## Announcement

- Final Presentations
  - June 10, 3:30-6:30 in Gates B-03
  - Final project write-ups due June 10 by 11:59pm

# Biomedical Informatics 260

Computer Reasoning with Images

Lecture 19

Spring 2019

## Review: Our Data Landscape

1. Images have a rich set of semantic and computational features
2. Representing semantic features (DICOM,AIM, RDF) give these data standard structure and make them machine accessible
3. Machine Learning algorithms help us to make a variety of applications (e.g., classification, prediction, etc.)

## Computerized Reasoning

- **What is computerized reasoning?**
- **What is reasoning by query?**
- **What are methods for image query?**
  - **String matching on text**
  - **Query AIM annotations with API**
  - **Query RDF annotations with SPARQL**
- **What is decision support?**
- **What are methods for decision support?**

**What is computerized reasoning?**

## Computer Reasoning

- Def: *Deducing new facts* or *answers to questions* based on domain knowledge and input data (usually *images* and factual *statements* about them
- Input data: images, texts, ontologies
  - NB: *annotated images/texts* are crucial

What is computer reasoning?

## Types of Computer Reasoning

**Query:** Help me ***find*** images or text

**Decision Support:** help me ***make decisions*** using image data

What is computer reasoning?

## Types of Computer Reasoning

**Query:** Help me ***find*** images or text

**Decision Support:** help me ***make decisions*** using image data

What is computer reasoning?

**What is reasoning by query?**

## Reasoning by Query

- The computer queries a resource based on inputs or information goals to answer a question
- Resources that may be queried:
  1. **Knowledge representation** (an atlas or ontology or data)
  2. **Images and texts** (semantically-annotated)

What is reasoning by query?

## Querying Knowledge Representations

- Two kinds of knowledge representations that can be queried:
  - Atlases
  - Ontologies

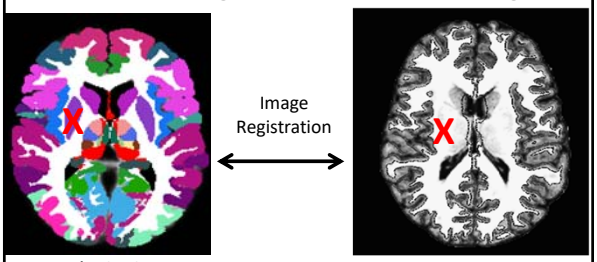
What is reasoning by query?

## When do we query an atlas?

To **transfer knowledge** to your image

What is reasoning by query?

## Transferring Anatomic Knowledge



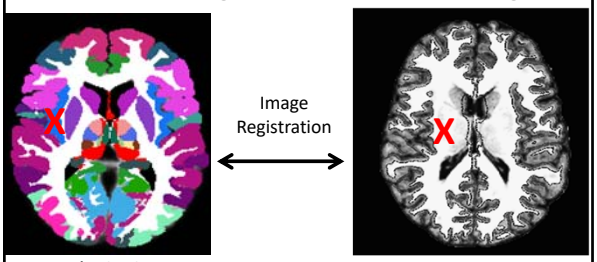

ATLAS (each color is a different anatomic region)

PATIENT IMAGE

- What anatomic structure is at point X? Caudate Nucleus

What is reasoning by query?

## Transferring Anatomic Knowledge




ATLAS (each color is a different anatomic region)

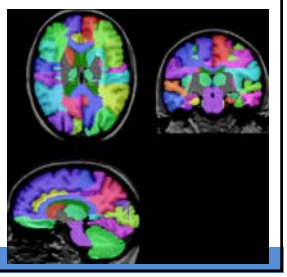
PATIENT IMAGE

- What anatomic structure is ***adjacent*** to my anatomic structure at point X? Insula

What is reasoning by query?

## Pitfalls of atlases

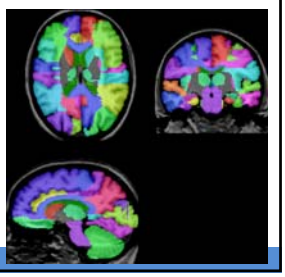
Class Question: What are ***challenges/pitfalls*** in using atlases for transferring knowledge to images? (hint: what do you do when you use an atlas to transfer knowledge to the image?)



What is reasoning by query?

## Encoding atlas info

Class Question: How would you create this atlas (i.e., how would you get the computer to recognize the the various anatomic structures in the image map)?



What is reasoning by query?

## Querying Knowledge Representations

- Two kinds of knowledge representations that can be queried:
  - Atlases
  - **Ontologies**

What is reasoning by query?

## When do we query an ontology?

1. **Find classes**
   - Is "chest" in RadLex?
2. **Find attributes values for a given class**
   - What are synonyms for "chest?"
   - What is the RadLex ID "chest?"
3. **Traverse relations**
   - Query expansion
     - E.g., "what are the parts of the chest?"
   - Answer questions
     - E.g., is "astrocytoma" a type of neoplasm?

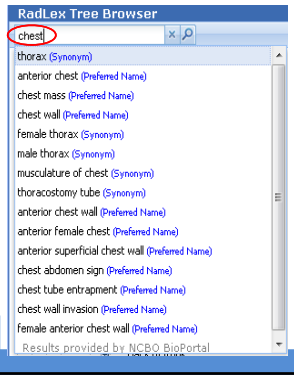
What is reasoning by query?

## 1. Find Classes

*http://radlex.org*

Is “chest” in RadLex?

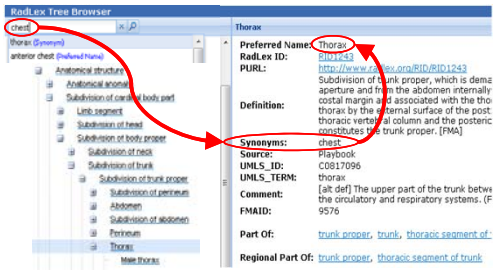
No “chest”




What is reasoning by query?

## 2. Find attribute values for a class

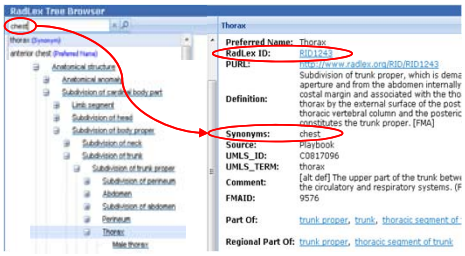
***What are synonyms for “chest?”***




What is reasoning by query?

## 2. Find attribute values for a class

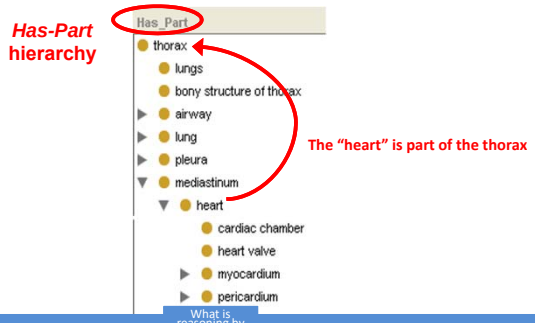
***What is the RadLex ID for “chest” (“thorax”)?***




What is reasoning by query?

## 3. Traverse relations

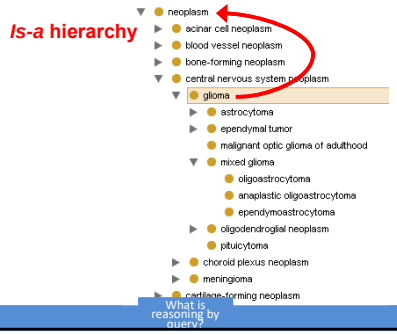
***What are the parts of the “chest” (“thorax”)?***




What is reasoning by query?

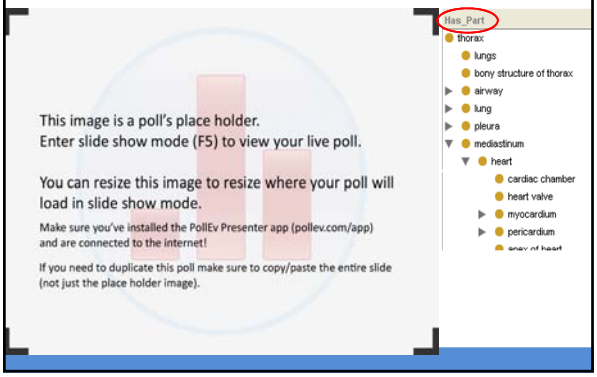
## 3. Traverse relations

***Is “glioma” a type of neoplasm?***




What is reasoning by query?

## Quiz



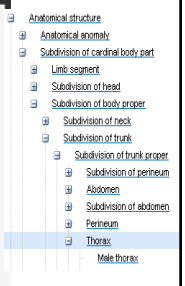
## Quiz

This image is a poll's place holder.
Enter slide show mode (F5) to view your live poll.

You can resize this image to resize where your poll will load in slide show mode.

Make sure you've installed the PollEv Presenter app (pollev.com/app) and are connected to the internet!

If you need to duplicate this poll make sure to copy/paste the entire slide (not just the place holder image).




## Quiz: Test your knowledge!

This image is a poll's place holder.
Enter slide show mode (F5) to view your live poll.

You can resize this image to resize where your poll will load in slide show mode.

Make sure you've installed the PollEv Presenter app (pollev.com/app) and are connected to the internet!

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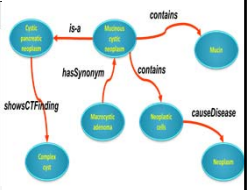



## Reasoning by Query

- The computer queries a resource based on inputs or information goals to answer a question
- Types of resources that may be queried:
  1. **Knowledge representation** (an atlas or ontology or data)
  2. **Images and texts** (semantically-annotated)

What is reasoning by query?

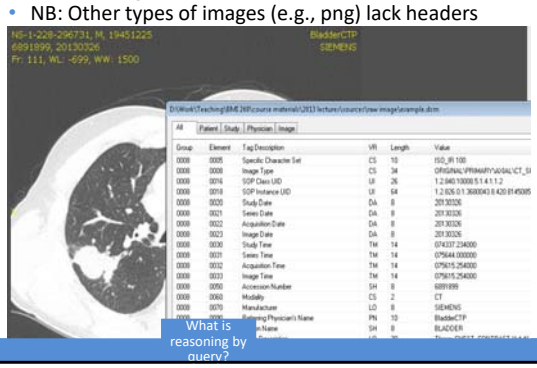
## Two places to query images

- Image header
  - Contains image metadata **directly associated with the image**
  - Acquired **at the time the image is created**
- Image annotations
  - Contains image metadata that are **separate from the images** (e.g., radiology report, image labels added by a reader)
  - Acquired af**ter the image is created**

What is reasoning by query?

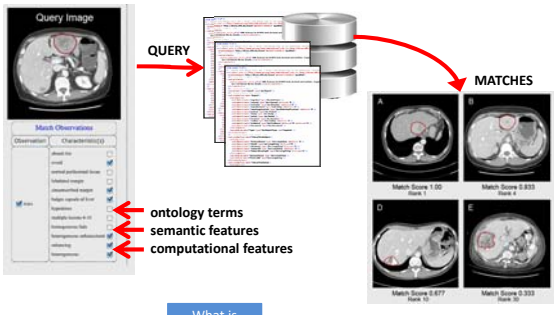
## Image query: ***Images*** as query input

- DICOM images
- NB: Other types of images (e.g., png) lack headers



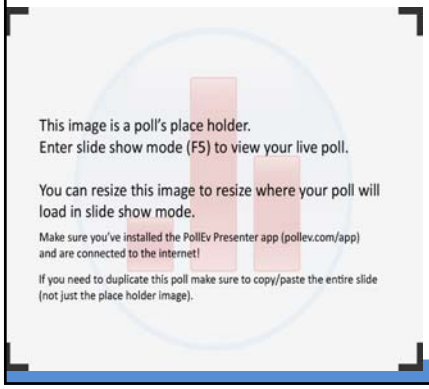
What is reasoning by query?

## Image Query: ***Annotated images*** as query input




What is reasoning by query?

## Quiz




- *PACS has three DICOM images with following info in "exam type" field:*
  1. "CT" [RID3]
  2. "Computed Tomography Chest" [RID3, RID82]
  3. "C.T. Thorax" [RID3, RID123]

## Quiz


- PACS with 3 images
  - "CT" [RID3]
  - "CT Chest" [RID3, RID82]
  - "CT Thorax" [RID3, RID82]

Hint: would you query by RID or by string value?

## When to use image query?

- **Search for images**
  - e.g., "Find CT images of the thorax with IV contrast"
  - e.g., "Find images showing a mass in the liver"
- **Summarize information in images**
  - e.g., "How much is the cancer size changing across multiple CT exams?"
- **Make decisions based on images**
  - e.g., "Is the patient's cancer responding well to treatment?"

How do I query?

## How do I query?

## How do I query?

- Querying DICOM header with **text matching**
- Query AIM annotations and RDF with **SPARQL**

How do I query?

## How do I query?

- Querying DICOM header with **text matching**
- Query AIM annotations and RDF with **SPARQL**

How do I query?

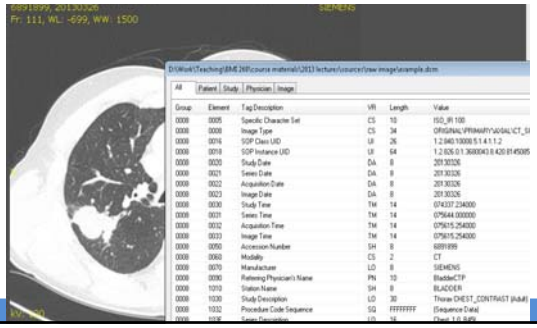
## 1) Search for images

- e.g., "Find CT images of the thorax with IV contrast"
- How?
  - **Perform string matching in fields of the DICOM header…**
  - (NB: you need to refer to DICOM standard to know which header fields to search; common ones are "modality" and "study description")

How do I query?

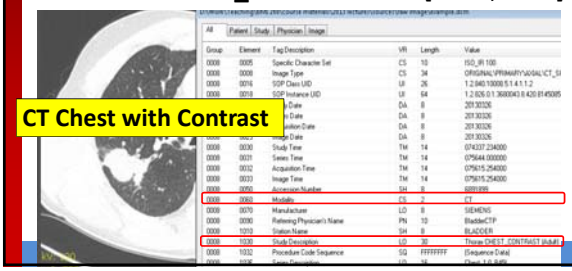
## String matching on DICOM headers

- E.g., how do we find **CT** images of the **thorax** with **contrast**?



## Do string matching in DICOM header…

- E.g., how do we find CT images of the thorax with IV contrast?
- Look for "**CT**" in tag [0008,0060] and "**Thorax CHEST_CONTRAST**" in [0008,1030]



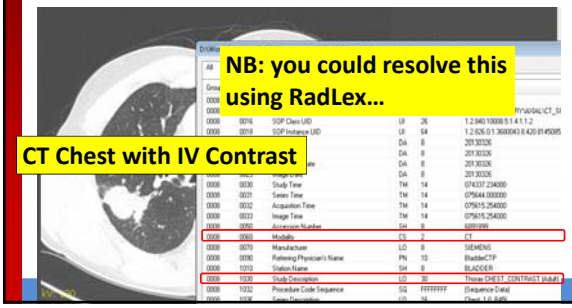

## Querying DICOM files

- DICOM libraries
  - PyDicom (python; code.google.com/p/pydicom/)
  - Pixelmed (java; www.medfloss.org)
  - DCMTK (C++; http://dicom.offis.de/dcmtk.php.en)
- Iterate through DICOM files, grab field values and do string matching

How do I query?

## But string matching may not be enough…

- What if we want find "**computed tomography** images of the **chest** with **IV contrast**?"




## How do I query?

- Querying DICOM header with **text matching**
- Query AIM annotations and RDF with **SPARQL**

How do I query?

## Motivation for needing to query using RDF or AIM

- AIM and RDF record ***semantic information about images*** (e.g., anatomy, imaging findings, quantitative image features) separate from the images
- You need a query language to query these formats
  - For RDF: SPARQL
  - For AIM: APIs or XML parsers
- In addition, you can do ***computer inference*** in addition to simple query

How do I query?

## What is SPARQL?

Simple Protocol And RDF Query Language

SPARQL Protocol And RDF Query Language

***Everything represented and queried via triples***

("Malcolm Gladwell", "authorOf","Blink")


RDF files (a specialized kind of XML)

How do I query?

## What does a query look like?

- **SELECT** variable(s)
  - Variables: **?x**
- **FROM** clause
  - Identify data sources to query
- **WHERE** clause
  - The ***triple/graph pattern*** to match
  - A conjunction of triples

```
SELECT ...
FROM ...
WHERE { ... }
```

How do I query?

## What does a query look like?

***Find the students who are taking BMI260***

SELECT **?student**

WHERE { **?student** sch:hasClass "BMI260" . }

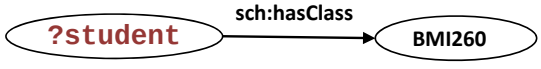
Variable names prefixed with "?" or "$"
Statements terminated by "."

How do I query?

## RDF queries are can be thought of as RDF graph traversals

SELECT **?student**

WHERE { **?student** sch:hasClass "BMI260" . }

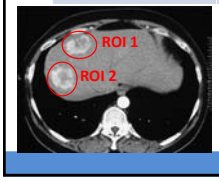


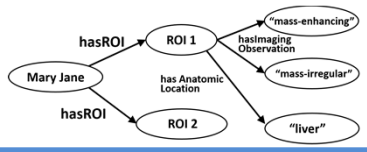

How do I query?

## RDF image annotations are "triples"

- Image annotations can be written as RDF triples
- E.g., annotations showing ***the imaging observations from liver lesions in Mary Jane***

| Subject | Predicate | Object |
|---|---|---|
| "Mary Jane" | has ROI | "ROI1" |
| "Mary Jane" | has ROI | "ROI2" |
| "ROI1" | has Imaging Observation | "mass-enhancing" |
| "ROI1" | has Imaging Observation | "mass-irregular" |
| "ROI1" | has Anatomic Location | "liver" |



## AIM/RDF annotations are "triples"

- An RDF query can ***summarize all the imaging observations from the liver lesion in Mary Jane***

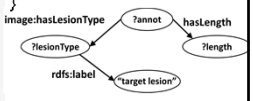
| Subject | Predicate | Object |
|---|---|---|
| "Mary Jane" | has ROI | "ROI1" |
| "Mary Jane" | has ROI | "ROI2" |
| "ROI1" | has Imaging Observation | "mass-enhancing" |
| "ROI1" | has Imaging Observation | "mass-irregular" |
| "ROI1" | has Anatomic Location | "liver" |

```
PREFIX rx: <http://radlex.org/#>
SELECT ?imgobs
WHERE {
 "Mary Jane" rx:hasROI ?roi
 ?roi rx:hasAnatomicLocation "liver"
 ?roi rx:hasImagingObservation ?imgobs.
}
```

## QUIZ: SPARQL for imaging

***Query: Get the lengths of "target lesions" seen in images***

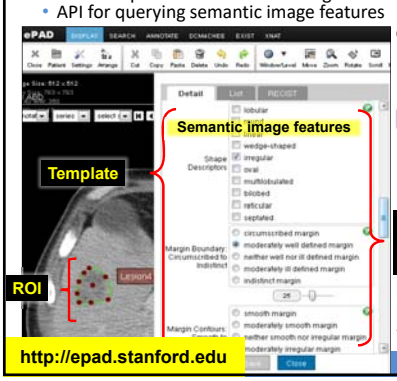

```
PREFIX image:
<http://protege.stanford.edu/rdf/image#>
SELECT ?length
FROM
<http://protege.stanford.edu/ontologies/image.owl#>
WHERE {
 ?annot  image:hasLesionType
         ?lesionType .
 ?lesionType  rdfs:label  ??
 ?annot  hasLength  ?length .
}
```

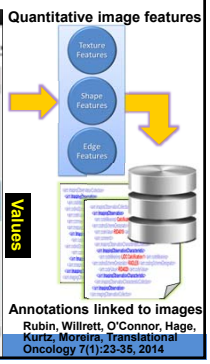



How do I query?

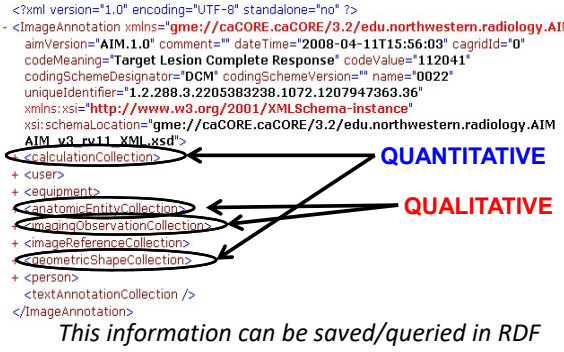
## AIM: ePAD image annotator

Web-based image viewer and annotator
- AIM-compliant annotation of images
- API for querying semantic image features




## AIM captures annotations in XML




*This information can be saved/queried in RDF*

How do I query?

## Example application using query: Find similar images

- With RDF you can search for other patients who have lesions with the same semantic features (i.e., similar-appearing lesions, content based image retrieval!)

| Subject | Predicate | Object |
|---|---|---|
| "Mary Jane" | has ROI | "ROI1" |
| **"Mary Jane"** | **has ROI** | **"ROI2"** |
| **"ROI1"** | **has Imaging Observation** | **"mass-enhancing"** |
| **"ROI1"** | **has Imaging Observation** | **"mass-irregular"** |
| **"ROI1"** | **has Imaging Observation** | **"mass-cavitary"** |
| "ROI1" | has Anatomic Location | "liver" |
| **"Joe Doe"** | **has ROI** | **"ROI 3"** |
| **"ROI 3"** | **has Imaging Observation** | **"mass-enhancing"** |
| **"ROI 3"** | **has Imaging Observation** | **"mass-irregular"** |
| **"ROI 3"** | **has Imaging Observation** | **"mass-cavitary"** |

How do I query?

## Types of Computer Reasoning

**Query:** Help me ***find*** images or text

**Decision Support:** help me ***make decisions*** using image data

What is computer reasoning?

What is decision support?

## What is decision support?

**Decision Support:** a type of **computer reasoning** that helps to ***make decisions:***

- **Patient diagnosis** (what disease causing the image abnormalities?)
- **Patient treatment selection** (how should we treat the disease?)
- **Treatment response** (is the disease responding to therapy?



## Types of DSS in radiology practice

1. **Computer-assisted diagnosis systems (CAD):** What/where is the disease?
2. **Treatment response assessment:** Analyze images to determine if patients are responding to treatment

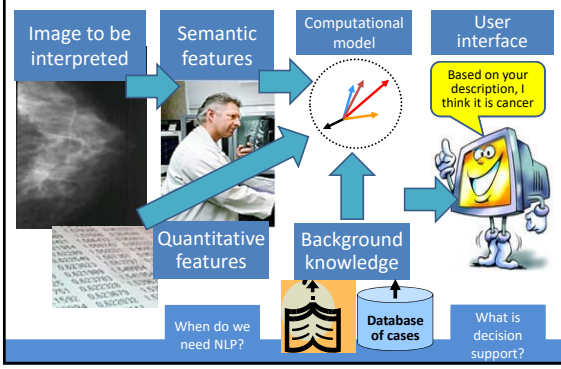


## Types of DSS in radiology practice

1. **Computer-assisted diagnosis systems (CAD):** What/where is the disease?
2. **Treatment response assessment:** Analyze images to determine if patients are responding to treatment



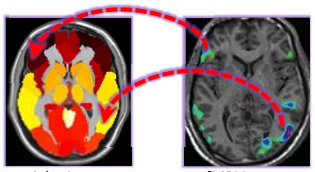
## CAD: What is the disease?






## CAD: Where is the disease?

***Image labeling to deduce structures affected by disease***



Atlas Image (anatomy overlay)

fMRI Image (functional map)

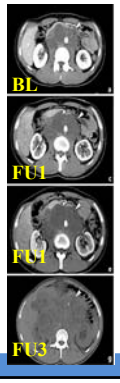
## Types of DSS in radiology practice

1. Computer-assisted diagnosis systems (CAD): What/where is the disease?
2. **Treatment response assessment:** Analyze images to determine if patients are responding to treatment

What is decision support?

## Treatment response assessment

- Assessed on **longitudinal imaging**
  - **Def**: Repeated imaging studies obtained over time
- **Approach**: Detect change in disease (change in size or other characteristics)
- **Reasoning tasks**: Analyze lesion measurements over time to determine if treatment is working




## Treatment response assessment

***How do we make an assessment?***

**We need:** standard criteria for describing the assessment

**R**esponse **E**valuation of **C**riteria in **S**olid **T**umors

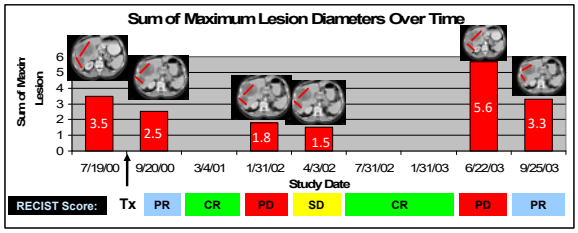
**RECIST CRITERIA**

CR = Disappearance of all target lesions
PR = 30% decrease or more in the SLD of target lesions
PD = 20% increase or more in the SLD of target lesions
SD = Small changes not meeting above criteria

What is decision support?

## Treatment response assessment

***"Is the patient's cancer responding to treatment?"***




Sum of linear dimensions (SLD) is assessed at each time point; change in SLD used to infer the treatment response

What is decision support?

**What methods for decision support?**

## Methods for Decision Support

- Rule Based
- Statistical/machine learning models

What are methods?

## Methods for Decision Support

- Rule Based
- Statistical/machine learning models

What are methods?

## Rule Based Methods

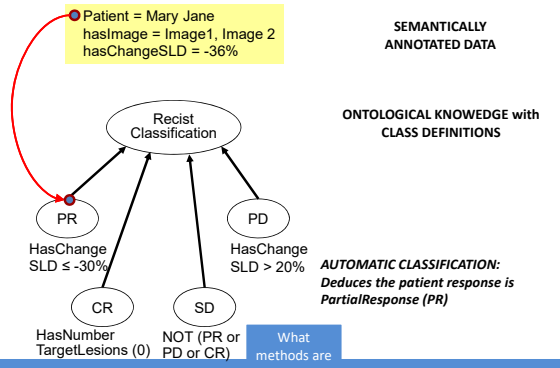
**INPUT:** rules developed by domain experts

**FORMAT**: IF <pre-conditions> THEN <action>

**OUTPUT**: a set of ***semantic annotations*** on text

What are methods?

## Automatic classification for response assessment



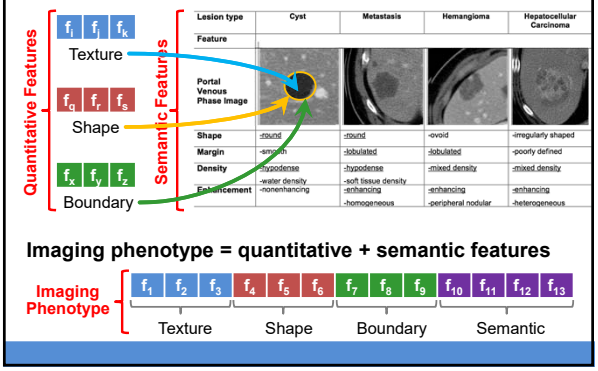

What methods are behind it?

## Methods for Decision Support

- Rule Based
- Statistical/machine learning models

What methods are behind it?

## Images are represented using feature vectors




## Statistical/machine learning models

- Using **quantitative features**:
  - Many machine learning methods (logistic regression, lasso, SVM etc.)
- Using **qualitative (semantic) features**:
  - Bayesian networks
  - Others machine learning methods could be used too

What are methods?

## Statistical/machine learning models

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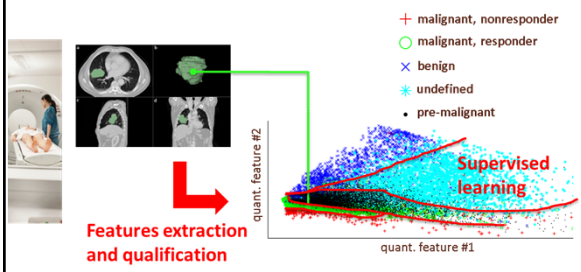
What are methods?

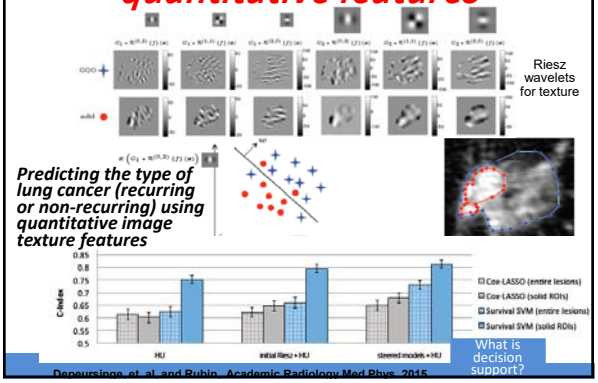
## Train models having quantitative image features with supervised machine learning




Radiomics: The process and the challenges, Kumar et al., Magn Reson Imaging, 30(9):1234-48, 2012.

What are methods?

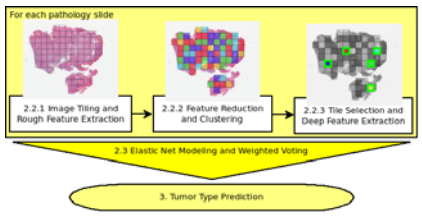
## Automated diagnosis using *quantitative features*




Depeursinge, et. al. and Rubin, Academic Radiology Med Phys, 2015

What is decision support?

## Pathology Classification Pipeline




Barker, J, Hoogi, A, Depeursinge, A, Rubin, D, "Automated Classification of Brain Tumor Type in Digital Pathology Images Using Local Representative Tiles, Medical Image Analysis [under review]

What are some examples?

## Statistical/machine learning models

- Using **quantitative features**:
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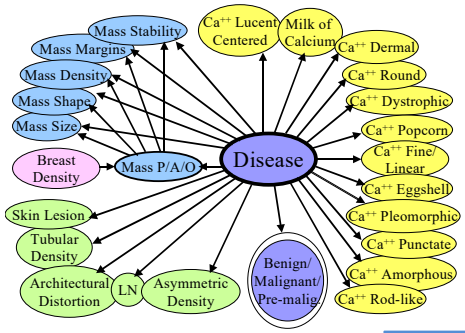
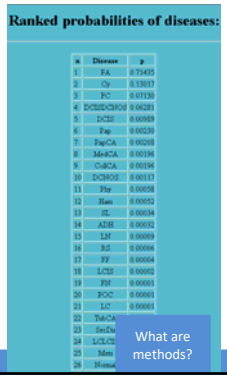
What are methods?

## A BN for Mammography




What are methods?

## What kind of DSS can I make?


What are methods?

## Output probabilities are actionable

- Decision support for **biopsy**
  - e.g., threshold chance of malignancy p > 2% → biopsy
- Decision support for **additional imaging** ("diagnostic mammography")
- Opportunity for shared decision-making
- Transparency of basis for decisions

What are methods?

## What have you learned?

**You want to search to find MRI images of the brain. What will you search to find them?**

- DICOM header
- RDF/AIM annotations
- Radiology reports

## What have you learned?

**You want to search to find MRI images showing a hemorrhage in the brain. What will you search to find them?**

- DICOM header
- RDF/AIM annotations
- Radiology reports

## What have you learned?

**You want to search AIM annotations for images showing pneumothorax, some annotations have this recorded as "pneumothorax," "PTX," or "pneumo." What resource could your query use to retrieve all of these?**

## What have you learned?

**You want to build a decision support system that tells a radiologist the probability that a lung nodule is a cancer based on what they say in thier report. What method would be best?**

- Deep learning model based on report text
- Bag of words model based on report text
- Bayesian model based on image features in report
- Rule-based model based on image features in report

*In summary…*

Computer reasoning deduces new facts or answers questions based on **domain knowledge**, **input images**, and **factual statements about them**

What is reasoning by query?

Reasoning by query is a type of computer reasoning that helps to find images (or text)

What is reasoning by query?

We can use **string matching** to query DICOM headers, and **SPARQL** to query RDF and AIM

How do I query?

Decision support systems help make physicians make decisions

What is decision support?

**Rule based** systems and **statistical models** (e.g., Bayesian networks with qualitative features or machine learning with quantitative features) are common and powerful implementations for decision support.

What are methods?

**Thank you!**