Computational Photography

* Study the basics of computation and its impact on the entire workflow of photography, from capturing, manipulating and collaborating on, and sharing photographs.

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Image Warping and Morphing

* Warping and morphing applied to images

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Lesson Objectives

1. Image Warping
2. Forward and Inverse Warping
3. Warping using a mesh
4. Image Morphing
5. Feature-based Image Morphing

Recall: Image Transformations

image filtering:
change range of image

$$g(x) = T(f(x))$$

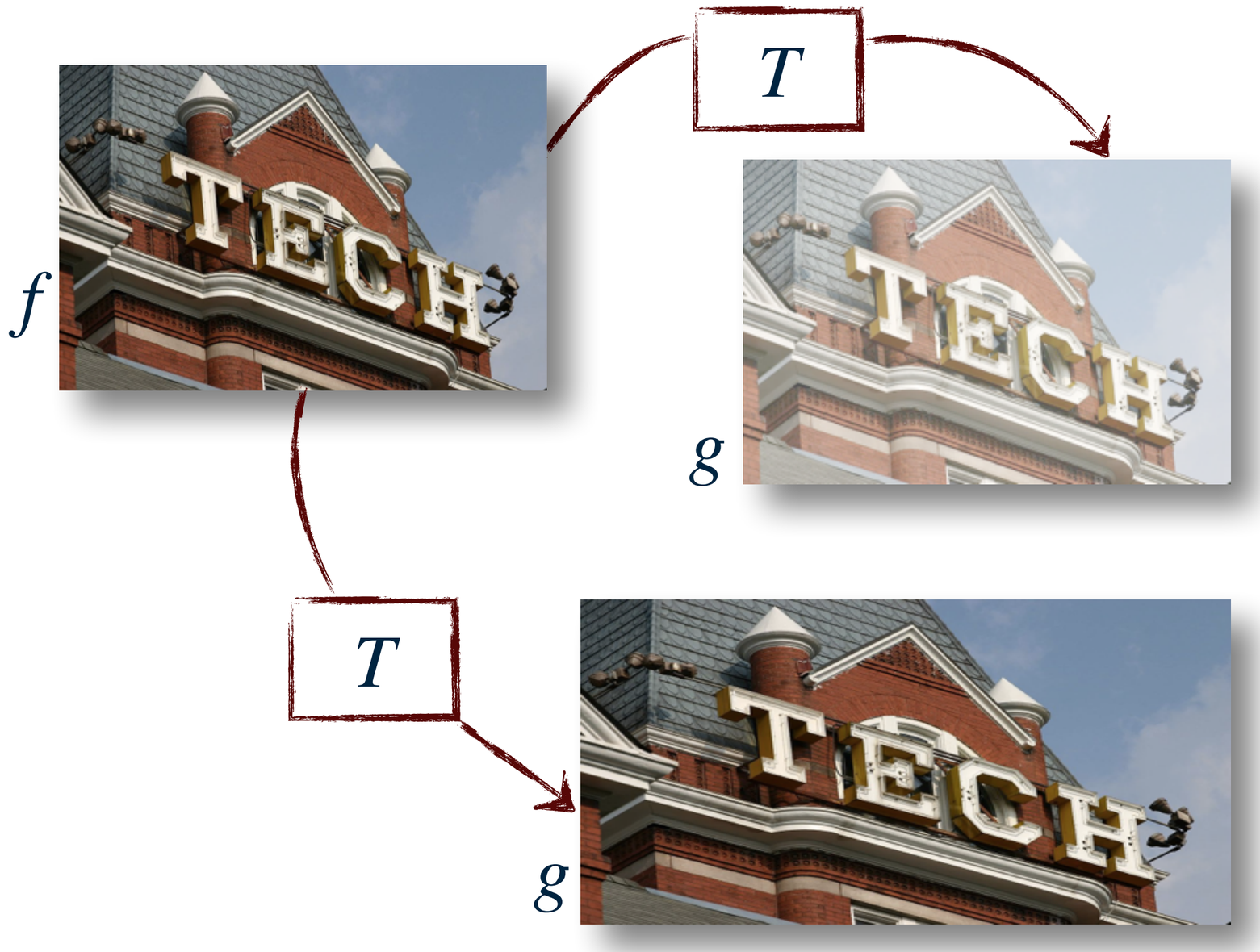


image warping:
change domain of image

$$g(x) = f(T(x))$$

Image Transformation vs. Warping

* Transformation: Lines remain lines
* Warping: Points are mapped to points
* A mathematical function for warping from a plane to the plane

Image Warping

- Distorted through simulation of optical aberrations
- Projected onto a curved or mirrored surface
- Partitioned into polygons and each polygon distorted
- Distorted using morphing

Two methods: Forward/Inverse

* Consider a S and T image
* S has pixel coordinates: (u,v)
* T has pixel coordinates: (x,y)

$S \Rightarrow (u,v)$

Forward $(x, y) = [X(u, v), Y(u, v)]$

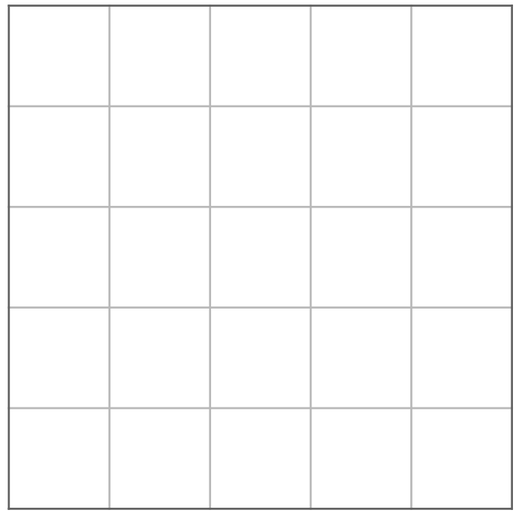
Inverse $(u, v) = [U(x, y), V(x, y)]$

$T \Rightarrow (x,y)$

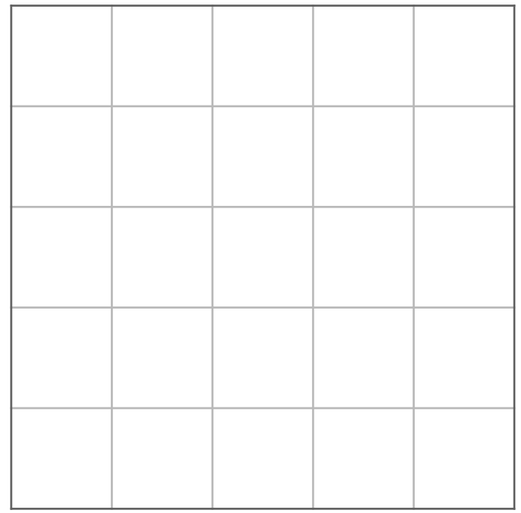
Forward/Inverse Warping

$$(x, y) = [X(u, v), Y(u, v)]$$

Input



(u,v) integer valued

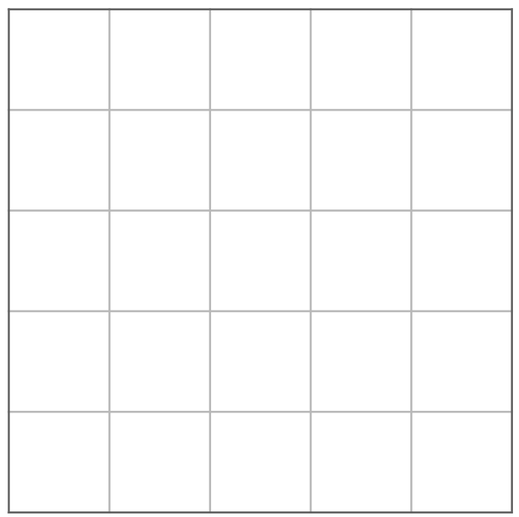


(x,y) real valued

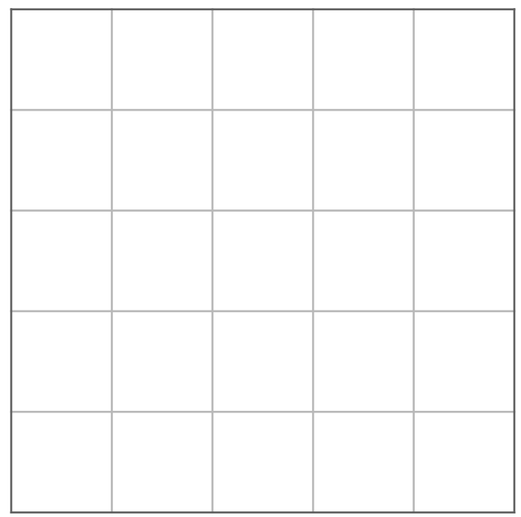
Output

$$(u, v) = [U(x, y), V(x, y)]$$

Input



(u,v) real valued



(x,y) integer valued

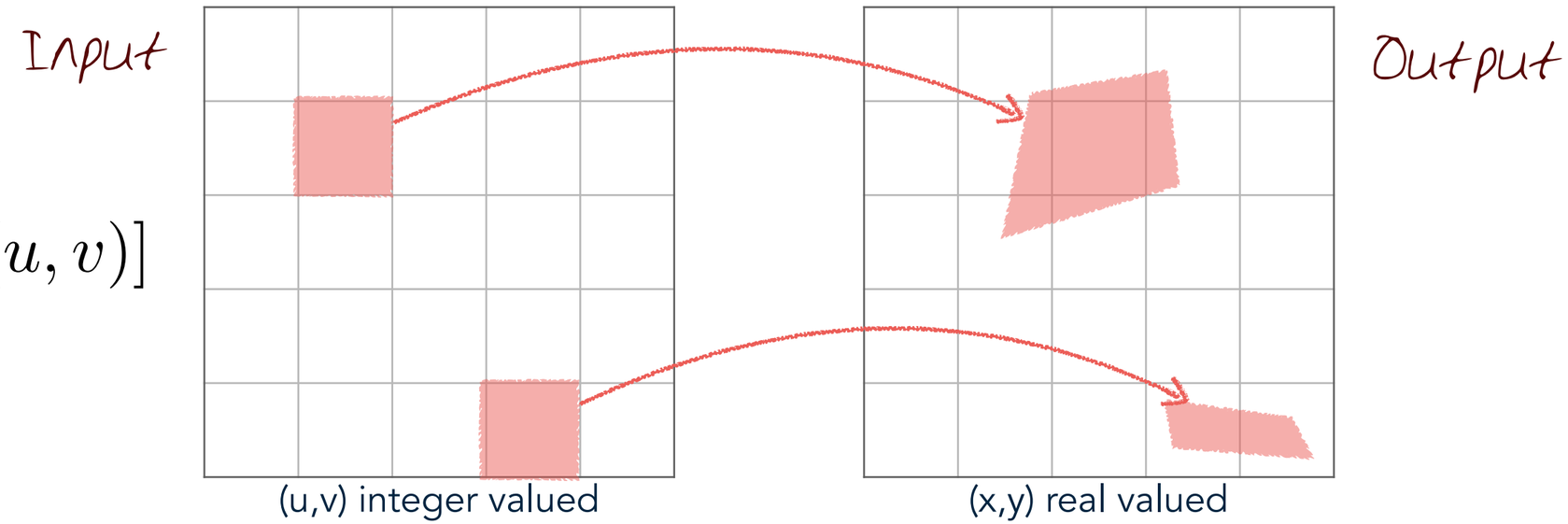
Output

Forward/Inverse Warping

$$(x, y) = [X(u, v), Y(u, v)]$$

Problems:

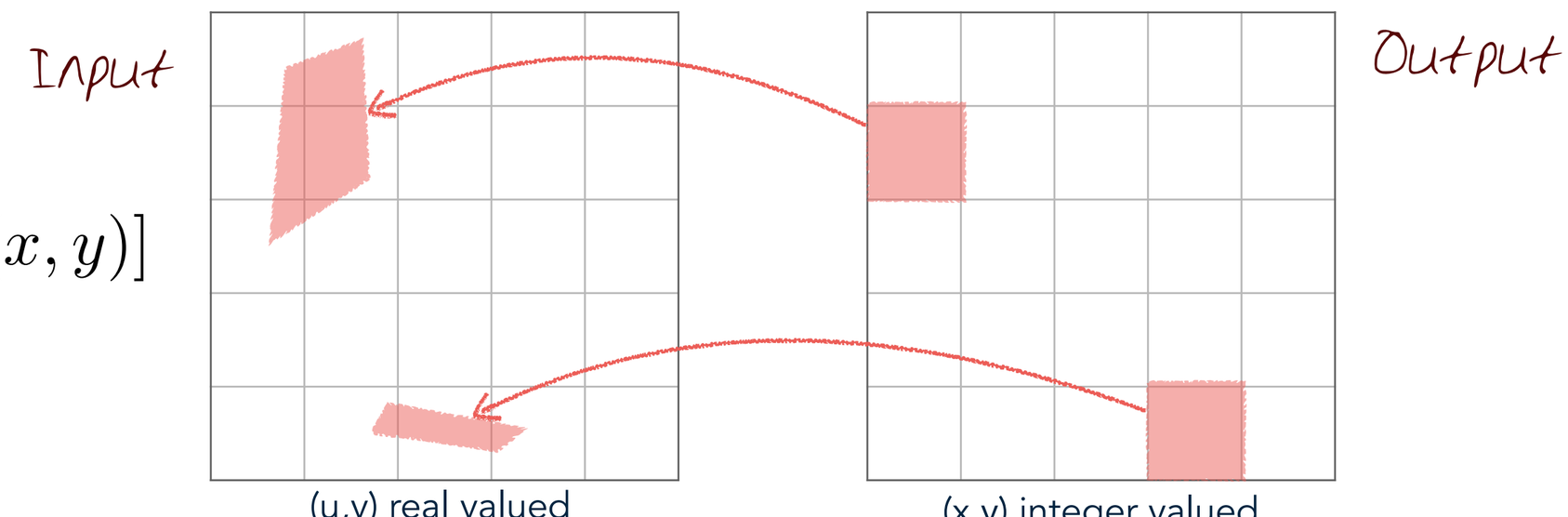
Holes, Overlaps



$$(u, v) = [U(x, y), V(x, y)]$$

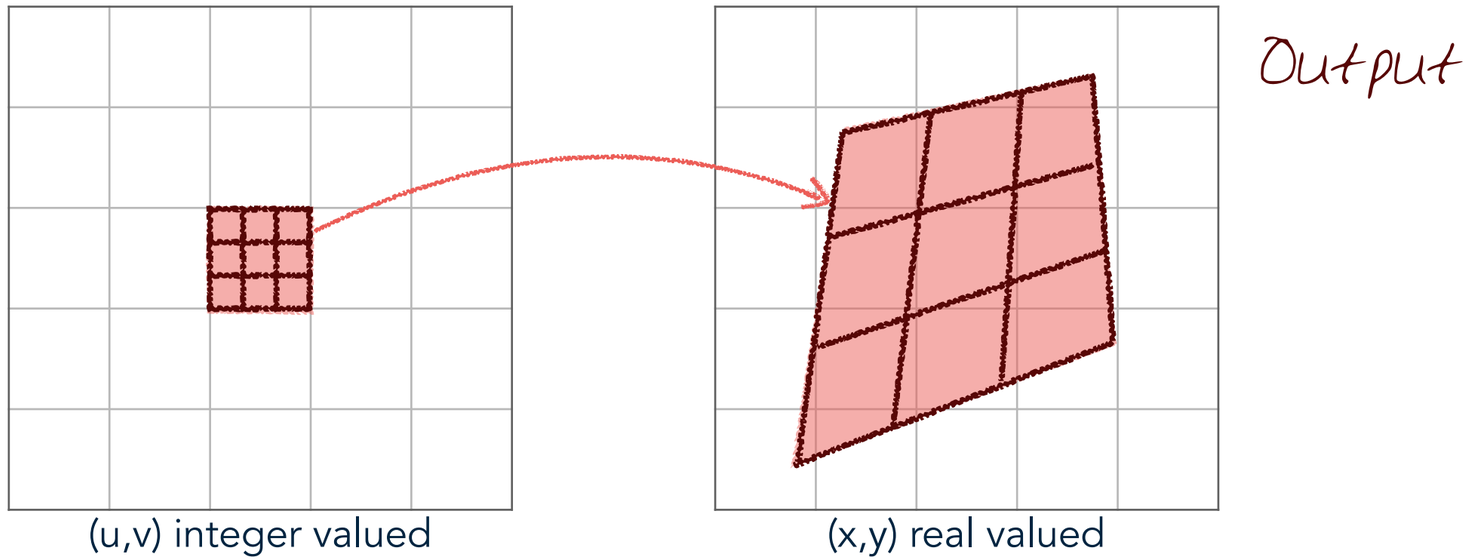
Problems:

Minification

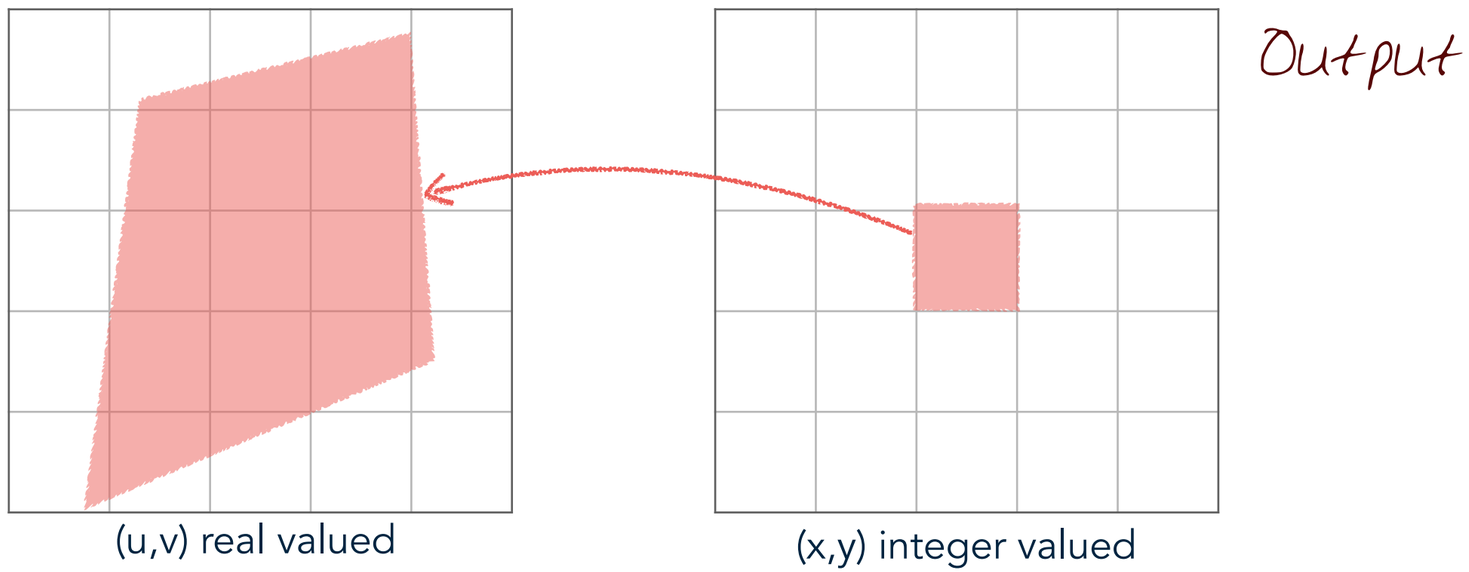


Magnification / Minification

$$(x, y) = [X(u, v), Y(u, v)]$$



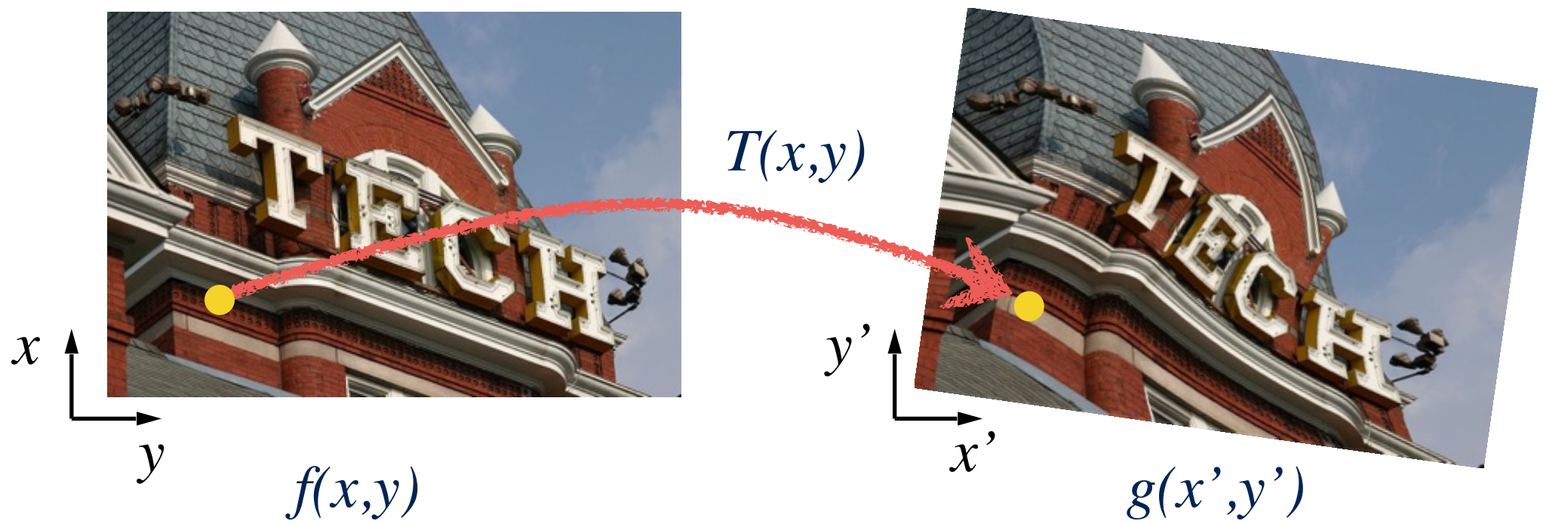
$$(u, v) = [U(x, y), V(x, y)]$$



Additional Info:

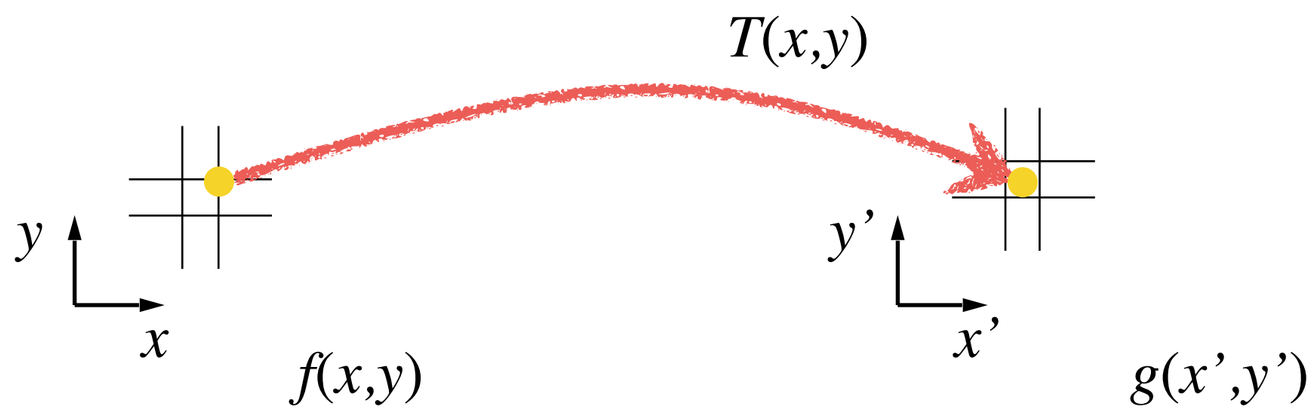
See Two-pass Transforms

Recall: Forward warping



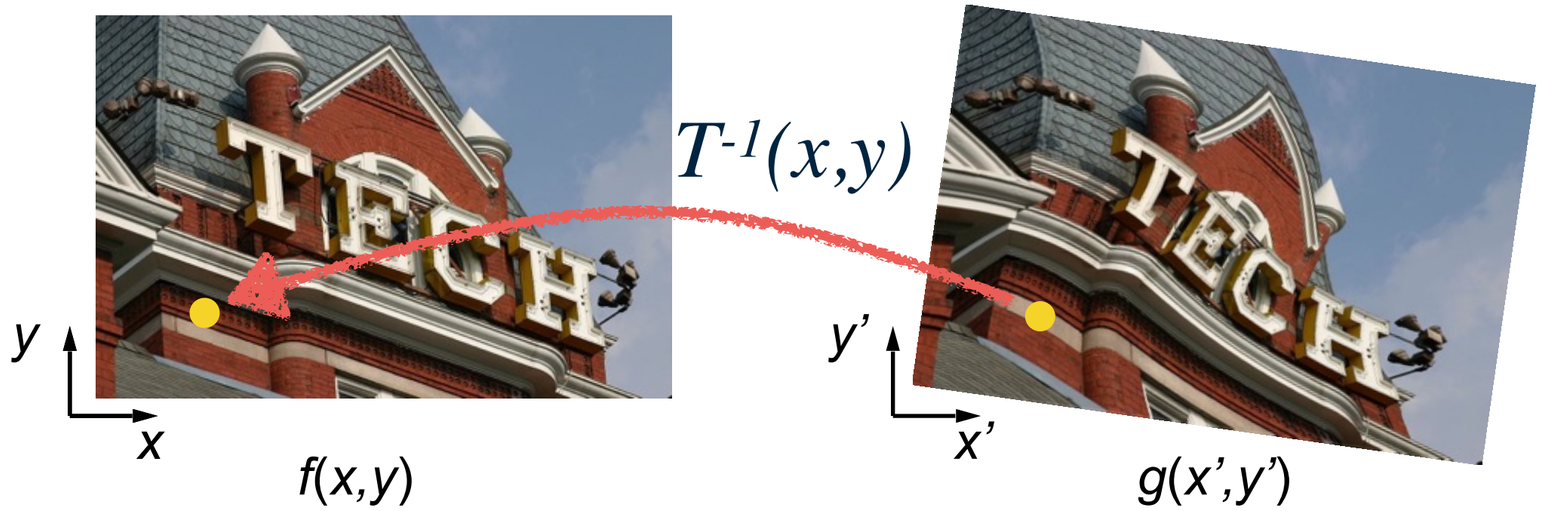
* Send each pixel $f(x,y)$ to its corresponding location
  * $(x',y') = T(x,y)$ in the second image
* Q: what if pixel lands "between" two pixels?

Recall: Forward warping



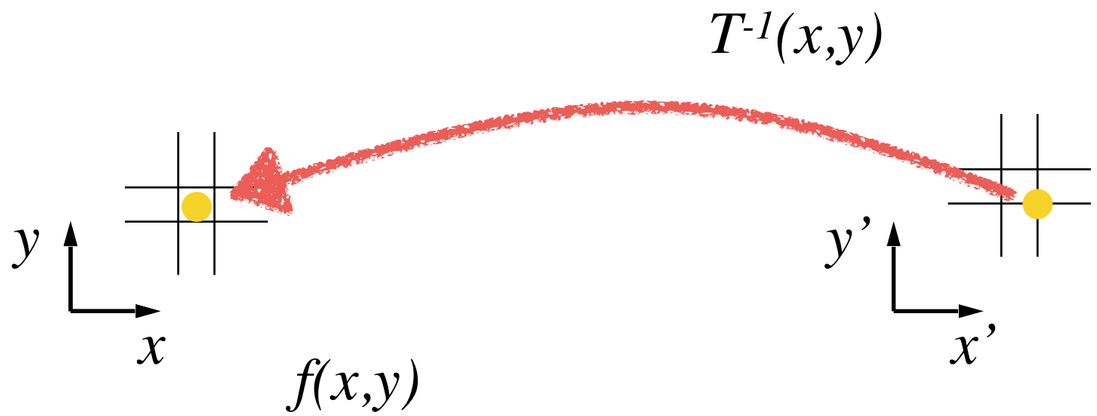
- Send each pixel $f(x,y)$ to its corresponding location
  - $(x',y') = T(x,y)$ in the second image
- Q: what if pixel lands "between" two pixels?
- A: distribute color among neighboring pixels (x',y')

Recall: Inverse warping



* Get each pixel $g(x',y')$ from its corresponding location
  * $(x,y) = T^{-1}(x',y')$ in the first image
* Q: what if pixel comes from "between" two pixels?

Recall: Inverse warping



* Get each pixel $g(x',y')$ from its corresponding location
  * $(x,y) = T^{-1}(x',y')$ in the first image
* Q: what if pixel comes from "between" two pixels?
* A: Interpolate color value from neighbors

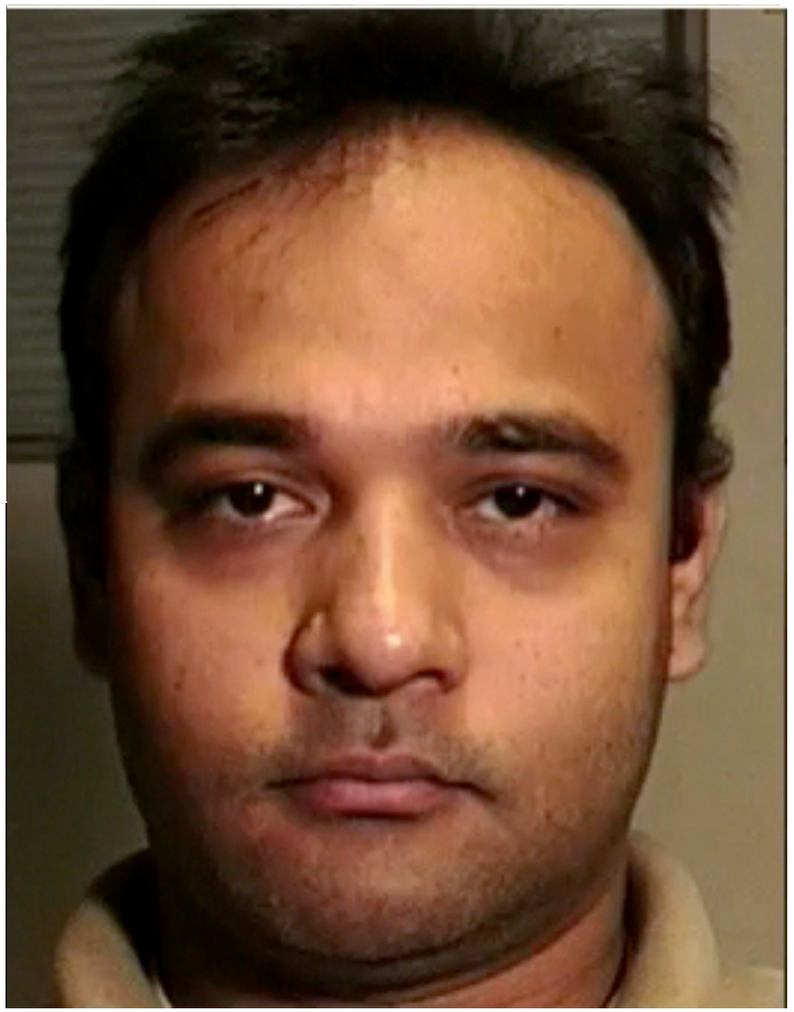
Forward vs. inverse warping

* Q: which is better?

* A: usually inverse ⇒ eliminates holes

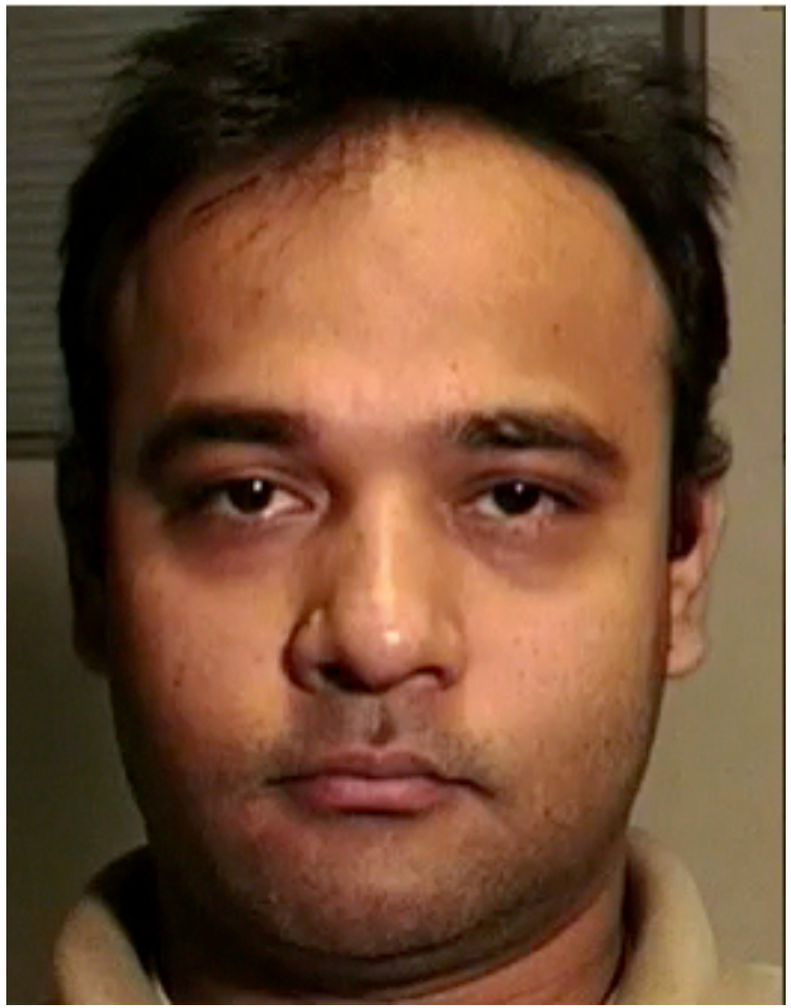
  * however, it requires an invertible warp function ⇒ not always possible...

Mesh-based Warping



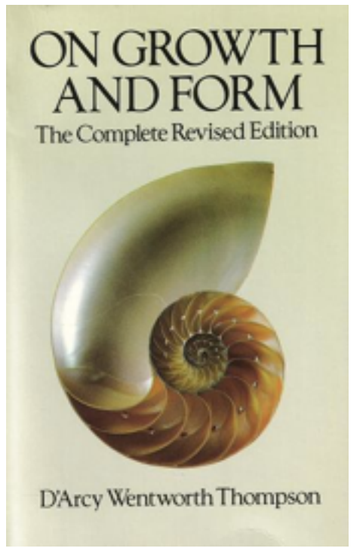
* Use a sparse set of corresponding points and interpolate with a displacement field
* Triangulate the set of points on Source
* Use the affine model for each triangle
* Triangulate Target with displaced Points
* Use inverse mapping

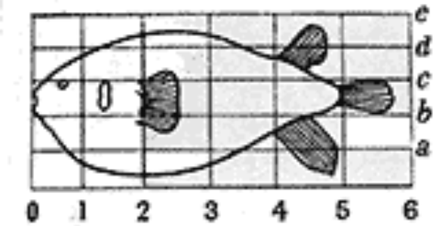
Image Morphing



* Animations that changes (or morphs) one image or shape into another through a seamless transition

* Widely used in movies





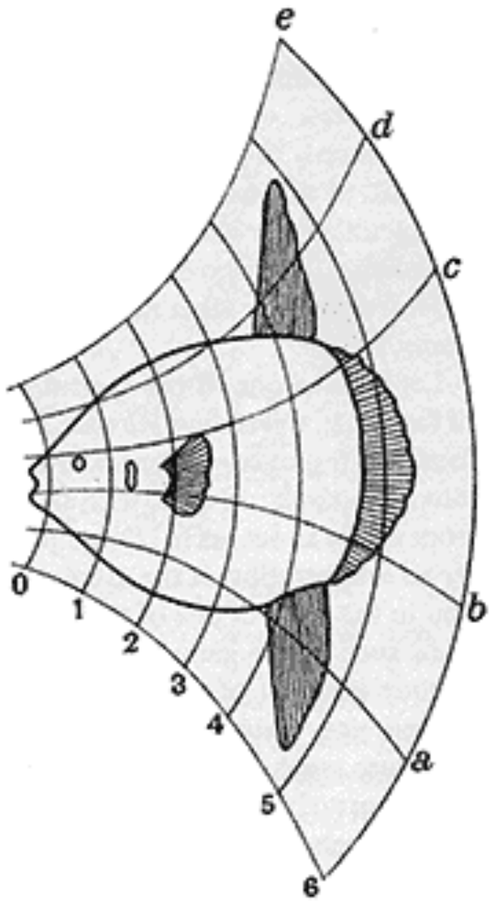
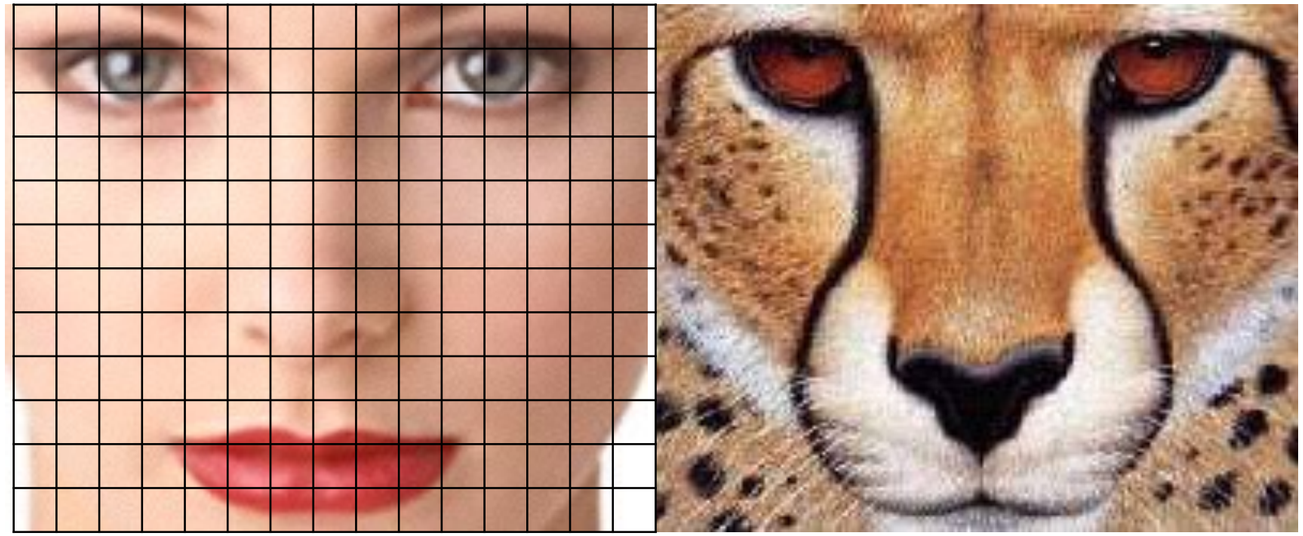


Image Morphing: Approaches

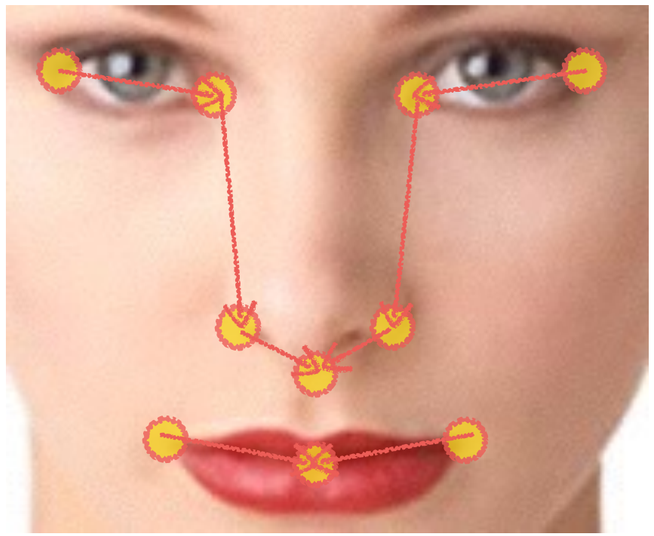
* Quadrilateral mesh displaced with variational interpolation

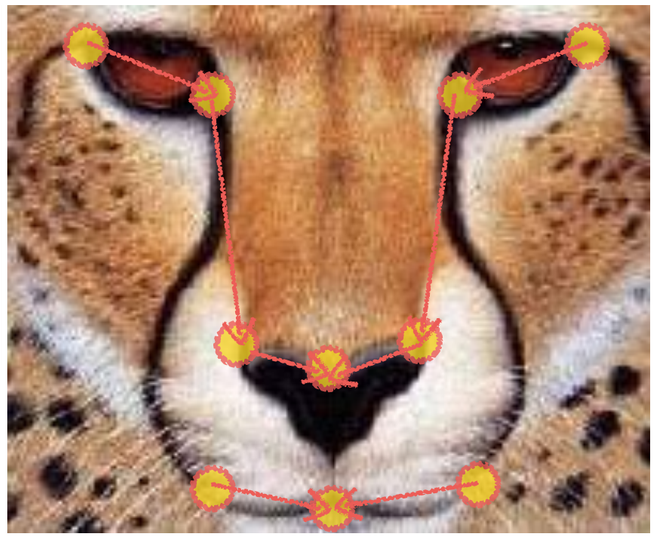


Images on this slide are for demonstration purposes only and may not reflect actual processed images
For more details see Szeliski Chapter 3

Image Morphing: Approaches

* Quadrilateral mesh displaced with variational interpolation
* Corresponding features/ points
* Corresponding orientated line segments (specifies translation, rotation, scaling)





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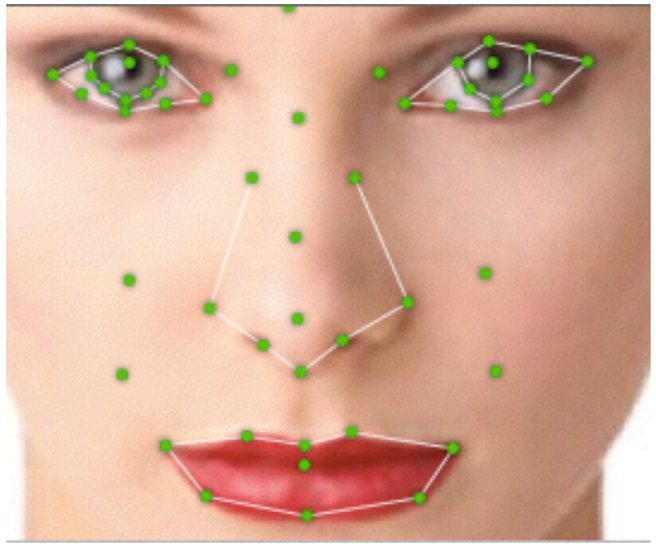
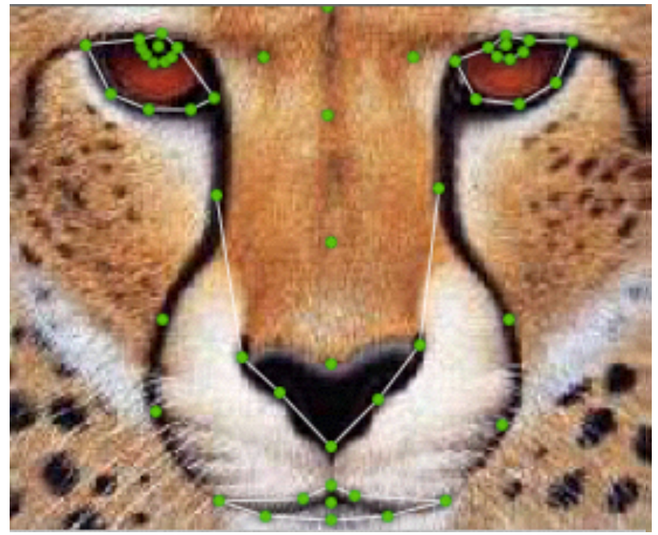
For more details see Szeliski Chapter 3

Feature-based Morphing





Beier and Neely (1992)

Software used: Fantamorph v5

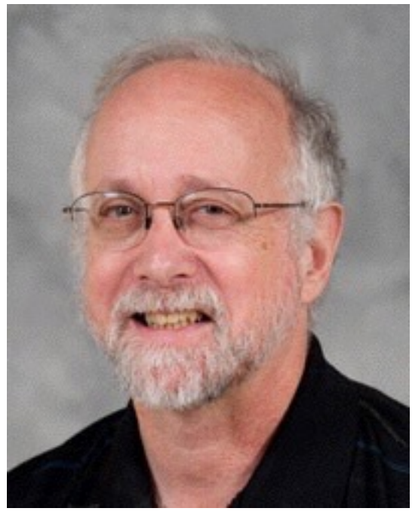
Feature-based Morphing

Michael Jackson - Black Or White

Beier and Neely (1992)

Feature-based Morphing

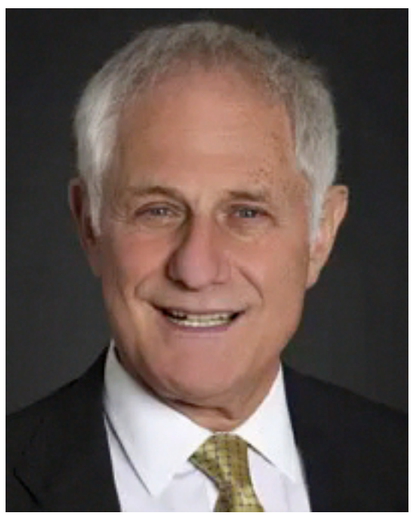
Zvi



Ron

Irfan

Charles



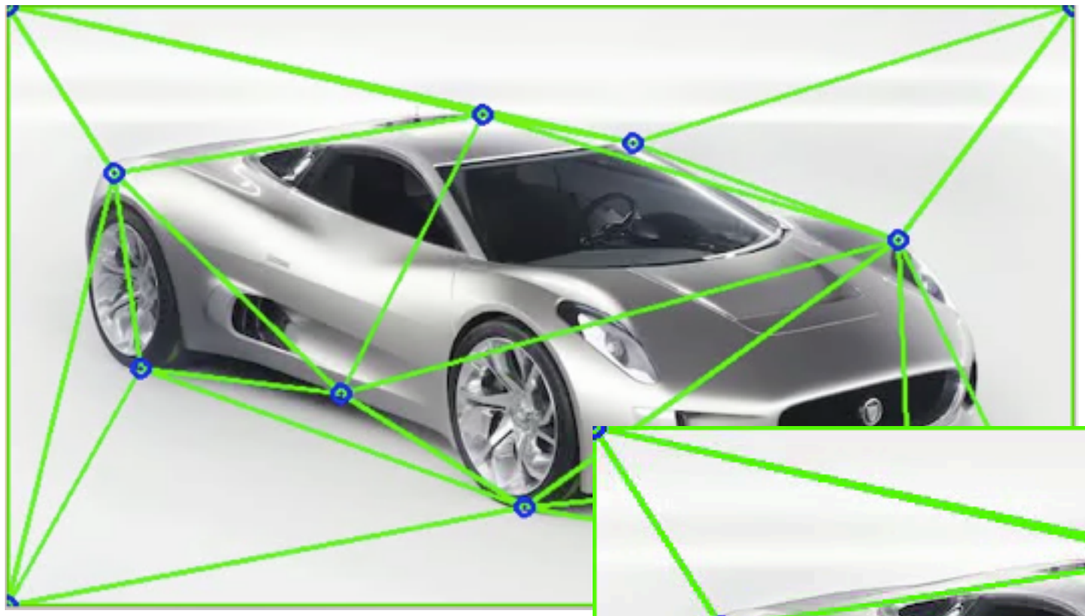
CoC Deans

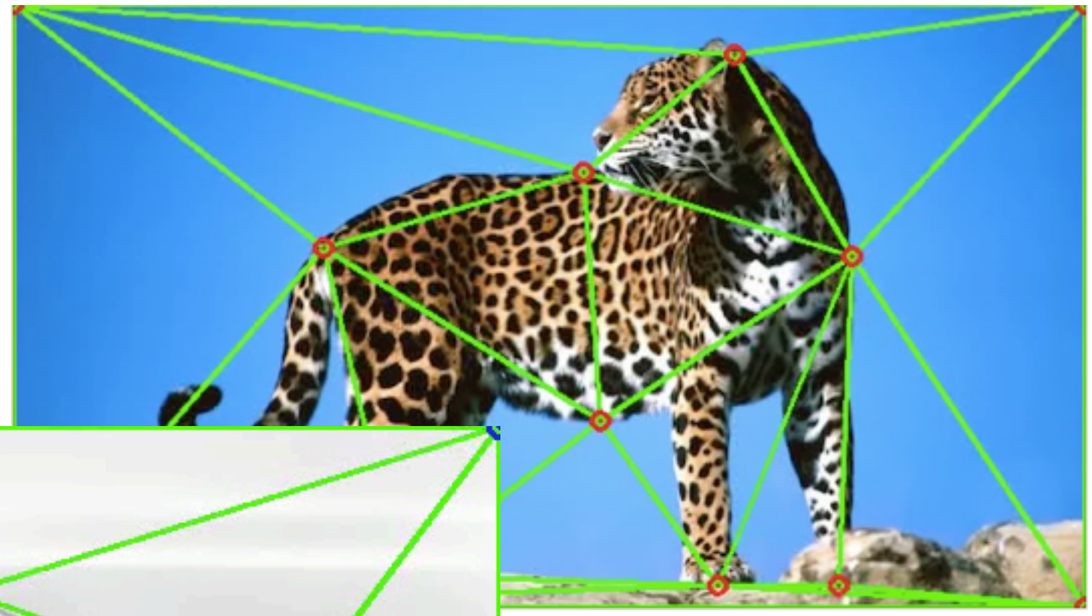
Morphed

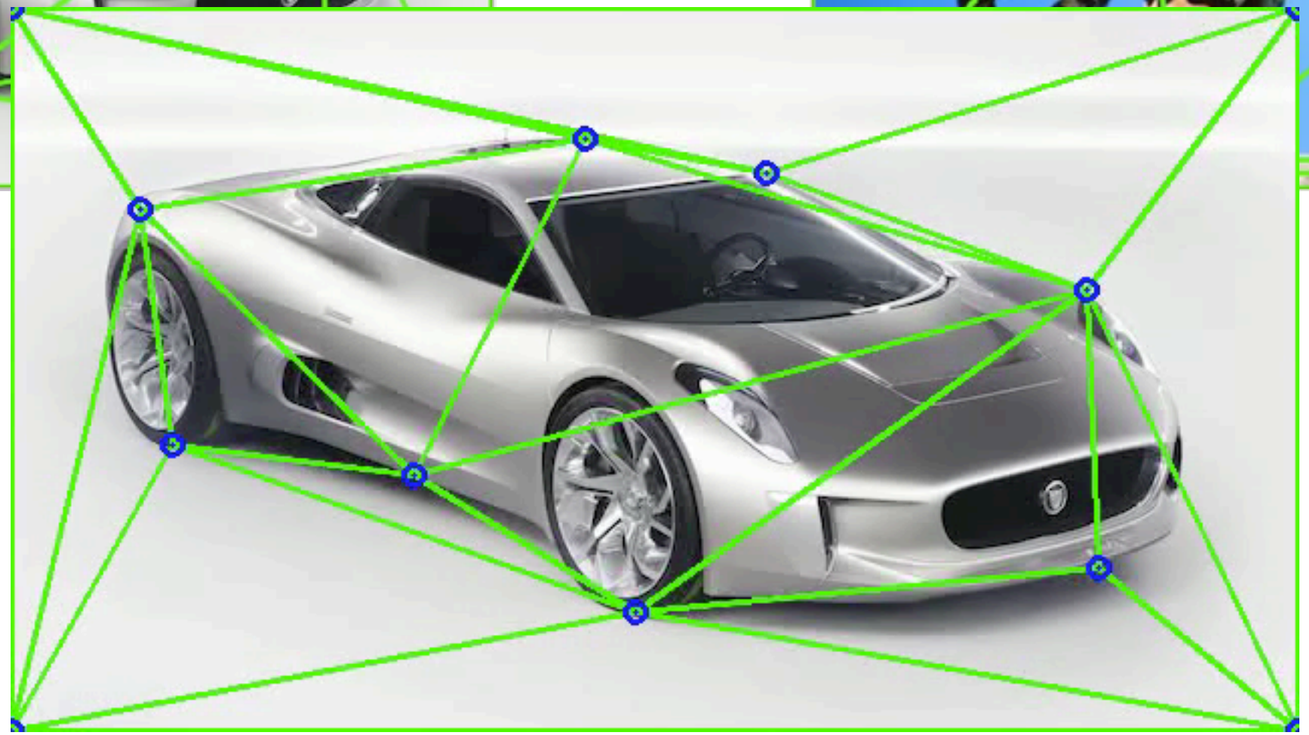
Beier and Neely (1992)

Software used: Fantamorph v5

Demo





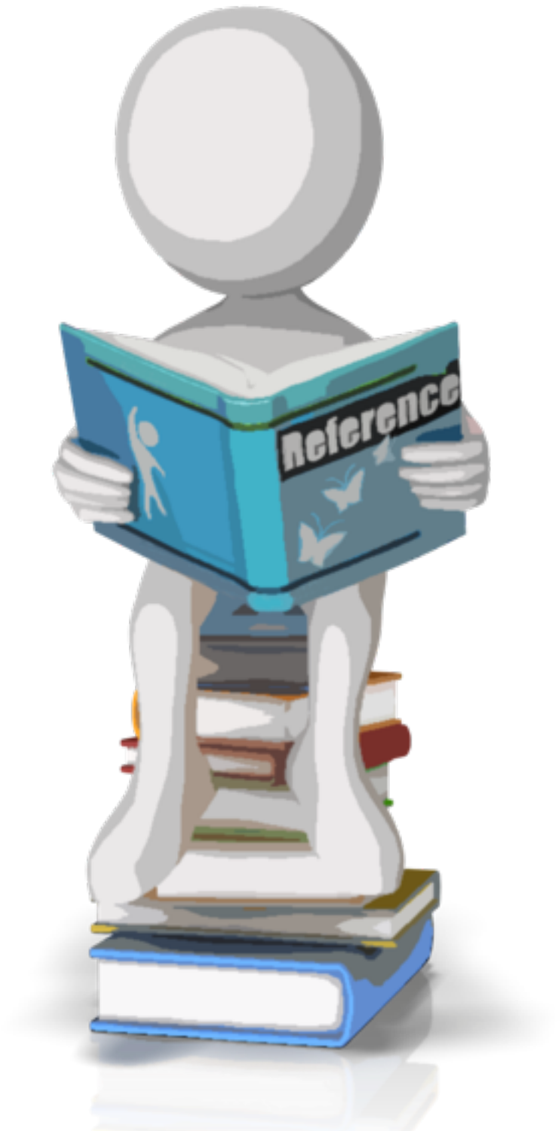


```
# Main script
if __name__ == "__main__":
    # Read two images: We want to morph from src to dst
    img_src = cv2.imread("jaguar-cx75.png")
    img_dst = cv2.imread("jaguar-standing.png")

    # Define corresponding point pairs (x, y)
    pts_src = np.float32(
        [[64, 100], [80, 217], [285, 65], [200, 232],
         [375, 82], [310, 300], [534, 140],[540, 278]])
    pts_dst = np.float32(
        [[185, 145], [230, 340], [340, 100], [350, 248],
         [430, 30], [420, 346], [500, 150], [492, 346]])

    # Visualize points [debug]
    '''
    img_src_out = img_src.copy()
    img_dst_out = img_dst.copy()
    drawPoints(img_src_out, pts_src, (255, 0, 0), (255, 0, 0))
    drawPoints(img_dst_out, pts_dst, (0, 0, 255), (0, 0, 255))
    cv2.imshow("src", img_src_out)
    cv2.imshow("dst", img_dst_out)
    '''

    # Call morphing function with src, dst images and points, and optional parameters
    num_frames = 31
    morph(img_src, img_dst, pts_src, pts_dst, num_frames, save_video=True, show_points=False,
show_triangles=False)
```

Summary

* More details about Image Warping
* Basics of Forward and Inverse Warping
* How to warp an image using a mesh
* Image Morphing
* Feature-based Image Morphing

Further Reading



* Beier and Neely (1992) "Feature-based Image Metamorphosis" ACM SIGGRAPH 1992

* Szeliski (2010) Chapter 3

Credits

* For more information, see:
  * Richard Szeliski (2010) Computer Vision: Algorithms and Applications, Springer (Chapter 3)
* Some concepts in slides motivated by similar slides by James Hays Alyosha Efros and Greg Turk
* Additional list will be available on website

Computational Photography

* Study the basics of computation and its impact on the entire workflow of photography, from capturing, manipulating and collaborating on, and sharing photographs.

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