The MAGIC-5 CAD for nodule detection in low dose and thin slice lung CT

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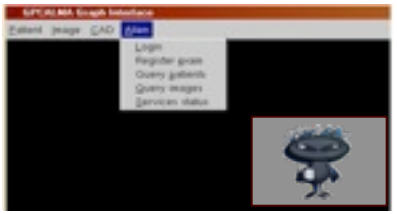
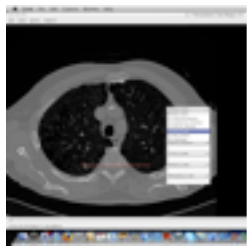
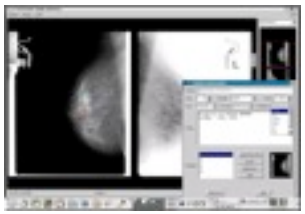
MAGIC-5

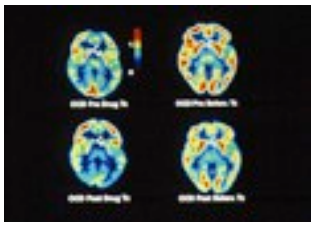
Computer Assisted Detection (CAD) & Distributed Computing Infrastructure (GRID)

- GRID
  - ✓ Why Medical ***Imaging*** Applications?
    - **Move the algorithm, not the data**
  - Interface to GRID Services (Meth. Inf. Med., 2005)
- Medical (Imaging) Applications
  - ✓ Analysis of Digital Images
    - **Mammography (2002 ->)**
    - **Lung CTs (2004 ->)**
    - **Brain MRIs (2006 ->)**









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CAD for Lung Cancer? (y 2003)

5 years survival rate for lung cancer: 14% (US), 10-15% (EU)
No significant improvement in the past 20 years

Low dose CT: 6 times more efficient than Chest X-Ray (CXR) in the detection of state I malignant nodules

CAD methods are being explored

Gurcan et al., Med. Phys. 29(11), Nov. 2002, 2552:

"…computerized detection for lung nodules in helical CT images is promising… large variations in performance, indicating that the computer vision techniques in this area have not been fully developed. Continued effort will be required to bring the performances of these computerized detection systems to a level acceptable for clinical implementation"

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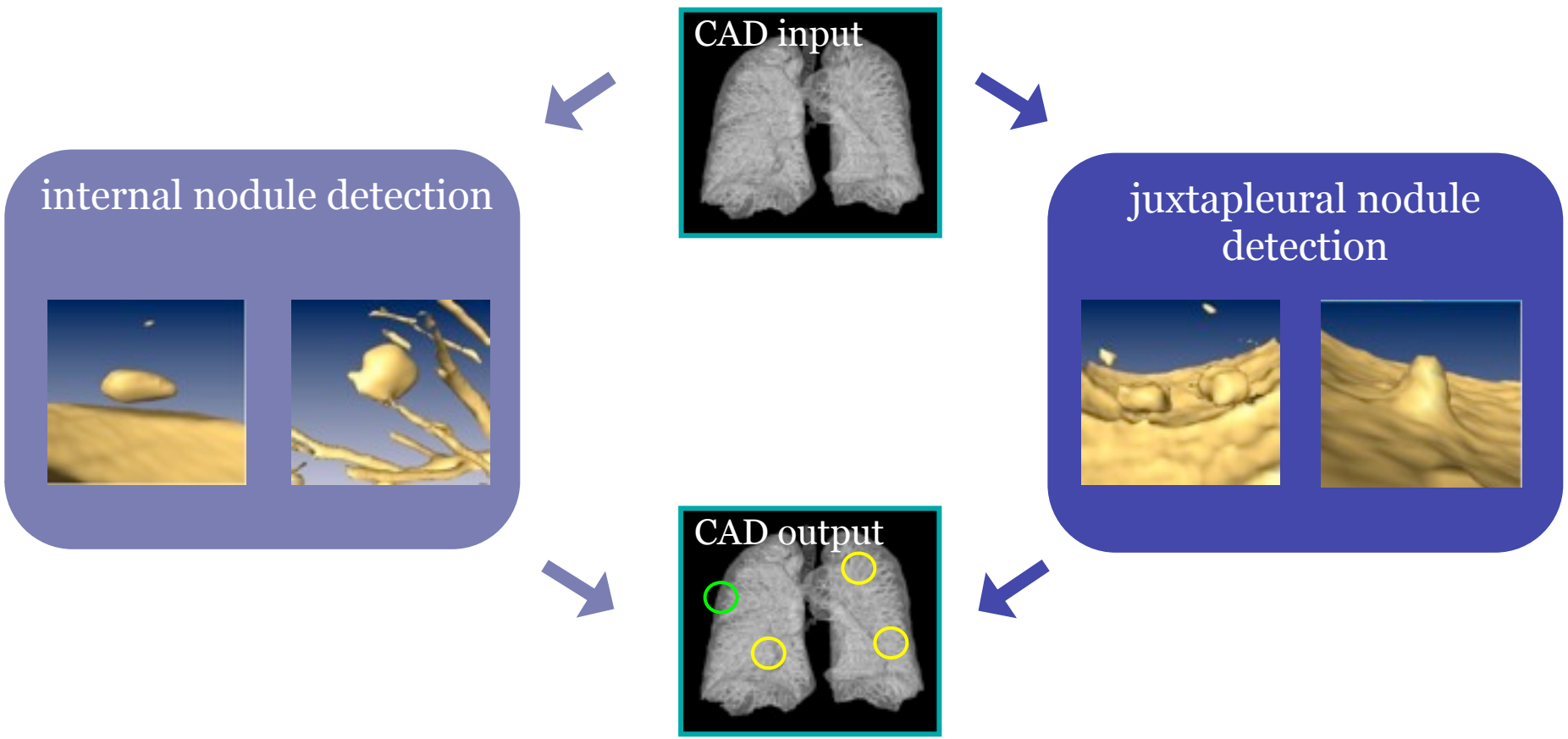
Lung CAD systems: the goal



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The MAGIC-5 Strategy

- CT scans DataBase(s):
  - Low-dose helical multi-slice CT: slice-thickness <= 1.25 mm
  - Annotation by 1 or more radiologists (up to 4)
  - Nodules of radius > 3, 4, 5 mm according to the different protocols
  - Agreement sometimes ~ 60% between radiologists
- Lung Segmentation
  - Lung Volume in CT
- Nodule Detection (3 parallel developments)
  - list of ROIs
- Nodule Classification
  - list of ROIs with probabilities
- Results and Validation

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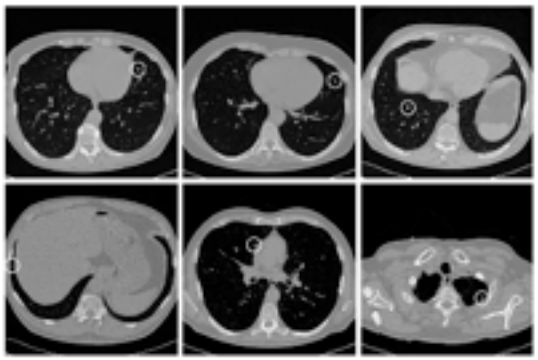
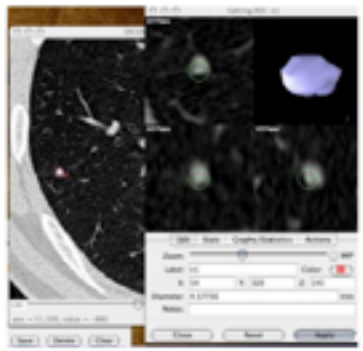
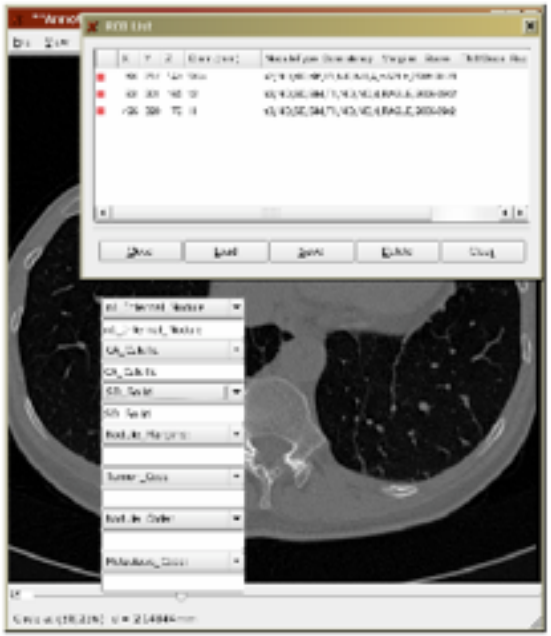
The Data Sets

The MAGIC-5 Database

- Lung Nodule Annotation (LUNA) tool developed
  - ~ 163 CT scans in the DB
  - Annotation by 2 to 4 radiologists from Pisa and Lecce
  - nodules with diameter > 5 mm







Data Size: ~ 250-500 slices, 512x512x2 bytes each: ~ 120-250 MB/scan

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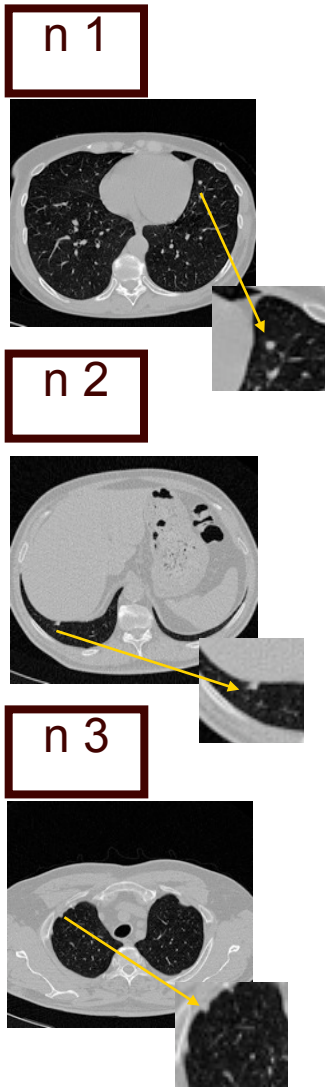
Other Databases



- LIDC

NBIA National Biomedical Imaging Archive

https://imaging.nci.nih.gov/ncia/login.jsf

~ 100 CT scans (rapidly increasing), with annotations by 1, 2, 3, 4, radiologists

nodules: > 3 mm diameter

- ANODE09

http://anode09.isi.uu.nl/

5 (50) scans with (without) annotation

nodules > 4 mm diameter

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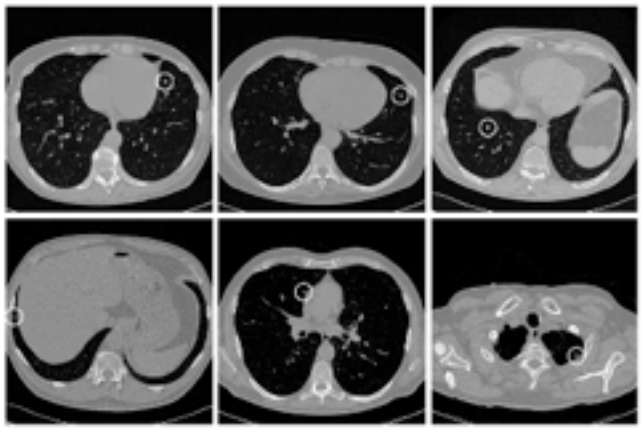
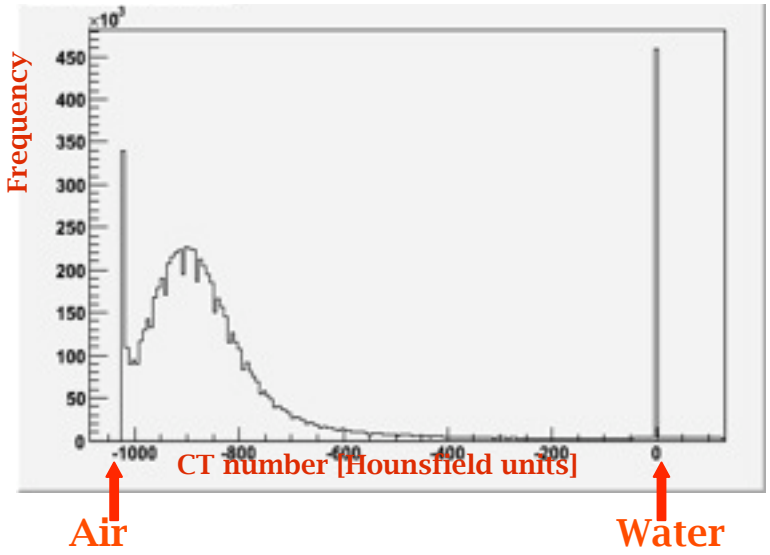
MAGIC-5 / Lung CT Analysis

A typical CT scan

- 3D Matrix recorded as a *DICOMDIR*
- Granularity (512x512x300 ca. voxels) $\Delta x = 0.5mm \quad \Delta y = 0.5mm \quad \Delta z = 1.25mm$
- Intensity: Hounsfield units: (X-rays attenuation in matter) [CT → (-1000,+3000)]

$$CTnumber = \frac{u_{tissue} - u_{H_2O}}{u_{H_2O}} \times 1000$$





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The Lung Volume

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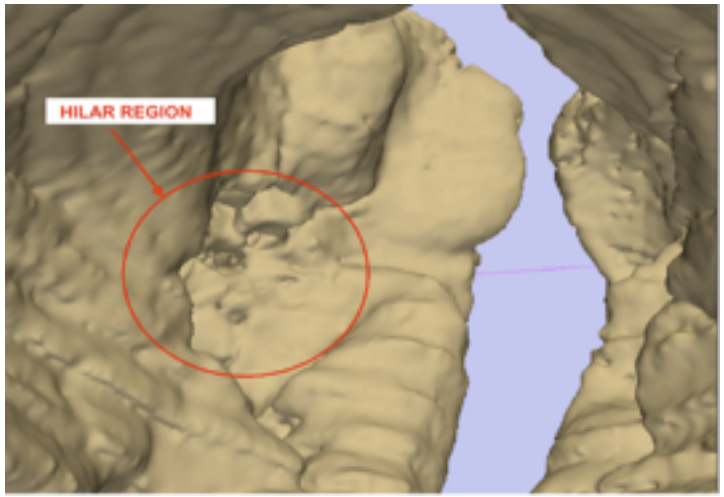
MAGIC-5 / Lung Segmentation

- **Segmenter: 3D approach**
  - **Region Growing**
  - **Wavefront Algorithm**



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MAGIC-5 / Lung Segmentation

- **Segmentation Steps**

Evaluation of an approximated threshold value (intensity histogram)

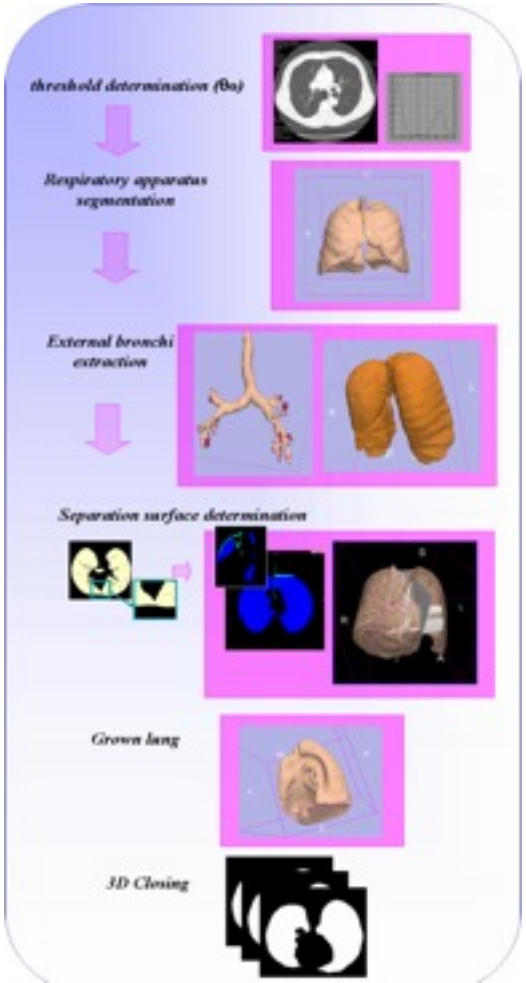
3D Region Growing (RG): tree segmentation

***Wavefront simulation algorithm*: trachea and external bronchi removal**

Left/Right Lung splitting

3D Region Growing on left and right lung

***Morphological 3D closing*: inclusion of pleural nodules**



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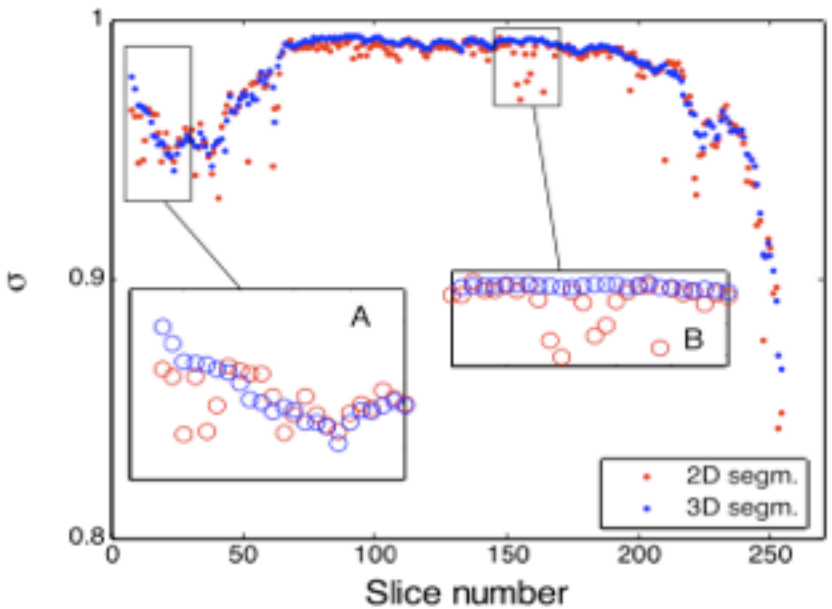
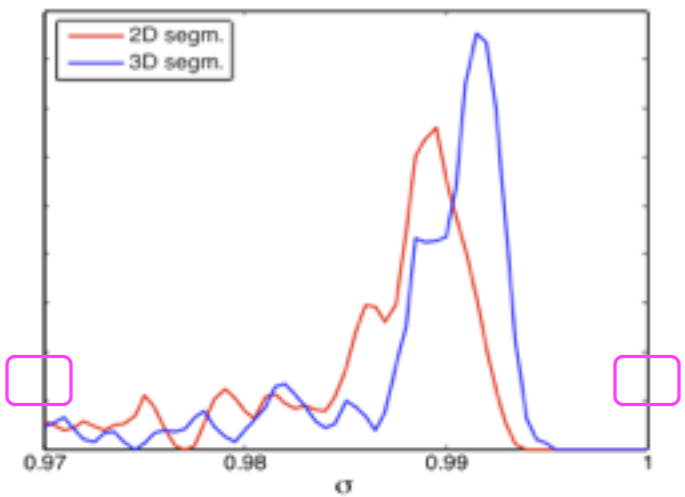
MAGIC-5 / Lung Segmentation

- **Segmenter Performance: smoothing test**
  - **Smoothing index**

    σ = Adjacent Slice Area Intersection / Adjacent Slice Area Union





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Voxel Based Neural Approach
Region Growing
Virtual Ant Colonies

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Voxel Based Neural Approach

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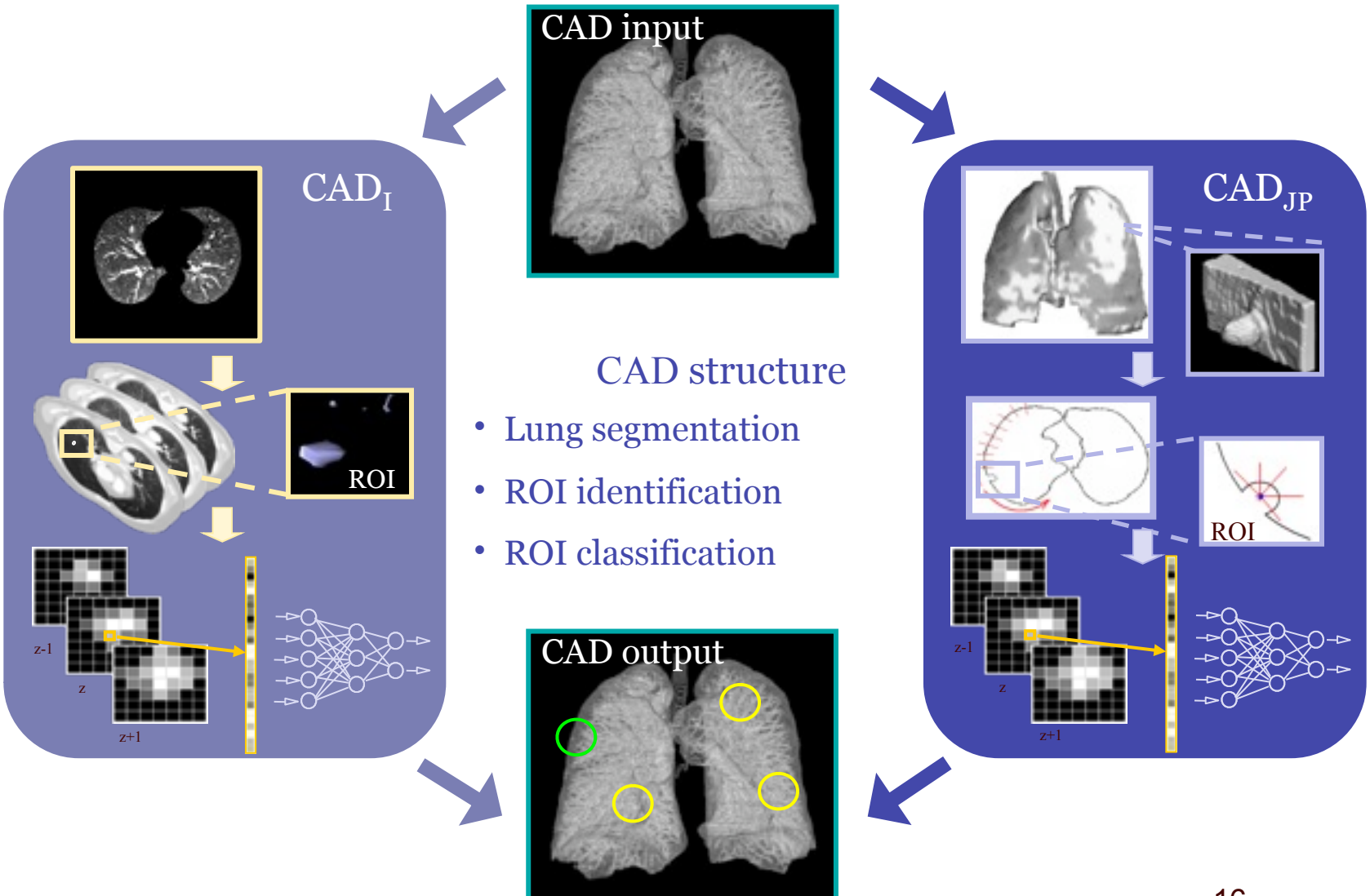
MAGIC-5 / VBNA



CAD structure

- Lung segmentation
- ROI identification
- ROI classification

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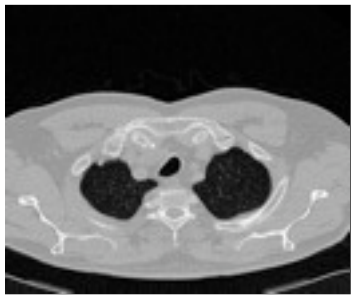
MAGIC-5 / VBNA



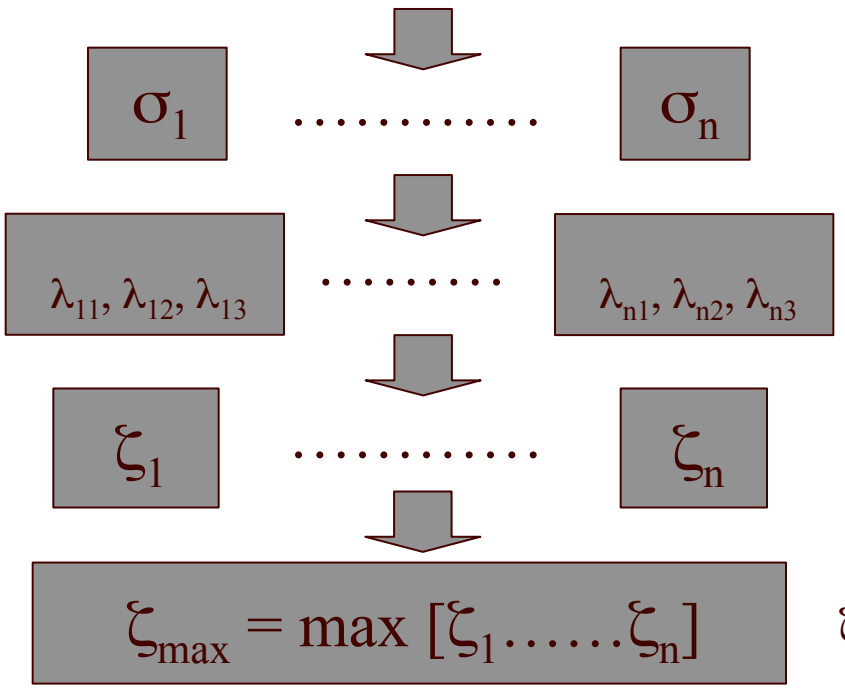
Modeling the lung structures:

- **Nodules → spherical shapes**
- **Blood vessels and airway walls → elongated shapes**
- **Fissures → planar shapes**

$$d(x,y,z)=\exp\left\{-\frac{x^2+y^2+z^2}{2\sigma^2}\right\}$$

$$l(x,y,z)=\exp\left\{-\frac{x^2+y^2}{2\sigma^2}\right\}$$

$$p(x,y,z)=\exp\left\{-\frac{x^2}{2\sigma^2}\right\}$$



Convolution with 3D gaussians

Eigenvalues of the Hessian matrix

Filter function

$$\begin{cases} \zeta\zeta_i = |\lambda_{i3}|^2/|\lambda_{i1}| \\ \quad \text{If } \lambda_{i1} \le \lambda_{i2} \le \lambda_{i3} < 0 \\ \zeta\zeta_i = 0 \quad \text{otherwise} \end{cases}$$

ζ_{max} is computed for each voxel

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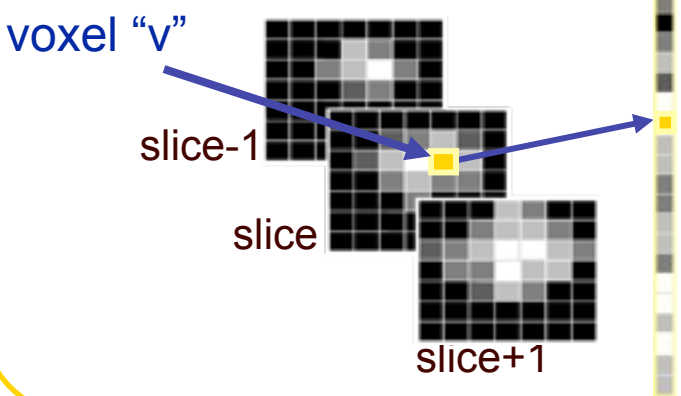
MAGIC-5 / VBNA

voxel "v" in ROI → vector of "features" (33) → neural classifier

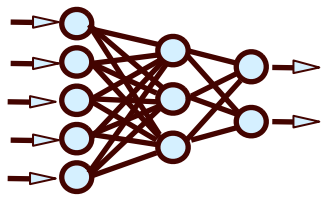
- "rolled-down" 3D neighborhood (27)



+ • 3 eigenvalues of *gradient matrix*

+ • 3 eigenvalues of Hessian matrix

three-layer feed-forward back-propagation neural network



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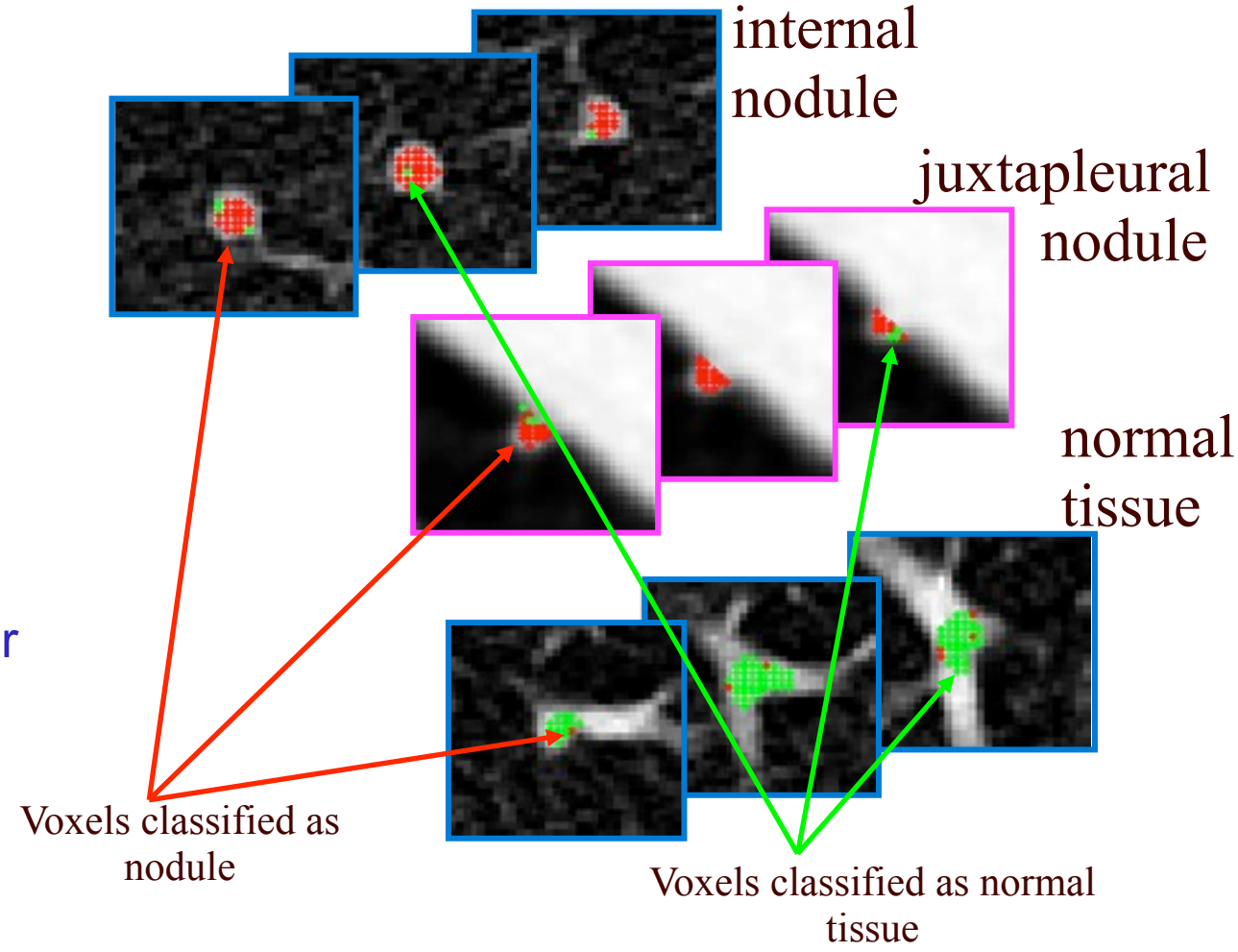
MAGIC-5 / VBNA

- From voxel classification to ROI classification:
- The trained neural network is applied to the voxels of each nodule candidate
- A nodule candidate is finally classified as “nodule” if the number of voxels tagged as “nodule” by the neural classifier is above a threshold



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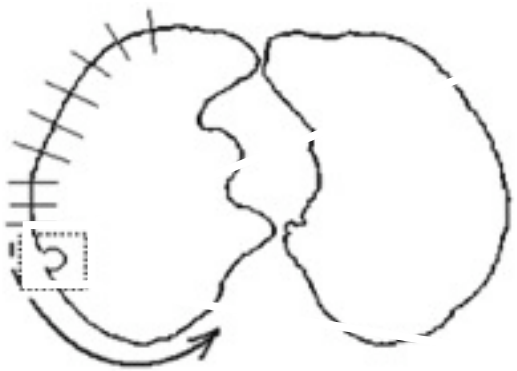
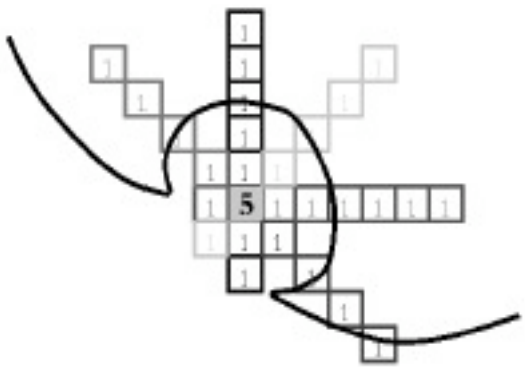
MAGIC-5 / VBNA

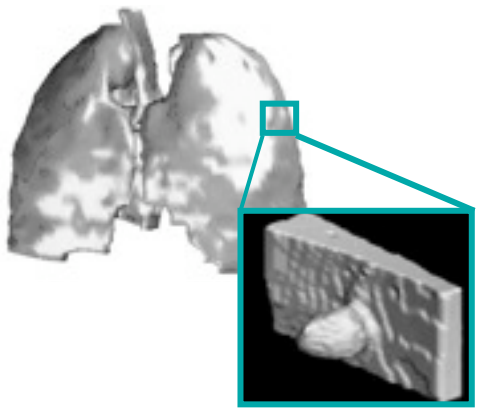
Pleural nodules: convex surface

the inward-pointing fixed-length surface normal vectors

crossing the nodule surface intersect within the nodule tissue







A 3D matrix A(x,y,z) counts the number of surface normals that pass through the voxel (x,y,z)

A(x,y,z) is smoothed with a gaussian to enhance the regions where many normals intersect

The local maxima in that matrix are nodule candidates

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Region Growing

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MAGIC-5 / Region Growing

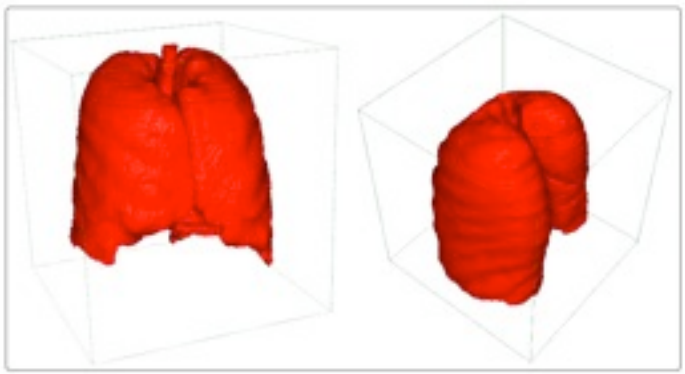
- Inside the lung segmented volume

✓ Search for ***seeds*** (voxels that meet the inclusion rules)

✓ Growth around the seeds by checking neighbours for inclusion rules, until no neighbour is accepted

✓ Grown regions are stored in memory and removed from the CT scan

-> Regions Of Interest list



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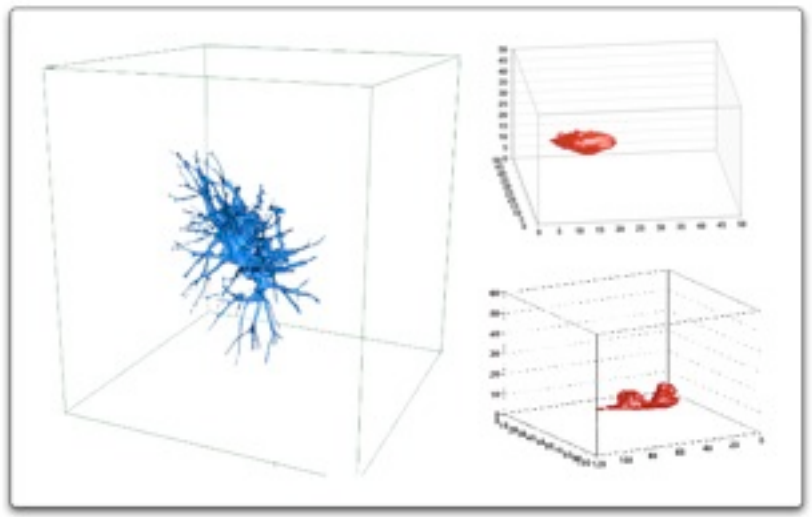
MAGIC-5 / Region Growing

- The inclusion rules
  - ✓ Average Bottom Threshold
    - Average intensity of voxel + 26 first order neighbours > Th_1
  - ✓ Simple Bottom Threshold
    - Voxel Intensity > Th_2



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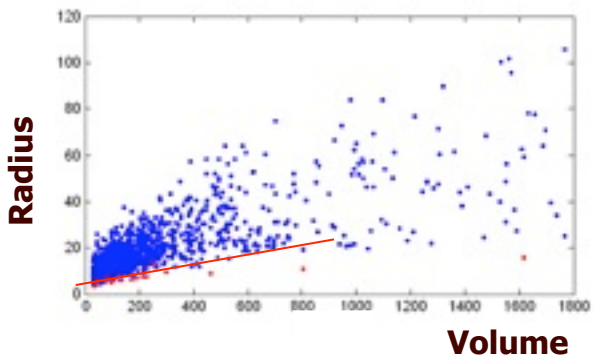
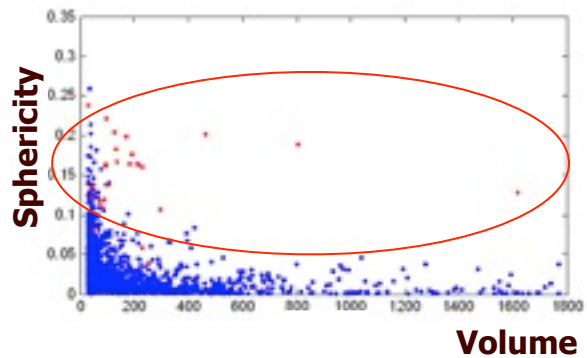
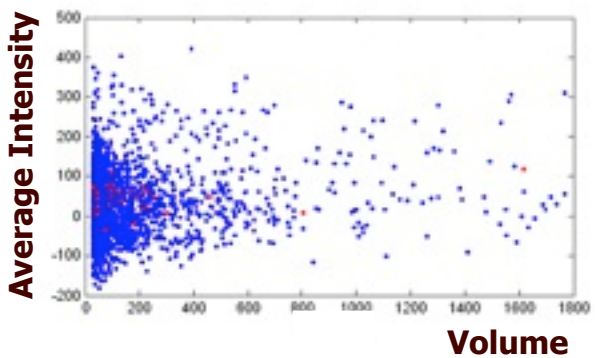
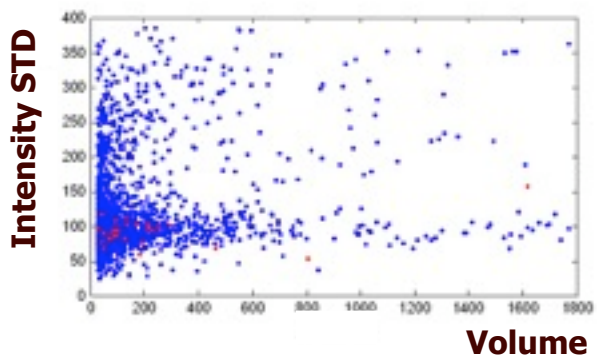
MAGIC-5 / Region Growing

- Nodule Hunter Filter
  - Volume ($V_1 < V < V_2$)
- Neural Network Classification
  - Sphericity
  - Radius
  - Average Intensity
  - Intensity Std. deviation









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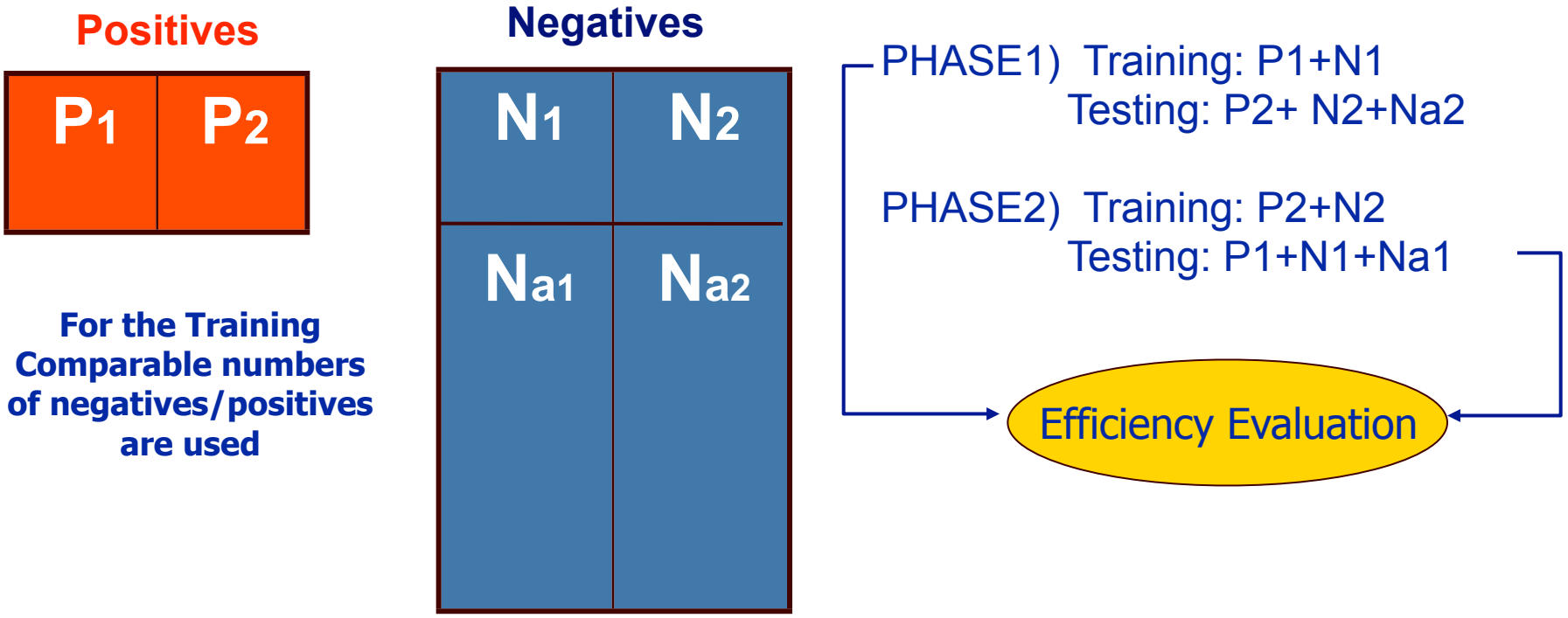
MAGIC-5 / Region Growing

- Neural Network Classification with Cross Validation



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Virtual Ant Colonies

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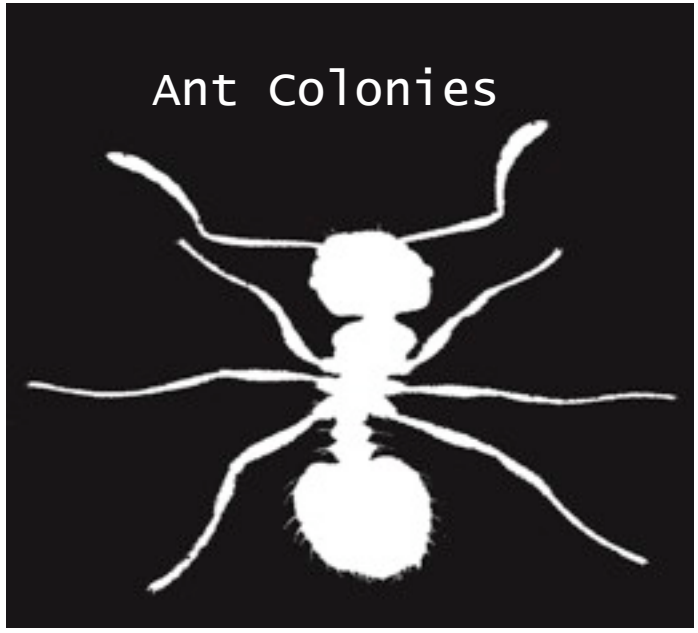
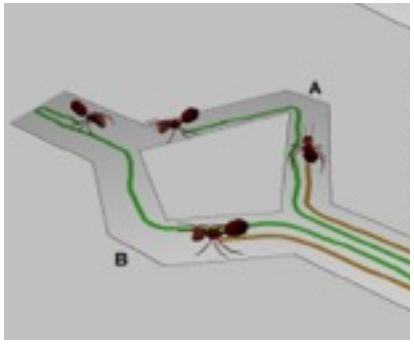
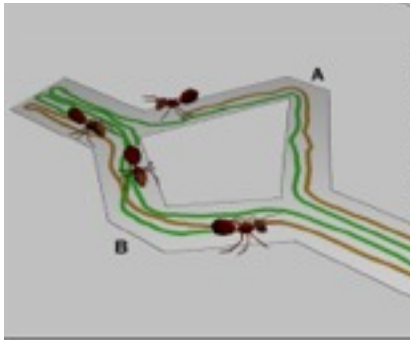
MAGIC-5 / Virtual Ant Colonies



- Communities of individuals that evolve according to the set of ant colonies biological rules
- Communication through modifications of the environment (i.e., depositing **pheromones**)
- The system is NON-LINEAR





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MAGIC-5
Virtual Ants in a Lung CT

Ants in nature show an ability to find:

- structures (sources of food)
- the shortest way to reach them

we need to find complex structures (food, i.e. bronchial and vascular trees), that are the background to our search for nodules

Ants can find structure borders

we need to find the pleura

Ants can define shapes

we look for ~ spherical nodules

Ant colonies act according to global information

ex: Region Growing implies a deterministic choice any time a voxel is analysed

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MAGIC-5
Ant Colony Evolution

The basic Idea

Segment the bronchial and the vascular tree
with a Virtual Ant Colony

- Remove the segmented bronchial and vascular trees
- Look for nodule structures in the subtracted image

with the same tools used for Region Growing
(Nodule Hunter & …)

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MAGIC-5 / Virtual Ant Colonies

- The Channeler Ant Model
  - The Queen
  - Pheromone Release
  - Moving Rules
  - Energy: birth, reproduction, death

MAGIC-5 / Virtual Ant Colonies

- The Queen
  - Sets the Anthill position (“hilus pulmonis”)
  - Manages the ant birth, movements, death
  - Manages the pheromone release
  - Extinguishes the colony

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MAGIC-5 / Virtual Ant Colonies

- The Pheromone Release
  - ✓ Before moving to another voxel, each ant releases an amount of pheromone *T* given by:

$$T = \eta + H_{fac} \times \Delta_{ph}$$

η is the minimum amount of released pheromone
H_{fac} is a scaling factor
Δ_{ph} is a function of the voxel intensity $I(v_i)$

$\eta = 0.07$
$H_{fac} = 2.0$

$$\Delta_{ph} = I(v_i) + I_{min}$$

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MAGIC-5 / Virtual Ant Colonies

- The Moving Rules

- ✓ Only neighbouring voxels are possible destinations
- ✓ Only free voxels are allowed
- ✓ The probability for a voxel to be selected is a function of its amount of pheromone
- ✓ Voxels with amount of pheromone above the maximum threshold are forbidden until the colony extinction

$$P_{ij}(v_i \rightarrow v_j) = \frac{W(\sigma_j)}{\sum_{n=1}^{26} W(\sigma_n)} \qquad W(\sigma_j) = \left(1 + \frac{\sigma_j}{1 + \delta \times \sigma_j}\right)^{\beta}$$

β osmotropotaxis sensitivity

$1/\delta$ sensory capacity

$1/\delta$	= 3.5
β	= 0.2

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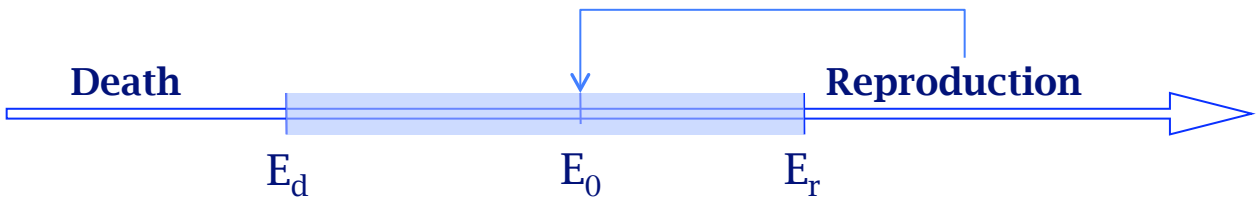
MAGIC-5 / Virtual Ant Colonies

- The Ant Energy
  - ✓ Energy at birth: $E_0 = 1 + \alpha$ $\quad \alpha = 0.2$
  - ✓ Energy variation:

$$E^k_{i+1} = E^k_i - \alpha + \alpha \times \frac{\Delta^k_{ph}(i+1)}{< \Delta_{ph} >_{tot}}$$

$\Delta^k_{ph}(i+1)$ is the amount of pheromone released in cycle i+1 by ant k

$< \Delta_{ph} >_{tot}$ is the average release of pheromone in the colony since its evolution started



$E_d = 1.0$
$E_0 = 1.2$
$E_r = 1.3$

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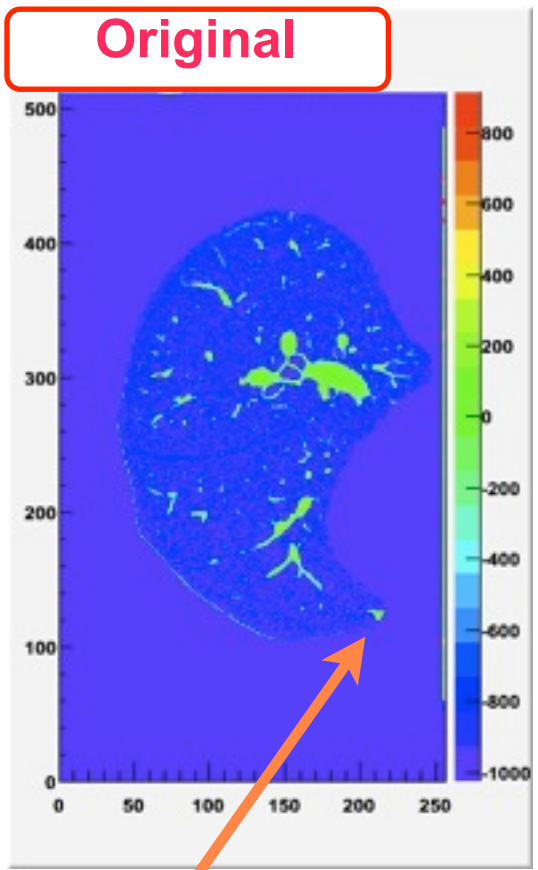
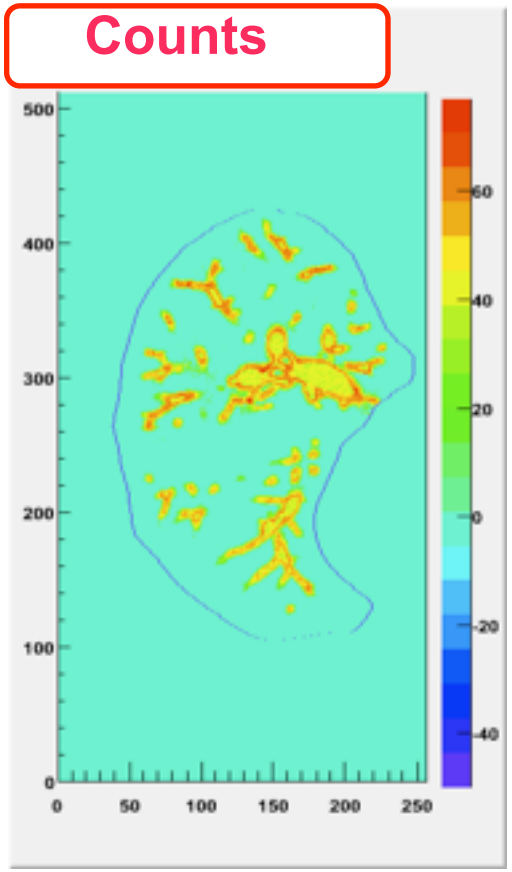
MAGIC-5
Virtual Ants in a Lung CT

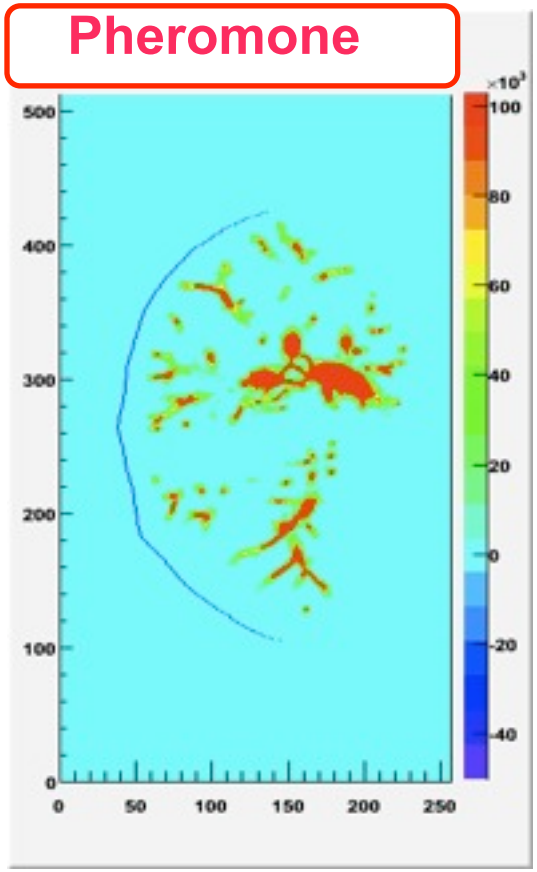
Original



Counts



Pheromone



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Results & Plans

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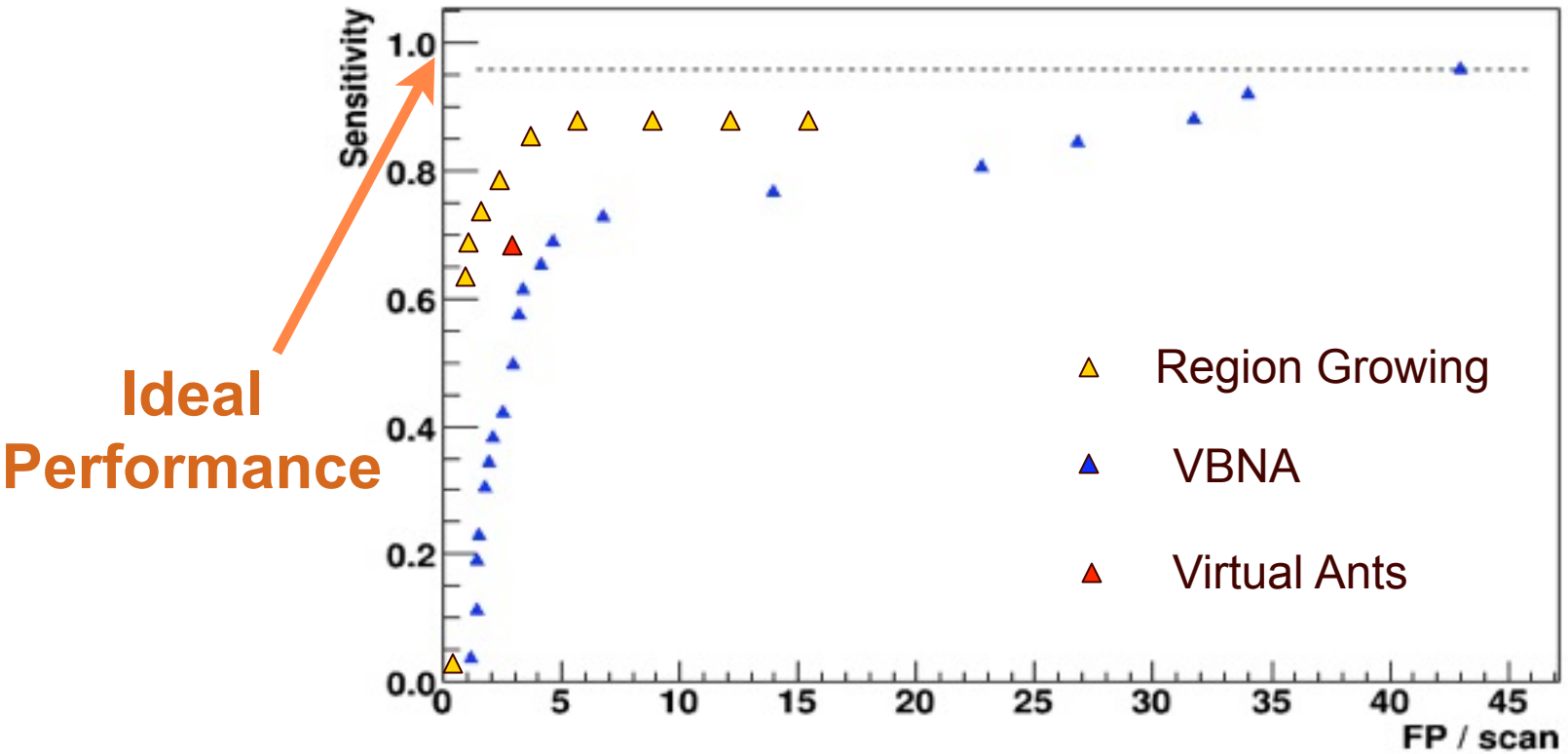
MAGIC-5 Lung CAD FROC curves

Gold Standard Validation DB (28 nodules)



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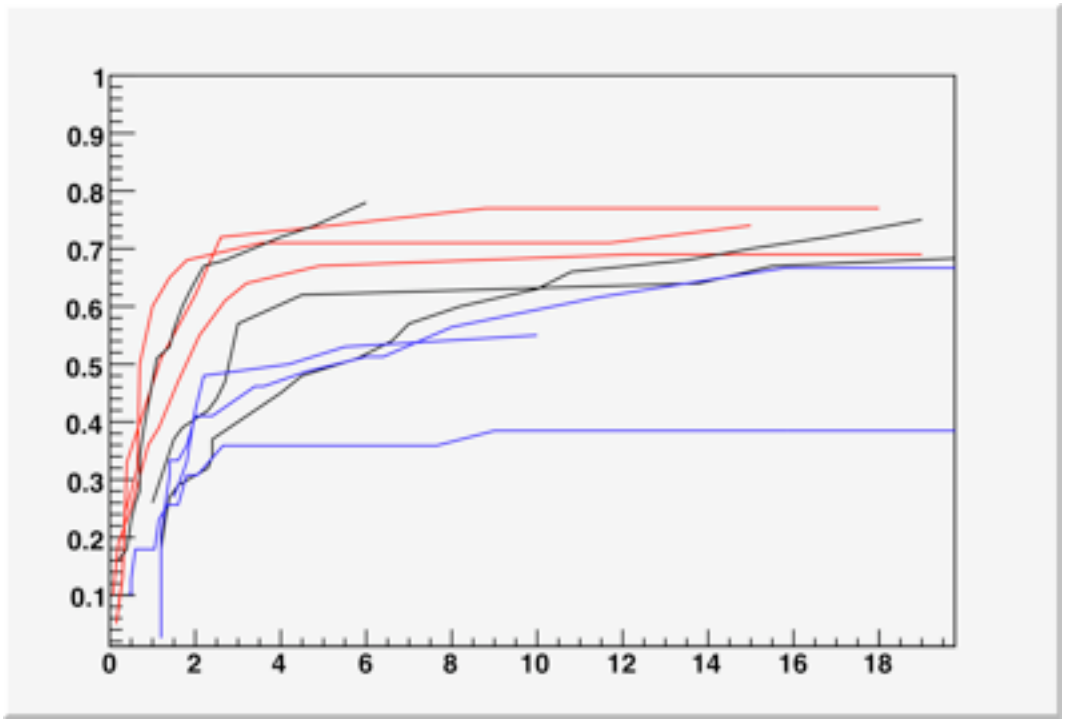
MAGIC-5 Lung CAD
FROC curves



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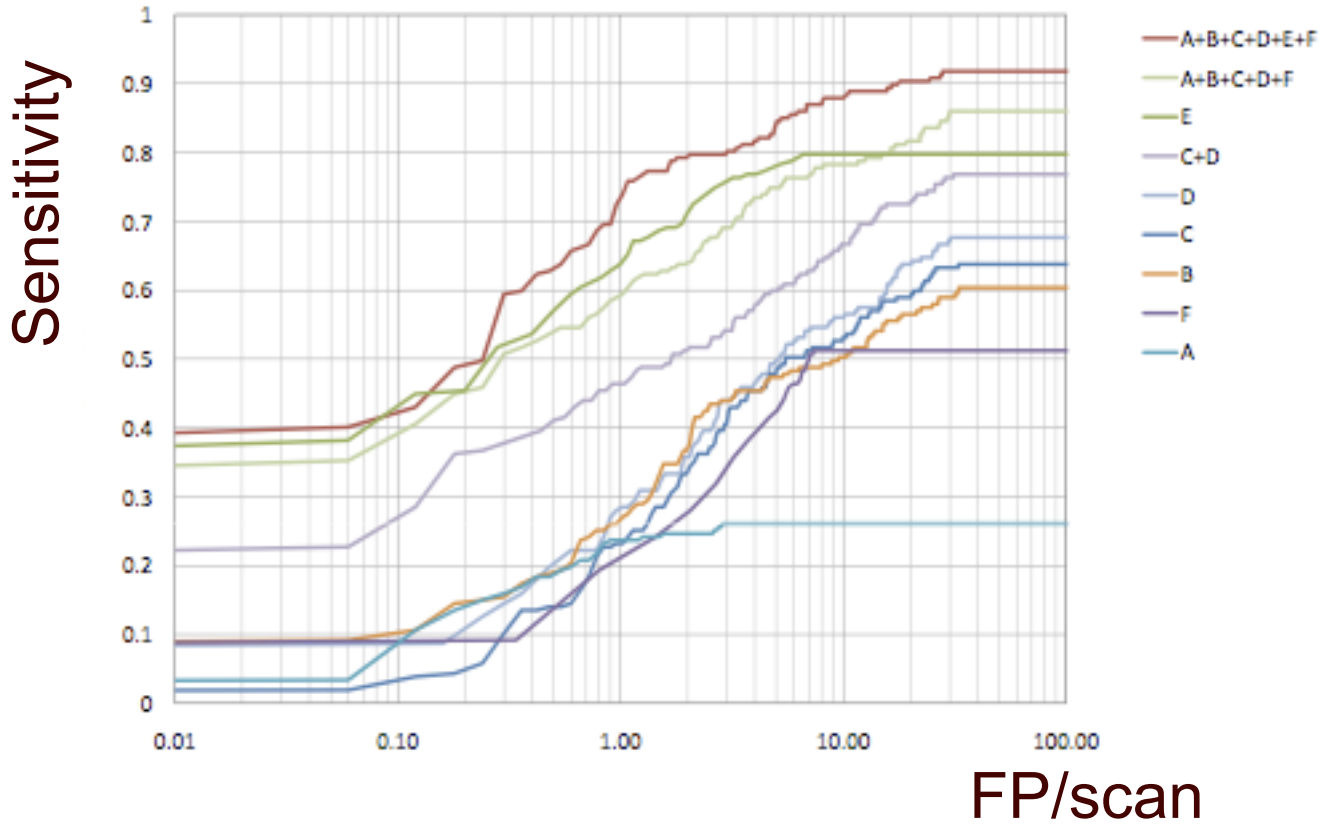
MAGIC-5 Lung CAD
ANODE09 Challenge



D = VBNA

B = RG

C = V-ANTS

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MAGIC-5 / Lung CAD

- Summary

Three parallel approaches to lung nodule detection

- The ANODE09 challenge showed that:
  - they are competitive
  - combining algorithms improves the global performance
  - there is room for further improvements
- Plans
  - Validation test on new CT data (from LIDC)
  - Algorithm improvements
  - Algorithm merging

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