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Introduction to Medical Imaging (5XSA0) Module 5

Segmentation

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Outline

* **Introduction**
* **Color Segmentation**
  - region-growing
  - *region-merging*
  - *watershed*
* **Background Subtraction**
  - background generation
  - change detection
* **Model-based Object Detection**
  - graph model

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Applications of Object Segmentation

* **Surveillance**
  - detect people in restricted areas
  - detect abnormal behavior (motion pattern)
* **Video/Image Analysis**
* **Video Editing**
* **Intelligent Video Databases**
  - object classification
* **Sports Analysis**
* **Object-Oriented Video-Coding (MPEG-4)**

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Definition of Object Segmentation

* **It's your turn. Segment this image !**

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Definition of Object Segmentation

* **Central question: what is an object ???**
* **Semantic problems of object definition:**
  - shadows
  - occlusions
  - reflections
  - object status change (parking cars)
  - small movements (waving trees)
  - hierarchical objects (man in car)

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Definition of Object Segmentation

* **The object definition and the segmentation algorithm to use depends on the context !**
* **There is no such thing as**
  "a general segmentation algorithm"
* **Possible definitions:**
  - regions with uniform color → color segmentation
  - regions with uniform texture → texture segmentation
  - regions with uniform motion → motion segmentation

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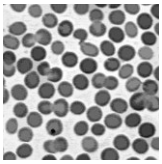
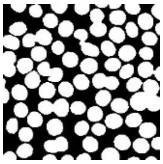
Color Segmentation: Example (1)

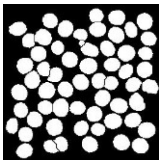
* Example medical application:
  – count number of blood cells



input image



binarized image

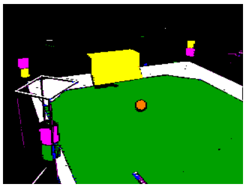


separate connected cells (requires further model knowledge)

Color Segmentation: Example (2)

* Preprocessing for special applications
  – colors help to detect objects and markers

input image



segmentation

Images taken from CMVision realtime color segmentation library

Color Segmentation: Example (3)

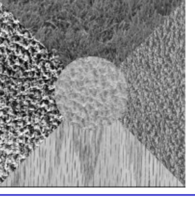
* Color segmentation on natural images:

input image

segmentation

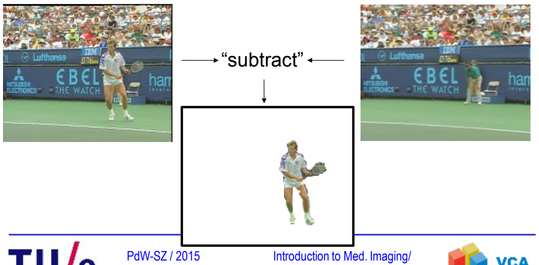
Texture Segmentation

* Group regions based on texture features.
* Usual approach:
  – extract texture descriptors (e.g., Gabor filter coefficients)
  – cluster similar descriptors (comparable to color segmentation)



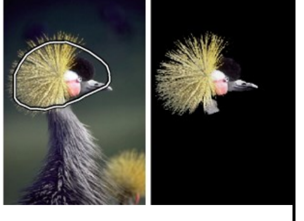
Background Subtraction

* Assume that a pure background image is known
  – detect changes between input image and background image (**Change Detection**)



Manual Segmentation

* Interactive segmentation
  – user controls the segmentation process
  – computer determines accurate object boundaries
* Edge based techniques
  – intelligent scissors
* Region based techniques
  – marker based watershed



Kar-Han Tan, Narendra Ahuja:
Selecting Objects with Freehand Sketches

Evaluating the Segmentation Result

* **oversegmentation**
  – result has ***more*** regions than expected
* **undersegmentation**
  – result has ***less*** regions than expected


oversegmented


undersegmented

Point detection

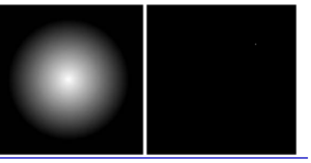
* **Look for a point that is different from its neighborhood**
* **Apply an isolating mask to calculate:**

$R = w_1 z_1 + w_2 z_2 + \ldots + w_9 z_9$

* **A point is detected at the center of the mask if**

$|R| \geq T$ **where** T **is a threshold**

−1	−1	−1
−1	8	−1
−1	−1	−1



Line detection

* **Masks responding to lines of different orientations:**

Horizontal

−1	−1	−1
2	2	2
−1	−1	−1

+45°

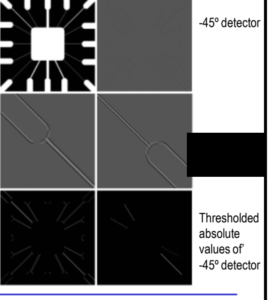
−1	−1	2
−1	2	−1
2	−1	−1

Vertical

−1	2	−1
−1	2	−1
−1	2	−1

−45°

2	−1	−1
−1	2	−1
−1	−1	2

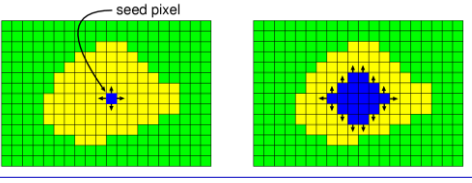


Outline

* **Introduction**
* **Color Segmentation**
  – region-growing
  – *region-merging*
  – *watershed*
* **Background Subtraction**
  – background generation
  – change detection
* **Model-based Object Detection**
  – graph model

Color Segmentation: Region Growing (1)

* **Start a new region with a seed pixel**
* **Consider neighboring pixels**
  – if their color is similar to the mean region color, add pixel to the region
  – continue growing until no more pixels can be added to the region



Color Segmentation: Region Growing (2)

* **Implementation**
  – input: seed (x_s, y_s), image $I(x,y)$
  – insert (x_s, y_s) into queue of positions Q
  – region color $C = I(x_s, y_s)$

  – while Q not empty
    • extract (x,y) from queue
    • if $\| I(x,y) - C \| < \tau$
      ▪ add neighbors of (x,y) into Q
      ▪ [update region color C with $I(x,y)$]

Color similarity threshold τ

Color Segmentation: Region Growing (3)
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* Regions have already been defined

$$R = \bigcup_{i=1}^{S} R_i \qquad R_i \cap R_j = \emptyset \qquad i \neq j$$

* We hope $H(R_i) = TRUE \qquad i = 1, 2, ..., S$

$$H(R_i \cup R_j) = FALSE \quad i \neq j, \quad R_i \ \ adjacent\ to \ \ R_j$$

homogeneous

Color Segmentation: Region Growing (4)
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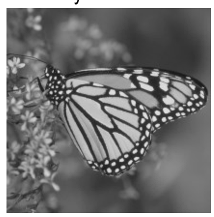
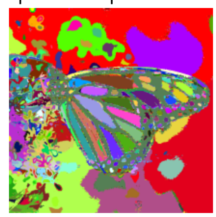
* Seed pixels can be
  – placed manually, or
  – arbitrarily chosen from the unprocessed pixel



input image



segmentation result

Color Segmentation: Region Growing (5)
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* Segmentation result is depending on
  – similarity threshold
  – choice of seed pixels
  – order in which seed pixels are processed
  – algorithm implementation (order in which neighboring pixels are processed)

Color Segmentation: Region Merging (1)
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* Alternative approach: *Region Merging*

* Start with a set of regions (obtained by another algorithm)

* Consecutively join the two most similar neighboring regions

Color Segmentation: Region Merging (2)
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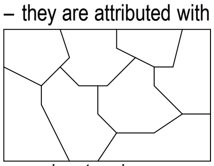
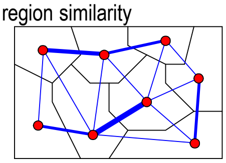
* Data-structure:
  – neighborhood graph of image regions
  – each node represents a region
  – graph edges denote adjacency
  – they are attributed with the region similarity



input regions



neighborhood graph

Color Segmentation: Region Merging (3)
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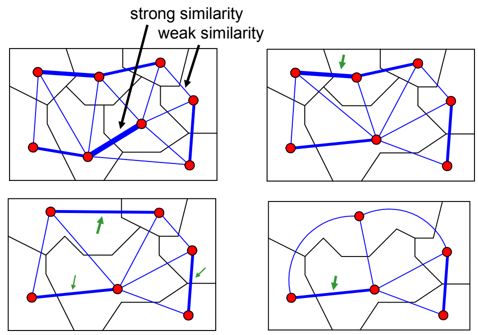


Color Segmentation: Region Merging (4)

- Several merging criteria are possible
- Simple model:
  - describe region color l_i by average luminance.

[redacted]

$I(x,y)$	luminance image
r_i	pixels in region

- Merging criterion:
  - **mean:** difference of mean region luminances

[redacted]

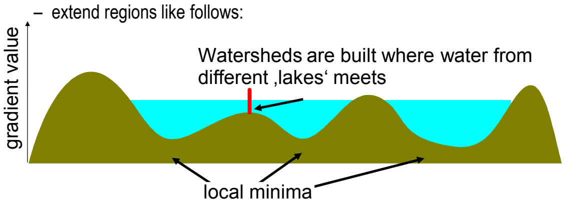
- Difference of mean luminances does not take region size into account

Color Segmentation: Watershed (1)

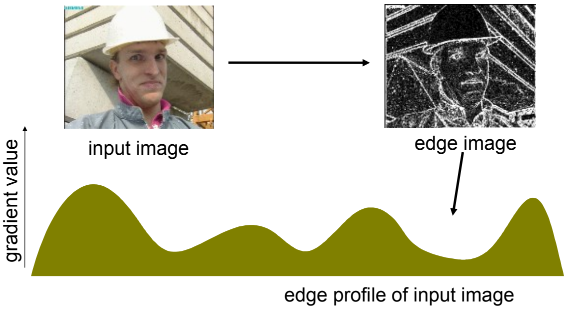
- The *watershed* algorithm
- Fast color segmentation algorithm
- Generally gives oversegmented results on natural images
- Well-defined output
- Often used as preprocessing operation
  - quickly convert a pixel image into a region-level description to speed-up further processing
- Variant: watershed with manually placed markers

Color Segmentation: Watershed (2)

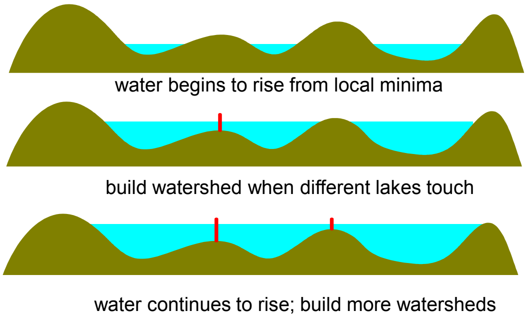
- Algorithm principle:
  - apply gradient filter on input image and work on the resulting edge image
  - search for local minima in edge image and initialize a new region for each minimum
  - extend regions like follows:



Color Segmentation: Watershed (3)

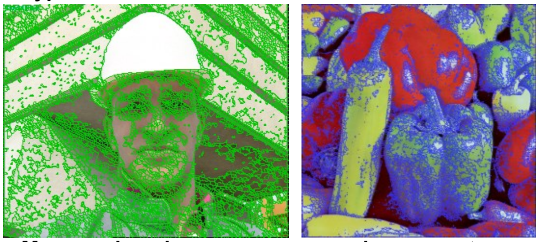


Color Segmentation: Watershed (4)



Color Segmentation: Watershed (5)

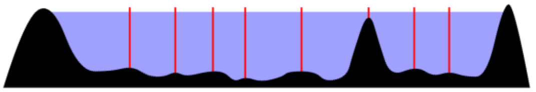
- Typical result:



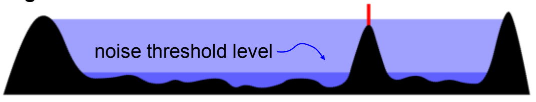
- Many regions because camera noise generates many local minima

Color Segmentation: Watershed (6)

* Noise in flat areas generates too many local minima



* Small noise regions can be avoided by clipping gradients to a minimum value



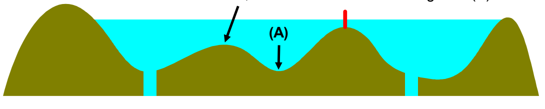
Color Segmentation: Watershed (7)

* Result with clipped gradient strength:

Color Segmentation: Watershed (8)

* Variant: manual watershed
* Instead of starting to flood from local minima, start flooding from markers

no watershed is built here, since no water is emanating from (A)



Color Segmentation

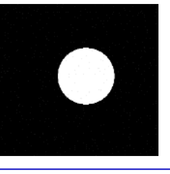
* Summary
  – Region Growing
    – easy implementation, low-quality results
  – Region Merging
    – difficult implementation, flexible control of segmentation process, high-quality results
  – Watershed
    – easy and fast implementation, predictable result, severe over-segmentation
    – no threshold to influence result (except gradient clipping)
  – Result only sufficient for specialized applications

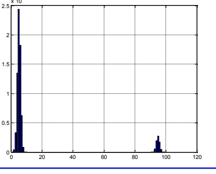
Outline

* Introduction
* Color Segmentation
  – region-merging
  – watershed
* Background Subtraction
  – background generation
  – change detection
* Model-based Object Detection
  – graph-models

Thresholding

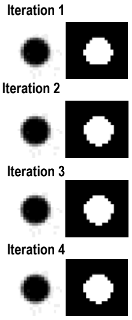
* Simple and computationally efficient
* Threshold selection uses intensity information → histogram
* Example: bimodal histogram





Optimal Thresholding

- What value of T will give us the best segmentation?
- Gonzalez and Woods:
  - Initialize T (e.g. halfway between min and max)
  - Iteratively set T=0.5*(μ1+μ2), where μ1, μ2 the mean values of pixels with value larger or smaller than T, respectively
  - Until T converges

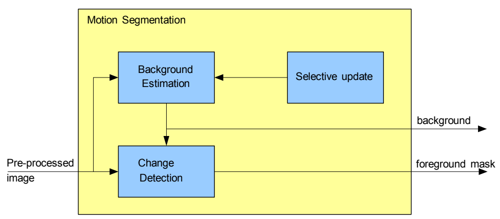


Bkg. Subtraction: Principle - (1)

- Assumption: background is static
- Input image is compared with background image
  - if the difference is small: background content
  - if the difference is large: foreground object
  - difference is generally not zero due to noise in the sequences
- For some applications, the background image can be captured separately
- For other applications, it must be synthesized from the input sequence

Bkg. Subtraction: Principle (2)

- Background image generation
- Change detection

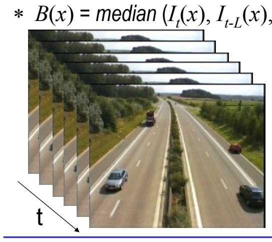


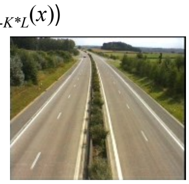
Bkg. Subtraction: Principle (3)

- Background image generation:
  - stack large number of input frames (camera motion must be compensated)
  - different techniques proposed in literature
    - weighted linear filter
    - temporal recursive filter
    - kalman filter
    - *Temporal Median*
    - *Gaussian Mixture Model*

Bkg. Sub: Background Generation (1)

- Temporal median filter
  - good performance can be achieved
  - relatively low computational complexity
- $B(x) = median\ (I_t(x), I_{t-L}(x), \ldots, I_{t-K*L}(x))$





background image

Bkg. Sub: Change Detection

- We have
  - current input frame I_t
  - background frame I_B
- We denote the image color channels as
  [redacted]
  - and the vector combining all channels as [redacted]
- Detect object, e.g., if
  [redacted]
- τ is a threshold that depends on the noise level

Bkg. Sub: Difference Metrics

* **What metric should be used for the image difference?**
  - greyscale difference

    [redacted]

  - sum of squared differences of RGB channels

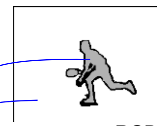
    [redacted]

  - sum of absolute differences of RGB channels

    [redacted]

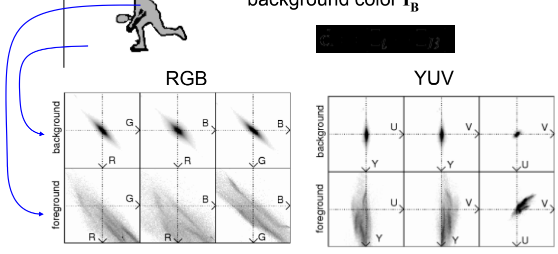
  - ... in YUV color-space
  - ... something else (L*u*v color-space, non-linear difference functions?)

Distribution of Color Differences (1)



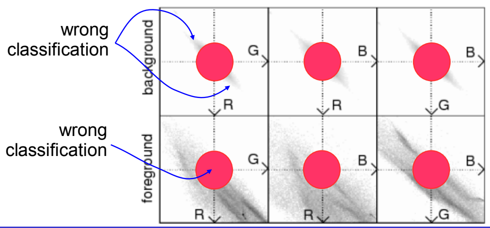
Distribution of difference vector **d** between input color $\mathbf{I}_t$ and background color $\mathbf{I}_B$

[redacted]



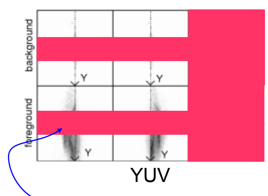
Distribution of Color Differences (2)

* **Each difference function defines a decision boundary**
  - here: Euclidean distance defines **sphere**
  - inside sphere: background, outside: foreground



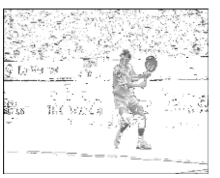
Distribution of Color Differences (3)

* **Greyscale difference only:** [redacted]
* **Defines slice in Y-dimension**
* **Better classification could be obtained by integrating color**



YUV

many false classifications



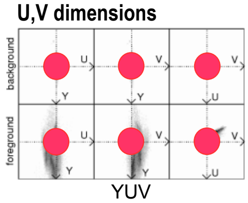
example result

Distribution of Color Differences (4)

* **Euclidean distance in YUV space**

  [redacted]

* **Defines sphere**
* **However, background distribution has lower variance in U,V dimensions**



YUV

example result

Background Subtraction

* **Summary**
  - change detection between input frame and background frame
  - independent pixel classification
    - RGB, YUV color difference
    - greyscale difference
    - sum of squared difference
    - Mahalanobis distance
  - classify groups of pixels
    - joint probability has less overlap
    - results are more robust to noise

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  - region-merging
  - watershed
- Background Subtraction
  - background generation
  - change detection
- **Model-based Object Detection**
  - graph model

GM Algorithm: Principle (1)

- How can we tell the computer what objects we want to extract?

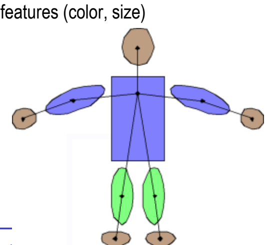
GM Algorithm: Principle (2)

- The same "object" can show in many deformed appearances

- Objects can be partly occluded

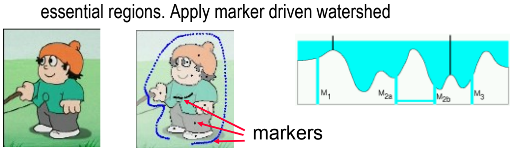
GM Algorithm: Principle (3)

- Idea: Describe objects with graph-based models
- The graph consists of:
  - **nodes** for the essential object regions
  - nodes have **attributes** with region features (color, size)
  - **edges** denote spatial relationships between regions



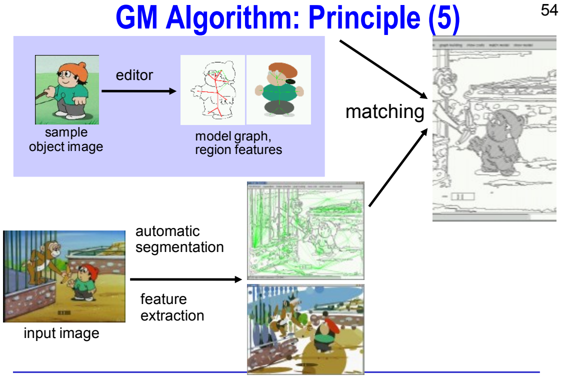
GM Algorithm: Principle (4)

- Generation of the object model:
  - user takes example image and places markers into essential regions. Apply marker driven watershed



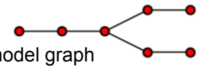
  - user specifies spatial relationships between regions that must be fulfilled

GM Algorithm: Principle (5)

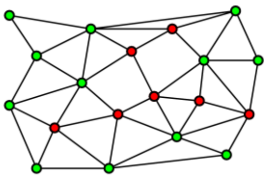


Graph-Model: Graph Matching (1)

* **Graph Matching**
  - model graph (V_M, E_M)
  - segmentation graph (V_S, E_S)
  - mapping [redacted]
  - cost function [redacted]
  - determine
    [redacted]



model graph



segmentation graph

Graph-Model: Graph Matching (2)

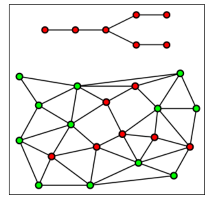
* **Matching cost function consists of**

[redacted]

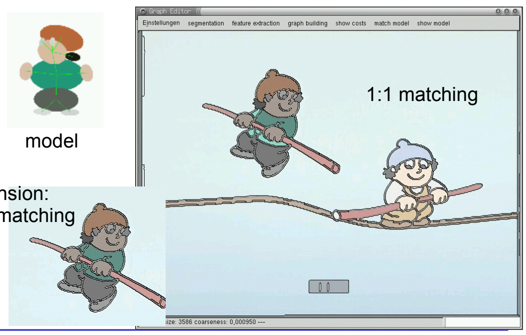
- Node costs
  - similarity of regions (color, shape, ...)

  [redacted]
- Edge cost
  - relations between regions (distances, size ratios)

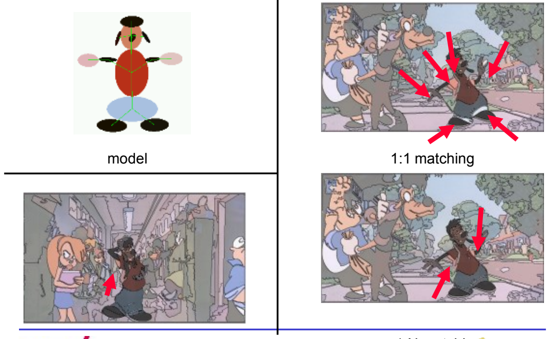
  [redacted]



Graph-Model: Result (1)



Graph-Model: Result (3)



Graph-Model based Object Detection

* **Summary**
  - algorithm to detect general objects
  - object is described with attributed graphs (only tree-shaped)
  - manual definition of model graph
  - automatic color segmentation to obtain segmentation graph
  - efficient graph-matching algorithm to detect model graph in segmentation graph

References (1)

* **Color segmentation**
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* **Background subtraction**
  - T. Aach, A. Kaup, "Statistical model-based change detection in moving video", Signal Processing 31, pp. 165-180, 1993

References (2)

* **Intelligent Scissors**
  - E.N. Mortensen and W.A. Barrett, “Interactive Segmentation with Intelligent Scissors”, Graphical Models and Image Processing, Vol. 60, No. 5, pp. 349-384, Sept. 1998.
* **Segmentation based on feature clustering**
  - J. Shi, J. Malik, “Normalized Cuts and Image Segmentation”, IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 22, No. 8, pp. 888-905, 2000.