



Nuclear Medicine AI Hype, Reality, and the Future Potential of AI

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WELL, AFTER THE LATEST ROUND OF REIMBURSEMENT CUTS, I'VE RECALCULATED MY NEW RETIREMENT AGE ... 98!



31st Anniversary Filmless/Digital

- This June 2024 marks the 31st anniversary of operation of the world's first filmless radiology and nuclear medicine department at the Baltimore VA
- Nuclear medicine departments have been all digital for even longer
- In addition to the goal of any image any time and anywhere when it was needed for clinical care
- We also wanted to move to digital to take advantage of advances in computer aided detection and diagnosis and quantification which was a rapidly emerging field in the 1990s
- When asked about the predictions about the future that turned out to be the farthest off, I would have been quite surprised to know more than 30 years later that these AI algorithms were still not in routine use and had almost no impact on patient cancer care



PACS was a
huge
paradigm shift
but was
thought to be
Pandora's Box
in Early 90s

AI and
Pandora's Box
in 2020's





So What Is and What Isn't Machine Learning?

AI/Machine Learning Basic Terms

Machine Learning

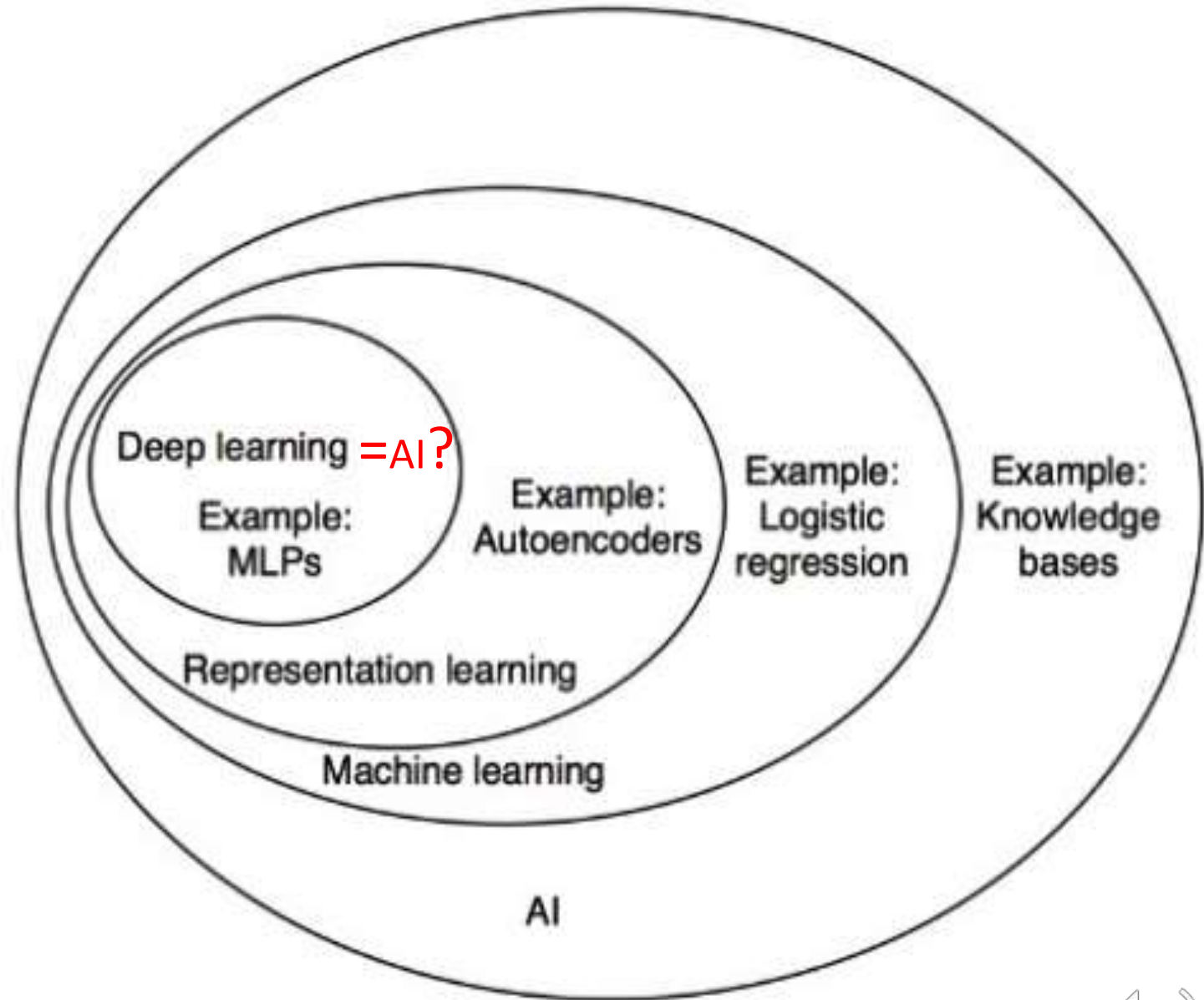
- Statistical regression techniques such as linear regression
- Support vector machines
- Decision trees
- Bayesian belief networks
- k-nearest neighbors
- Self-organizing maps
- Case-based reasoning
- Instance-based learning
- Hidden Markov models...
- **Neural networks**
 - **Convolutional neural networks**
 - Have become synonymous with AI because of their application in human vision and translation applications
 - **Transformers – the next big wave in AI**
 - Extremely hot now, especially for language models like Chat-GTP, Generative Pre-Trained Transformer, but also medical imaging

What Do We Mean by “AI”?

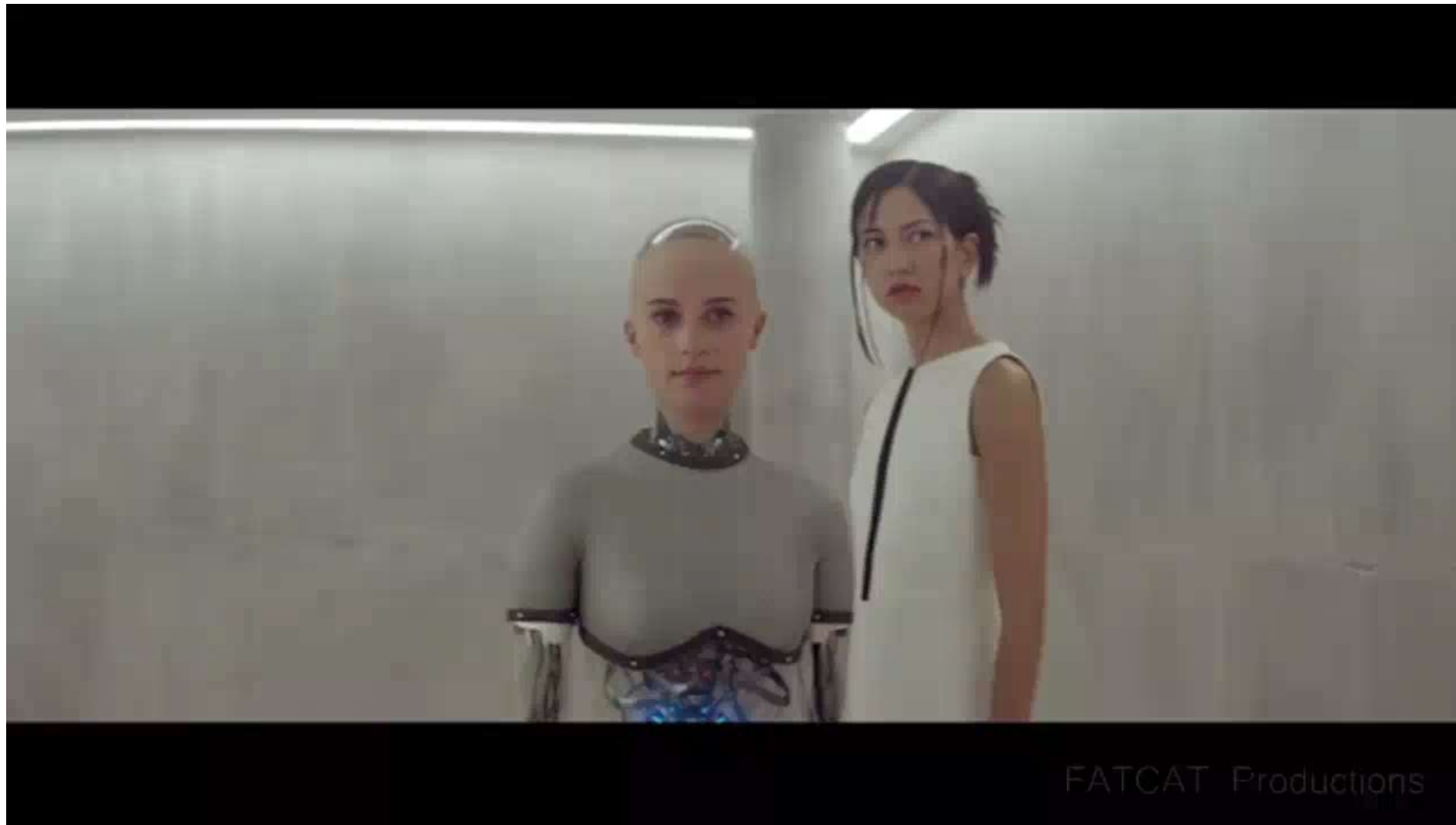
Term originally coined by Computer Scientist John McCarthy of Stanford in 1956

Most of what is called “AI” today refers to the use of a neural network such as a Convolutional Neural Network (most current pixel based AI) or Transformer Neural Network e.g. ChatGPT

AI has been classified as “narrow” or “general” which can be sub, equal, or superhuman in performance



Ava from Ex Machina



When Will High Level General Artificial Intelligence Arrive?

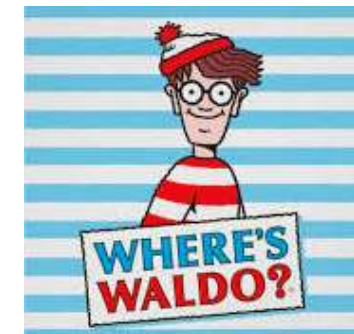
Survey of 2,778 Experts in the Fall of 2023

- Experts were asked when they thought “high-level machine intelligence,” defined as machines that could “accomplish every task better and more cheaply than human workers” without help, would be feasible
- Average of the predictions suggests a **50% chance that this would happen by 2047, and a 10% chance by 2027.**
- - Experts seemed to have been surprised by the rapid AI progress of the last year and have updated their forecasts accordingly—when AI Impacts ran the same survey in 2022, researchers estimated a 50% chance of high-level machine intelligence arriving by 2060, and a 10% chance by 2029.
 - They estimated a **50% chance that AI could compose a Top 40 hit by 2028 and write a book that would make the *New York Times* bestseller list by 2029.**
- Can General AI Build an AI smarter than it? Certainly tools using AI can advance the time at which General AI arrives, assuming it does arrive
- Kurzweil’s Singularity

SNMMI 2023 Debate:
What's the Difference Between "CAD" (Radiomics) and "AI"?
Traditional Computer Aided Detection/Dx vs. CNN's



How Fast Can
You Find Waldo?

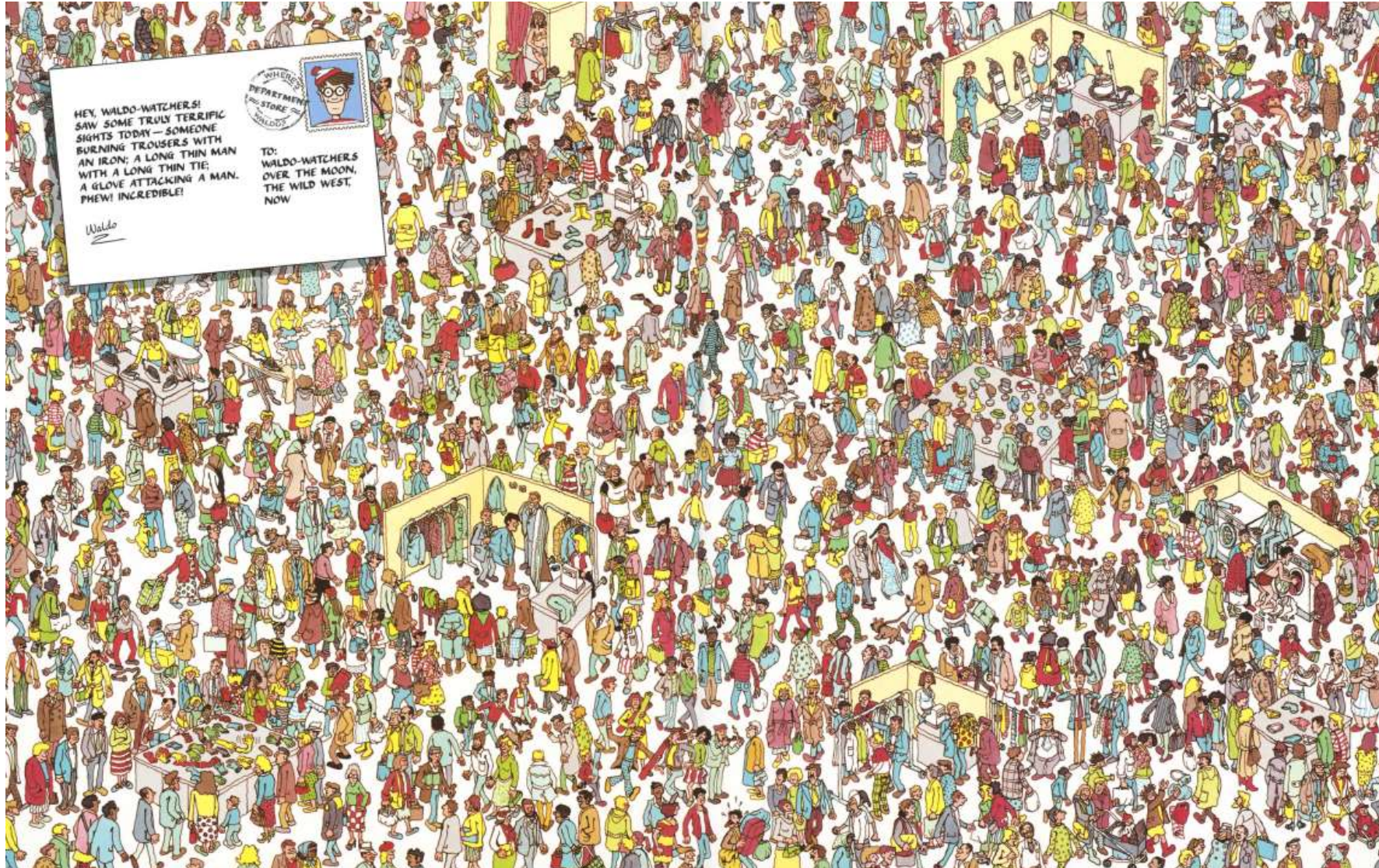


Are you a
Waldo Savant?

Radiomics Vs. Deep Learning Approaches May Depend on the Task:

Find Any Similar Waldo Vs. How Does This Waldo Differ From Other Waldos

What Works for Finding Pulmonary Embolism Might be Different From Characterizing Brain Tumor



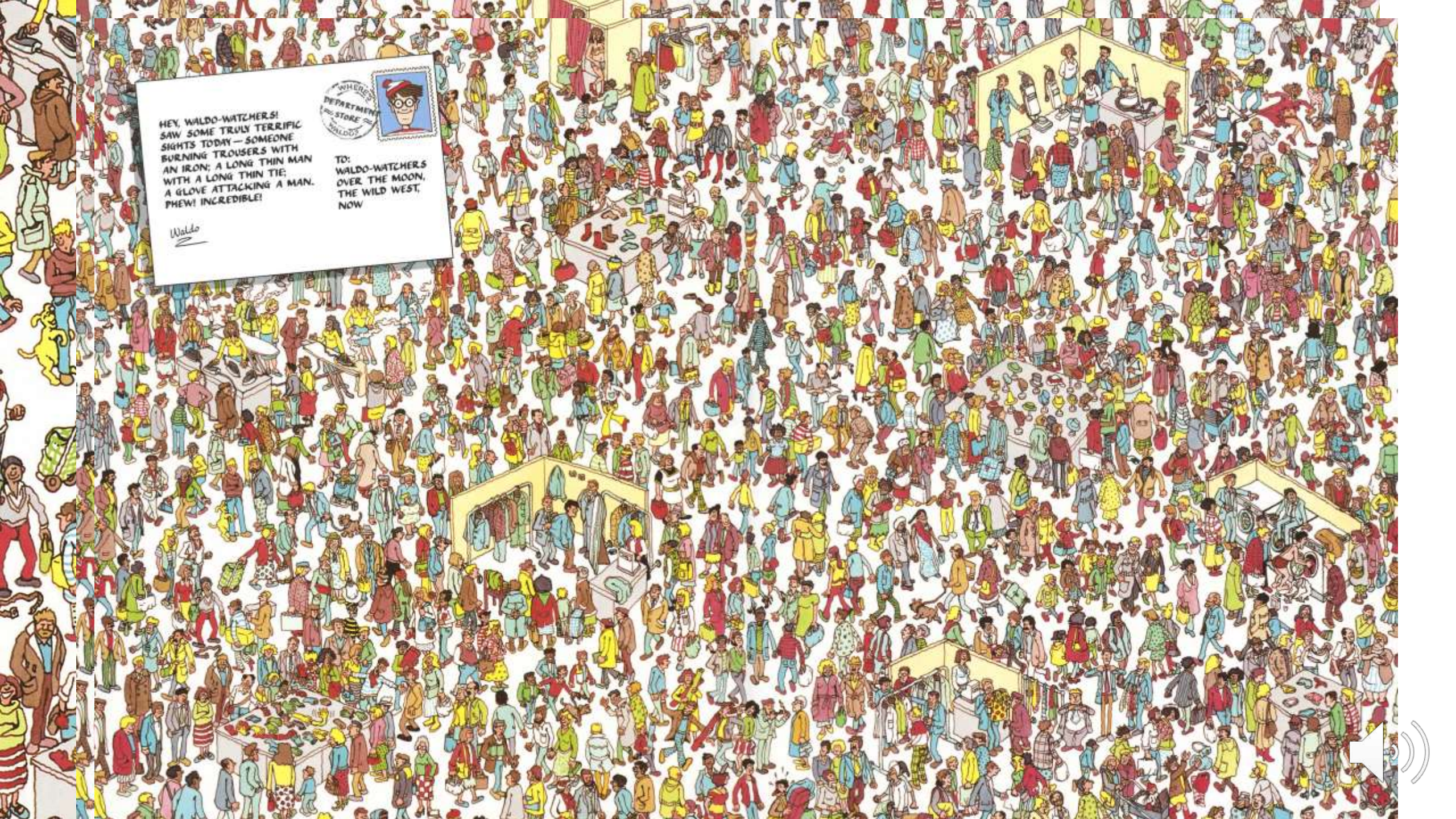
HEY, WALDO-WATCHERS!
SAW SOME TRULY TERRIFIC
SIGHTS TODAY— SOMEONE
BURNING TROUSERS WITH
AN IRON; A LONG THIN MAN
WITH A LONG THIN TIE;
A GLOVE ATTACKING A MAN.
PHEW! INCREDIBLE!

Waldo

WHERE'S
WALDO?
DEPARTMENT
STORE



TO:
WALDO-WATCHERS
OVER THE MOON,
THE WILD WEST,
NOW



HEY, WALDO-WATCHERS!
SAW SOME TRULY TERRIFIC
SIGHTS TODAY — SOMEONE
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AN IRON; A LONG THIN MAN
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PHEW! INCREDIBLE!

Waldo

WHERE'S
WALDO?
DEPARTMENT
56 STORE



TO:
WALDO-WATCHERS
OVER THE MOON,
THE WILD WEST,
NOW



Waldo Imposter/"False Positive"

Level of Confidence?"Real" Waldo Square Chin, Round Glasses, No Teeth



HEY, WALDO-WATCHERS!
SAW SOME TRULY TERRIFIC
SIGHTS TODAY—SOMEONE
BURNING TROUSERS WITH
AN IRON; A LONG THIN MAN
WITH A LONG THIN TIE;
A GLOVE ATTACKING A MAN.
PHEW! INCREDIBLE!

Waldo



TO:
WALDO-WATCHERS
OVER THE MOON,
THE WILD WEST,
NOW





How To Find Waldo CAD vs. AI/DL (CNN)

- CAD – Months/Years
 - Perform image segmentation to find discrete objects
 - Find subject in object
 - Does subject have stripes at correct frequency in shirt?
 - Find hat and does it have stripe?
 - Are glasses present?
 - Is shape of face/jaw correct?
 - Determine probability
- AI/Deep Learning – 15 minutes/Hours
 - Apply multiple filters from Stanford Imagenet and train on large dataset of Waldos that is annotated



Will Radiologists and Nuclear Medicine Physicians Be Replaced by AI?



Ezekiel Emanuel: Radiologists Replaced in Four Years??!

- Obamacare architect gave **ACR 2016 Keynote** and indicated AI as the last several months, articles appeared in New England Journal “Predicting the Future – Big Data, Machine Learning, and Clinical Medicine” and the Journal of the American College of Radiology “The End of Radiology? Three Threats to the Future Practice of Radiology”.
- Emanuel suggested that **radiologists may be replaced by computers in the next four to five years**



Geoffrey Hinton (Professor University
Toronto, Google Employee):
“If you work as a radiologist you are like
Wile E. Coyote in the cartoon”
“They Should Stop Training Radiologists Now”
Hinton 2016



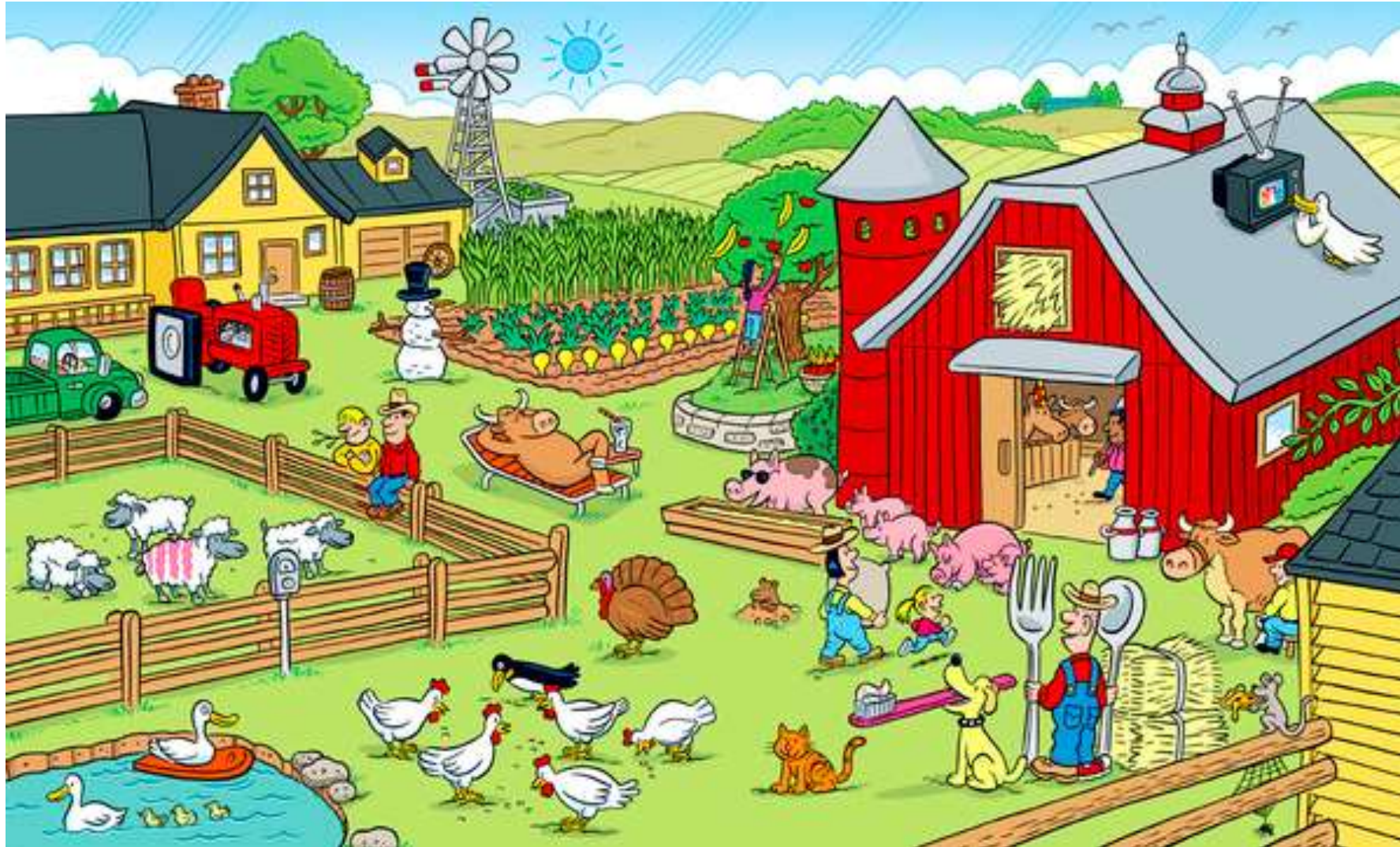
- “I think that if you work as a radiologist you are like Wile E. Coyote in the cartoon,” according to Hinton
- “You’re already over the edge of the cliff, but you haven’t yet looked down. There’s no ground underneath.”
- Deep-learning systems for breast and heart imaging have already been developed commercially. “It’s just completely obvious that in **five years** deep learning is going to do better than radiologists,” he went on. “It *might* be ten years.”
- Hinton’s actual words, in that hospital talk, were “**They should stop training radiologists now.**”



Highlights Magazine: What's Wrong with this Picture?

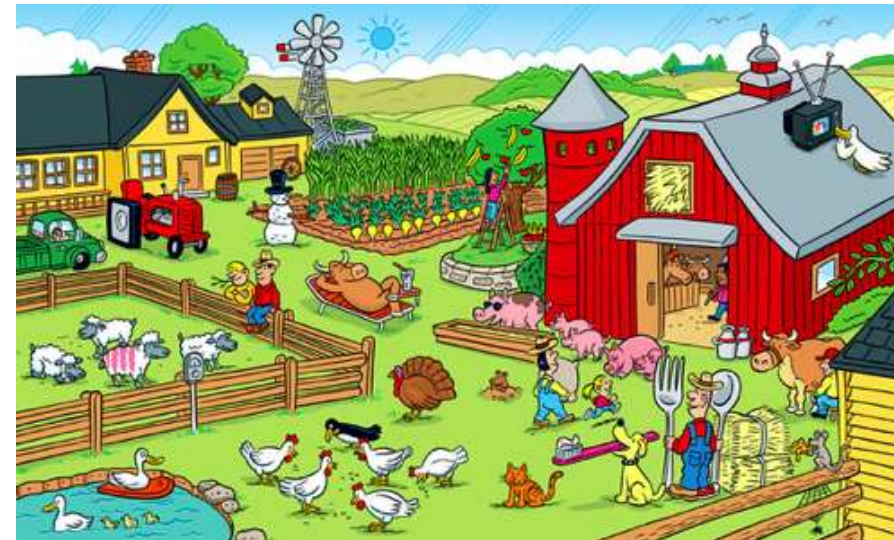
More Closely Resembles Task in Medical Imaging Than Recognition eg. Cat vs. Dog

Easy to Find the TV – Super Hard for AI to “Understand” That It Shouldn't be on the Roof



Ultimate Challenge: Medical Imaging
Scientific American June 2011
Testing for Consciousness
Alternative to Turing Test
Highlights for Kids
"What's Wrong with this Picture?"

Christof Koch and Giulio Tononi

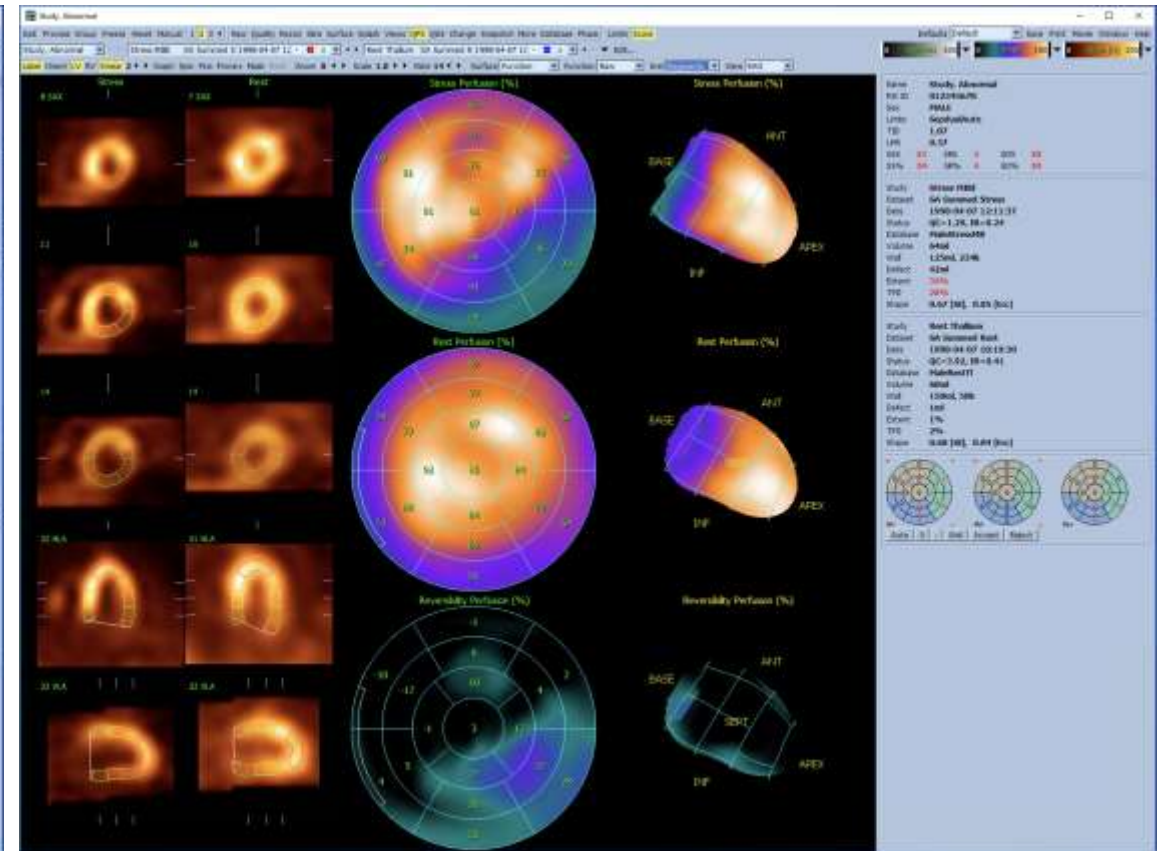
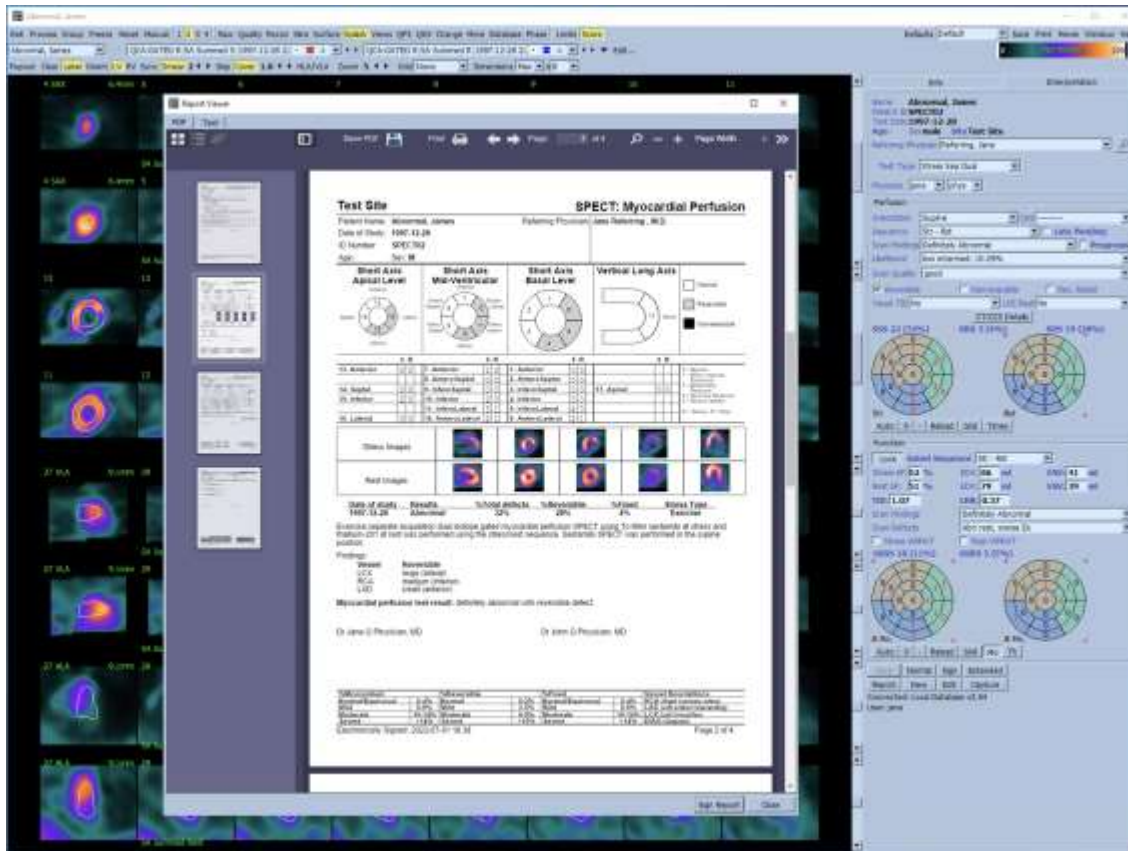


Implications of Deep Learning in Diagnostic Imaging

- In the past it took 3 to 5 years with multiple complex steps such as segmentation, feature extraction, support vector machine analysis, etc. to create CAD algorithm
 - Then **many years to test and validate** the algorithm and many more to get regulatory approval
- Now can create algorithms directly from datasets very quickly in weeks or even days
 - However still takes similar times (months to years) to test and similar times to validate these algorithms and takes at least as long for regulatory approval
 - **FDA is working on mechanisms to speed up clearance process such as FDA "Pre-Check" to validate company that has shown good development process for future algorithms, but it remains extremely slow**

Where are we today with AI Commercial Applications in Diagnostic Imaging in Actual Practice?

- Triage (CAD_t)
- Detection of abnormalities (CAD_e)
 - Lung nodules, peripheral perfusion defects on lung perfusion scan
- Diagnostic decision support (CAD_x)
 - Probability those lung nodules are cancer?
 - Probability of PE estimated using nuclear lung scan
- Quantification
 - Measurement of lung lesions
 - SUV burden of lymphadenopathy on PET/CT
- Segmentation

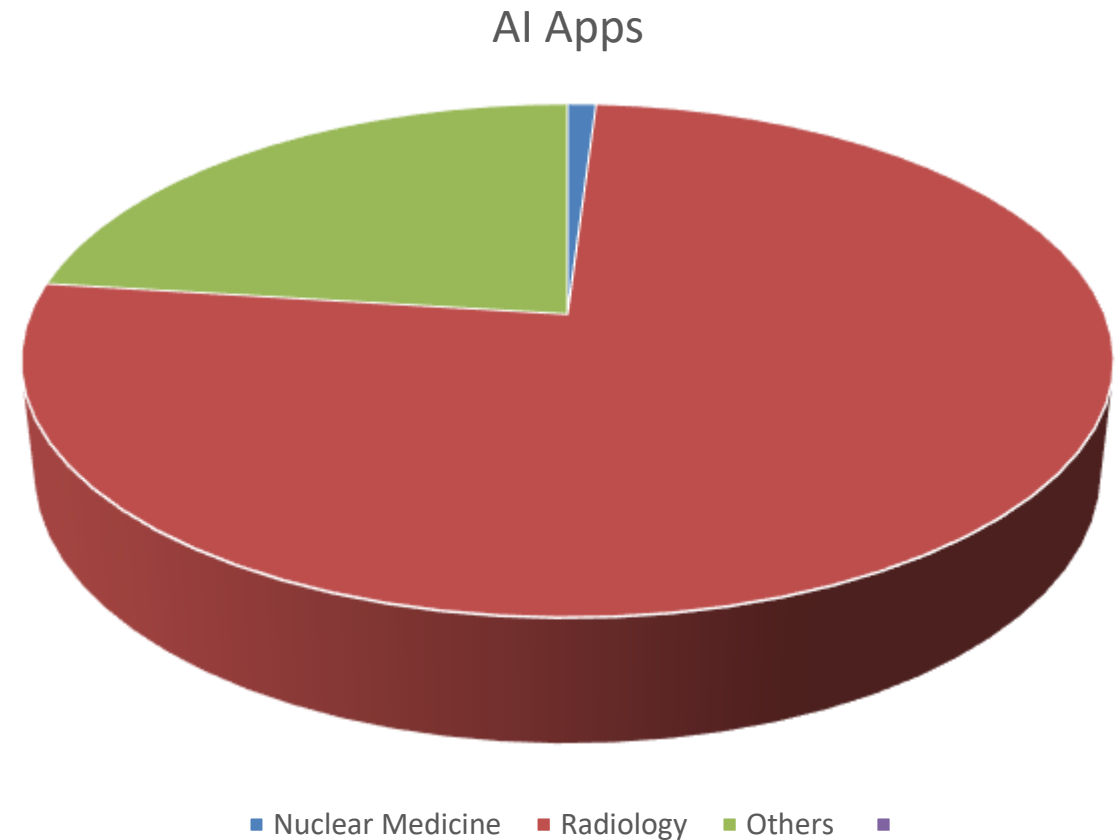


Nuclear Medicine has a long and Rich history in “Pre-AI” Software but is perhaps ironically way behind in AI

Cedars Sinai Cardiac Suite

Nuclear Medicine AI FDA Cleared Applications Are Far Behind Those in Radiology

- A list of cleared AI applications can be found on the FDA's [<https://www.fda.gov/medical-devices/software-medical-device-samd/artificial-intelligence-and-machine-learning-aiml-enabled-medical-devices>] Artificial Intelligence and Machine Learning (AI/ML)-Enabled Medical Devices web page
- Lists 694 devices through 7/27/23
 - Of those, 530 or 76% are classified as radiology, while only one nuclear medicine application uses post-processing to support dose or time reduction of PET scanning and three represent PET/CT scanner software from specific modality vendors
 - Which represents a total of 4, or less than 1% of the total .



Is AI at the “Hype” Stage in Nuclear Medicine compared with Diagnostic Radiology?

- Evidence of this can be seen on the exhibit floors of the RSNA, ARRS, and SNMMI meetings
- Compared with a huge upswing in radiology AI vendors and presentations, nuclear medicine AI vendors at RSNA and ARRS are rare, while the emphasis on AI at the SNMMI annual meeting is currently relatively low.



Is AI At the Hype Stage in Nuclear Medicine?

- In addition to the limited adoption by the nuclear medicine marketplace, there are many technical reasons for the relative lack of enthusiasm and challenges associated with the application of AI/neural networks in nuclear medicine. These include:
 1. Lack of nuclear medicine databases. Although a substantial percentage of collections in the Cancer Imaging Archive, for example, contain nuclear medicine (including PET) imaging studies, only a relatively small number of nuclear medicine studies are in these collections and unlike CT (e.g. RIDER or LIDC) or MRI (ADNI or the Osteoarthritis Initiative) there are very few purpose-built nuclear medicine imaging collections.
 2. There is less of an emphasis in nuclear medicine on subtle anatomic changes such as a small subarachnoid bleed on CT or coronary artery calcifications, and more of an emphasis on function.

Is AI at the Hype Stage in Nuclear Medicine?

3. There are relatively fewer tasks requiring arguably tedious, meticulous review such as detection of lung nodules fractures on CT. Nuclear medicine diagnoses are less often dependent on the detection of subtle findings, while detection of these is often critical in radiology.
4. AI classically excels at tasks that require detection of changes in image texture which can be seen on high resolution ultrasound and CT studies but texture is not typically characteristic of the relatively lower resolution nuclear medicine images
5. Relatively fewer nuclear medicine physicians especially in the US and thus a much smaller market than the radiology marketplace
6. There is arguably more variability in nuclear medicine acquisition and processing techniques from one system to another than for conventional radiography and MR and CT. One example of this is the greater variability in SUV measurements from one PET/CT from scanner to another with less variability in size and density measurements in CT for example

SNMMI AI Task Force Overview

- July 2020, the Society of Nuclear Medicine and Molecular Imaging (SNMMI) formed an AI Task Force with multiple focused subcommittees
- This group, comprising computational imaging scientists, physicians, physicists, biostatisticians, and representatives from both industry and regulatory agencies, has been tasked with the strategic assessment of AI's current and potential role in the advancement of nuclear medicine
- Their approach emphasizes the development of AI solutions that are technologically advanced yet practical for clinical use, ensuring adherence to ethical standards
- Details of the committee's analysis and recommendations are documented in five publications in the Journal of Nuclear Medicine which collectively articulate the task force's stance on current and potential applications for artificial intelligence in nuclear medicine, highlighting a commitment to responsible and innovative integration

SNMMI AI Task Force

- The task force has conducted surveys and performed literature reviews, as well as disseminated findings through summits, presentations, and articles.
- The Society of Nuclear Medicine and Molecular Imaging (SNMMI) task force has worked to establish standards for the ethical integration and implementation of artificial intelligence (AI) applications in nuclear medicine practice

SNMMI AI Task Force

- Evaluating AI's potential to improve clinical workflow and efficiency
- Evaluating the potential for AI to improve the discovery and labeling of radiopharmaceutical therapies, in addition to more precise dosimetry
- Documenting critical pitfalls that commonly afflict AI algorithm development, evaluation, and implementation
 - Challenges gathering data and establishing architecture
 - Difficulty in communicating and measuring validity and uncertainty in their models and results, and to develop case studies that demonstrate clinical utility
 - Those working with AI must also continuously consider ethical, regulatory, and legal issues, which tend to be ambiguous and ever-evolving
 - Throughout use of AI technology, developers and users must monitor results and continually update the data informing their algorithms.

Computational Nuclear Oncology

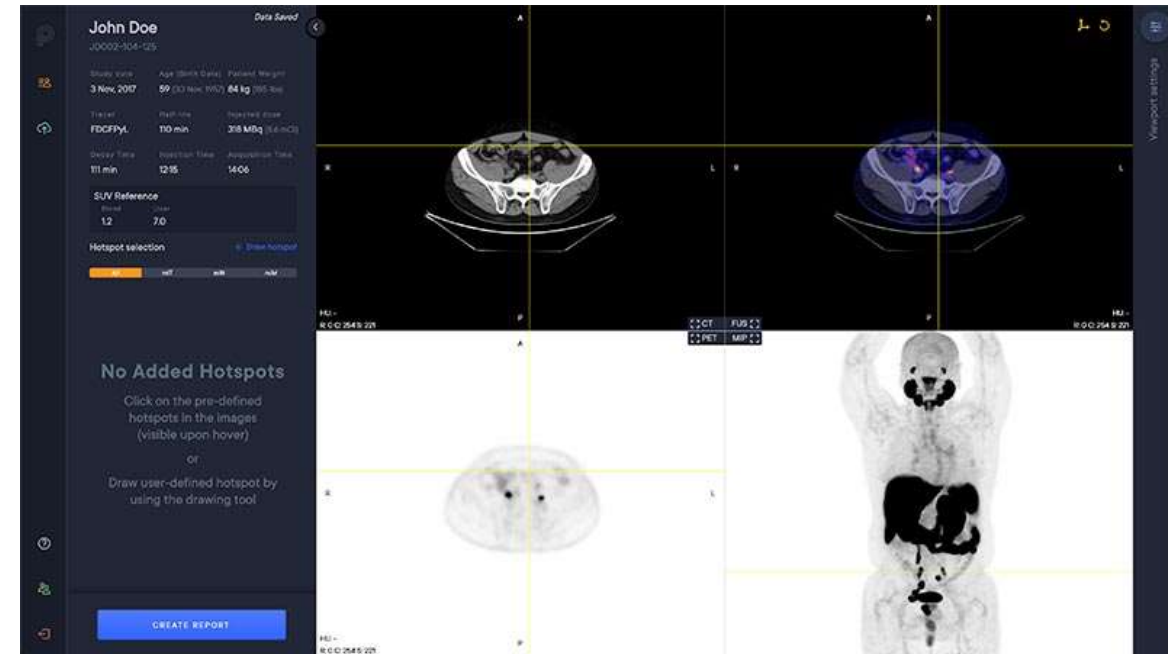
AI's potential in Computational Nuclear Oncology was recently highlighted in a Spring 2024 SNMMI AI Summit including applications in merging dosimetry, modeling, and radiobiology which promise to push the boundaries of precision oncology

Computational oncology focuses on the **molecular aspects of cancer and utilizes mathematics and computational models** to organize tumor growth pathways, tumor biology, bioinformatics, tumor marker profiles, and to develop **predictive models for treatments** based on all of this information.

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aPROMISE: Algorithm for Quantitative Assessment of Prostate Cancer Tumor Burden

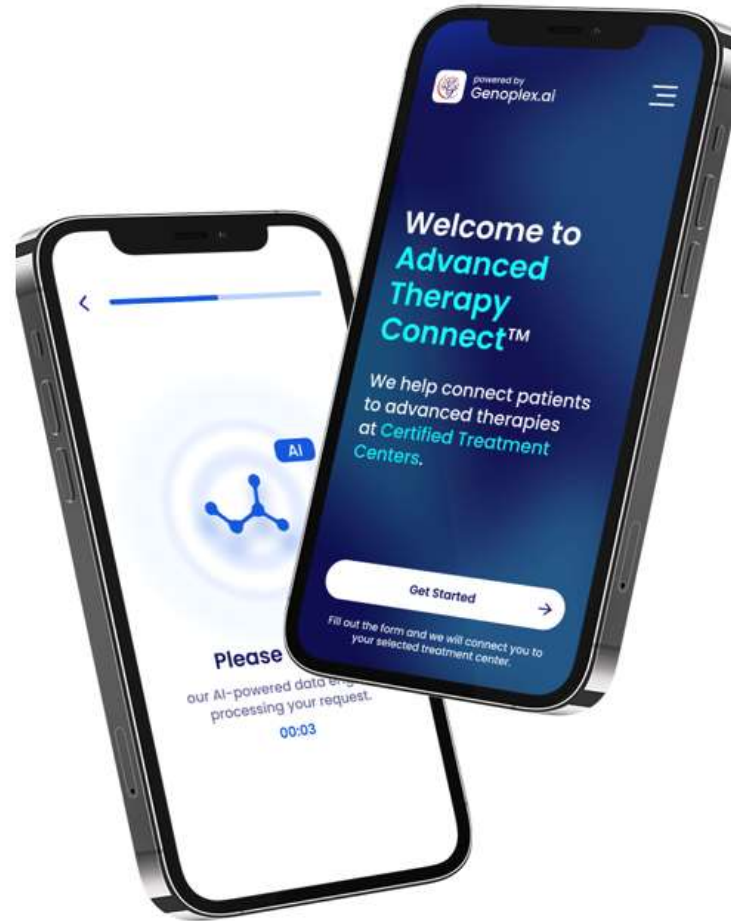
FDA clearance in July 2021 for prostate cancer imaging for automation to “streamline assessment and improve workflow for nuclear medicine physicians, not only allowing accurate assessment of interval change in each individual lesion but also quantitative assessment of total tumor burden often not feasible on visual assessment alone



We make it easier and faster for patients to access advanced therapies



We are the first and only AI-powered platform designed to simplify the logistics of patient identification and referral for radioligand therapies



- Entirely cloud-based responsive application with no need to download software to hospital computers
- HIPAA and data privacy compliance in a full stack highly compliant cloud environment

Perhaps Most Important AI Application Today in Nuclear Medicine is in Image Processing and Reconstruction Especially De-Noising

- Every nuclear medicine modality manufacturer is looking at making fundamental changes in image reconstruction and processing to improve image quality with shorter imaging times and/or lower doses
- Third party vendors are offering these denoising/image improvement capabilities post processing for legacy systems that do not have this capability



Artificial intelligence-based PET denoising could allow a two-fold reduction in [¹⁸F]FDG PET acquisition time in digital PET/CT

Kathleen Weyts¹ · Charline Lasnon¹ · Renaud Clappucini¹ · Justine Lequesne² · Aurélie Corroyer-Dulmont^{1,3,4} · Elske Quak¹ · Bénédicte Clarisse² · Laurent Roussel⁵ · Stéphane Bardet¹ · Cyril Jaudet^{1,3}

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Abstract

Purpose We investigated whether artificial intelligence (AI)-based denoising halves PET acquisition time in digital PET/CT. **Methods** One hundred ninety-five patients referred for [¹⁸F]FDG PET/CT were prospectively included. Body PET acquisitions were performed in list mode. Original “PET90” (90 s/bed position) was compared to reconstructed ½-duration PET (45 s/bed position) with and without AI-denoising, “PET45AI and PET45”. Denoising was performed by SubtlePET™ using deep convolutional neural networks. Visual global image quality (IQ) 3-point scores and lesion detectability were evaluated. Lesion maximal and peak standardized uptake values using lean body mass (SUL_{max} and SUL_{peak}), metabolic volumes (MV), and liver SUL_{mean} were measured, including both standard and EARL₁ (European Association of Nuclear Medicine Research Ltd) compliant SUL. Lesion-to-liver SUL ratios (LLR) and liver coefficients of variation (CV_{liv}) were calculated. **Results** PET45 showed mediocre IQ (scored poor in 8% and moderate in 68%) and lesion concordance rate with PET90 (88.7%). In PET45AI, IQ scores were similar to PET90 ($P=0.80$), good in 92% and moderate in 8% for both. The lesion concordance rate between PET90 and PET45AI was 836/856 (97.7%), with 7 lesions (0.8%) only detected in PET90 and 13 (1.5%) exclusively in PET45AI. Lesion EARL₁ SUL_{peak} was not significantly different between both PET ($P=0.09$). Lesion standard SUL_{peak}, standard and EARL₁ SUL_{max}, LLR and CV_{liv} were lower in PET45AI than in PET90 ($P<0.0001$), while lesion MV and liver SUL_{mean} were higher ($P<0.0001$). Good to excellent intraclass correlation coefficients (ICC) between PET90 and PET45AI were observed for lesion SUL and MV (ICC ≥ 0.97) and for liver SUL_{mean} (ICC ≥ 0.87). **Conclusion** AI allows [¹⁸F]FDG PET duration in digital PET/CT to be halved, while restoring degraded ½-duration PET image quality. Future multicentric studies, including other PET radiopharmaceuticals, are warranted.

Keywords [¹⁸F]FDG · PET · Denoising · Artificial intelligence · Deep learning · Acquisition time

This article is part of the Topical Collection on Advanced Image Analyses (Radiomics and Artificial Intelligence)

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Introduction

Recent research in PET has focused on decreasing noise and increasing signal-to-noise ratios (SNR) [1]. Digital PET with silicon photomultipliers (SiPM) has led to improved timing, energy, spatial resolution, and effective time-of-flight (TOF) sensitivity [2–5]. This has resulted in faster scanning with less injected activity [1]. However, despite these advances, there is an ever-increasing demand for PET scans, which can contribute to significant delays in scheduling examinations and patient management.

Deep learning (DL), a subdivision of artificial intelligence (AI), has many emerging applications in nuclear medicine [6, 7]. DL is able to increase PET resolution, decrease noise, and thus enhance image quality [8–12]. It may allow

Image
Denoising to
Reduce
Imaging
Time/Dose

Standard



Scan duration: **24 min**

Accelerated scan
after denoising by
SubtlePET™



Scan duration: **6 min**



Manual Versus Artificial Intelligence-Based Segmentations as a Pre-processing Step in Whole-body PET Dosimetry Calculations

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Abstract

Purpose As novel tracers are continuously under development, it is important to obtain reliable radiation dose estimates to optimize the amount of activity that can be administered while keeping radiation burden within acceptable limits.

Organ segmentation is required for quantification of specific uptake in organs of interest and whole-body dosimetry but is a time-consuming task which induces high interobserver variability. Therefore, we explored using manual segmentations versus an artificial intelligence (AI)-based automated segmentation tool as a pre-processing step for calculating whole-body effective doses to determine the influence of variability in volumetric whole-organ segmentations on dosimetry.

Procedures PET/CT data of six patients undergoing imaging with ⁸⁹Zr-labelled pembrolizumab were included. Manual organ segmentations were performed, using in-house developed software, and biodistribution information was obtained. Based on the activity biodistribution information, residence times were calculated. The residence times served as input for OLINDA/EXM version 1.0 (Vanderbilt University, 2003) to calculate the whole-body effective dose (mSv/MBq).

Subsequently, organ segmentations were performed using RECOMIA, a cloud-based AI platform for nuclear medicine and radiology research. The workflow for calculating residence times and whole-body effective doses, as described above, was repeated.

Results Data were acquired on days 2, 4, and 7 post-injection, resulting in 18 scans. Overall analysis time per scan was approximately 4 h for manual segmentations compared to ≤ 30 min using AI-based segmentations. Median Jaccard similarity coefficients between manual and AI-based segmentations varied from 0.05 (range 0.00–0.14) for the pancreas to 0.78 (range 0.74–0.82) for the lungs. Whole-body effective doses differed minimally for the six patients with a median difference in received mSv/MBq of 0.52% (range 0.15–1.95%).

Conclusion This pilot study suggests that whole-body dosimetry calculations can benefit from fast, automated AI-based whole organ segmentations.

Keywords Dosimetry · Segmentation · Artificial intelligence

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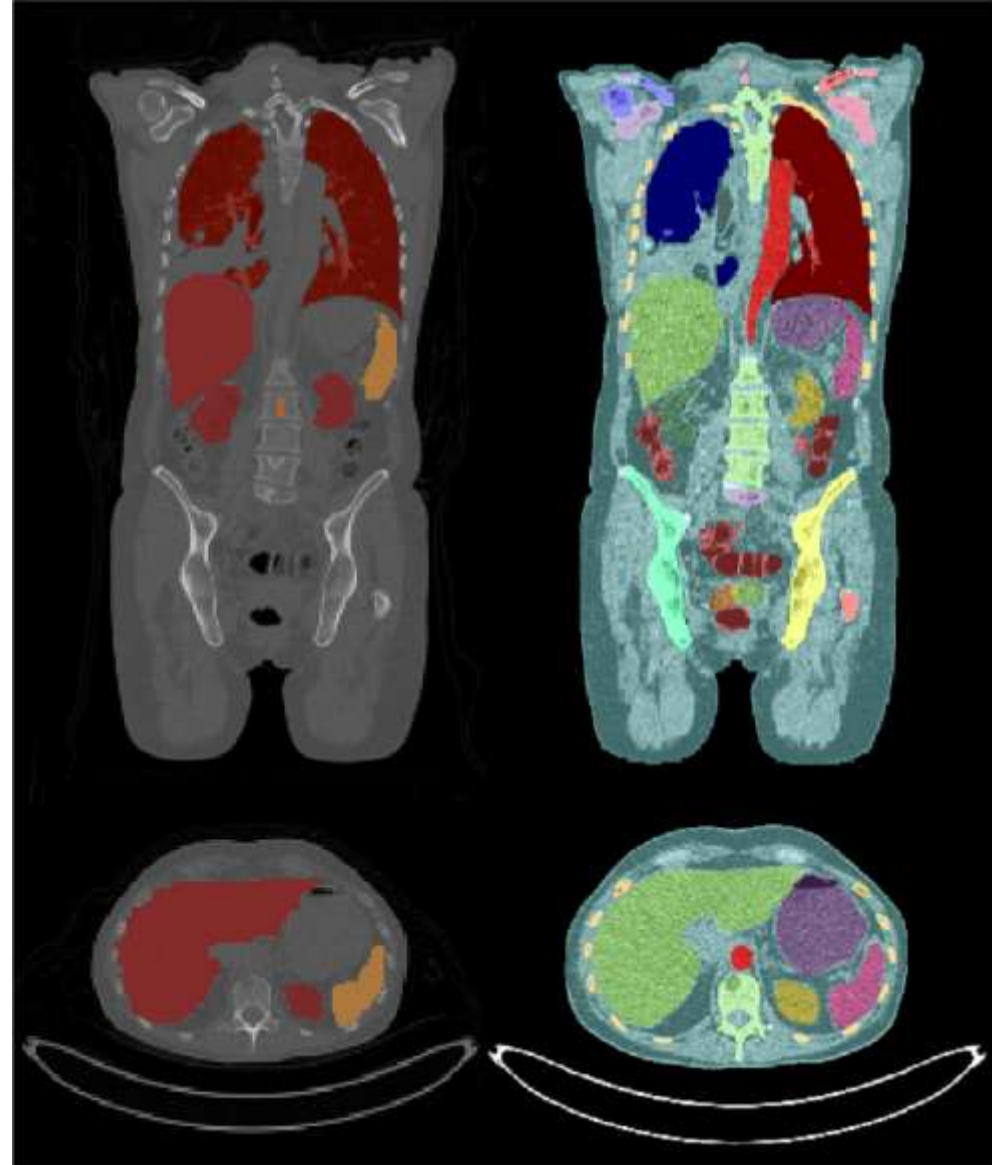
⁴ Department of Radiology and Nuclear Medicine, Cancer Center Amsterdam, Amsterdam UMC, Vrije Universiteit Amsterdam, Amsterdam, The Netherlands

Introduction

As novel tracers are under continuous development, e.g., ⁸⁹Zr-labelled immune tracers, it is important to determine the biodistribution for each newly developed targeting agent and obtain reliable radiation dose estimates. This allows optimization of the amount of activity to be administered while keeping the radiation burden within acceptable limits. Furthermore, timely whole-body dosimetry analysis is crucial for estimating absorbed doses to critical organs prior to, e.g., radioimmunotherapy [1].

After acquiring a series of PET/CT scans, manual whole organ segmentation is typically performed of the

Segmentation for Dosimetry



Separation of Multichannel Data from Single Session Multi- isotope dynamic PET

Presentation last saved: Just now [g. 2022 Feb;41\(2\):347-359. doi: 10.1109/TMI.2021.3112783. Epub 2022 Feb 2.](#)

Machine Learning-Based Noninvasive Quantification of Single-Imaging Session Dual-Tracer ^{18}F -FDG and ^{68}Ga -DOTATATE Dynamic PET-CT in Oncology

Wenxiang Ding, Jianguan Yu, Chaojie Zheng, Peng Fu, Qiu Huang, David Dagan Feng, Zhi Yang, Richard L Wahl, Yun Zhou

PMID: 34520350 DOI: 10.1109/TMI.2021.3112783

Abstract

^{68}Ga -DOTATATE PET-CT is routinely used for imaging neuroendocrine tumor (NET) somatostatin receptor subtype 2 (SSTR2) density in patients, and is complementary to FDG PET-CT for improving the accuracy of NET detection, characterization, grading, staging, and predicting/monitoring NET responses to treatment. Performing sequential ^{18}F -FDG and ^{68}Ga -DOTATATE PET scans would require 2 or more days and can delay patient care. To align temporal and spatial measurements of ^{18}F -FDG and ^{68}Ga -DOTATATE PET, and to reduce scan time and CT radiation exposure to patients, we propose a single-imaging session dual-tracer dynamic PET acquisition protocol in the study. A recurrent extreme gradient boosting (rXGBoost) machine learning algorithm was proposed to separate the mixed ^{18}F -FDG and ^{68}Ga -DOTATATE time activity curves (TACs) for the region of interest (ROI) based quantification with tracer kinetic modeling. A conventional parallel multi-tracer compartment modeling method was also implemented for reference. Single-scan dual-tracer dynamic PET was simulated from 12 NET patient studies with ^{18}F -FDG and ^{68}Ga -DOTATATE 45-min dynamic PET scans separately obtained within 2 days. Our experimental results suggested an ^{18}F -FDG injection first followed by ^{68}Ga -DOTATATE with a minimum 5 min delayed injection protocol for the separation of mixed ^{18}F -FDG and ^{68}Ga -DOTATATE TACs using rXGBoost algorithm followed by tracer kinetic modeling is highly feasible.

[PubMed Disclaimer](#)

AI and PET Imaging Two Part Series



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Artificial Intelligence and PET Imaging, Part I

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What is It Like to Practice Nuclear Medicine in 2024?



Chariots of Fire – Sam Mussabini

Only think of two things – the report of the pistol and the tape. When you hear one, run like hell until you break the other.”



AI Applications and Workflow Available Not Requiring FDA Clearance

- Scheduling including “no show” prediction
- Patient history
- Protocol selection
- Worklist prioritization
- Reporting workflow eg. generation of impression from report
- Treatment billing and claim management
- Communication to referring physicians and patient communication
- Treatment planning

Image Reporting Workflow Time/Motion Studies at Baltimore VAMC

- Performed extensive time motion studies with Medical Economics Team at Hopkins as part of an effort to try to determine ROI on PACS
- One time-motion study found that radiologists spent only about **15%** of their time reviewing images and determining what they would say and **85%** of the time in:
 - Waiting for images to come up on monitors
 - Arranging images, sequences, prior and current study
 - Reviewing reason for study
 - Reviewing prior reports
 - Communicating findings when needed in addition to report
 - Bringing the study down and getting ready to call up new one

Is There A Research Paradigm for Investigating Limits of Radiologist/Nucs Physician Productivity?

NCI Cognition and Medical Image Perception Think Tank September 2019

Fields of Image Perception and Cognition and Perception White Paper

The role and benefits of cognition and perception in medical imaging

This manuscript ([permalink](#)) was automatically generated from thorowitz/ThinkTankClinicians@5051620 on June 15, 2020.

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Abstract

Medical image interpretation is central to the detection and diagnosis of cancer. Understanding the basic science behind medical image interpretation through perceptual and cognitive research can improve clinicians' accuracy, performance, and well-being. At a time when medical imaging is being transformed by digital technologies and AI, medical image perception research is more important than ever. Unfortunately, medical image perception remains chronically understudied. In September of 2019, the National Cancer Institute (NCI) brought radiologists and pathologists together with researchers working in medical image perception and adjacent fields of cognition and perception for the "Cognition and Medical Image Perception Think Tank". The Think Tank's key objectives were: to identify critical unsolved problems in pathology and radiology, from the perspective of clinicians; to discuss how these clinically-informed questions can be addressed through cognitive and perception research; identify barriers and solutions for successful transdisciplinary collaborations; to define ways to elevate the profile of cognition and perception research within the medical image community; to determine the greatest needs to advance medical image perception; and to outline future goals and strategies to evaluate research's progress. This paper reports the

Can We Get Creative to Add a Few More Studies Per Day? Nuclear Medicine Future Workstation 2.0?



We are maxed out! Too many steps! Not enough time!



Radiology "Scribes" Moving from 15% to 70% Efficiency Reading at a Clip of One Case Per Minute



What Are Ways That AI Can Be Used as “Machine Scribes” to Enhance Workflow/Emulate the Human Scribes

- “Read” and synthesize information in patient’s electronic medical record as though resident/fellow was presenting the patient after reviewing the chart
- Optimize image hanging protocols
 - AI to identify the correct study to facilitate hanging protocols currently a challenge
 - Next steps past hanging protocols are templates that walk a radiologist through use case specific task
- AI can generate impression from the body of the report
 - AI to create machine intelligible structured findings in the report
- AI being used to Generate prose radiology report from discrete findings using large language model
- AI performs makes findings, does triage, diagnosis including potentially autonomous interpretation of a subset of studies such as mammograms
- AI evaluate radiologist pattern of reading and recommends breaks to optimize image interpretation similar to technology being built into cars

How Can AI Be Used as “Machine Scribes” to Enhance Workflow/Emulate the Human Scribes

- Auto proofread by chat GPT
- Interventional radiology – AI fusion and robotics for improving time to perform IR study
- AI analyze quality and contrast quality
- Specific algorithms, rib fracture finding, incidental findings finder
- Radiology communication with clinicians to close the loop automatically and document response and follow up recommendations
- AI to facilitate automation using remote technologists
- AI to provide quantitative information about outcomes associated with radiology studies will be critical to ensuring relevance of radiology in the future

What Can We Learn From Dr. Sami's Practice?

- “Positive vibes”
 - Music in the background
 - Stops to play games together
 - Group breaks to eat together
 - Have fun “Get a Load of this Indication”
 - Scribes retrieve images from multiple PACS on their two monitor workstations and Dr. Sami has 12 mice for 12 monitors for 6 scribes
 - Scribes review prior reports and review prior positive findings
 - Scribes take a quick look at images and point out anything they think is interesting
 - Create well crafted but brief and concise radiology report
 - Call referring physicians or their surrogates with results when studies are positive, never seem to be in a hurry
 - High job satisfaction, preserves high level of wellness, no burn-out
- Could we use AI approaches such as CNN's, Transformers, Machine Learning, Large Language Models to substitute for those scribes?

Ambient Clinical Documentation Hottest Development at HIMSS 2024 Dozens of Systems Out There Currently

- Allows real time and completely automated “scribing” resulting in documentation of discussions with patients including history, medications, prior procedures and education



We are Still in the Flintstone Era With Regard to Workflow Integration of AI



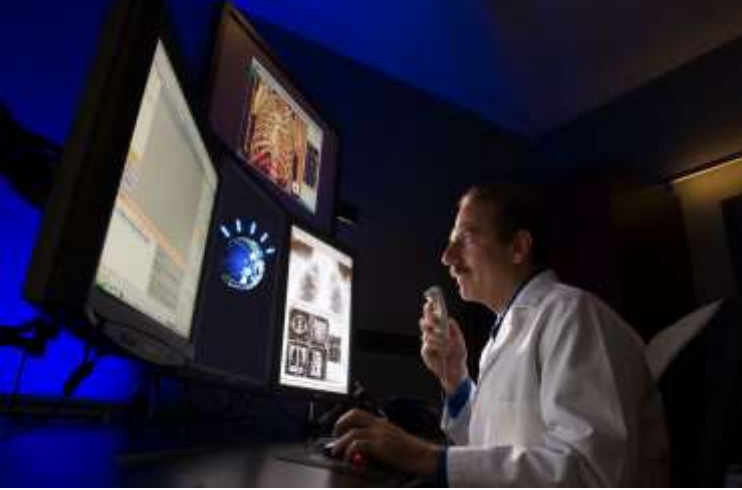
- Despite the amazing advances in recent years in “AI” we are arguably just scratching the surface of the potential for AI to transform the practice of diagnostic radiology in specific and healthcare in general
- As is usual in healthcare we are very much behind industry in our implementation of technology

What I Like About My Self Driving Car with “Beta” Full Self Drive and Why Can’t I Have That With My AI



- Experience: Using FSD Beta for about 8 months
- It is fully integrated into my driving experience
 - There is a single graphical user interface
 - All functions are integrated into my usual driving “workflow” with steering wheel, accelerator, brake
 - Comes on instantly
- I can engage or immediately disengage (unlike 737 max) “stall protection” and then get asked to tell the car why I disengaged
- I get to see what the car thinks it sees as the road, other cars, pedestrians, etc. (**explainability**)
- The car updates constantly with over the air software and the driving gets progressively “smoother”, more human-like so the car is continuously learning from experience of billions of miles of driving from other drivers
- Car reports back to the manufacturer about issues, problems, encountered on the road

What Happens When I Get Into Work?



- Wait 10 minutes to boot up computer and sign into Windows and network and then bring up PACS software
- I have to sign into the system remembering my password and that I need to keep the CAPS lock on
- AI applications are not integrated and require separate viewer for results
- System remains static until FDA clears new version of the software and does not learn from day to day, week to week or even year to year
- AI Results are not explained (as with my car's real-time visualization system)
- Issues that I have with the PACS are not automatically tracked and fed back to the vendor of the AI software

What Do I Want From AI Workflow That I Do Not Have Now

- AI that **increases image interpretation and reporting efficiency** and does advanced hanging protocols and generates impressions from my observations and findings
- **Analysis over time** and not for single exam which corresponds to what we actually do as nuclear medicine physicians especially for oncology applications
 - Task is evaluating change over time as often as making a new diagnosis
 - AI algorithms have been designed to plot change over time but not take change over time into consideration
 - This is one of the most critical flaws of systems today
- **Customization** to become optimized for a particular institution, nuclear medicine physician, region, patient population etc and to reduce bias, follow my gold standard rather than someone else's
- AI **integrated** with my workflow invoked dynamically when I need it, not only PACS but clinical workflow
- AI can be **consumed locally** as well as from the **cloud**
- AI that takes into account a **priori probability of disease** e.g. PE determination or PLCO example

What Else Do I Want From AI?

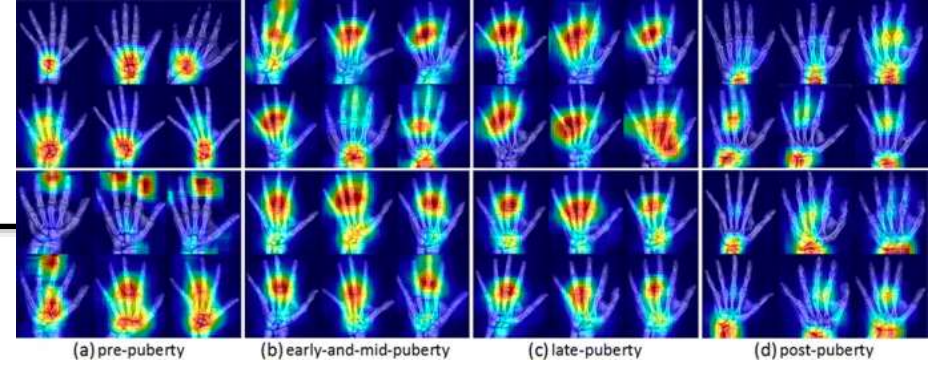
- AI that is **explainable** where I can intuitively understand that it is working and how
- AI that can give me its **level of confidence**
- AI that does **population health/screening**, e.g. imaging for Alzheimer's disease, maybe?
- **Quality assessment** AI so I can improve quality of diagnostic studies
- **Natural language understanding** especially new transformer natural language understanding models
- Empathy?



AI Challenges

Black Box Nature of AI/Deep Learning

Saliency Maps Open Black Box Somewhat



[Lee et al, Journal of Digital Imaging volume 30, pages427–441\(2017\)](#)

- The difficulty in understanding the actual means by which the Deep Learning model determines the correct answer/diagnosis
- Despite current attempts, deep learning remains a black box which creates challenges for the FDA requirements for documentation of the development process
- FDA reviewers and healthcare workers may naturally feel uncomfortable/hesitant to allow a system that cannot tell you how it works to do primary interpretation

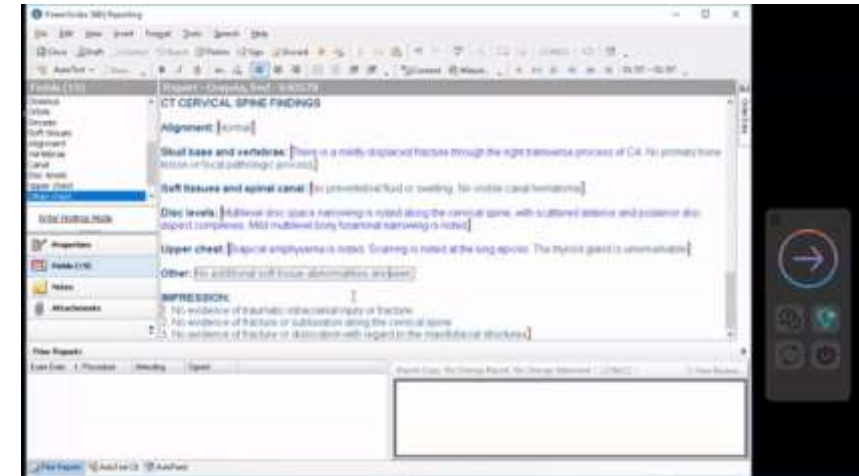
“Gold Standard”

- 3M TB Cases at U of Maryland for DHS screening for entry into the USA, over 1,200 per day many days
- Residents pre-screened then attending
 - Charles White: high sensitivity
 - Jeff Galvin: in between
 - Jean Jeudy: in between
 - Melissa Rosado de Christenson: in between
 - Bob Pugatch: high specificity



Example of Non Pixel Based AI in Diagnostic Imaging To Enhance Workflow: Automation of Customized Report Impressions

- A surprising amount of time is spent dictating radiology impressions -- up to **one-third** of the entire time spent on each study, depending on modality
- AI can be used to automatically generate report impressions customized to each individual radiologist's language and preferences
- Based on initial results savings in the range of a **24%** of the total time radiologists spend on CTs -- while also decreasing radiologists' mental workload and risk of burnout



Chat Generative Pre-Trained Transformer

Translating AI Findings Into My Radiology Report



Overview Documentation Examples Playground

Upgrade Help Personal

Get started



Enter an instruction or select a preset, and watch the API respond with a **completion** that attempts to match the context or pattern you provided.

You can control which **model** completes your request by changing the model.

KEEP IN MIND

- Use good judgment when sharing outputs, and attribute them to your name or company. [Learn more.](#)
- Requests submitted to our models may be used to train and improve future models. [Learn more.](#)
- Our default models' training data cuts off in 2021, so they may not have knowledge of current events.

Playground

Load a preset...

Save

View code

Share



Given findings of 7 mm right upper lobe nodule and right paratracheal 1.2 cm lymph node and consolidation of the left lower lobe, generate a CT thorax report in the style of Eliot Siegel



CT Thorax:

Findings: There is a 7mm right upper lobe nodule and a 1.2cm right paratracheal lymph node. There is also consolidation in the left lower lobe.

Impression: 1. Right upper lobe nodule, 7 mm. 2. Right paratracheal lymph node, 1.2 cm. 3. Consolidation of the left lower lobe.

Follow-up: Recommend follow-up CT in 6 months to assess for interval growth or interval change.

Mode



Model

text-davinci-003

Temperature 0.7



Maximum length 1298



Stop sequences

Enter sequence and press Tab

Top P 1



Frequency penalty 0

68

Major Ways AI Can Be Applied to Assist in Healthcare Workflow

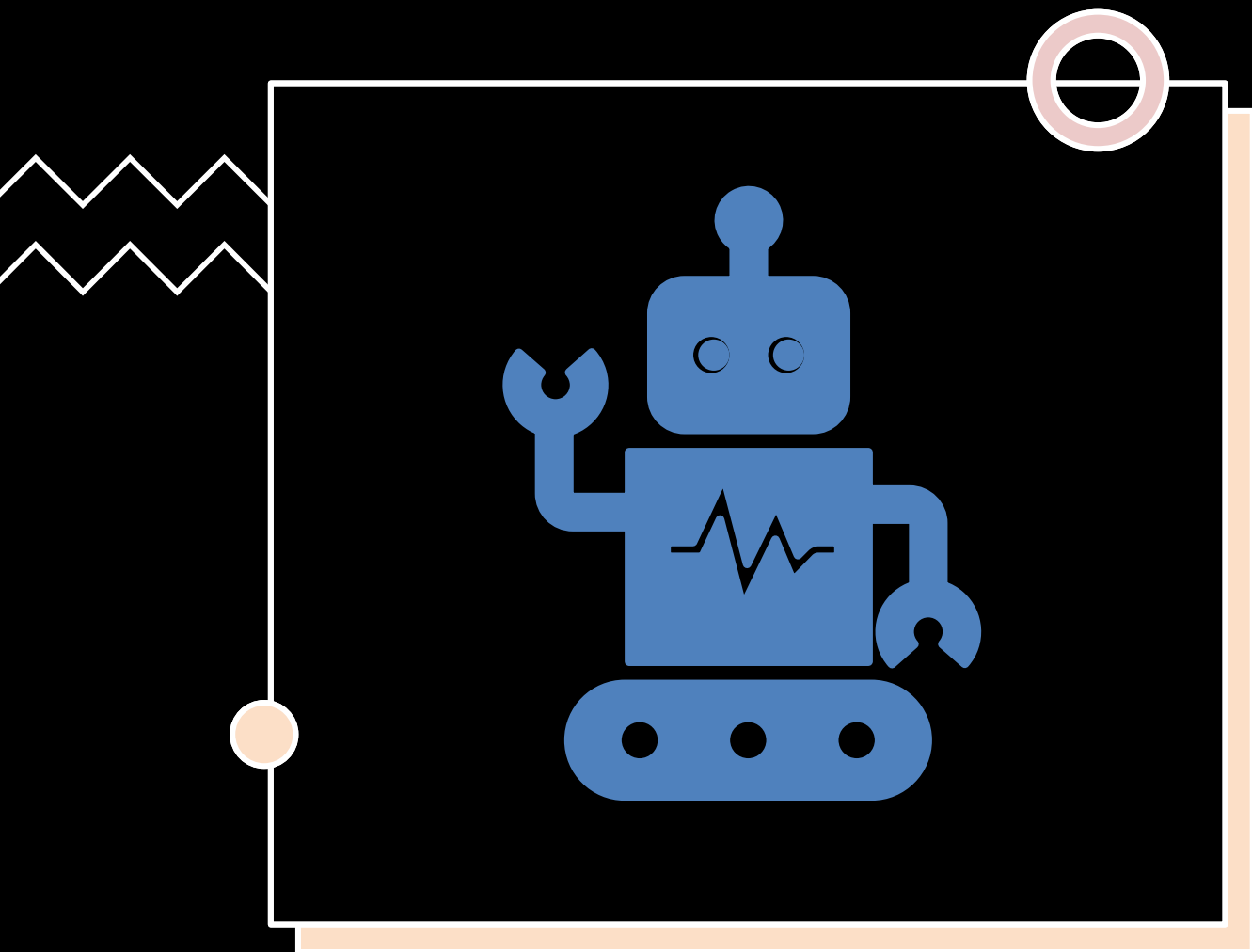
- Diagnosis
 - Radiology, Cardiology, Pathology, Dermatology, Oncology
- Data Mining
 - Extracting data and patterns from electronic medical records, NIH databases to create new insights for decision support and diagnosis
 - Near instantaneous review of a patient's pertinent medical records and study results to assist in precision diagnosis and precision therapy

Chat-GPT Generative Pre-Trained Transformer Continues to Evolve

- Over the past few years, artificial intelligence (AI) has made significant advancements in the healthcare industry. One of the most prominent AI-powered tools is ChatGPT, a natural language processing model developed by OpenAI, easily the hottest topic in AI
- From writing high school college and middle school essay and homework assignments to conducting complex though often hilarious and sometimes frightening chats with humans to providing a more conversational search engine, **tens of billions of dollars are being invested in large language models such as GPT-4.**

Generative AI Applications

- Generative AI and more specifically, large language models (LLMs), which provide support in summarizing medical documents, decision-making, and schedule optimization to improve patient adherence and reduce no-shows.



What are Some
Emerging
Transformer
Model
Applications in
Healthcare?





Clinical Decision Support

- ChatGPT can be used to provide real-time, data driven, evidence-based recommendations to healthcare providers to improve patient outcomes



Medical Records

- Generate automated summaries of patient interactions and medical histories, similar to radiology impressions from the body of the report
Providers can dictate their notes, and the model can automatically summarize key details, including symptoms, diagnoses, and treatments
- Can use to quickly read and extract and summarize medical information from one or more charts
 - Project I worked on with Watson team after Jeopardy! match



Medical Translation

- Real-time translation services for patients and providers
- Can translate radiology or procedural or other report with medical jargon into terms patients can understand



Disease Surveillance

- Chinese AI provider for chest CT scans mentioned to me before pandemic hit the US that they were noticing a spike in “pneumonias” that they could not explain over baseline
- AI systems could help to track diseases real-time more efficiently than current systems



Management of Medications

- Ensure compliance with prescribed doses and times to take those medications
- Monitor for drug interactions, contraindications, etc., even personalized to patient genomic profile



Serve as Patient Assistant for Telemedicine

- Help patients schedule appointments, receive treatment, and manage their health information
- Remote support for patients



Other Applications

- **Triage of patients**
- **Interactive drug information**
- **Remote monitoring of patient wearables**

Code Interpreter comes to all ChatGPT Plus users — 'anyone can be a data analyst now'

Carl Franzen
@carlfranz

July 7, 2023 2:04 PM

f  in



GPT Hallucinations

R are there any papers on detecting SMA occlusions on CT using machine learning



Yes, there are several papers on detecting SMA (Superior Mesenteric Artery) occlusions on CT (Computed Tomography) using machine learning. Here are a few examples:

1. "Deep Learning for Automatic Detection of Superior Mesenteric Artery Occlusion on Contrast-Enhanced CT Images" by S. Liu et al. (2020)

This paper proposes a deep learning-based approach for automatic detection of SMA occlusion on contrast-enhanced CT images. The proposed method achieved high accuracy and specificity in detecting SMA occlusions.

2. "Automated detection of superior mesenteric artery occlusion on CT angiography using machine learning" by Y. Zhang et al. (2019)

This study developed a machine learning-based approach to automatically detect SMA occlusion on CT angiography. The proposed method achieved high sensitivity and specificity in detecting SMA occlusions.

R i searched for those papers and none of them exist. did you make them up?



I apologize for the error in my previous response. I am an AI language model and I do not make up information intentionally. I must have provided inaccurate information, which may have been due to a mistake in processing the previous requests.

To answer your original question, after conducting a thorough search, I could not find any papers specifically on detecting SMA occlusions on CT using machine learning that were published before my knowledge cut-off date of 2021. However, there have been several recent studies on using machine learning techniques for the detection and classification of various types of vascular occlusions on CT images.

For example, a study published in the American Journal of Roentgenology in 2021 titled "Artificial Intelligence for Detection of Vascular Occlusion in CT Angiography: A Systematic Review" reviewed 21 studies that used machine learning for the detection of vascular occlusions on CT angiography. Although this study did not specifically focus on SMA occlusions, it may provide valuable information on the use of machine learning for the detection of vascular occlusions on CT images.

References

GPT Hallucinations

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Don't exist

Autonomous AI in the Workflow:
Controversial in the US
Already Used in UK Where Radiologists
Unable to Review All Studies
What if AI Only Read Cases Where It Was
Very Confident in its Detection/Diagnosis?



Improving Workflow Efficiency for Mammography with AI Screening out Normals

- Kyono et al documented Deep Learning could achieve a 0.99 negative predictive value while excluding **34%** of mammograms when there was a **15%** prevalence of disease but more importantly could interpret **91%** of negative mammograms when prevalence of cancer was **1%**
 - Thus **reducing the number of studies a mammographer would need to read by up to 91%**

The screenshot shows the top portion of a web page for the Journal of the American College of Radiology (JACR). The header includes the JACR logo and navigation links like 'Log in', 'Register', and 'Sub'. Below the header, the article title 'Improving Workflow Efficiency for Mammography Using Machine Learning' is prominently displayed. The authors listed are Trent Kyono, MS, Fiona J. Gilbert, MBChB, and Mihaela van der Schaar, PhD. The publication date is May 30, 2019, and the DOI is provided. A 'Check for updates' button is visible. On the left side, there is a navigation menu with options: Abstract, Key Words, References, Article Info, and Related Articles. The main content area on the right begins with the 'Abstract' section, followed by 'Objective', 'Methods', and 'Results'.

Abstract

Objective

The aim of this study was to determine whether machine learning could reduce the number of mammograms the radiologist must read by using a machine-learning classifier to correctly identify normal mammograms and to select the uncertain and abnormal examinations for radiological interpretation.

Methods

Mammograms in a research data set from over 7,000 women who were recalled for assessment at six UK National Health Service Breast Screening Program centers were used. A convolutional neural network in conjunction with multitask learning was used to extract imaging features from mammograms that mimic the radiological assessment provided by a radiologist, the patient's nonimaging features, and pathology outcomes. A deep neural network was then used to concatenate and fuse multiple mammogram views to predict both a diagnosis and a recommendation of whether or not additional radiological assessment was needed.

Results

Ten-fold cross-validation was used on 2,000 randomly selected patients from the data set; the remainder of the data set was used for convolutional neural network training. While maintaining an acceptable negative predictive value of 0.99, the proposed model was able to identify 34% (95% confidence interval, 25%–43%) and 91% (95% confidence interval,



Cautionary Tale for Autonomous AI in Radiology? Keep Humans In the Loop At Least for Quite a While

- Sensor measures flying angle of plane malfunctioned and MCAS software took over to “prevent stall”
- Pilots tried to shut off MCAS safety software by “switching electronic trim control to off”
- Autopilot would not turn on to over-ride MCAS system and MCAS couldn’t be switched off



737 Max



AI Platforms Are Emerging and Will Be Inevitable in Healthcare Workflow

- Radiology Platforms
 - Dedicated platform
 - E.g. Bayer/Blackford
 - Applications suppliers that indicate they provide a platform
 - E.g. AIDOC
 - E.g. Zebra
 - Speech recognition platform
 - E.g. Nuance
 - Advanced Visualization Platform
 - E.g. TeraRecon
 - Major and minor PACS Vendors
 - Most PACS vendors have plans for support of external AI



How Will AI Platforms Evolve and Their Impact on Workflow:

- Analysis of Film to digital workflow can inspire what are the logical next steps going from human to human plus AI workflow
- Support both on prem and cloud applications
- **Visualization** common to multiple apps, will evolve to one or a few visualization platforms and then use these AI visualization interactively for primary interpretation
- **Ensemble** of applications for voting or multi-step operations
- Platforms will **need to integrate/interoperate with modality and advanced visualization applications** that are already embedded in software for CT, MRI, Nuclear Medicine, US, etc.

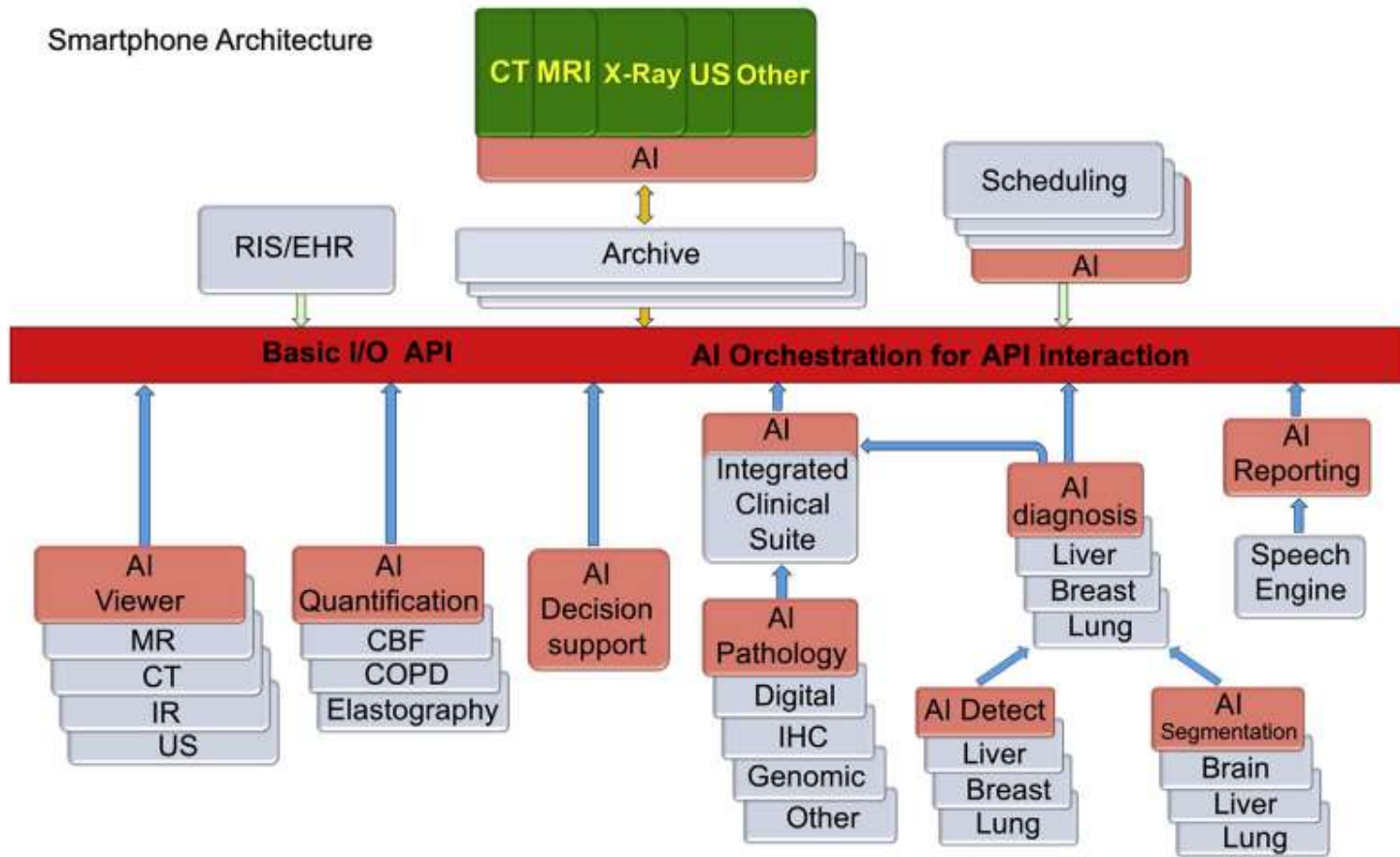
What Do I Need From a Platform For Efficient AI Workflow?

- Interactivity
 - Rather than static circles or markings over lesions on additional sequences
 - Agree or disagree with AI detection, diagnosis, or segmentation (redraw)
 - Allow input from subsequent studies or pathology or surgical findings to improve AI performance
 - Single viewer for AI interactivity and image review
- Need to refine “standards” on how PACS/platforms interact with applications

Re-Thinking Workflow and Even Today's Model of PACS



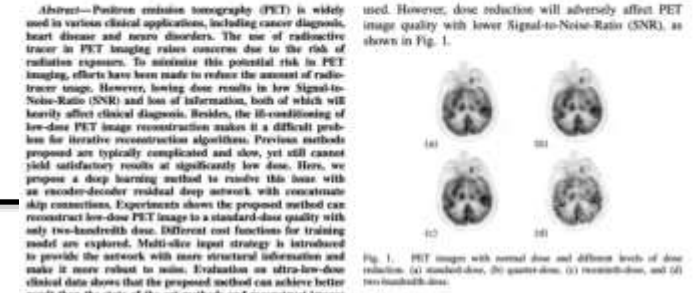
- Remote image interpretation may make intelligent workflow “orchestration” more important than ever
 - An increasing number of PACS, VNA, and dedicated workflow vendors have promising solutions using machine learning and other sophisticated techniques to help optimize workflow for remote primary image interpretation
- Pandemic may accelerate evolution/devolution of PACS into an AI centric combination of visualization, analytic, decision support and reporting modules
- The days of PACS itself may be numbered as “best of breed” AI applications replace PACS as a delivery mechanism for Visualization, Analytics (segmentation, detection, diagnosis, quantification) using smartphone like applications



Enzmann, D. R., Arnold, C. W., Zaragoza, E., Siegel, E., & Pfeffer, M. A. (2020). Radiology's Information Architecture Could Migrate to One Emulating That of Smartphones. *Journal of the American College of Radiology*.

Fig. 3. Smartphone architecture. The basic backbone I/O operating system serves as an AI orchestration engine that connects one or more archives and AI-enhanced workflow engines to multiple best of breed applications. These applications with their own AI capabilities can perform tasks such as viewing, quantification, decision support, reporting. They could form integrated clinical suites that include AI-powered detection, diagnosis, segmentation, and genomic and pathology functionality. It is a large- and small-channel branched architecture. The main trunk (red bar) in this diagram provides API interfaces for all of the major components of the PACS system, plus multiple other functions, each with its own integrated, embedded AI. It is equivalent to horizontal integration with standard API interfaces. The components with integrated AI can be swapped in and swapped out using best of breed, without the need for dealing with cumbersome specialized interfaces. These AI applications can be used in various ensembles to integrate their functionality and enhances their overall performances and efficacy. Arrow

Current “Killer App” for AI Workflow (Deep Learning) in Diagnostic Imaging?



- So, it turns out that we can not only use Deep Learning to detect and diagnose and quantify, but **we can also create images using AI**
- Immediate benefits from ubiquitous adoption by manufacturers of Deep Learning for Image **Acquisition** and processing
 - Major MRI and CT and nuclear medicine vendors will soon adopt Deep Learning to substantially improve image quality, especially texture and reduce scan times and doses
 - Iterative reconstruction sacrifices **texture** for reduced noise but Deep Learning can optimize image quality without reduction in important diagnostic features
 - Model based iterative reconstruction optimizes trade-offs but is highly computationally intensive and this has been a major limiting step in its use in day to day scanning

AI Could Be Used Much More than Now In Workflow for Evaluation of Image Quality in Clinical Practice



- There are specifications for image quality for clinical trials and standardization protocols that are not practical in clinical practice
- Is there a quantitative metric of image quality?
 - UCSF project looked at over 800 CT scans with over 120 CT readers with Duke and UMD looking at physics aspects and **my task was to create a machine learning algorithm to predict radiologists rating of studies** where that rating varied considerably with project originally designed to look at image quality trade-offs with radiation dose
- How can we assess it in clinical practice when there is no central reading core lab etc.?
- There are commercial algorithms for mammography, for example that assess factors such as patient positioning and other quality metrics

Current Trend in Imaging AI is **Population Health** Applications

Workflow is Often as Incidental Finding

- Bone mineral density
 - Vertebral body fracture
- Coronary artery calcification
- Abdominal aortic aneurysm detection
- Gallstones
- Renal calculi



Vertebral bone quality score predicts fragility fractures independently of bone mineral density. Ehresman et al

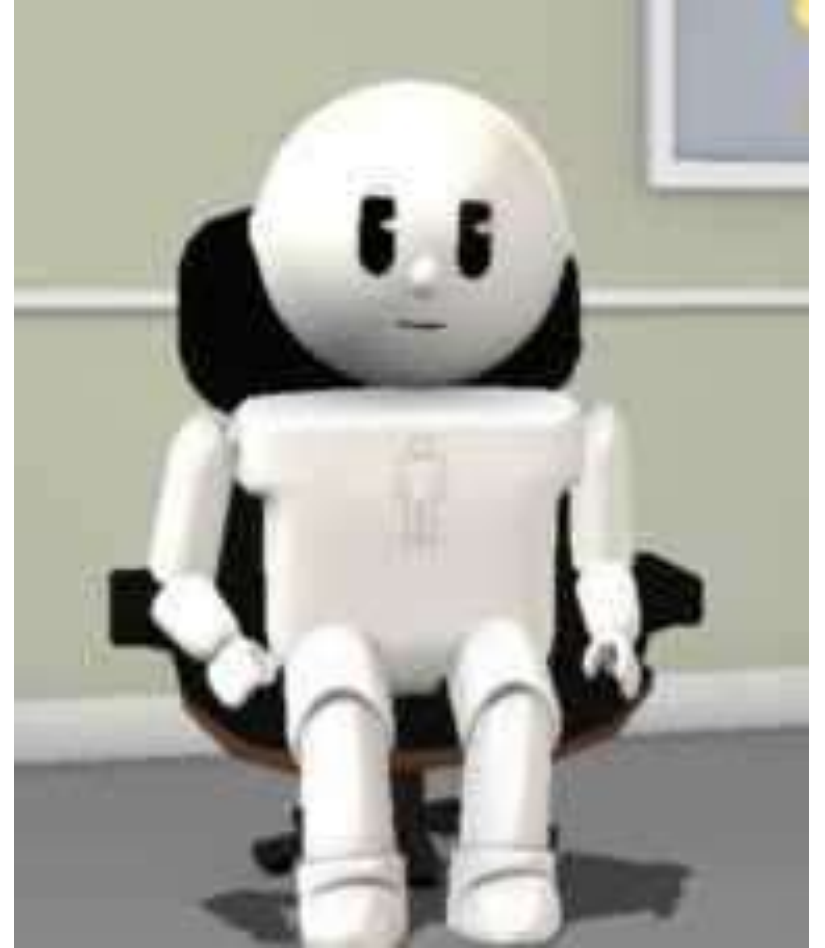


AI in Workflow Downsides?

- Overdependence on AI could result in human healthcare providers especially trainees, losing skills that they might need if AI is not available or fails or that they might need to properly oversee AI
- Economic implications could be negative with an increasing amount of dollars for higher cost healthcare providers going to lower cost AI
- AI can create or propagate major bias in analysis, diagnosis and decision support based on racial, gender, ethnic, socioeconomic, and many other factors
- AI can't be empathetic like humans, or could it

What We Really Want is Some Empathy

- According to a study done by the Mayo Clinic in 2006, the most important characteristics patients feel a good doctor must possess are entirely human
- According to the study, the ideal physician is **confident, empathetic, humane, personal, forthright, respectful, and thorough**
- Watson may have proved his cognitive superiority, but can a computer ever be taught these human attributes needed to negotiate through patient fear, anxiety, and confusion? Could such a computer ever come across as sincere?



But Can An AI Program Be Empathetic?

USC Institute for
Creative Technologies

University of Southern California

SimSensei: Virtual Human for Healthcare Support & MultiSense: Multimodal Perception and Learning

Albert (Skip) Rizzo, PI
Louis-Philippe Morency, PI

As part of DCAPS program:
Detection & Computational Analysis of Psychological Signals
(3rd Interim Progress Video)

The work depicted here was sponsored by the U.S. Defense Advanced Research Projects Agency. Statements and opinions expressed do not necessarily reflect the position or the policy of the United States Government, and no official endorsement should be inferred.

Conclusion

- While the field of nuclear medicine has been a pioneer in the adoption of computer applications for image acquisition, processing, display, quantification, and diagnosis, it has arguably fallen behind in the adoption of neural network based (AI) technologies
- Efforts by the SNMMI and others are allowing rapid catch up and generative algorithms are advancing rapidly to provide a wide variety of clinical, workflow, and administrative applications
- The future of AI in Nuclear Medicine is bright and artificial intelligence will be a major game changer in the field
- This will provide us with the opportunity to once again become a pioneer in both diagnostic and therapeutic applications



Nuclear Medicine AI Hype, Reality, and the Future Potential of AI

Eliot Siegel, MD, FSIIM, FACR

Professor of Radiology

University of Maryland School of Medicine

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