



## The MAGIC-5 lung CAD system

*Roberto Bellotti* 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 (2004present)
- Brain MRI for the early diagnosis of the Alzheimer's disease (2006-present)

#### (\*) Medical Application on a Grid Infrastracture Connection



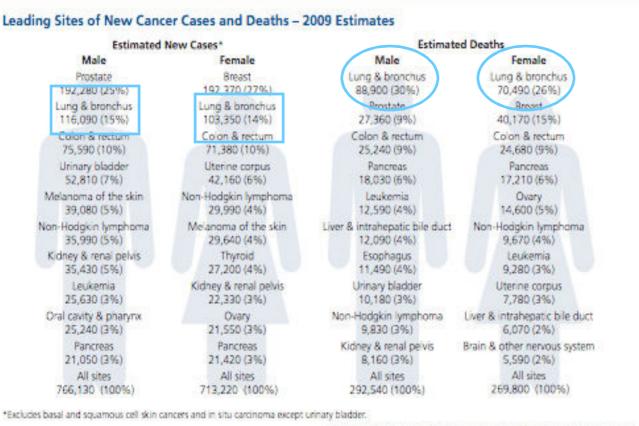
## The MAGIC-5 Project



### 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



@2009, American Cancer Society, Inc., Surveillance and Health Policy Research

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 reductionBach 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



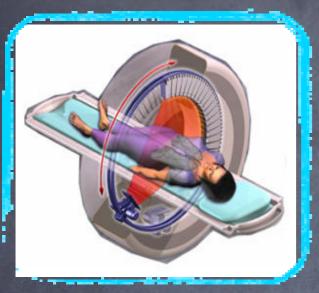


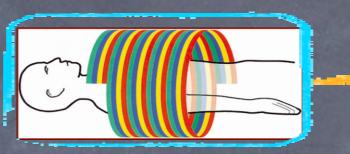


"Our data indicate that the introduction of CAD and [...] accumulation of experience of our multidisciplinary nodule management team will further improve the diagnosis accuracy of the protocol."

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 ~ 60% between radiologists



# 3-D image processing



### General approach

### Lung CAD system

Definition of the lung volume

Segmentation

> Region of interest list

Feature Extraction

Classification

Characterization of the candidate nodules True/false positive classification

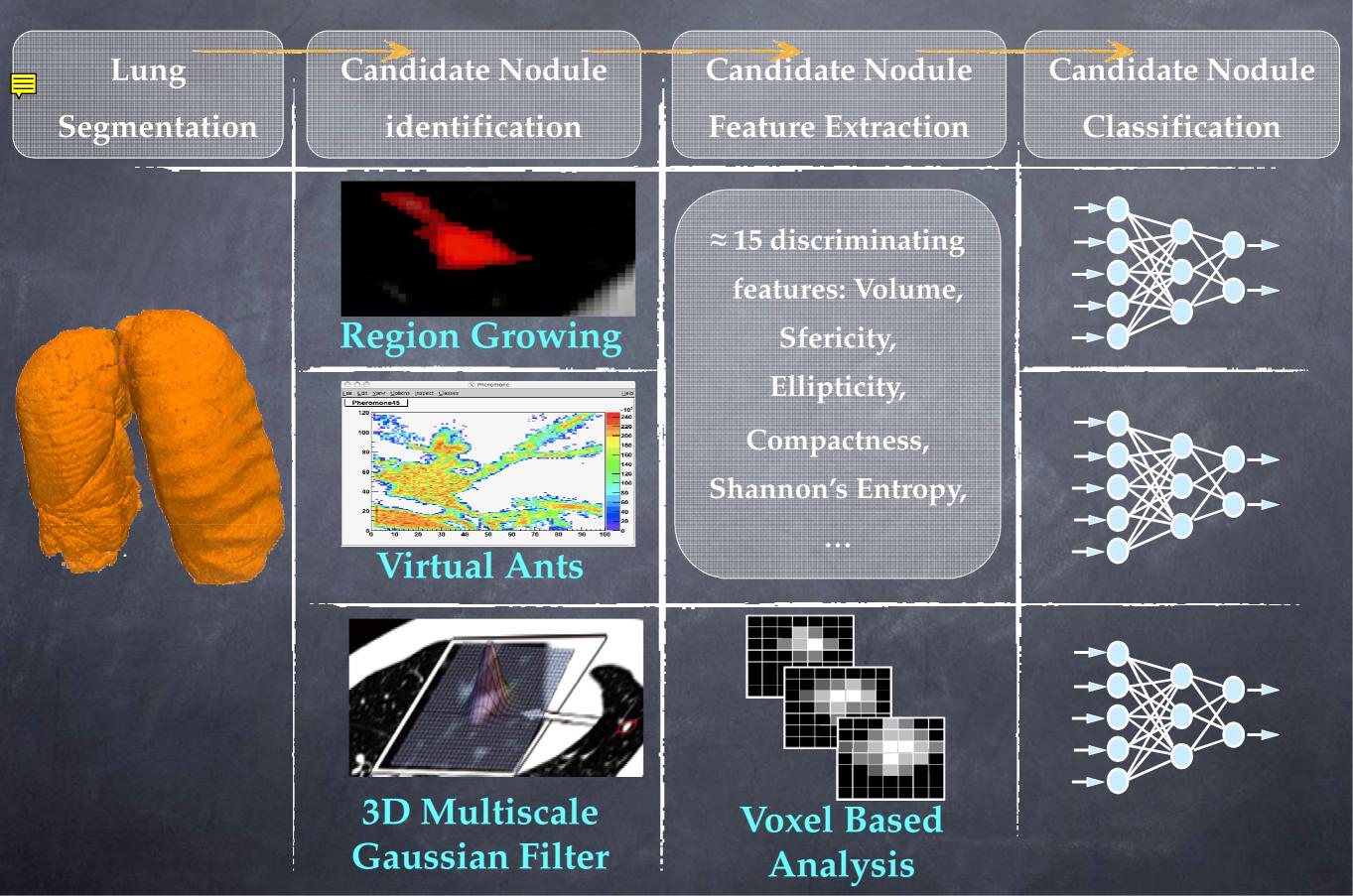


# The MAGIC-5 CADs



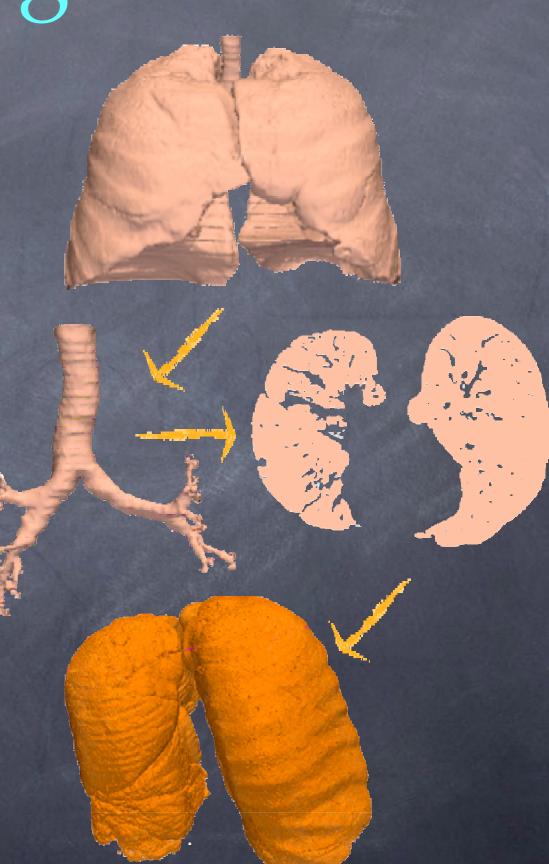
- Parallel approach: three different lung CADs are implemented in the same software framework;
  Some algorithms/procedures in common;
  The data analysis is performed in cross validation (i.e. blinded);
- The CAD systems were validated with three different databases.

## MAGIC-5 overall approach



# 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

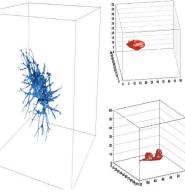


Candidate nodule identification Region growing-based iterative algorithm



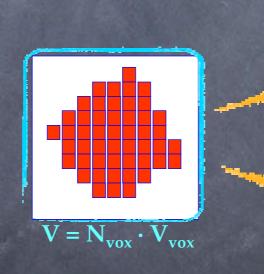
 $V_{\rm S} = 4/3 \pi r_{\rm m}^3$ 

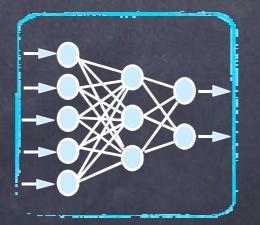
 $V_e = 4/3 \pi r_m^2 d_m$ 



Feature Extraction
 Geometrical and Statistical
 chararacteristics

Module classification:
 Rule-based filter +
 Neural Network or SVM





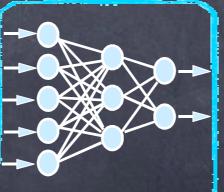
Maximum distance,  $d_m$ Volume,  $V = N_{vox} \cdot V_{vox}$ Sfericity,  $S = V / V_S$ Ellipticity,  $E = V / V_e$ Shannon's Entropy  $E_S = \sum_i p(I_i) \cdot \log[p(I_i)]$ p = probability, I = intensity



## Virtual Ants CAD



Lung segmentation 0 Candidate nodule identification 0 A virtual Ant Colony detects the vascular tree and the candidate nodules Feature Extraction 0 **Geometrical and Statistical chararacteristics** Module classification: **Rule-based filter + Neural Network** 





### Voxel-based Neural CAD

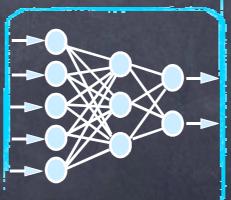


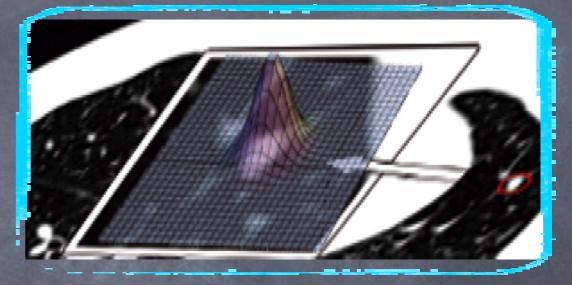
Lung segmentation

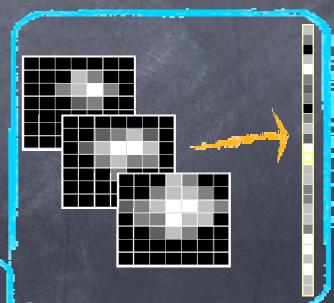
Candidate nodule identification
 3D Multiscale Gaussian Filter + Detection
 of Inward Pleura Surface Normal
 Intersections

 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



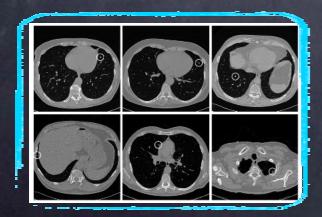
~ 100 CT scans (rapidly increasing), with annotations by 1, 2, 3, 4, radiologists; Nodules with diameter > 3 mm

### ANODE09

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

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### 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



#### Home Details Dates Results Register Download Submit

#### Automatic Nodule Detection 2009

omputer-aided detection (CAD) of nodules in chest computed tomography (CT) scans has ttracted massive interest in the last eight years. There are now multiple commercial systems on te market and a large number of papers have been published that describe systems developed in cadema. ANODE09 is an initiative to compare systems that perform automatic detection of ulmonary nodules in chest CT scans on a single common database, with a single evaluation rotocol. Data is provided by the **Nelson study**, the largest CT lung cancer screening trial in urope. Any team, whether from cademia or industry, can join the study.

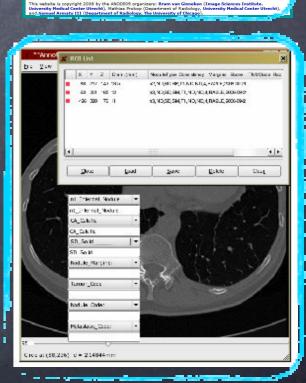
#### How does it work?

anode09.isi.uu.nl

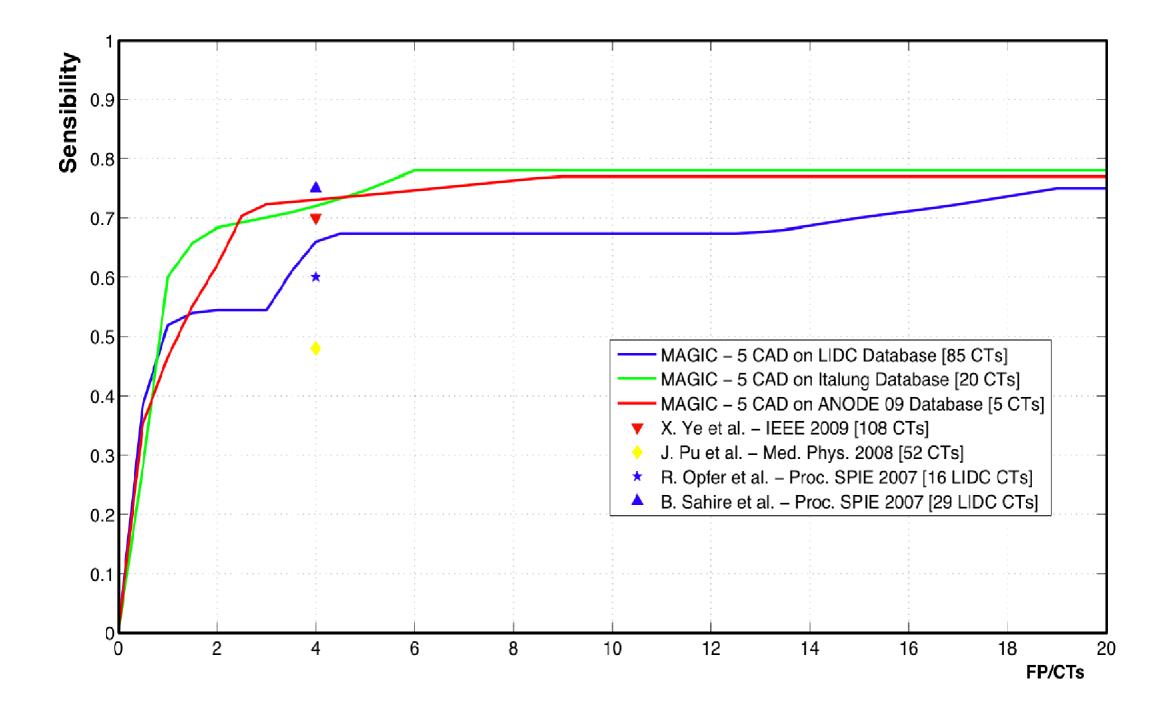
In this website, teams can register to participate in the study. After registration, an example lataset of 3 annotated scans and a test set of 50 scans without annotations can be lownloaded. Results of CAD systems on those test scans, consisting of a list of locations in the cans and a degree of suspicion that this location is a nodule, can be submitted on this site. Iter submitting results, teams receive a score, based on FROC analysis. Teams should submit a paper describing their system to the CAD Conference of SPIE Medical Imaging 2009. The results will be presented as regular conference contributions and in a special workshop included in that neeting, held in Disney's Coronado Springs Resort in Kissimmee, Florida, 7-12 February 2009. forcever, during the workshop teams can participate in a live contest in which the systems will be compared on a second test set of scans. An overview paper describing the results of the competition, jointly authored by all teams, will be submitted to a high-ranking journal.

After February 2009, the **results** will be posted on this website, and the site will remain open to register new teams and receive and post new results.

For more information, consult the section of this site that has all the details.



## MAGIC-5 lung CAD results





### Conclusions



 MAGIC-5 CAD system: three parallel approaches to lung nodule detection and classification:

- o 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
- Partecipation 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



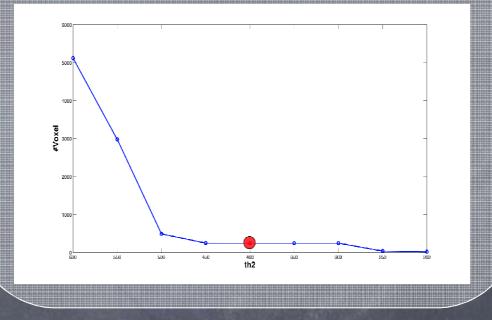
Iterative Region Growing finds nodules inside Lung Parenchima

Region Growing segments connected voxels that obey a *rule* 

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

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

A certain structure will almost always have a proper value *th*<sub>2</sub> for which it will be segmented from the air background.





*th*<sub>1</sub> is a watchdog and is fixed at air Hounsefield unit value

*th*<sub>2</sub> is defined iteratively nodule by nodule



### Virtual Ants CAD



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segment structures insid

9 ossible Pheromone Map  $\mathcal{O}$ Ē threhsold With a simple

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



## Voxel-based Neural CAD



Multi-scale Filter Function is applied to the lung parenchima

A peak detector algorithm finds the local maxima



Inward-pointing fixed-length surface normal vectors from every point of pleural surface

A peak detector algorithm finds voxel where many surface normals intersect



List of ROIs

#### Voxel-based Neural CAD INFN **Fisica Nucleare** "rolled-down" 3D neighborhood slice-1 slice List of From every voxels in a ROI ROIs 3 eigenvalues of gradient *matrix:* $\sum_{neigh} \partial_{x_i} I \partial_{x_i} I$ *i,j*=1,2,3 3 eigenvalues of Hessian matrix: 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



#### Automatic Nodule Detection 2009

Computer-aided detection (CAD) of nodules in chest computed tomography (CT) scans has attracted massive interest in the last eight years. There are now multiple commercial systems on the market and a large number of papers have been published that describe systems developed in academia. ANODE09 is an initiative to compare systems that perform automatic detection of pulmonary nodules in chest CT scans on a single common database, with a single evaluation protocol. Data is provided by the **Nelson study**, the largest CT lung cancer **screening trial** in Europe. Any team, whether from academia or industry, can join the study.

#### How does it work?

On this website, teams can **register** to participate in the study. After registration, they can **download**an example dataset of 5 annotated scans and a test set of 50 scans without annotations. Results of CAD systems on those test scans, consisting of a list of locations in the scans and a degree of suspicion that this location is a nodule, can be **submitted**. After submitting, the **results** will be available on-line.

A special session devoted to the ANODE09 study was held at the 2009 CAD Conference of SPIE Medical Imaging. More information including the first results can be found in this technical report and on the section of this site that has all the details.

This website is copyright 2008-2009 Bram van Ginneken (Image Sciences Institute).

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

## ANODE09: MAGIC-5 CADs

### results

CAD participants (SCORE)

- **OVBNA MAGIC-5 (0.29)**
- **@ RGVP MAGIC-5 (0.29)**
- **•** V-ANTS MAGIC-5 (0.25)
- Philips Lung Nodule (0.23)
- Fujitalab (0.21)

<b>⇔ → - 6</b> ⊙	The ANODEGO Competition for Nodble Detection in Chest CI; Home - /
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Smart Bookmarks *	🗭 Getting Started 🛛 Latest Headlines 👻
Home Details Lin	IODE09
Automatic	Nodule Detection 2009
interest in the last eig of papers have been compare systems that common database, w	clion (GAD) of nodules in check computed tomography (CT) scare has attracted mas phytemar. There are now multiple commercial systems on the market and a large our published that describe systems developed in academia. ANODE06 is an initiative to the perform automatic detection of pulmonary nodules in check TC scares on a single with a single evaluation protocol. Data is provided by the Netson study, the largest C girtial in Europe Any team, whether from academias in cirkustry, can join the study.
How does it v	vork?
example dataset of 5 systems on those tes	ns can register to participate in the study. After registration, they can <b>download</b> an annotated scans and a test set of 50 scans without annotations. Results of CAD t scans, consisting of a list of locations in the scans and a degree of suspicion that th can be <b>submitted</b> . After submitting, the results will be available on-line.
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**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

