PUBLIC HEALTH FOUNDATION OF INDIA

ASSOCIATION OF HEALTHCARE PROVIDERS INDIA

Indian Institute of Science

Indian Institute of Space Science and Technology

Certificate Course in

Healthcare Technology (CCHT)

Module 2 -Technology- led Health Care Part 1

AI in Healthcare – Medical Image Analysis

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AI in Healthcare – Medical Image Analysis

Learning Objectives:

- Brief History of Medical Image Computing
- Roles for AI in Medical Image Computing
- CAD Development Process
- Bottlenecks in CAD Development in India
- Case study – CAD for Prevention of Blindness

Overview of Session:

Medical images form a key type of evidence in evidence-based medicine practiced in healthcare delivery. Radiologists read and write reports and hence exclusively deal with interpretation of images. However, interpreting is a role that is required for a wider variety of images other than scans from CT, MR and nuclear imaging systems. For example, pathologists and ultrasound (US) specialists deal images acquired through microscopy and US scanners.

This module takes a closer look at the role of AI in handling/processing medical images from a variety of imaging systems. The module is divided into 4 parts. These start with a) history of computing with medical images and b) description of the different roles for AI in medical image computing (MIC). Then we shift focus to a key area in (b), namely Computer aided diagnostics or CAD in short. We will look at the stages in CAD development, bottlenecks for CAD development in the Indian context and end with a brief case study.

1. History

In the early years, medical images were largely film based. Over time, digitisation of images either at the source or converting it to digital later became popular. A digital camera such as the ones in smartphones today is a good example of source of digital images. Film-based X-ray scanned with special devices to obtain a digital X-ray image is an example of conversion to digital image later. The invention of PACS or Picture Archival and Communication Systems greatly encouraged healthcare management in a digital form. PACS help store and archive images for retrieval at any time. This facilitated hospitals associate images with electronic medical records of patients thus providing a comprehensive case history for a patient. It also led to the creation of huge repositories of images.

The computing research community developed expertise to process digital images in the 1950s. A decade later attention turned to medical images. The main interest was to develop algorithms that could process images and assist doctors in dealing with potentially fatal diseases like heart attack, cancer of the breast and lung. The first paper reporting such an attempt appeared in 1963 in the Journal of Radiology. This paper explored the use of computers for analysing digitised X-rays to detect lung cancer. The early algorithms which processed images and gave decisions were called "expert systems". Such systems were not able to meet the expectations from the clinical community which led to frustration and conclusions (even in late 1980s) that such attempts were futile or did not hold much promise! However, the field of MIC saw continued interest in building automated image analysis solutions. The new name for such solutions was CAD. The continued interest in CAD development looked for inspiration from even unlikely sources. For example, Levinson et. al. (2015) reported that they were able to train pigeons to discriminate between normal and cancerous (as evidenced by mitoses) H&E images. Pigeons were reported to perform the task with above 90% accuracy after just a few days of training!

CAD saw a huge turnaround post-2015 with performances of CAD systems equalling or surpassing human medical experts. Such systems are therefore considered as systems with artificial intelligence (AI). The key developments behind this turnaround were: i) design of more sophisticated computational models of neural networks found in our brain, ii) a new paradigm called deep learning which made it possible for training deep neural networks to perform challenging tasks and iii) Availability of powerful computer hardware such as GPUs (Graphical processing unit) at reasonably affordable cost. GPUs were originally designed to run the computer gaming algorithms at real time. The success prompted Prof Hinton who was the key figure behind (i) and (ii) to comment in 2016 that the profession of Radiologists was at peril. While this was an exaggeration, the success did signal the entry of AI in medical practice.

2. Different roles of AI:

AI has potentially a variety of roles in healthcare. This ranges from the earlier intended virtual assistant to a clinician; it can also be a replacement in some instances to better utilize the human experts' skills. Finally, it can be an enabler helping a smarter practice of medicine.

The earliest example of AI as a virtual assistant is where the CAD system automatically processed images and provided different types of assistance: i) highlight parts that were possibly abnormal to draw an expert's attention, ii) identify (label) the image as 'not normal' or 'normal' with or without a probability/confidence score, iii) retrieve and show similar samples with diagnosis, iv) derive analytics from the image to support decision-making.

The emerging role for AI is based on some reports that CAD systems can outperform medical experts (ex. Radiologists). Such systems can therefore be considered in first-level screening or triage. Advances in AI also have identified a role where replacement is of not a human expert but for a data source. For example, in radiotherapy planning CT and MRI are used. CAD solutions have been reported to predict the CT scan (at high accuracy) from a given MR scan of a patient. This means the patient need not be scanned twice and an invasive imaging (CT) can be avoided.

The future roles of AI include predicting disease progression from images and helping plan treatment in oncology and assisting in delivery of treatment as well. For example, the pulmonary fibrosis can be staged using a prediction of the Forced vital capacity (FVC) values of lungs given CT images of patients.

3. The CAD system Development process

The CAD development process has several stages starting from problem formulation, data collection, to algorithm development/implementation and testing in lab as well as in the field (clinic).

The problem formulation ideally should be initiated by the healthcare community where need for automation is felt and clinicians have the requisite understanding of the disease domain. However, the initial formulation has largely happened in an opportunistic manner with the computing community looking for new application areas for their general tools in AI. This situation is changing with increased awareness of AI and its potential within the healthcare community. Once the problem has been defined, requisite knowledge and data have to be acquired. The current Deep learning-based AI systems are data driven in the sense that the systems are designed to infer patterns and insights from data directly. The data in question here in the context of this module are medical images and associated annotations. There are different types of annotations done in practice, with the type dictated not only by the nature of the problem but also ease of annotation. The degree of manual effort involved in annotation varies with the type of annotation. For example, a delineation of the boundary of a tumour in an image is much more labour intensive compared to placing a box indicating the rough boundary of the tumour. The delineation type of annotation becomes more challenging when the lesions to be marked are small, distributed and numerous in the image.

Hospitals and clinics are the sites for sourcing image data. Protection of patients' rights and privacy is a key consideration is data sharing. Patients are the owner of the data and have the right to decide whether their images can be used for any purpose other than diagnosis of their individual medical problem. Even if a patient has consented to let their images be used for a research study, they have the right to insist that their identity is protected via a thorough anonymisation process prior to the use of data for any study. Approval by an ethics committee or Institutional review board is the standard protocol followed globally for any study including for collection of images and sharing the same with a third party.

Deep learning paradigm relies on vast quantities of data for training CAD systems and achieve good performance. However in the medical domain most data is unstructured/uncurated and unannotated. This results in a data bottleneck for CAD development. This problem has been addressed in 3 ways: i) CAD solutions are developed only for diseases for which publicly released data is available; these are usually from western countries, ii) Collaborate with researchers in universities abroad who have access to data and iii) synthesise images using special neural networks called Generative Adversarial Neural networks (GANs). These 3 methods have differing strengths and weaknesses.

4. Indian Scenario:

Interdisciplinary research, which is ideally required for developing CAD systems, is particularly challenging in the Indian scenario. This is largely because of the limitations in the ecosystem created by our educational system. The Universities in western countries are truly multidisciplinary. I.e. Departments dedicated to full range of disciplines (Arts, Humanities, business, science, engineering, medicine) are housed in one university providing natural ecosystems promoting collaborations and cross fertilization of ideas. This is not the case in India which has dedicated institutions for the 'professional' disciplines: IITs, AIIMS and IIMs and Universities. This poses a serious impediment and challenge to do multidisciplinary research in general and in particular for fostering truly interdisciplinary research such as in applications of AI in healthcare. The public hospitals (ex. AIIMS) are overburdened with delivering healthcare to large section of the under-served segment of the population. Private, corporate hospitals (ex. Apollo) provide quality healthcare but being businesses, are driven by commercial interests and hence focused largely on service. Some exceptions do exist. This has affected the development of strong academic teams in the medical image computing domain at least until recently. A recognition of this difficulty has led to some changes. IIT-Kharagpur is the first one to set up a hospital recently and start postgraduate teaching and research programmes in medical and information sciences.

End note

The CAD systems are penetrating the industry, both within India and globally. Many start-ups can be seen to work in this space for a wide range of problems such as detection of tuberculosis, cancer prognosis, eye screening and computer assisted pathology. FDA approval for an autonomous AI-based system was awarded in 2018 for the very first and only time so far. This system was developed by a start-up (IDx) for diabetic retinopathy or DR screening. This is a successful example of the replacement role for AI as it acts autonomously to decide on the presence of DR from image data. This is an interesting development spurring the growth of this sector. India will surely have a share in this growth story given its excellent human resource power in Computing Technology and Medicine.

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AI in Healthcare – Medical Image Analysis

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CERTIFICATE COURSE IN HEALTHCARE TECHNOLOGY

Dr. Jayanthi Sivaswamy
Professor and Dean (Academics) at IIIT Hyderabad

Jayanthi Sivaswamy's research interest is in medical image analysis in general and specifically, computer aided diagnostics. She collaborates with leading hospitals in India. Her work on the creation of the first brain atlas for the Indian population received a lot of attention.

She received her MS and PhD in Electrical Engineering from Syracuse University and worked at the University of Auckland, New Zealand before joining IIITH in 2001.

Overview

- A Brief History of Medical Image Computing
- Roles for AI in Medical Image Computing
- CAD Development Process
- Bottlenecks in CAD Development in India
- Case study – CAD for Prevention of Blindness

A Brief History of Medical Image Computing

The Early Drivers

The trigger for automatic analysis of medical images or medical image computing:

- Invention of PACS (Picture archival and communication system)
- Need to manage fatal diseases - Cardiovascular, cancer of the breast and lung

↓

How to automatically process X rays to detect diseases of the

- heart (DSA)
- breast (Mammogram)
- chest

The Beginning

VOL. 81 NO. 2

Radiology

AUGUST 1963

a monthly journal devoted to clinical radiology and allied sciences

PUBLISHED BY THE RADIOLOGICAL SOCIETY OF NORTH AMERICA, INC.

The Coding of Roentgen Images for Computer Analysis as Applied to Lung Cancer[1]

GWILYM S. LODWICK, M.D., THEODORE E. KEATS, M.D., and JOHN P. DORST, M.D.

THIS PAPER WILL DESCRIBE a concept of converting the visual images on roentgenograms into numerical sequences that can be manipulated and evaluated by the digital computer and will report the results of employing this system to determine the significance of certain radiographic findings in lung cancer. The cause, against a background of air density, the intimate details of the relationship between tumor and host may be faithfully reproduced roentgenographically. Parenthetically, it may be stated that similar density ranges exist in the relationships between bone and soft tissue and that an equally effective descriptive system

2 - 3 decades later..

WHY EXPERT SYSTEMS FOR MEDICAL DIAGNOSIS ARE NOT BEING GENERALLY USED: A VALEDICTORY OPINION

RALPH L. ENGLE, JR., M.D.
Department of Public Health
Cornell University Medical College
New York, New York

BETTY J. FLEHINGER, PH.D.
IBM Thomas J. Watson Research Center
Yorktown Heights, New York

In *Attempts to Use Computers as Diagnostic Aids in Medical Decision Making, - 30 year experience* ***Engle*** **concludes that**

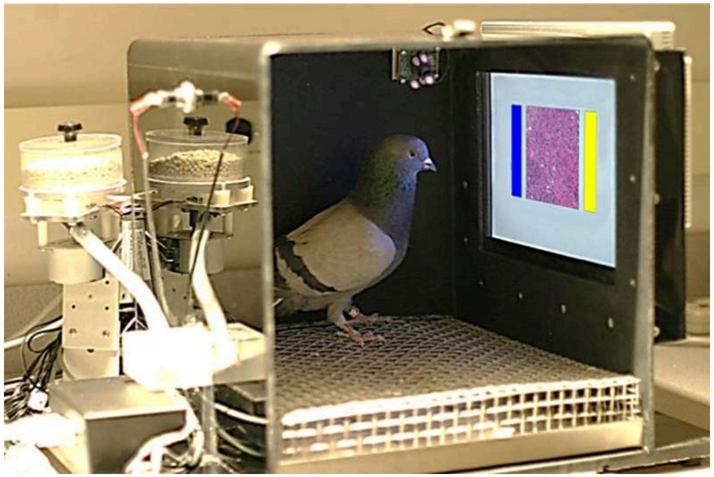
"However, after many years we have concluded that we should stop trying to make computers act like diagnosticians practicing the medicine of today."

"Thus, we do not see much promise in the development of computer programs to simulate the decision making of a physician....

RL Engle and BJ Flehinger , Bull. NY Acad. Med.,1987

RL Engle, Perspectives in Biology and Medicine, 1992

50 years later



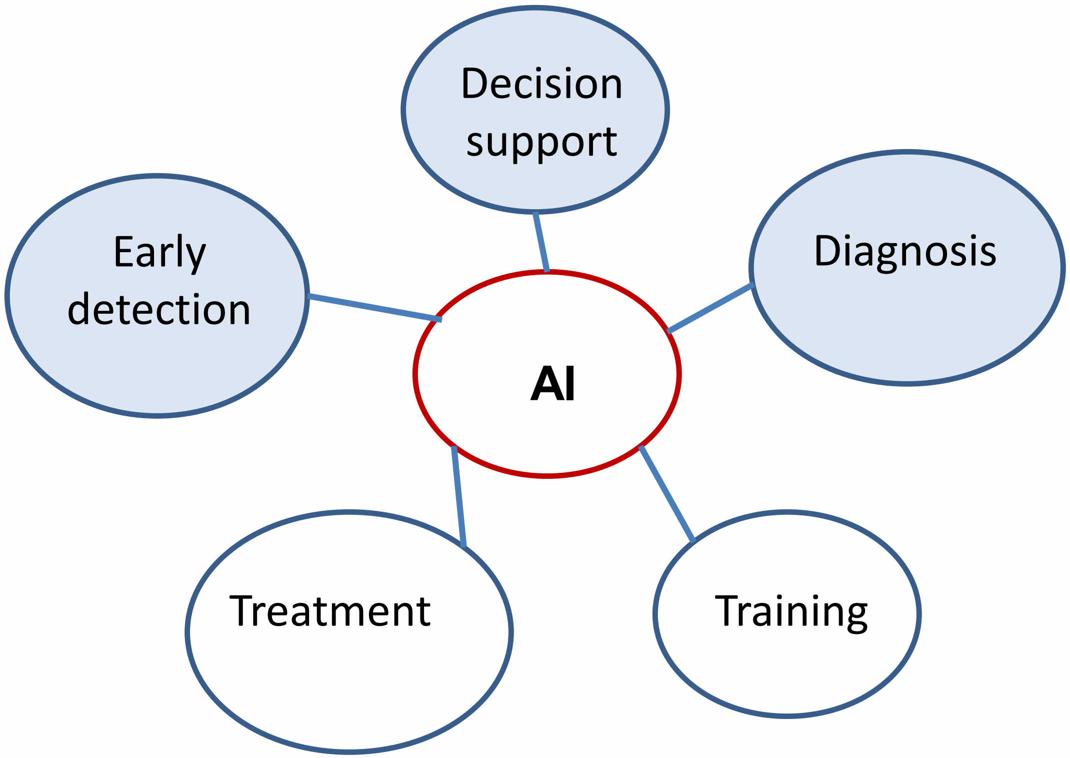
“We found pigeons to be remarkably adept at several medical image classification tasks…. Their performance …… could play a key role in the development of computer-assisted medical image recognition tools.

Levenson et al. PLoS One 2015

Radiologists are “ the coyote already over the edge of the cliff who has’nt yet looked down”

Prof. G Hinton in 2016

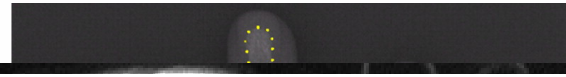
Roles for AI in Medical Image Computing

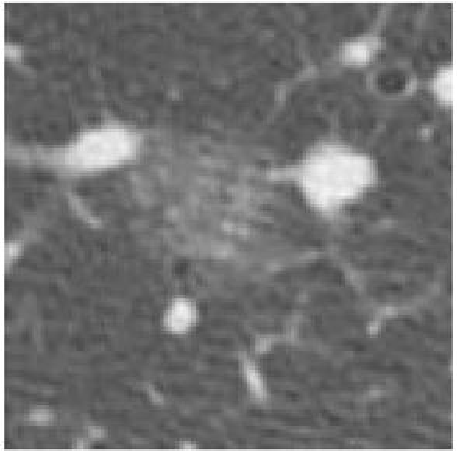

Decision support
Early detection
Diagnosis
AI
Treatment
Training

Traditional role

- Virtual **Assistant** (Computer assisted diagnosis or CAD)
  - To the clinician

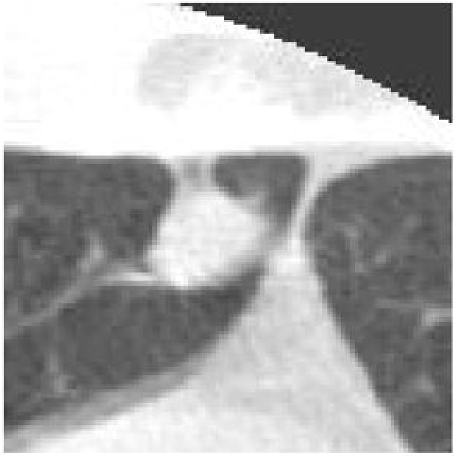
- CAD output forms the **basis** for diagnosis
  - “second opinion”
  - “score” to be interpreted
  - “focus of attention”
  - morphometry/count/analytics





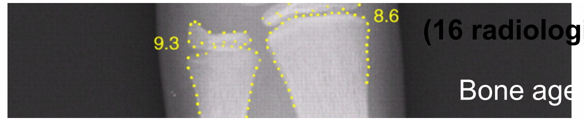
Malignant nodule

Initial rating (0-1.0): 0.49
Computer output: 0.97
2nd rating: 0.67

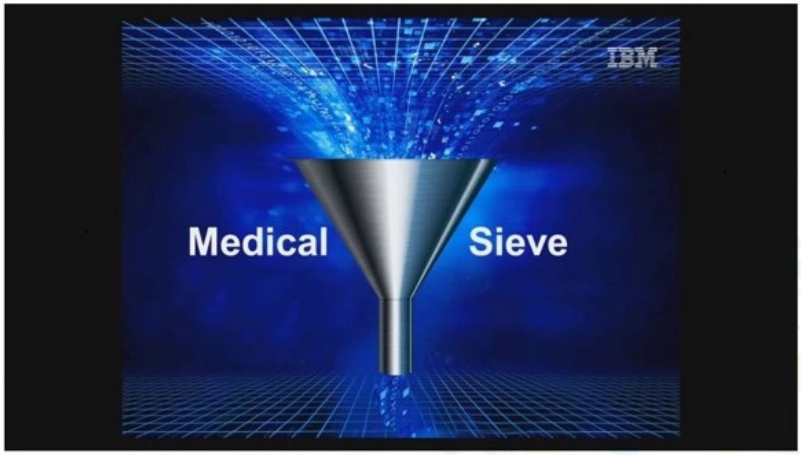


Benign nodule

Initial rating (0-1.0): 0.46
Computer output: 0.01
2nd rating: 0.27



(16 radiologists in a 2004 study)



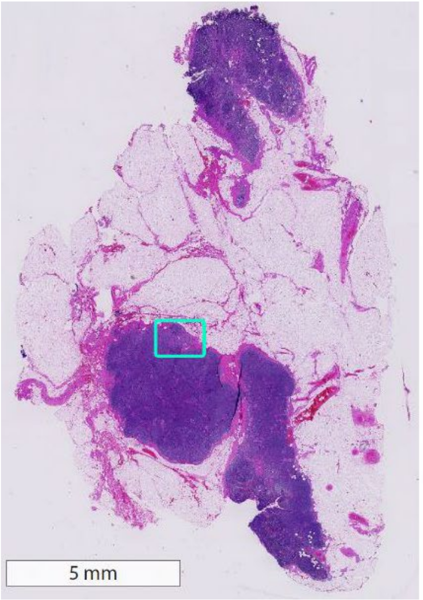
- IBM's Medical Sieve
  - a cognitive assistant system for radiologists and cardiologists
  - filter and detect anomalies from image, text and clinical data

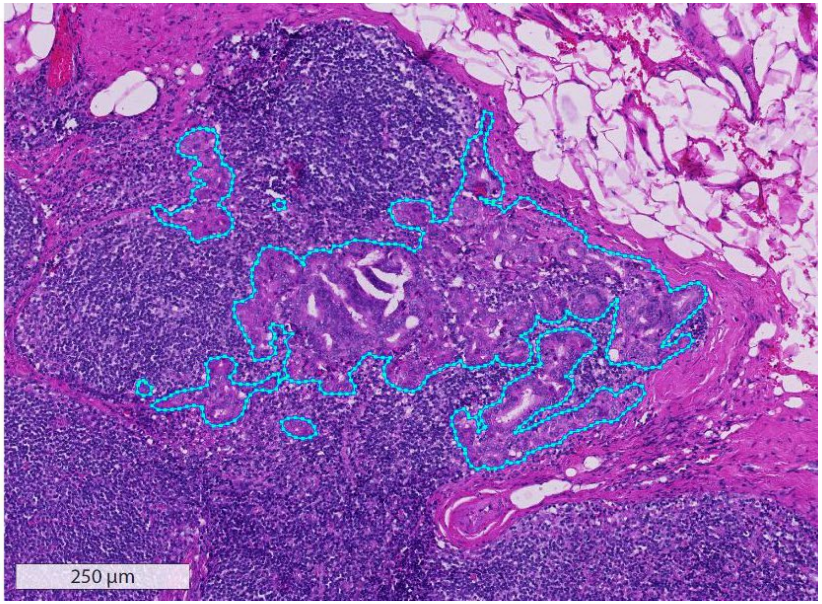
- Google-Deep mind
  - Aid healthcare provision systems (NHS) with AI solutions
  - "Augment (not replace) the experts" [S Thrun]

Emerging role

- As a **replacement**
  - For a medical expert
    - As CAD matures and **outperforms** experts in specific tasks
  - For some diagnostic imaging
    - **Predict** modality X based on modality Y

CAD outperforming experts





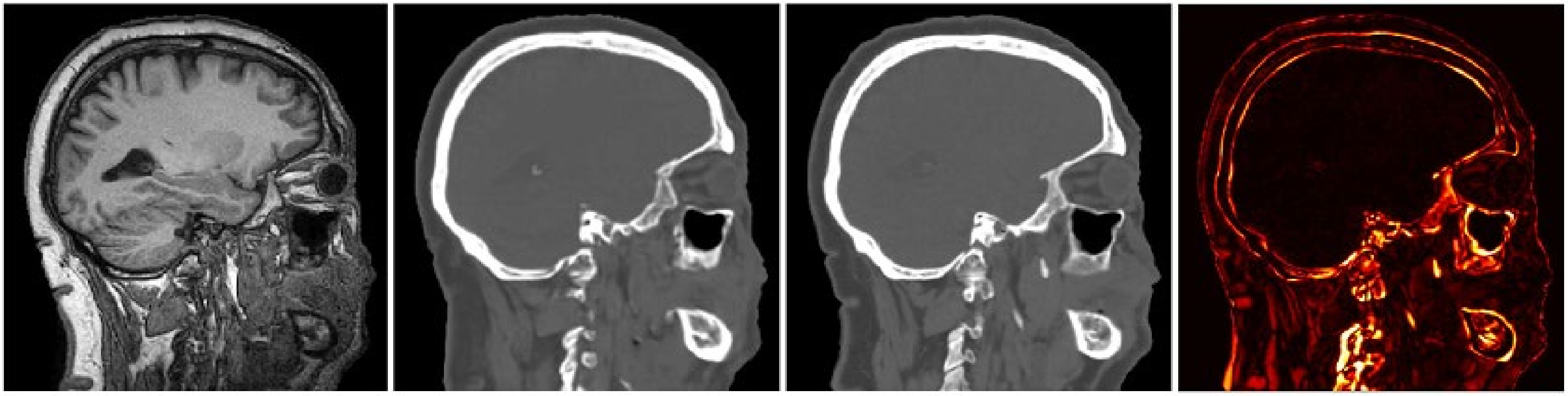
Lymph node metastases detection

Conclusions

In the setting of a challenge competition, some deep learning algorithms achieved better diagnostic performance than a panel of 11 pathologists ……….

Bejnordi et al JAMA 2017

CAD predicts X from Y



Radiation therapy planning

Conclusions: …
Dosimetric evaluation suggests that dose calculations performed on the sCTs are accurate, and can therefore be used for MR-only intracranial radiotherapy treatment planning.

Dinkla et al. IJRO 2018

Emerging role of AI

- As an **enabler** of smarter medical practice
  - From diagnosis to prognosis
    - Help plan treatment by predicting disease trajectory
  - From not possible to possible
    - Aid devising new solutions to problems

CAD Development Process

Key stages in CAD system development

- Problem formulation/definition
- Sourcing image data
- Design of algorithms
- Validation of computed results – in the lab
- Validation of computed results – in the clinic, field

Annotated images are needed for training and validating algorithms

Problem formulation

This is done by either

- The computing community
  - Wish to apply technique to a new application area

  Or

- The clinical community
  - Wish to solve a problem in healthcare

The data bottleneck

- Ethical and privacy issues → difficult to source data
  - Sourcing longitudinal data is even more difficult
- Most groups do not share data
  - Public datasets address this
- Annotations are even harder to collect
  - Mountains of data in hospitals
  - Only small mounds (noisy) with annotation

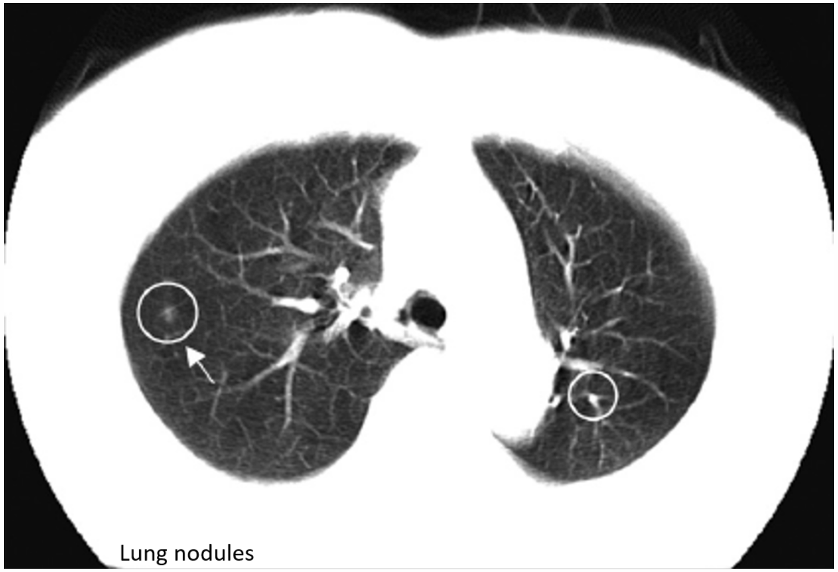
Million images for training (as in ImageNet) is practically ruled out

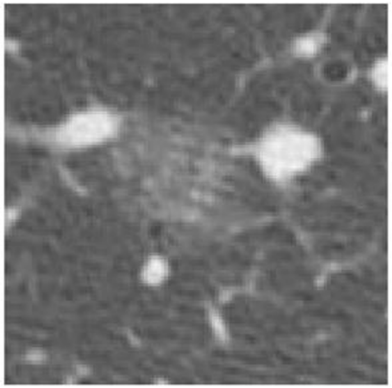
Collecting images

- Retrospectively
  + Minimal time for access, possibly one-time transfer
  – Convince/cajole hospitals to share
  – Acquisition protocol can be varying

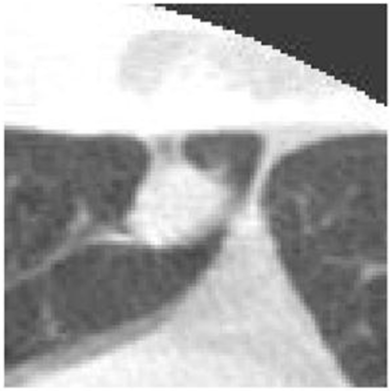
- Prospectively
  + Collaborative
  + Better control over image acquisition protocol
  – Longer time for collection and research

Annotations - coarse





Malignant nodule



Benign nodule

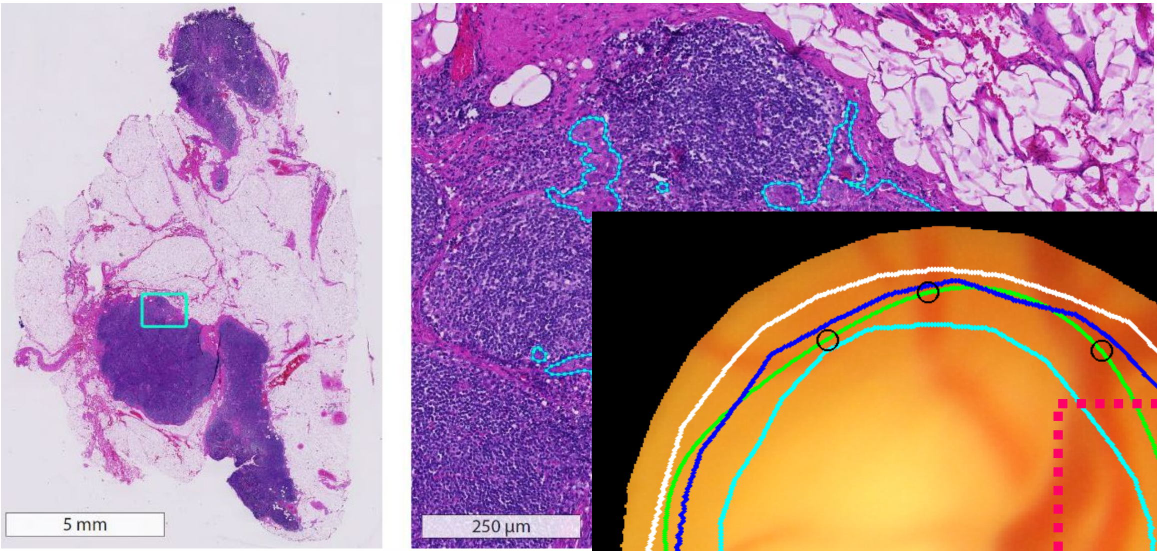
Two ROIs

Labels for ROI

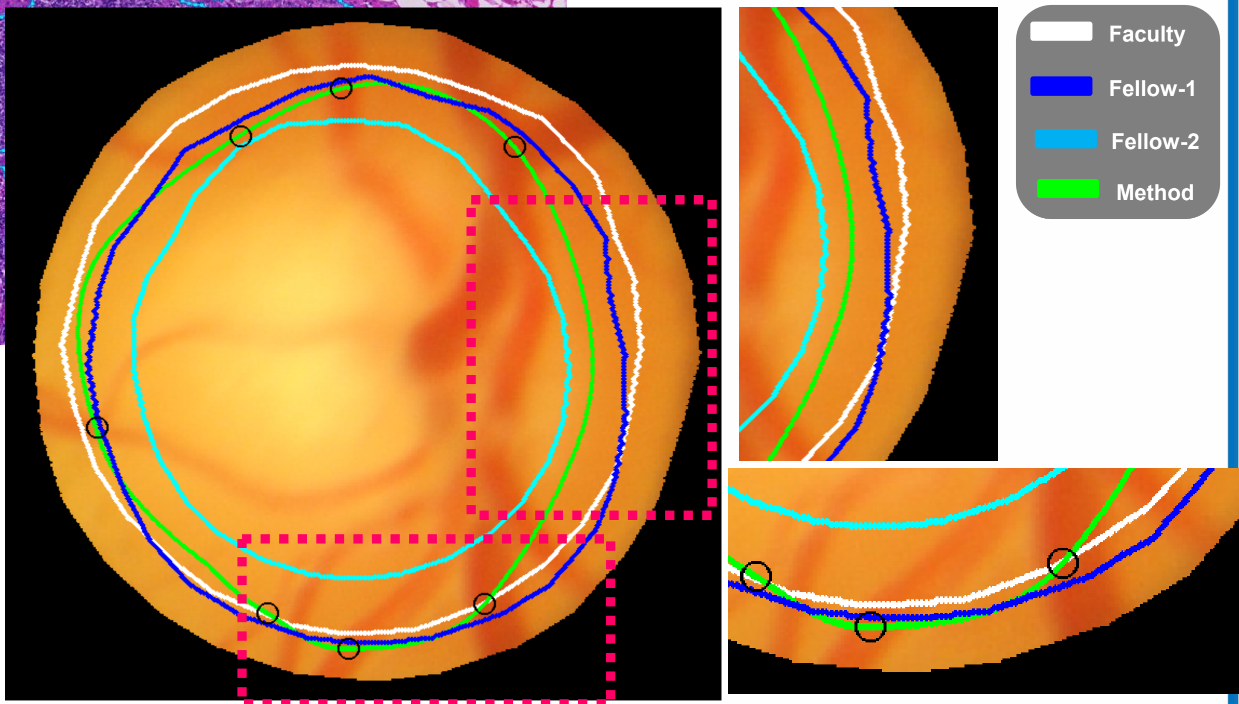
A slice of CT

Annotations - fine

Microscopy image



Fundus image



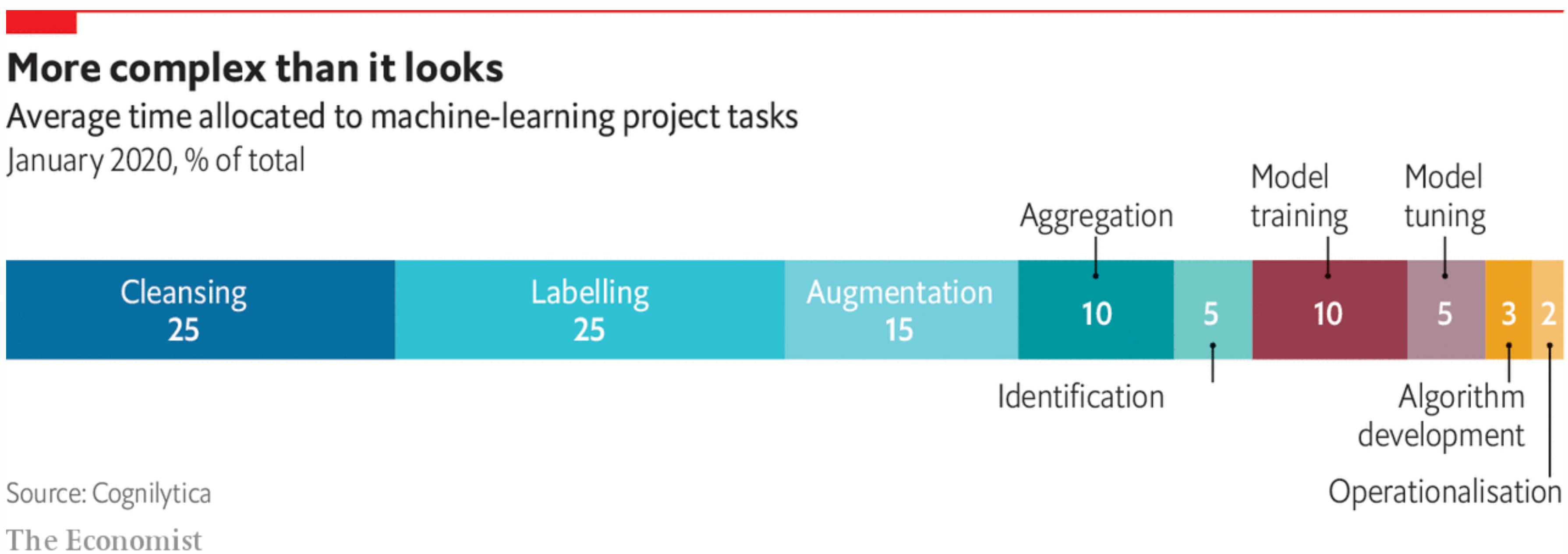
- Variability in annotations
- Depends on the annotator's
  - experience level
  - individual style
  - state of attentiveness

CAD system building

Perception

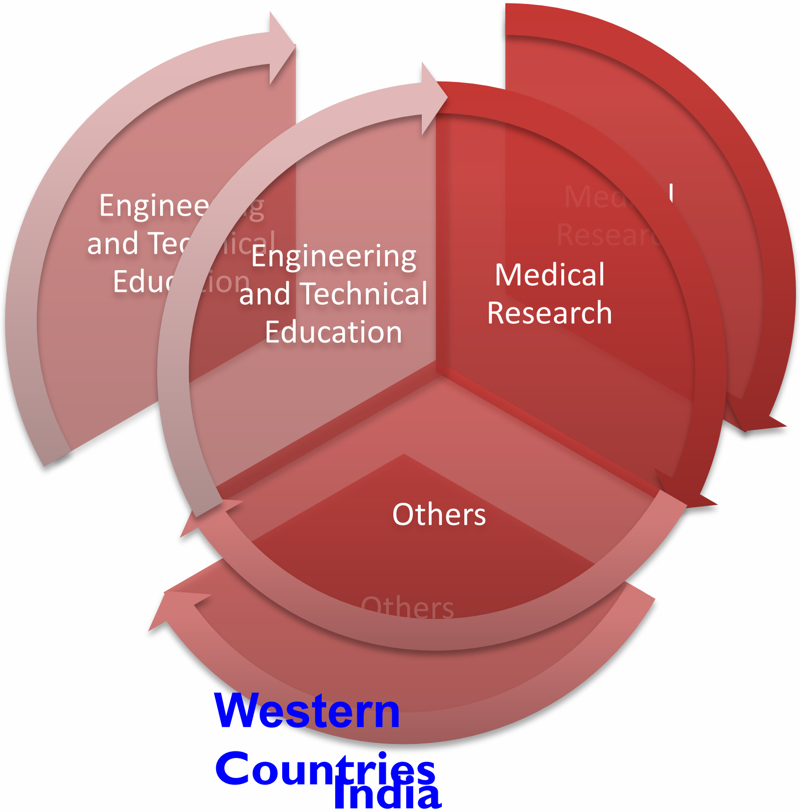
Get data | Write code

Reality

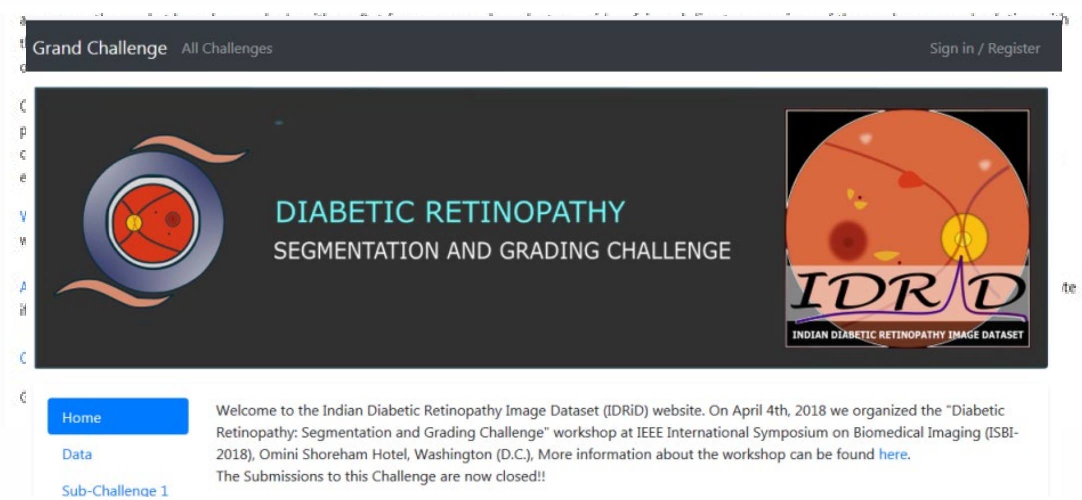


Indian scenario

The education system



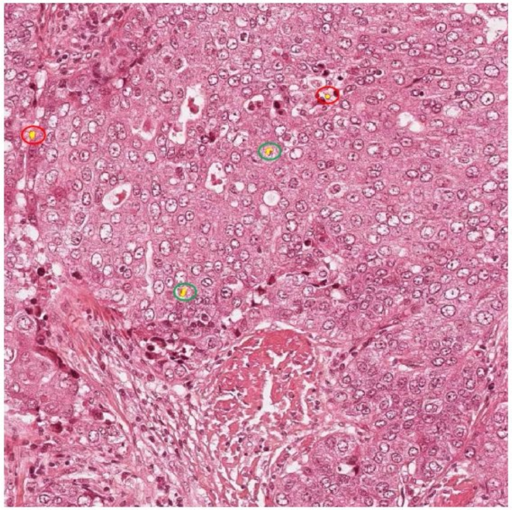
Defining problem and sourcing data - wide practice



Rely on public sources

Going beyond data

- An understanding of what the data represents
  - Ex. mitosis detection
- An understanding of the end-use of the solution
- Collaborations with a clinician
- None of these happens naturally here



Case study – Prevention of blindness

- Work done with a leading eye hospital ~ 1000 Km away
  - Reached out to hospital for collaboration
- Funding raised jointly from Govt of India for a 3-year project
  - Goal: to design and build a CAD system for glaucoma detection from fundus images
- Travel back and forth for consultation, planning, reviewing
  - Annotation worked best when doctors were taken away from the hospital

Outcomes: Nearly 1000 Images collected with patient consent

  - 101 images with annotation by 4 experts released as a public dataset
- Several joint publications in clinical and technical journals + a PhD thesis

- Cost of imaging device proved to be finally a road block to *system deployment* !

End note

- AI is projected to play a big role in Healthcare
  - Big (IBM, Google, Microsoft, etc.,) and small players are investing

Projection for healthcare in 2022 in India

- Market worth - $372 billion
  - among top 3 in the world
- Diagnostics worth - $32 billion
  - 75% in the private sector

Lots of opportunity for AI interventions!

https://www.investindia.gov.in

For more Information please contact

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