AI in Diagnostic Imaging: An Opportunity to Reinvent the Clinical Workflow

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Disclosures

- Royalties, Osler institute
- Board Member (SIIM, AUR)
- Member, RSNA Radiology Informatics Committee
- Member, ACR Informatics Commission
- Director, National Imaging Informatics Course
- Chair, Informatics Committee of ACR's Patient- and Family-Centered Care Commission
- Fellowship Director, Imaging Informatics, Penn Radiology
- Penn Center for Healthcare Innovation (2013-14)
- CURE Award, PA Department of Health & ACRIN (2017-18)
- Beryl Institute Patient Experience Improvement Award (2018)
- Society for Imaging Informatics in Medicine (2019)
- Departmental agreements with Nuance Healthcare, TeraRecon, Siemens Healthineers

Outline

AI in diagnostic imaging

Deploying AI in the clinical workflow

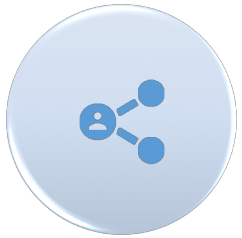
Examples of our AI work

Developers' opportunities

Physicians' opportunities

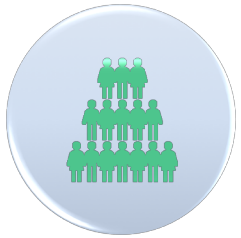
AI in Diagnostic Imaging

Current Challenges in Radiology and Diagnostic Imaging



DOING MORE… WITH LESS

INCREASING IMAGING VOLUMES

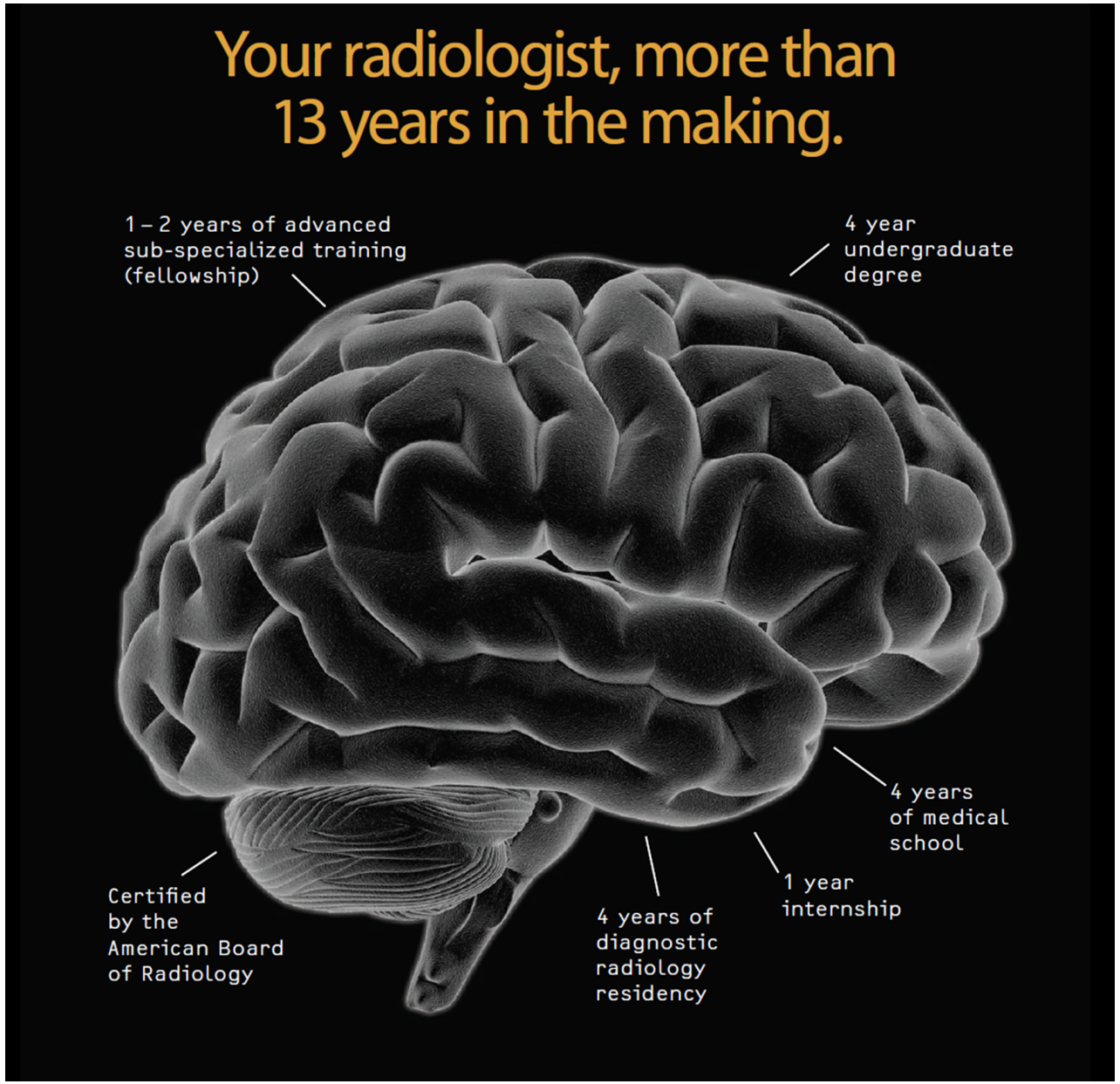


GREATER COMPLEXITY OF DISEASES

NEW INTERVENTIONS AND THERAPIES

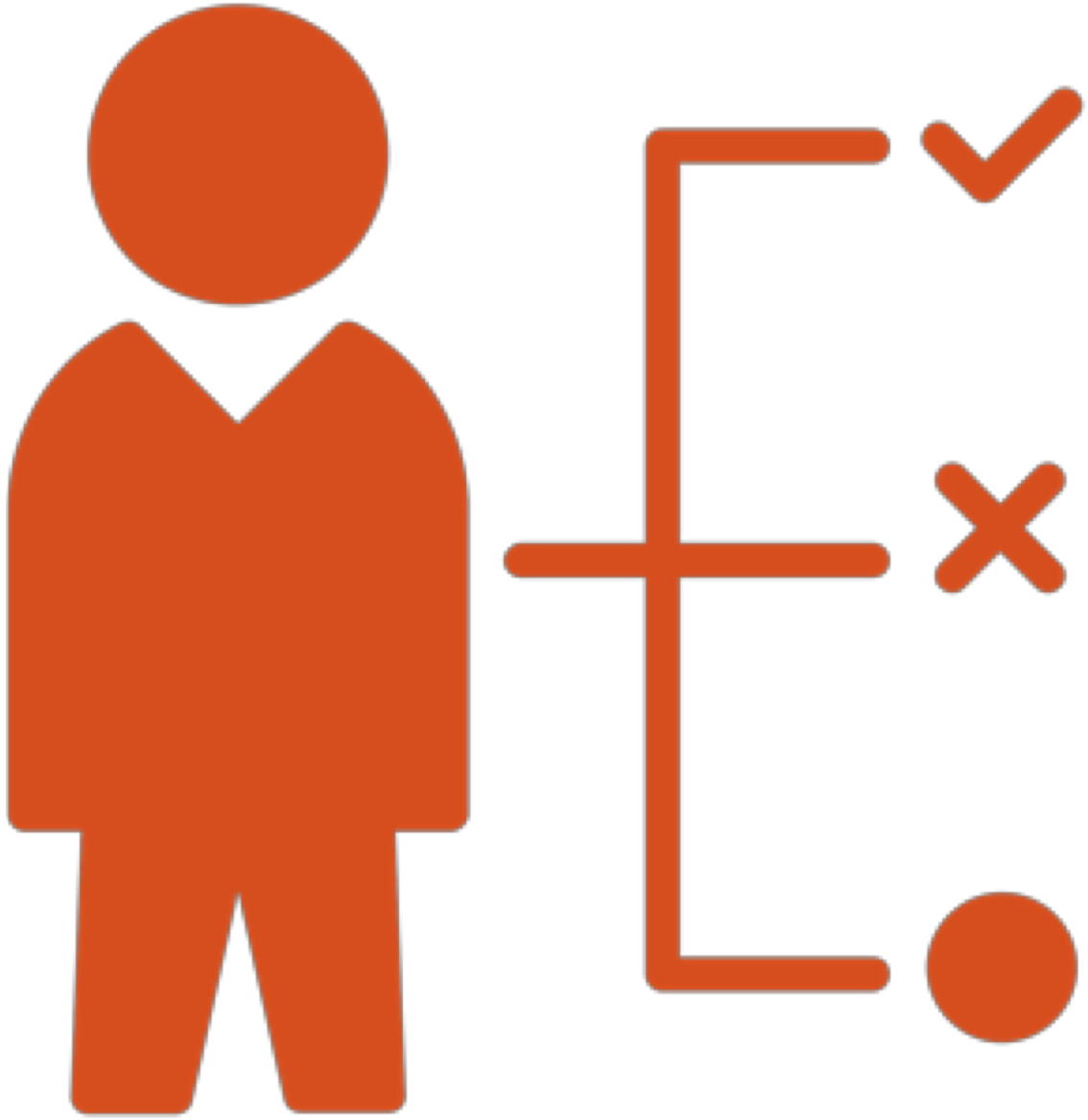
RADIOLOGY WORKFORCE SIZE

To understand the role AI might play in radiology and diagnostic imaging, we must first understand the role of the radiologist in diagnostic imaging—before, during, and after the imaging examination.



The Role of the Radiologist: **Before** the Imaging Examination

- Decision support to ordering physicians
- Image vs. don’t?
- Which test?
- When?
- How?



The Role of the Radiologist: **During** the Imaging Examination

- Image acquisition protocol optimization
- Imaging supervision

Identification of findings

- Comparisons

Interpretation of findings

- EMR review

Reporting of findings

- Recommendations for further management

The Role of the Radiologist: **After** the Imaging Examination

The Role of the Radiologist: **After** the Imaging Examination

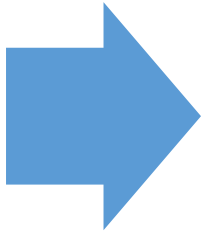
- Communication of findings & interpretation
- Consultation with other physicians
- Consultation with patients

How AI Can Help Radiologists: **Before** the Imaging Examination

Prior imaging / workup

Relevant medical history

New clinical question



Automated imaging protocol recommendation

Optimized image acquisition using scanner raw data

Radiation exposure

Intravenous contrast dose

Image quality

How AI Can Help Radiologists: **During** the Imaging Examination

How AI Can Help Radiologists: **After** the Imaging Examination

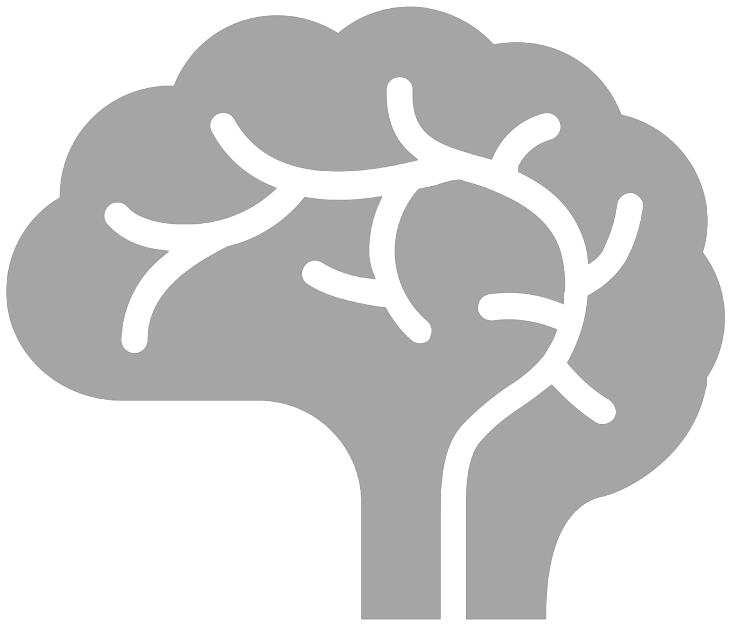
- Case triage
- Automated, contextual information retrieval
- Consistent, reproducible measurements
- Lesion comparison to prior examinations
- Intelligent report proofreading

How AI Can Help Radiologists: **After** the Imaging Examination (The Future)

- Analysis of image characteristics not visible to the human eye
- Disease prediction in asymptomatic individuals
- Objective assessment of currently subjective diagnoses

The Challenge

- Resist temptation to replace manual step with AI
- Can we use AI as an opportunity to disrupt workflow to improve care?



Deploying AI in the Clinical Workflow

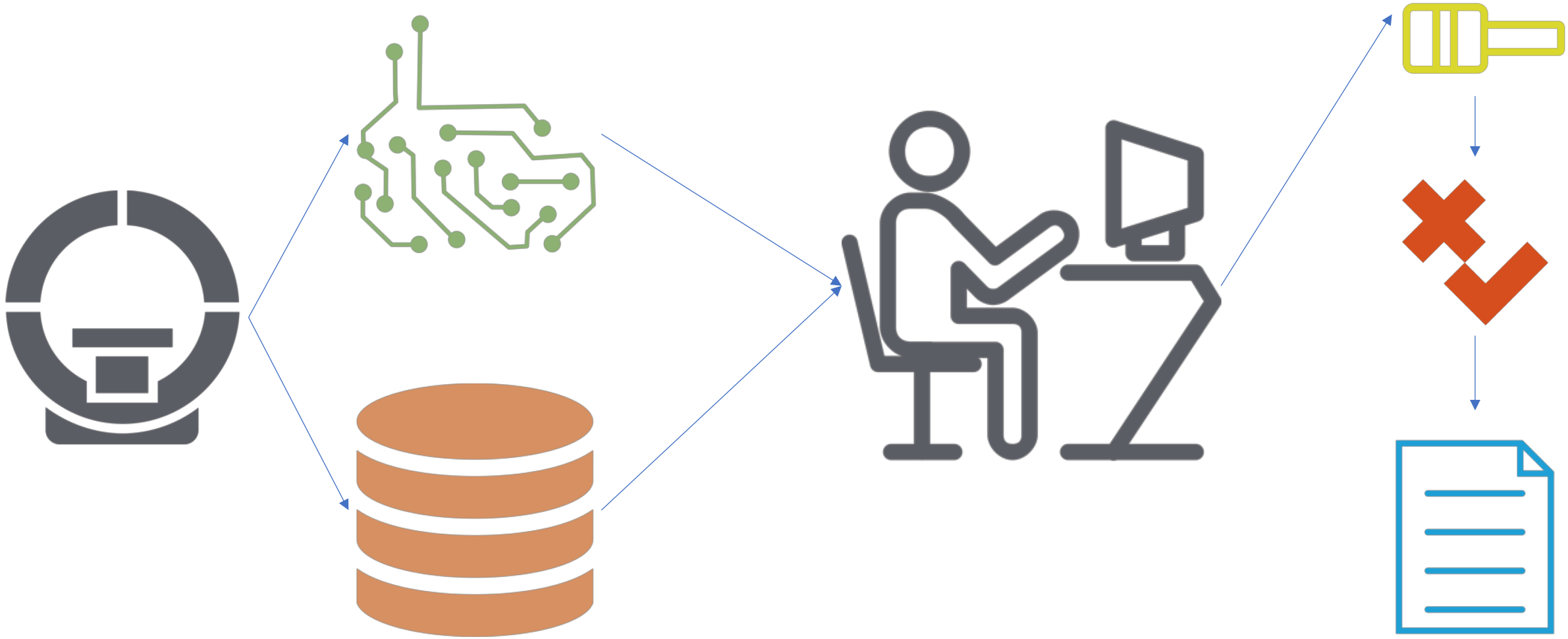
Modern Radiology Workflow

- PACS: picture archiving and communications system
- RIS: radiology information system
- EMR: electronic medical record
- Other thin-client image post-processing applications
- Workflow: PACS-driven vs. RIS-driven

Deploying AI in the Clinical Radiology Workflow

- Integration into existing workflow
- Interactive results review
- Auto-population of results → report
- Medicolegal considerations

Integrating AI into the Clinical Radiology Workflow



Medicolegal Considerations

- Explainable AI becomes even more important in medical imaging
- Radiologists will need to trust it in order to use it
- What happens when the radiologist disagrees with the AI?

Our Approach to Evaluating AI for the Clinical Workflow

Staged rollout

Retrospective review of cases with known results

Prospective evaluation of new cases without known results

No AI outputs archived in PACS/RIS/EMR during evaluation

- Stipulated by the Institutional Review Board

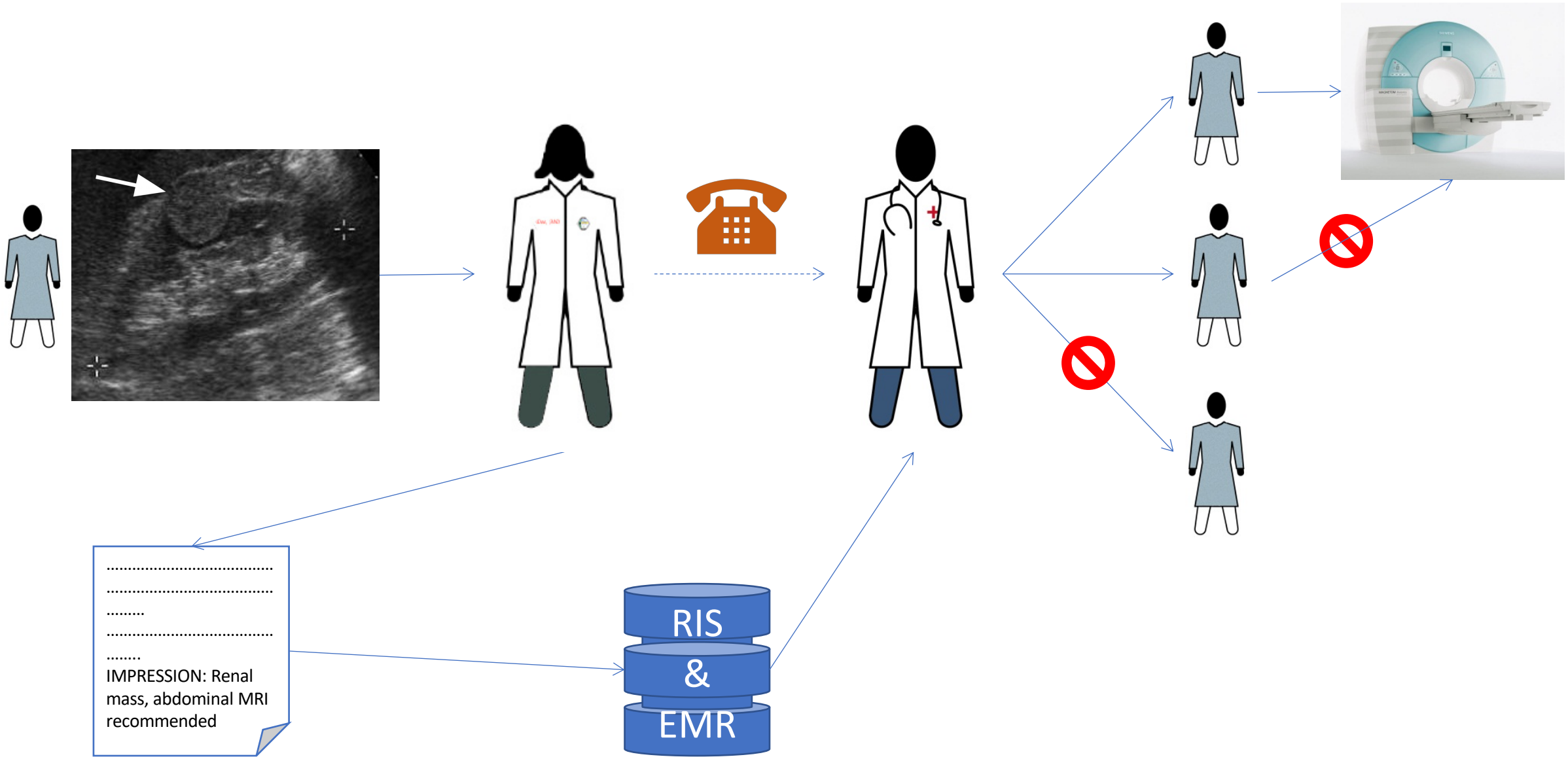
Penn Radiology AI Initiatives

Penn Radiology AI Initiatives

- Lung nodule detection and tracking*
- Lesion change detection for brain and spine imaging
- Bayesian network-driven radiologist decision support
- Acute findings detection in brain imaging*
- Follow-up monitoring

*vendor collaborations

Follow-Up of Non-Critical Actionable Findings



Adding Structured Data to Unstructured Radiology Reports

START FOCAL MASS ASSESSMENT SUMMARY

Liver: Category 2: Benign

Pancreas: Category 1: Normal

Kidney: Category 3: Indeterminate. If indicated within the patient's clinical context, follow-up enhanced MRI of the abdomen may be obtained within 3 months.

Adrenals: Category 7: Completely treated cancer.

Other: No Category

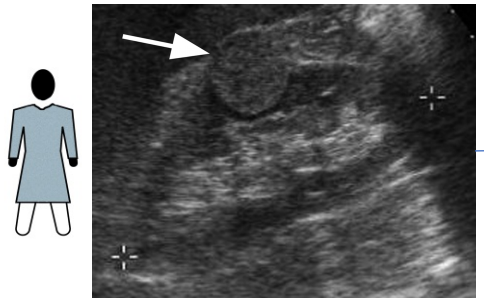
END FOCAL MASS ASSESSMENT SUMMARY

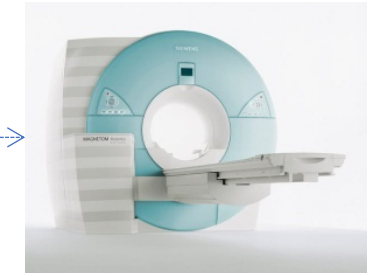
Table 1. Code Abdomen categories, classifications, descriptors, and examples

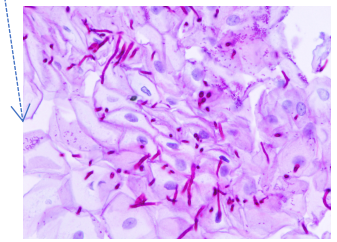
Category	Classification	Descriptor	Example
0	Indeterminate	Incompletely evaluated. If indicated within the patient's clinical context, follow-up [MODALITY] is advised.*	Adrenal lesion with attenuation > 10 HU on enhanced CT in patient with known malignancy. Follow-up adrenal CT or MRI recommended.
1	Benign	No mass.	
2	Benign	Benign. No further follow-up needed.†	Simple hepatic or renal cyst.
3	Indeterminate	Indeterminate. Future imaging follow-up may be needed. If indicated within the patient's clinical context, follow-up [MODALITY] is advised within [TIME PERIOD].*‡	Atypical hepatic hemangioma on CT or MRI. Follow-up CT or MRI recommended in 3-6 mo.
4	Suspicious	Suspicious. May represent malignancy.	Enhancing hepatic mass in cirrhotic patient without other classic imaging features of hepatocellular carcinoma (eg, delayed washout).
5	Suspicious	Highly suspicious. Clear imaging evidence of malignancy.	New hepatic soft tissue density lesions in patient with known colorectal cancer.
6	Malignant	Known cancer.	Biopsy-proven cancer or metastatic lesions
7	Benign	Completely treated cancer.	Renal cell carcinoma, status post nephrectomy without abnormality in surgical bed.
99	Cannot be classified	Technically inadequate for evaluation of masses.	Unenhanced CT in cirrhotic patient.

Zafar et al. *JACR* 12(9): 947-50; 2015

ARRTE: The Automated Radiology Recommendation Tracking Engine







IMPRESSION

Kidney Mass:
Indeterminate
Abdominal MRI
recommended

Reports

ARRTE

RIS
&
EMR

Completed

Scheduled

Missed

Not Scheduled

Escalating notifications

Cook et al. JACR, 14(5), 629-36, 2017
Zafar et al. *JACR* 12(9): 947-50; 2015

Closing the Imaging Follow-Up Loop

Imaging

- Look for structured data in subsequent reports
- What if none?

Pathology

- Free-text reports
- Correlation to radiology finding?
- Benign? Malignant? Indeterminate?

Non-radiology testing & clinic visits

1. Radiology-Pathology Correlation with AI

Data

- 1,814 free-text pathology reports manually reviewed & labeled with relevant abdominal and pelvic organ(s)

Methods

- Regex string matching
- TF-IDF + machine learning {SVM, xgBoost, RF}
- Neural networks {CNN, LSTM}

Results

- Neural networks outperform other approaches

1. Radiology-Pathology Correlation with AI

Non-Gyn Cytopathology Report

Specimen Source
Pancreas Body, FNA.
This case is 2 of 2 cases.

Case list:
_XX99-9999, XX99-9999.

Statement of Adequacy
Satisfactory for Evaluation.

Diagnostic Category
Other - See Interpretation.

Final Interpretation
Pancreas Body, EUS-FNA:
Glandular cells and cyst contents identified; no high grade dysplasia identified.

The case material was reviewed and the report verified by: Jane Doe, MD

(Electronic signature)

Verification Date: XX/XX/XXXX

Initially
screened by: John Doe, CT(ASCP)

Recommendation
Recommend clinical correlation and additional work-up as clinically indicated.

Clinical Information
Not provided.

Gross Description
Specimen Labeled As: Pancreatic Body FNA
Appearance: Fresh, Cloudy Amount: 50 cc
Date collected: x/xx/xx

_ smear(s), _ cytospin(s), _ filter(s), _ cell block slide(s), 1 liquid-based prep(s), _ special stain slides
Total number of slides: x

Pathologist(s)
John Doe, MD

“pancreas”

Steinkamp et al. *ARRS 2019*

1. Radiology-Pathology Correlation with AI

Best-performing system now implemented in ARRTE

Organ(s) of interest defined by Code Abdomen category labels generated by radiologists

System flags “relevant” pathology report if it describes the organs of interest

Radiologist can quickly review for benign, indeterminate, malignant

Next phase: auto-classification of benign, indeterminate, malignant

Steinkamp et al. *ARRS 2019*

2. Identification of Follow-Up Recommendations in Radiology Reports

Useful for free-text or semi-structured reports, without built-in radiologist tags/labels

Can generate large volume of weakly-labeled data for image-based AI

Trained a radiology model using embeddings from language models (ELMo) & a report classification system

Trained on >100,000 pre-labeled abdominal imaging reports with labels removed

Accuracy 92-99% (higher for more common organs)

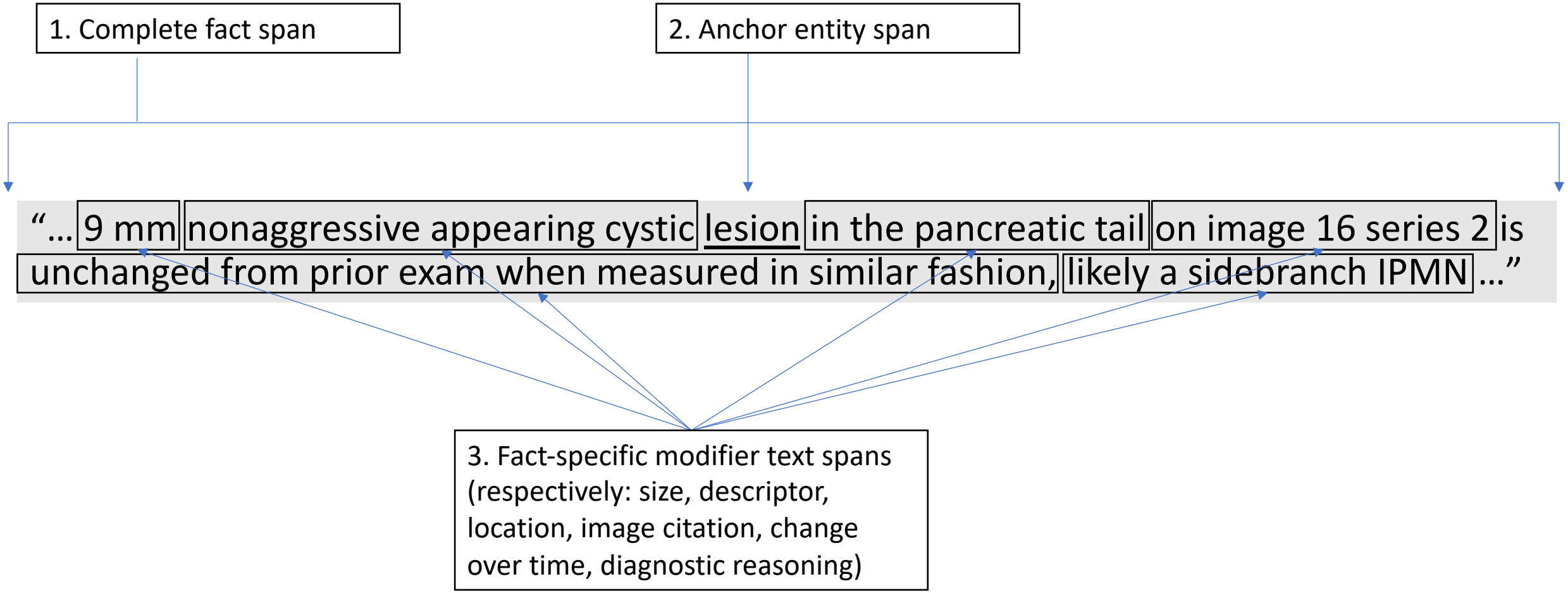
Steinkamp et al., under review

3. Towards Complete Information Extraction from Unlabeled Radiology Reports

- Extract structured information from unstructured radiology report
- Information schema based on natural language questions, e.g.
  - Retrieval, e.g., “What are all of the findings in this report?” “What are all the follow-up recommendations active for this patient?”
  - Specific / referential e.g. “What size was that kidney lesion?”, “What did the radiologist think the most likely explanation for this finding was?”
- 18 types of facts and associated entities cover >95% of report text

Steinkamp et al., under review

3. Towards Complete Information Extraction from Radiology Reports



Steinkamp et al., under review

3. Towards Complete Information Extraction from Radiology Reports

120 abdominal reports manually labeled with their complete factual content (>10,000 pieces of information)

Neural network models trained to retrieve “anchor” entities (e.g., finding, recommendation, anatomic region) and their modifiers (e.g., size, diagnostic reasoning, uncertainty)

Small initial dataset, but promising early performance

Working on expanding size of data set & labeling other types of radiology reports

Steinkamp et al., under review

Related Projects

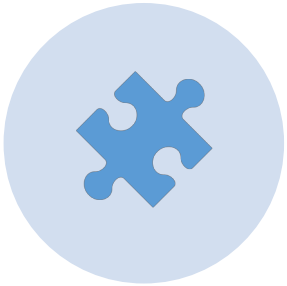
- Datasets and models for natural language question-answering as labeling technique for radiology reports
- Protocol selection/optimization based on free-text indication for an imaging examination
  - Currently requires manual radiologist review
  - Hundreds of exams/day
  - Dataset of 3+ years' worth of protocols

Opportunities for Developers in Medical Imaging AI

Team Up with Radiologists

- Clinical domain experts + AI experts
- Many imaging (informatics) societies actively working in this area
  - Society for Imaging Informatics in Medicine (SIIM)
  - Radiological Society of North America (RSNA)
  - American College of Radiology (ACR)

Understand Medical Imaging Data



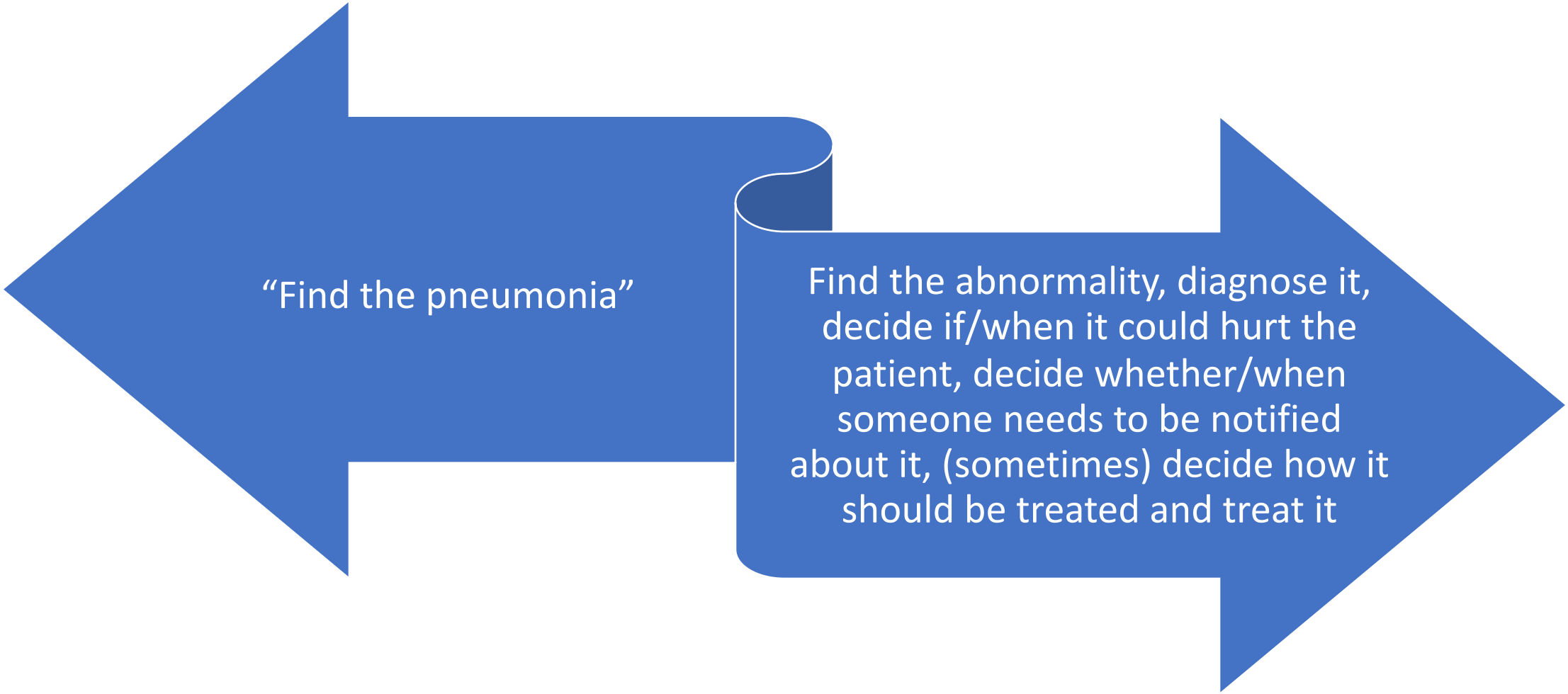
Complex data

Multiple sources

High-quality training data is scarce (compensate with weak labels, GANs?)

Who owns the data – imaging center, health system, patient?

Understand What Radiologists Do



Understand the Workflow

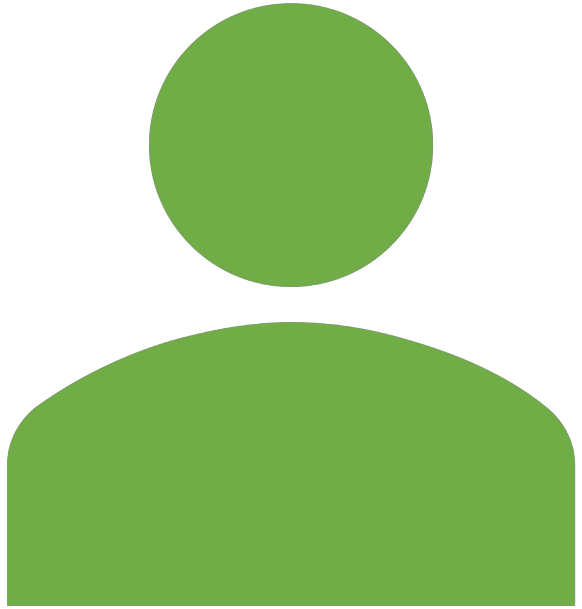
- Remember the challenge: do more, with less
- AI tools should not create more work for radiologists
  - Low tolerance for false positives and false negatives
  - Integration into the workflow is critical

Learn Imaging Informatics

- DICOM, HL7, FHIR, PACS, RIS, VNA, ontologies & lexicons
- Worklists
- Presentation states
- Voice recognition
- Results notification
- SIIM, RSNA, ACR are resources here

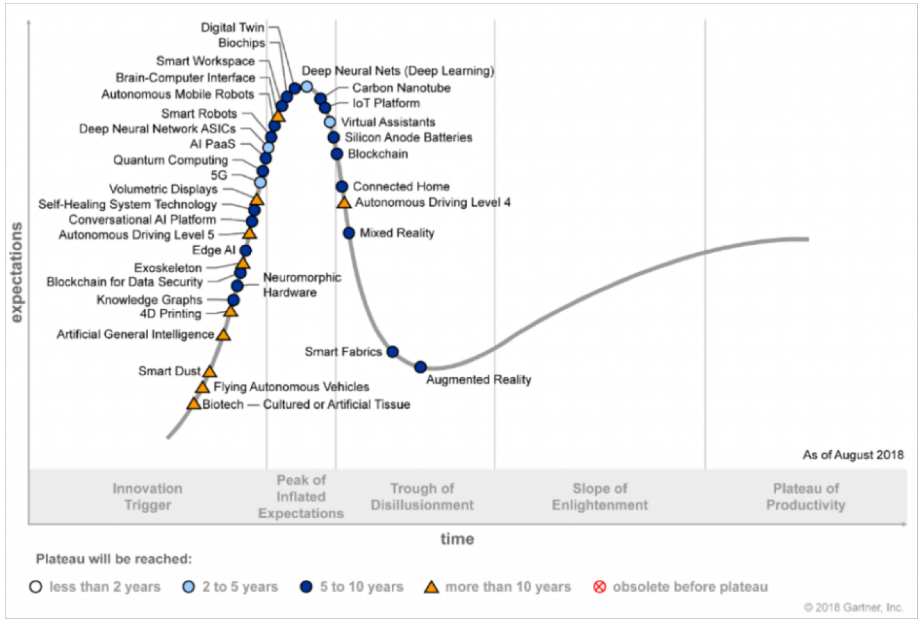
The Goal is Not a Robot Radiologist

- It is a radiologist whose expertise is complemented by AI, to enable better delivery of patient care
  - Information retrieval
  - Productivity
  - Accuracy
  - Reporting
  - Communication



Opportunities for Physicians in Medical Imaging AI

Radiologists' Opinions about AI



- Sorting through the hype
- AI is like the next new modality (CT, MRI, molecular imaging)
- Radiologists are no strangers to adoption of new technology (PACS, voice recognition, structured reporting)

https://www.criticallink.com/2018/11/gartners-latest-emerging-technologies-hype-cycle/

Validate and Evaluate Models

- AI tools will only succeed if radiologists trust them enough to use them
- As the clinical domain experts, we have to form collaborations with developers to evaluate new models
- Trust takes time – and experience

Who Will Pay for AI?

AI is expensive

Reimbursements continue to decline in radiology

Radiologists need to advocate for CMS/payor coverage

How do we address care disparities?

”How Do I Learn AI?”

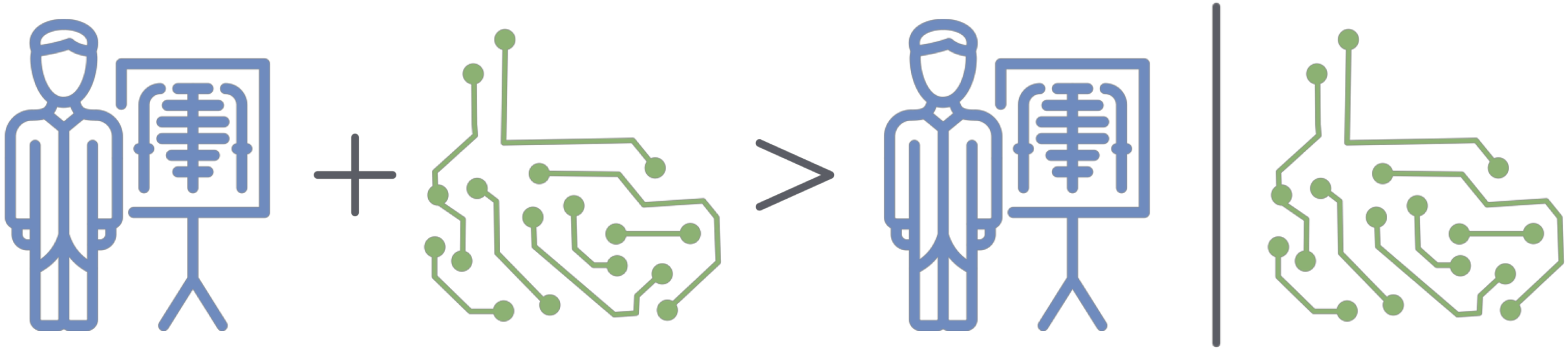
- The current generation of (radiology) residents is asking, often

- Learn imaging informatics first, then learn AI

- Just like for developers, it’s important to understand the environment in which AI will operate and the technical aspects of what it will need to interact with

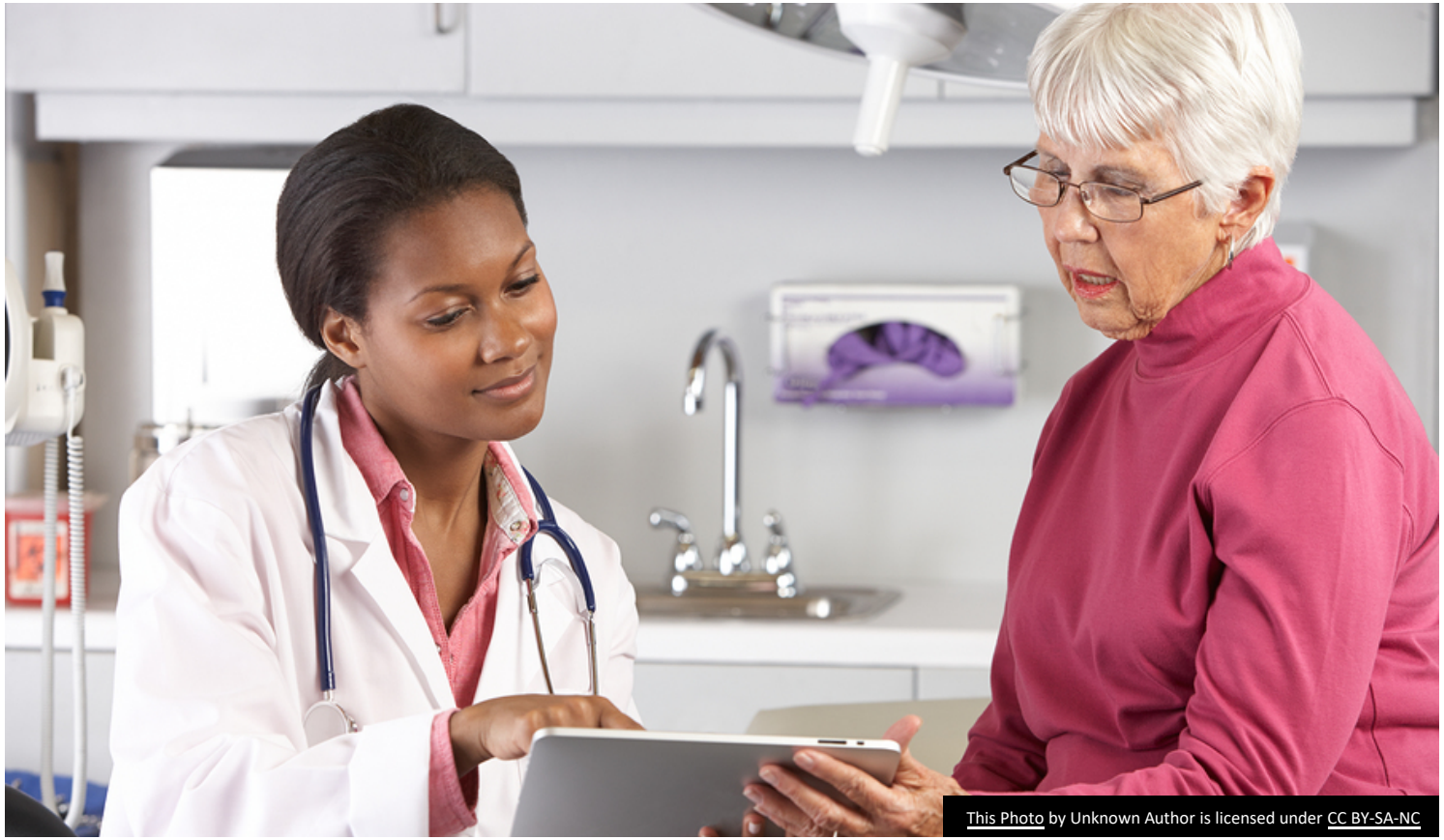
The AI-Enabled Future of Radiology

The Future of AI in Medical Imaging



The AI-Enabled Future of Radiology: The Diagnostic Cockpit

- Actionable information from multiple sources
- Prioritization of abnormal/complex exams
- Automated measurements
- Patient-specific alerts



Radiologists + AI = More Human Interactions

- Time to talk to patients
- Time to consult with other professional colleagues

- Radiologists practicing both as the doctor's doctor and the patient's physician

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