# Change Detection: Current State of the Art and Future Directions

Dapeng Oliver Wu
Electrical & Computer Engineering
University of Florida
http://www.wu.ece.ufl.edu/

# Outline

- Motivation & problem statement
- Change detection techniques
  - Radiometric adjustment
  - Geometric adjustment
  - Stochastic modeling and hypothesis testing
- Future directions
  - Probabilistic approach
  - Geometric approach



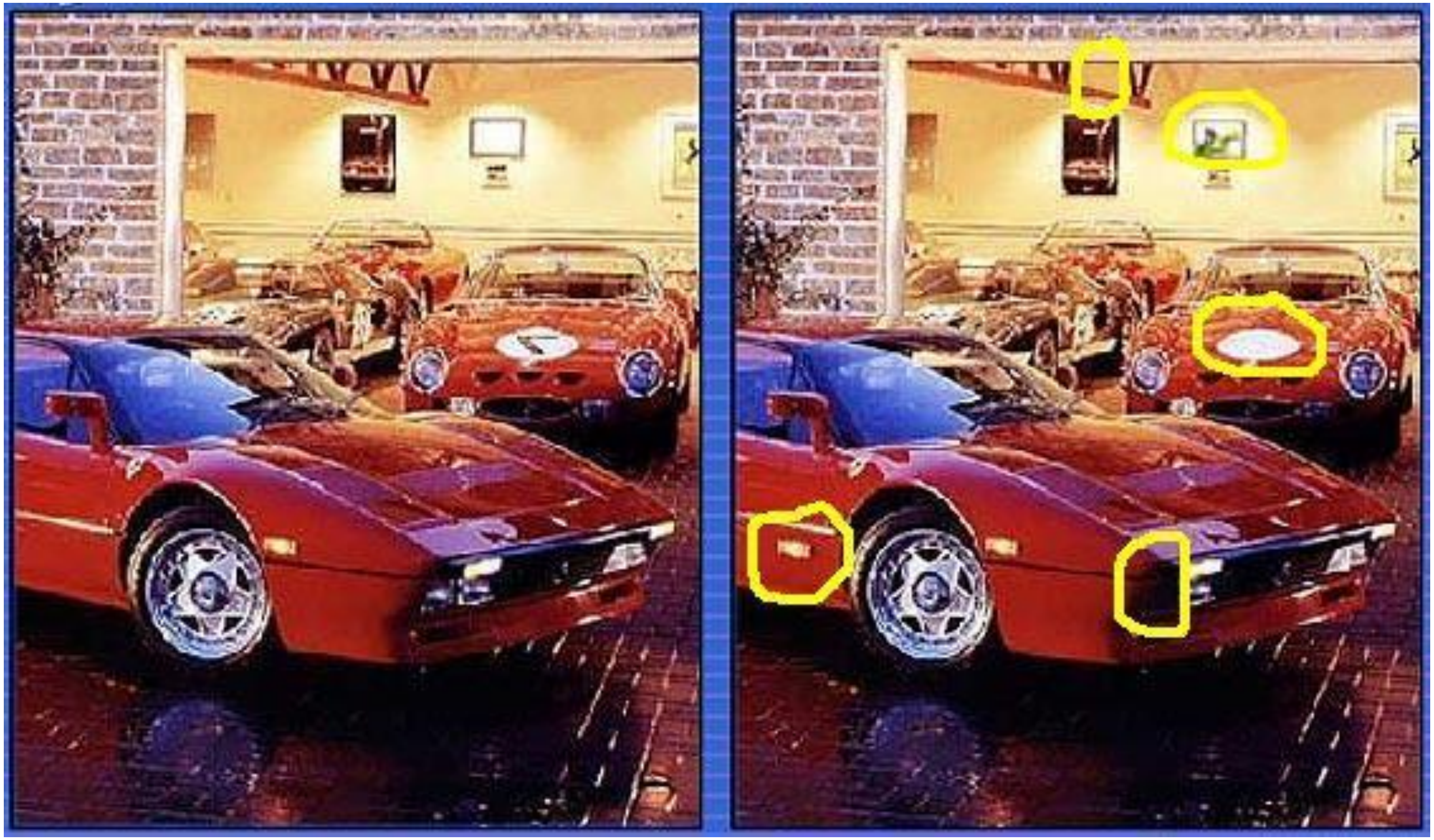
2

# What's Change Detection?

- Open your eyes wide, find 5 differences

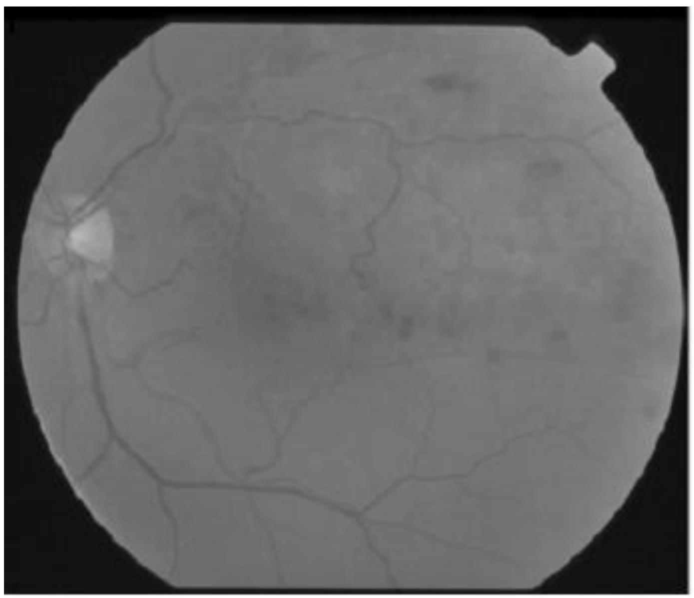
# What's Change Detection?

- Open your eyes wide, find 5 differences

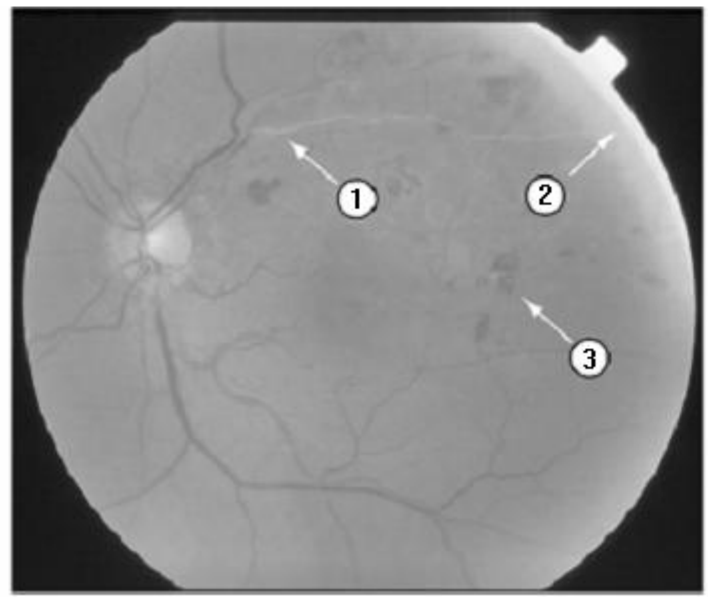


# Motivations (1)

- In medical diagnosis, change detection can help detect diseases.



Healthy




1 month later: retina disease?


5

# Motivations

- In remote sensing, change detection can help assessing damage from natural disaster.


Biloxi before Hurricane Katrina

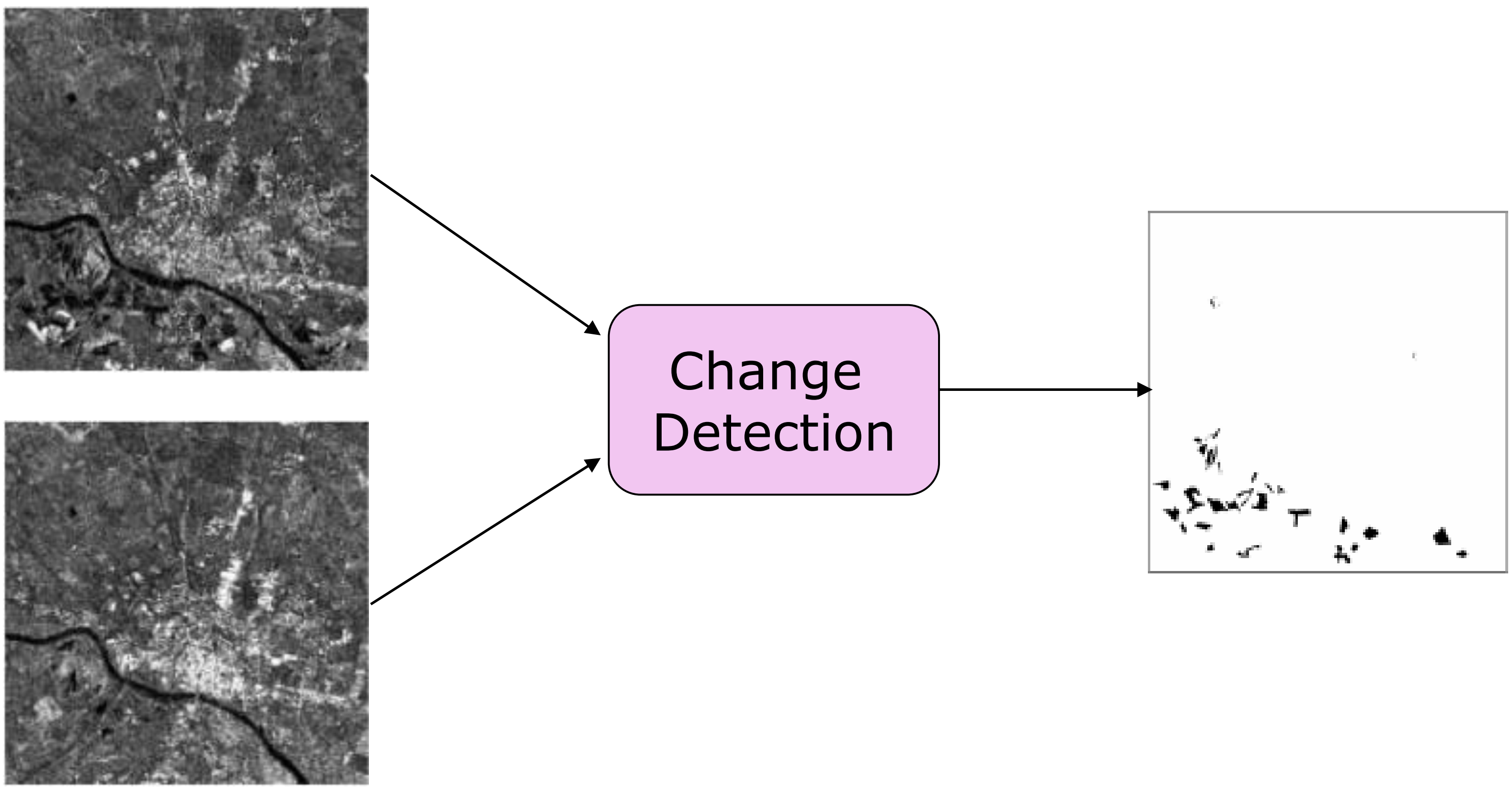

Biloxi after Hurricane Katrina


6

# Motivations

- In video surveillance, change detection can help detecting suspicious activities (activity monitoring).


# Problem Statement



# Technical Challenges

- Change detection is an ill-posed problem
  - since it is hard to define "changes" between images
    - Need to serve specific purposes (surveillance, disease diagnosis, etc.); hard to quantify meaningful changes
- Need to remove insignificant changes
  - Lighting variation
    - Bright under sunshine
    - Dark under cloudy weather
  - Camera motion
    - Changes caused by camera motion are insignificant

→ Should not be regarded as change

↓

Detecting changes is challenging!

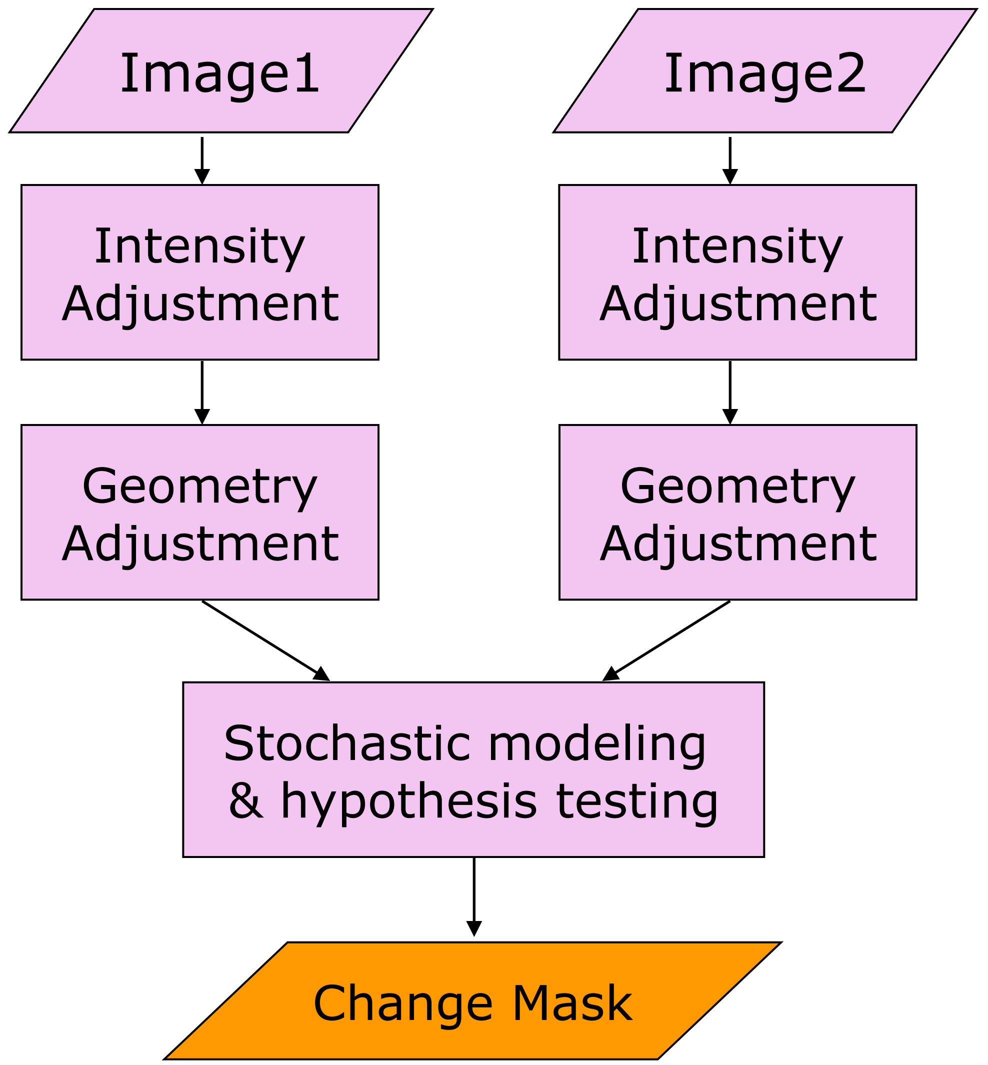
# Outline

- Motivation & problem statement
- Change detection techniques
  - Radiometric adjustment
  - Geometric adjustment
  - Stochastic modeling and hypothesis testing
- Future directions
  - Probabilistic approach
  - Geometric approach



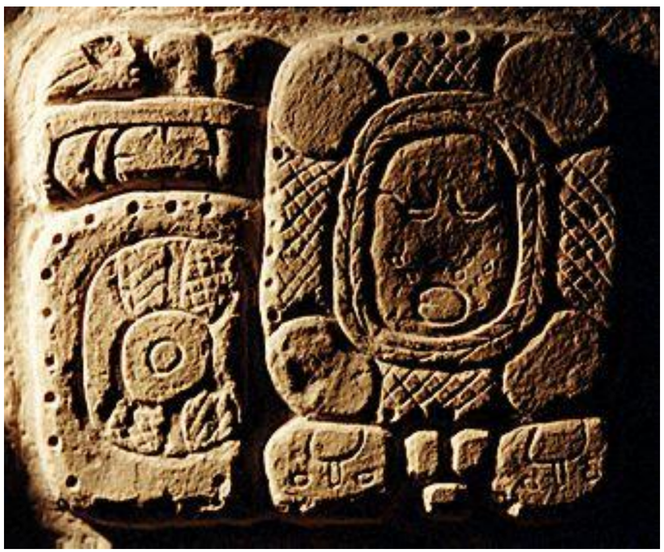
10

# Typical Procedure of Change Detection



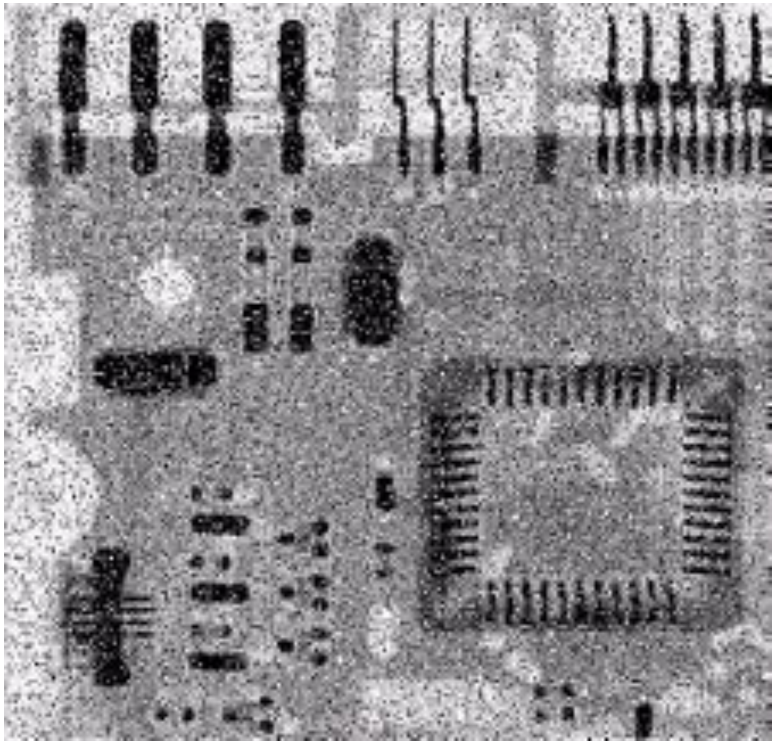
# Radiometric Adjustment – Why?

- Eliminate lighting variations

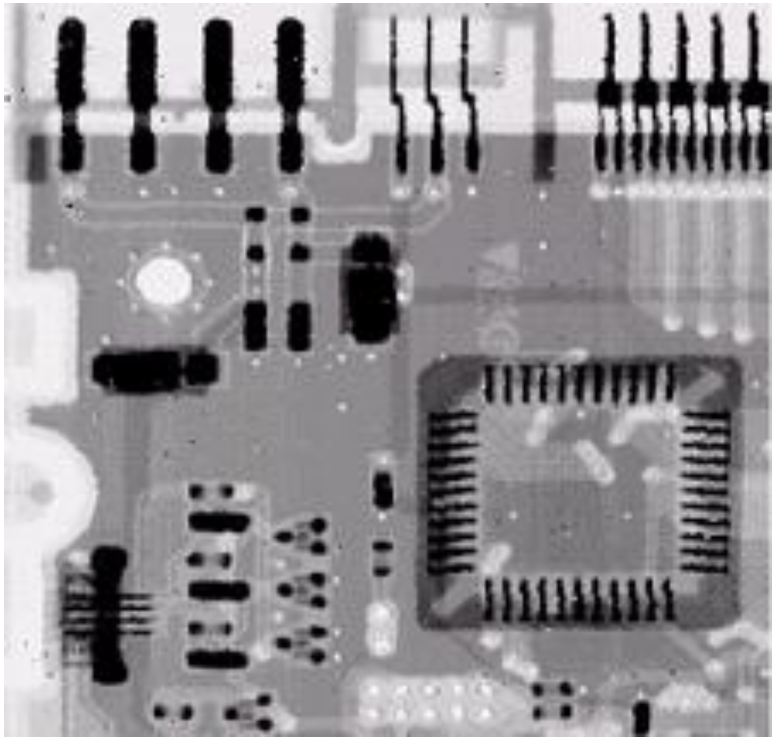


# Radiometric Adjustment – Why? (2)

- Mitigate noise



X-ray image of circuit board corrupted by salt-and-pepper noise



Noise reduction with a 3×3 median filter

# Radiometric Adjustment – How?

- Histogram matching: make two images have the same histogram
- Homomorphic filtering: $I(x) = I_l(x) I_o(x)$

$$\ln I(x) = \ln I_l(x) + \ln I_o(x) \qquad I_o(x) = \exp\{HPF(\ln I(x))\}$$

Homomorphic Filtering

# Noise Mitigation

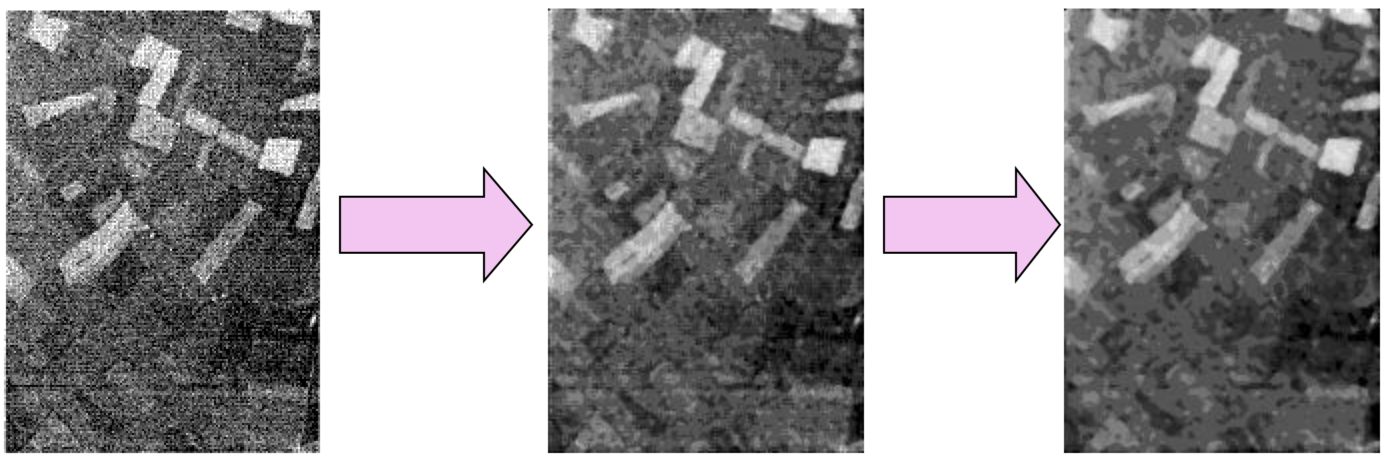
- Intensity modeling: $I(x) = I_l(x) I_o(x) + N(x)$
- Gaussian noise
  - Frame/local spatial averaging
- Speckle noise – salt and pepper noise
  - Widely exist in coherent imagery, such as SAR, ultrasound
  - PDF:

$$p(z) = \begin{cases} P_a & z = a \\ P_b & z = b \\ 0 & else \end{cases}$$

  - How to mitigate it?
    - Median filter

$$f(x, y) = \underset{(s,t) \in S_{xy}}{median} \{ g(s,t) \}$$

# Median Filtering Example



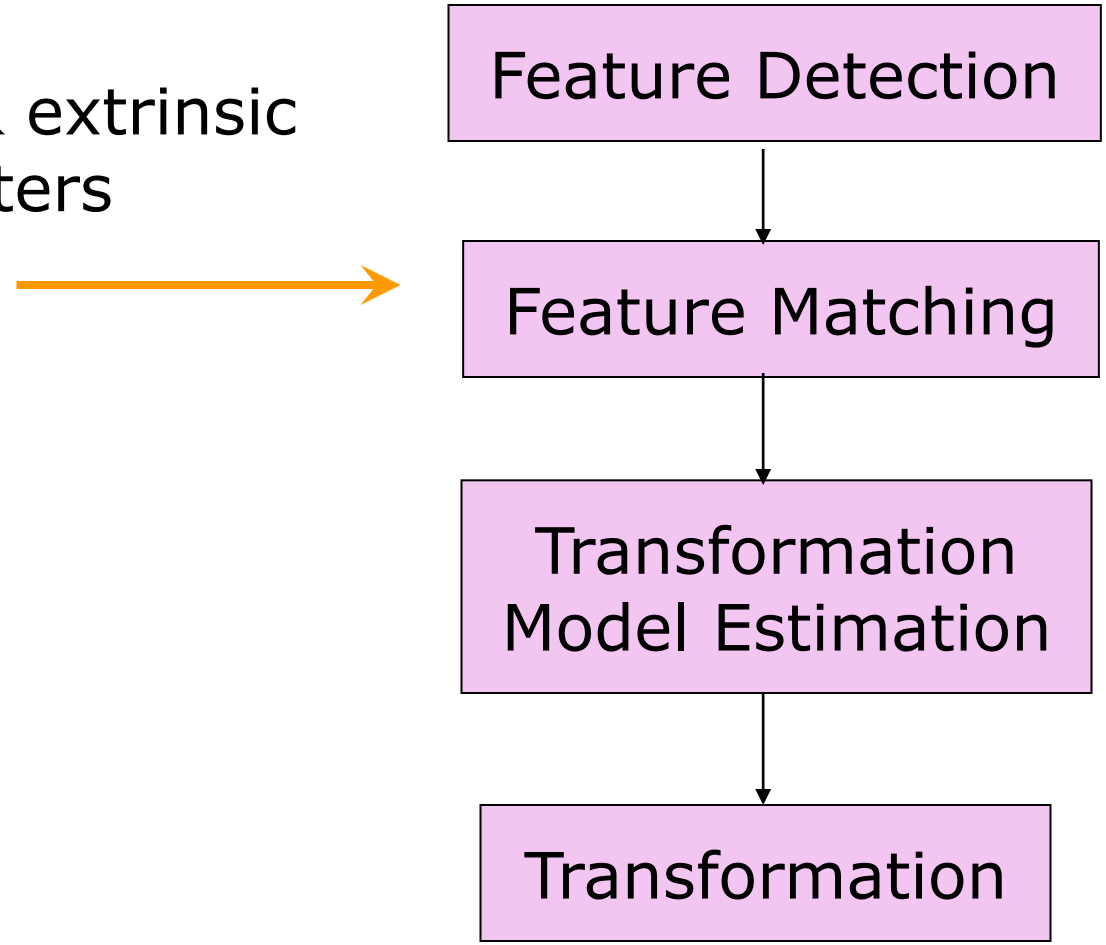
# Geometric Adjustment – Why?

- A.k.a. image registration
- Camera may move

⇒ Need to align images into the same coordinate system

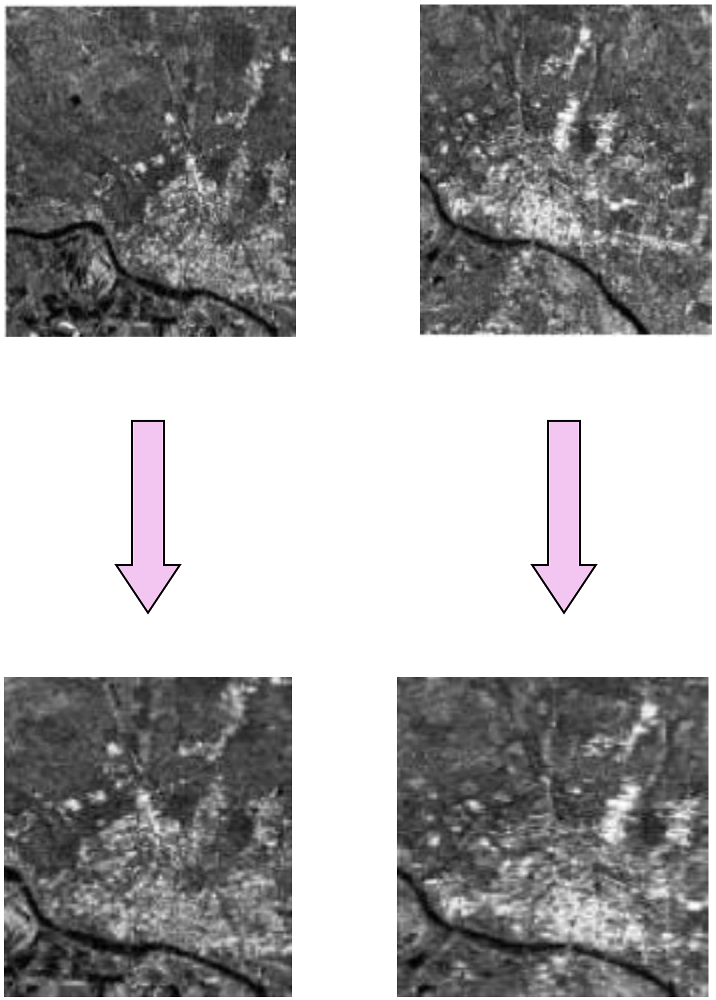
# Geometric Adjustment – How?

- Need Intrinsic & extrinsic camera parameters
- General steps



# Geometric Adjustment – Example

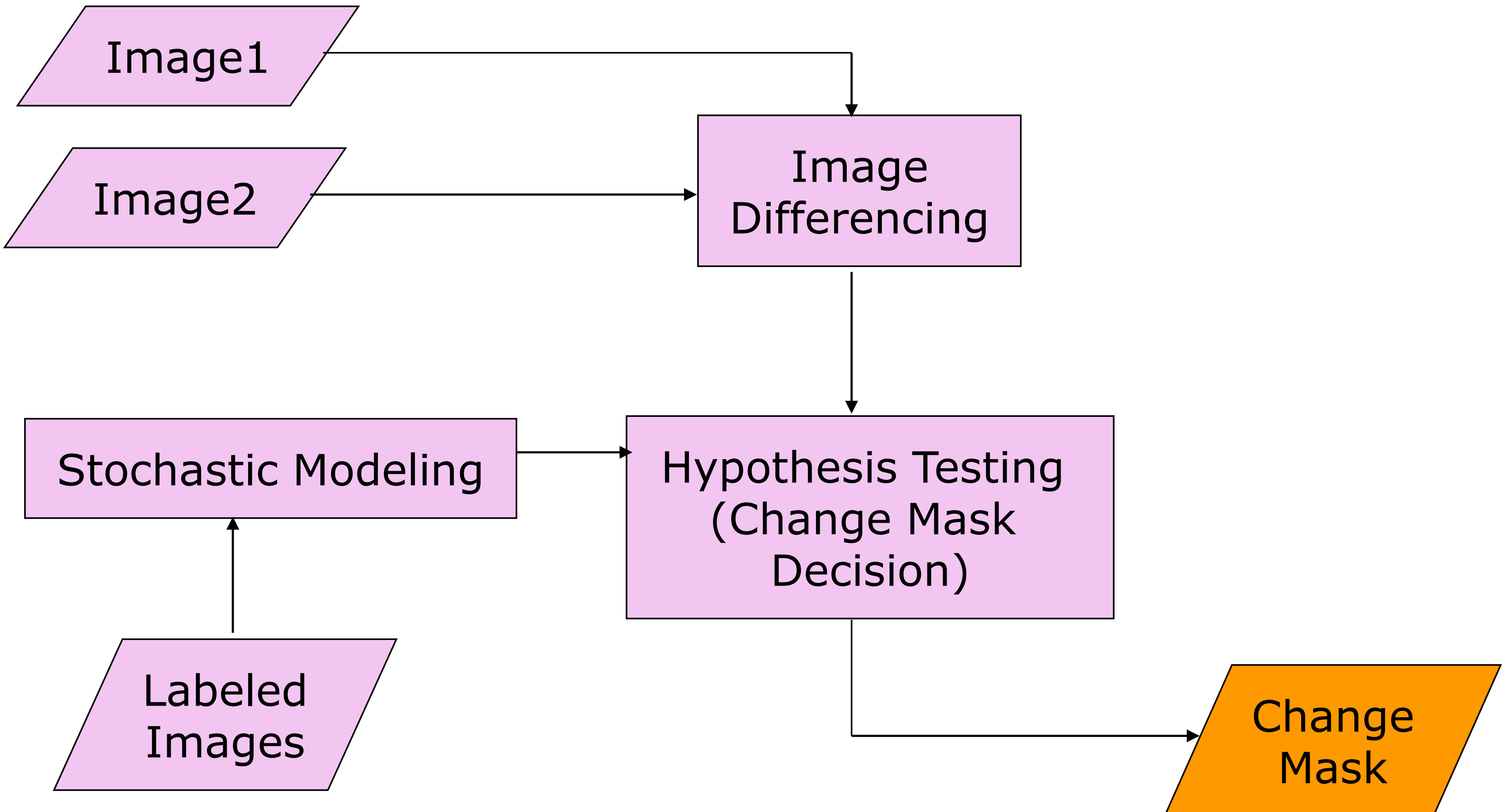
- Input images:
- Adjusted Images:



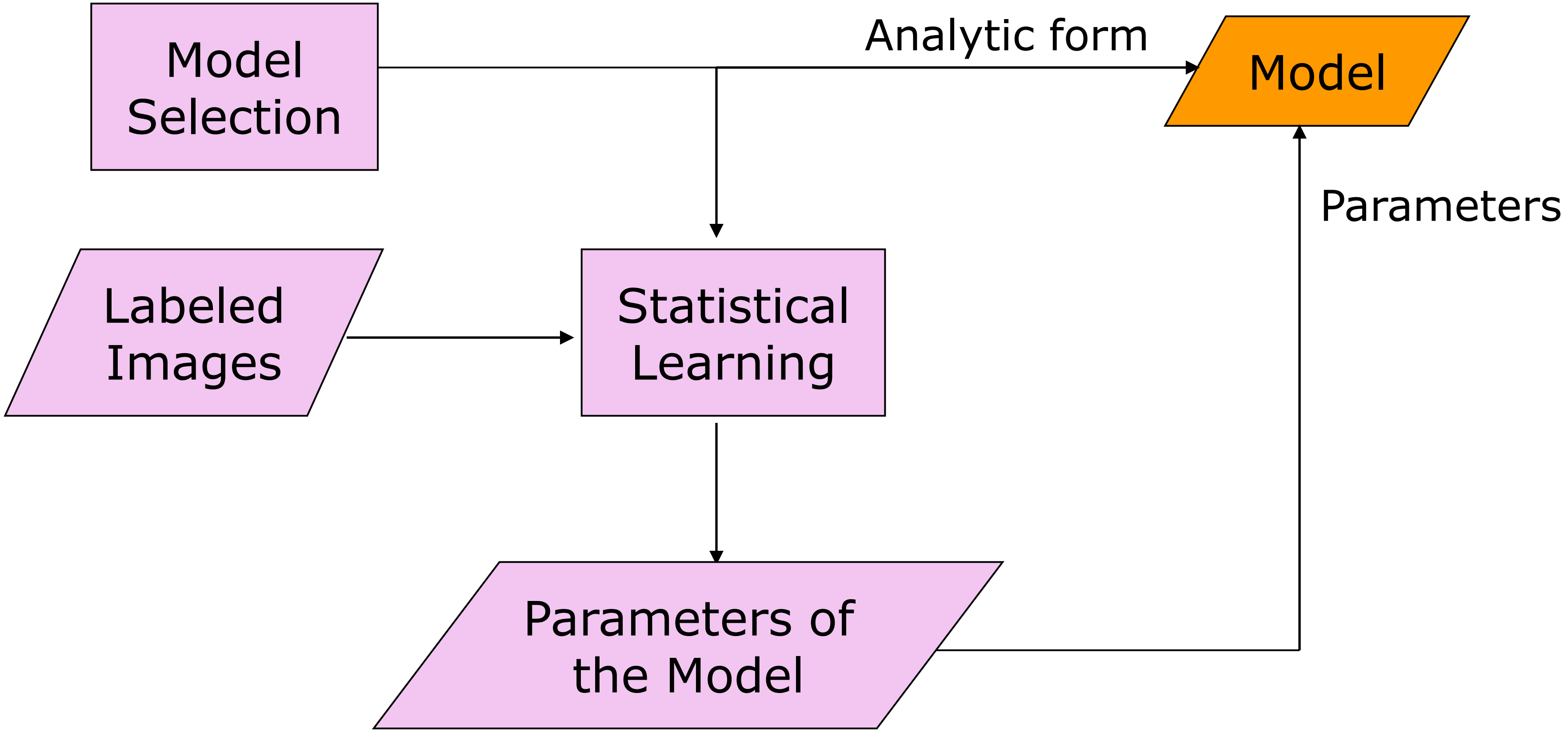


19

# Stochastic Modeling and Hypothesis Testing



# Stochastic Modeling Process

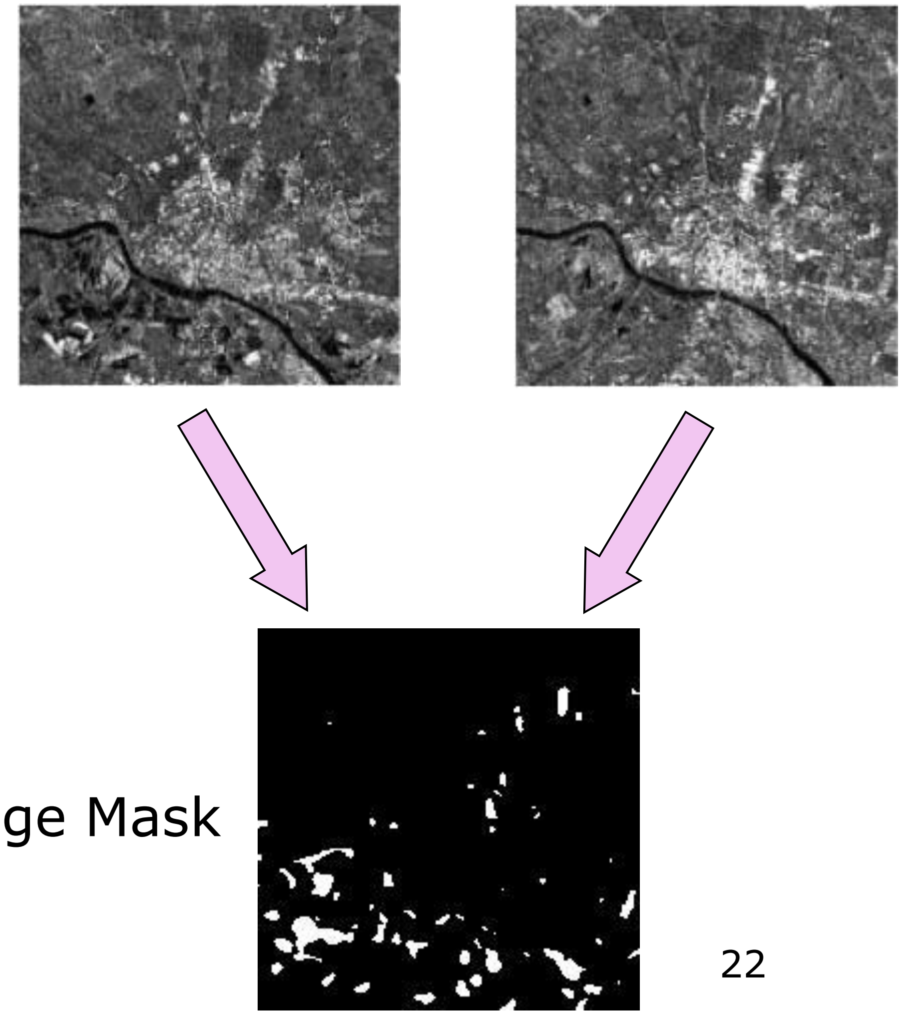


# Hypothesis Test

- Hypotheses
  - $H_0$: no change
  - $H_1$: change
- Testing:

maximum likelihood

$$k = \arg\max_{k \in \{0,1\}} p(x \mid H_k)$$





22

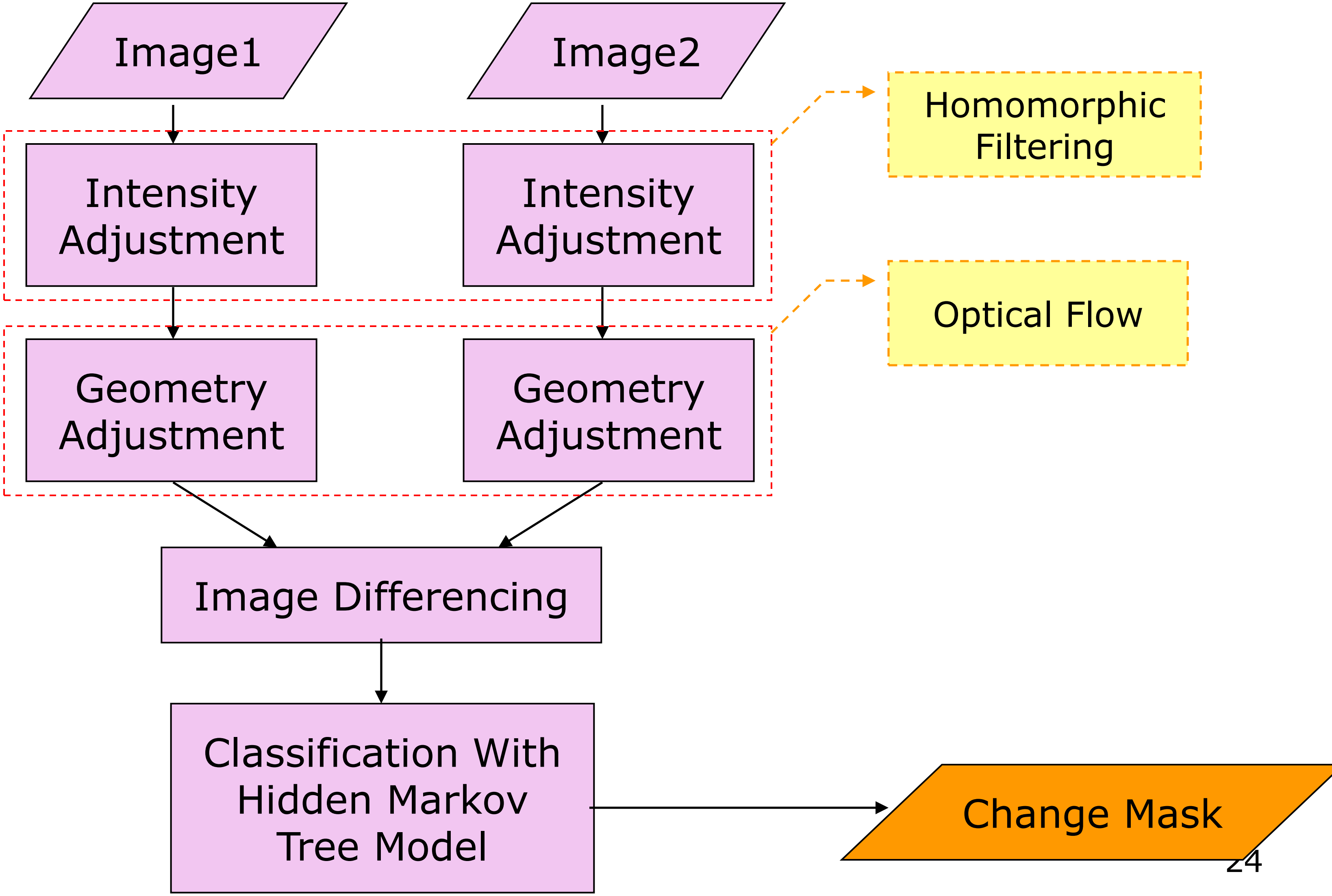
# Outline

- Motivation & problem statement
- Change detection techniques
  - Radiometric adjustment
  - Geometric adjustment
  - Stochastic modeling and hypothesis testing
- Future directions
  - Probabilistic approach
  - Geometric approach

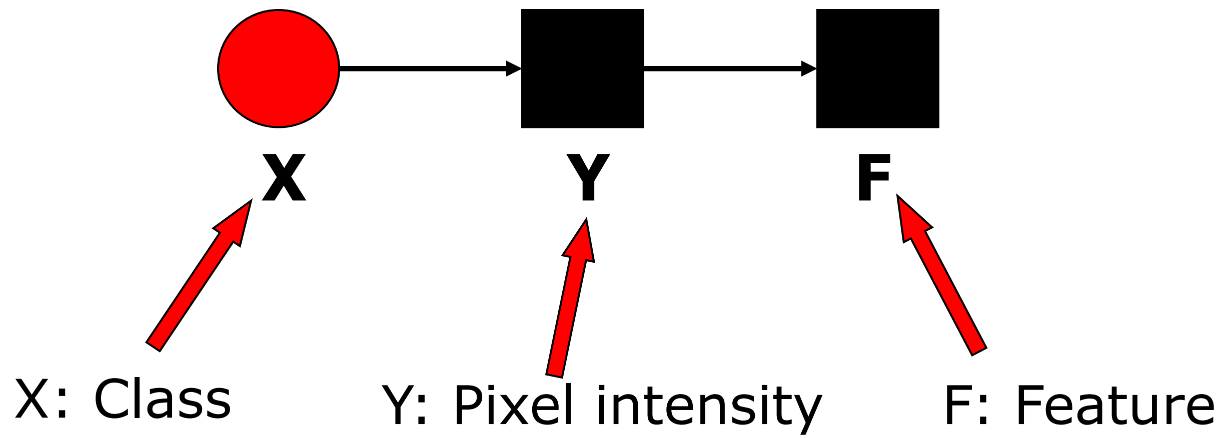


23

# Probabilistic Approach – Flowchart



# Statistic Model – One Pixel

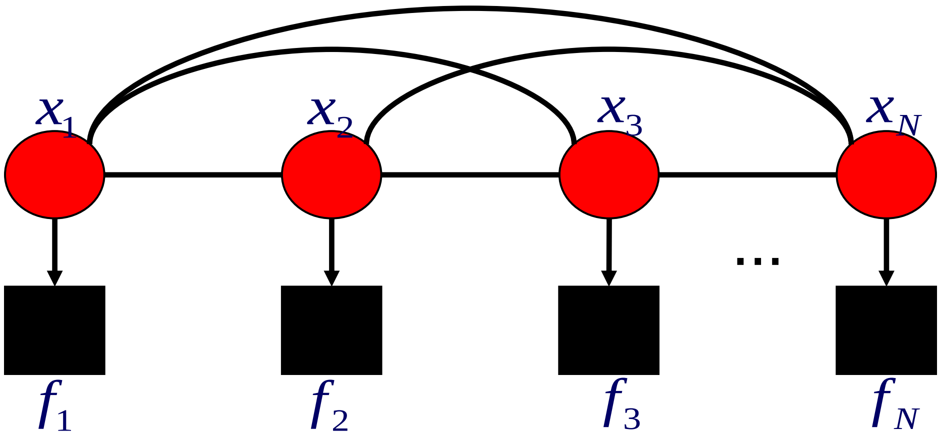



- MAP criterion:

$$\hat{x} = \arg\max_{x} P(x \mid f) = \arg\max_{x} p(f \mid x) P(x)$$

- Limitation:
  - It does not consider spatial correlation

# Statistic Model – Multiple Pixel



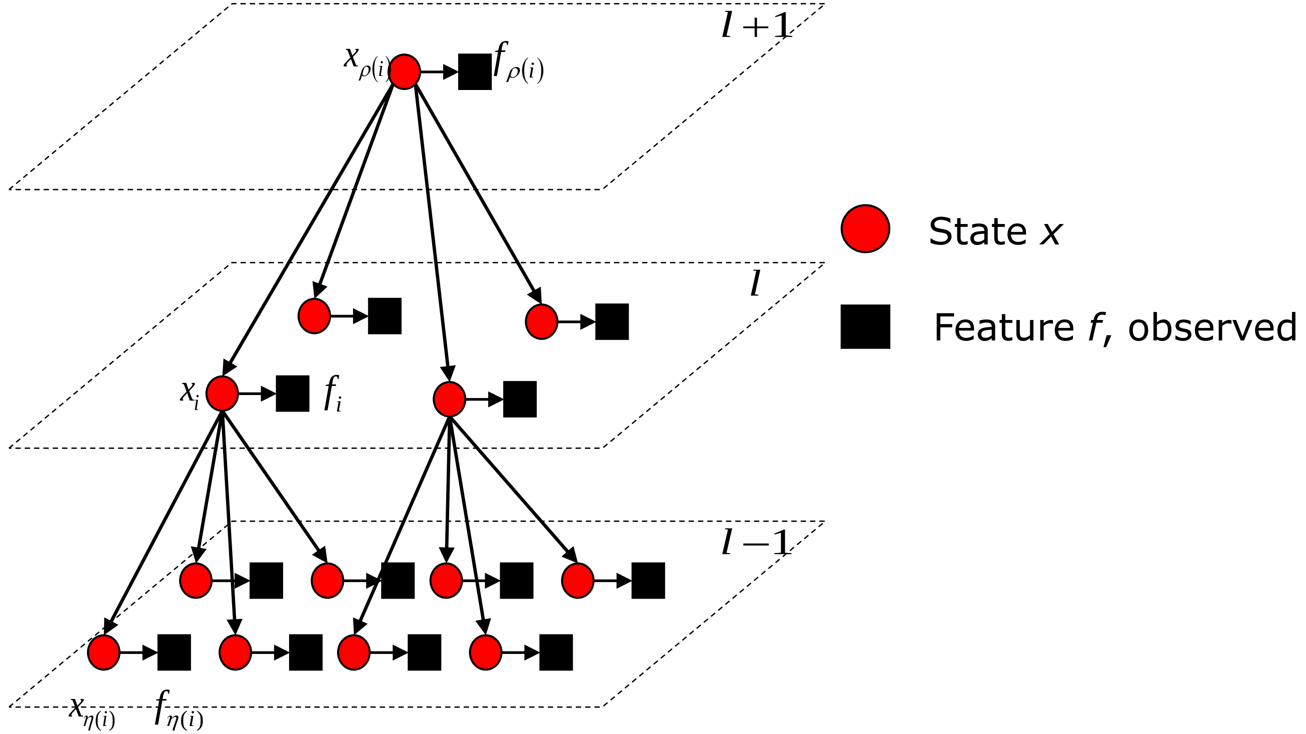

- MAP criterion: $\hat{\mathbf{x}} = \arg\max_{\mathbf{x}} \prod_{i=1}^{N} \mathrm{p}\left(f_i \mid x_i\right) \bullet \mathrm{P}\left(\mathbf{x}\right)$

  where $\mathbf{x} = [x_1, x_2, \ldots, x_N]^T$

- Advantage: consider spatial correlation
- Limitation: complexity is too high
  - $2^N$ possible **x**, i.e., $O(2^N)$ complexity, if $x_i$ has 2 possible values.

# Hidden Markov Tree Model

- What is hidden Markov tree (HMT)?
- Advantages of HMT:
  - Utilization of spatial correlation
  - Can use Viterbi algorithm whose complexity is O(N²)

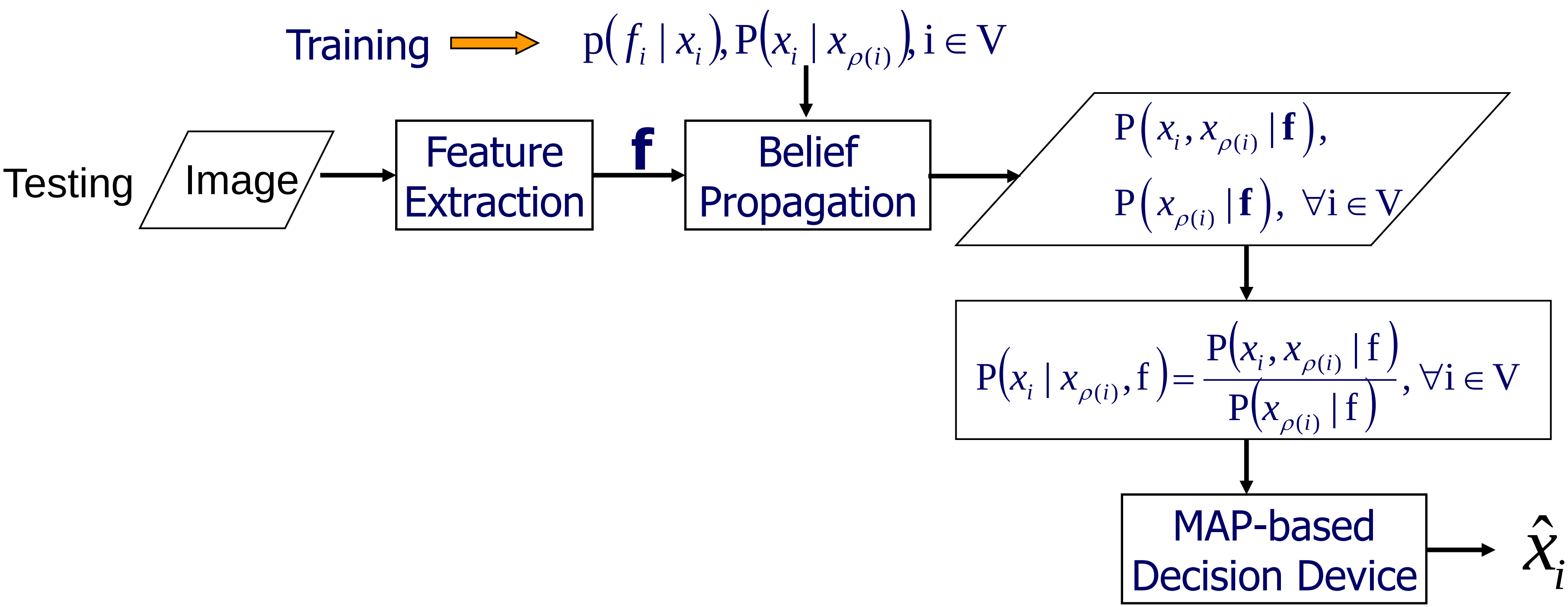


# Classification

- Decision: MAP criterion

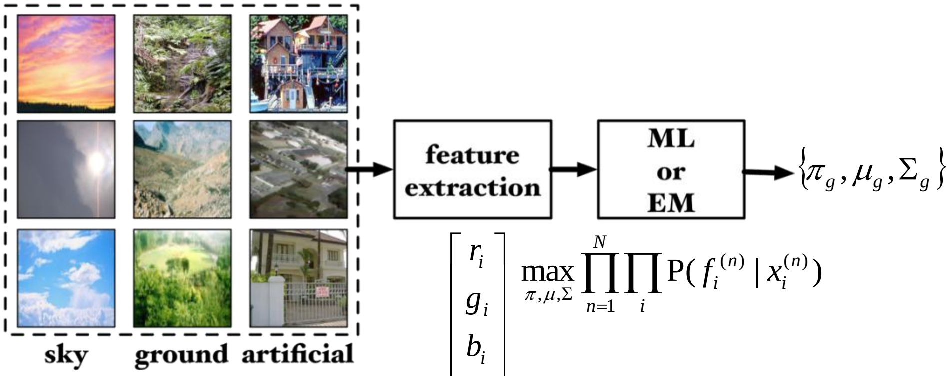
$$\hat{x}_i = \arg\max_{\mathbf{x}} \mathrm{P}(\mathbf{x} \mid \mathbf{f}) = \arg\max_{x_i, x_{\rho(i)}, \cdots} \mathrm{P}(x_i \mid x_{\rho(i)}, \mathbf{f})\, \mathrm{P}(x_{\rho(i)} \mid x_{\rho(\rho(i))}, \mathbf{f}) \cdots \mathrm{P}(x_{root} \mid \mathbf{f}), \text{ for } \forall i \in V$$

- How to calculate:



# Training

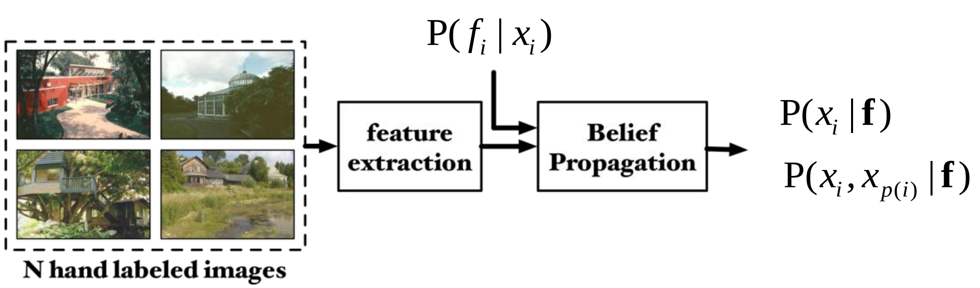
$$P(f_i \mid x_i = m) = \sum_{g=1}^{G} \pi_g(m) N(f_i; \mu_g(m), \Sigma_g(m))$$




$$\max_{\pi,\mu,\Sigma} \prod_{n=1}^{N} \prod_{i} P(f_i^{(n)} \mid x_i^{(n)})$$

$$f_i = \begin{bmatrix} r_i \\ g_i \\ b_i \\ w_i \\ . \\ . \\ . \end{bmatrix}$$

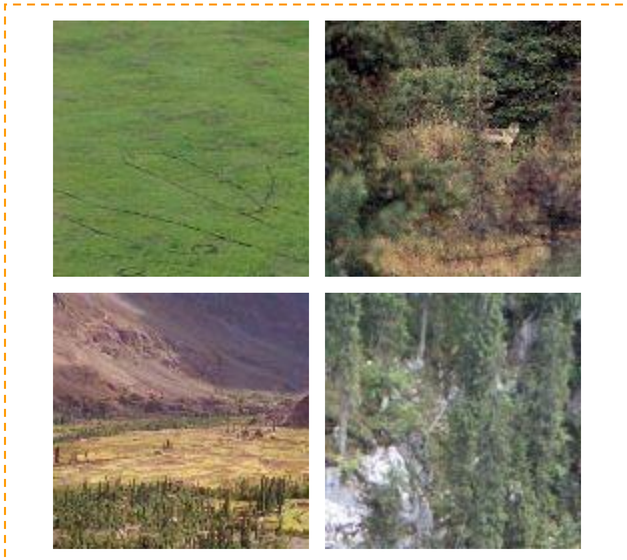
$$P(x_i \mid x_{\rho(i)}) = \frac{1}{K} \sum_{k=1}^{K} \frac{P\left(x_i, x_{\rho(i)} \middle| \mathbf{f}^{(k)}\right)}{P\left(x_{\rho(i)} \middle| \mathbf{f}^{(k)}\right)}$$



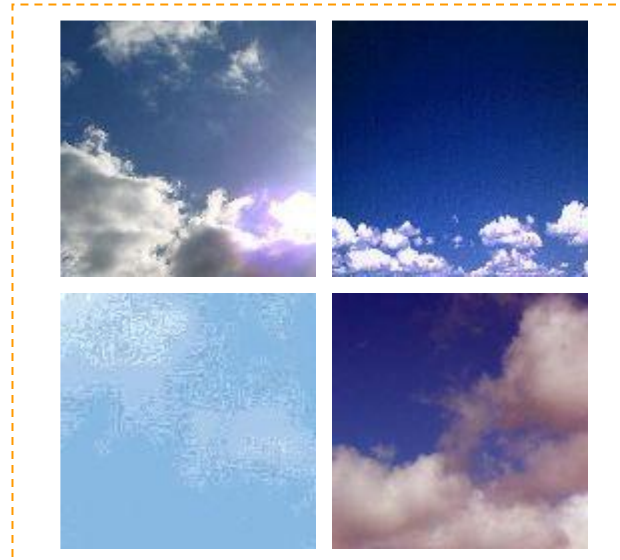
# Experimental Results

Training samples:

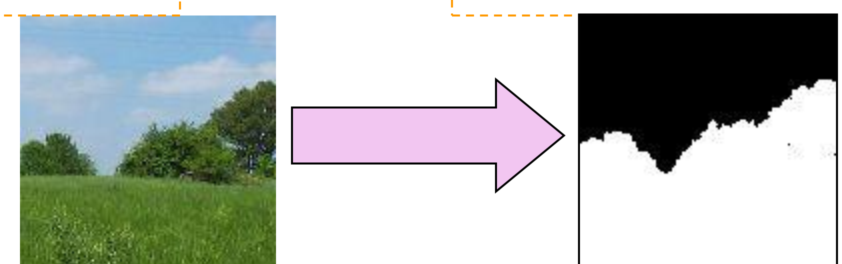
Ground

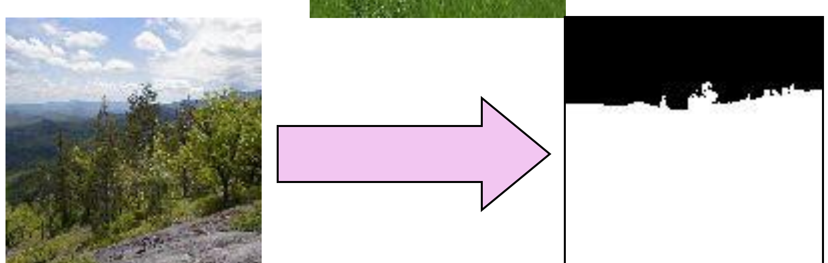


Sky



Testing images:

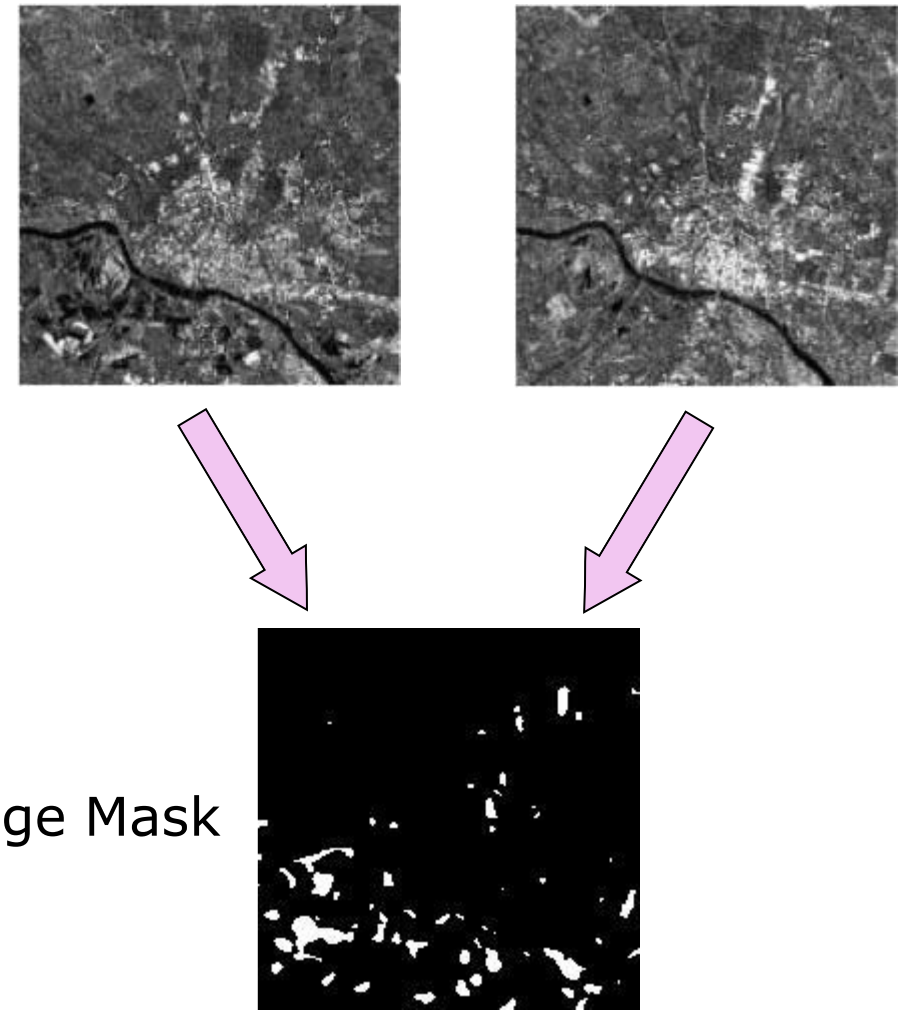




Output of classifier

# Experimental Results (2)

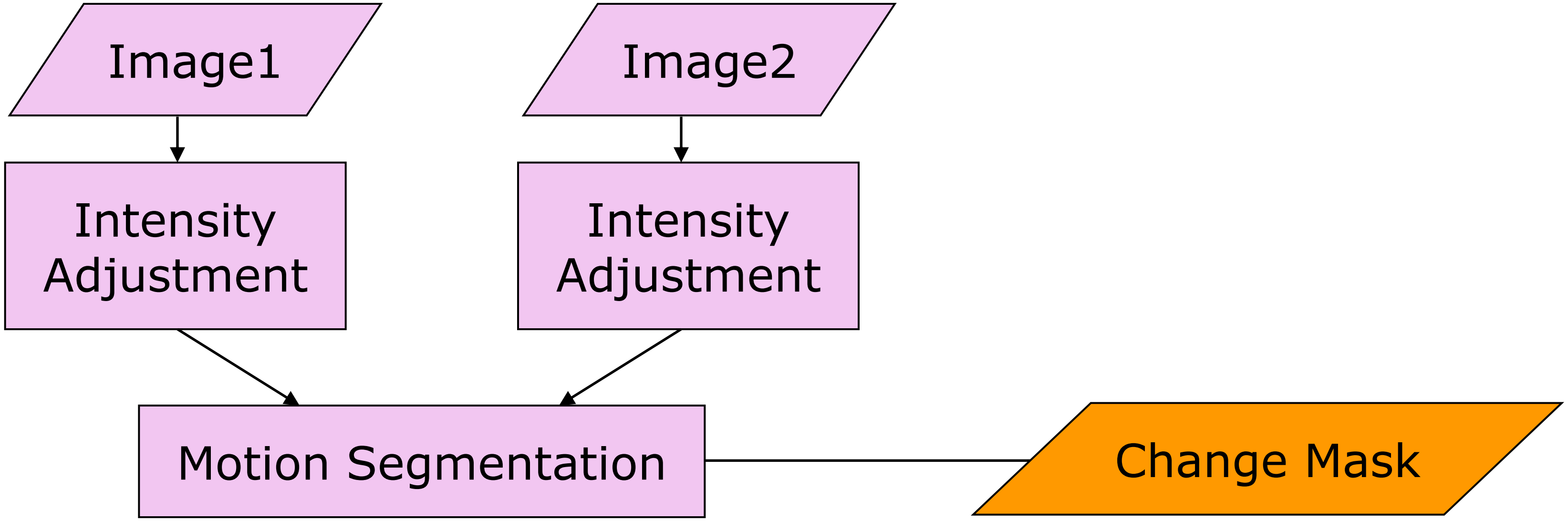
Input Images



Change Mask

# Geometric Approach: Motion-based Change Detection

- Does motion mean change?
  - Global motion is caused by camera motion
  - Local motion is caused by object motion, which is useful.



# Motion-based Change Detection (2)

- How to define 2D motion?
  - Translation

$$u = x + t_x$$
$$v = y + t_y$$

  - Affine motion

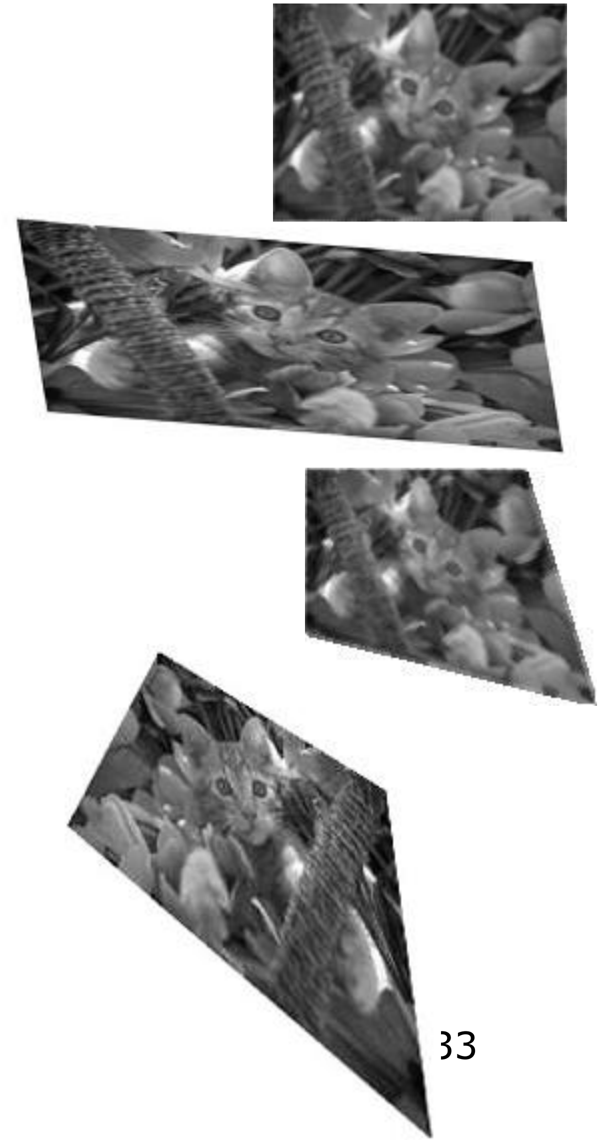
$$u = a_0 + a_1 x + a_2 y$$
$$v = b_0 + b_1 x + b_2 y$$

  - Bilinear motion

$$u = a_0 + a_1 x + a_2 y + a_3 xy$$
$$v = b_0 + b_1 x + b_2 y + b_3 xy$$

  - Projective mapping

$$u = \frac{a_0 + a_1 x + a_2 y}{1 + c_1 x + c_2 y}$$
$$v = \frac{b_0 + b_1 x + b_2 y}{1 + c_1 x + c_2 y}$$



# Motion-based Change Detection (3)

- Single-body motion model $f_i(x, M_i) = 0$
- Multibody motion model

$$g(x, M) = f_1(x, M_1) \cdot f_2(x, M_2) \cdots f_n(x, M_n) = 0 \quad (\text{for} \quad \forall x)$$

- Multibody motion estimation: estimate *M*
  - *n* and *M* can be obtained linearly after embedding *x* into a higher-dimensional space
- Motion segmentation: $M \rightarrow \{M_i\}_{i=1}^{n}$
- Refine motion models
- Do it recursively until it converges.

# Experimental Results

Camera motion

Object motion

# Grand Challenges in Image Processing & Computer Vision

# Change Detection in 3D Space

- Change detection in 3D space is important for homeland security and military
- Key component of detection & classification of moving personnel in DARPA VisiBuilding program
- Challenges: need better understanding & exploitation of physics and imaging modalities

See through walls, using radar, MMW, X-ray, acoustic, UWB, SAR, neutron, gamma-ray, etc.

# Real-time 3D Imaging of Interior of Building & Underground Structure

- Critical for urban warfare
  - Provide critical information for commanders to make tactical decisions; help assess enemy course of action
- Need synergistic efforts from different areas
  - Wall/ground penetrating sensors
  - Microwave imaging
  - Vision processing
  - 3D image reconstruction
  - Circuits

# Super Resolution in Satellite Imaging

- Can we improve the resolution of current satellite imagery by a factor of 10 or even 100?
- Potential impact: why this is important?
  - Able to see details never available previously, e.g., recognize human, car, objects of size ~1m
  - Particularly important for intelligence, Department of Defense, and homeland security
- Possible solutions
  - Multi-view image processing of multiple satellite images
  - New imaging techniques based on physics

Thank you!