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# SEAM CARVING: HOW TO "RESIZE" PICTURES

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## CHANGING IMAGE SIZE

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...while keeping content intact

- problem: target many devices
- scaling? cropping? seam carving!



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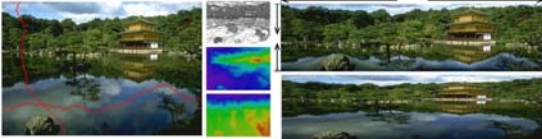
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## BASIC IDEA

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Remove inconspicuous pixels

- one pixel from each (and every) row (or column)



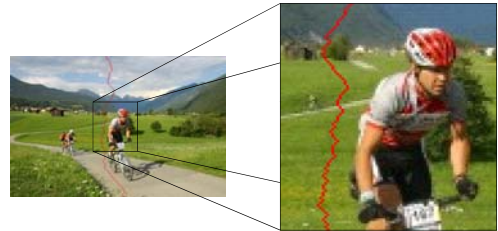
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## SEAMS IN ACTION

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## SEAMS IN ACTION

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## FINDING THE SEAM?

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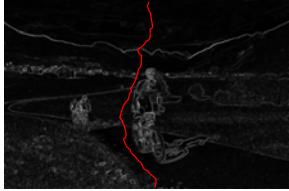


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## THE OPTIMAL SEAM

$$E(I) = |\partial_x I| + |\partial_y I| \quad E(s^*) = \min_s E(s)$$



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## OPTIMAL PATH

What is a valid path?

- monotonic, continuous
- cost is evaluated per pixel
  - e.g., centered difference
  - other cost measures...
- find by dynamic programming
  - optimal substructure...
  - lots over overlapping sub problems

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## CONSTRUCTION

Top to bottom (for vertical seams)

- from second to last row

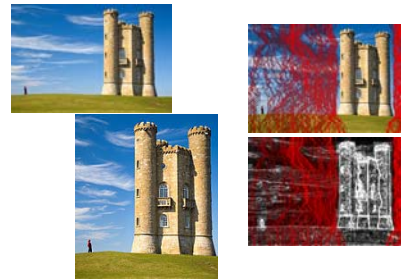
5	8	9	3
9	2	3	9
7	3	4	2
4	5	7	8

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

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## TYPICAL SEAMS



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## IMAGE ENLARGEMENT

Run "in reverse"

- insert seams as interpolants of neighbors by increasing energy



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## IMAGE ENLARGEMENT

Run "in reverse"

- insert seams as interpolants of neighbors by increasing energy



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## BOTH DIMENSIONS

Retargeting horizly. and vertly.

- what order for given size?
- dynamic programming again

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

- binary array of decisions

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## OBJECT REMOVAL

Additional weighting possible

- lower or higher energy on demand



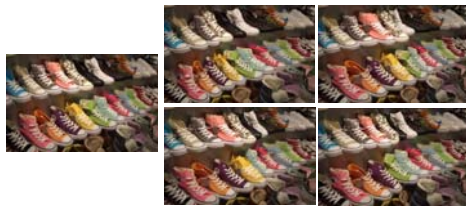
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## OBJECT REMOVAL

Additional weighting possible

- lower or higher energy on demand



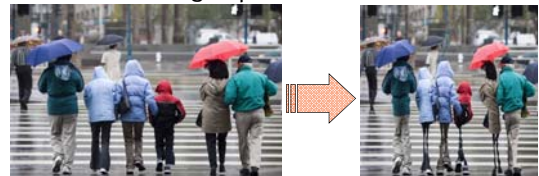
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## REFINEMENTS

Forward and backward energy

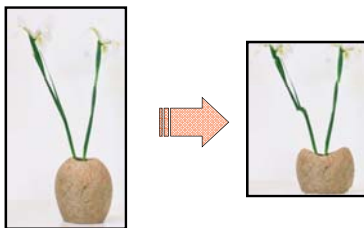
- energy after removing seam?
  - could go up!



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## ARTIFACTS



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(c) ariel shamir 17

## CHANGES IN IMAGE



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## CHANGES IN IMAGE



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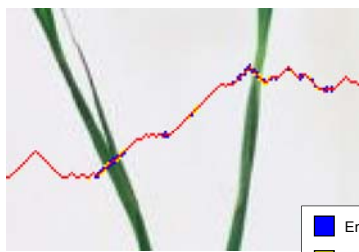
## CHANGES IN IMAGE



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## ENERGY INSERTED/REMOVED

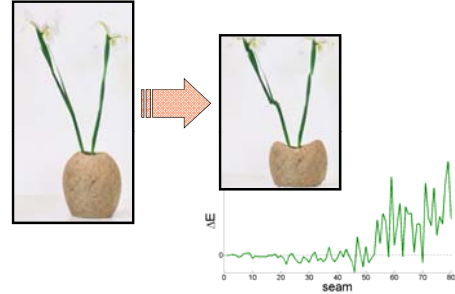


■ Energy Reduced  
■ Energy Increased

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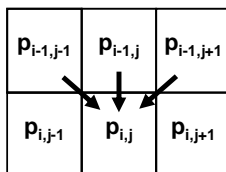
## CHANGES IN ENERGY



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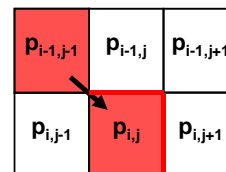
## TRACKING ENERGY



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## PIXEL $P_{I,J}$ : LEFT SEAM

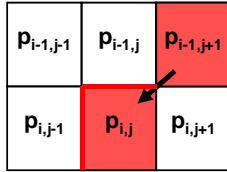


$$C_L(i, j) = |I(i, j+1) - I(i, j-1)| + |I(i-1, j) - I(i, j-1)|$$

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## PIXEL $P_{I,J}$ : RIGHT SEAM

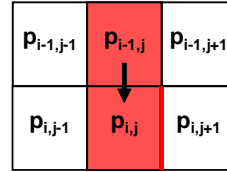


$$C_R(i, j) = |I(i, j + 1) - I(i, j - 1)| + |I(i - 1, j) - I(i, j + 1)|$$

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## PIXEL $P_{I,J}$ : VERT. SEAM



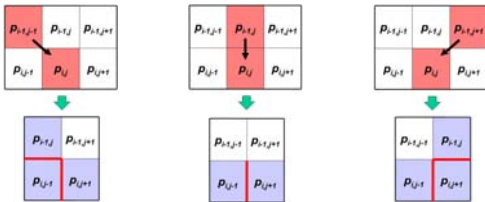
$$C_V(i, j) = |I(i, j + 1) - I(i, j - 1)|$$

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## NEW ENERGY FUNCTION

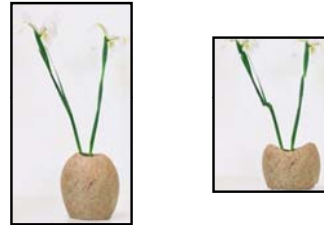
$$M(i, j) = P(i, j) + \min \begin{cases} M(i-1, j-1) & \dots \\ M(i-1, j) \\ M(i-1, j+1) \end{cases}$$



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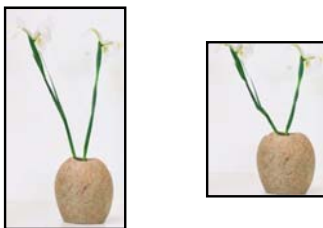
## BACKWARD (SIG 07)



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## FORWARD (SIG 08)



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## BACKWARD



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## FORWARD



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## BACKWARD



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## FORWARD



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## BACKWARD EXPAND



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## FORWARD EXPAND



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## AS GRAPH CUT PROBLEM

Motivated by video...

- set up graph so that optimal seam is optimal cut of graph  $O(VE^2)$ 
  - or LP
- expensive...
  - need other tricks to make practical
- we'll ignore that for now

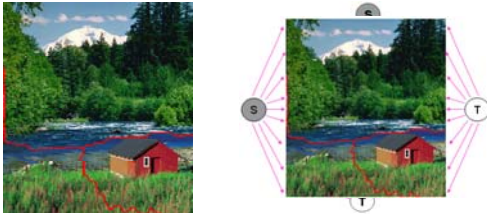
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## CHALLENGE

### How to Define a Seam from a Cut?

Kwatra et al. Siggraph 2003, *Graph cut textures*



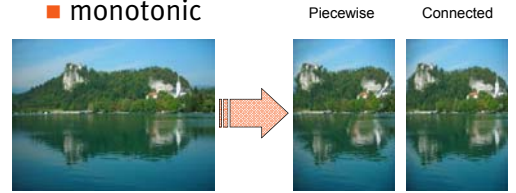
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## CONSTRAINTS

### Seams need to be...

- connected
- monotonic



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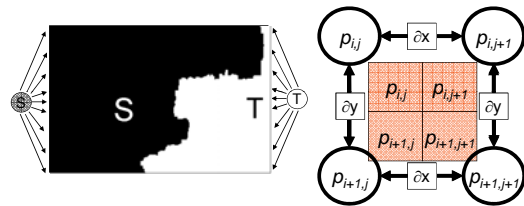
## PIECEWISE VS. CONNECTED



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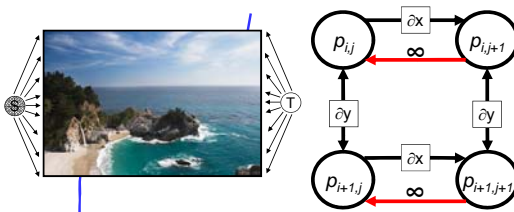
## STANDARD CONSTRUCTION



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## MONOTONICITY



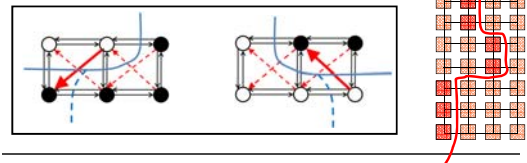
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## SEAM FROM CUT

### Conditions

- monotonic
- connected



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# SEAM FROM CUT

## Conditions

- monotonic
- connected

