

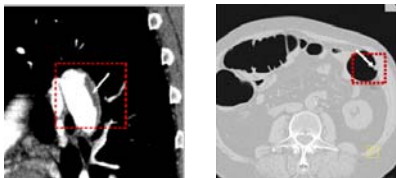
Introduction

We proposed a learning formulation to combine cascade classification and multiple instance learning (MIL) in a unified min-max framework and applied it to the computer aided diagnosis (CAD) of detecting pulmonary embolism (PE) and colon cancer from computed tomography images.

Computer Aided Diagnosis

The CAD problems of detecting potentially diseased structures from medical images are typically distinguished by

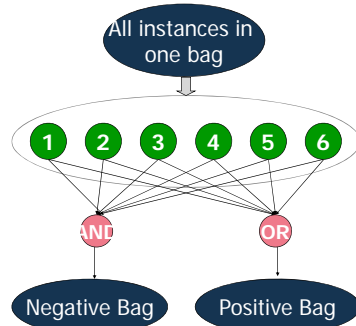
- Extremely unbalanced data between negative and positive classes
- Stringent real-time requirement of online execution
- Multiple positive candidates generated for the same malignant structure that are highly correlated and spatially close to each other.



Pulmonary Emboli

Colon Polyp

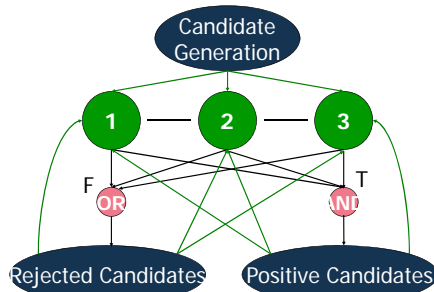
Multiple Instance Learning (MIL)



A bag is

- positive if at least one instance in the bag is positive
- negative if all instances in the bag are negative

Cascade of Hyperplane Classifiers



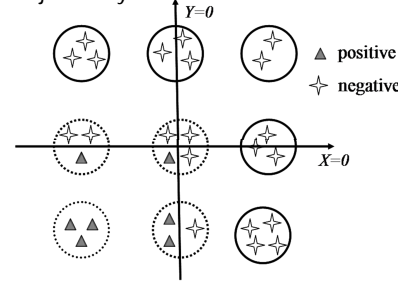
A candidate is

- rejected if labeled as negative at any stage in the cascade
- detected if labeled as positive at all stages in the cascade

Min-Max Optimization of Cascaded Classifier with MIL

A single formulation to combine MIL and cascaded classification in a single min-max framework. A bag is

- positive if at least one instance of this bag is recognized by all stages in the cascade
- negative if all instances of this bag is rejected by at least one classifier



$$\arg \min_{\xi, \eta, \omega, b} \gamma \sum_{k=1}^L \|\omega_k\|_1 + \sum_{i=1}^{N_{B^+}} \min_{j \in B_i^+} \{ \max_{1 \leq k \leq L} \{ \xi_{j,k} \} \}$$

$$+ \sum_{i=1}^{N_{B^-}} \max_{j \in B_i^-} \{ \min_{1 \leq k \leq L} \{ \eta_{j,k} \} \}$$

$$s.t. \quad \xi_{j,k} \geq 1 - (\omega_k^T x_{j,k} + b_k), \quad \xi_{j,k} \geq 0$$

$$j \in C^+, \quad 1 \leq k \leq L$$

$$\eta_{j,k} \geq 1 + (\omega_k^T x_{j,k} + b_k), \quad \eta_{j,k} \geq 0$$

$$j \in C^-, \quad 1 \leq k \leq L$$

Converted to an equivalent and tractable quadratically constrained quadratic problem:

$$\arg \min_{\lambda, \zeta, \mu, \nu, \xi, \eta, \omega, b} \gamma \sum_{k=1}^L \|\omega_k\|_1 + \sum_{i=1}^{N_{B^+}} \sum_{j \in B_i^+} \lambda_j \zeta_j + \sum_{i=1}^{N_{B^-}} \mu_i$$

$$s.t. \quad \xi_{j,k} \geq 1 - (\omega_k^T x_{j,k} + b_k), \quad \xi_{j,k} \geq 0$$

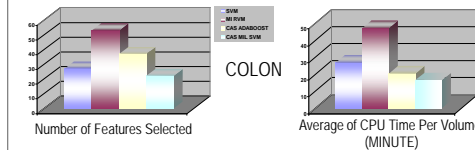
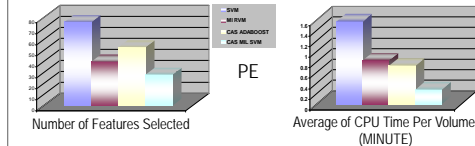
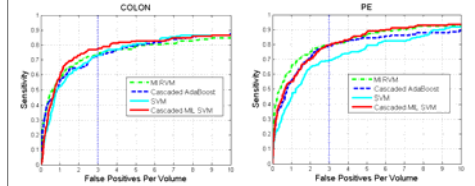
$$\zeta_j \geq \xi_{j,k} \quad (\forall 1 \leq k \leq L) \quad \sum_{j \in B_i^+} \lambda_j = 1, \quad \lambda_j \geq 0$$

$$\eta_{j,k} \geq 1 + (\omega_k^T x_{j,k} + b_k), \quad \eta_{j,k} \geq 0$$

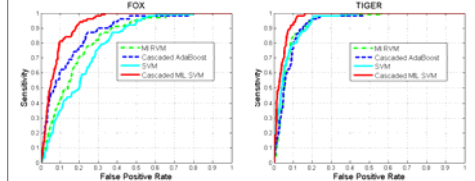
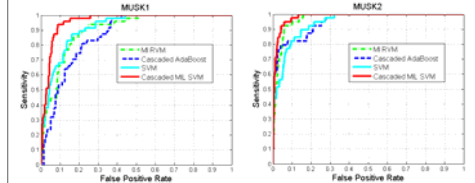
$$\mu_i \geq \sum_{k=1}^L \nu_{j,k} \eta_{j,k} \quad (\forall j \in B_i^-) \quad \sum_{k=1}^L \nu_{j,k} = 1, \quad \nu_{j,k} \geq 0$$

Results

CAD datasets



Benchmark dataset



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