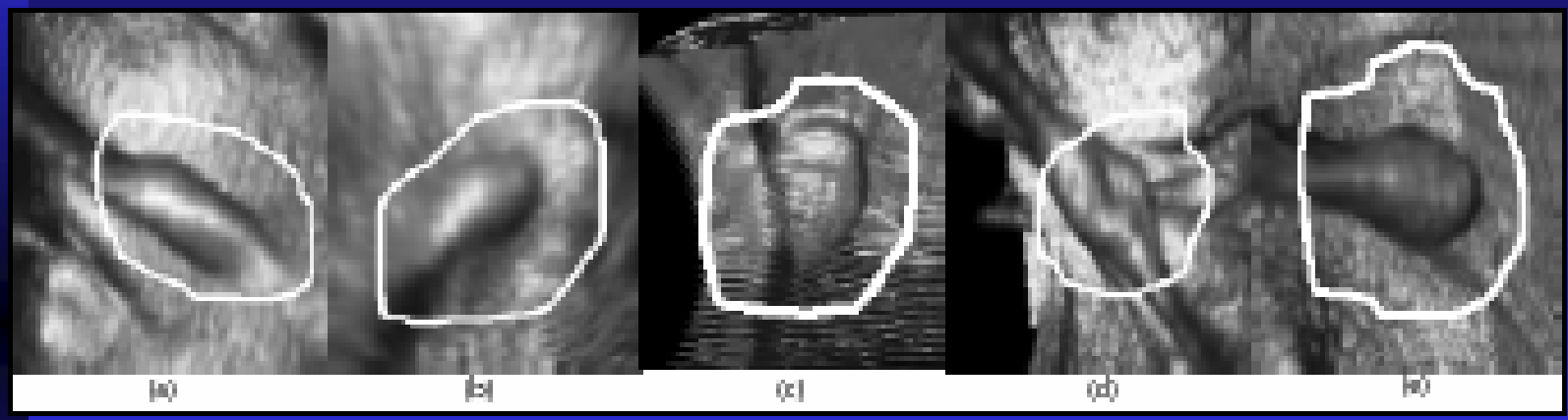
Virtual Colonoscopy with Computer Aided Detection

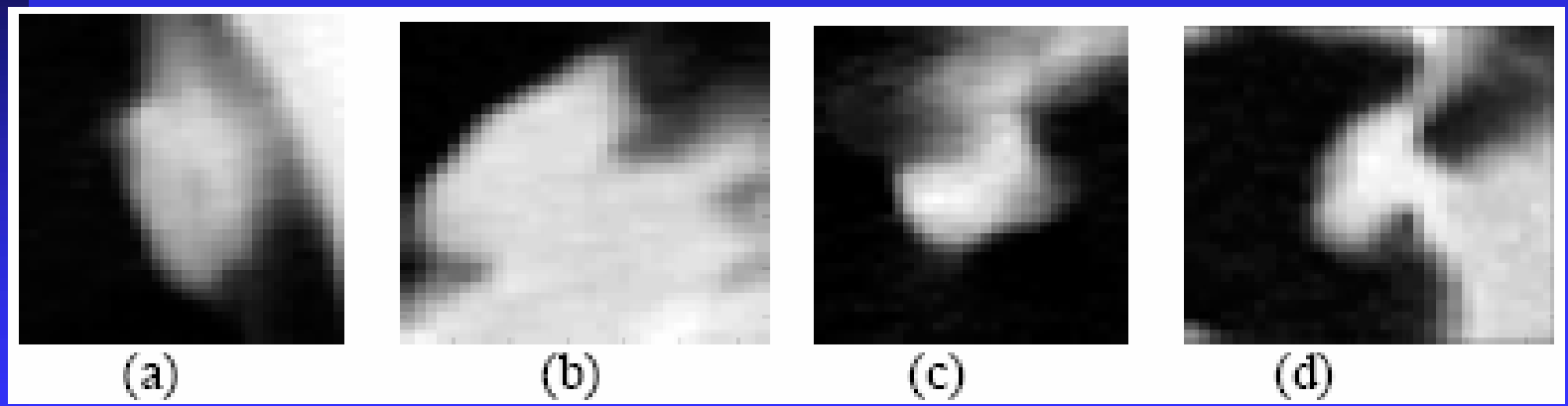
Gábor Blázsovits

Introduction

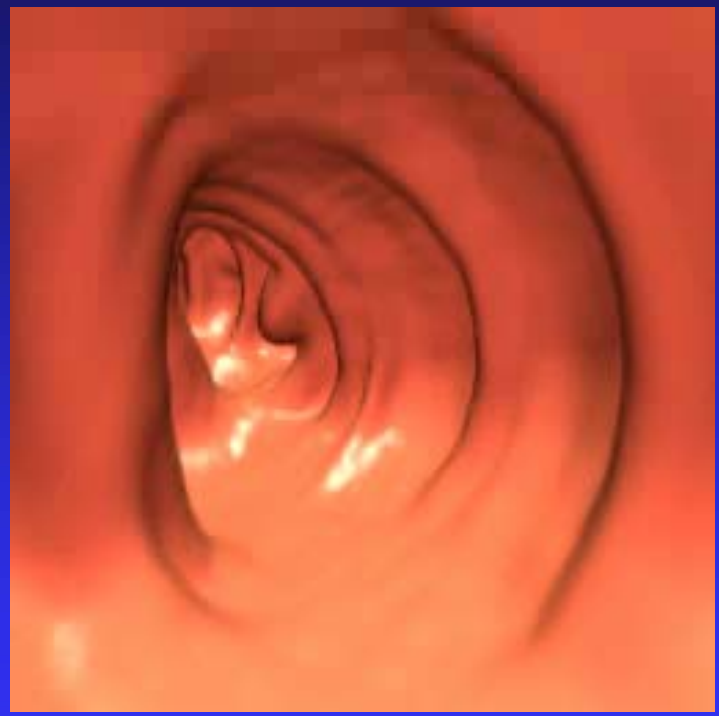
- Polyp and Colon cancer
- Colonoscopy and Virtual colonoscopy (VC)
- VC with computer aided detection (CAD)

Polyp examples

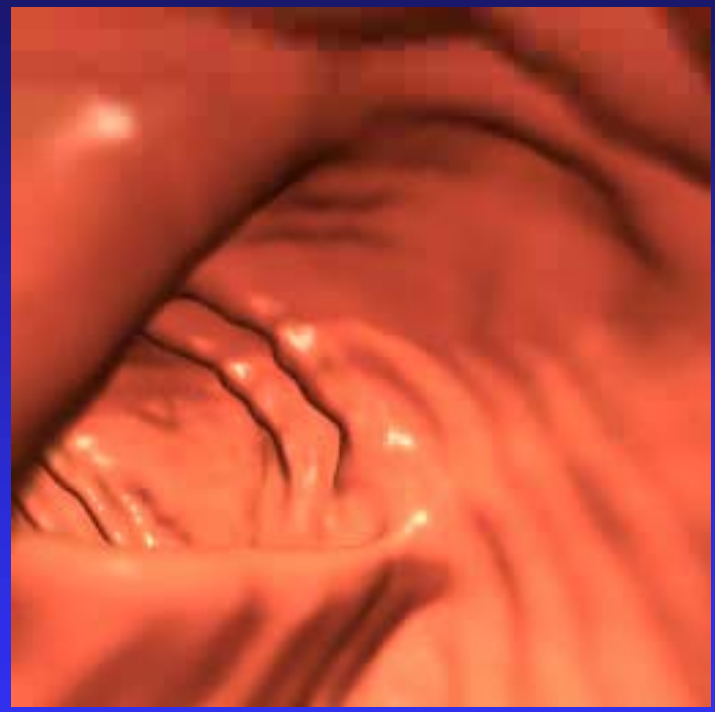




VC examples



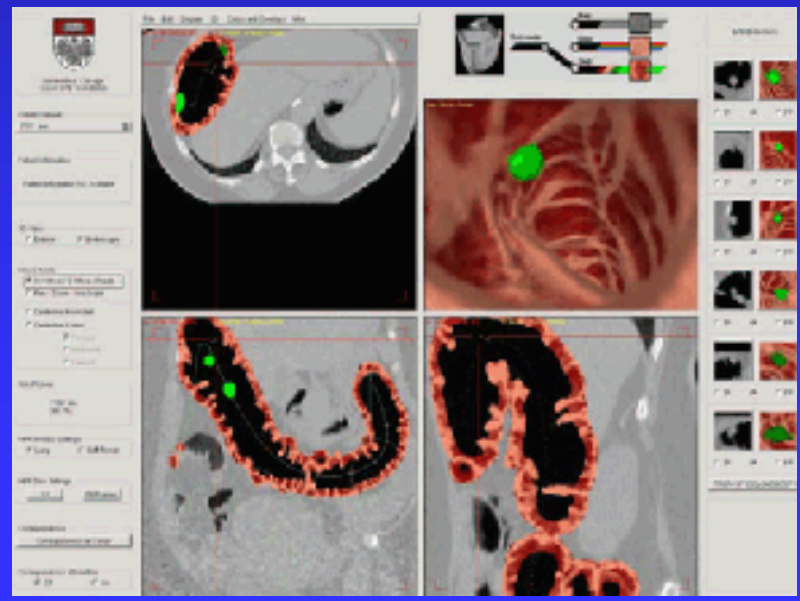
Big polyp example



Small polyp example

VC with CAD

- Colon wall segmentation
- ROI identification
- Feature derivation from the ROI
- Feature based classification



Colon wall segmentation

- 3D Region growing with thresholding

$$D_{thresh} \approx D_{air} + \frac{D_{colon} - D_{air}}{2}$$

  - Seed pints
- Iso-surface techniques

Material	Density (HU)
Air	-1500
Fat	-40
Water	0
Soft Tissue	80
Calcium	400
Metal	2000

ROI identification

- Curvature estimation:
  - Kernel-based convolution methods
  - Surface patch fitting methods

Curvature estimation

by kernel-based convolution methods

- $$k_t = -\frac{\mathbf{t}^T \mathbf{H} \mathbf{t}}{\|\mathbf{g}\|},$$

  k – curvature t – direction H – Hessian matrix

  g – gradient
- We can use edge filters to get partial derivatives
- On the ridges or in the valleys of thin structures the gradient magnitude is equal to or nearly zero

Curvature estimation

by Surface patch fitting methods 1

Least square fitting:

- Find the neighborhood Σ of p_0
- Compute the normal N_0 at p_0
- Rearrange the coordinate system
- Find the patch $f(x,y)$ by minimizing $\sum_{i=0}^{n-1} \| z_i - f(x_i, y_i) \|^2$

Three patch fitting methods:

- Cubic B-spline
- Paraboloid $f(x,y) = ax^2 + bxy + cy^2$
- Quadratic polynomials $f(x,y) = ax^2 + bxy + cy^2 + dx + ey$

Curvature estimation

by Surface patch fitting methods 2

z=f(x,y) can be parametrized by

$$\mathbf{x}(u,v) = (u, v, f(u,v))^T,\ (u,v) \in U \subset \mathbf{R}^2$$

The curvature k at a point p in the direction t:

$$k_t = \nabla_t \mathbf{N}$$

$$\mathbf{N}(x,y) = \frac{\mathbf{x}_u \times \mathbf{x}_v}{\|\mathbf{x}_u \times \mathbf{x}_v\|} = \frac{(-f_x, -f_y, 1)^T}{(1 + f_x^2 + f_y^2)^{1/2}}$$

Principal curvatures k1, k2:

$$k_1 = H + \sqrt{H^2 - K}$$

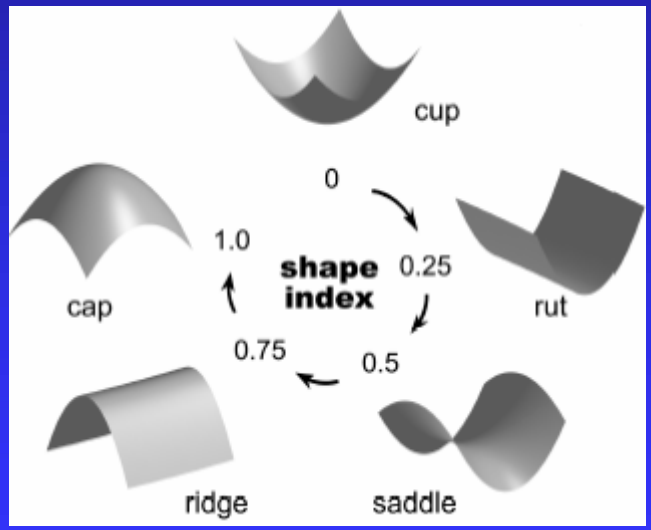
$$k_2 = H - \sqrt{H^2 - K}$$

$$K = \frac{f_{xx} f_{yy} - f_{xy}^2}{(1 + f_x^2 + f_y^2)^2}$$

$$2H = \frac{(1 + f_x^2) f_{yy} - 2 f_x f_y f_{xy} + (1 + f_y^2) f_{xx}}{(1 + f_x^2 + f_y^2)^{3/2}}$$

ROI identification 2

- Curvature characteristics
- 3D shape

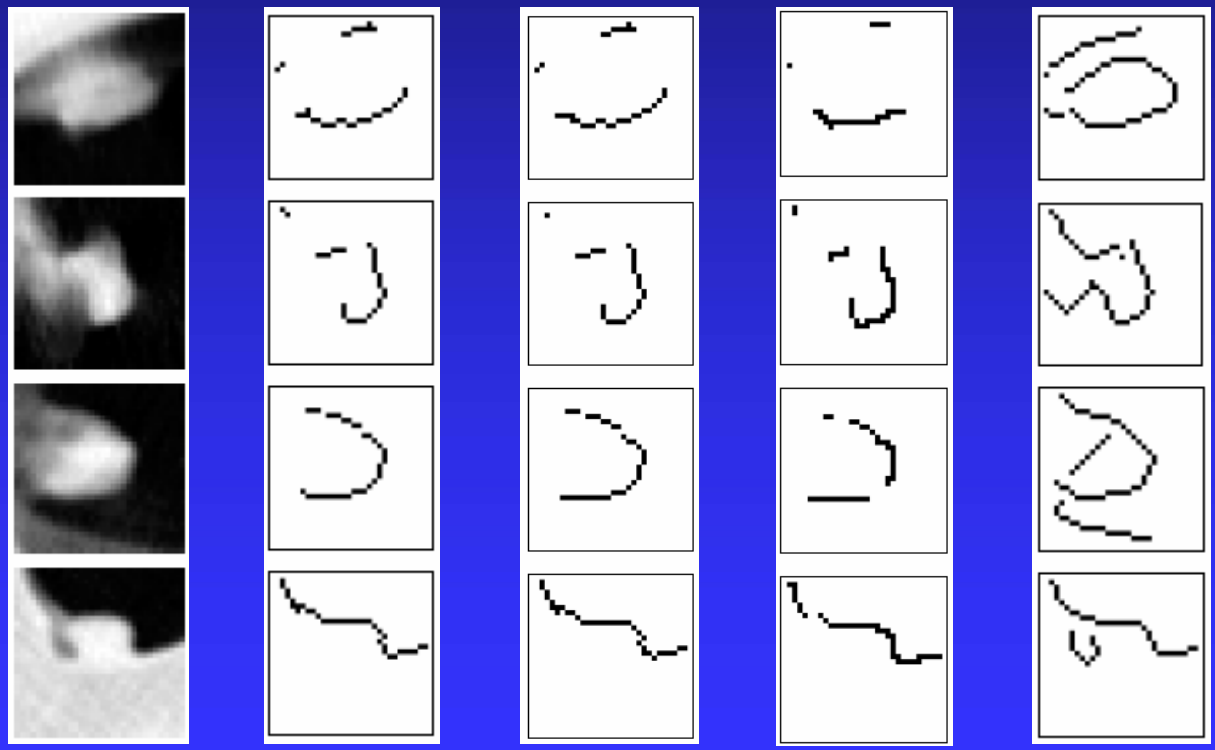


Feature derivation form the ROI

- Polyp segmentation
  - 2D methods
  - 3D methods
- Feature extraction

Polyp segmentation by 2D methods 1

- Detect boundaries by edge detectors



Original Sobel Prewitt Roberts Canny

Polyp segmentation by 3D method using dynamic deformable surfaces 1

- Preparation stage
  - Colon surface extraction
  - Classification of the surface vertices using their curvature and local density distribution
  - ROI of 64x64 pixels x 32 slices
- Enhancement stage
  - 3D knowledge-guided intensity adjustment
  - Fuzzy clustering
- Segmentation stage
  - Deformable models

Polyp segmentation by 3D method

using dynamic deformable surfaces 2

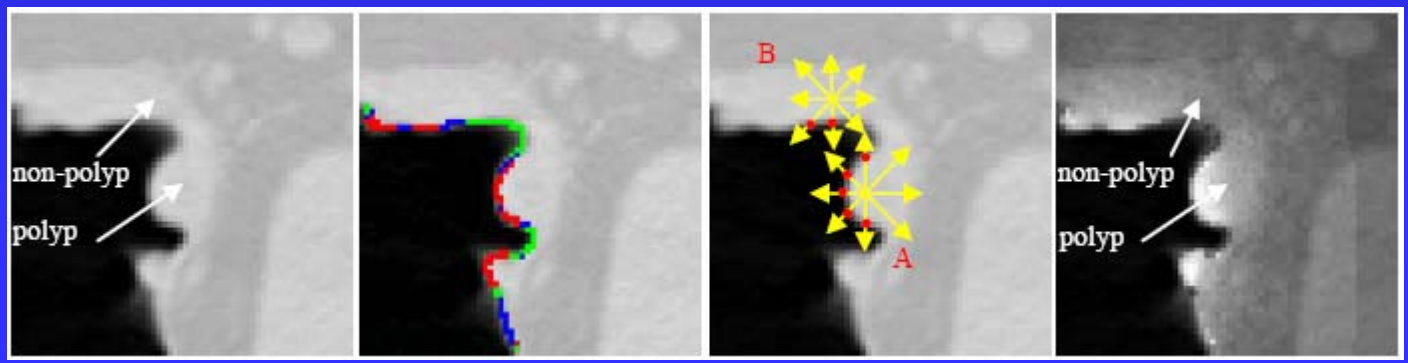
3D knowledge-guided intensity adjustment:

- Categorize the boundary points: convex, flat, concave
- Shot rays
- Calculate the score

$$Adjustment(v) = score(v) \times r$$

$$score(v) = \sum_{k=1}^{N} E(v, d_k, m)$$

$$E(v, d_k, m) = \begin{cases} 1, \text{hit a convex boundary within distance } m \\ 0.5, \text{hit a flat boundary within distance } m \\ -1, \text{hit a concave boundary within distance } m \\ -1, \text{no hit within distance } m \end{cases}$$

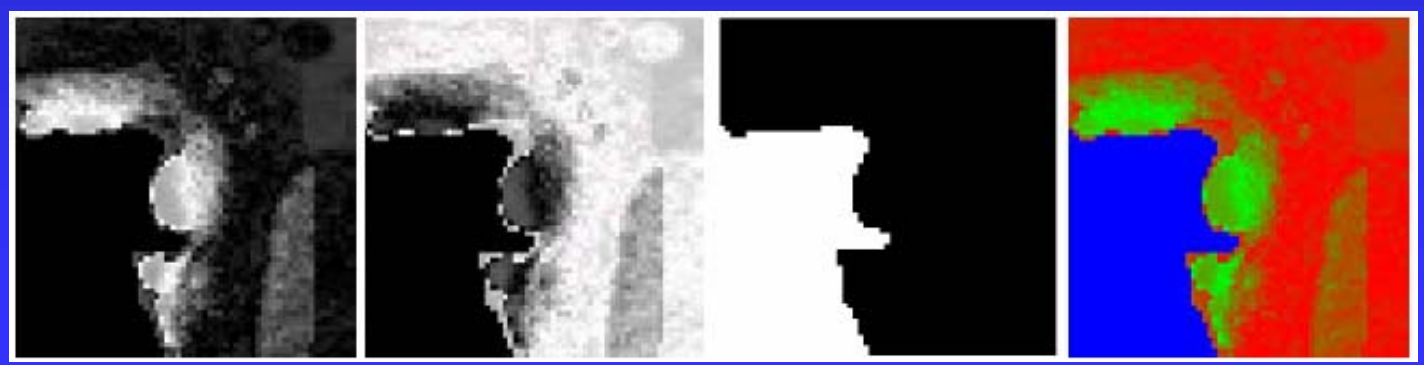


Polyp segmentation by 3D method

using dynamic deformable surfaces 3

Fuzzy c-mean clustering:

- Polyp tissue class
- Non-polyp tissue class
- Lumen air class



Polyp segmentation by 3D method

using dynamic deformable surfaces 4

Dynamic deformable surfaces:

- The initial surface is a cube (2x2x2 pixels)
- Deformation force: $F(v) = w_{internal}F_{internal}(v) + w_{image}F_{image}(v) + w_{balloon}F_{balloon}(v)$
  - Internal forces – smoothness, continuity

$$F_{internal}(v) = \alpha\nabla_v^2 s(v) - \beta\nabla_v^2(\nabla_v^2 s(v))$$

  - Image forces – attract the surface to polyp boundaries

$$F_{image}(v) = \nabla\left(G_\sigma\left(\left|\nabla G_\sigma(\mu(v))\right|^2\right)\right)$$

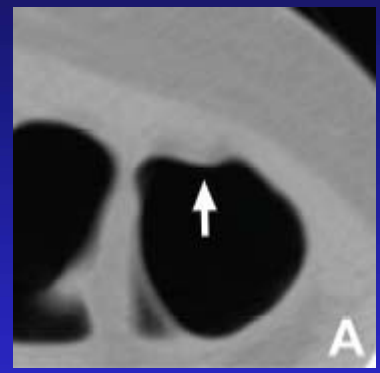
  - External forces – balloon forces helps to speed up the converging process

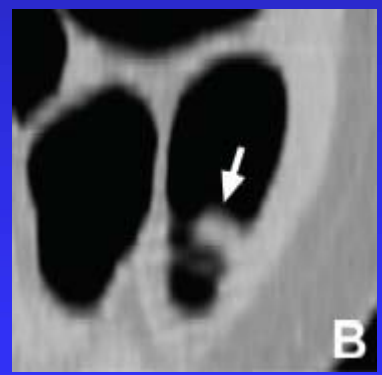
$$F_{balloon}(v) = \frac{v - v_c}{\|v - v_c\|}$$

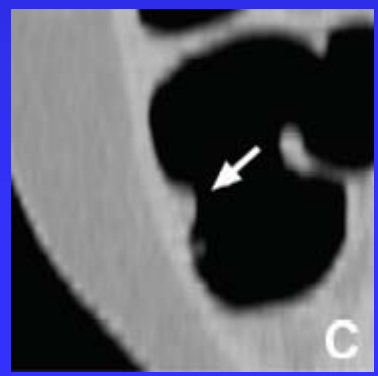
Feature derivation

Characterizing features:

- Shape
- Curvature
- Geometric features







Polyp feature extraction

- Polyp baseline
- Height
- Radius
- Boundary length
- Mean intensity

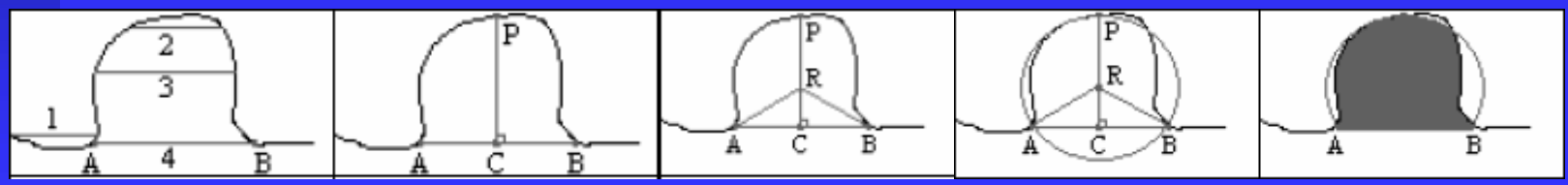
$$polyp\ height = \left[(C_x - P_x)^2 + (C_y - P_y)^2\right]^{1/2}$$

$$polyp\ radius = \frac{l^2}{8h} + \frac{h}{2}$$

$l = dist(A,B)$ and $h = dist(P,\ C)$

$$boundary\ length \approx \sqrt{l^2 + \frac{16h^2}{3}}$$

$$mean\ intensity = \frac{\sum_{\forall (x,y) \in p(x,y)} I_{(x,y)}}{N}$$



Feature based classification

CAD system has two phases:

- Training phase
  - Feature selection methods:
    - Forward stepwise search(FSS)
    - Genetic algorithm(GA)
- Application phase

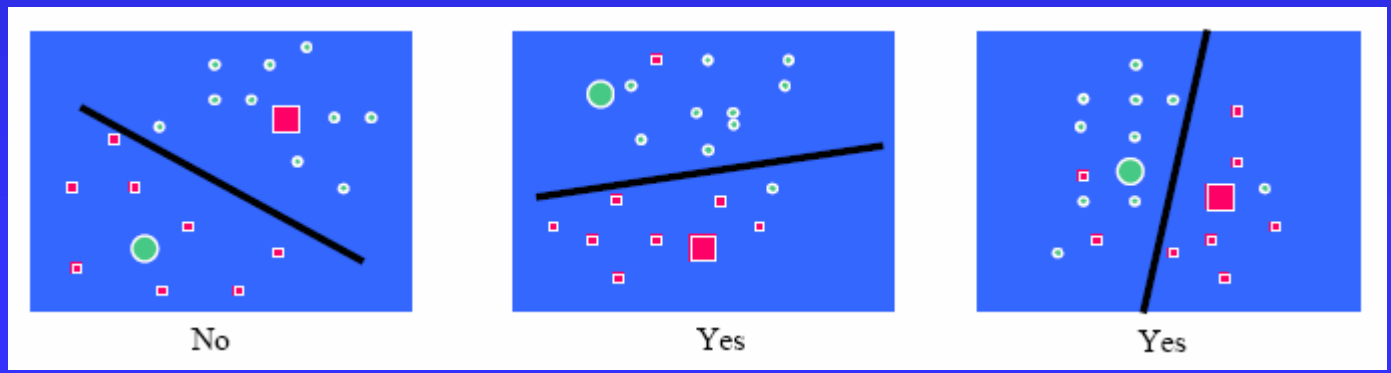
Classifiers:

- Support Vector Machines (SVM)
- Neural Networks (NN)

Support vector machines

SVM Committee

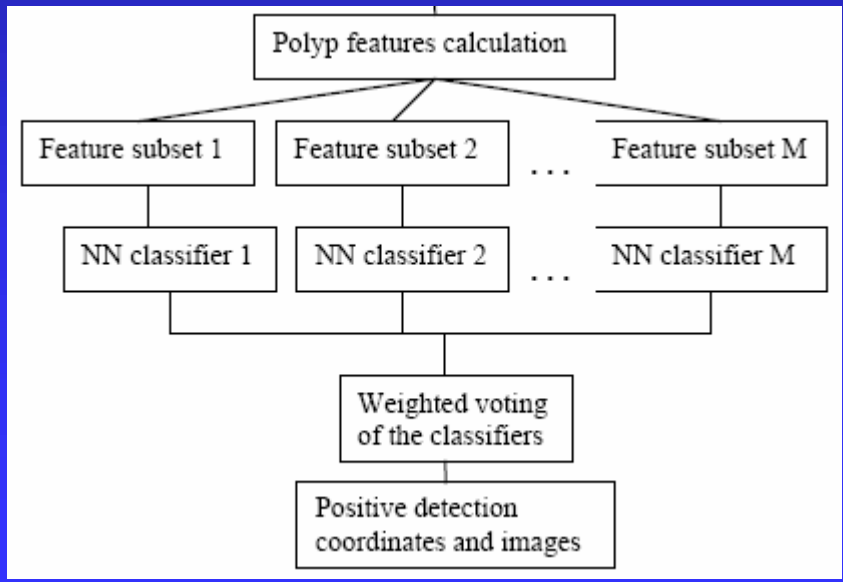
- M different SVMs
- N-feature vector
- Determine the optimal committee configuration by Two-way ANOVA analysis



Neural Networks

Multi network classification scheme

- Classification scheme containing several neural networks (NN forest).
- Different sets of features
- Voting system



References

Anna K. Jerebko, Sheldon B. Teerlink, M. Franaszek, Ronald M. Summers, Polyp Segmentation Method for CT Colonography Computer Aided Detection, Medical Imaging 2003 SPIE

Anna K. Jerebko, James D. Malley, M. Franaszek, R. M. Summers, Multi network classification scheme for detection of colonic polyps in CT colonography data set.

A. Huang, R.M. Summers, A. K. Hara, Surface curvature estimation for automatic polyp detection, Medical Imaging 2005 SPIE

J. Yao, R. M. Summers, A. Hara, Optimizing the Support Vector Machines (SVM) Committee Configuration in a Colonic Polyp CAD System, Medical Imaging 2005 SPIE

J. Yao, M. Miller, M. Franaszek, R.M. Summers, Colonic Polyp Segmentation in CT Colonography - Based on Fuzzy Clustering and Deformable Models, 2004 IEEE

J. Yao, R.M. Summers, 3D colonic polyp segmentation using dynamic deformable surfaces

J. Yao, M. Miller, M. Franaszek, R.M. Summers, Automatic Segmentation of Colonic Polyps in CT Colonography Based on Knowledge-Guided Deformable Models. Medical Imaging 2003 SPIE

S.B. Göktźrk, C. Tomasi, A New 3-D Pattern Recognition Technique with Application to Computer Aided Colonography, IEEE 2001 CVPR

H. Yoshida, Y. Masutani, P. MacEneaney, D.T. Rubin, A.H. Dachman, Computerized Detection of Colonic Polyps at CT Colonography on the Basis of Volumetric Features: Pilot Study.

R.M. Summers, Current concept and future directions in computer-aided diagnosis for CT colonography

F. Vas, I. Serlie, R. van Gelder, J. Stoker, H. Vrooman, F. Post, A review of Technical Advances in Virtual Colonoscopy.