# Texture Synthesis and Manipulation
Final Report

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EN 256: Computer Vision

18 December 2006

# Outline

- *Brief Review and Introduction to Inpainting*
- Exemplar-based Image Inpainting
- Image Editing Results
- Conclusions and Future Work

# Texture Synthesis Review

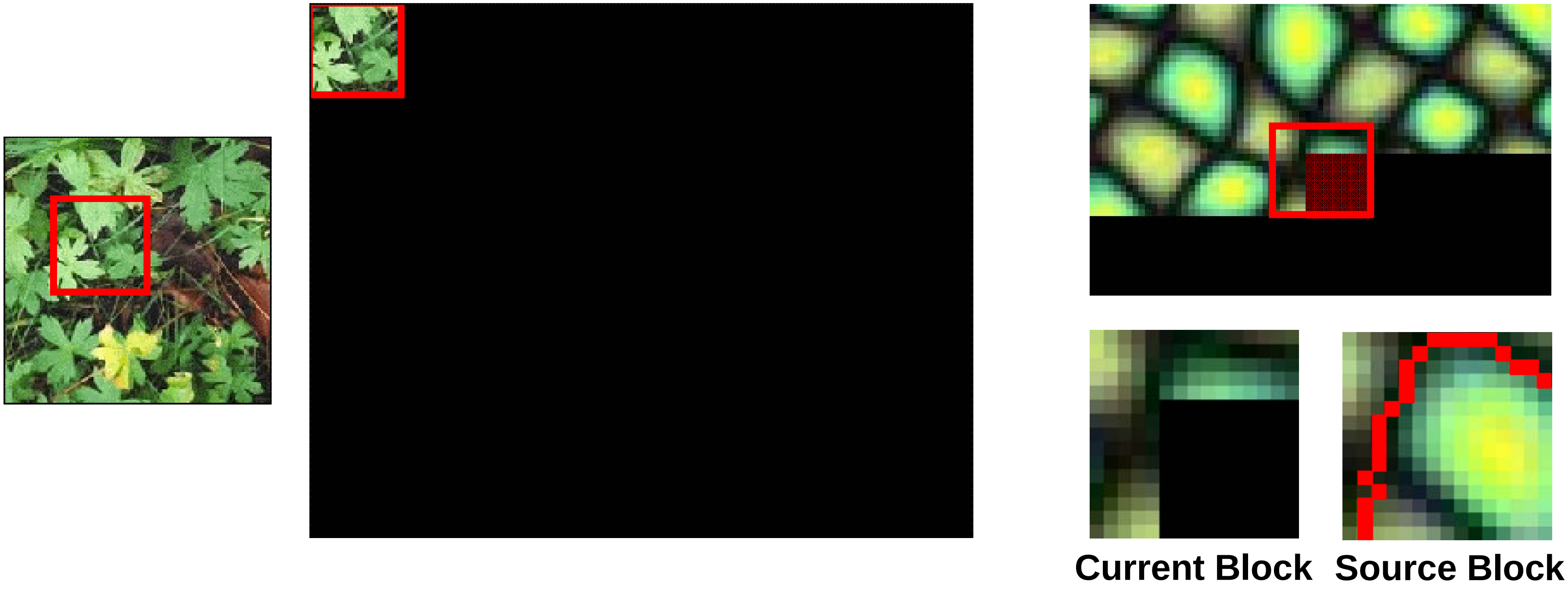


**Image Quilting Texture Synthesis [Efros and Freeman '01]**

- Starting from an initial patch, search the input texture for similar neighborhoods and assign next patch randomly from this set
- Define similarity using $L_2$-norm applied to every pixel/color in block
- Optimize overlap region using minimum error boundary cut
- Synthesize in raster scan order until complete

# Applications of Texture Synthesis

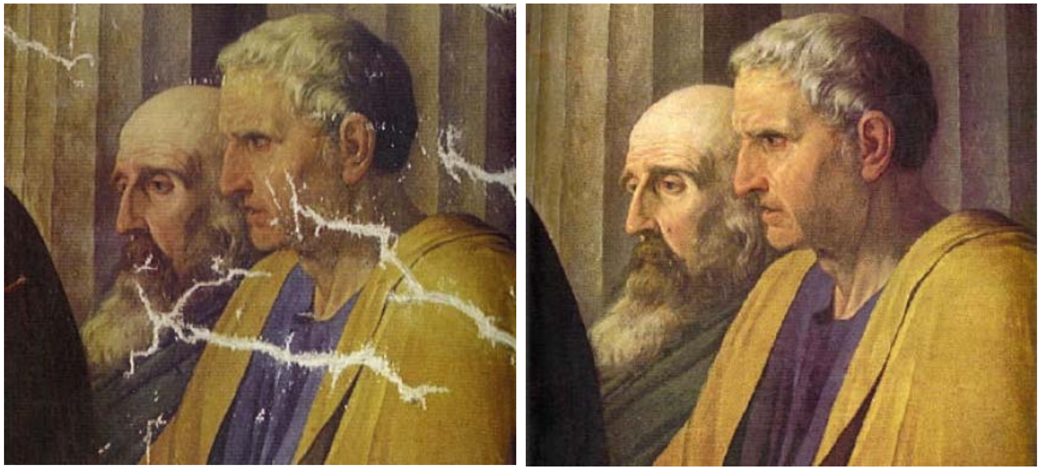
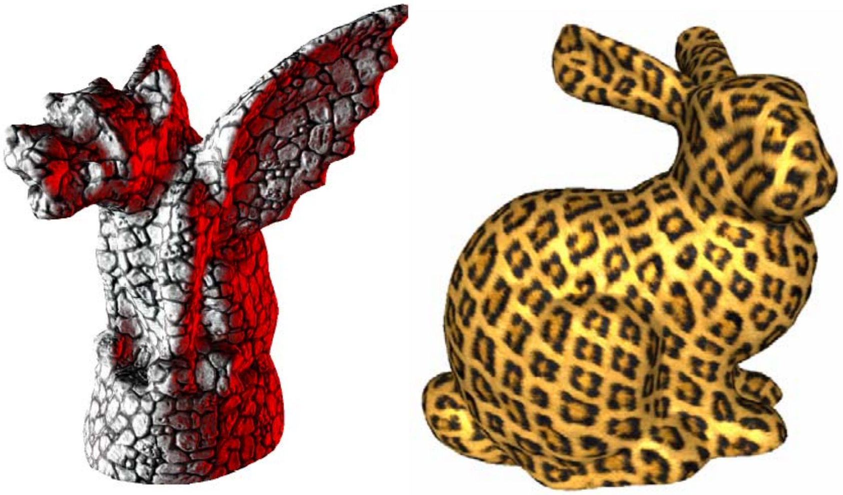
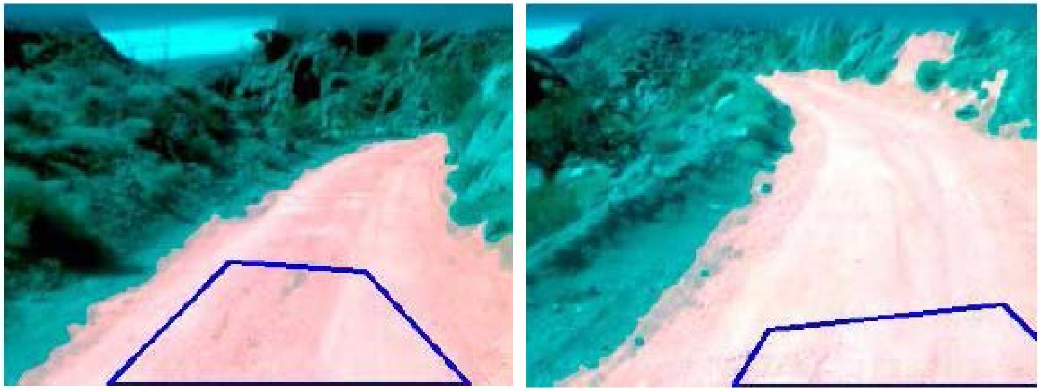


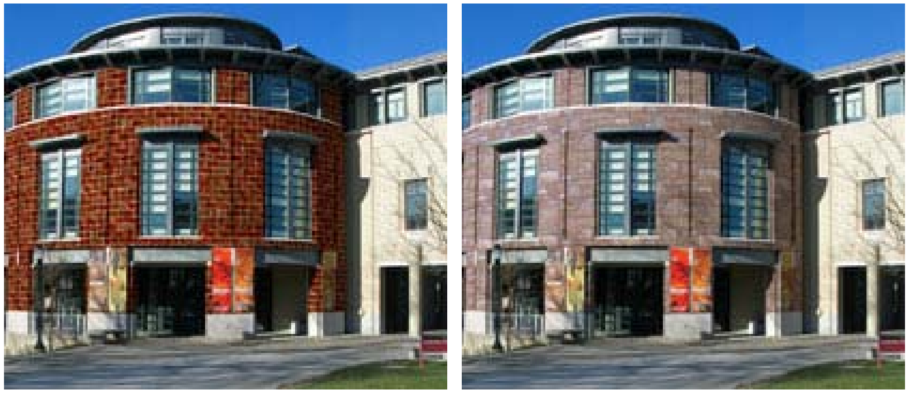
Image Inpainting (e.g., scratch removal)



Non-periodic Texture Mapping



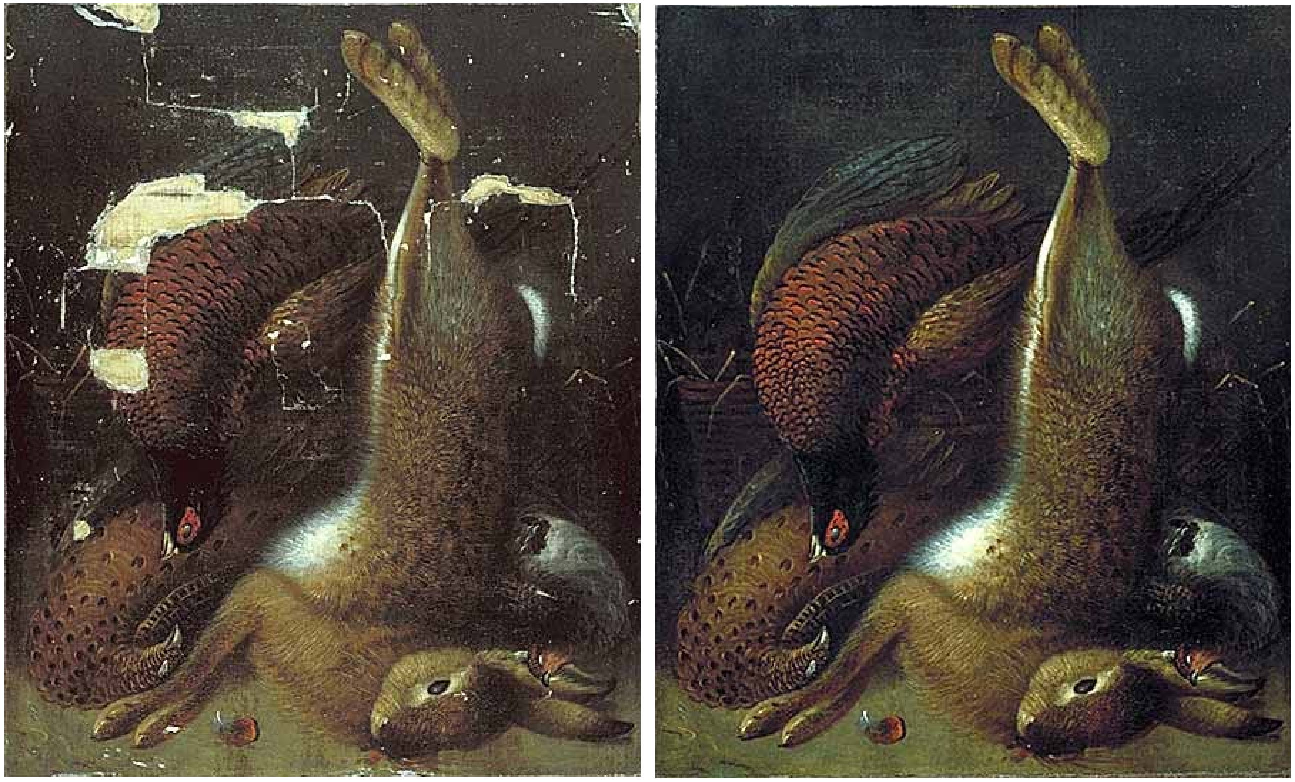
Texture Analysis and Classification



Texture Modification

References: [3,4,9]

# Overview of Image Inpainting



Professional Restoration

Image Inpainting

**Image Inpainting [Bertalmío *et al.* SIGGRAPH '00]**

- Attempt to follow professional inpainting procedures
- Basic idea is to smoothly propagate information along isophotes
- Only successfully fills thin regions (e.g., scratches and small gaps)

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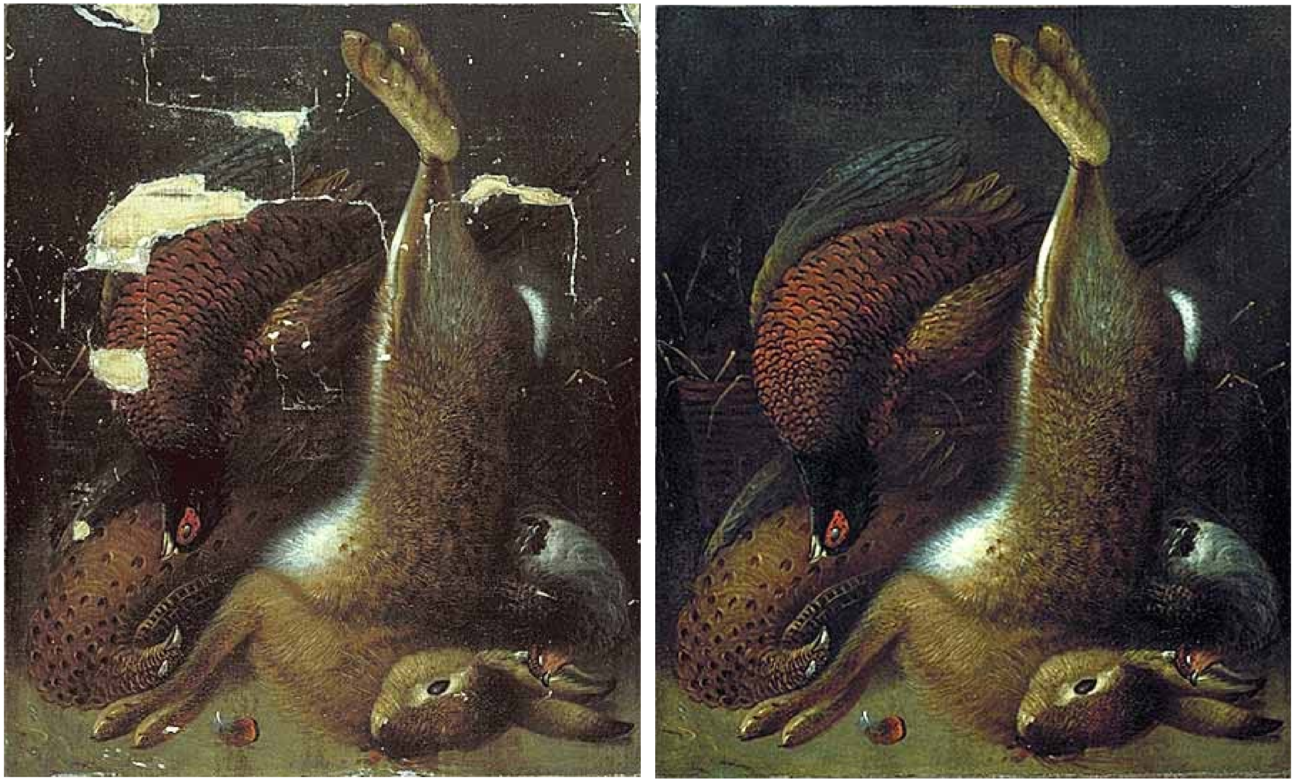

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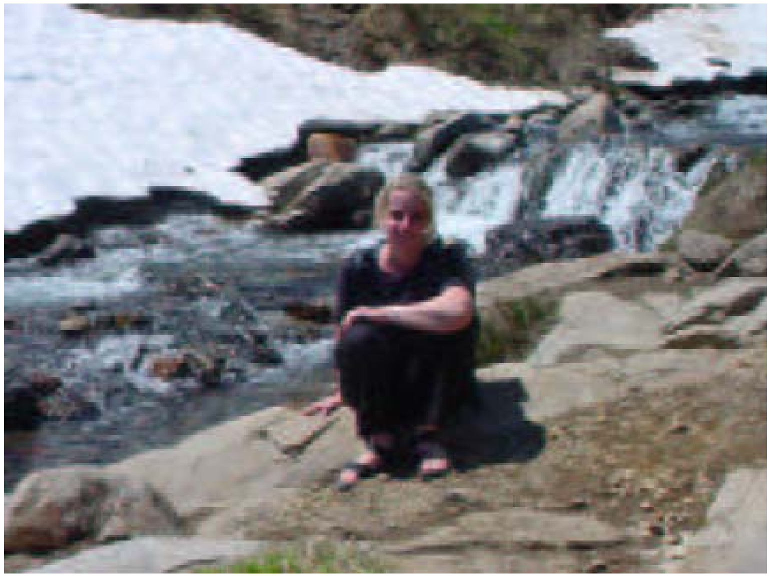
References: [11,12]

# Image Inpainting using Texture Synthesis



Exemplar-based Image Inpainting

Fragment-based Image Completion

## Fragment-based Completion [Drori *et al.* SIGGRAPH '03]

- Attempts to synthesis missing regions from coarse-to-fine scale
- Assign fragments (i.e., circular regions) with higher confidence

## Exemplar-based Inpainting [Criminisi *et al.* CVPR 2003]

- Combines patch-based texture synthesis with Bertalmío's inpainting

References: [14,16]

# Image Inpainting using Texture Synthesis

Exemplar-based Image Inpainting

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- *Exemplar-based Image Inpainting*
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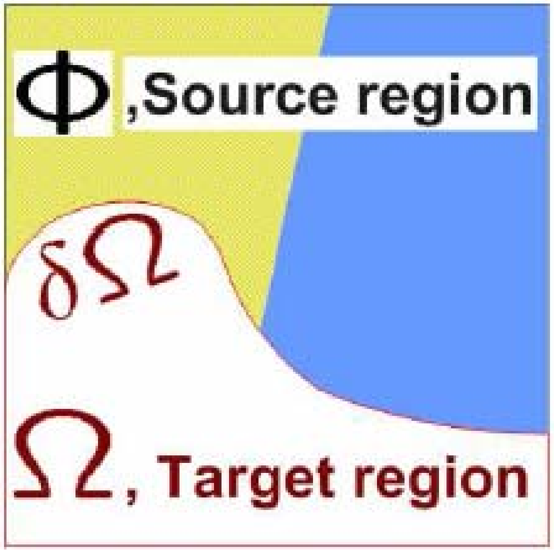
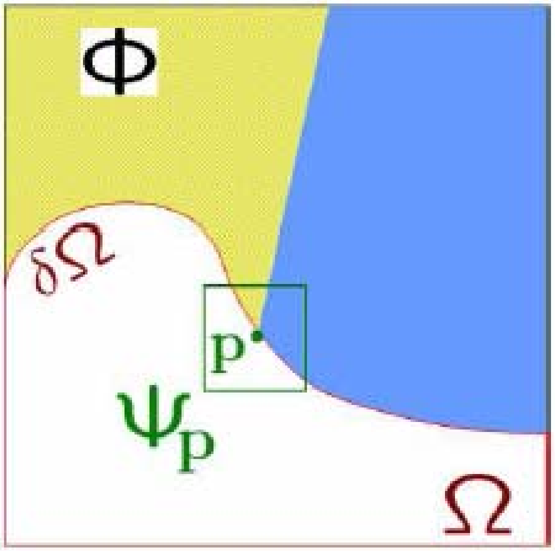
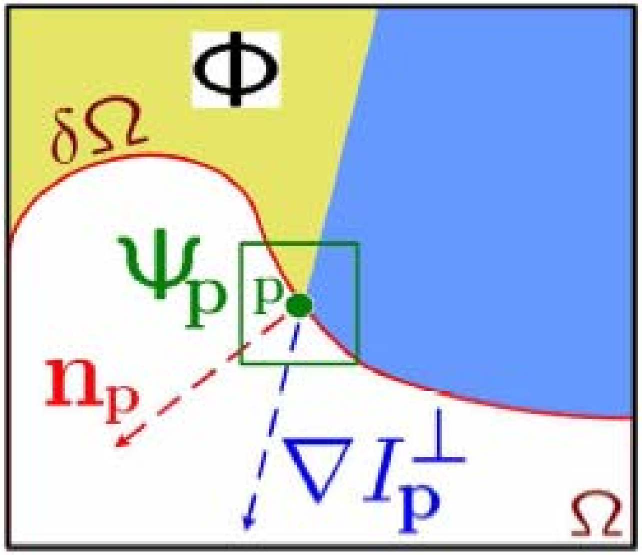
# Overview of Exemplar-based Inpainting



Inpainting Notation



Synthesis Procedure



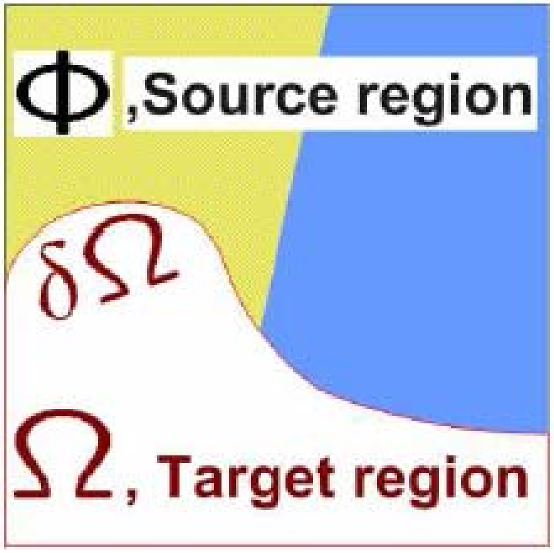
Extended Notation

**Exemplar-based Image Inpainting [Criminisi *et al.* 2003]**

- Observed that patch-based synthesis is effective if order is optimized
- Select next patch based on completed area and isophote strength

$$P(\mathbf{p}) = C(\mathbf{p})D(\mathbf{p}) \qquad C(\mathbf{p}) = \frac{\sum_{\mathbf{q}\in\Psi_{\mathbf{p}}\cap(\mathcal{I}-\Omega)} C(\mathbf{q})}{|\Psi_{\mathbf{p}}|} \quad D(\mathbf{p}) = \frac{|\nabla I_{\mathbf{p}}^{\perp}\cdot\mathbf{n}_{\mathbf{p}}|}{\alpha}$$

# Overview of Exemplar-based Inpainting



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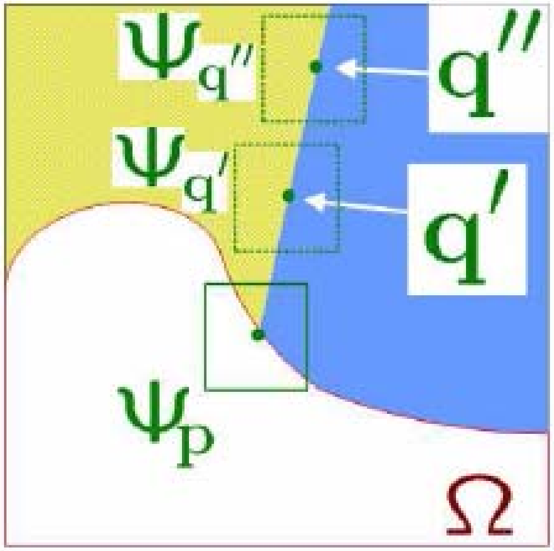

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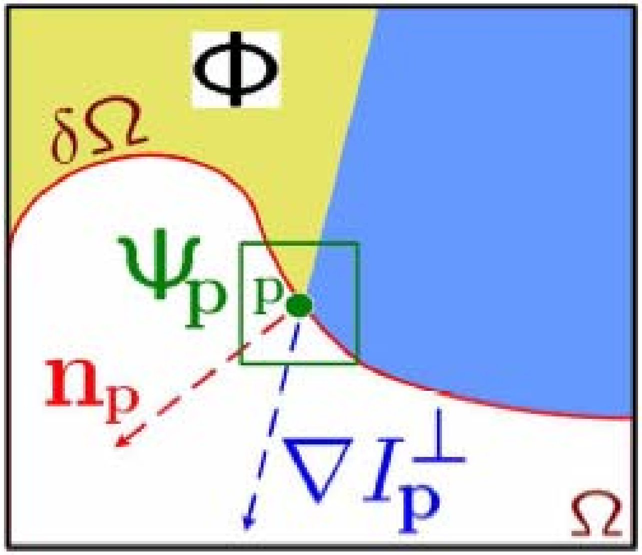

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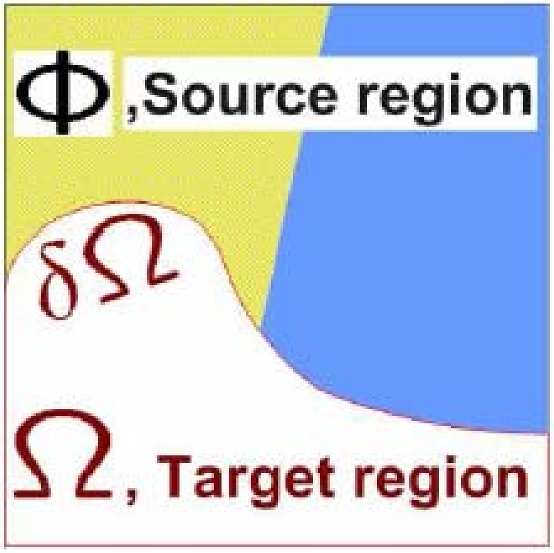
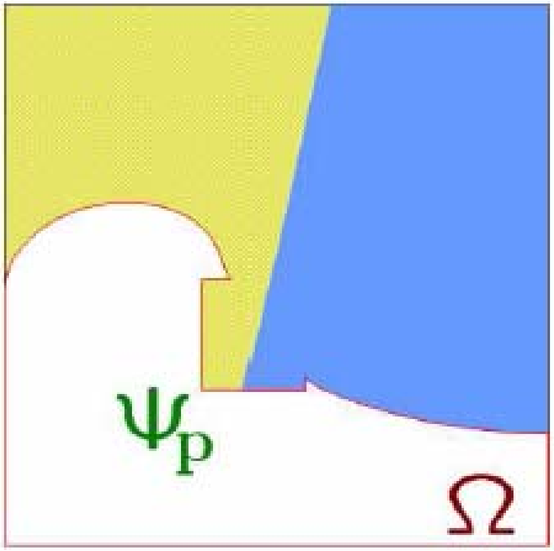
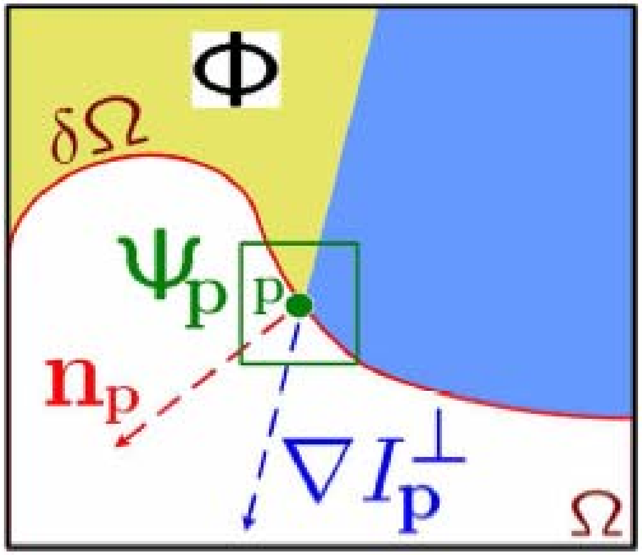


Inpainting Notation



Synthesis Procedure



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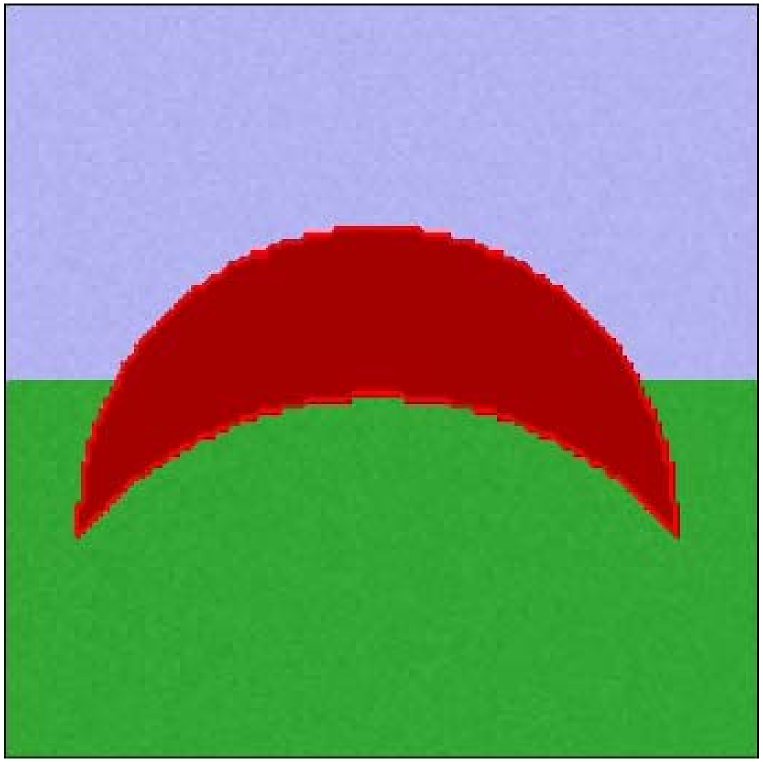
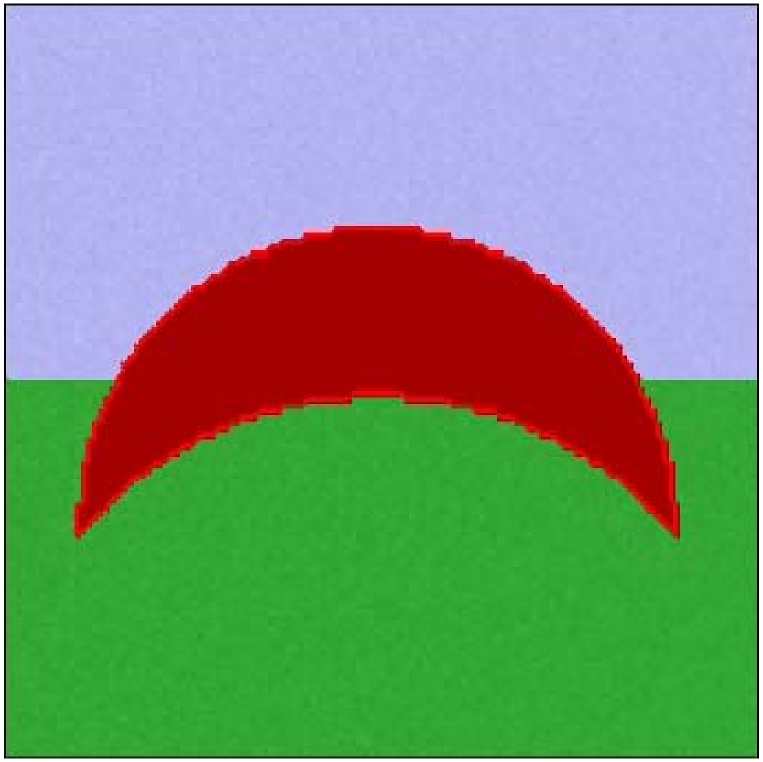
References: [16]

# The Importance of the Filling Order



"Onion Peel" Order

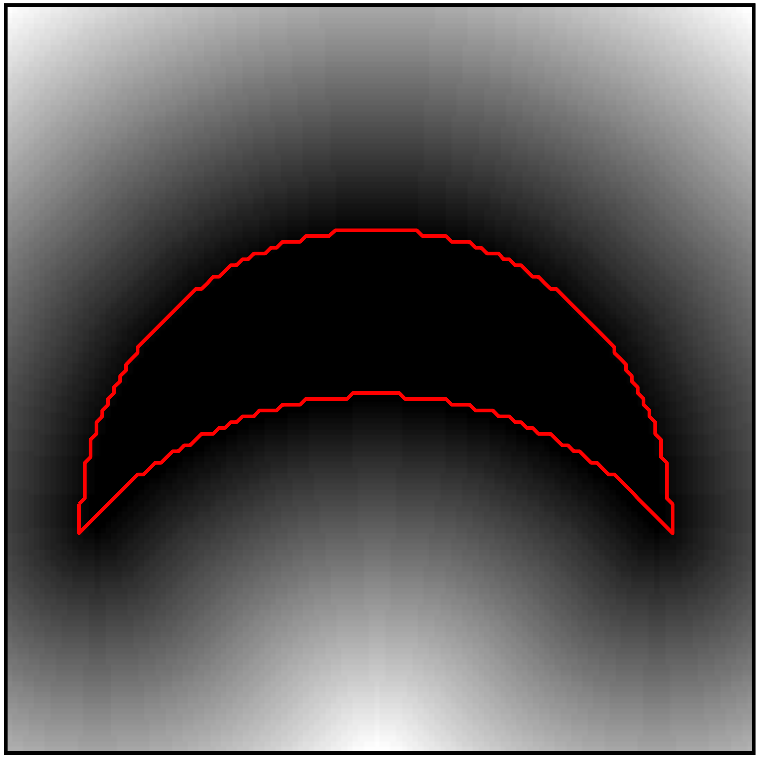


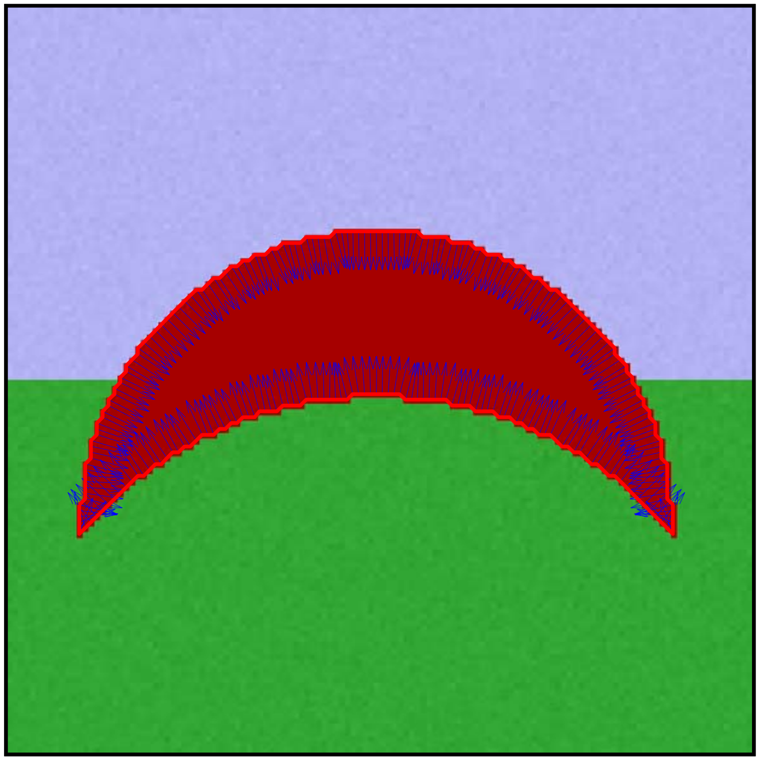
Exemplar-based Inpainting

- Naïve inpainting solutions use the "onion peel" order
- Criminisi *et al.* observed that greedy priority-based selection is better
- Requires balancing the isophote vs. confidence driving terms

References: [16]

# Estimating Inpainting Boundary Normals

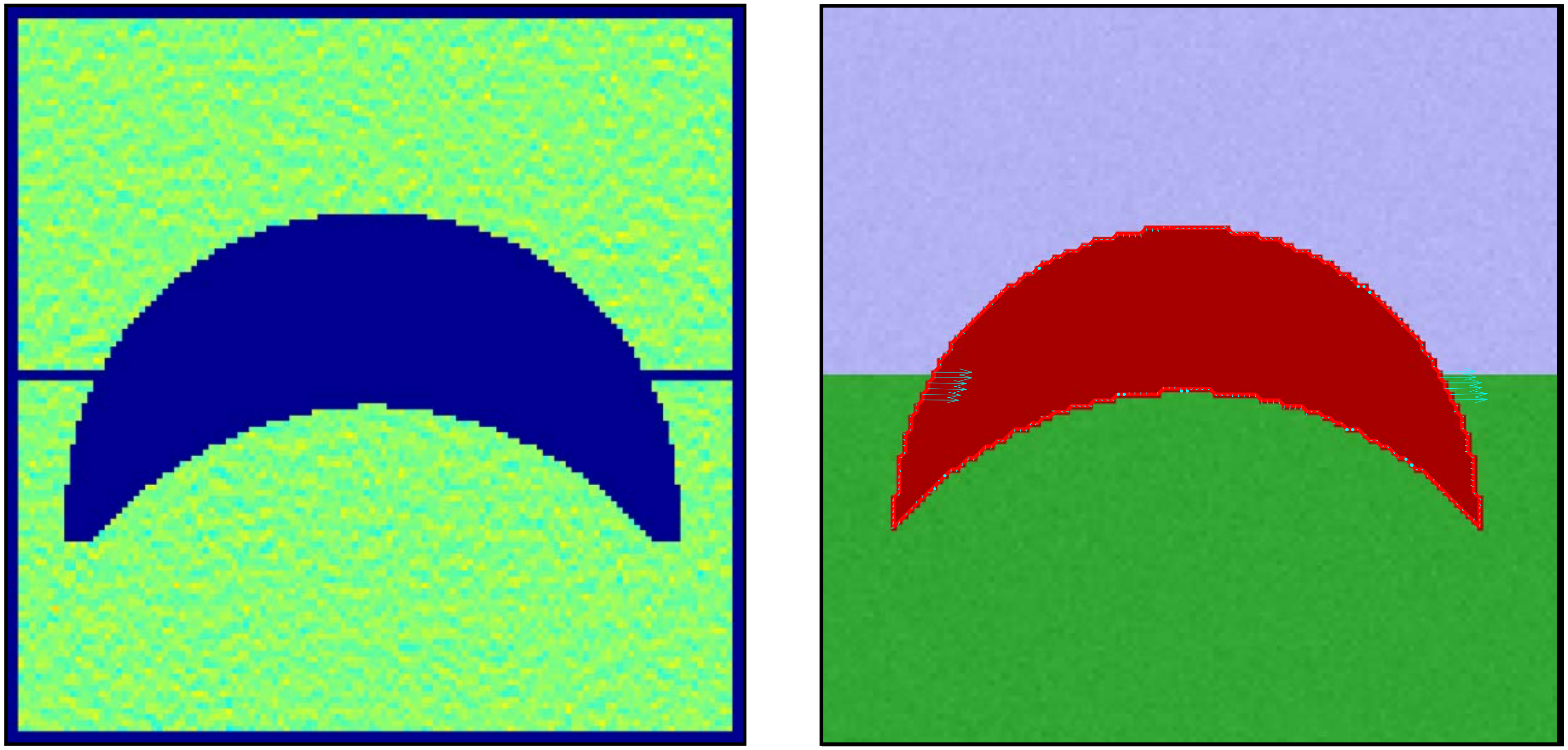




## Boundary Normal Estimation Procedure

- Evaluate the distance transform of the current inpainting mask
- Assign boundary normals using gradient of the distance transform
- Use robust gradient operator for improved results
- Repeat procedure for each iteration

# Determining Image Isophotes

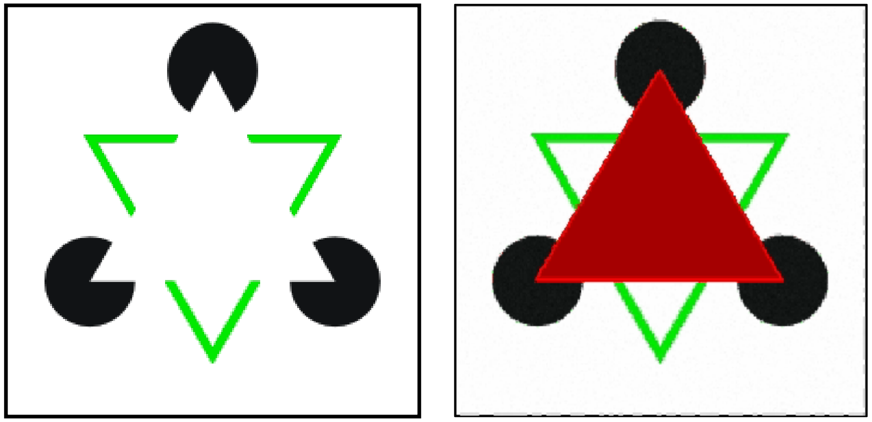


## Isophote Estimation Procedure

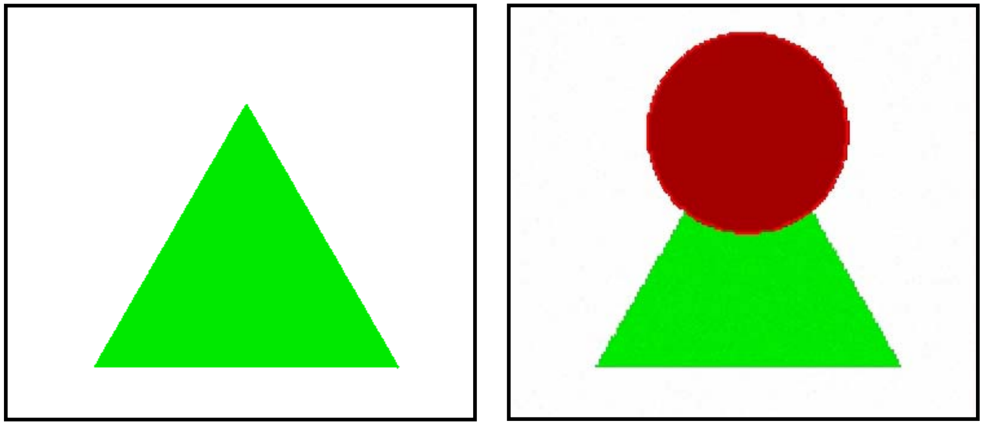
- Evaluate the image gradients (using robust operators)
- Select largest gradient within the candidate patch
- Assign isophote using vector orthogonal to largest gradient
- Repeat procedure for each iteration

References: [16]

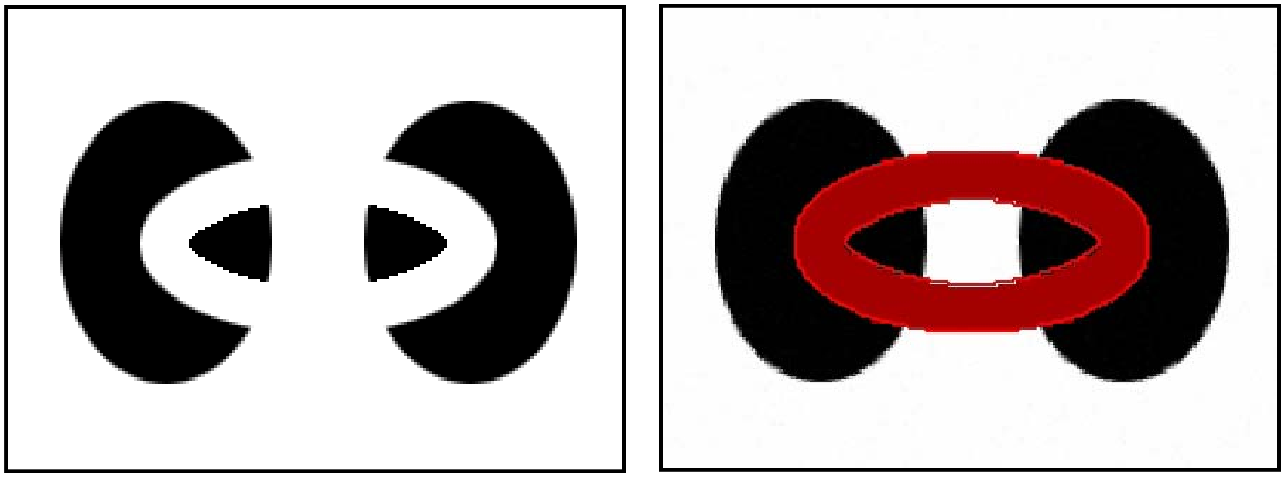
# Illustrative Examples



Connectivity Principle



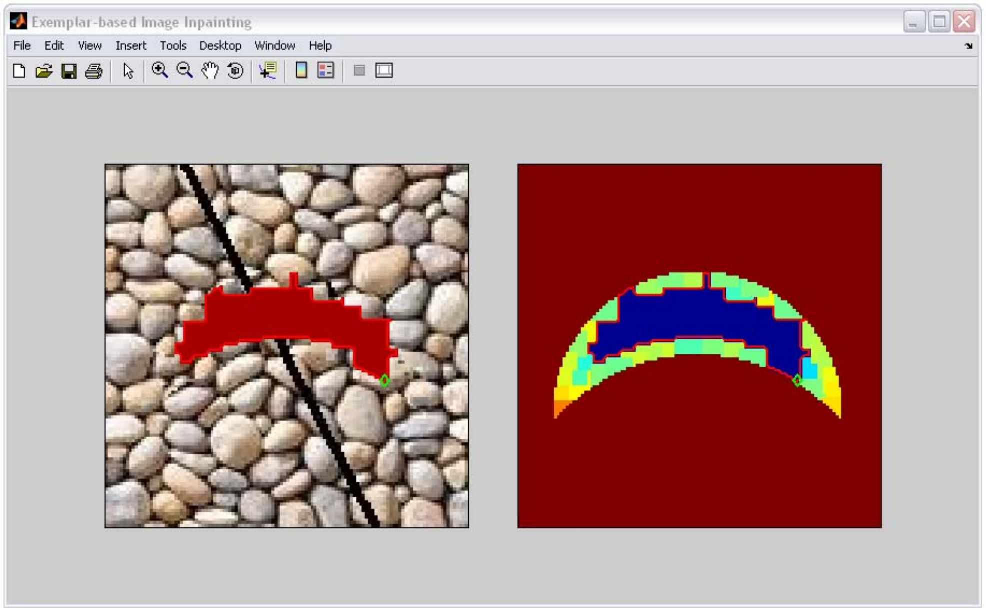
“Overshooting” Artifacts

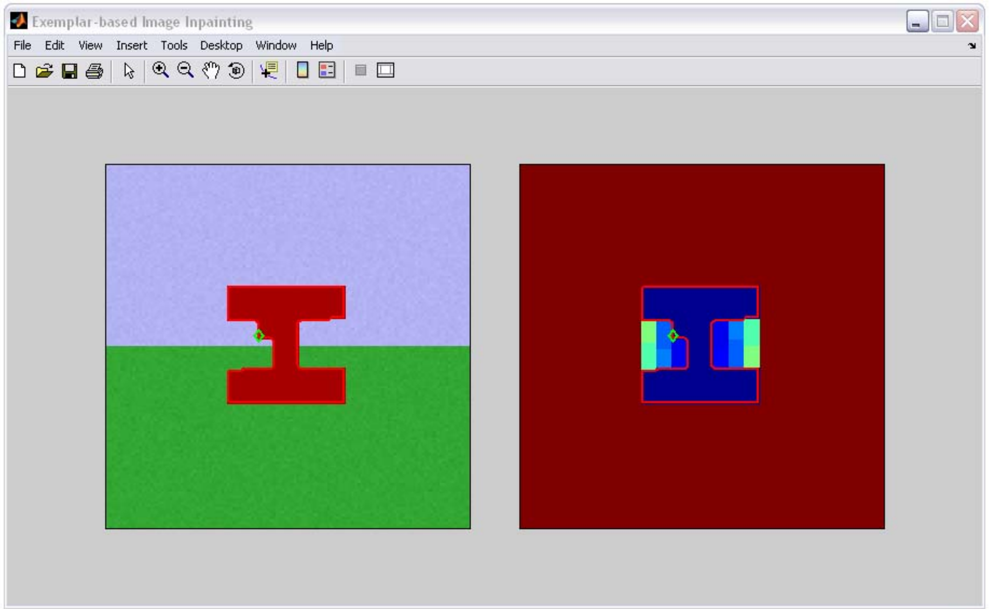


Structure Completion

References: [16]

# MATLAB Demo


Exemplar-based Image Inpainting
File Edit View Insert Tools Desktop Window Help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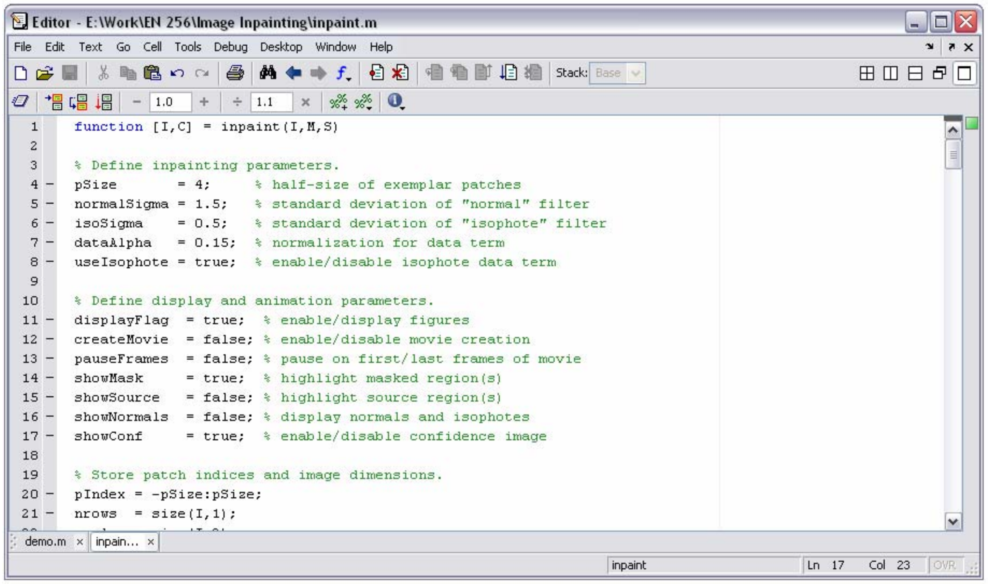
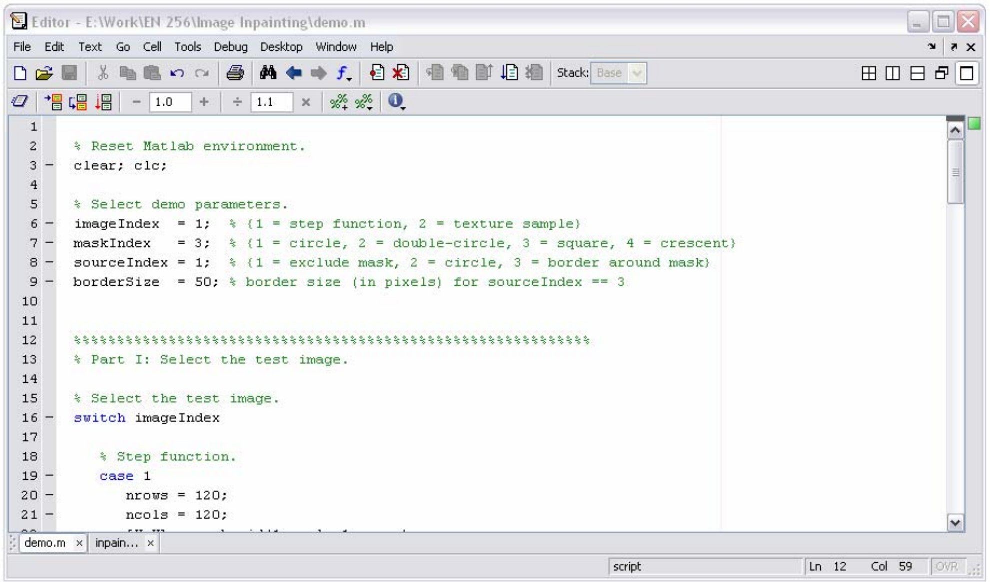

Editor - E:\Work\EN 256\Image Inpainting\inpaint.m

```
function [I,C] = inpaint(I,M,S)

% Define inpainting parameters.
pSize       = 4;     % half-size of exemplar patches
normalSigma = 1.5;   % standard deviation of "normal" filter
isoSigma    = 0.5;   % standard deviation of "isophote" filter
dataAlpha   = 0.15;  % normalization for data term
useIsophote = true;  % enable/disable isophote data term

% Define display and animation parameters.
displayFlag  = true;  % enable/display figures
createMovie  = false; % enable/disable movie creation
pauseFrames  = false; % pause on first/last frames of movie
showMask     = true;  % highlight masked region(s)
showSource   = false; % highlight source region(s)
showNormals  = false; % display normals and isophotes
showConf     = true;  % enable/disable confidence image

% Store patch indices and image dimensions.
pIndex = -pSize:pSize;
nrows  = size(I,1);
```


Editor - E:\Work\EN 256\Image Inpainting\demo.m

```

% Reset Matlab environment.
clear; clc;

% Select demo parameters.
imageIndex  = 1;  % {1 = step function, 2 = texture sample}
maskIndex   = 3;  % {1 = circle, 2 = double-circle, 3 = square, 4 = crescent}
sourceIndex = 1;  % {1 = exclude mask, 2 = circle, 3 = border around mask}
borderSize  = 50; % border size (in pixels) for sourceIndex == 3


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Part I: Select the test image.

% Select the test image.
switch imageIndex

   % Step function.
   case 1
      nrows = 120;
      ncols = 120;
```

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- Brief Review and Introduction to Inpainting
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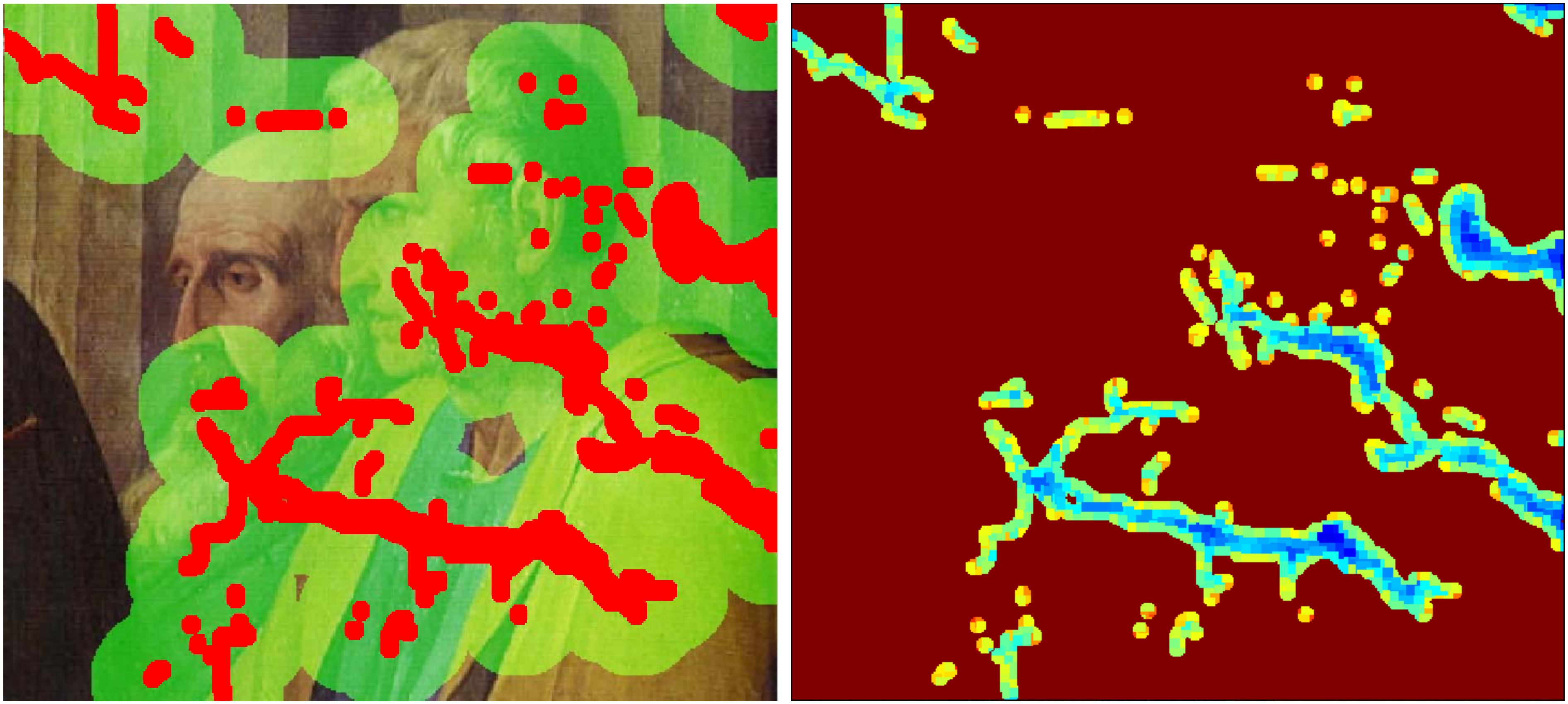
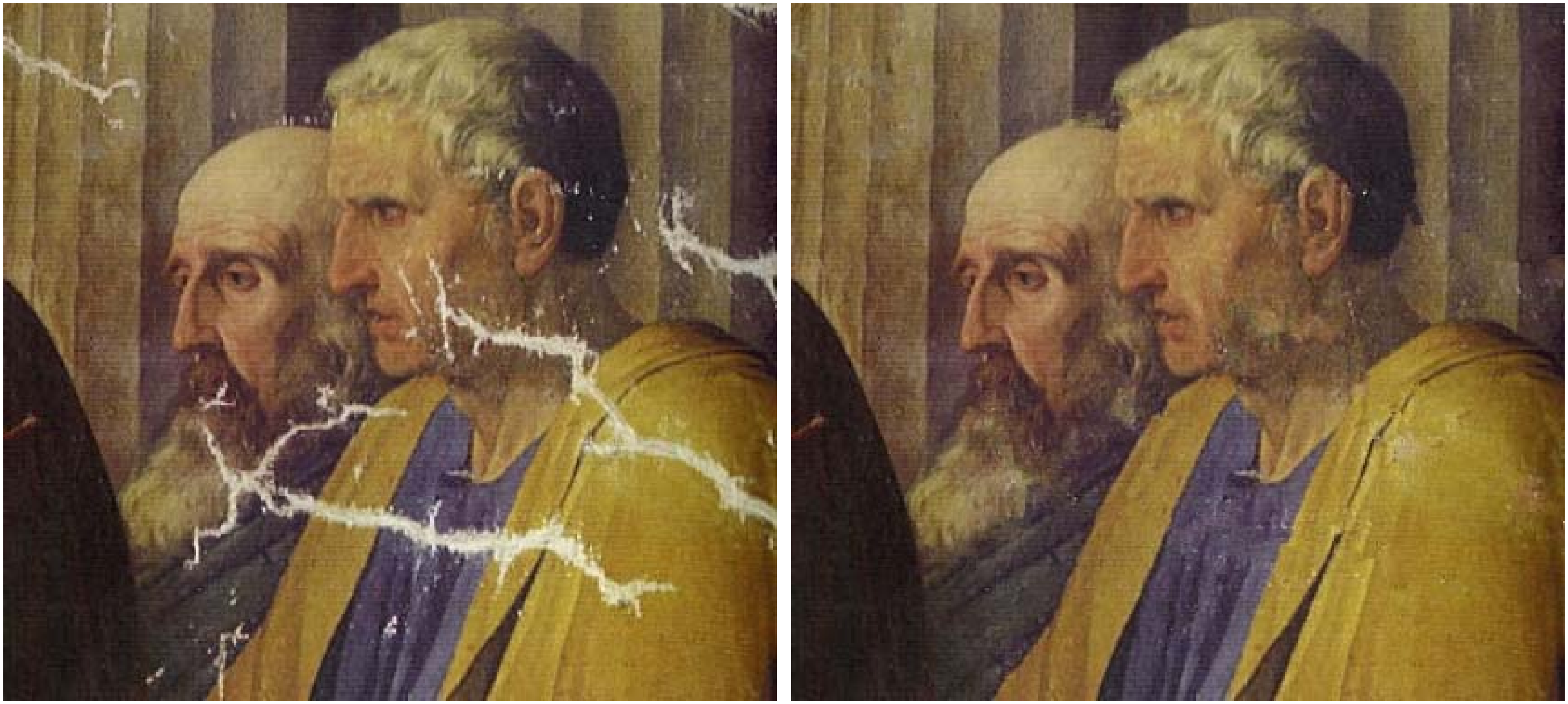
# Removing Scratches and Small Artifacts



### Exemplar-based Inpainting Parameters

- 9x9 block size (red: user-defined mask, green: source region)
- Source blocks located within 30 pixels of user-defined mask

# Removing Scratches and Small Artifacts



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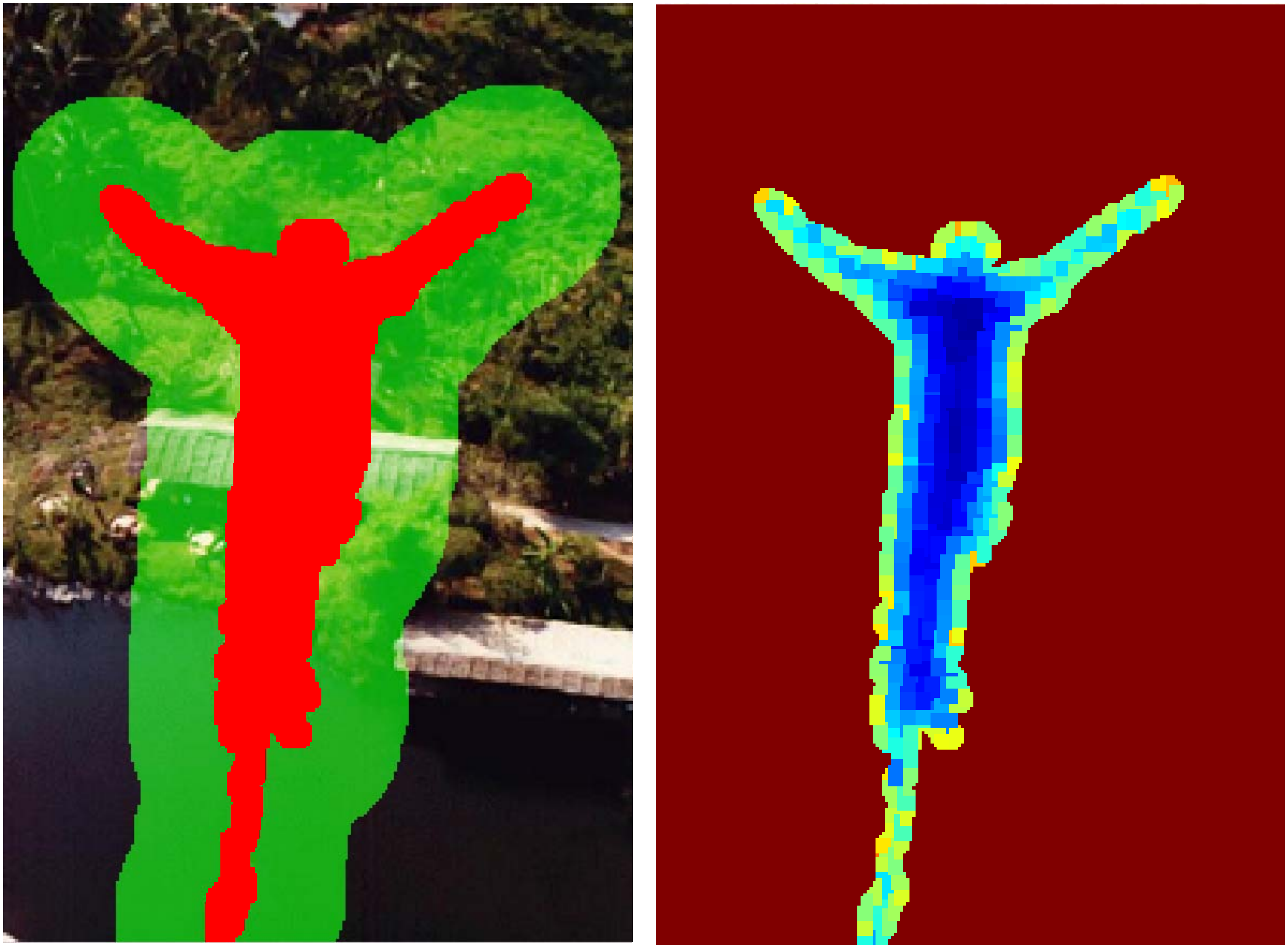
# Removing Objects and Filling Large Regions



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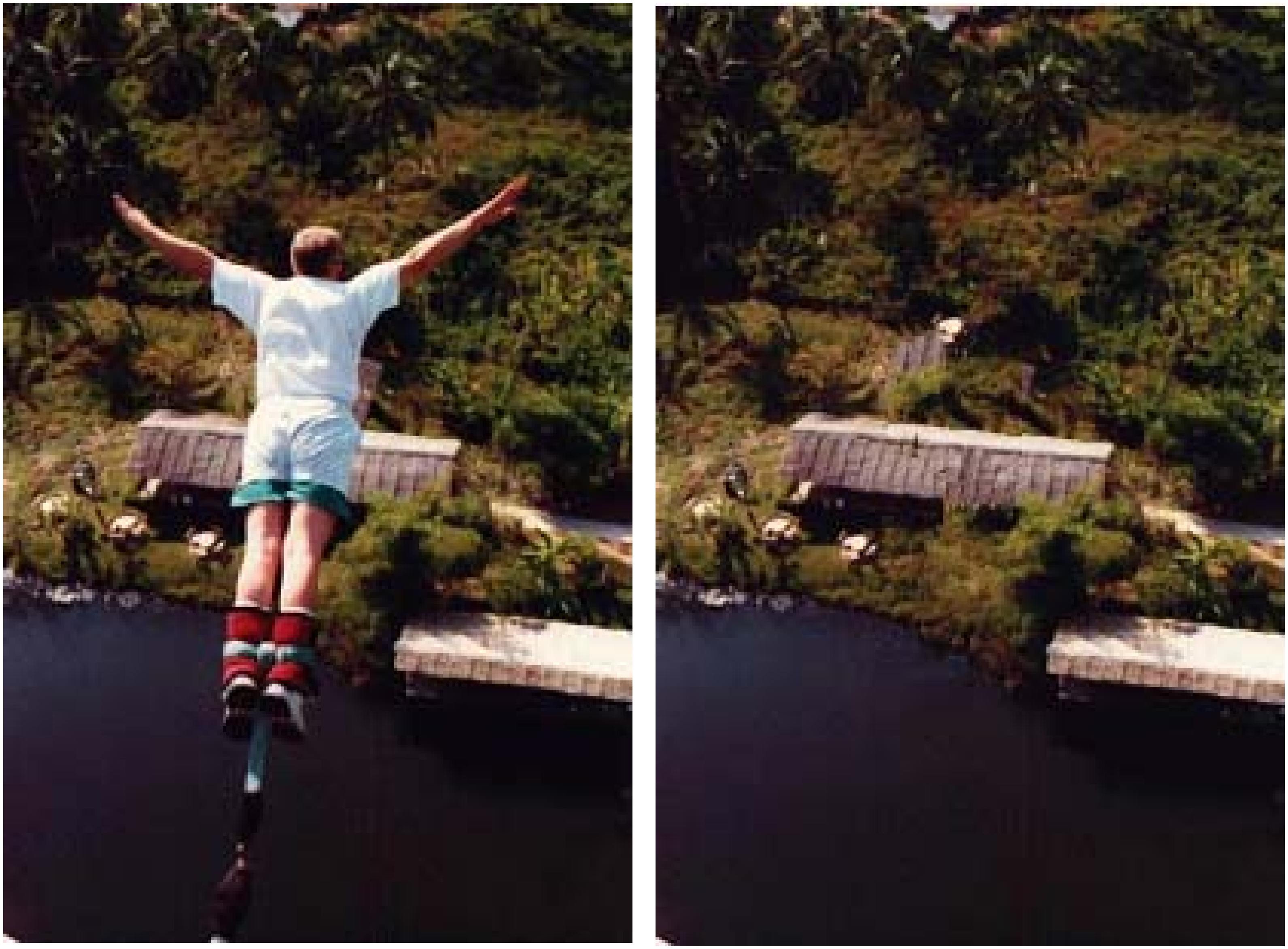

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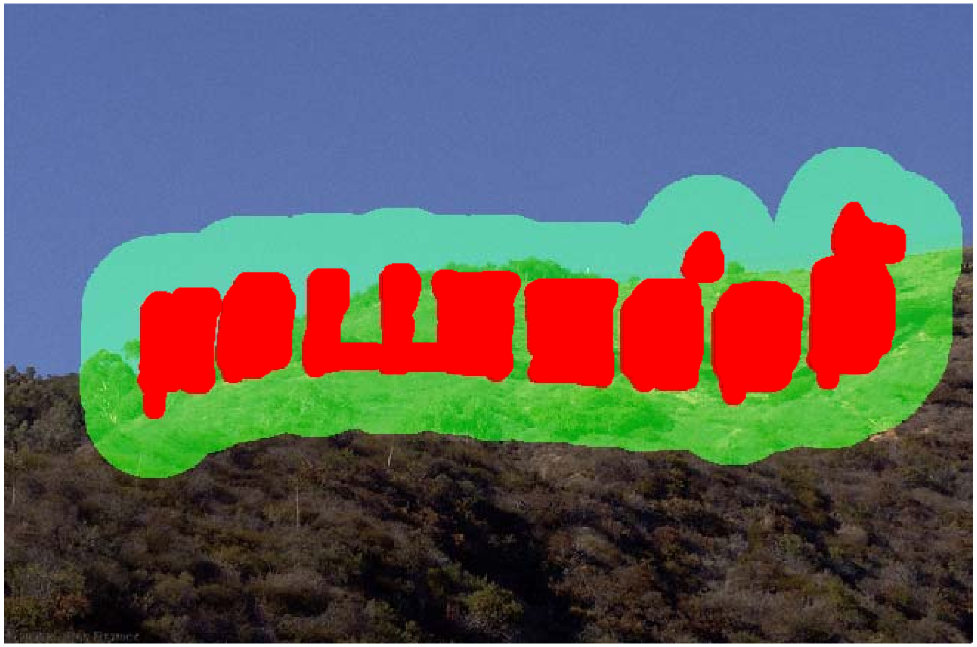
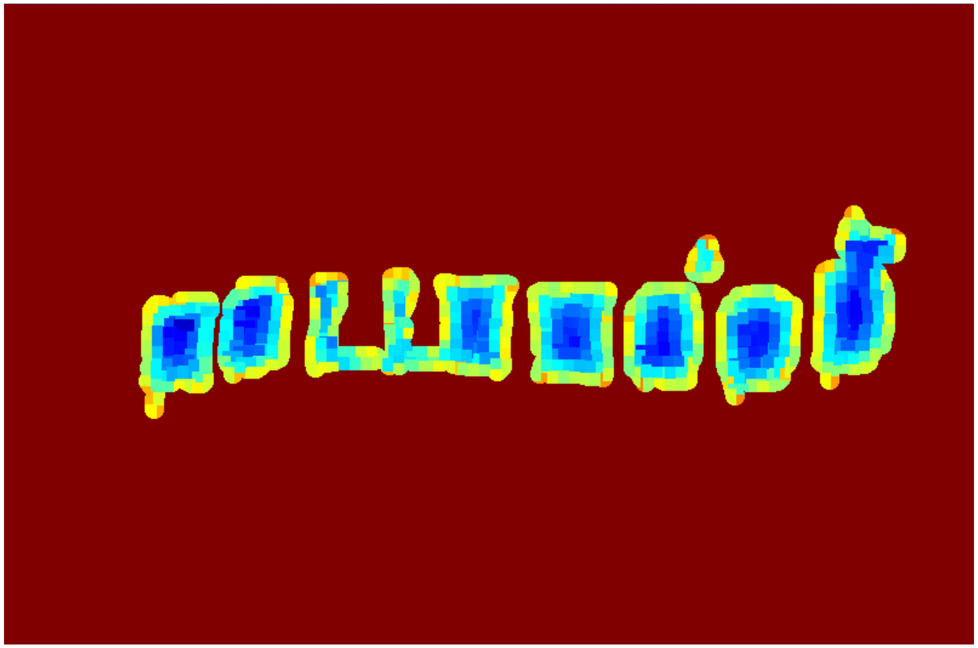


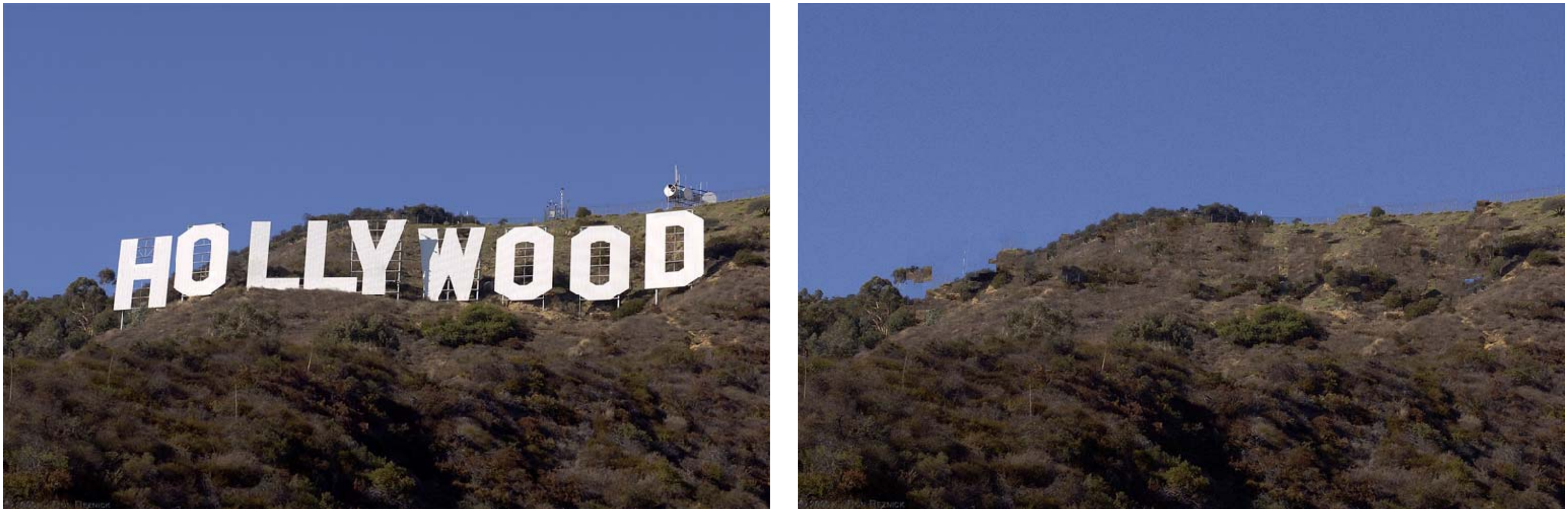


### Exemplar-based Inpainting Parameters

- 17x17 block size (red: user-defined mask, green: source region)
- Source blocks located within 50 pixels of user-defined mask

References: [14]

# Removing Objects and Filling Large Regions



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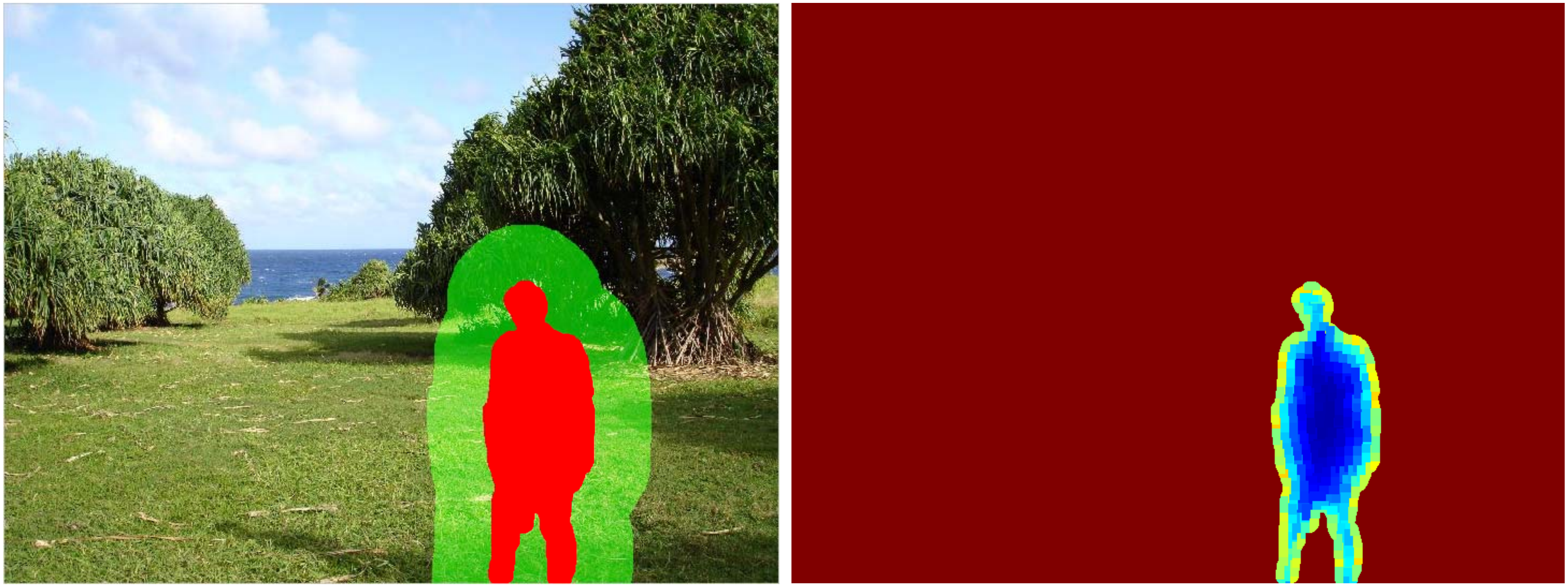
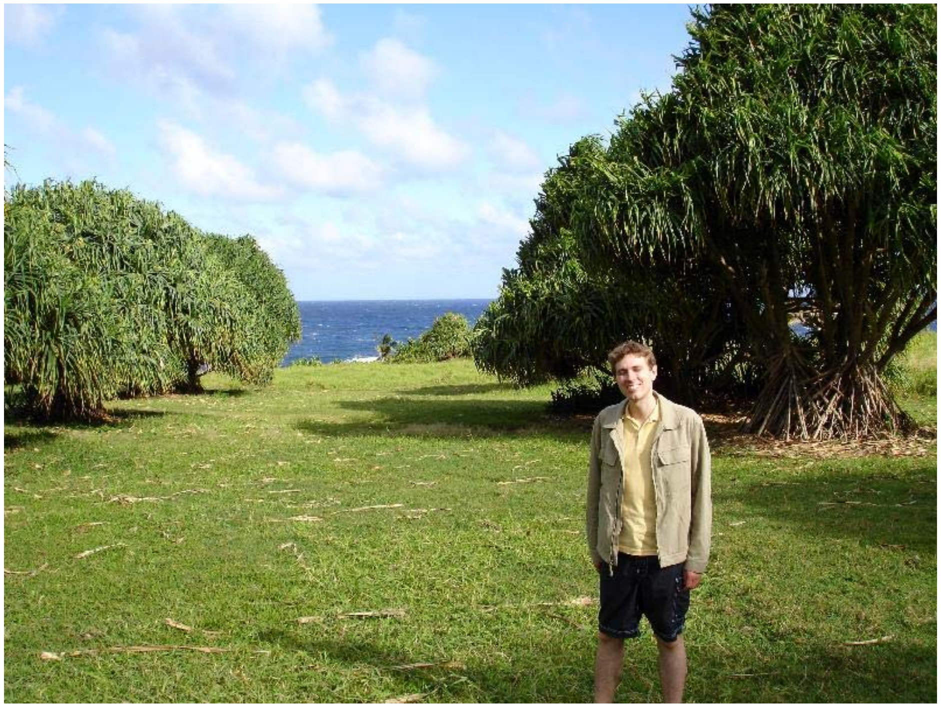
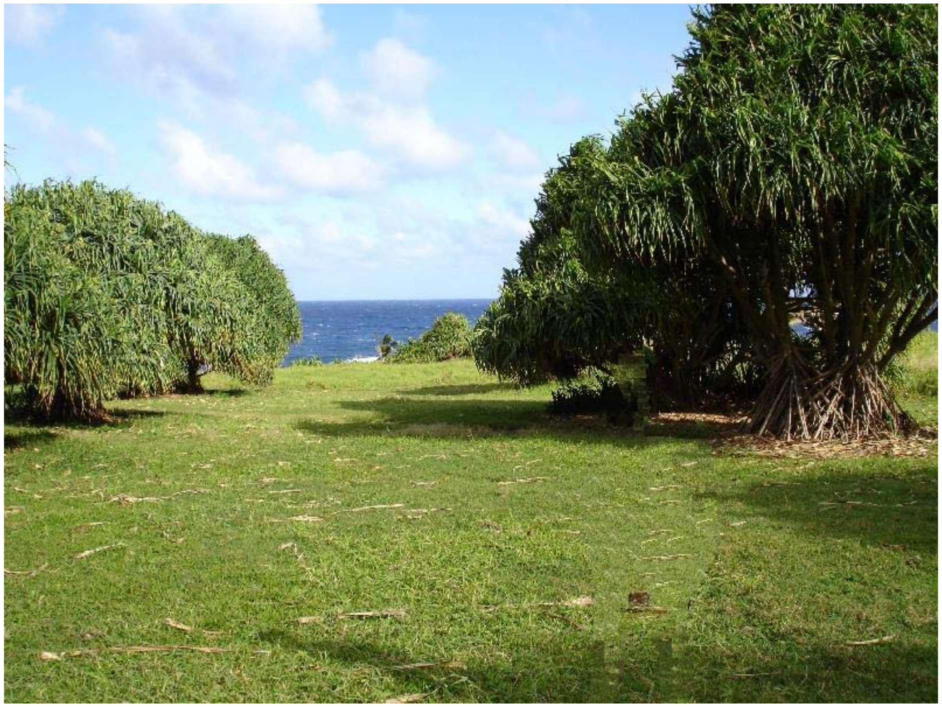


## Exemplar-based Inpainting Parameters

- 17x17 block size (red: user-defined mask, green: source region)
- Source blocks located within 60 pixels of user-defined mask

# Removing Objects and Filling Large Regions





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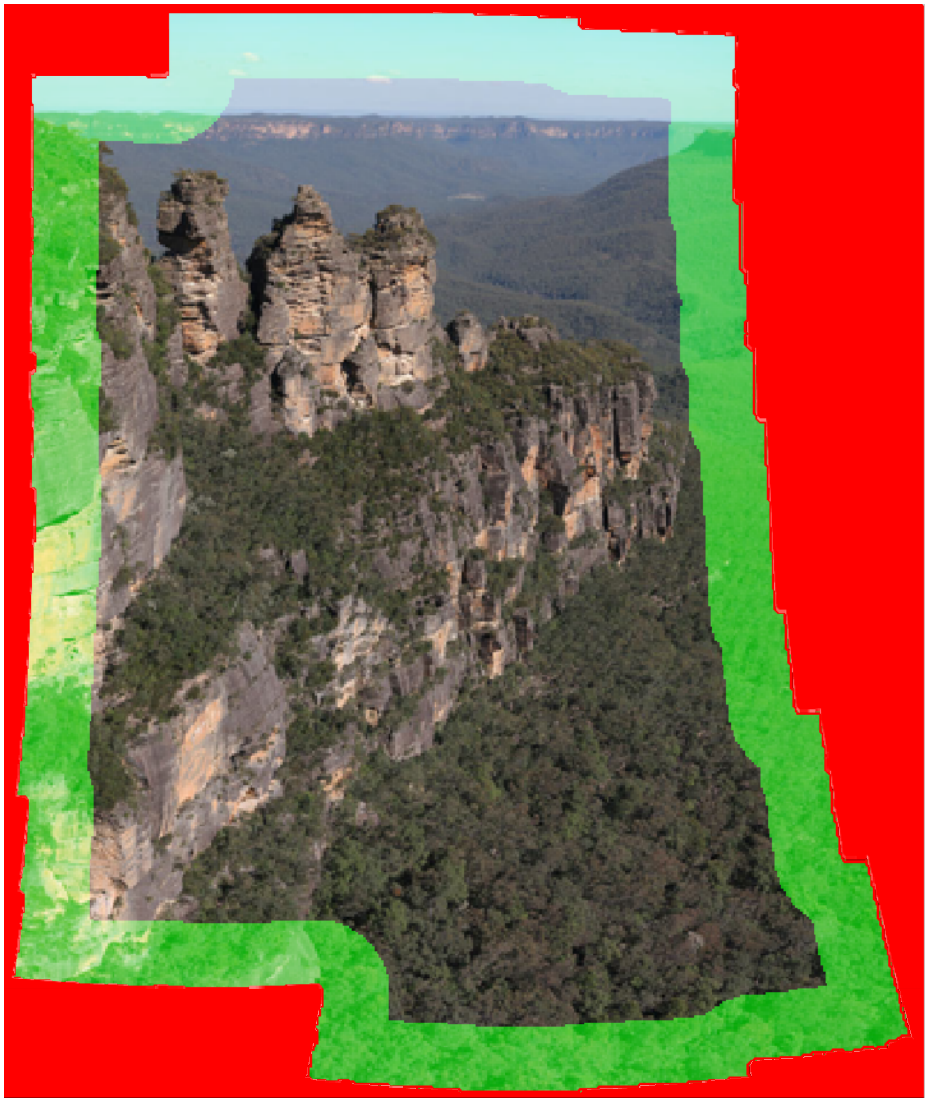
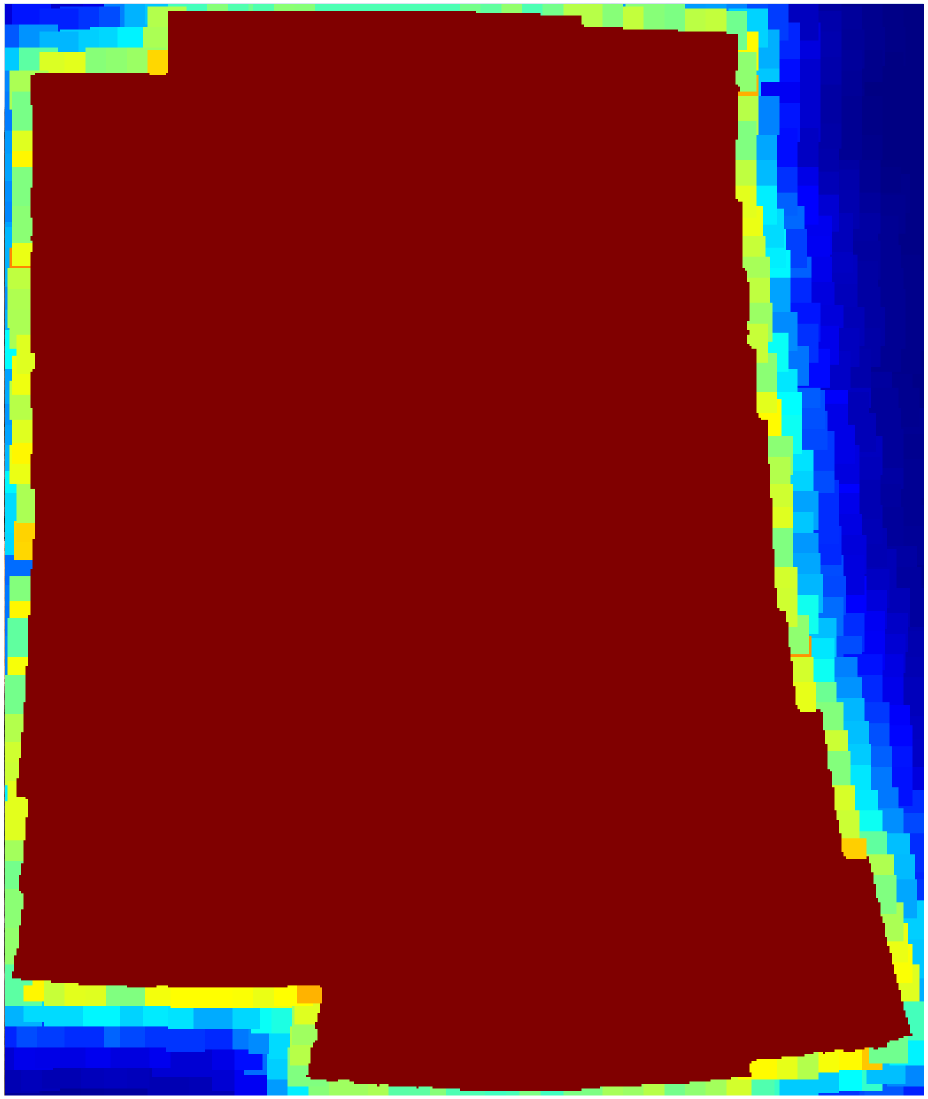
# Completing Image Mosaics





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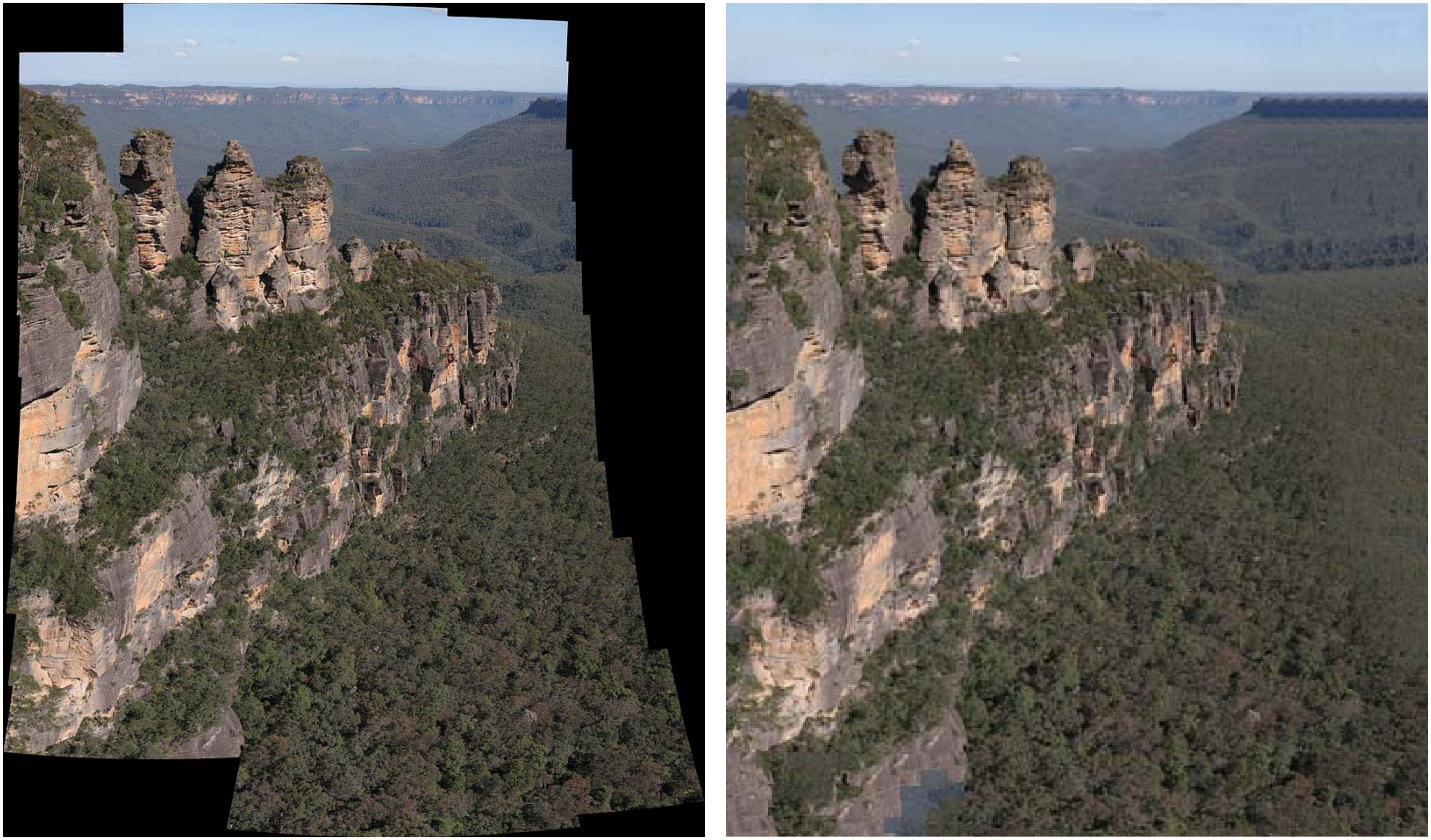
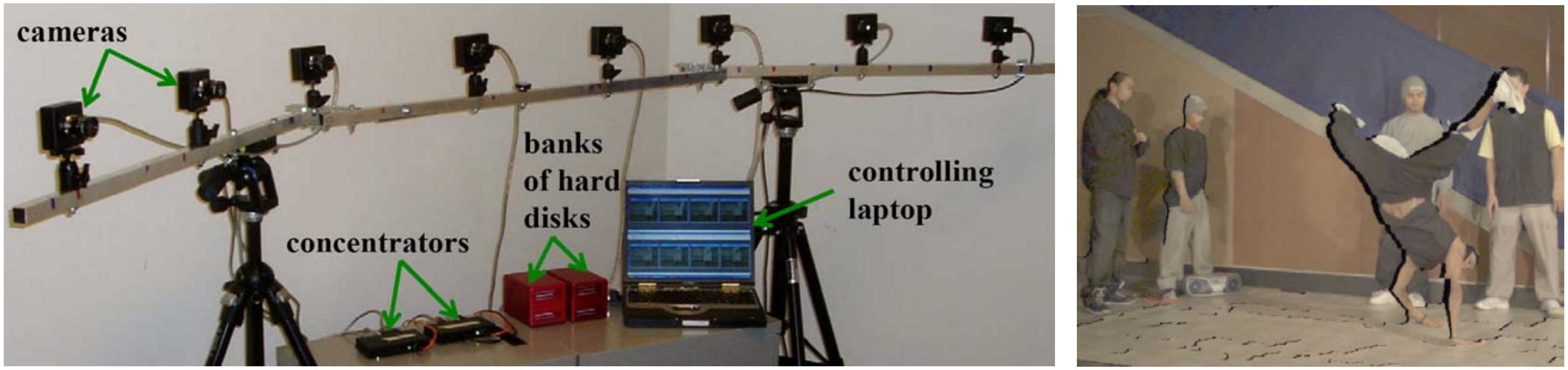


# Filling Occlusions Due to Image Manipulation

Motion Magnification [Liu *et al.*, SIGGRAPH '05]



Video View Interpolation [Zitnick *et al.*, SIGGRAPH '04]

References: [20,21]

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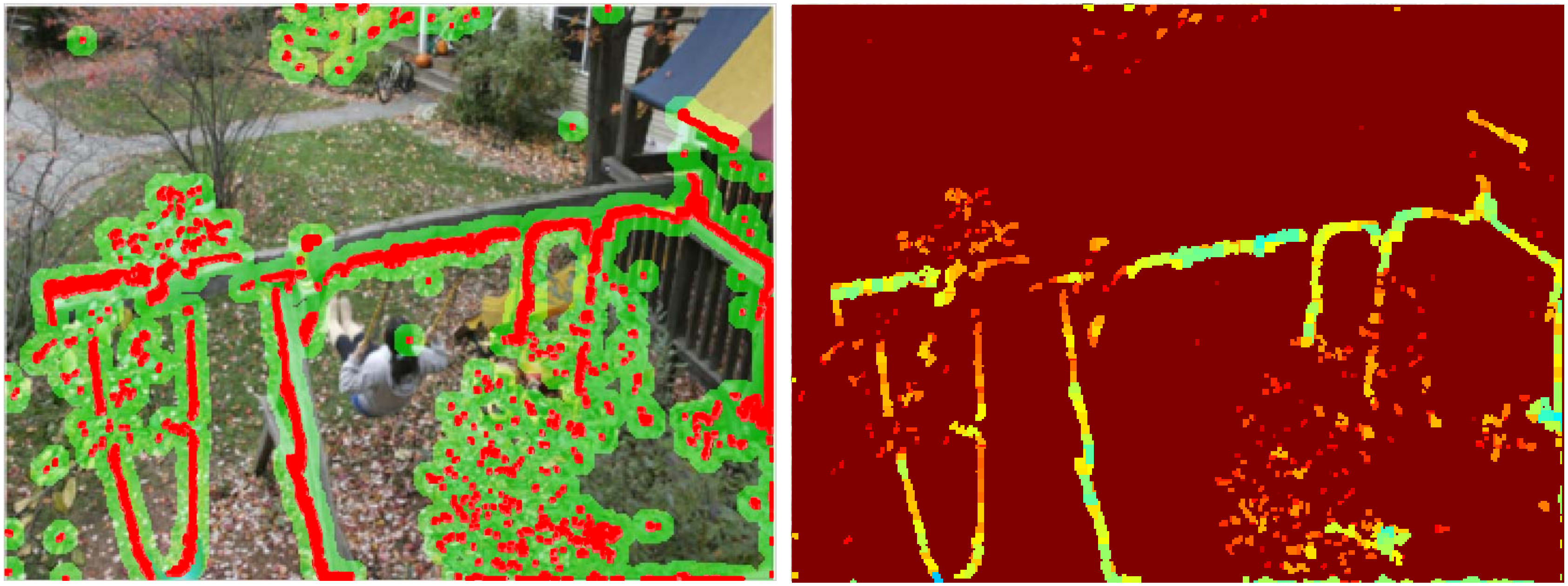

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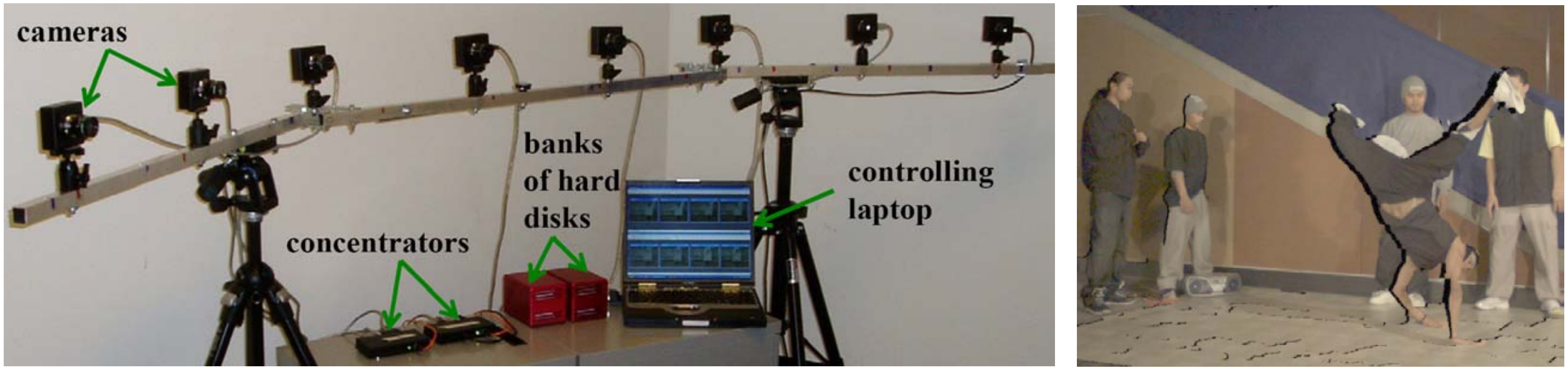

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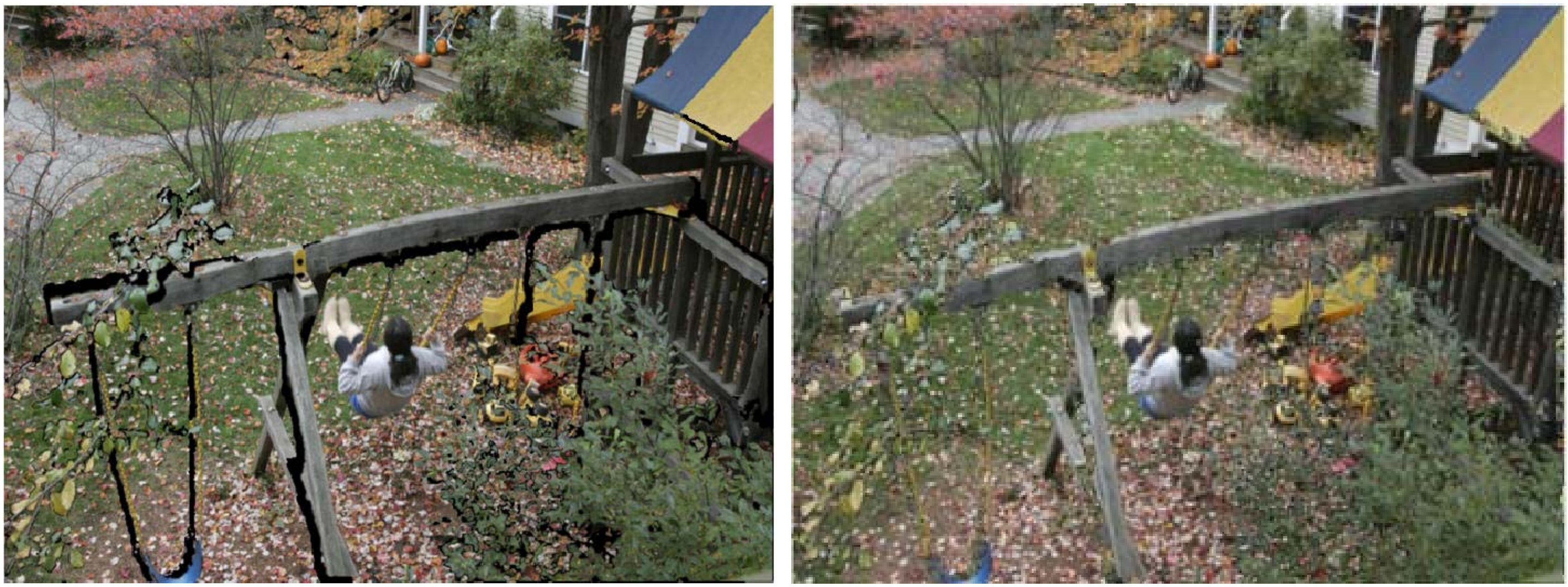

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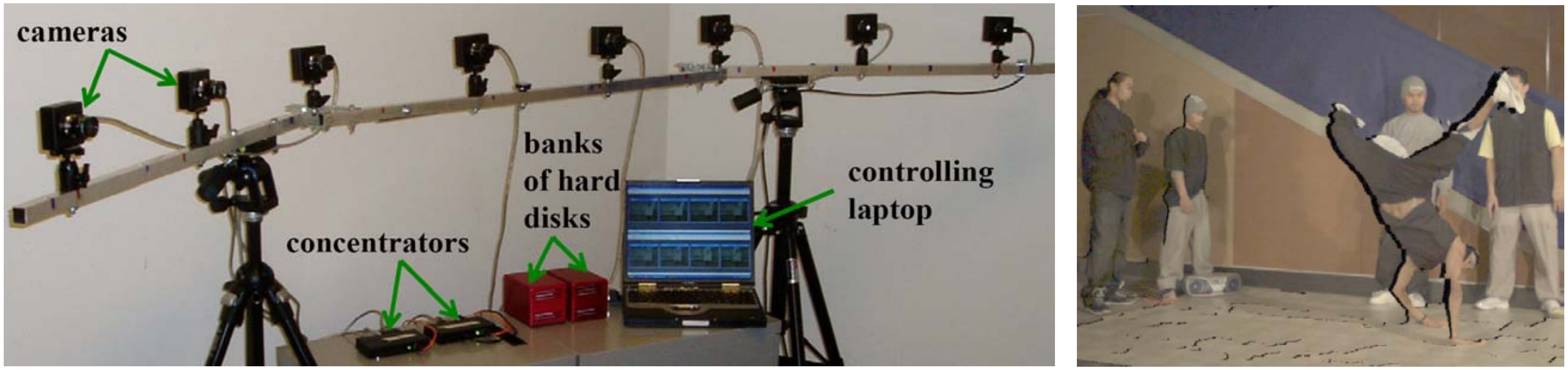

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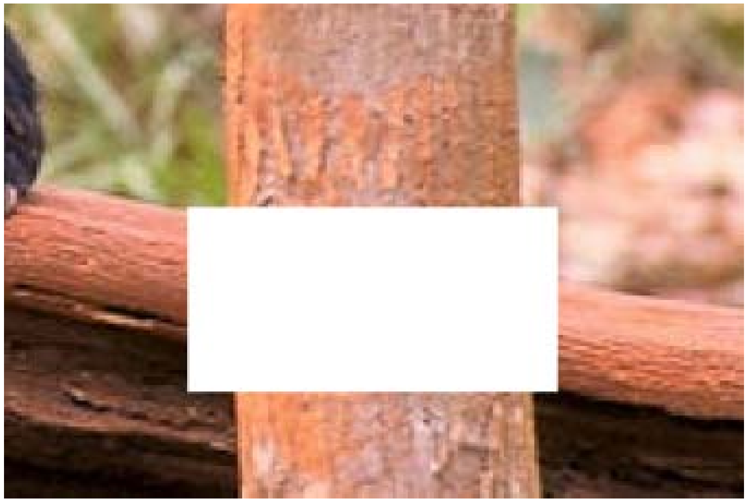
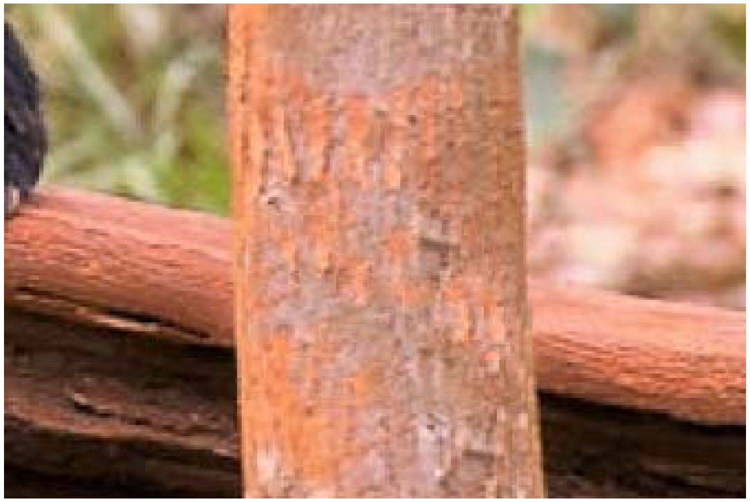
References: [20,21]

# Limitation: Preserving Depth Ordering

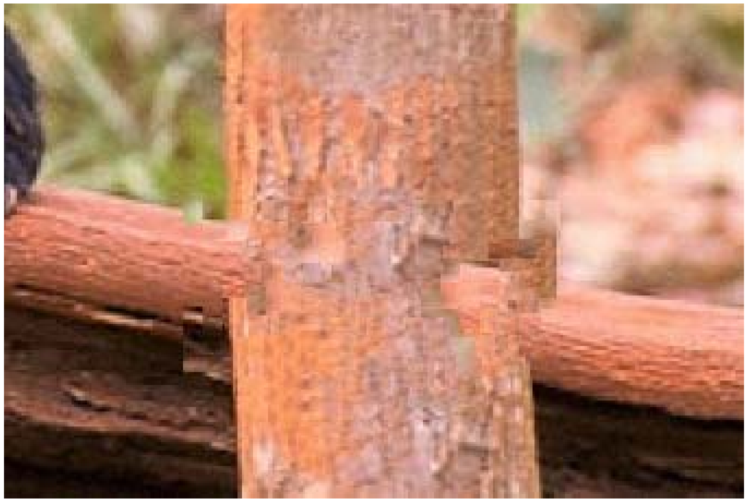


Original Image



Desired Solution

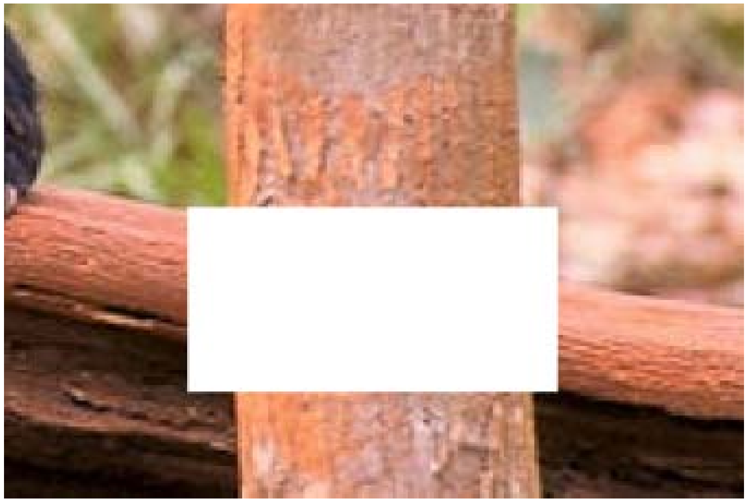
Exemplar-based Inpainting



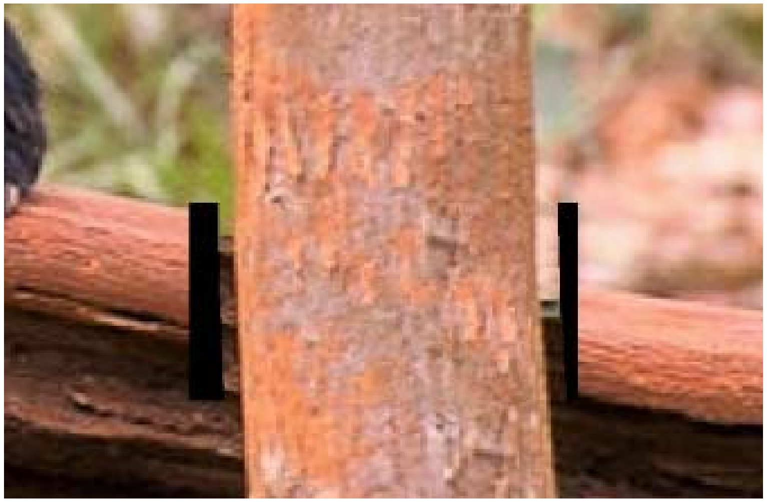
Output Image

References: [19]

# Image Completion with Structure Propagation



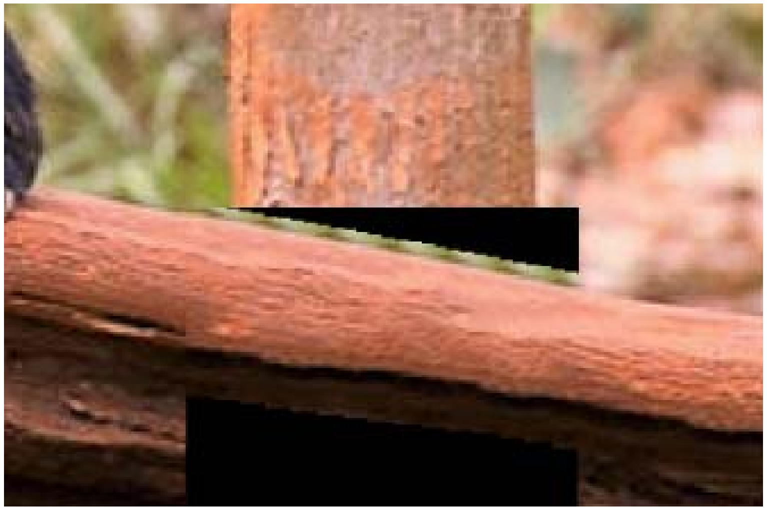
Original Image



Vertical Completion

### Structure Propagation Approach

- Due to Sun *et al.* (SIGGRAPH '05)
- Augment masked regions with line segments denoting linear structures
- Determine optimal patch placement along lines, then fill regions
- Utilizes Dynamic Programming and/or Belief Propagation



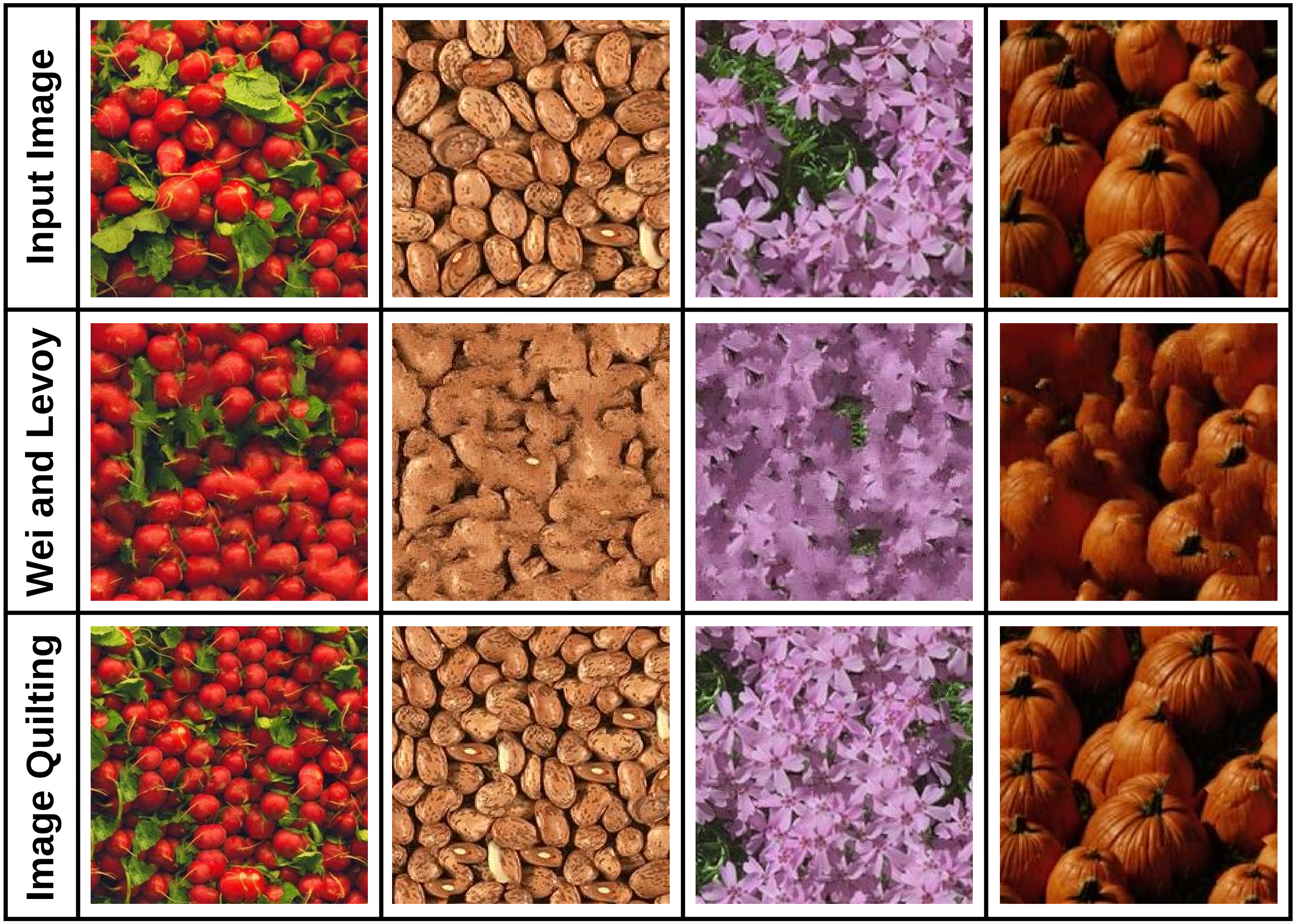
Horizontal Completion

References: [19]

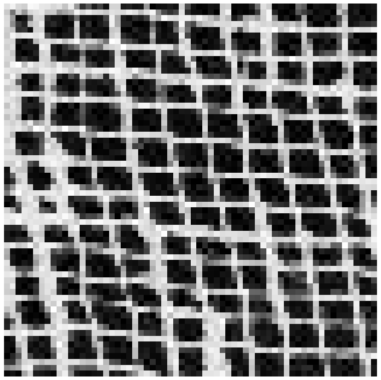
# Outline

- Brief Review and Introduction to Inpainting
- Exemplar-based Image Inpainting
- Image Editing Results
- *Conclusions and Future Work*

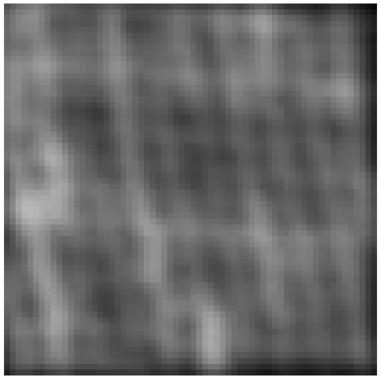
# Review: Image Quilting



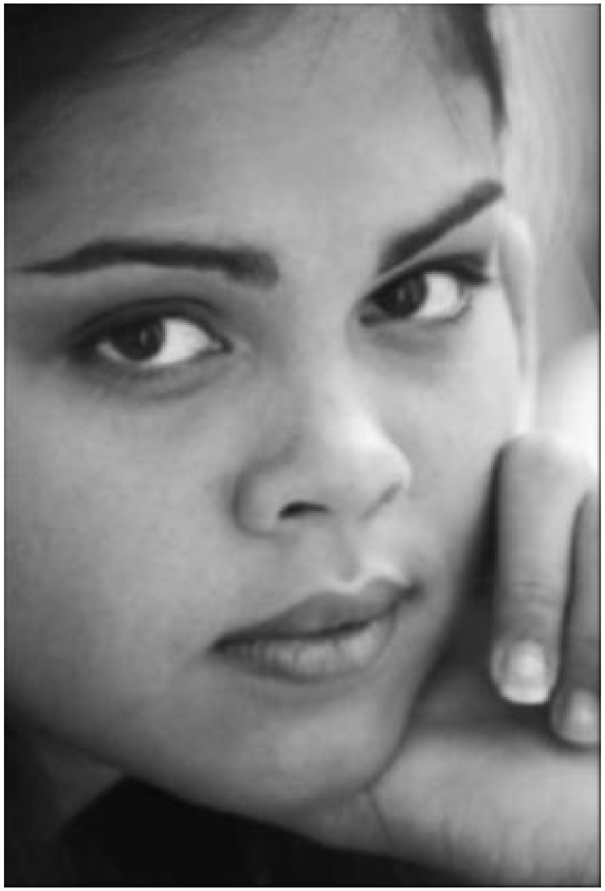
# Review: Texture Transfer



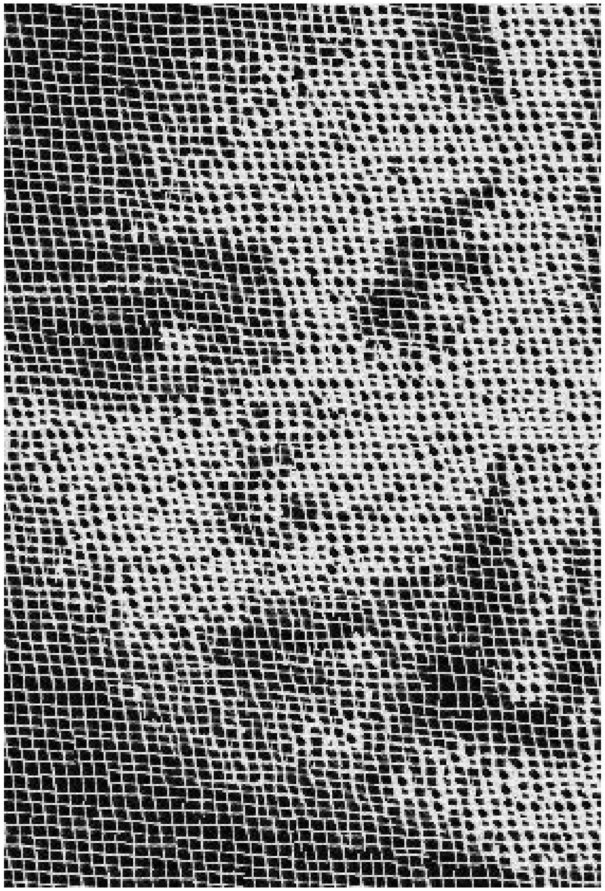
Source Image



Blurred Luminance



Target Image



Texture Transfer Result

- From an initial patch, search source texture and luminance map for similar neighborhoods and assign next patch randomly from this set

References: [8]

# Conclusions and Future Work

**Key Accomplishments**

- ✓ Full implementation of patch-based texture synthesis using *Image Quilting*
- ✓ Complete system for *Exemplar-based Image Inpainting*

**Image Quilting Results**

- ✓ Evaluated regular, stochastic, and quasi-periodic textures
- ✓ Demonstrated texture transfer for controlled synthesis
- ✓ Compared results to existing methods

**Image Completion Results**

- ✓ Demonstrated benefits of isophote-driven synthesis
- ✓ Evaluated performance for a variety of tasks
(e.g., object removal, hidden surface completion)

**Future Work**

- Improved synthesis methods (e.g., graphcut)
- Patched-based Image Analogies
- Feature matching and projective texture deformation
- Hybrid structure and texture completion

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