

Seam carving for content-aware image resizing



By: Burcum Eken, Reagan Sanz

Quiz Questions:

1. Seam Carving was originally proposed by which researchers?
2. What topic from this class is utilized in seam carving to find the optimal cut through an image?
3. What is the name of the feature in Adobe Photoshop that utilizes Seam-Carving?



Get to know us: Reagan

- **Hometown:** Knoxville!
 - **High School:** Karns
- **Degree Program:** Master's in Computer Science
 - **Minor:** Art and Cybersecurity!
 - **Advisor:** Dr. Beck
- **Favorites:**
 - **Fav Movie/Show:** Guardians of the Galaxy, Ted Lasso
 - **Fav Book:** Hunger Games
 - **Fav Video Games:** Pokemon, Baldur's Gate 3



Get to know us: Reagan

- **What got me into Comp Sci?**
 - Video Games! They helped me through my hospitalizations as a kid, and I want to one day create a game that helps other children the way it did for me.
- **Fav Part of CS:** Front-End development, UI/UX, video game development, and human factors in cybersecurity. I love the creative and human side of technology
- **Career Experience:**
 - **Research @ MoSIS Lab:** Machine Unlearning and protecting Audio Data from AI models by adding imperceptible noise to copyrighted audio data.
 - **Internship at the City of Oak Ridge Electric Department**
 - **GTA**
 - **Starbucks Barista**

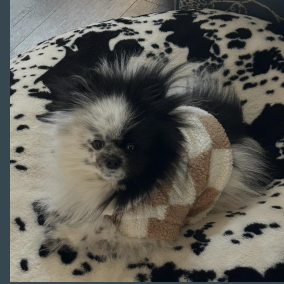


Me at 6:30 AM the next morning:



Get to know us: Reagan

- My Dog: Loki
- (yes, named after the Marvel Character)



Get to know us: Reagan

- My Dog: Zeus (a menace)



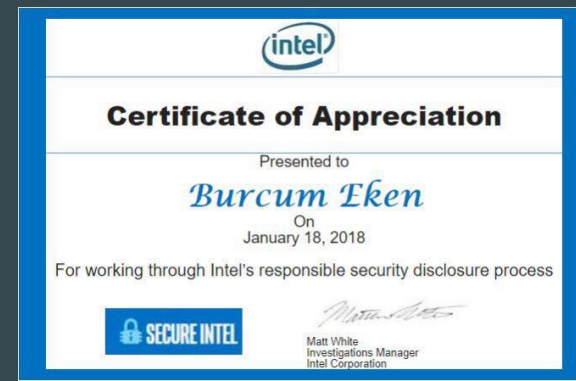
Get to know us: Burcum

- **Hometown:** Ankara, Turkey
 - Bachelor: Computer Engineering, Gazi University
 - Master: Computer Engineering, UTK
- **Degree Program:** Doctorate in Computer Science
 - Minor: Cybersecurity
 - Advisor: Dr. Stella Sun, Dr. Seddik Djouadi
- **Favorites:**
 - **Hobbies:** Reformer Pilates, Horseback Riding, visiting other countries, cooking
 - **Fav Movie/Show:** Harry Potter Series
 - **Fav Book:** Mustafa Kemal Ataturk
 - **Fav Games:** Lol

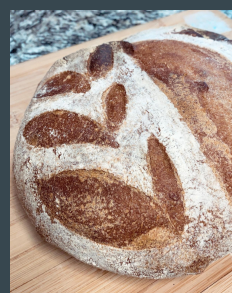


Get to know us: Burcum

- What got me into Comp Sci?
 - Games, Technology, Cyber Security
- Fav Part: analyzing the logs, vulnerability research,
 - Email gateway, SSL/TLS Management, WAF, Load Balancer
- Career Experience:
 - 🎓 Co-Founder of Cyber Security Group, Gazi University
 - 🏢 Security Engineer, TRT
 - 🎓 GTA, UTK
- Recognition
 - 🏆 Certification of Appreciation, Intel
 - 🛡️ CEH and Certified in CyberSecurity, ISC2
 - 🏆 Multiple Gonzalez Family Awards and
 - 🏆 Excellence in Graduate Teaching Assistant-UTK Chancellor



Get to know us: Burcum



Get to know us: Burcum

- My Cat: Lokum (Turkish Delight)



Outline:

- **Overview-** Definitions and Applications
- **History-** Dynamic Programming, Image Resizing, Object Removal
- **The Seam-Carving Algorithm**
- **Implementations**
- **Examples / Mask/Object Removal**
- **Applications-** Dynamic Web Content, Adobe Photoshop
- **Open Issues**

Overview: Definitions

- **Optimal Seam**: an optimal path of pixels on a single image from top to bottom, or left to right, where optimality is defined by an image energy function using **Dynamic Programming**.
- **Energy Function**: criteria to determine the “importance” of each pixel within the image, based how similar the pixel is to its neighbors.



Figure 1: Seam Example: Optimal “slice” (red line) to find unimportant pixels to remove

Overview: Applications

- Content-aware image resizing
- Object removal
- Adaptive web and mobile layouts
- Photo editing tools such as Adobe Photoshop

History

History: Dynamic Programming!

- A quick review, though we've already covered this in class!
- [1954]: Dynamic Programming by Richard E. Bellman
 - This optimization paradigm was introduced by Mathematician Bellman

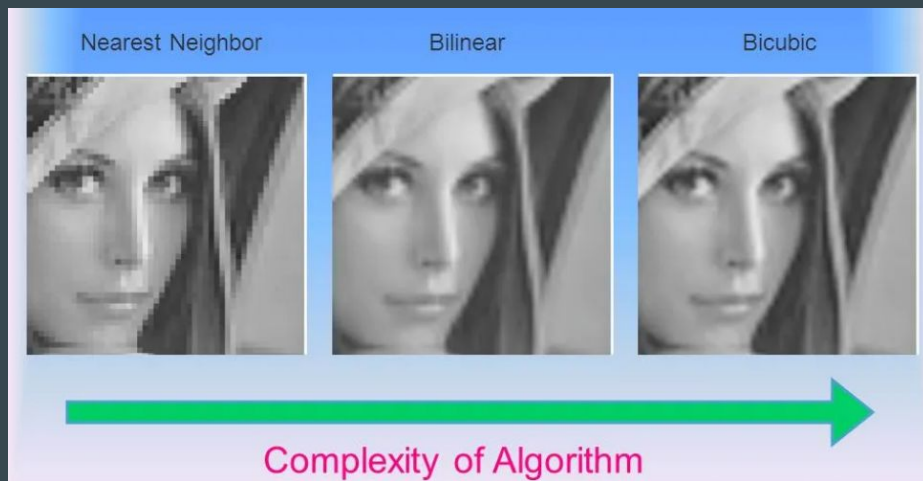
Dynamic programming is all about breaking one *complex task* into *simpler sub-tasks*. The optimal solution to each of these individual sub-tasks are then utilized to find the optimal solution of the main complex task. This is known as the *principle of optimality*.

History: Image Resizing

- **Early Digital Foundations (1970s–1980s)** In computer graphics and digital imaging, image scaling (resizing) is a form of image resampling — the conversion of a discrete signal from one sampling rate to another, interpreting it through the **Nyquist sampling** theorem. The simplest early method was **nearest-neighbor interpolation** , where every pixel is simply replaced with the nearest pixel in the output — fast but blocky.

History: Image Resizing

- **Interpolation Algorithms (1980s–1990s)** More sophisticated approaches emerged to improve quality. The three most common resizing algorithms that developed were bicubic, bilinear, and nearest-neighbor interpolators, each offering different trade-offs between speed and visual quality. Bilinear and bicubic became the workhorses of professional image editing software.



History: Image Resizing

- Seam Carving / Content-Aware Resizing (2005–2008) Building on this, seam carving (also called liquid rescaling) was developed by Shai Avidan of Mitsubishi Electric Research Laboratories and Ariel Shamir. It works by establishing paths of least visual importance in an image and automatically removing or inserting those seams to resize while preserving important content.



History: Object Removal

- **Physical Origins (1744–1821)** Inpainting is a conservation process where damaged or missing parts of an artwork are filled in to present a complete image. The modern use of inpainting can be traced back to Pietro Edwards, Director of the Restoration of the Public Pictures in Venice, Italy, who used a scientific approach focused on the intentions of the original artist.



Before restoration



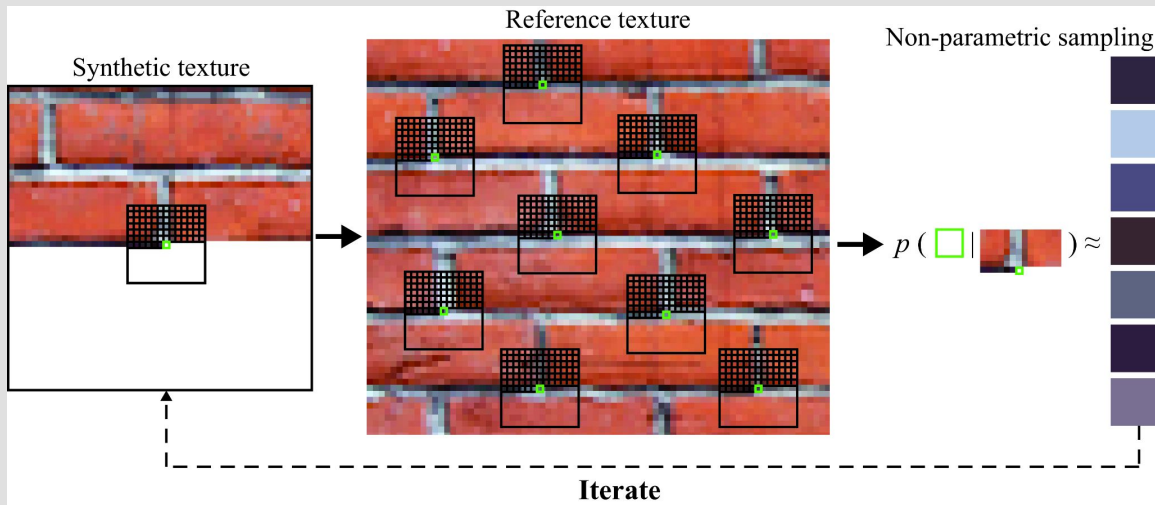
During restoration



After restoration

History: Object Removal

- **Digital Beginnings (1990s)** Since the evolution of digital technology, computer vision has experienced enormous research in image transformations, including inpainting, beginning notably with work by Efros and Leung in 1999.



[11] Texture Synthesis by Non-Parametric Sampling

History: Object Removal

- **Deep Learning Revolution (2014–2018)** The Context Encoder (CE) network, proposed by Pathak et al., was the first to combine CNN and GAN for inpainting, using adversarial loss to produce clearer images. Subsequent research introduced local and global discriminators to ensure both local detail and global consistency.



[10] Context Encoders: Feature Learning by Inpainting

The Seam-Carving Algorithm

The Goal: remove unnoticeable pixels that blend with their surroundings that connect from top-to-bottom (or right-to-left) in order to resize the image without greatly distorting the image

Step 1: Find the *Energy* of each Pixel (Make Energy Map)

- The energy Function is used to determine the energy at each pixel in the image.
- Pixels that are in flat, uniform areas will have **LOW energy**
 - Ex: On a smooth wall/ground, the blue of the sky, etc.
 - These are less important
 - Can be removed/changed without impacting the image greatly
- Pixels that form edges or complicated patterns will have **HIGH energy**
 - Ex: Complex patterns, sides of objects, etc
 - There are important to the image
 - removing them = significant distortion.

- **Energy Function:**

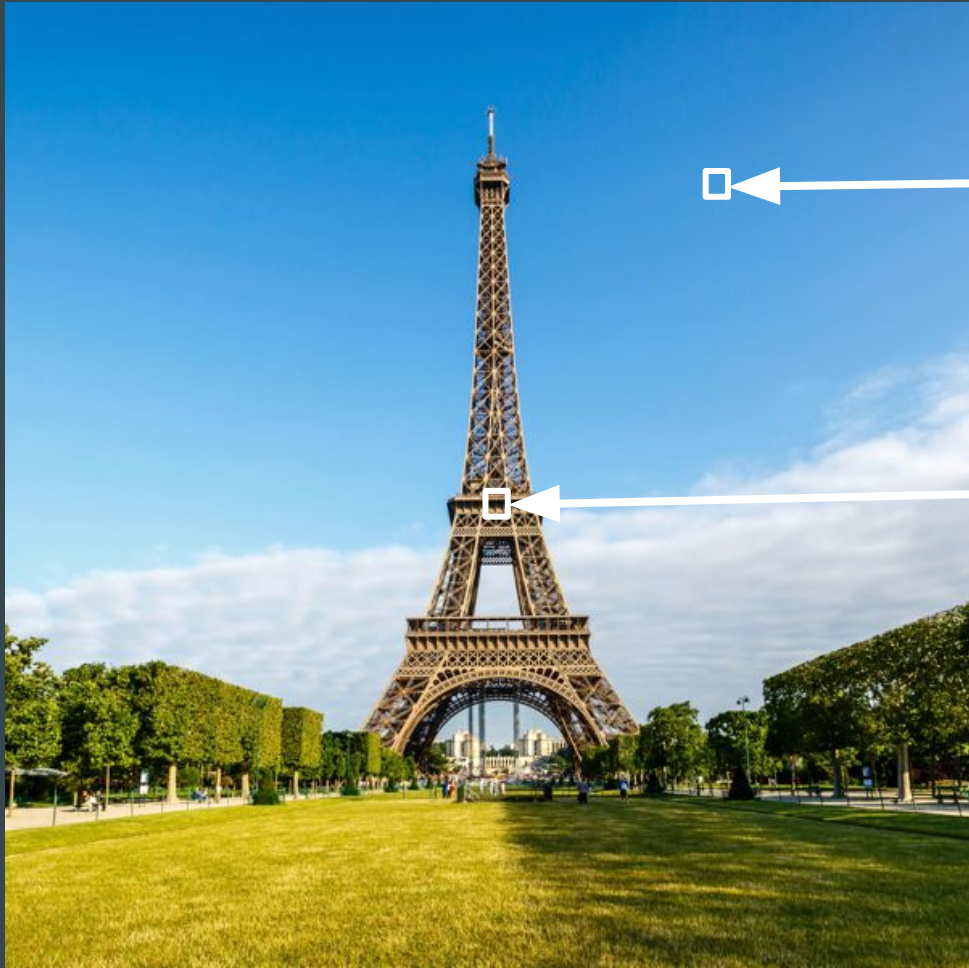
$$e_1(I) = \left| \frac{\partial}{\partial x} I \right| + \left| \frac{\partial}{\partial y} I \right|$$

where:

I = image

$\left| \frac{\partial}{\partial x} I \right|$ is the change in intensity in the horizontal direction

$\left| \frac{\partial}{\partial y} I \right|$ is the change in intensity in the vertical direction



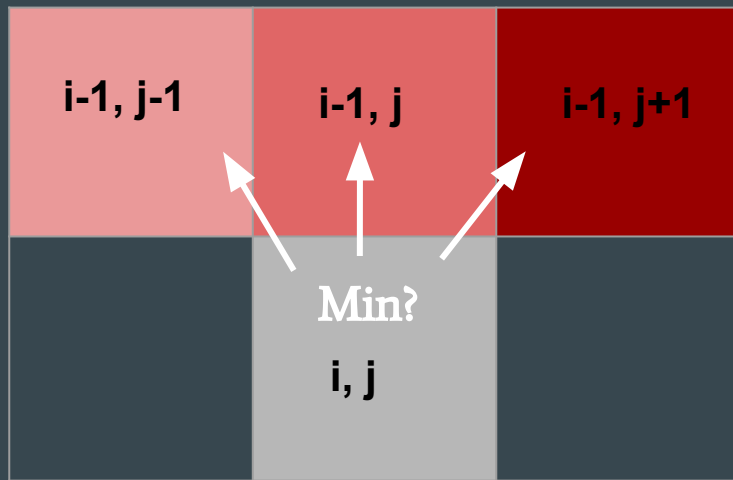
**Low Energy
(less important)**



**High Energy
(more important)**

Step 2: Build *Cumulative* Energy Map

- This map stores cost of the cheapest (minimal) path reaching each specific pixel.
 - Each pixel (i,j) finds the minimum of its surrounding neighbors in the row above:
 - $(i-1, j-1)$, $(i-1, j)$ and $(i-1, j+1)$



- Once this map is filled, the optimal cut (minimum cost) can be determined.

Step 3: Identifying the Optimal Seam / Removing

- Now that the map is filled, the **minimum value** in the bottom row (in the case of a vertical seam) determines the best seam/cut.
- Then, we **backtrack** from that minimum point back upwards through map through each pixel that produced the minimum.
- These pixels are then **removed** from the image, and the map shifts to the left to fill the gap.
- This successfully reduces the image size by 1 px in the horizontal direction.



Visualization:

NOTE: This table is flipped, so its building bottom-to-top instead of top-to-bottom



[5]

Step 1: Energy of each pixel (Energy map E)

Step 2: Cumulative Energy Map (M)

Step 3: Backtrack and find optimal seam path

Example: $1 + \min(2, 9, 7) = 1 + 2 = 3$

Scaling Down



Scaling Up



Removing Object



Implementation

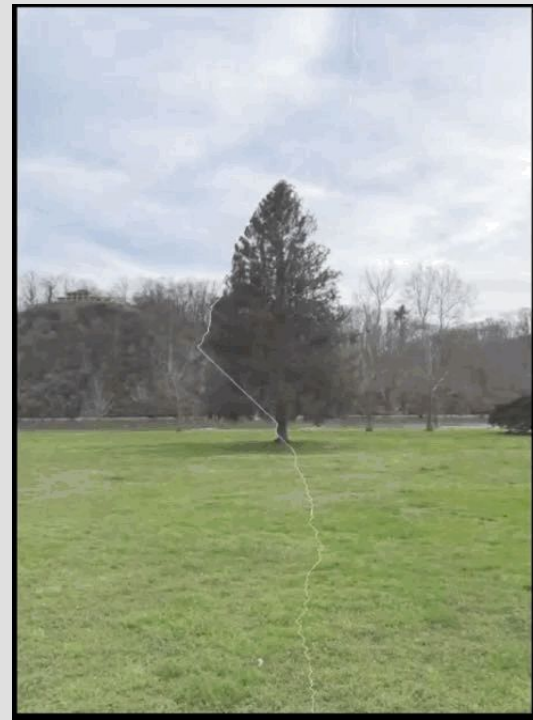
Object Removal and Mask



1- The user identifies high-energy regions to preserve and low-energy regions to target.

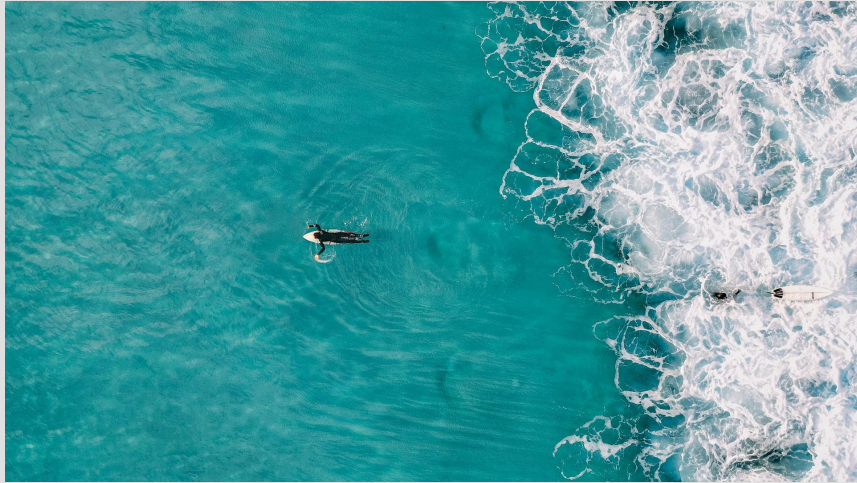
2 – Remove Object Seams (connected pixel paths of lowest energy) are detected and removed iteratively.

3 – After seam removal, the remaining pixels are shifted to close the gap naturally.



Implementation

Mask and Object Removal, Resizing

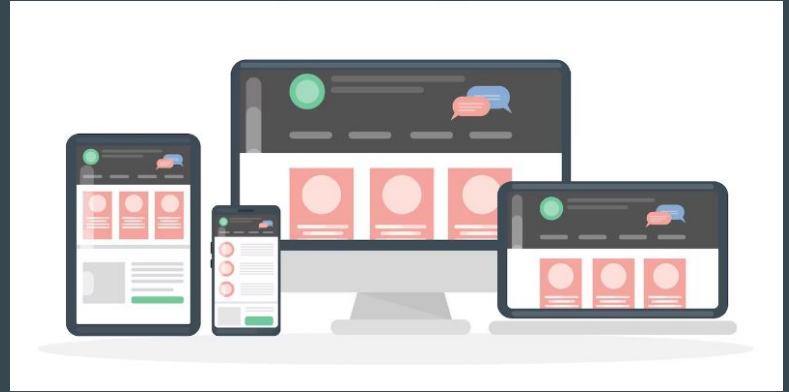


Applications

Applications: Dynamic Image Resizing in Web Content

- **Front-End**

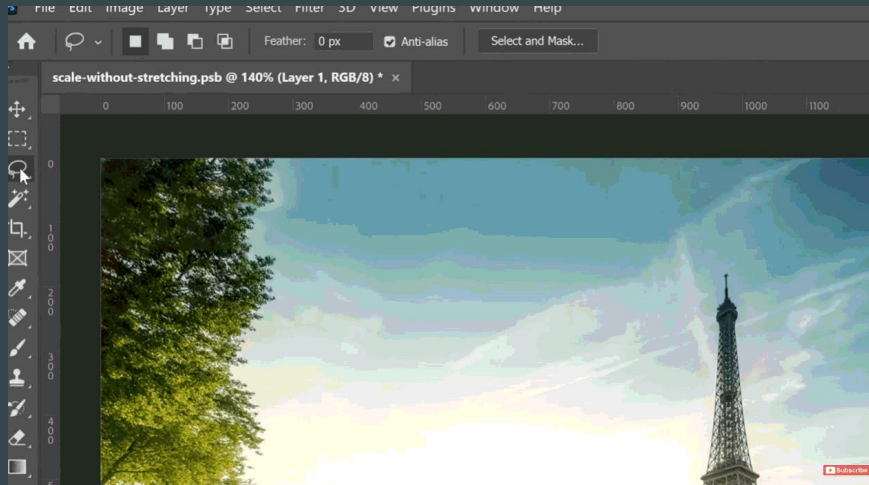
- Different Layouts must be created across different media devices and web content (viewing content on a laptop vs. mobile phone, etc).
- HTML even allows for dynamic changes of page layout
- Despite this,, images are often static and can't deform to fit different layouts.
- Standard image scaling is not sufficient because it doesn't consider the **image content** and typically can be applied only uniformly



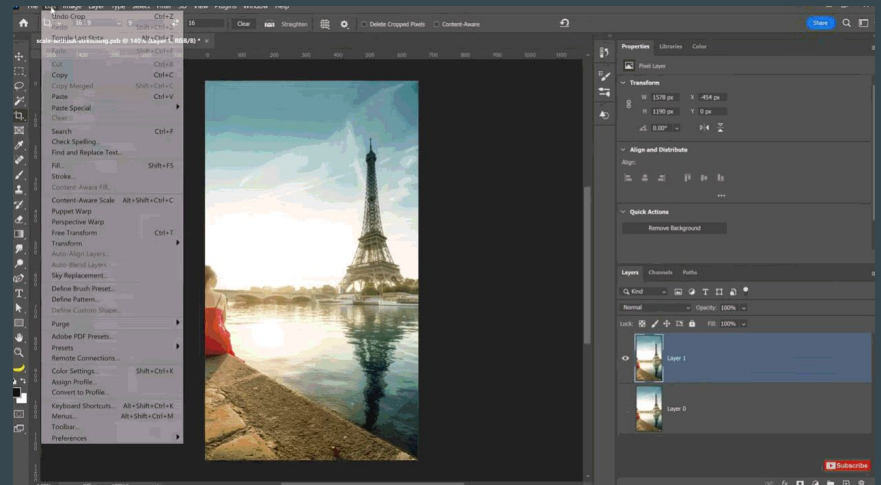
- ❖ **Seam-Carving** can allow for dynamic images that can resize for web pages while still maintaining the *key features and important aspects of the images* .

Applications: Adobe Photoshop

- Adobe's *Content Aware Scaling*
 - Adobe implements this Algorithm for image resizing within Photoshop [5]



Step 1: Create Mask



Step 2: Resize while keeping masked objects protected

Open Issues

Visual artifacts

Seam carving can create distortions when the image contains repeated structures, strong edges, or large important objects [6].

Energy function limitations

A simple energy function may fail to capture semantic importance. For example, a person's face may be visually important even if some nearby pixels have low local energy [7].

Computational cost

Recomputing energy maps and seams many times can be expensive for large images or video[8].

Discussion:

What are some other potential uses of Seam Carving that you could think of?

Quiz Questions (Review)

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References

- [1] Avidan, S. and Shamir A. *Seam Carving for Content-Aware Image Resizing*, SIGGRAPH07: Computer Graphics and Interactive Techniques Conference, 2007. <https://dl.acm.org/doi/10.1145/1275808.1276390>
- [2] vivianhylee, GitHub Seam Carving, 2017. <https://github.com/vivianhylee/seam-carving>
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- [5] https://www.researchgate.net/figure/Toy-example-of-the-dynamic-programming-algorithm-for-vertical-seam-carving-using-an_fig2_362430400
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- [7] M. Rubinstein, A. Shamir, and S. Avidan, “*Improved Seam Carving for Video Retargeting*,” ACM Transactions on Graphics, 2008.
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Thank you!