MAI4CAREU | Master programmes in Artificial Intelligence 4 Careers in Europe

Visual Computing Group

CYENS CENTRE OF EXCELLENCE

University of Cyprus – MSc Artificial Intelligence

MAI644 – COMPUTER VISION

Lecture 7: Features – Corners

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Last time

- What can we do with convolutions
- What is an edge – image derivatives
- Sobel filters
- Laplacian filters
- Difference of Gaussian filters
- Canny edge detection

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Today’s Agenda

- Features
- Self-difference
- Harris corner detection

[material based on Joseph Redmon’s course]

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What else is there?

So what can we do with these convolutions anyway?

- Blurring
- Sharpening
- Edges
- Features
- Derivatives
- Super-resolution
- Classification
- Detection
- Image captioning
- ...

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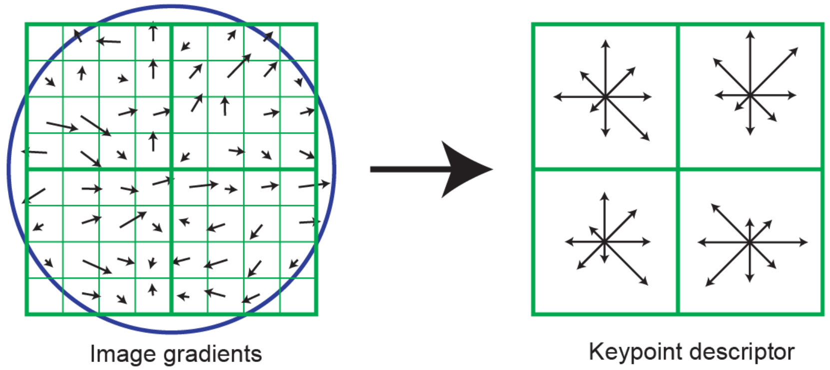
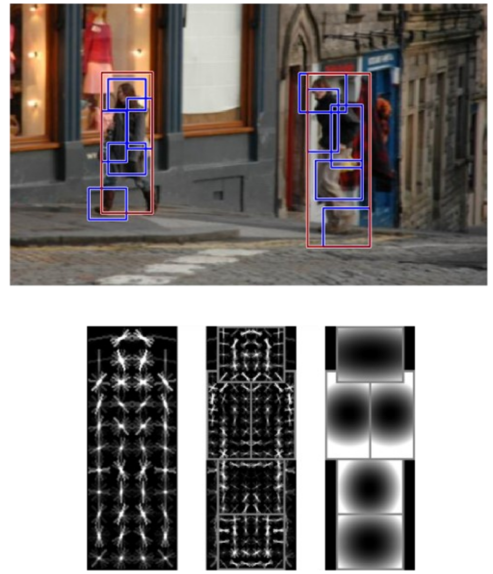
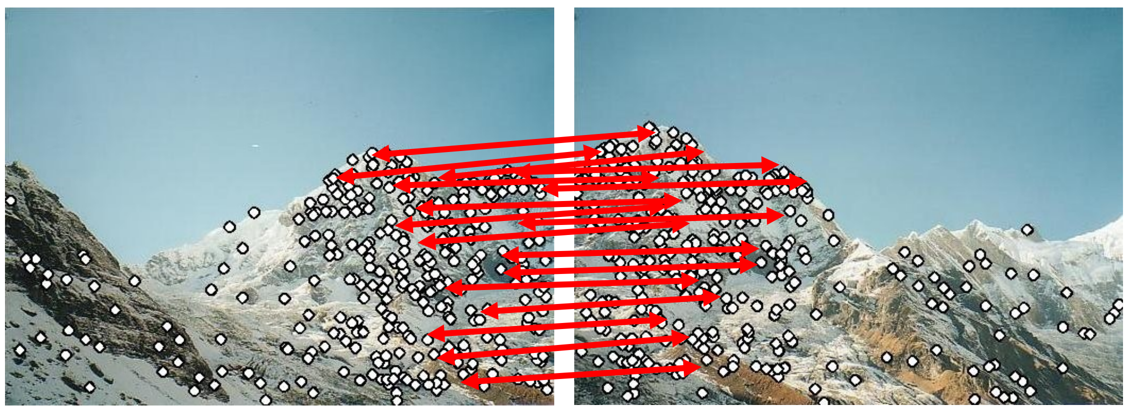
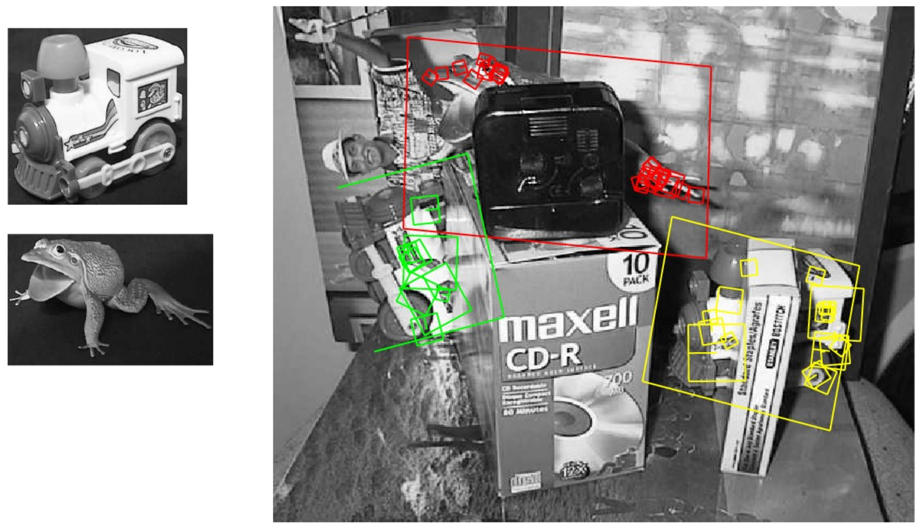
Features!

- Highly descriptive local regions
- Ways to describe those regions
- Useful for:
  - Matching
  - Recognition
  - Detection









What makes a good feature?

- Want to find patches in image that are useful or have some meaning
- For objects, want a patch that is common to that object but not in general
- For panorama stitching, want patches that we can find easily in another image of same place
- Good features are unique!
  - Can find the "same" feature easily
  - Not mistaken for "different" features

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Application - How to create a panorama

- Say we are stitching images to create a panorama
- Want patches in one image to match to patches in another image
- Hopefully only match one spot

How close are two patches?

- (weighted) Summed squared difference
- Images I, J
- $\Sigma_{x,y}\ w(x,y)\ (I(x,y) - J(x,y))^2$

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How can we find unique patches?

- Sky: bad
  - Very little variation
  - Could match any other sky

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How can we find unique patches?

- Sky: bad
  - Very little variation
  - Could match any other sky
- Edge: ok
  - Variation in one direction
  - Could match other patches along same edge

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How can we find unique patches?

- Sky: bad
  - Very little variation
  - Could match any other sky
- Edge: ok
  - Variation in one direction
  - Could match other patches along same edge
- Corners: good!
  - Only one alignment matches

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How can we find unique patches?

- Want a patch that is unique in the image

- Can calculate distance between patch and every other patch, a lot of computation

- Instead, we could think about auto-correlation:
  - How well does image match shifted version of itself?

- Autocorrelation: $\Sigma_{\mathbf{d}}\Sigma_{x,y}\ w(x,y)\ (\ I(x+\mathbf{d}_x,y+\mathbf{d}_y) - I(x,y)\ )^2$

- Measure of self-difference (how much am I not myself?)

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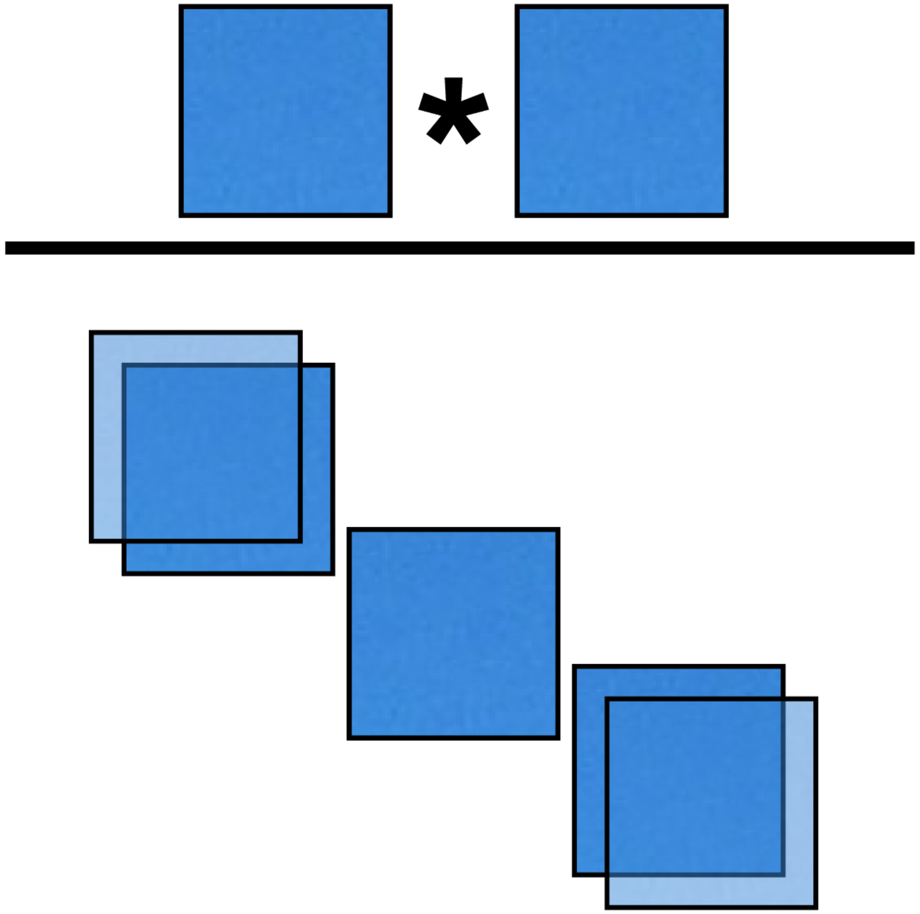
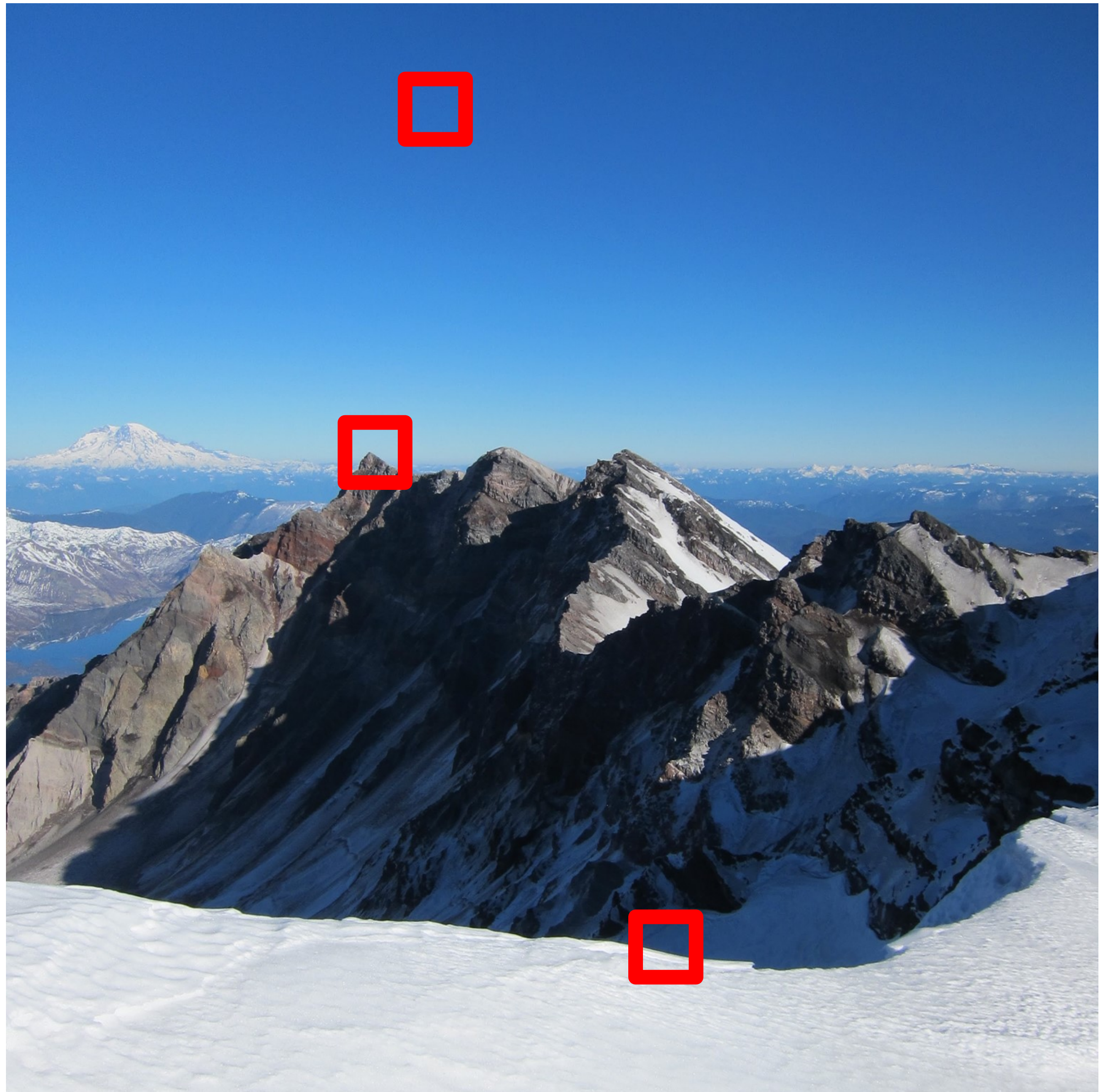
Self-difference

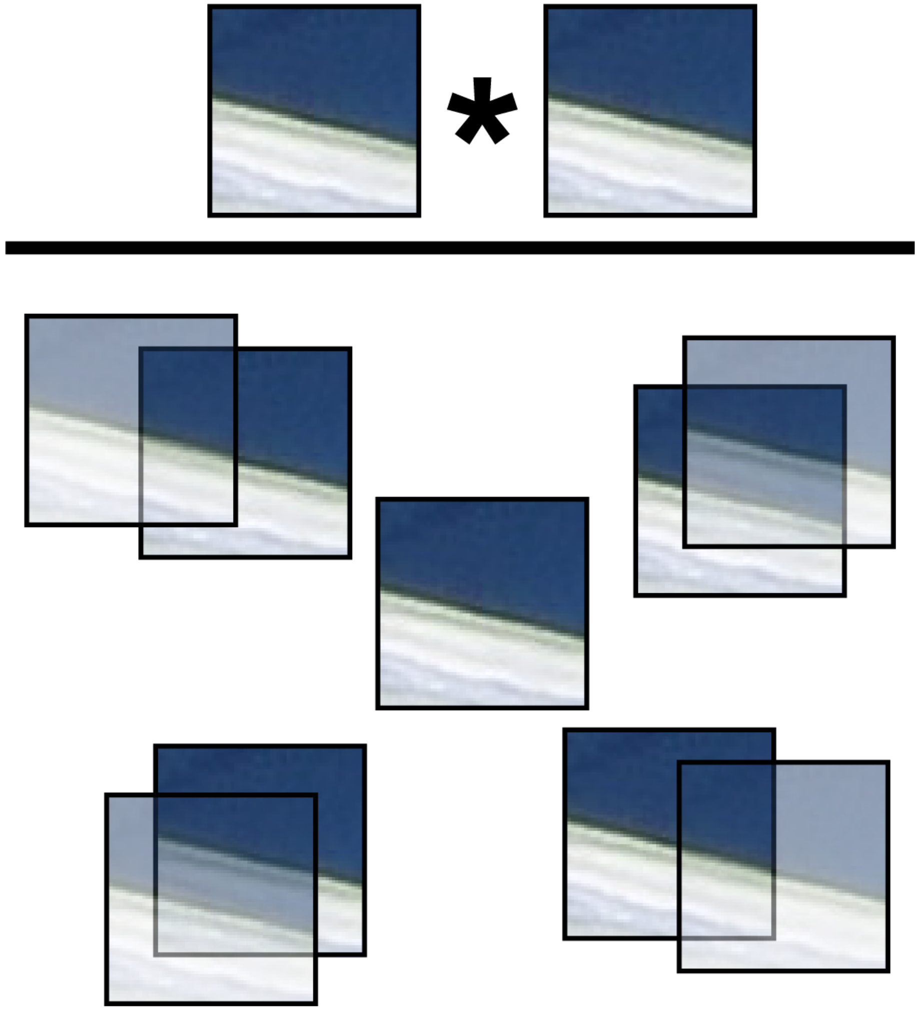
Sky: low everywhere

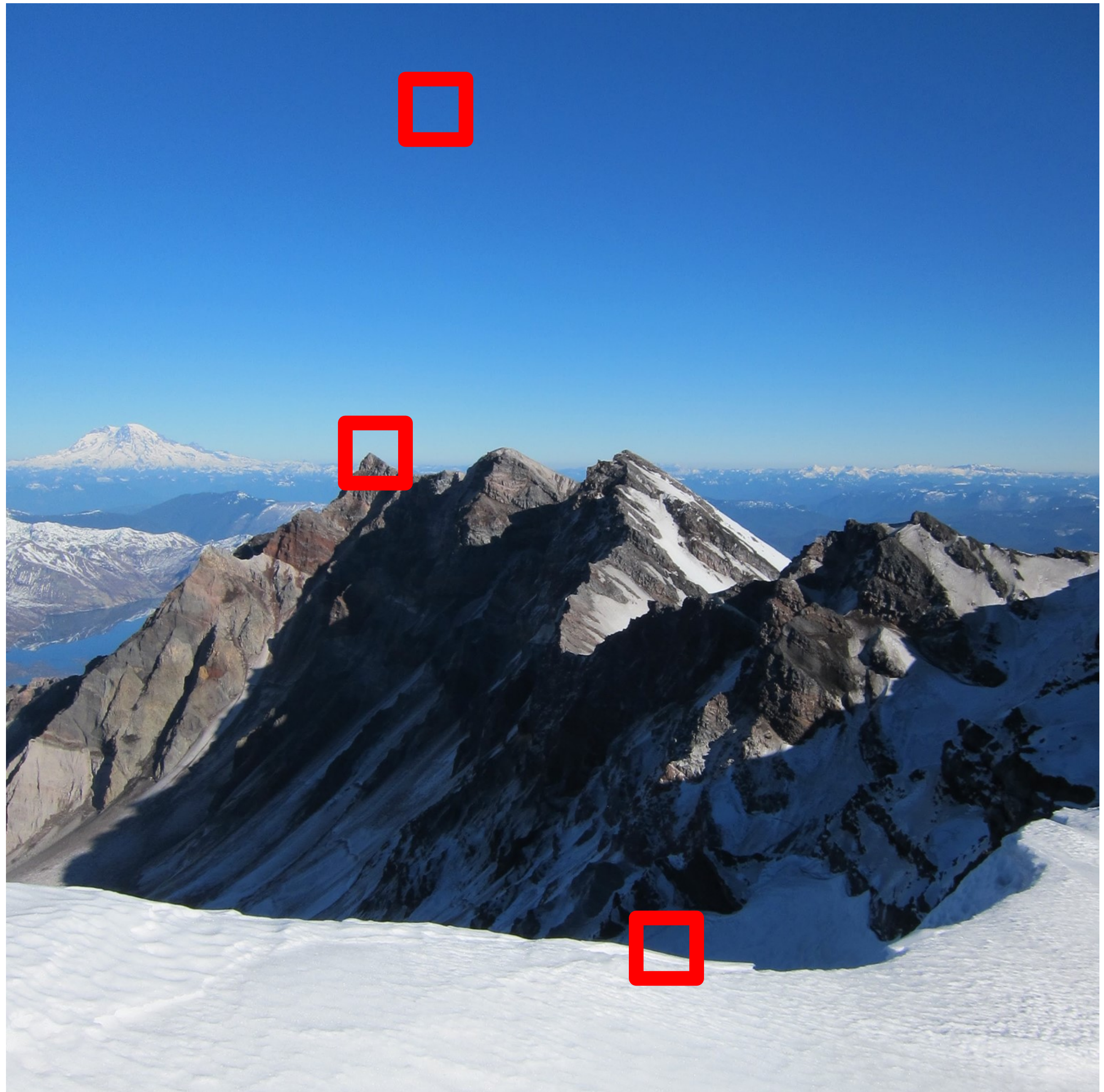




Self-difference

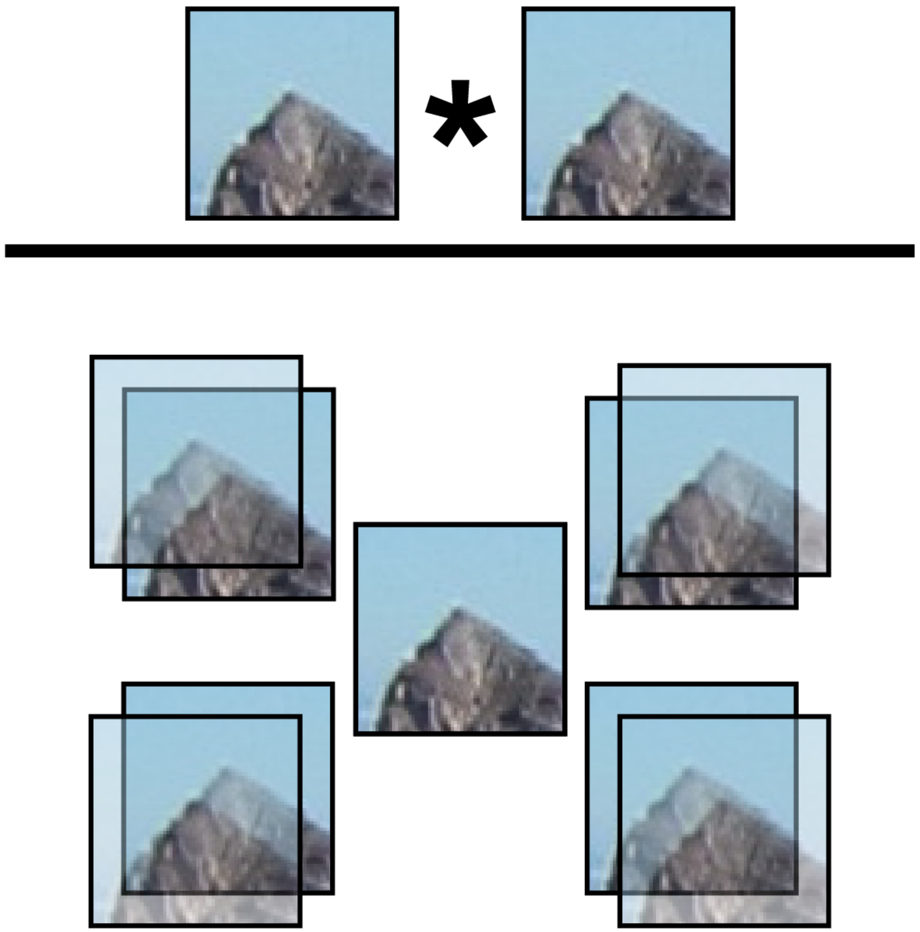
Edge: low along edge

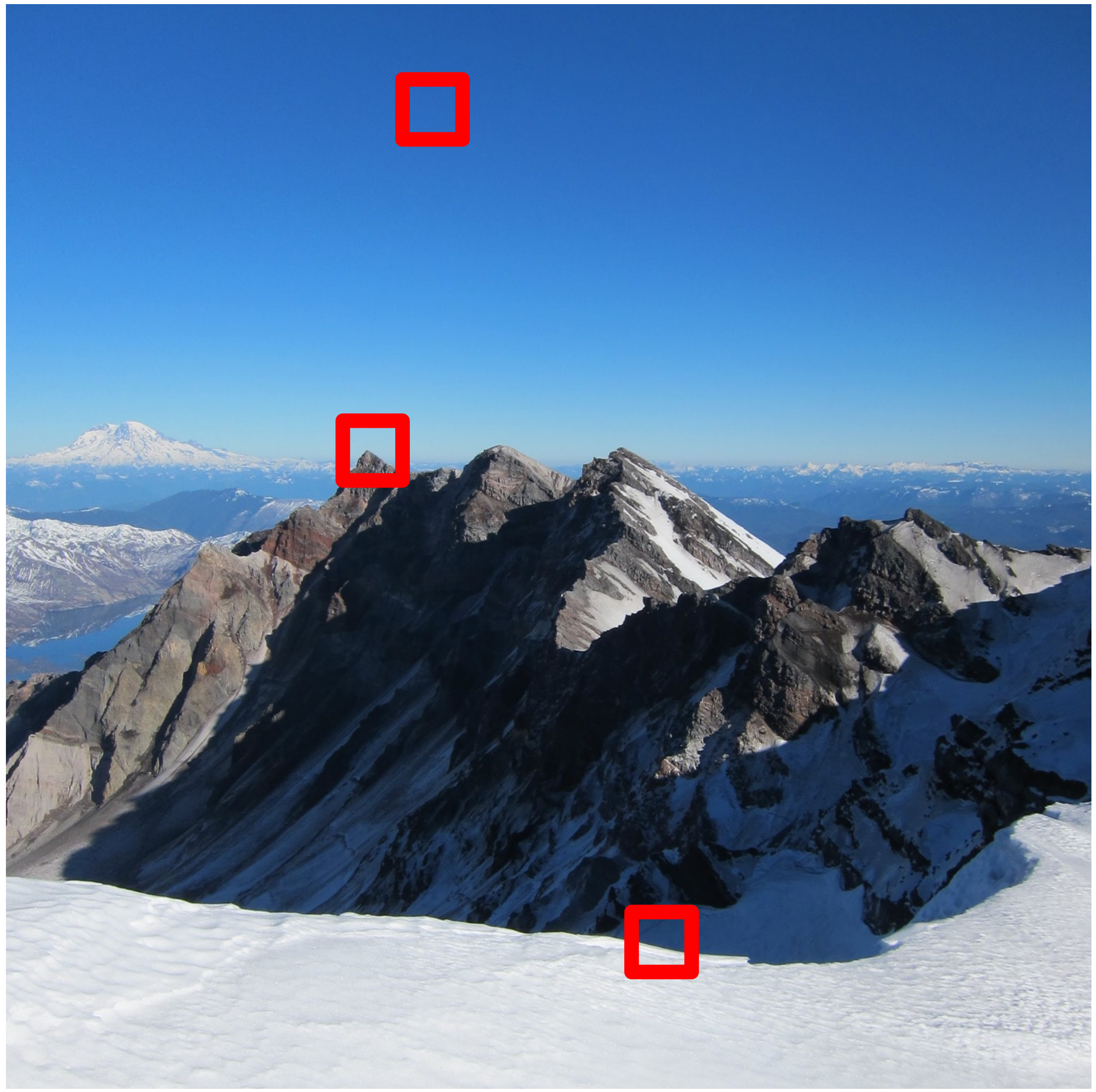




Self-difference

Corner: mostly high





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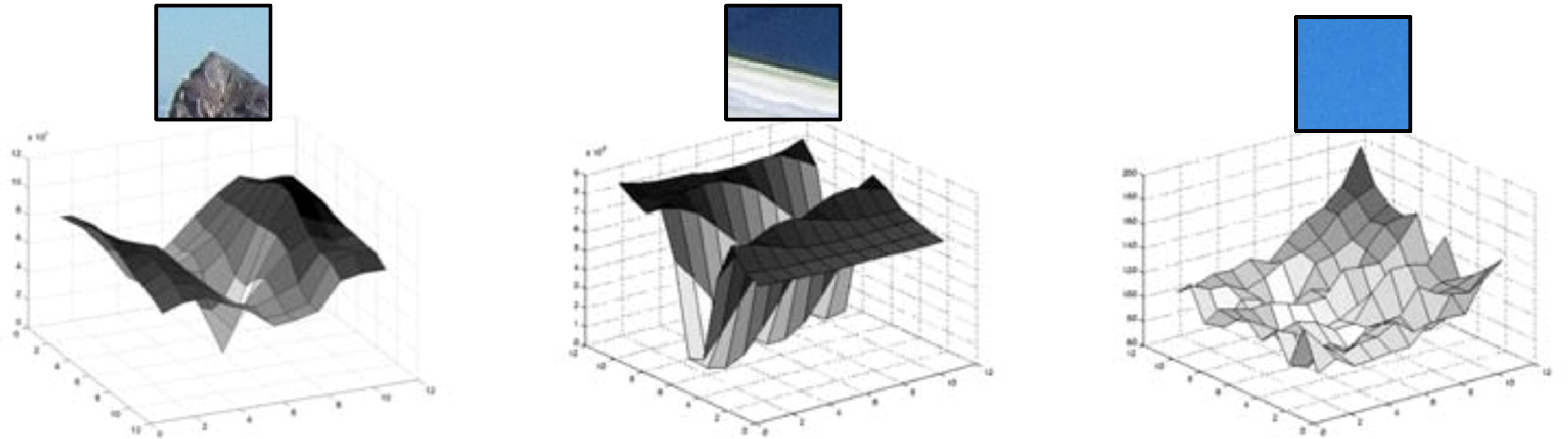
Self-difference

Sky: low everywhere

Edge: low along edge

Corner: mostly high



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Self-difference is still expensive

- $\Sigma_{\mathbf{d}}\Sigma_{x,y}\ w(x,y)\ (\ I(x+\mathbf{d}_x,y+\mathbf{d}_y) - I(x,y)\ )^2$
- Lots of summing
- Need an approximation
  - Use Taylor Series expansion of the image function (see Szeliski book Section 7.1.1)
  - $I(x+\mathbf{d}_x,y+\mathbf{d}_y) \sim= I(x,y) + \mathbf{d}_x\, I_x(x,y) + \mathbf{d}_y I_y(x,y)$

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Approximate self-difference

- Look at nearby gradients I_x and I_y
- If gradients are mostly zero, not a lot going on
  - Low self-difference
- If gradients are mostly in one direction, edge
  - Still low self-difference
- If gradients are in two(ish) directions, corner!
  - High self-difference, good patch!

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Approximate self-difference

- How do we tell what's going on with gradients?
- Eigenvectors/values!
- Need structure matrix for patch, just a weighted sum of nearby gradient information

$$\begin{vmatrix} \Sigma_i w_i I_x(i) I_x(i) & \Sigma_i w_i I_x(i) I_y(i) \\ \Sigma_i w_i I_x(i) I_y(i) & \Sigma_i w_i I_y(i) I_y(i) \end{vmatrix}$$

- Not as complex as it looks, weighted sum of gradients near pixel

https://en.wikipedia.org/wiki/Structure_tensor

Structure matrix

- Weighted sum of gradient information

$$\begin{vmatrix} \Sigma_i w_i I_x(i) I_x(i) & \Sigma_i w_i I_x(i) I_y(i) \\ \Sigma_i w_i I_x(i) I_y(i) & \Sigma_i w_i I_y(i) I_y(i) \end{vmatrix}$$

- Can use Gaussian weighting

- Eigenvectors/values of this matrix summarize the distribution of the gradients nearby

- λ_1 and λ_2 are eigenvalues
  - λ_1 and λ_2 both small: no gradient
  - $\lambda_1 >> \lambda_2$ or $\lambda_1 << \lambda_2$: gradient in one direction
  - λ_1 and λ_2 both large: multiple gradient directions, corner

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Estimating eigenvalues

- Use determinant and trace:
  - $\det(S) = \lambda_1 * \lambda_2$
  - $\text{trace}(S) = \lambda_1 + \lambda_2$
- Response function (R score): $\det(S) - \kappa\, \text{trace}(S)^2 = \lambda_1\lambda_2 - \kappa(\lambda_1+\lambda_2)^2$
- If this score is large, both λ_1 and λ_2 are large

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Harris Corner Detector

- Calculate derivatives I_x and I_y
- Calculate 3 measures I_xI_x, I_yI_y, I_xI_y
- Calculate weighted sums
  - Want a (weighted) sum of nearby pixels, guess what this is?
  - Gaussian – or weights could just be ones
- Estimate response based on R score
- Non-max suppression in a neighborhood

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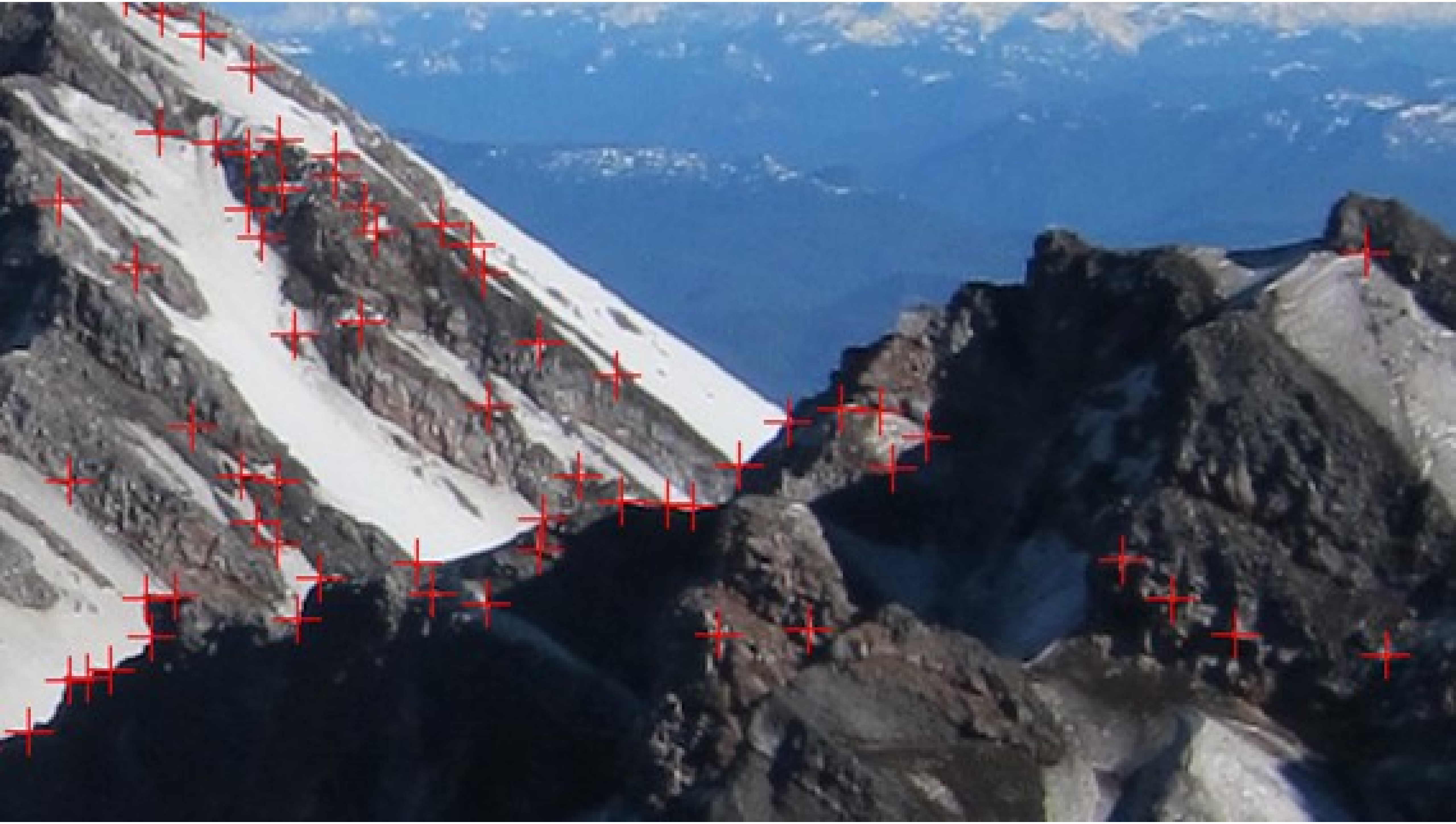

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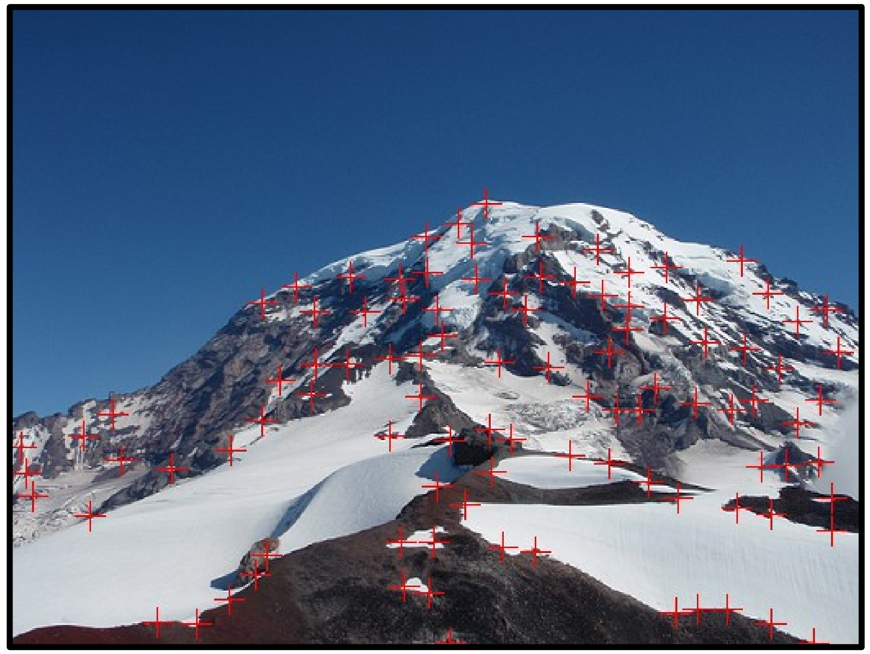
Ok, we found corners, now what?

- Need to match image patches to each other
- Need to figure out transform between images



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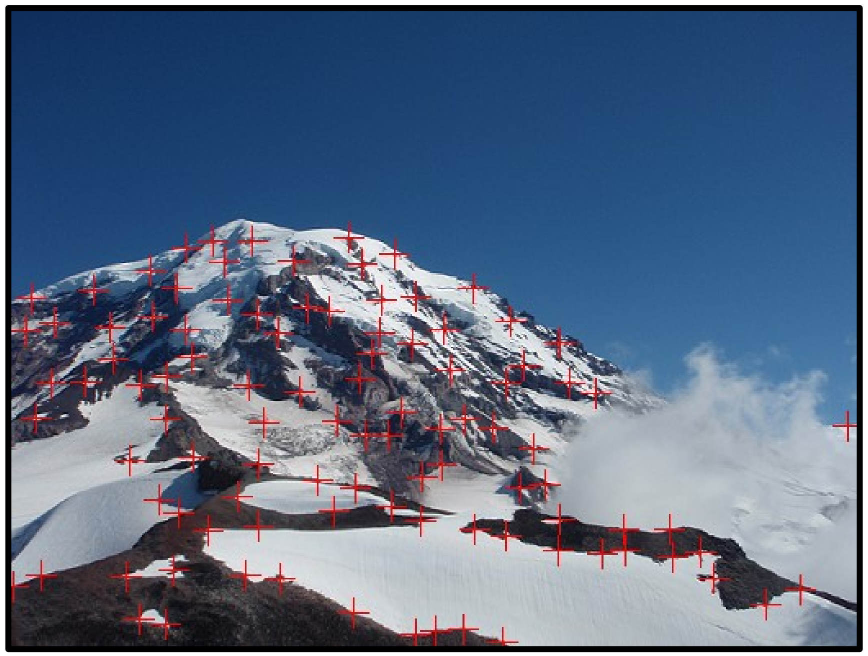
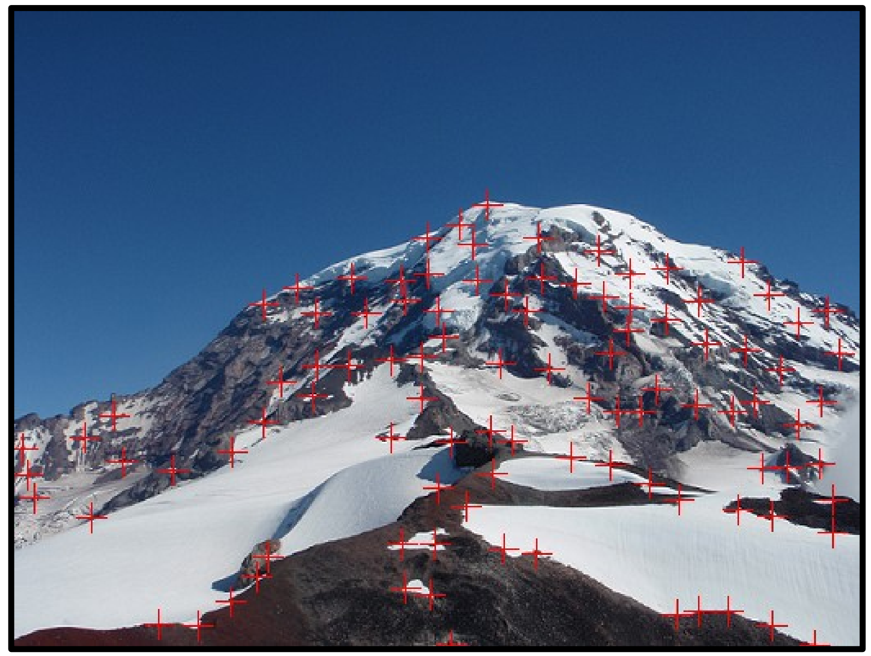
Ok, we found corners, now what?

- Need to match image patches to each other
  - What is a patch? How do we look for matches? Pixels?
- Need to figure out transform between images
  - How can we transform images?
  - How do we solve for this transformation given matches?





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Thank you.

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