

Removal of vertical seams

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Is it optimal...

- ... for removing ONE seam?
- ... for removing multiple seams?





Is it optimal...

- ... for removing ONE seam?
- ... for removing multiple seams?

Consider HVV (how many possible orderings?)
Cost(V) on HV not necessarily equal Cost(V) on VH
But we keep track of only one: min(HV,VH)...



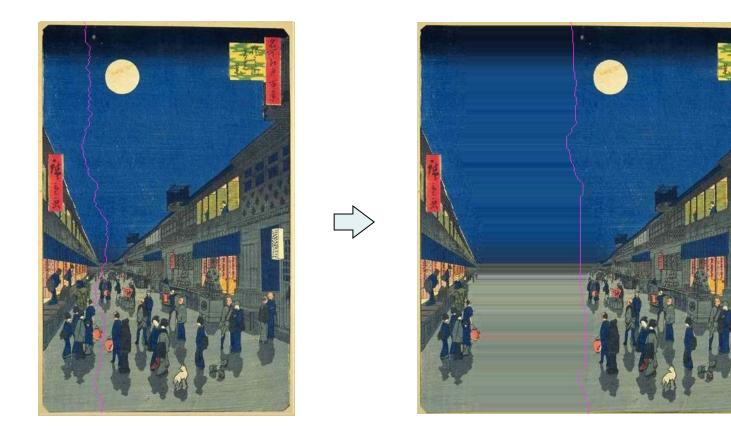
Today's agenda

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

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Image expansion - Repeat the lowest energy seam?



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Image Expansion – Repeat the K lowest energy seams



Scaling



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





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Combined Insert and Remove





Insert & remove seams



Scaling

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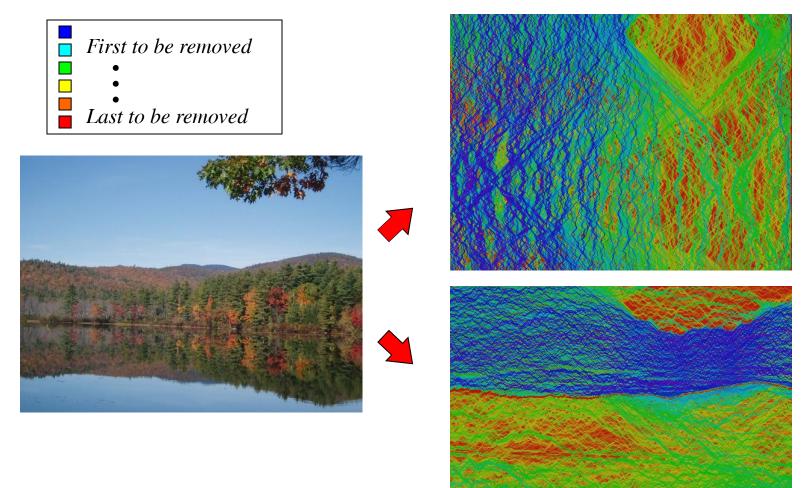
Multi-Size Images

- We can create a new <u>representation</u> of an image that will allow adapting it to different sizes!
 - 1. Precompute all seams once
 - 2. Realtime resizing / transmit with content

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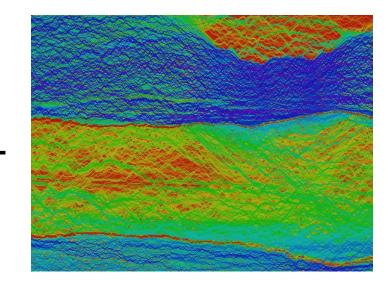
Multi-Size Images



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Multi-Size Image Representation





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Multi-Size Image Representation









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Content Enhancement



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

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

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Object Removal





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Lecture 9 - 84

Object Removal



Input

Retargeted

Pigeon Removed

Girl Removed

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Let's delete a shoe from this image



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Find the missing Shoe in the left image!





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Solution: black shoe is gone



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







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Solution



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









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Solution



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Use face detector to set energies of faces high







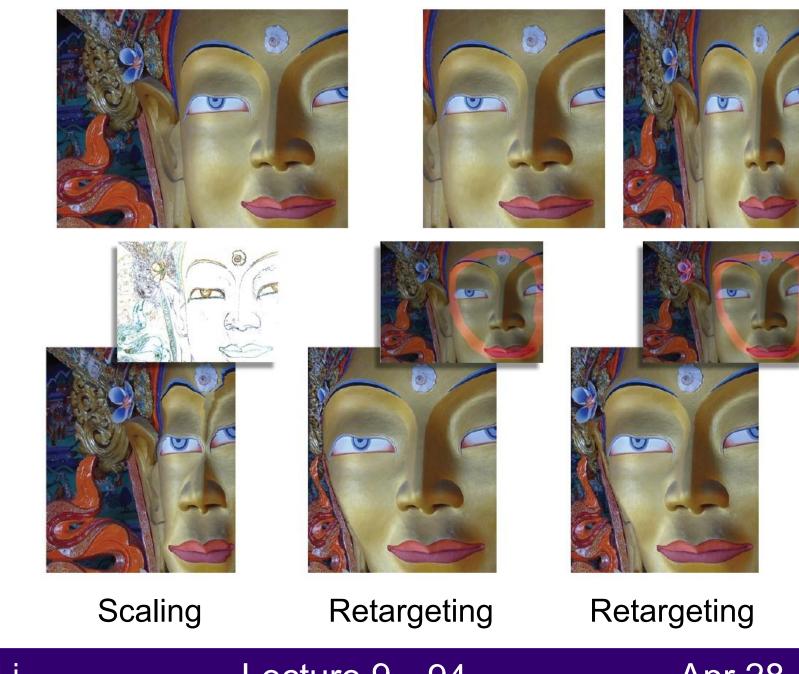
Energy with gradients

Energy with face detectors

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With User Constraints



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Today's agenda

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

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Seam carving creates artifacts breaks edges



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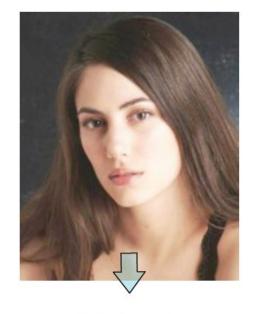
Limitations

Content





Structure





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Questions

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

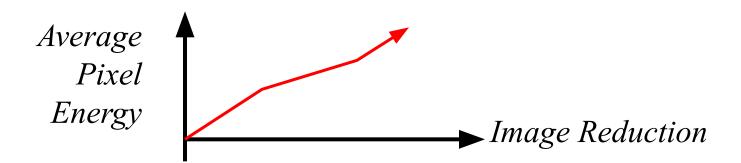
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Preserved Energy

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

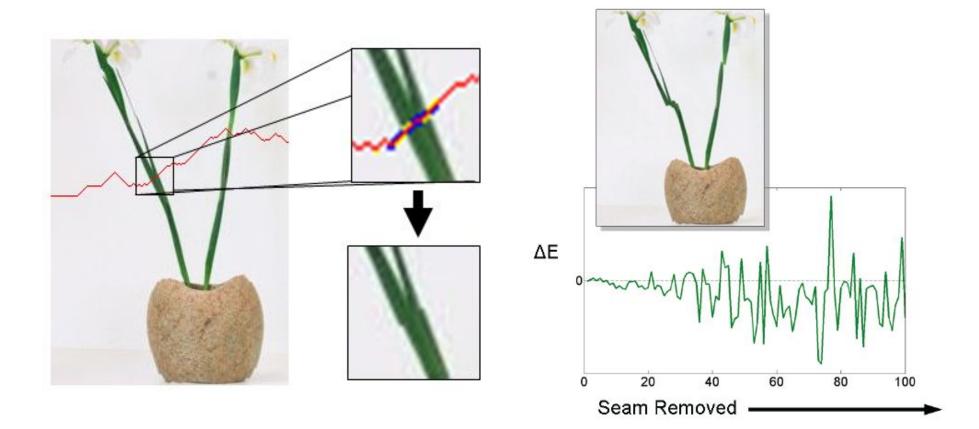
...the average should increase!



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Inserted Energy

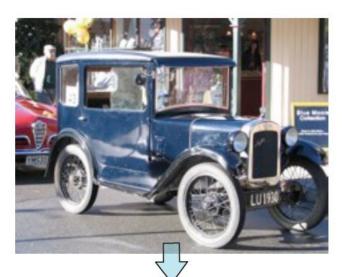


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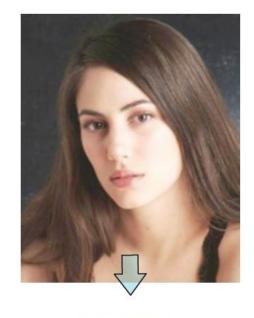
Limitations

Content





Structure





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Seam carving creates artifacts breaks edges







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Preserved Energy





Energy



E(i, j)



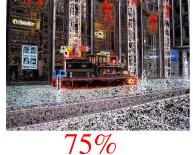
Energy increases after 15% every seam removal



30%



40%



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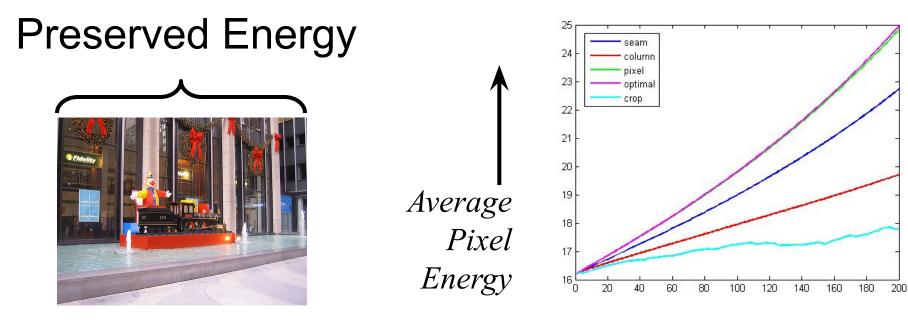
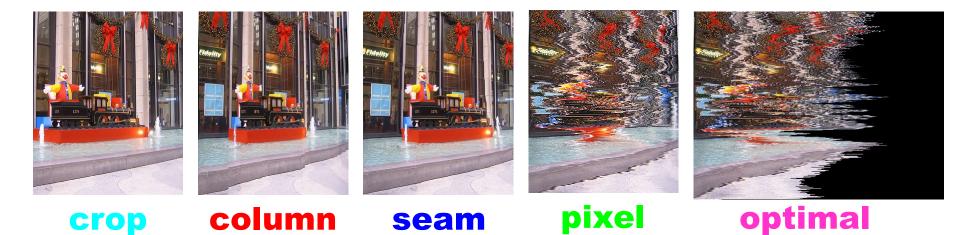


Image Reduction \longrightarrow



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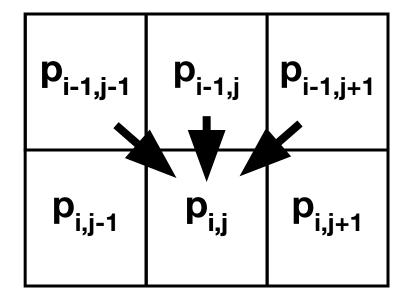
Minimize Inserted Energy

 Instead of removing the seam of least energy, remove the seam that <u>inserts the least energy</u> to the image (forward looking) !





Tracking Inserted Energy

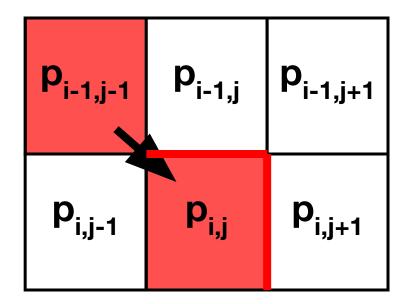


Three possibilities when removing pixel P_{i,j}

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Pixel P_{i,j} : Left Seam



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

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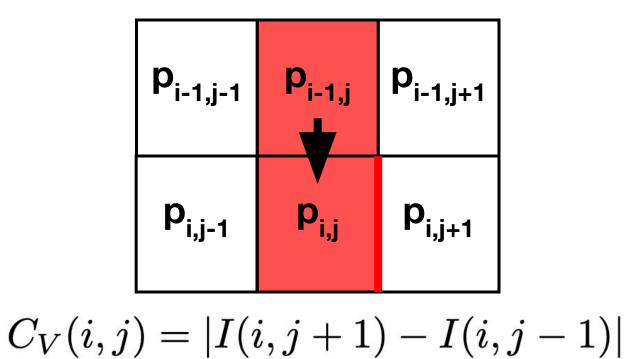
Pixel P_{i,j} : Right Seam

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

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Pixel P_{i,j} : Vertical Seam



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Old Backward Cost Matrix

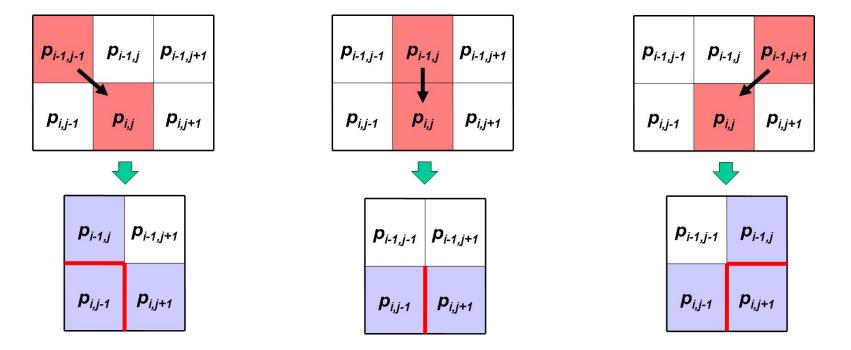
$$M(i,j) = E \quad (j) + \min \begin{cases} M(i-1,j-1) \\ M(i-1,j) \\ M(i-1,j+1) \end{cases}$$

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New Forward Looking Cost Matrix

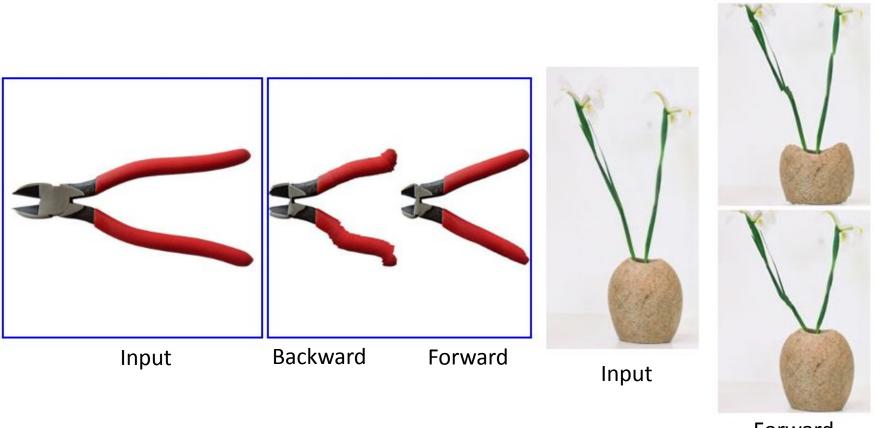
$$M(i,j) = E(i,j) + min egin{cases} M(i-1,j-1) + C_L(i,j) \ M(i-1,j) + C_V(i,j) \ M(i-1,j+1) + C_R(i,j) \end{cases}$$



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Results



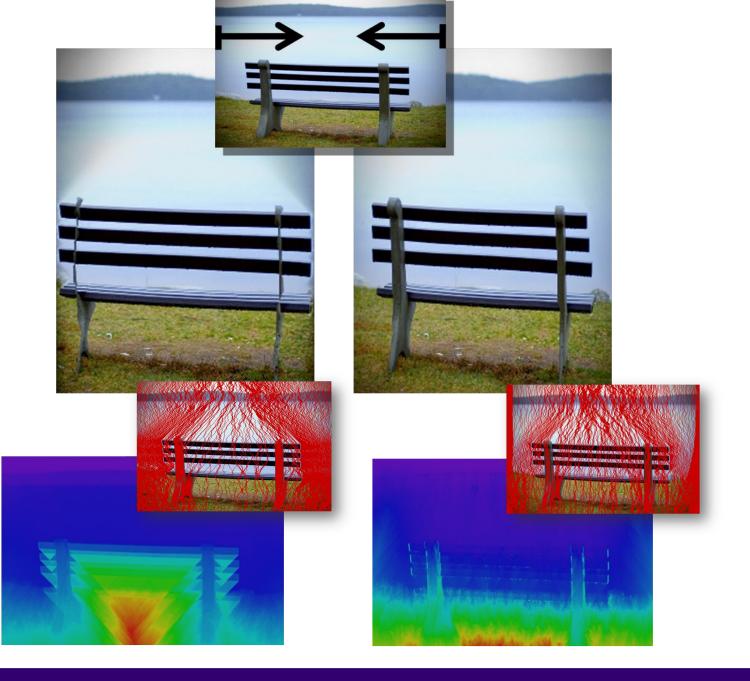
Forward

Backward

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Results



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Backward vs. Forward



Backward

Forward

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Results



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From Images to Videos

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

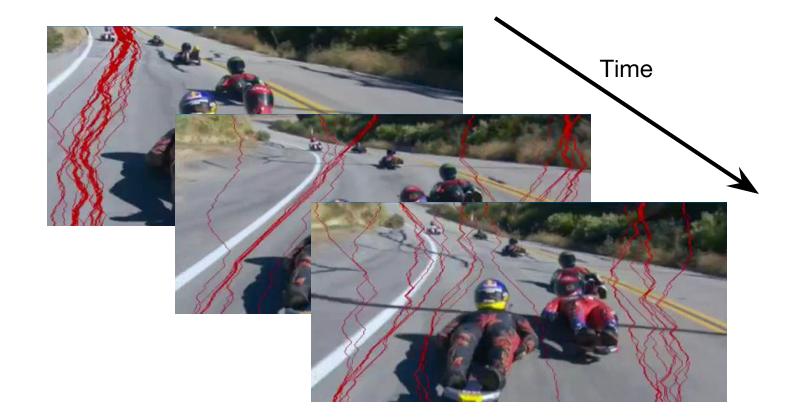
- 1. Cardinality
 - Suppose 1min of video x 30 fps = 1800 frames
 - Say your algorithm processes an image in 1 minute
 - 1 video would take 30 hours !!
- 2. Dimensionality/algorithmic
 - Temporal coherency: human visual system is highly sensitive to motion!

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Seam-Carving Video?

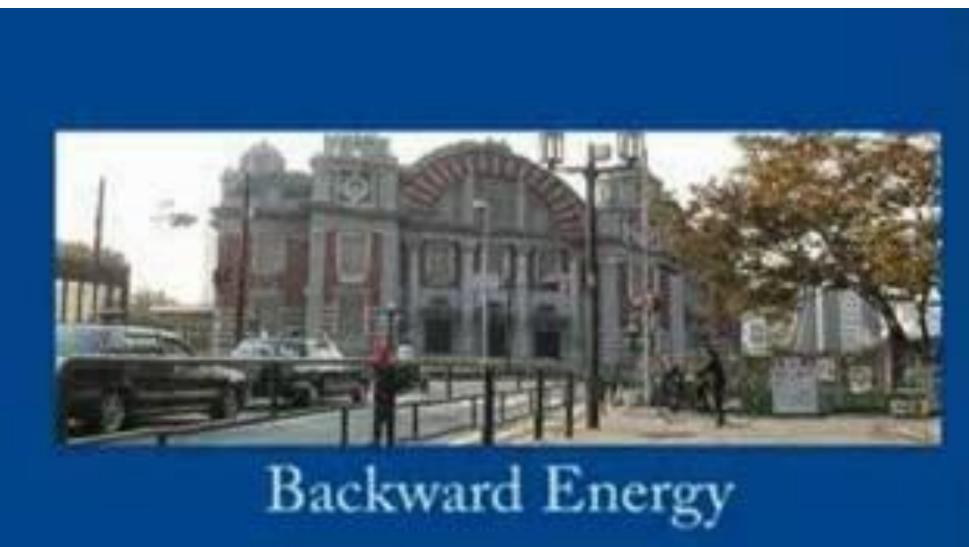
• Naive... frame by frame independently



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Frame-by-frame Seam-Carving

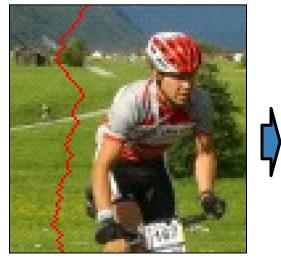


Let's check out this video

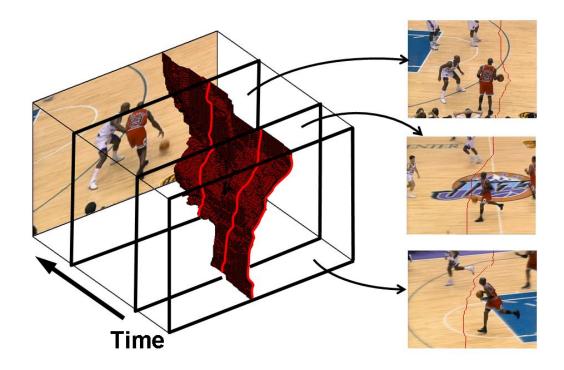
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From 2D to 3D



1D paths in images

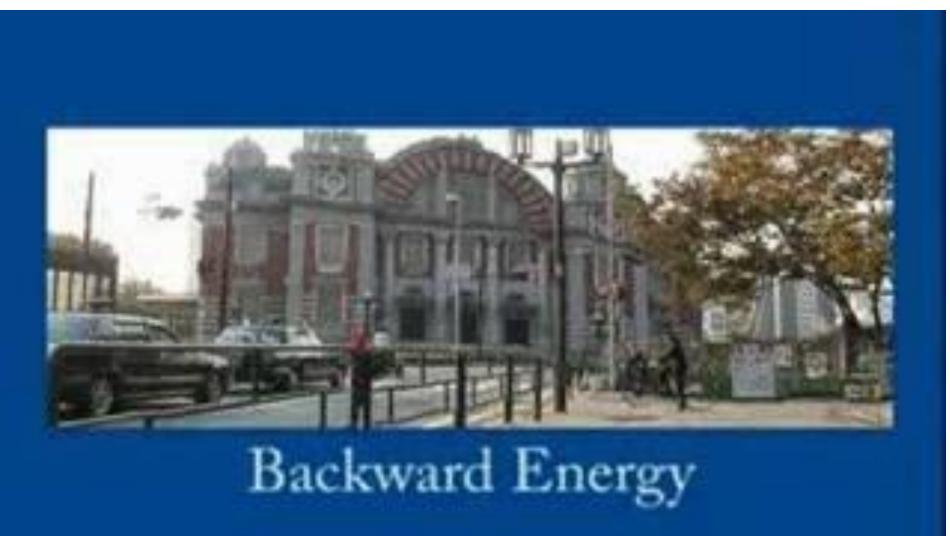


2D manifolds in video cubes

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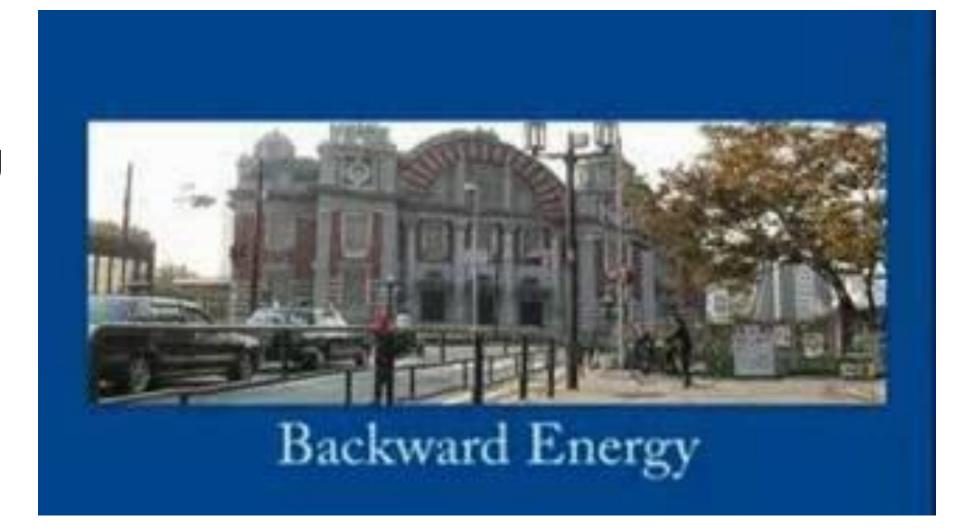
Example video retargeting



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Object detection + seam carving



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Today's agenda

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

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Next lecture

Motion & Camera

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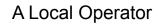


References

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- 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: <u>http://help.adobe.com/en_US/Photoshop/11.0/WS6F81C45F-2AC0-4685-8FFD-DBA374BF21CD.html</u>

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