

The MAGIC-5 lung CAD system

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*on behalf of the MAGIC-5 Collaboration
(Università di Bari & INFN - Italy)*

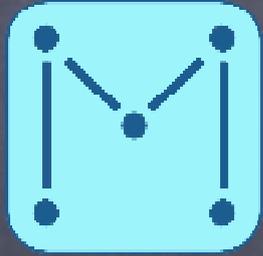
PHYSICS FOR HEALTH IN EUROPE WORKSHOP

**Towards a European roadmap for using
physics tools in the development
of diagnostics techniques and new cancer therapies**



2- 4 February 2010





The MAGIC-5 Project*



Main research activities

Developing models and algorithms for the analysis of biomedical images:

- To support the medical diagnosis with Computer-Aided Detection (CAD) systems;
- To allow large-scale image analyses.

Analysis of Medical Images

- Mammographic images for the early diagnosis of breast cancer (2001-2005)
- Computed Tomography images for the early diagnosis of lung cancer (2004-present)
- Brain MRI for the early diagnosis of the Alzheimer's disease (2006-present)

(*) Medical Application on a Grid Infrastructure Connection



The MAGIC-5 Project

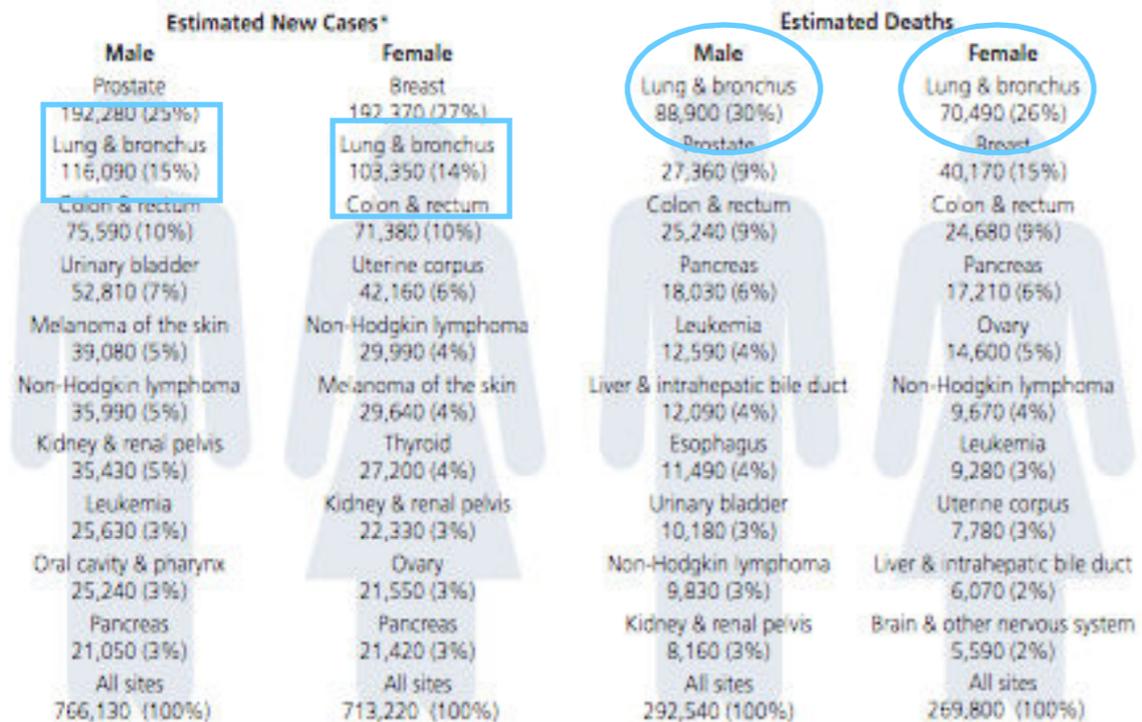


6 Research Groups
~ 40 Researchers

The Project is conducted by **INFN** - the Italian National Institute of Nuclear Physics in close collaboration with italian hospitals and the academic world.

Lung Cancer

Leading Sites of New Cancer Cases and Deaths – 2009 Estimates



*Excludes basal and squamous cell skin cancers and in situ carcinoma except urinary bladder.

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A lung cancer diagnosis imparts a poor prognosis, with about 60% of patients dying within 1 year of diagnosis.

Surgical resection of an early lung cancer has a favorable prognosis: after resection of a first stage bronchogenic carcinoma, the 5-year survival rate is 80% to 90%.

The goal of a chest computed tomography (CT) screening is the detection of pulmonary nodules in patients at risk for lung cancer.

LUNG SCREENING PROGRAMMES



International Early Lung Cancer Action Program (I-ELCAP)

- 31000 individuals, mortality reduction: 8% (14%) in 5 (10) years of screening.

Henschke et al., N Engl J Med (2006)

Bach

- 3210 individuals, no mortality reduction

Bach et al., JAMA (2007)

Mayo Clinic Experience

- 1520 individuals, mortality reduction: 28% (15%) in 6 (15) years of screening.

McMahon et al., Radiology (2009)

National Lung Screening Trial (NLST)

- about 50.000 current or former smokers, results expected in 2010-11



Lung CAD

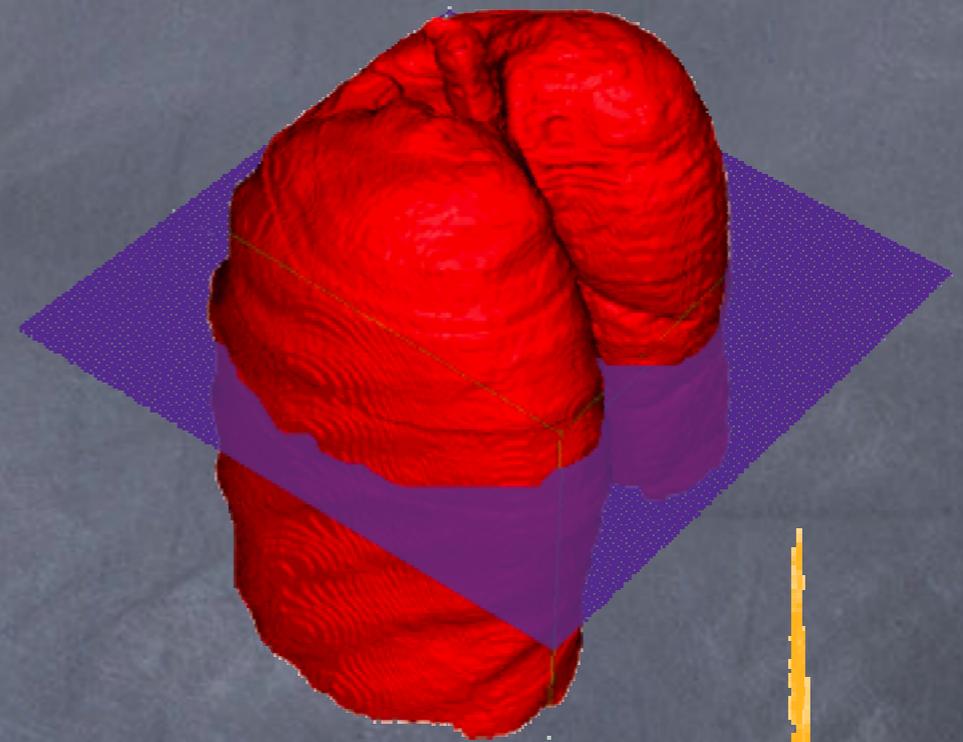
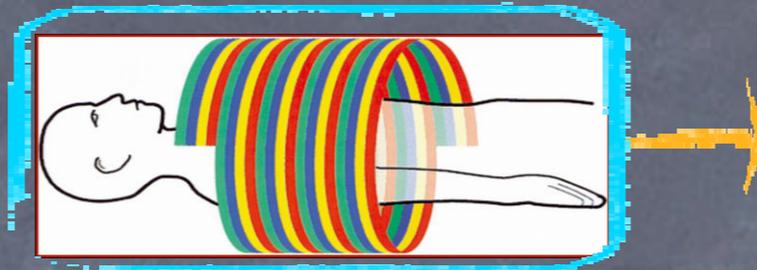
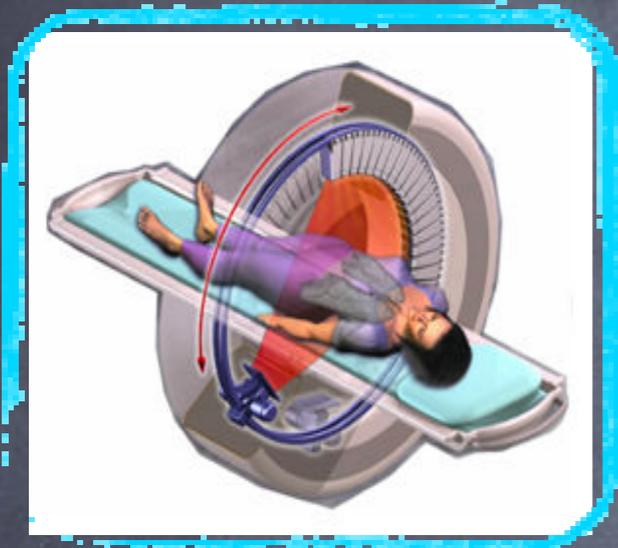


“Our data indicate that the introduction of CAD and [...] accumulation of experience of our multidisciplinary nodule management team will further improve the diagnosis accuracy of the protocol.”

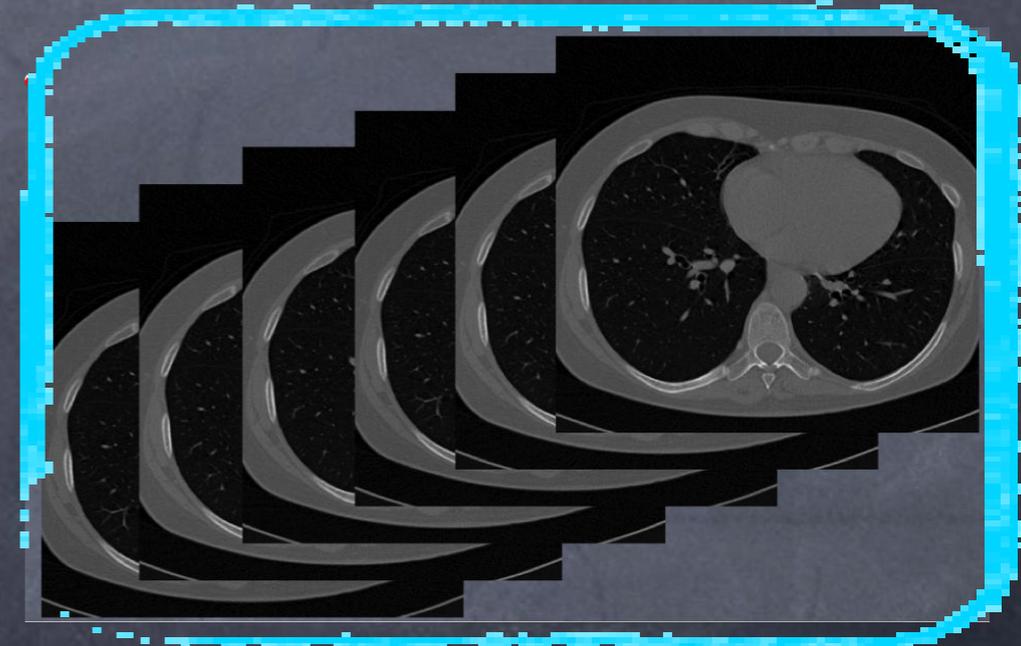
G. Veronesi et al.,

The Journal of Thoracic and Cardiovascular Surgery,
(2008)

CT in screening programmes



- Each low-dose helical multi-slice CT = 300 2-D images with slice-thickness ≤ 1.25 mm
- Each annotation by 1 or more radiologists (up to 4)
- Nodules of diameter > 3 to 5 mm, according to the different protocols
- Agreement sometimes $\sim 60\%$ between radiologists





3-D image processing



General approach

Lung CAD system

- Segmentation
 - Definition of the lung volume
 - Region of interest list
- Feature Extraction
 - Characterization of the candidate nodules
- Classification
 - True/false positive classification



The MAGIC-5 CADs



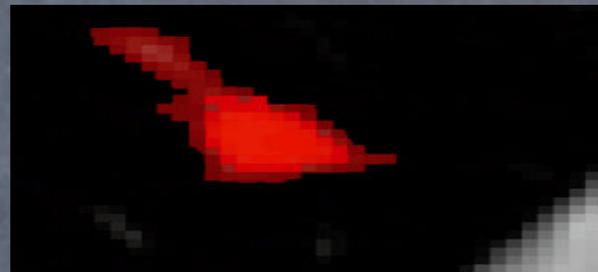
- Parallel approach: three different lung CADs are implemented in the same software framework;
- Some algorithms/procedures in common;
- The data analysis is performed in cross validation (i.e. blinded);
- The CAD systems were validated with three different databases.

MAGIC-5 overall approach

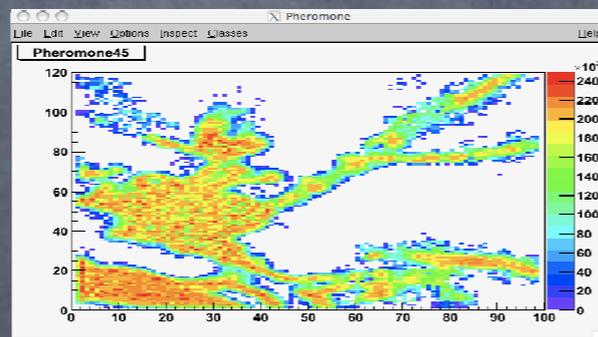
Lung
Segmentation



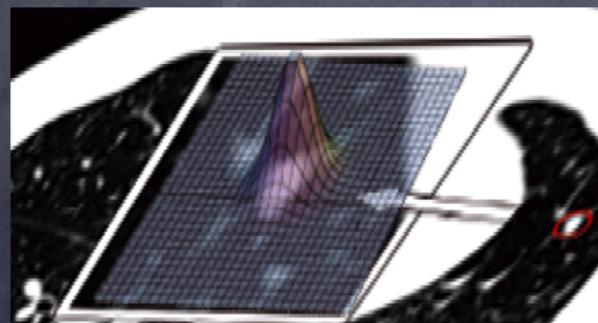
Candidate Nodule
identification



Region Growing



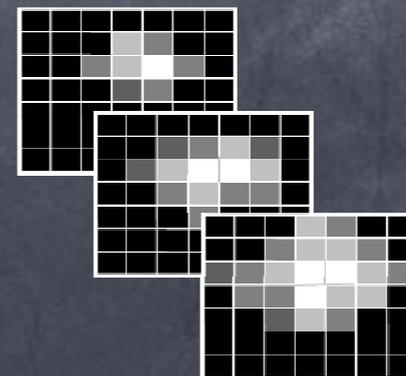
Virtual Ants



3D Multiscale
Gaussian Filter

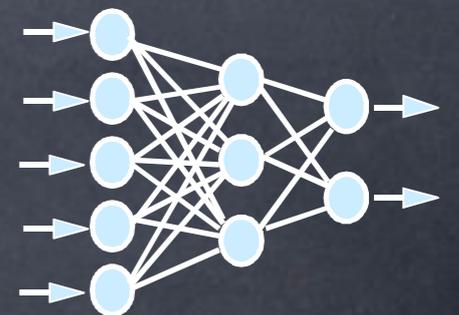
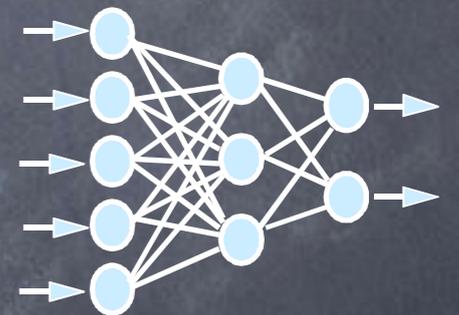
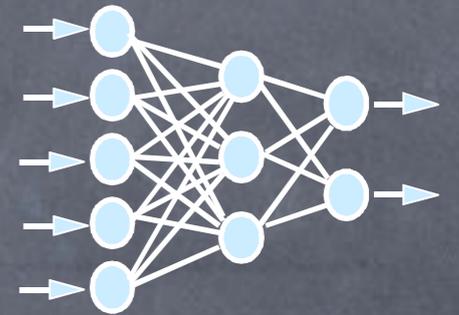
Candidate Nodule
Feature Extraction

≈ 15 discriminating
features: Volume,
Sphericity,
Ellipticity,
Compactness,
Shannon's Entropy,
...



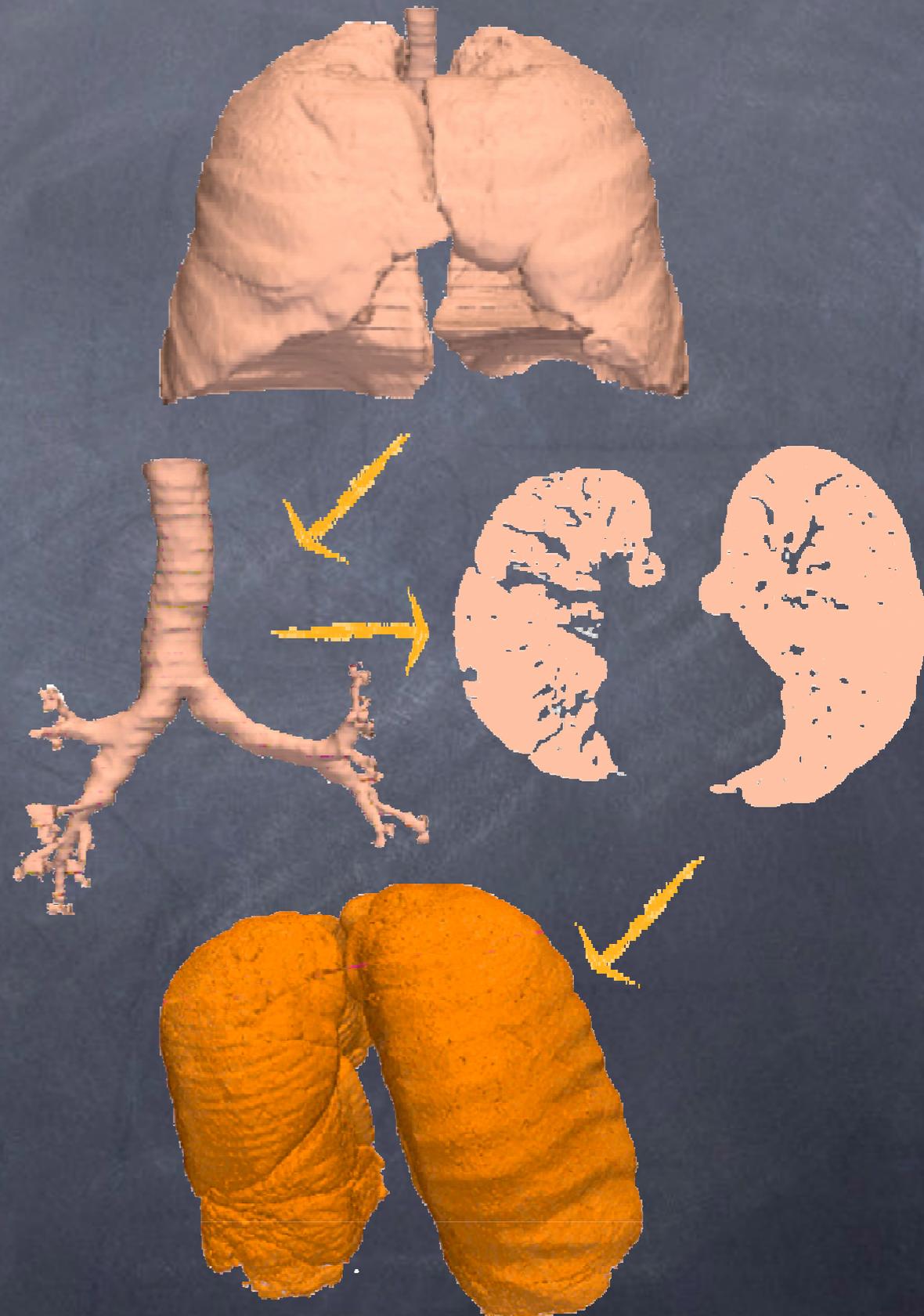
Voxel Based
Analysis

Candidate Nodule
Classification



MAGIC-5 lung segmentation

- Simple-threshold 3D Region Growing is applied to the CT in order to segment air inside lung;
- Region Growing Wavefront simulation algorithm is applied in order to segment and remove trachea and external bronchi;
- Morphological 3D closing is applied in order to refine lung volume and include pleural nodules.

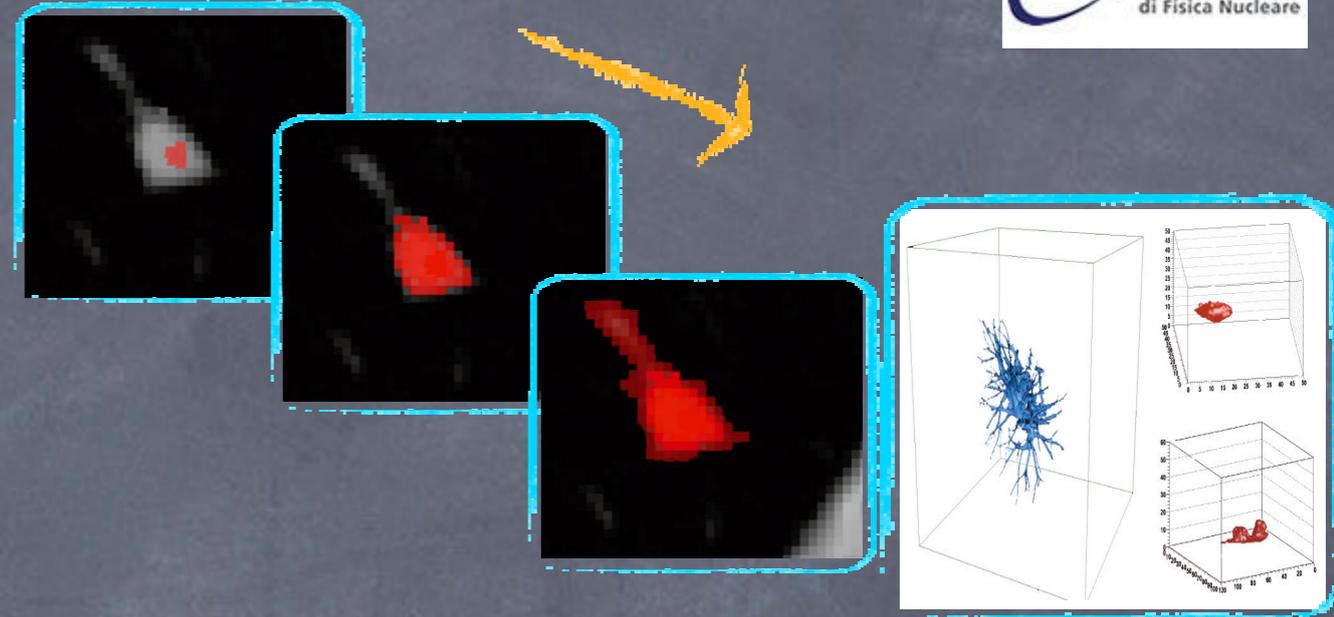




Region Growing CAD



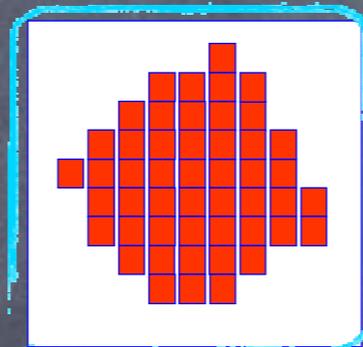
Candidate nodule identification



Region growing-based iterative algorithm

Feature Extraction

Geometrical and Statistical characteristics



$$V = N_{\text{vox}} \cdot V_{\text{vox}}$$



$$V_S = 4/3 \pi r_m^3$$

Maximum distance, d_m

Volume, $V = N_{\text{vox}} \cdot V_{\text{vox}}$

Sphericity, $S = V / V_S$

Ellipticity, $E = V / V_e$

Shannon's Entropy

$E_S = \sum_i p(I_i) \cdot \log[p(I_i)]$

p = probability, I = intensity

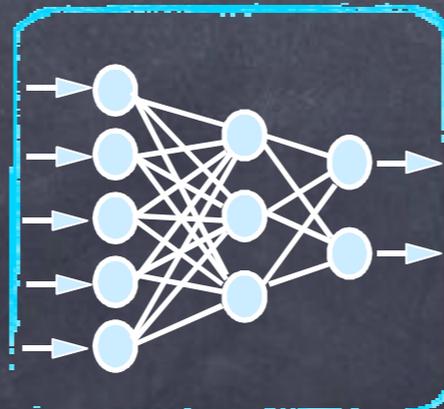


$$V_e = 4/3 \pi r_m^2 d_m$$

Nodule classification:

Rule-based filter +

Neural Network or SVM





Virtual Ants CAD

- Lung segmentation
- Candidate nodule identification

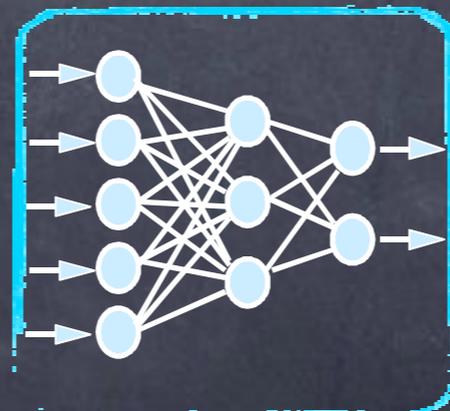
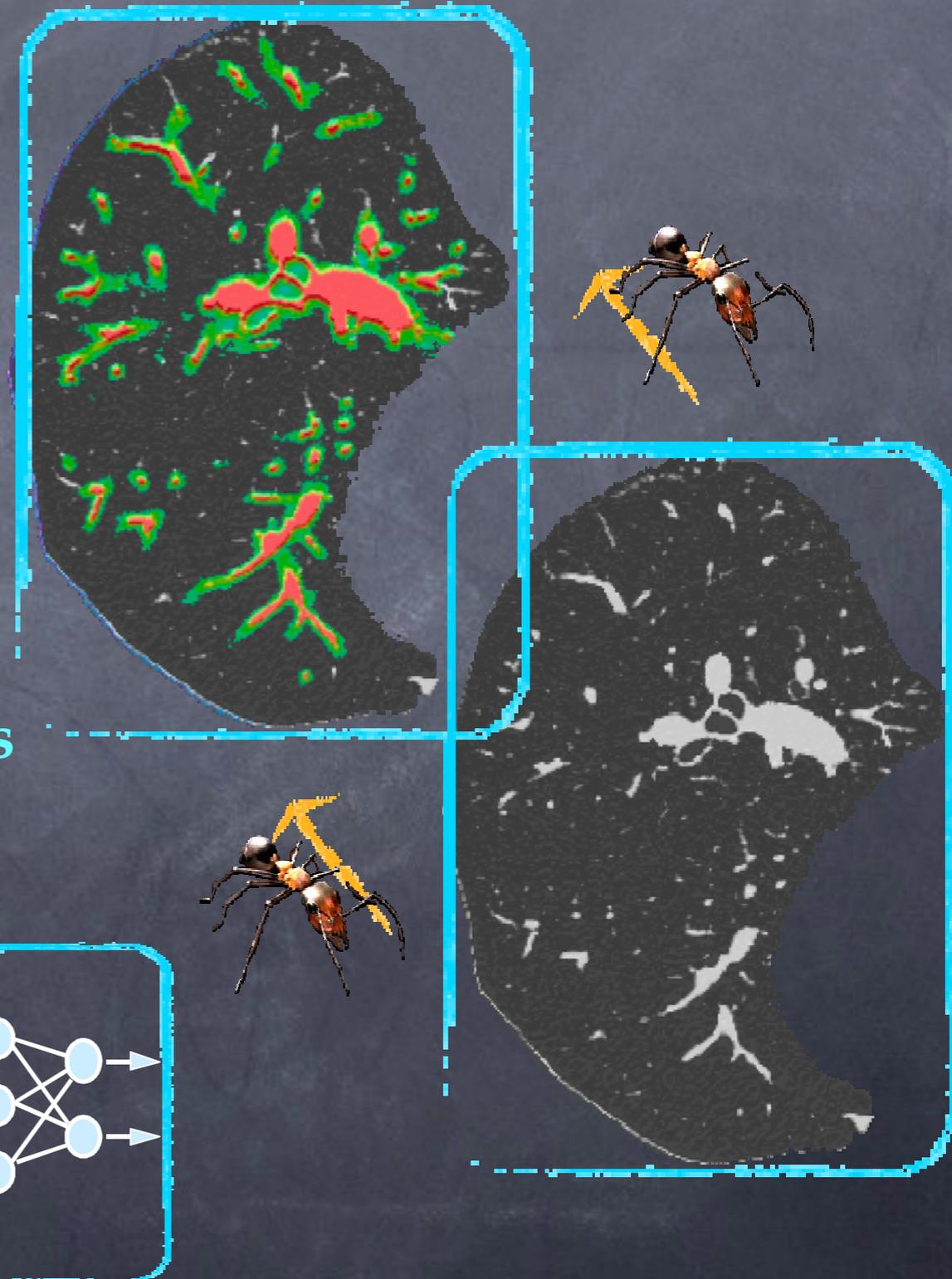
A virtual Ant Colony detects the vascular tree and the candidate nodules

- Feature Extraction

Geometrical and Statistical characteristics

- Nodule classification:

Rule-based filter + Neural Network

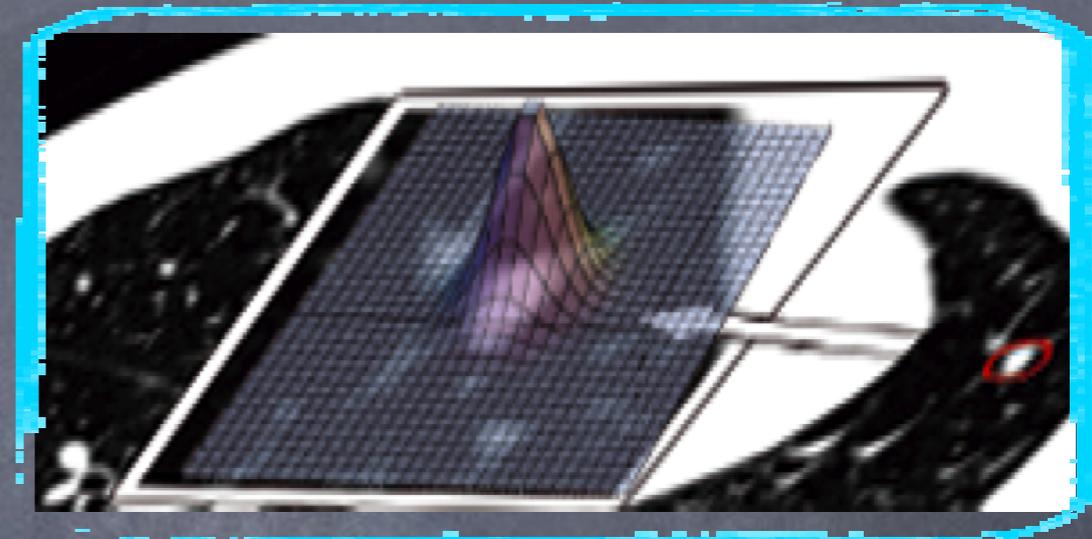




Voxel-based Neural CAD

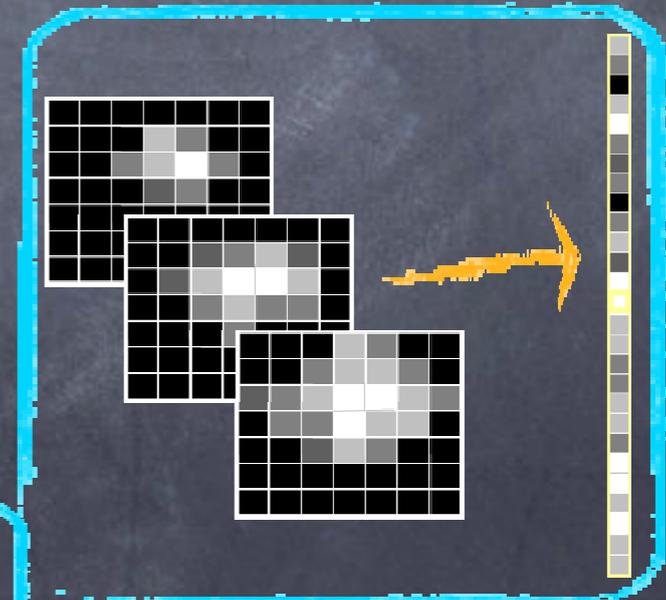
- Lung segmentation
- Candidate nodule identification

3D Multiscale Gaussian Filter + Detection of Inward Pleura Surface Normal Intersections



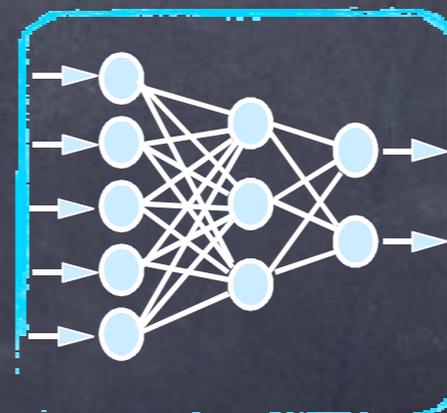
- Feature Extraction

Rolled Down 3D Neighbors Intensity + Eigenvalues of Hessian and Gradient matrix for each voxel of nodules



- Nodule classification:

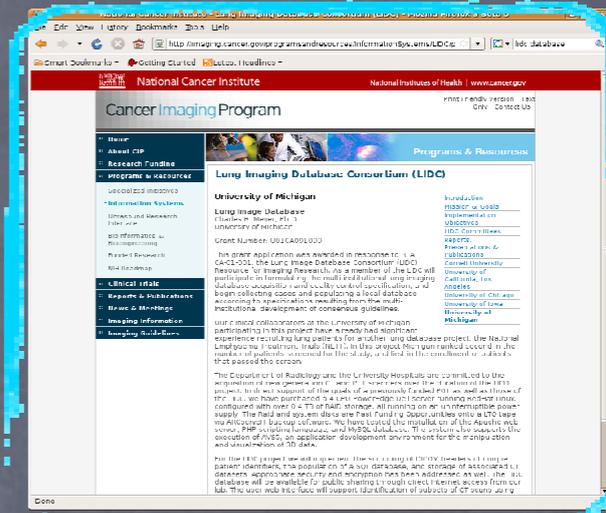
Neural Network



The data sets

LIDC

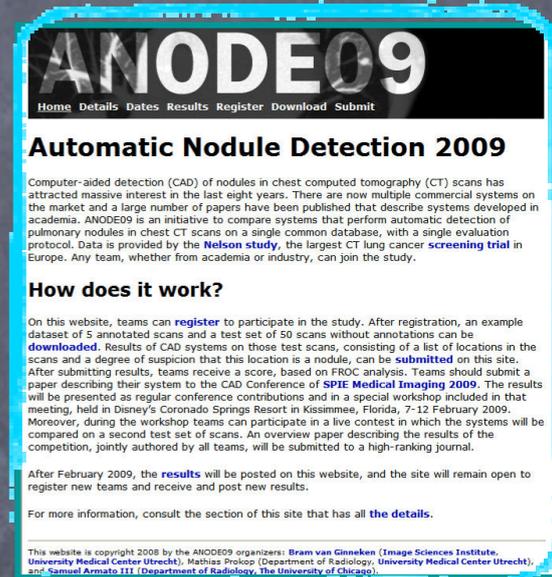
~ 100 CT scans (rapidly increasing), with annotations by 1, 2, 3, 4, radiologists; Nodules with diameter > 3 mm



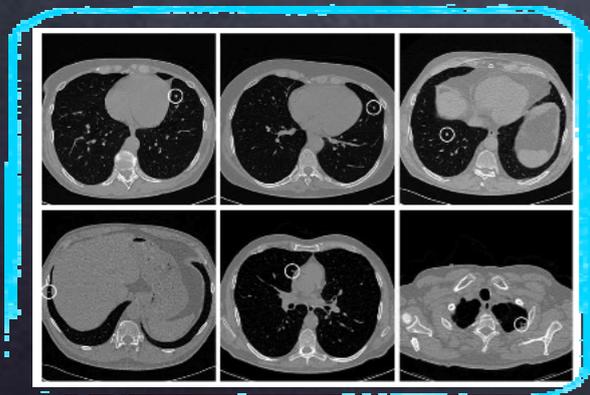
ANODE09

anode09.isi.uu.nl

5 (50) scans with (blind) annotation; Nodules with diameter > 4 mm



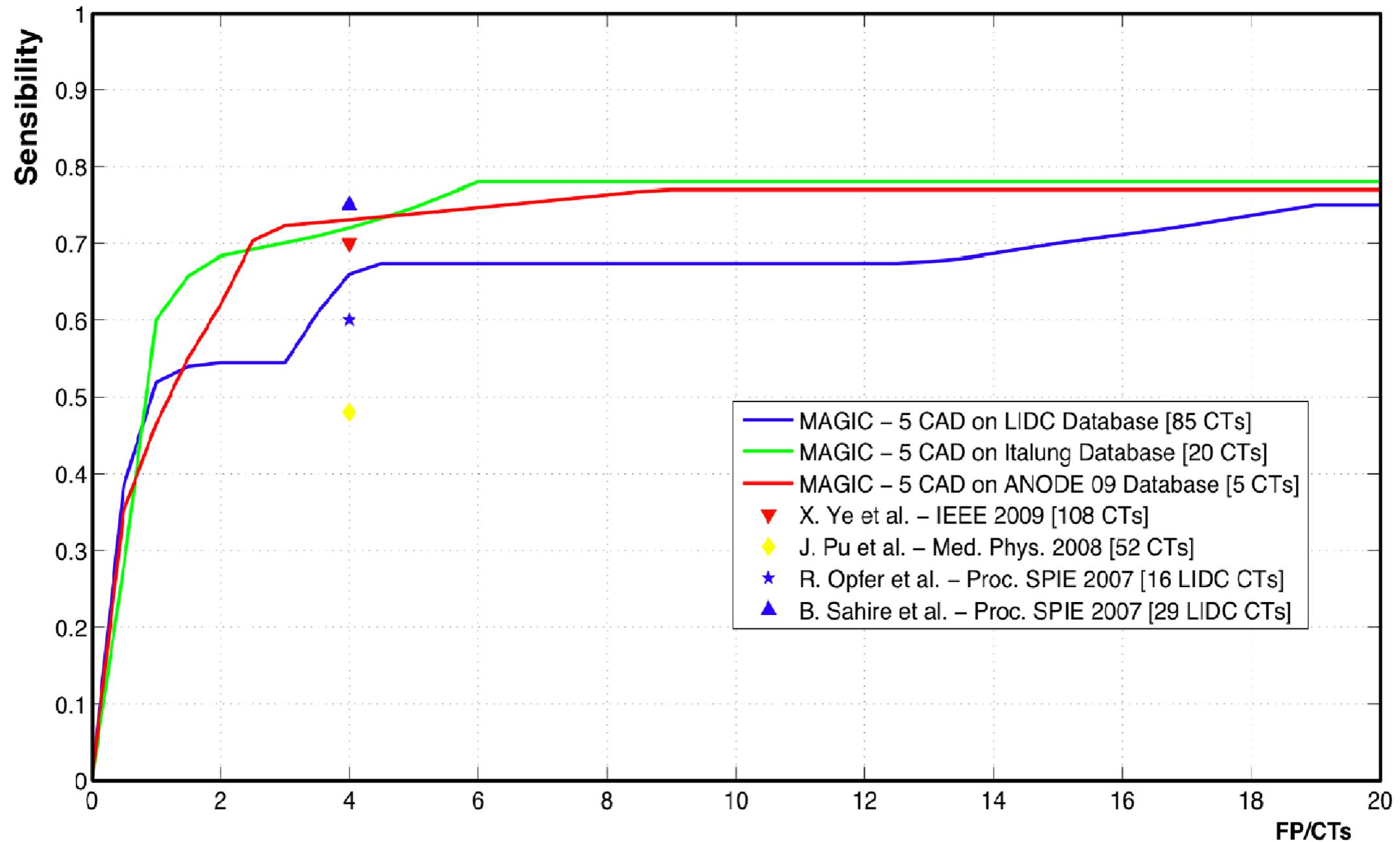
MAGIC-5/ITALUNG DATABASE



- Lung Nodule Annotation tool developed
- ~ 163 CT scans in the DB
- Annotation by 2 to 4 radiologists
- Nodules with diameter > 5 mm



MAGIC-5 lung CAD results





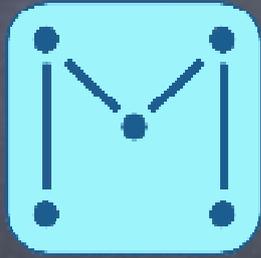
Conclusions



- **MAGIC-5 CAD system: three parallel approaches to lung nodule detection and classification:**
 - validated using three different CT lung image databases
 - competitive with respect to the state-of-the-art systems

Future activities

- Continuous testing on new CT data
- Algorithm improvements and result merging
- Extensive testing as second opinion to the radiologist's judgement
- Participation to the large-scale screening or clinical programmes



Publications



- 
- [1] Lung nodule detection in low-dose and thin-slice computed tomography, COMPUTERS IN BIOLOGY AND MEDICINE;
 - [2] A CAD system for nodule detection in low-dose lung CTs based on region growing and a new active contour model, MEDICAL PHYSICS
 - [3] Multi-scale analysis of lung computed tomography images, JOURNAL OF INSTRUMENTATION;
 - [4] Automatic lung segmentation in CT images with accurate handling of the hilar region, JOURNAL OF DIGITAL IMAGING;
 - [5] 3-D Object Segmentation using Ant Colonies, PATTERN RECOGNITION;
 - [6] Pleural nodule identification in low-dose and thin-slice lung computed tomography, COMPUTERS IN BIOLOGY AND MEDICINE;
 - [7] Performance of a CAD system for lung nodules identification in baseline CT examinations of a lung cancer screening trial, INTERNATIONAL JOURNAL OF IMAGING;
 - [8] A novel multi-threshold surface-triangulation method for nodule detection in lung CT, MEDICAL PHYSICS.



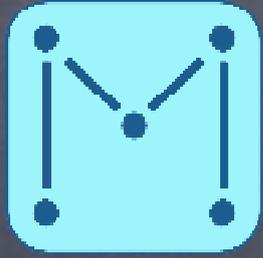
Thank you for your attention!

*I am grateful to all the members of the
MAGIC-5 Collaboration for their
contribution*

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Region Growing CAD

Iterative Region Growing finds nodules inside Lung Parenchima



Region Growing segments connected voxels that obey a rule



The rule is:
a voxel is included in the growing region if:

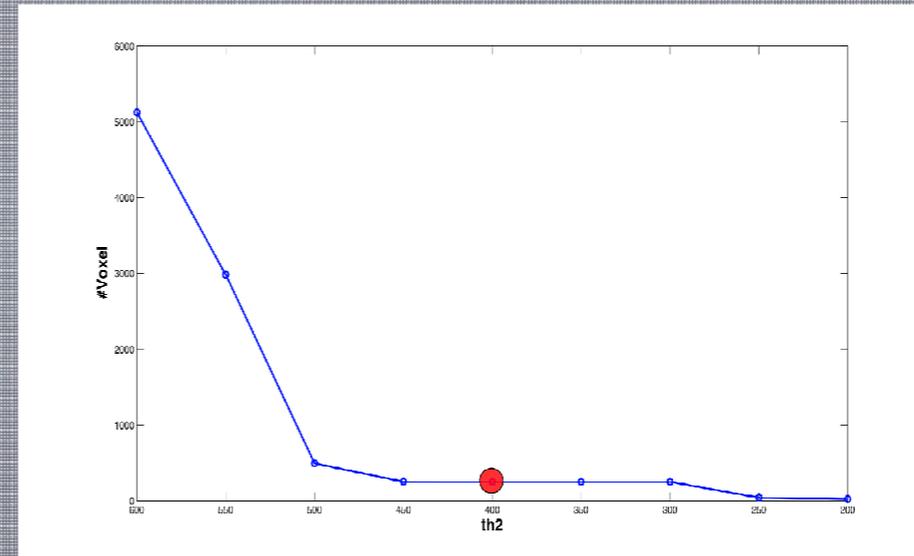
$$I > th_1 \ \& \ \sum_{neigh} I_i > th_2$$



th_1 is a watchdog and is fixed at air Hounsefield unit value

th_2 is defined iteratively nodule by nodule

A certain structure will almost always have a proper value th_2 for which it will be segmented from the air background.





Virtual Ants CAD

An Anthill is placed inside the Lung Parenchima.



Ants movements are guided by pheromone deployed by other ants.



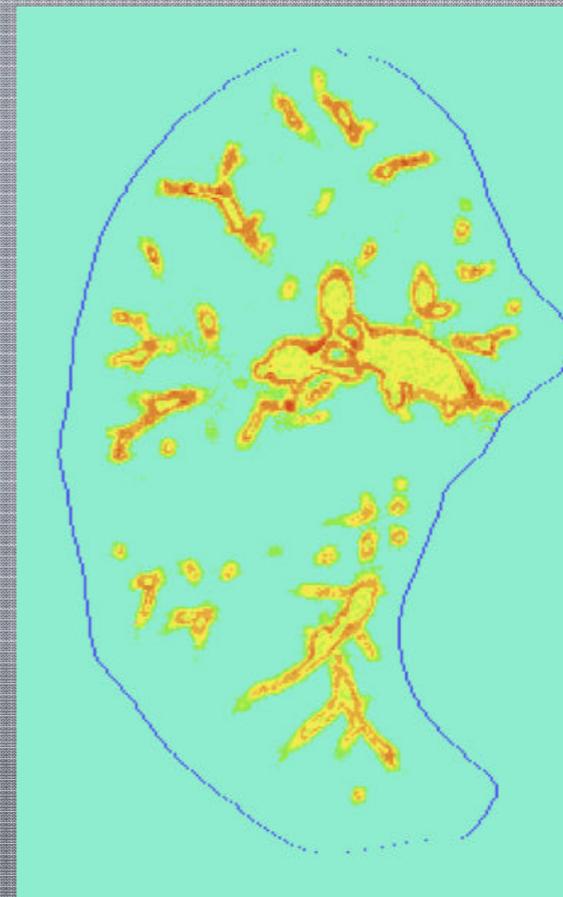
Before moving to the future destination, ants release a pheromone quantity related to the CT voxel intensity



All Ants behavior



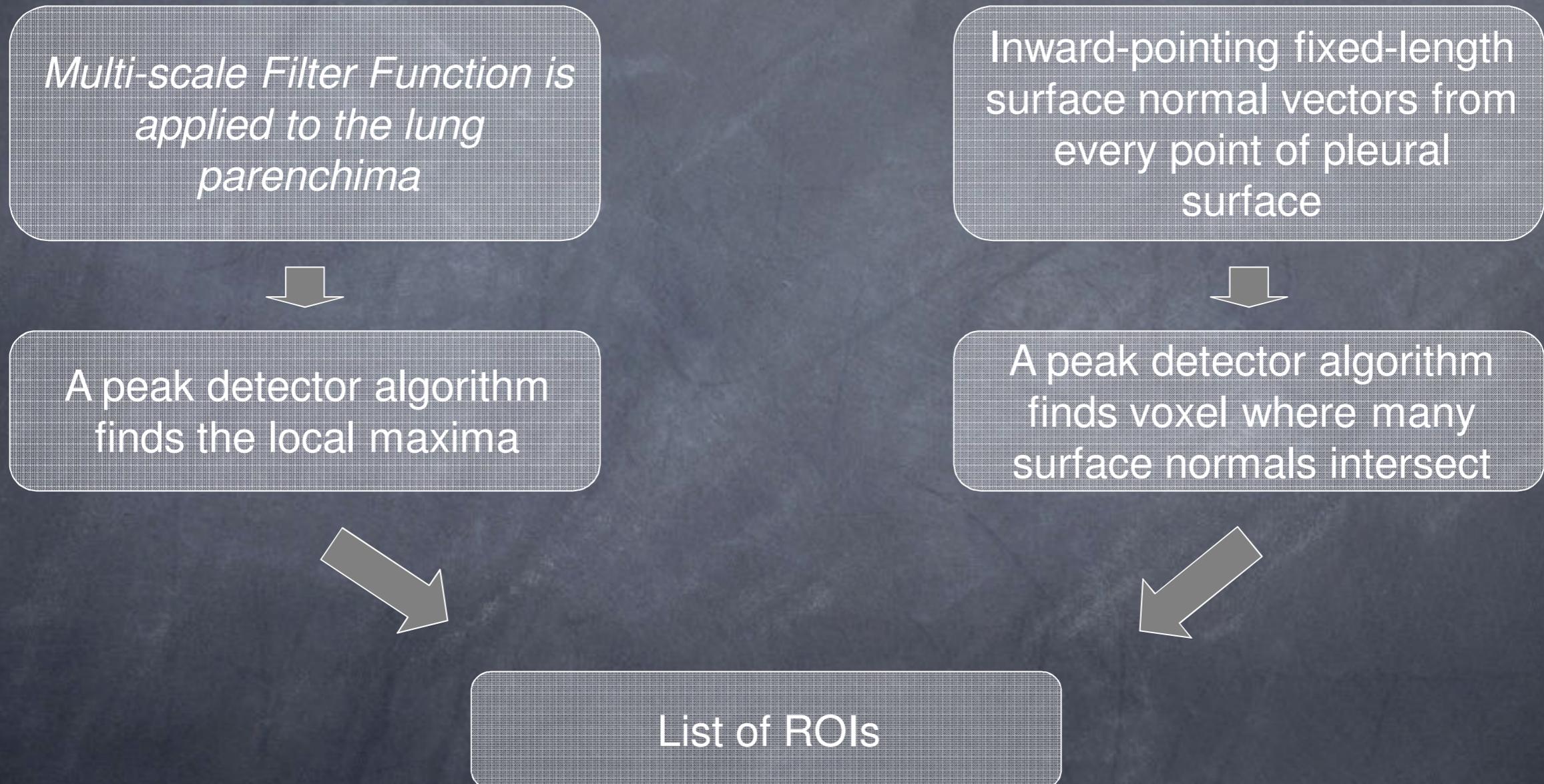
Pheromone Map



With a simple threshold cut it is possible to segment structures inside the lung.



Voxel-based Neural CAD



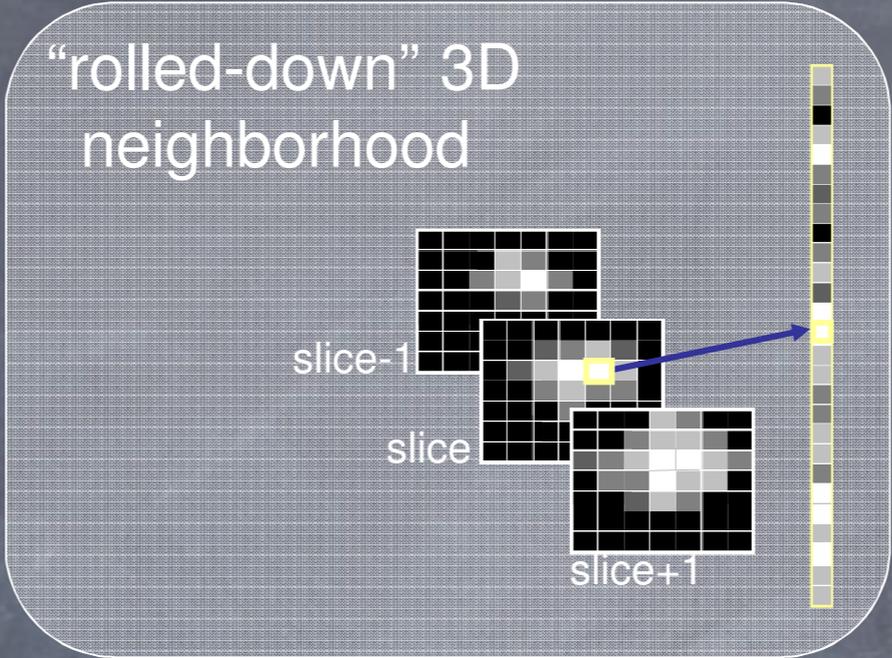


Voxel-based Neural CAD

List of ROIs

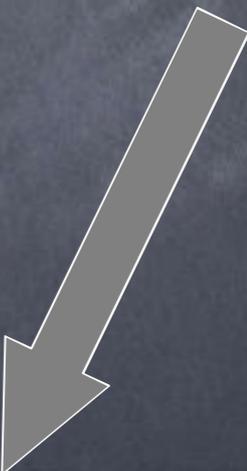
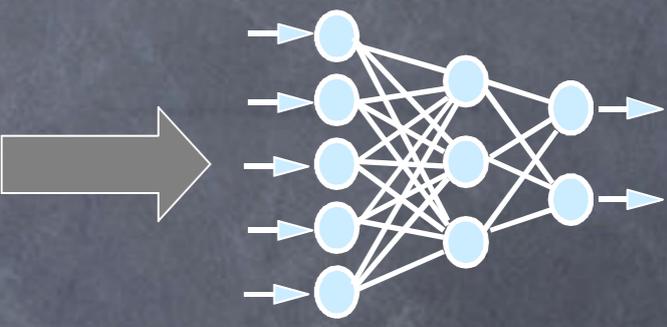


From every voxels in a ROI



3 eigenvalues of *gradient* matrix:
$$\left[\sum_{neigh} \partial_{x_i} I \partial_{x_i} I \right]_{i,j=1,2,3}$$

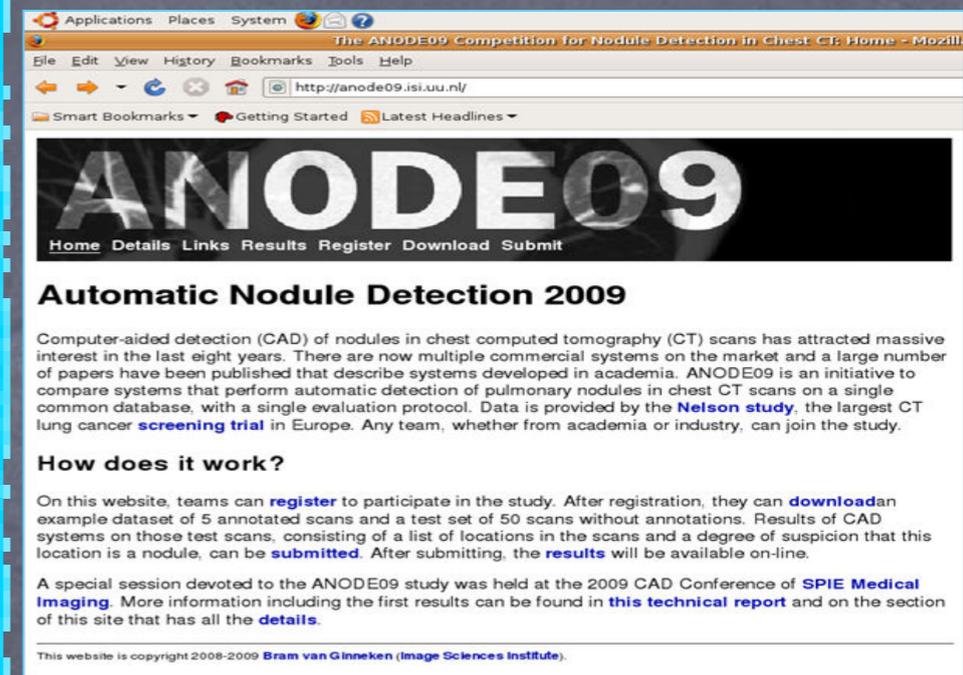
3 eigenvalues of *Hessian* matrix:
$$\left[\sum_{neigh} \partial_{x_i x_j}^2 I \right]_{i,j=1,2,3}$$



A ROI is classified as “nodule” if the percentage of voxels tagged as “nodule” by the neural classifier is above a threshold.

ANODE09 international competition

- Participants had to download an example dataset of 5 annotated scans and a test set of 50 scans without annotations
- Nodules reported in the database are classified in two subsets: relevant and not relevant calcified nodules.
- Results submitted to SPIE Medical Imaging: Bram van Ginneken et al., *Comparing and combining algorithms for computer-aided detection of pulmonary nodules in computed tomography scans: the ANODE09 study*, accepted by Medical Image Analysis

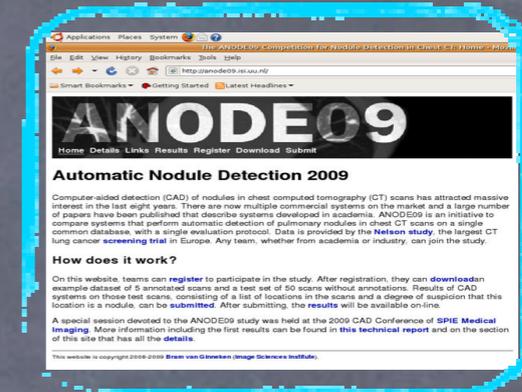


<http://anode09.isi.uu.nl/>

ANODE09: MAGIC-5 CADs results

CAD participants (SCORE)

- ⑥ VBNA MAGIC-5 (0.29)
- ⑥ RGVP MAGIC-5 (0.29)
- ⑥ V-ANTS MAGIC-5 (0.25)
- ⑥ Philips Lung Nodule (0.23)
- ⑥ Fujitalab (0.21)



Results submitted to SPIE Medical Imaging: Bram van Ginneken et al., *Comparing and combining algorithms for computer-aided detection of pulmonary nodules in computed tomography scans: the ANODE09 study.*

RESULTS: ANODE09 competition (50 CT)

| | RG-VP | V-ANTS | VBNA |
|----------------|-------|--------|-------|
| small | 0.379 | 0.251 | 0.391 |
| large | 0.160 | 0.275 | 0.203 |
| isolated | 0.389 | 0.314 | 0.412 |
| juxta-vascular | 0.269 | 0.260 | 0.340 |
| juxta-pleural | 0.231 | 0.212 | 0.223 |
| peri-fissural | 0.249 | 0.310 | 0.232 |
| ALL | 0.278 | 0.262 | 0.304 |

Results "ALL nodules" for the other systems: **0.005, 0.195, 0.074**

