Lecture 1:
Course Introduction

Welcome

- This course is EECS 598-007: Artificial Intelligence in Biomedicine (Biomedical AI)
  - Graduate-level research-oriented course focusing on biomedical AI
  - Aim to cover both various algorithms of deep learning and different applications in the biomedical domain
  - Provide students from diverse backgrounds with the fundamental grounding necessary for conducting cutting-edge research in this interdisciplinary field
  - NOT teach basic knowledge in machine learning, deep learning or computer vision
    - Assumed prior experience as in prerequisites

Welcome

- What we hope you will get out of this course:
  - Knowledge:
    - Broad knowledge of cutting-edge machine learning / deep learning algorithms
    - Insight for important computational problems in real-world biomedical applications
    - Understand the opportunities and challenges for deploying AI algorithms in practical biomedical problems
  - Skills:
    - Paper reading and review
    - Critical thinking and research idea proposal
    - Design and conduct experiments to validate your idea
    - Paper writing

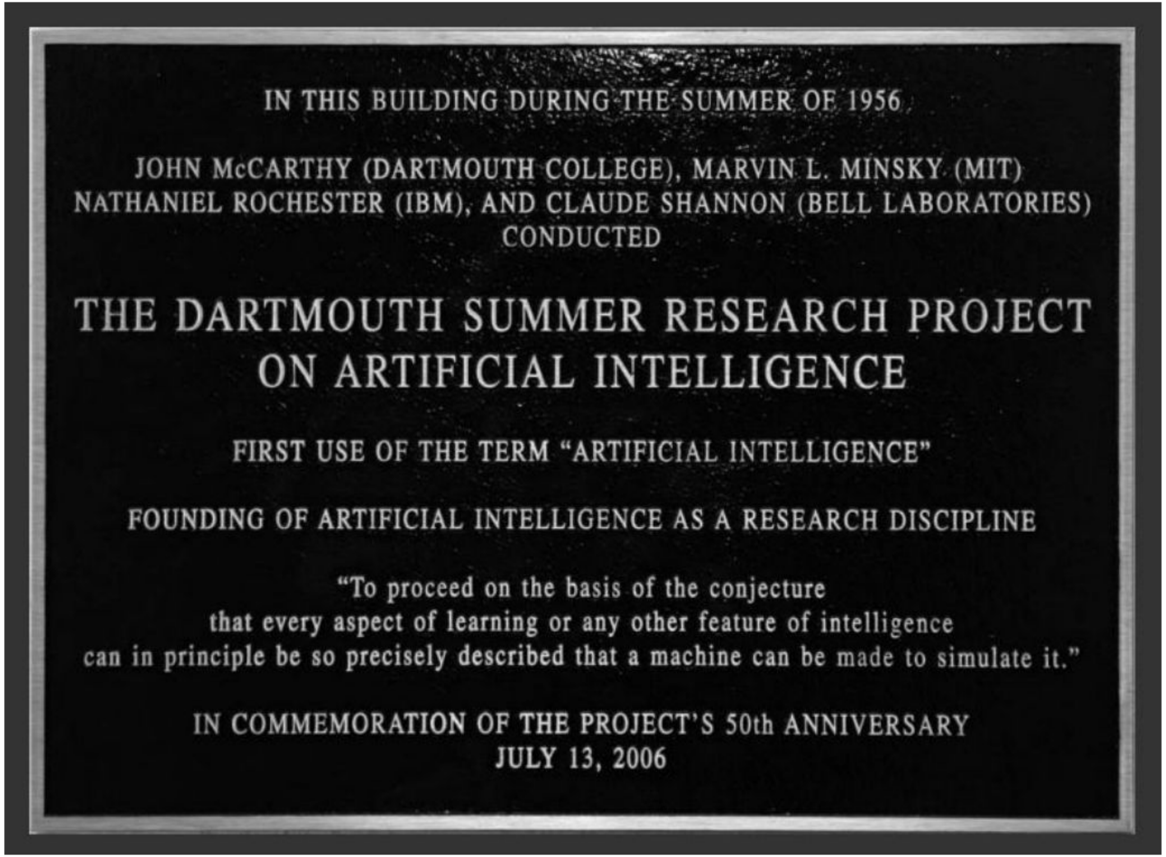
Today's agenda

- A brief overview of Biomedical AI
- Course logistics

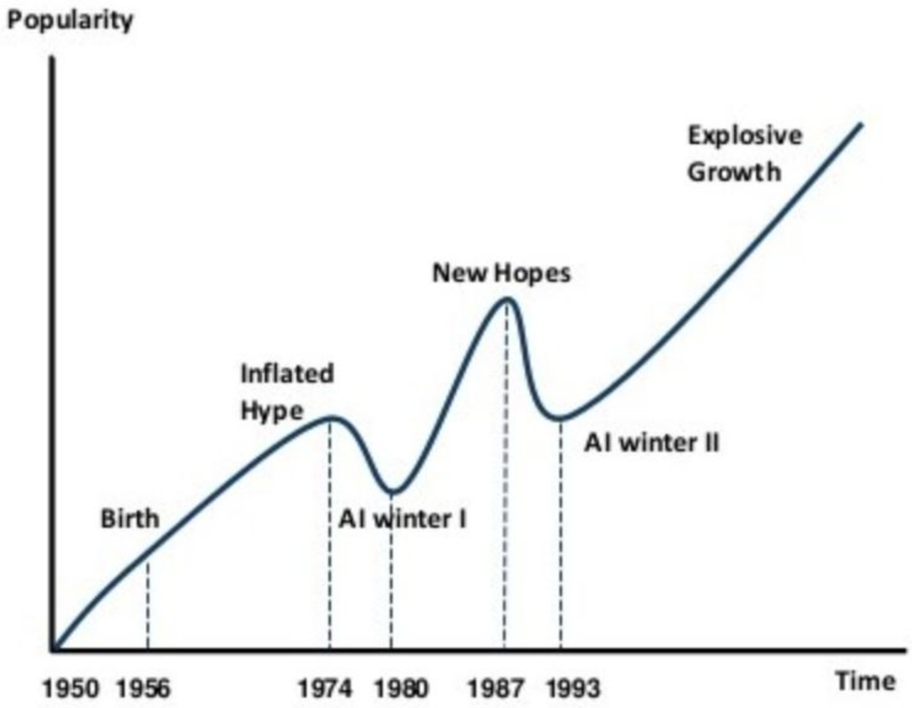
Beginning of AI research

1956: Birth of AI as a modern research discipline

John McCarthy



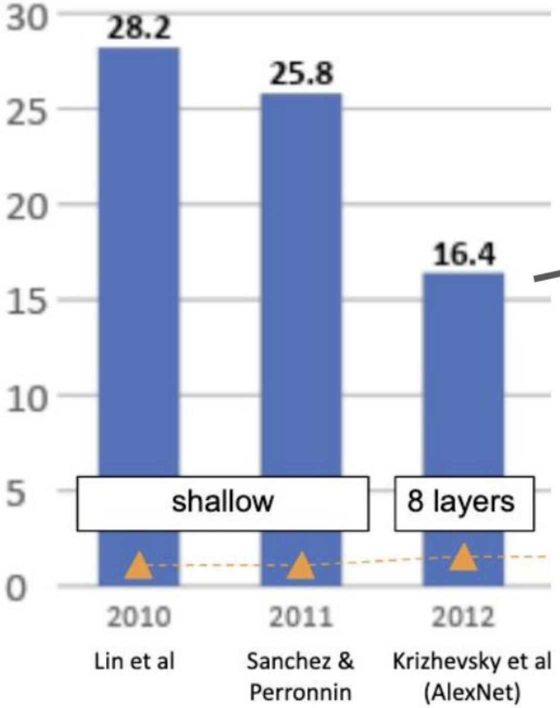
AI winters follow …



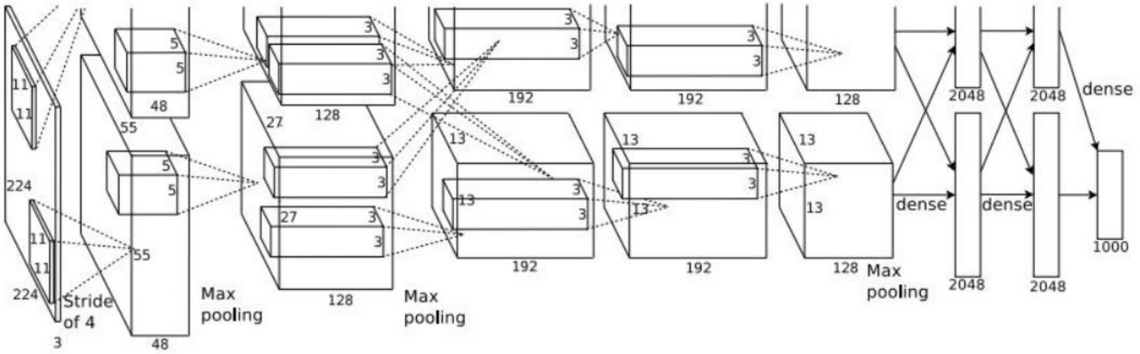
Timeline of AI Development

- **1950s-1960s**: First AI boom - the age of reasoning, prototype AI developed
- **1970s**: AI winter I
- **1980s-1990s**: Second AI boom: the age of Knowledge representation (appearance of expert systems capable of reproducing human decision-making)
- **1990s**: AI winter II
- **1997**: Deep Blue beats Gary Kasparov
- **2006**: University of Toronto develops Deep Learning
- **2011**: IBM's Watson won Jeopardy
- **2016**: Go software based on Deep Learning beats world's champions

2012: Deep learning breakthrough in computer vision



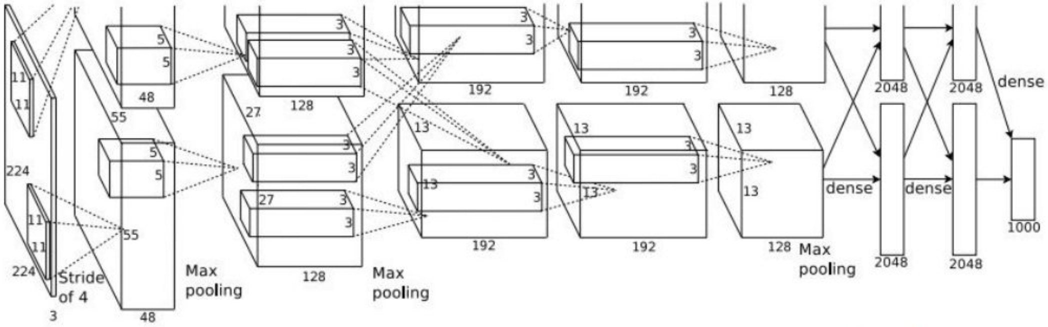
ImageNet Visual Recognition Challenge results.



Krizhevsky et al. 2012. 8-layer "AlexNet".

Convergence of key ingredients of deep learning

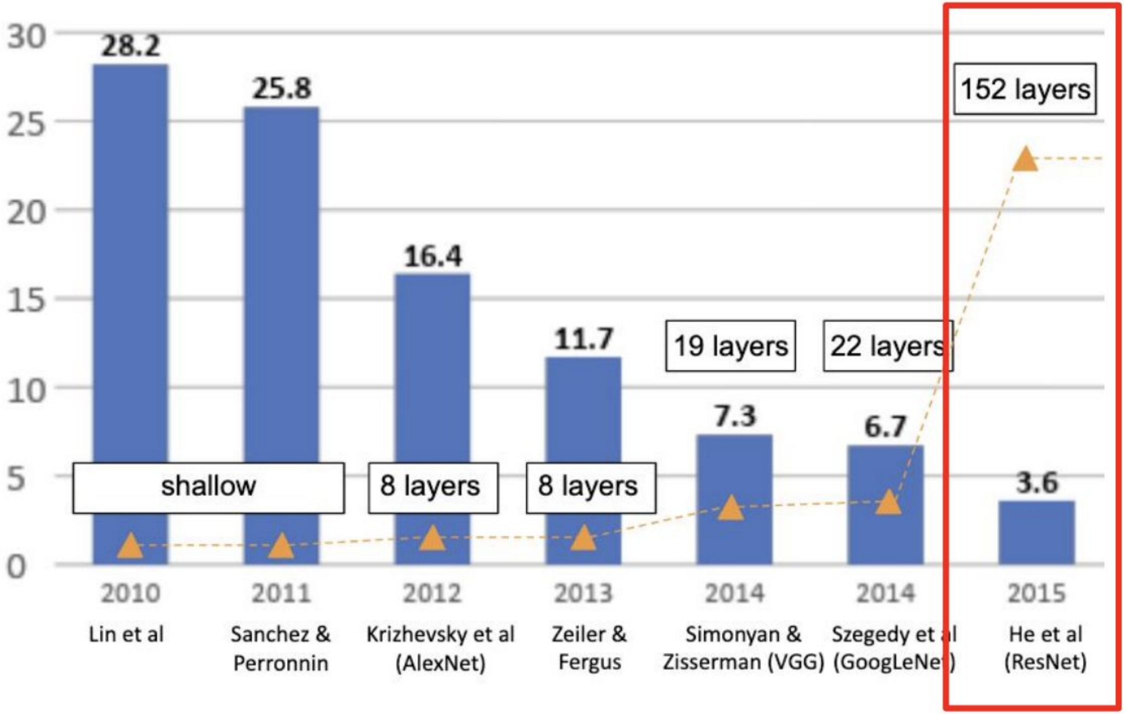
Algorithms



Compute

Data

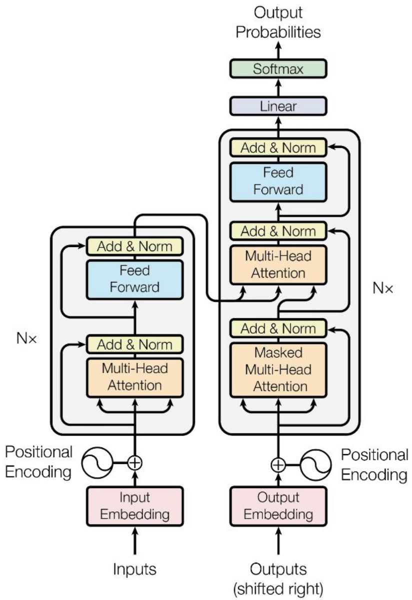
2015: Very deep ConvNet and challenging vision tasks



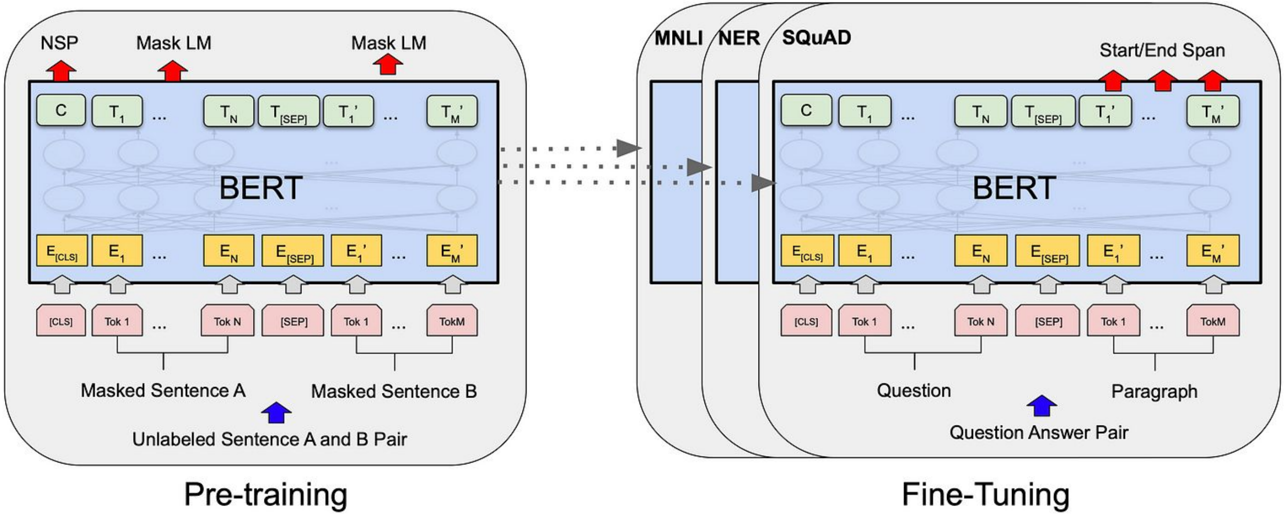
He et al. 2015. ResNet.

2018: Deep learning breakthrough in natural language processing

- BERT achieves State-of-the-art (SOTA) on 11 NLP benchmarks



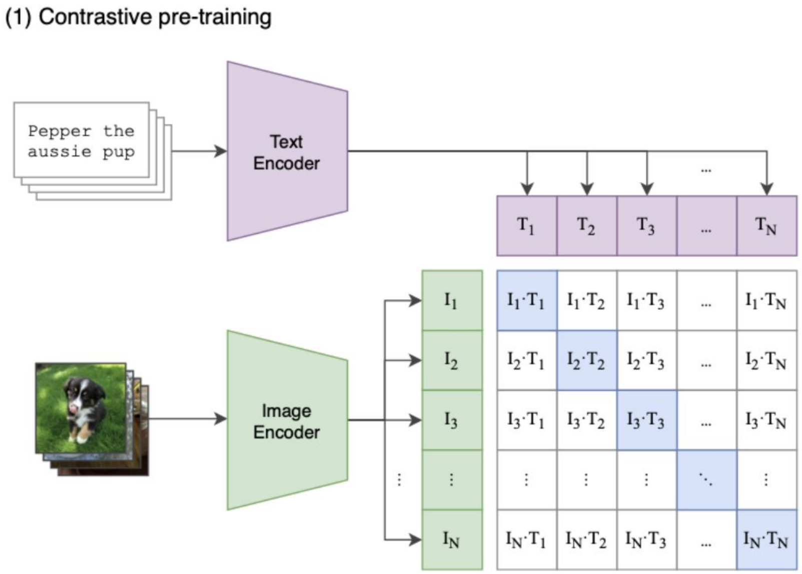
Vaswani et al. 2017. Transformer



Devlin et al. 2018. BERT

2021: Multi-modal vision-language models and image generation

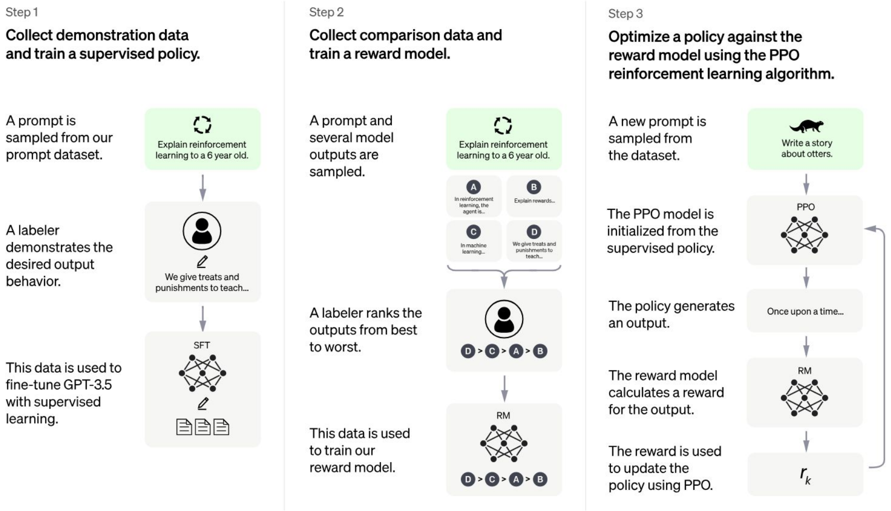
- Self-supervised learning (contrastive learning)



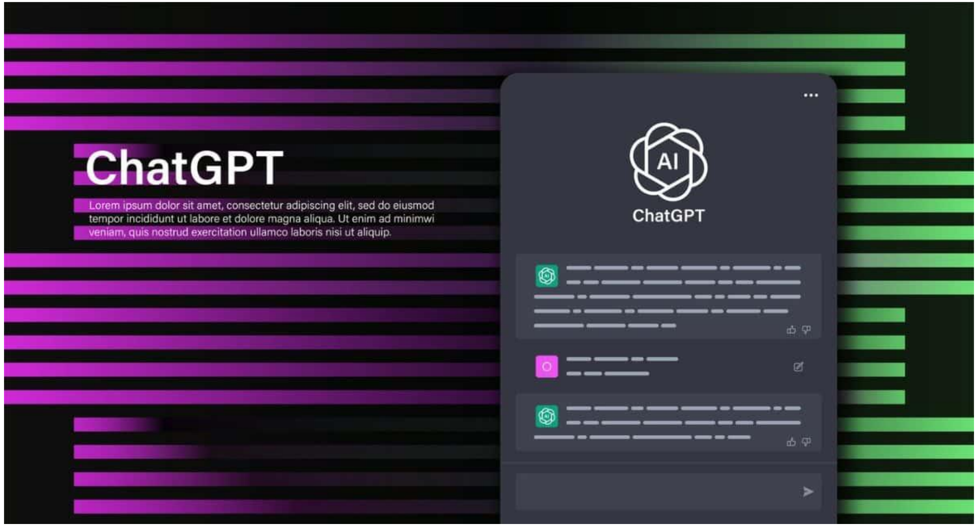
Radford et al. 2021. CLIP

Ramesh et al. 2021. DALL-E

2022: Large language model for zero-shot text generation

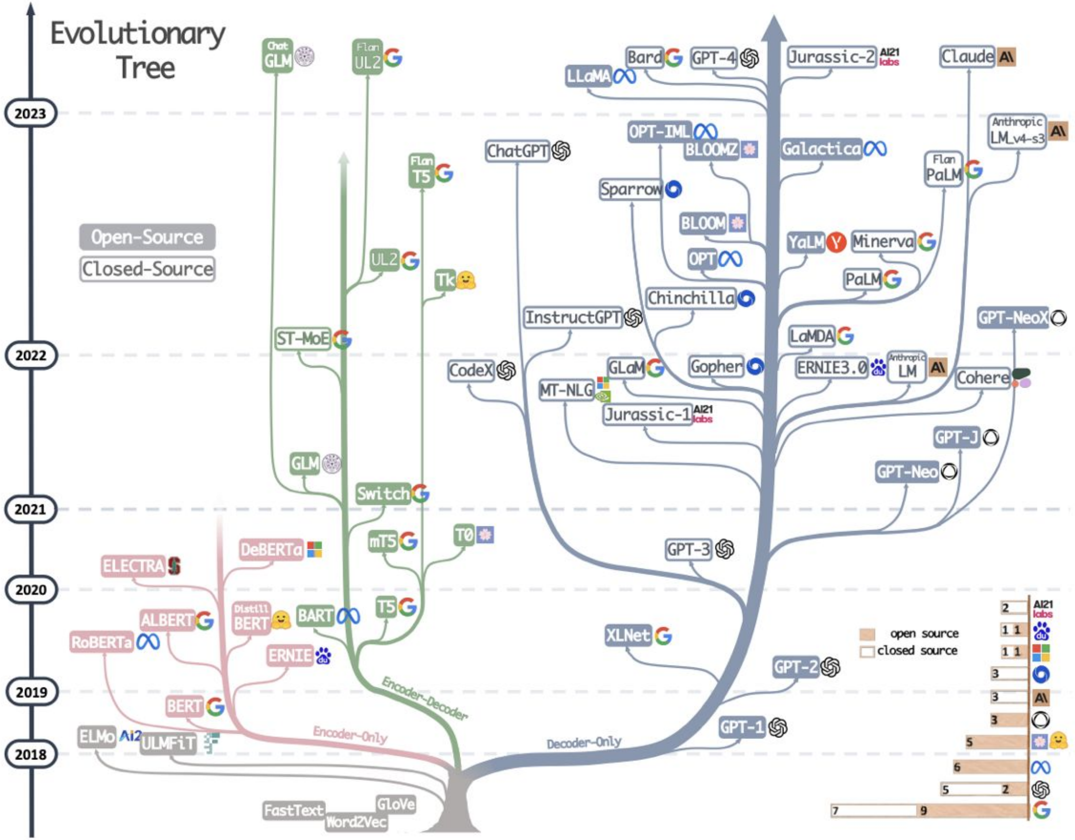


Ouyang et al. 2022. InstructGPT



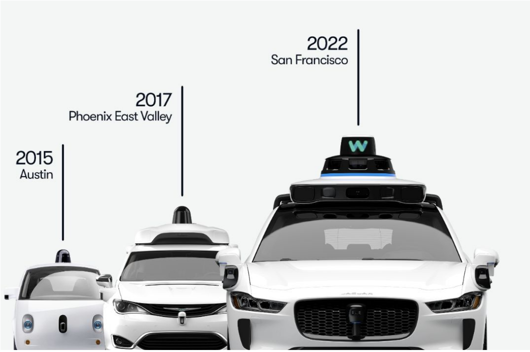
OpenAI 2022. ChatGPT

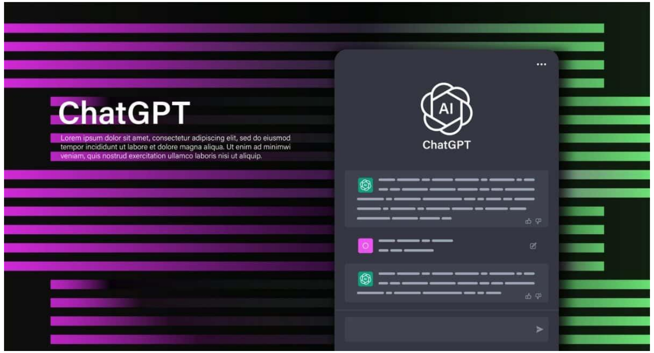
2022: Large language model for zero-shot text generation



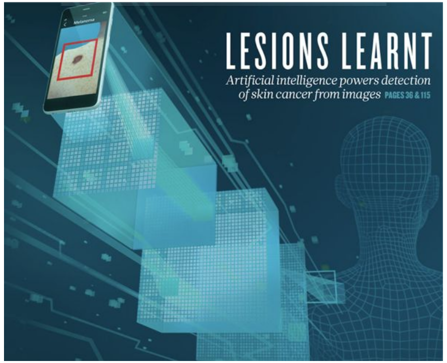
AI to GAI (General Artificial Intelligence)

- Applications in real world:

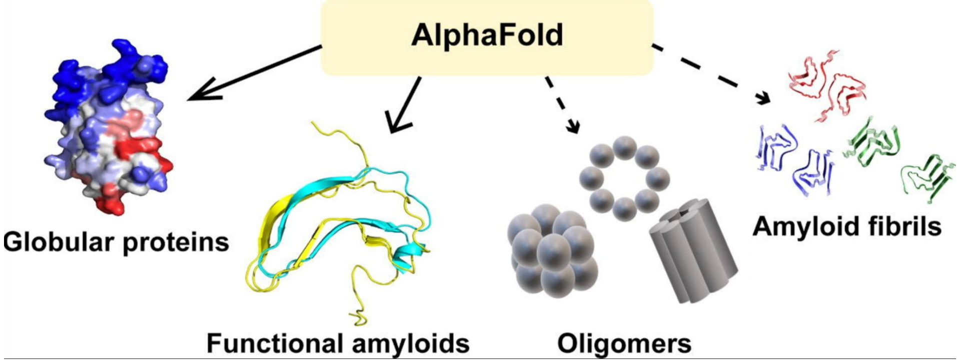




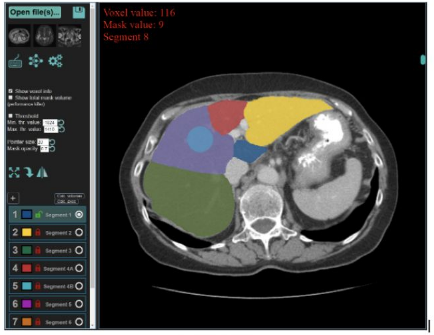
AI in biomedicine and healthcare

- 

Esteva et al. 2016. Skin image classification



Jumper et al. 2021. Protein structure prediction



Medical image segmentation

Patient care

Biomedical AI: a rapidly expanding field (industry)

Apple's future healthcare market moves will rely heavily on AI analysis

By Malcolm Owen
Monday, September 16, 2019, 09:03 am PT (12:03 pm ET)

Apple's moves in the healthcare market could involve the tracking of user data for further analysis by artificial intelligence and billing model based on cost-savings, with analysts pointing out areas of the consumer health industry Apple could easily advance by building upon its already-released technology and services.

Google to Store and Analyze Millions of Health Records

The tech company's deal with Ascension is part of a push to use artificial intelligence to aid health services.

SCIENCE \ BUSINESS \ TECH

Amazon is buying 'membership-based' healthcare provider One Medical for $3.9 billion

19

One Medical's Netflix-for-primary-care is a $199 subscription to a modern doctor's office

By Richard Lawler | @rjcc | Jul 21, 2022, 9:40am EDT | 19 comments

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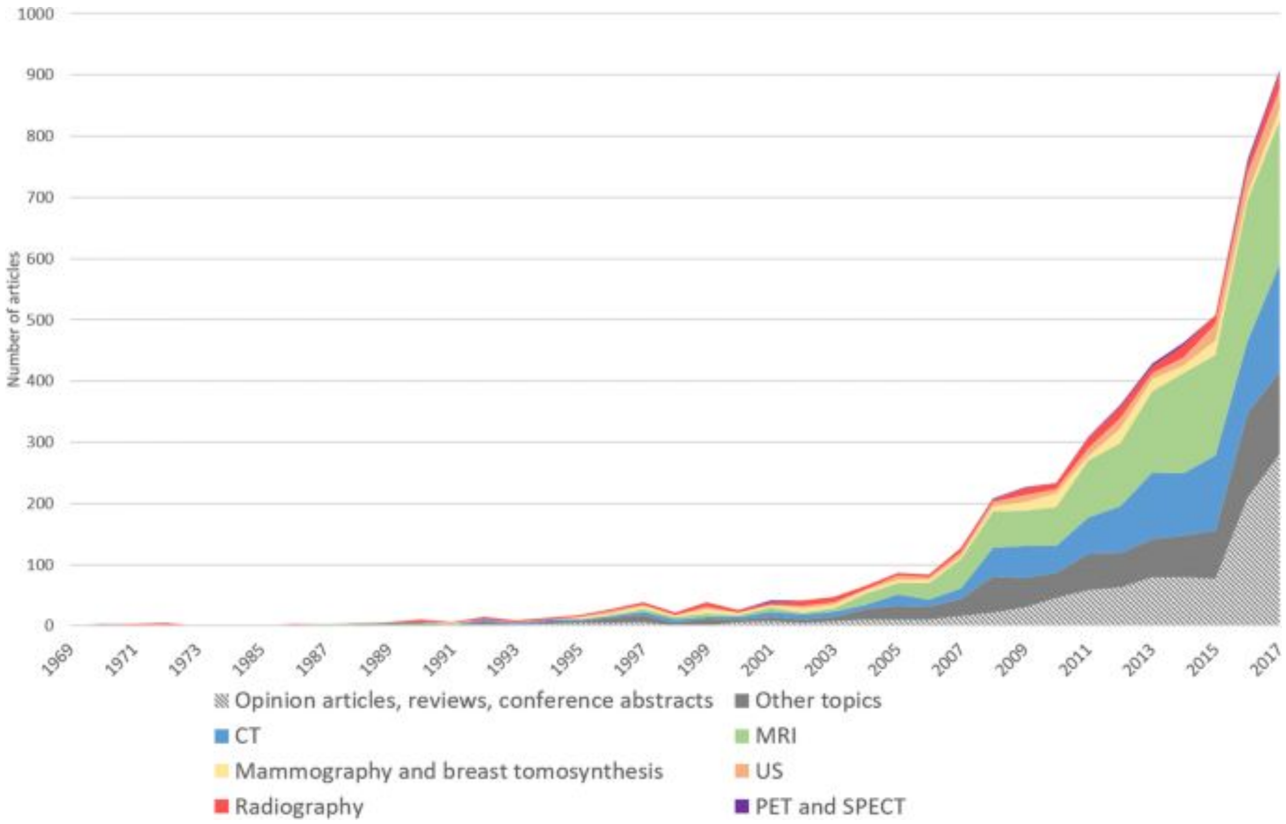
Microsoft Healthcare is a new effort to push doctors to the cloud

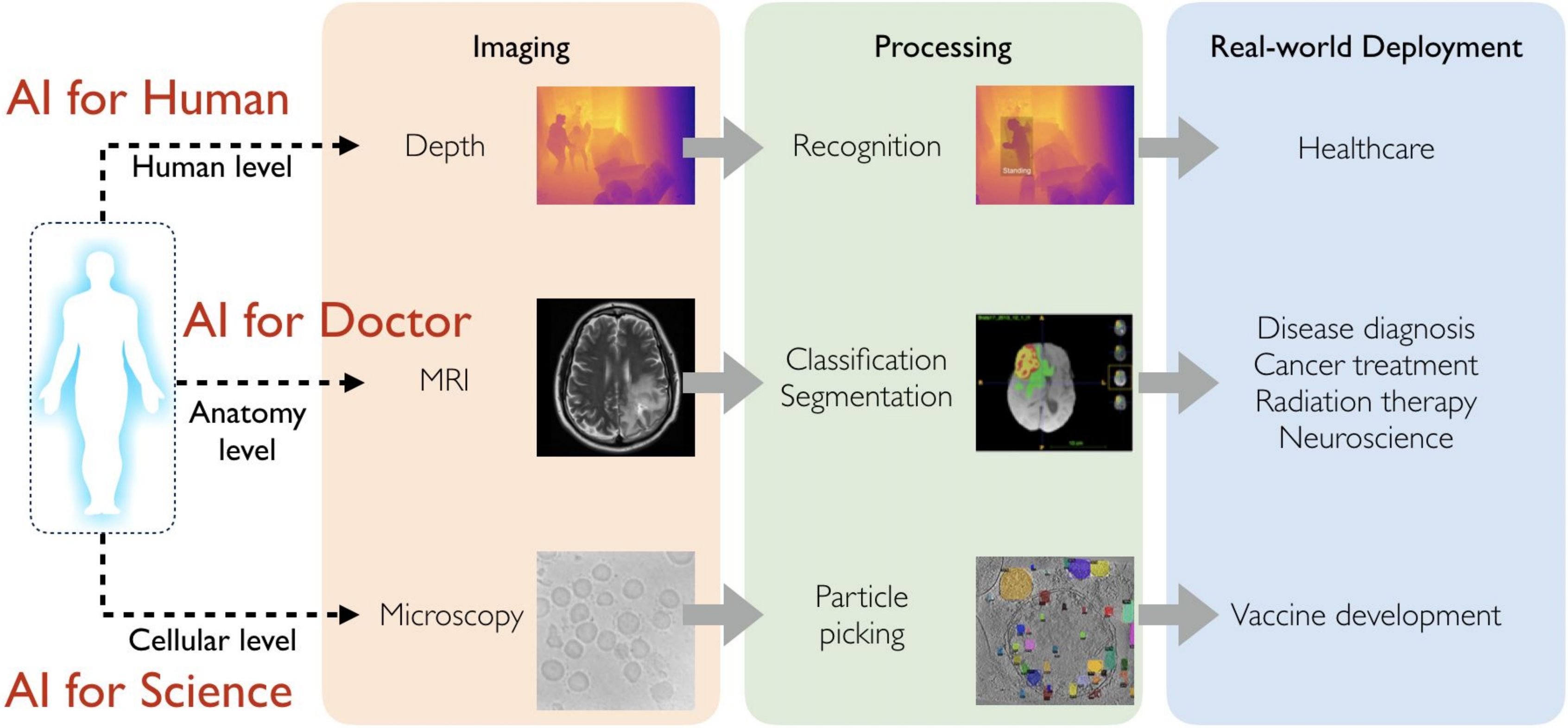
Microsoft wants to be a big part of the cloud and AI healthcare race

By Tom Warren | @tomwarren | Jun 27, 2018, 6:50am EDT

Biomedical AI: a rapidly expanding field (academia)

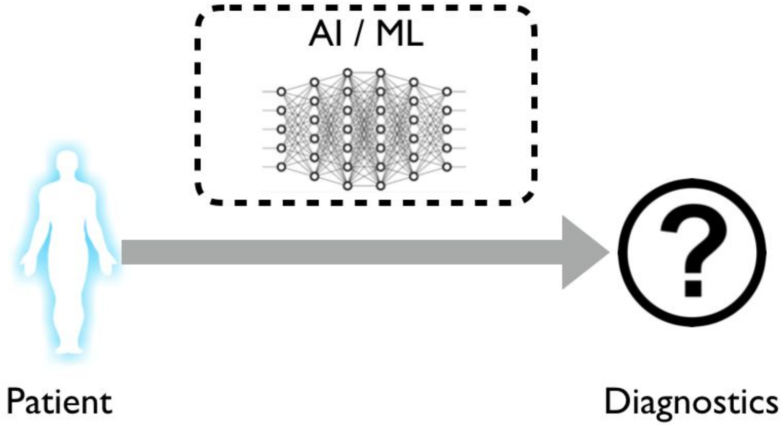


AI helps to understand human health in different levels



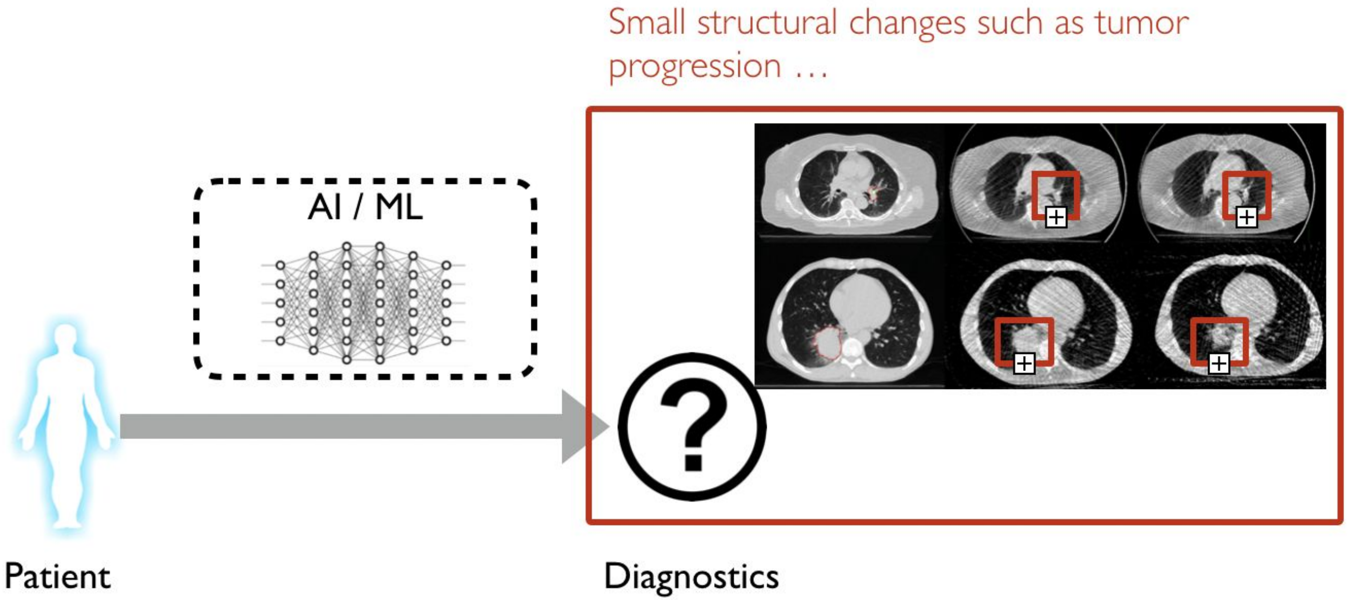
Challenges of Biomedical AI

- Reliability
- Generation
- Data efficiency
- Multi-modality



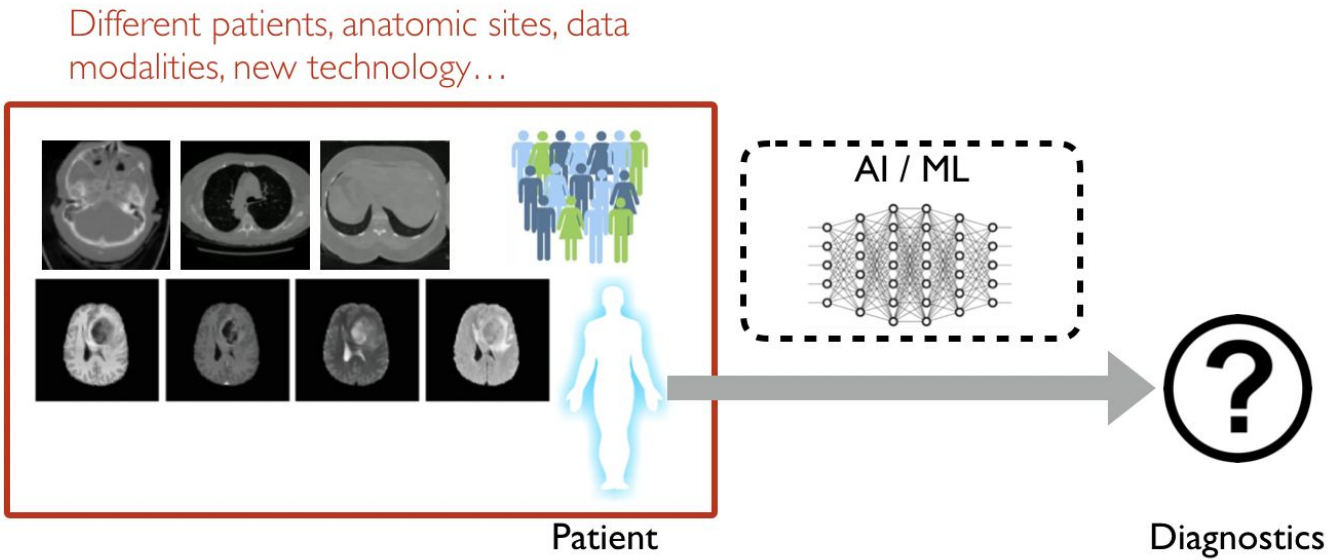
Challenges of Biomedical AI: Reliability

- AI can be insensitive to tumor shrinkage, lesion progression, etc.



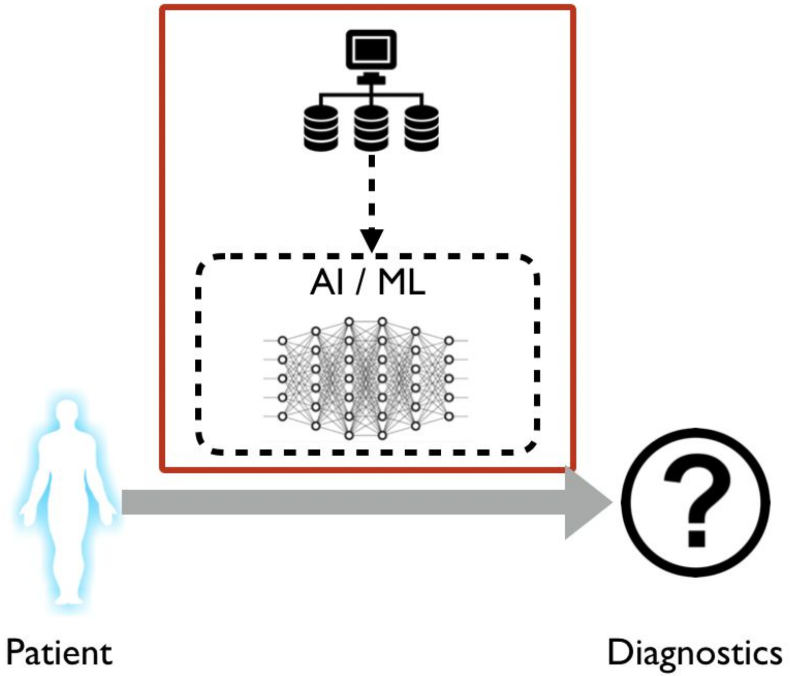
Challenges of Biomedical AI: Generalization

- AI model is limited when generalized to different input data



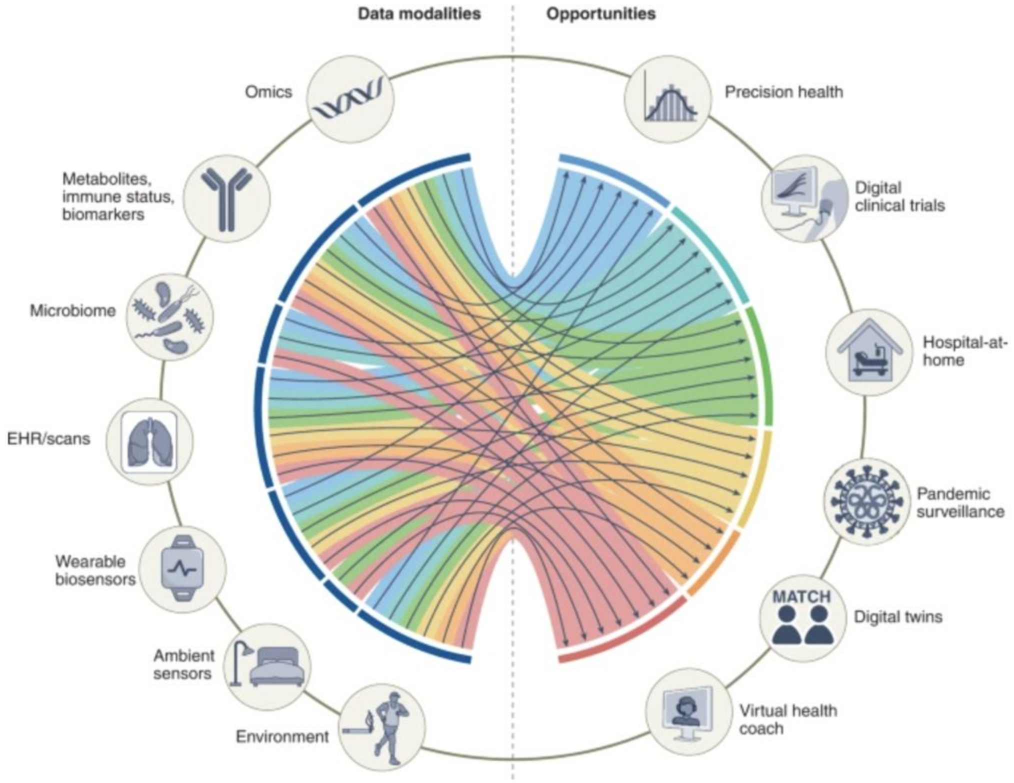
Challenges of Biomedical AI: Data efficiency

- Data collection and annotation can be a bottleneck for AI model development



Challenges of Biomedical AI: Multi-modality

- Biomedical data is inherently multi-modality

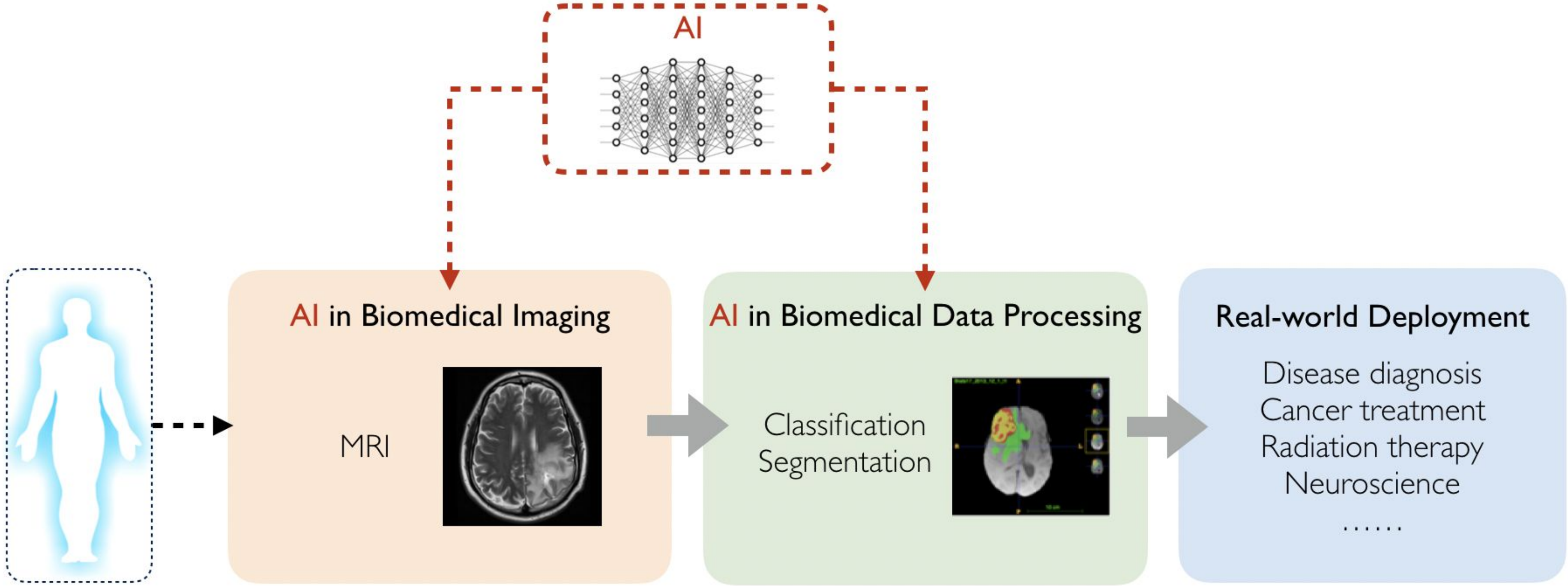


In this class:

- See the values and opportunities of biomedical AI
- Understand the challenges of biomedical AI
- After the class: Contribute to the development of biomedical AI
  - Research
  - Deployment
  - ……

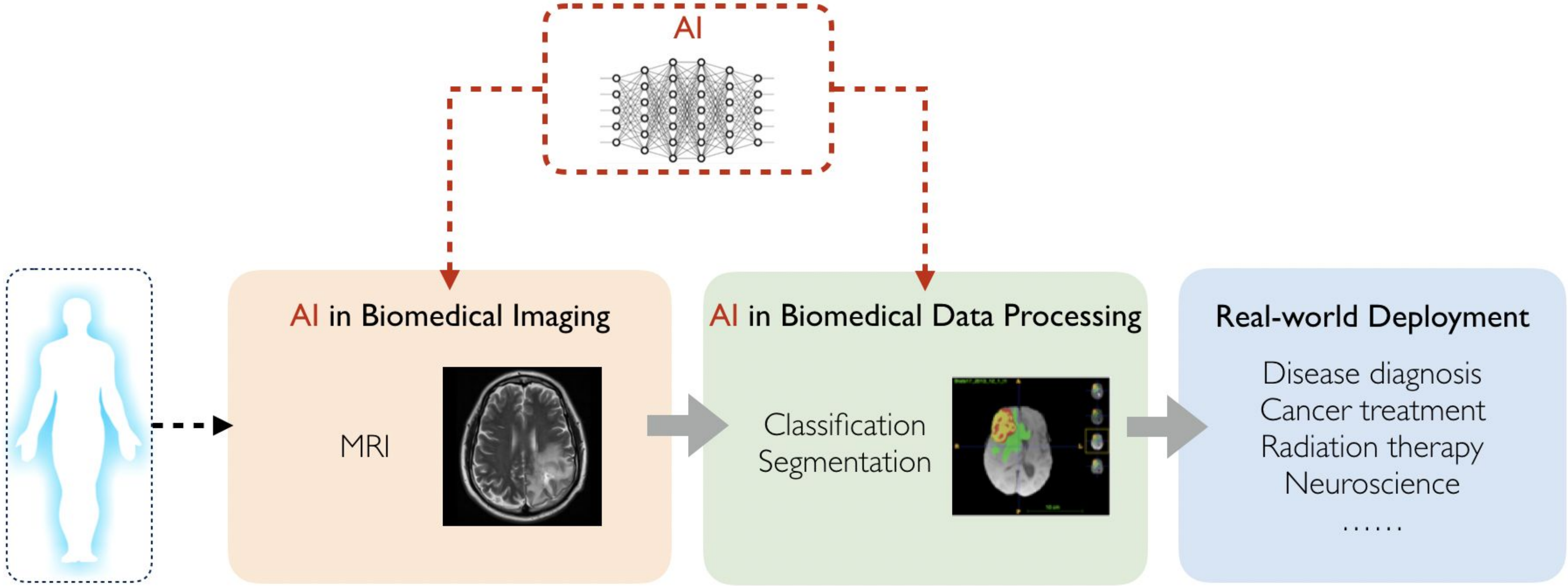
In this class:

- Part I: AI in biomedical imaging
- Part II: AI in biomedical data processing



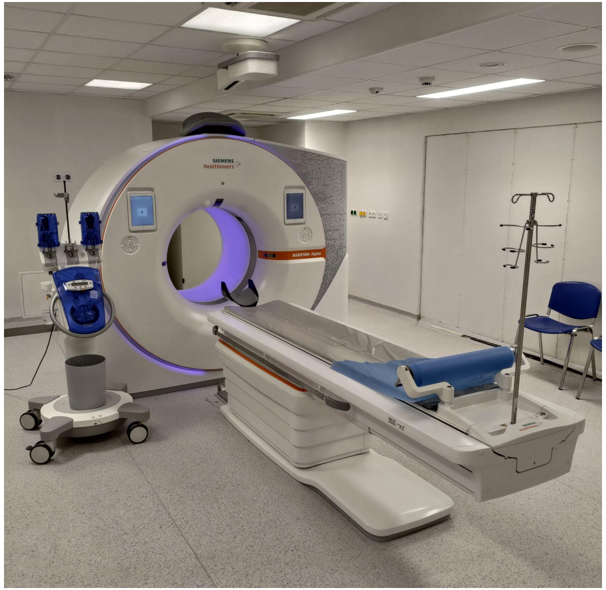
In this class:

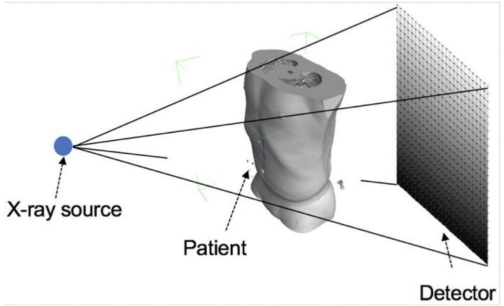
- Part I: AI in biomedical imaging
- Part II: AI in biomedical data processing

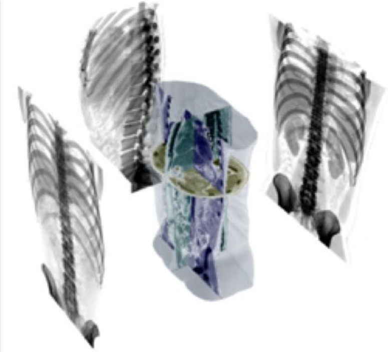


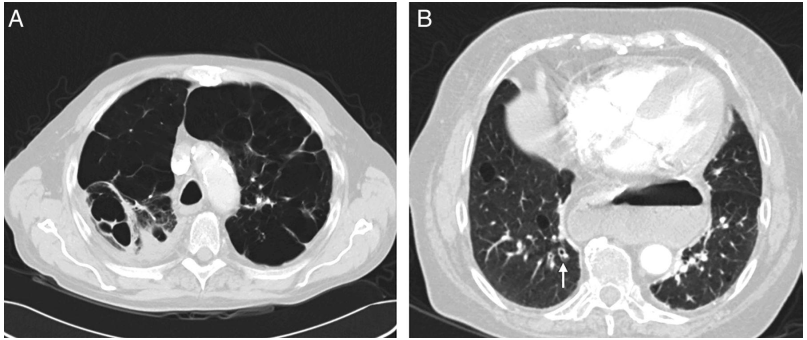
Biomedical imaging

- X-ray Computed Tomography (CT) imaging
    - Reconstruct cross-sectional images of internal structures from X-ray projections at different angles



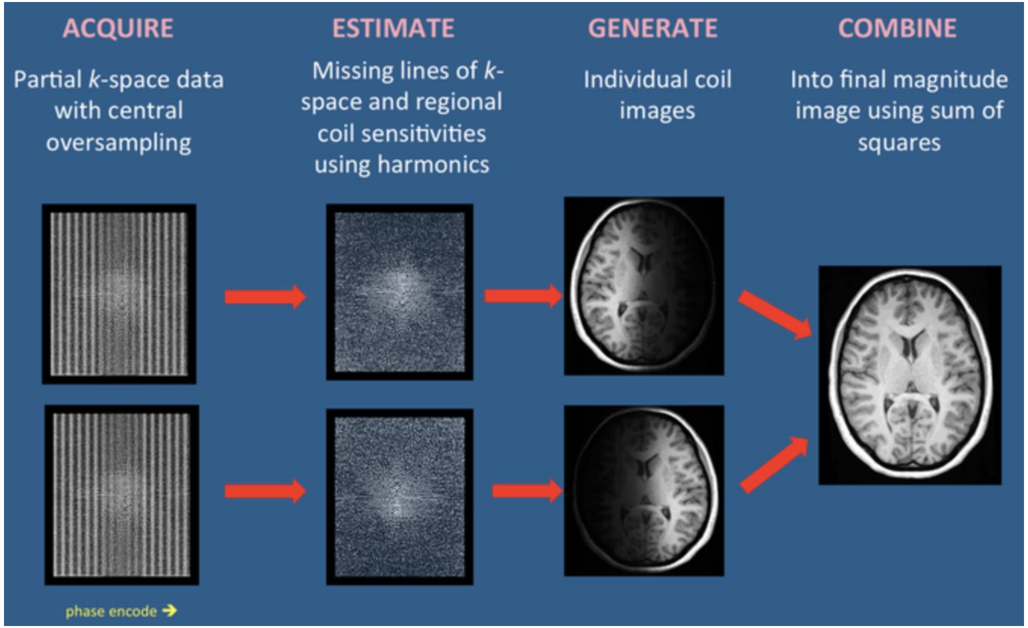




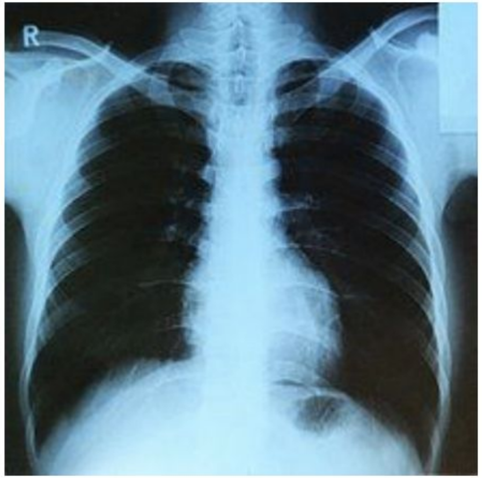


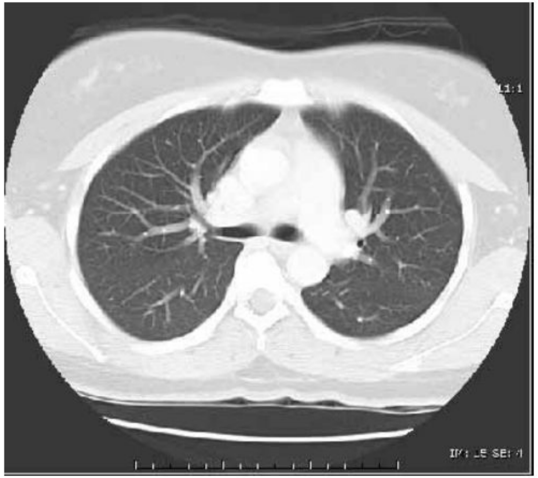
Biomedical imaging

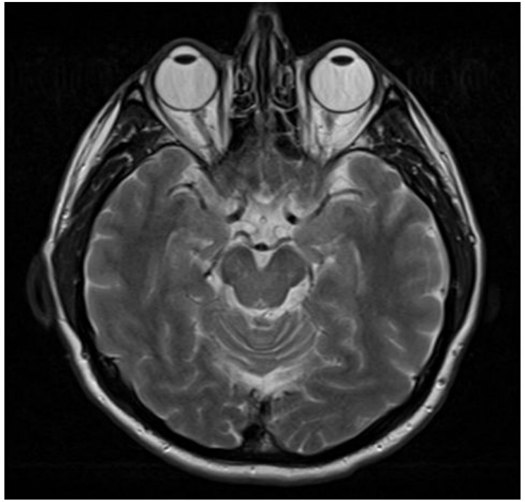
- Magnetic Resonance Imaging (MRI)
  - Reconstruct cross-sectional images of internal structures from measurements in frequency space



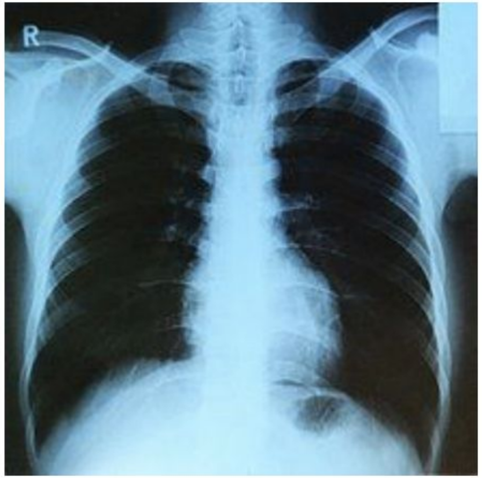
Biomedical imaging



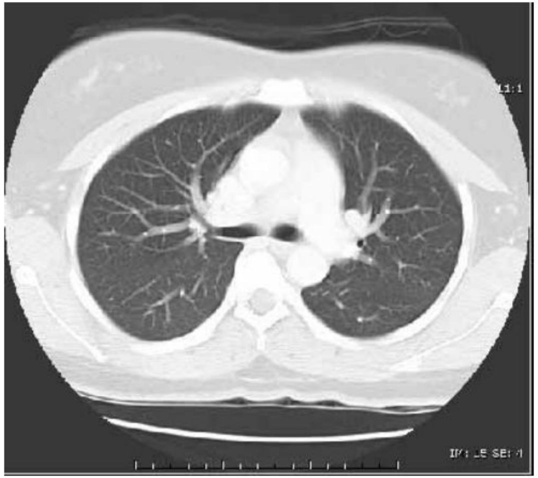




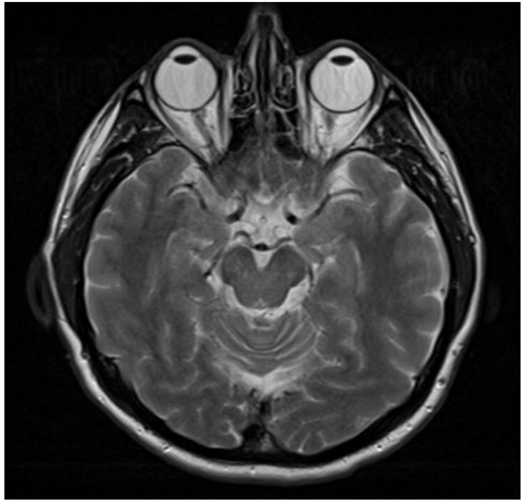
Biomedical imaging



X-ray
(invented 1895)



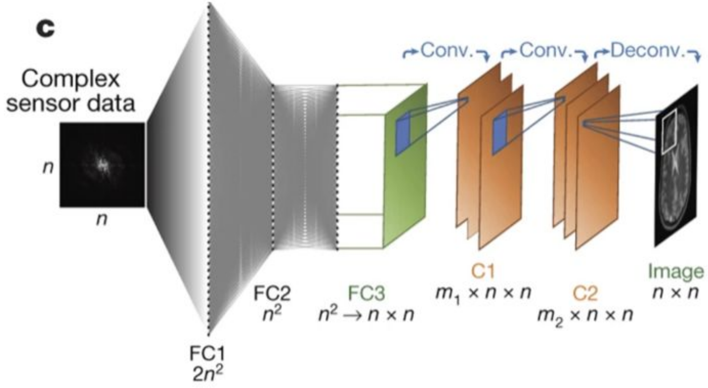
CT
(invented 1972)



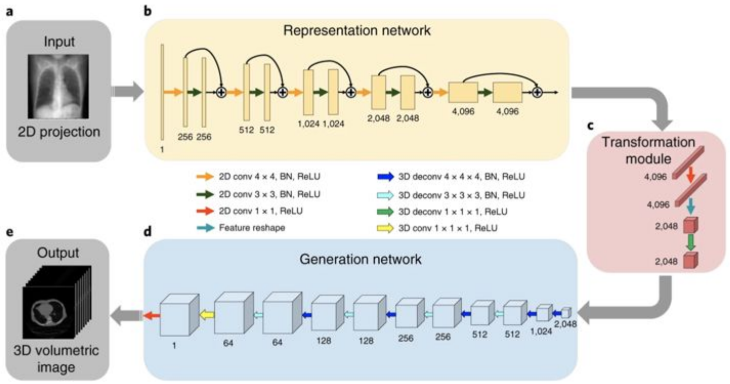
MRI
(invented 1977)

AI in biomedical imaging: Deep learning-based image reconstruction

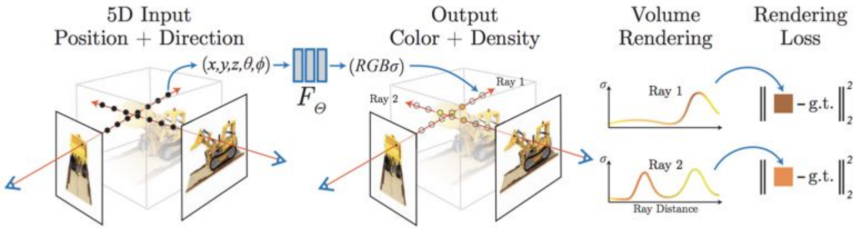
Sparse-sampling MRI reconstruction
Zhu et al. 2018



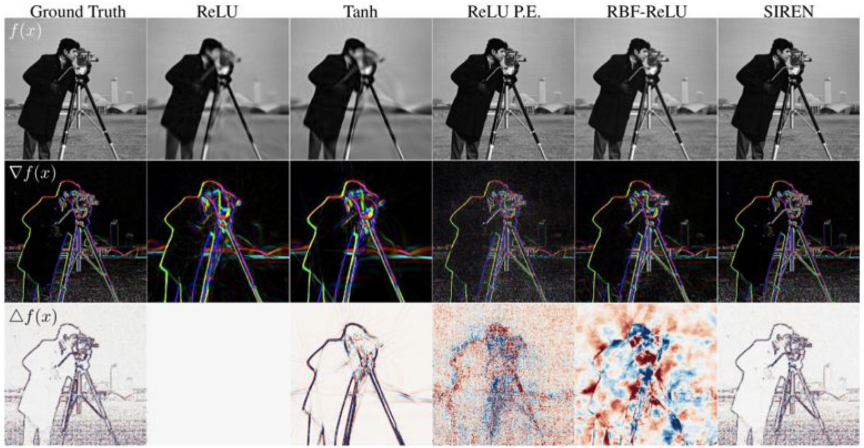
Sparse-view CT reconstruction
Shen et al. 2019



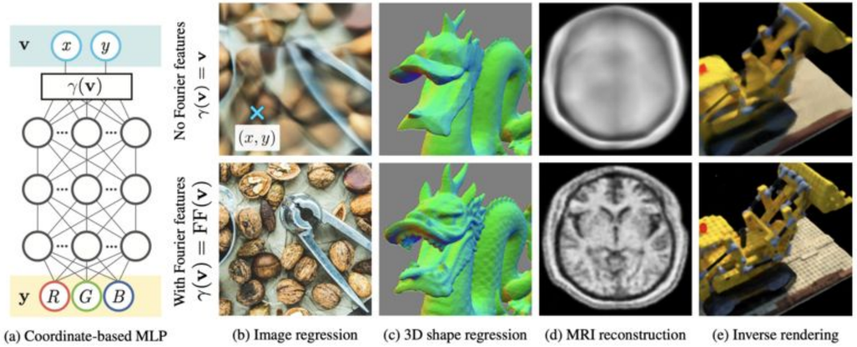
AI in biomedical imaging: Implicit neural representation learning



NeRF (ECCV 2020)

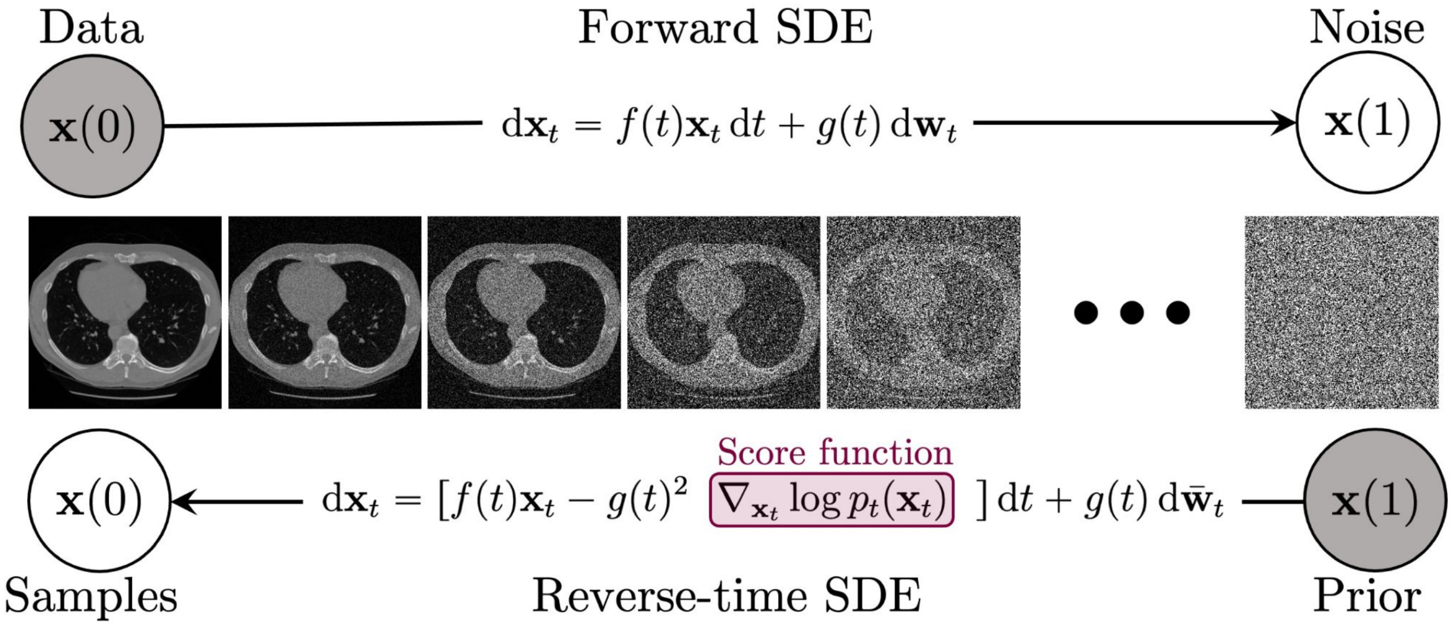


SIREN (NeurIPS 2020)



GRFF (NeurIPS 2020)

AI in biomedical imaging: Generative diffusion models



AI in biomedical imaging: Implicit neural representation learning

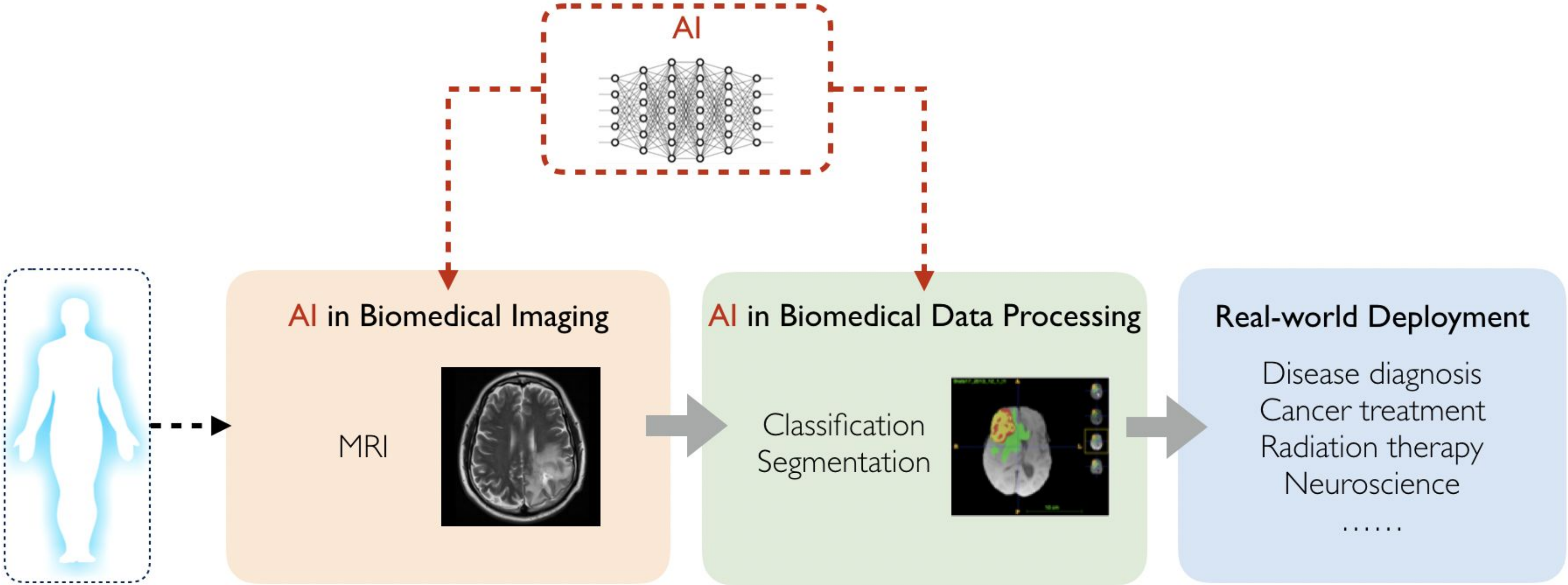
- Paper reading list: Implicit neural representation learning
  - View synthesis and reconstruction
  - Fast optimization
  - Large-scale scene representation
  - Image editing
  - Biomedical applications

AI in biomedical imaging: Generative diffusion models

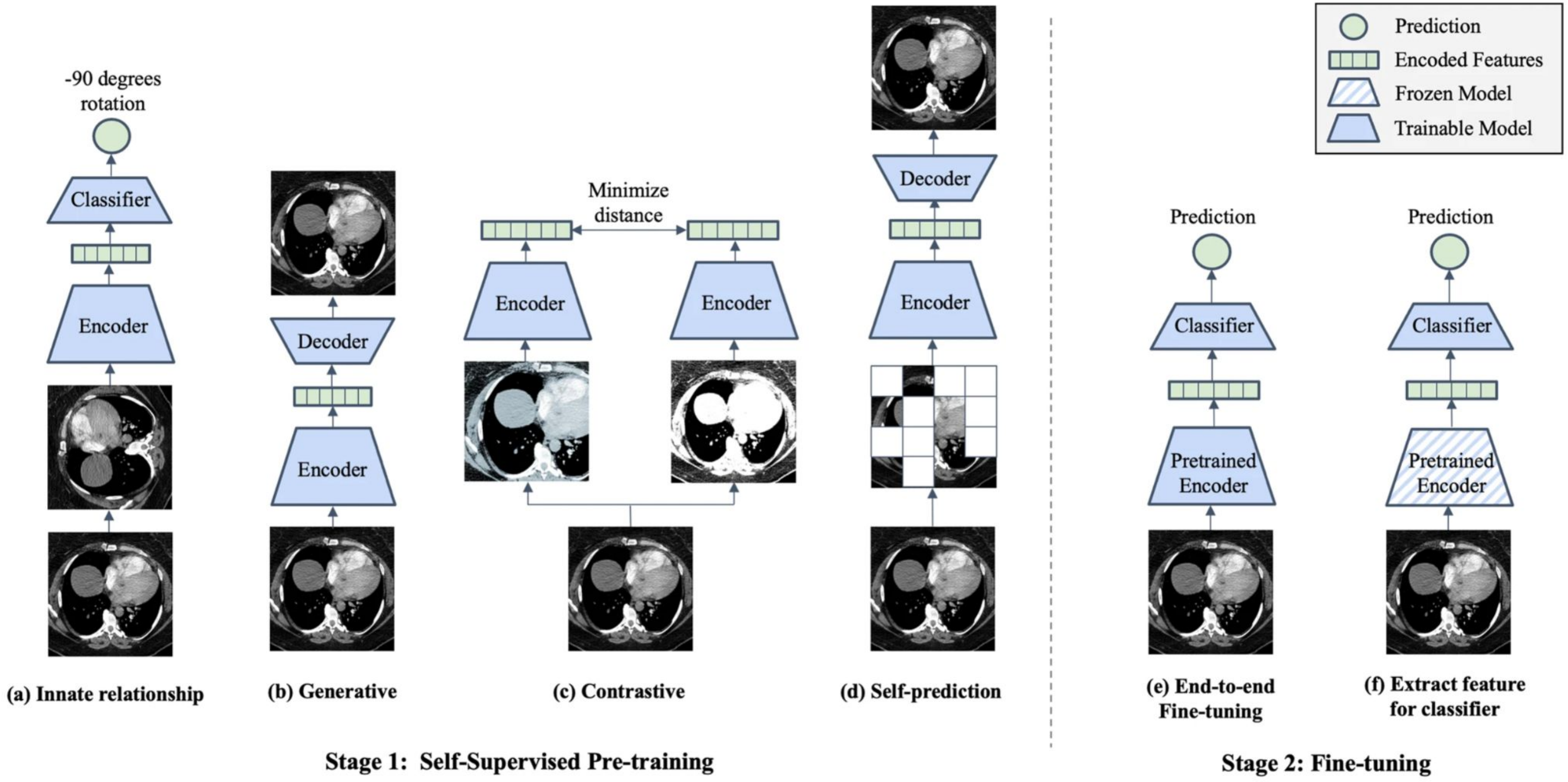
- Paper reading list: Generative diffusion models
  - Image generation and editing
  - Inverse problem solving
  - Latent diffusion
  - Diffusion Schrödinger Bridge
  - Image-to-image translation
  - Object detection
  - Video diffusion
  - Fast solver
  - Biomedical applications

In this class:

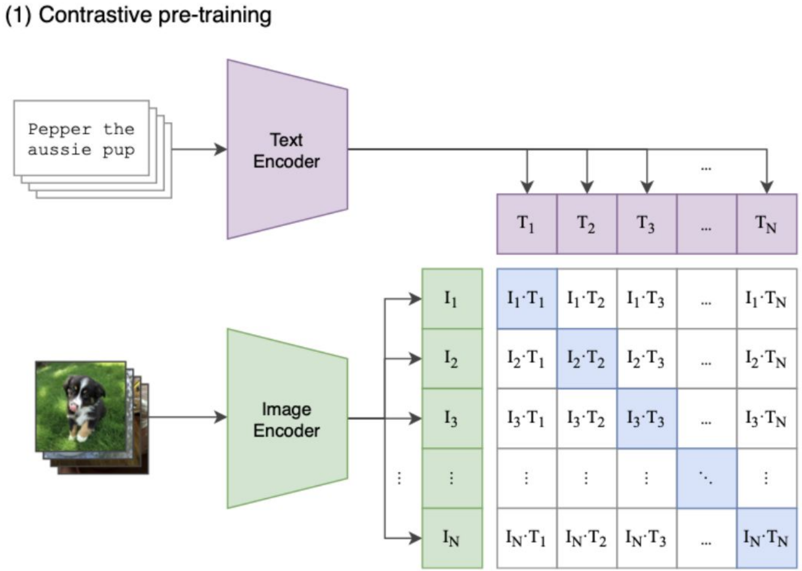
- Part I: AI in biomedical imaging
- Part II: AI in biomedical data processing



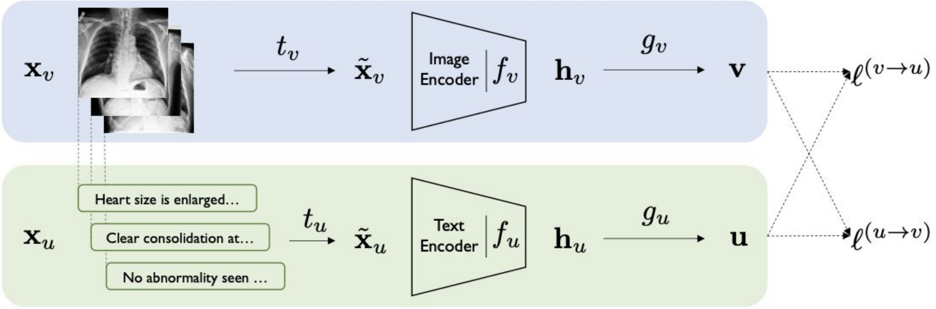
AI in biomedical data processing: Self-supervised learning



AI in biomedical data processing: Multimodal learning



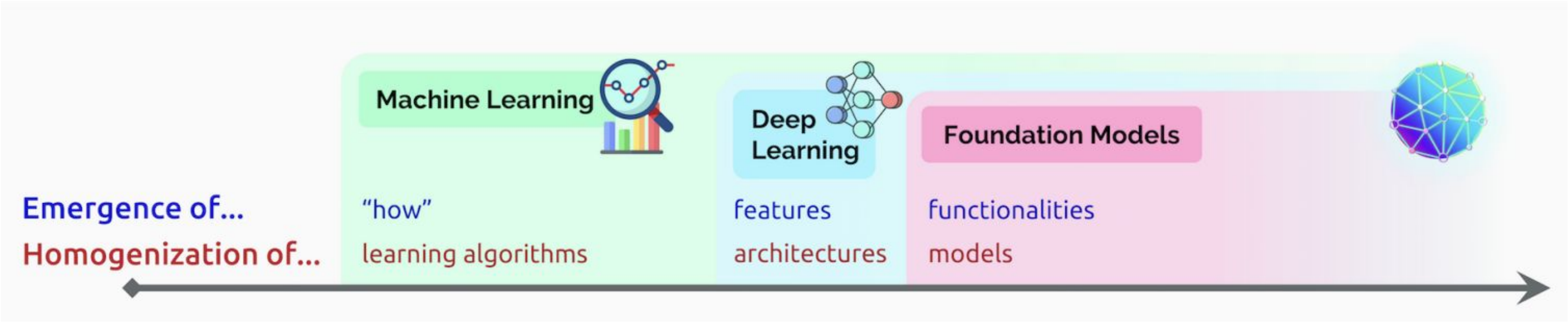
Radford et al. 2021. CLIP



Zhang et al. 2020. ConVIRT

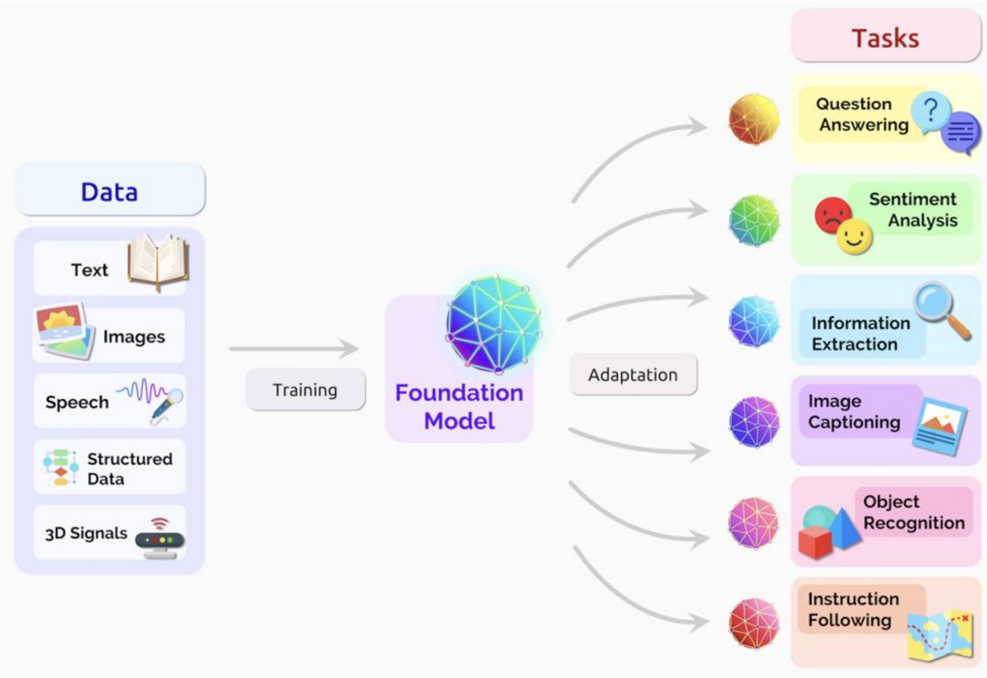
AI in biomedical data processing: Foundation model

- A new paradigm for building AI systems:
  - Bommasani et al. 2021 Stanford.



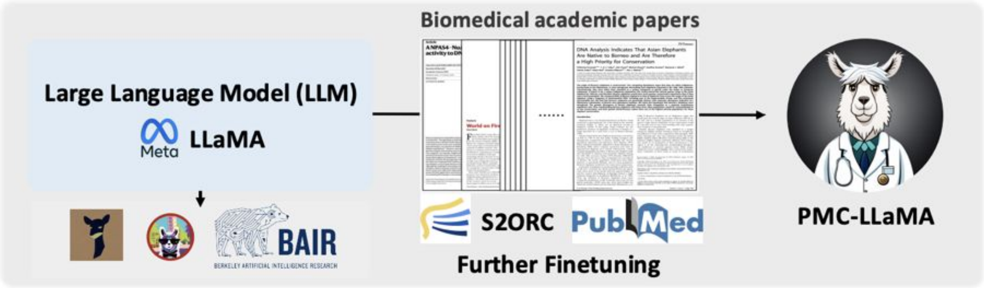
AI in biomedical data processing: Foundation model

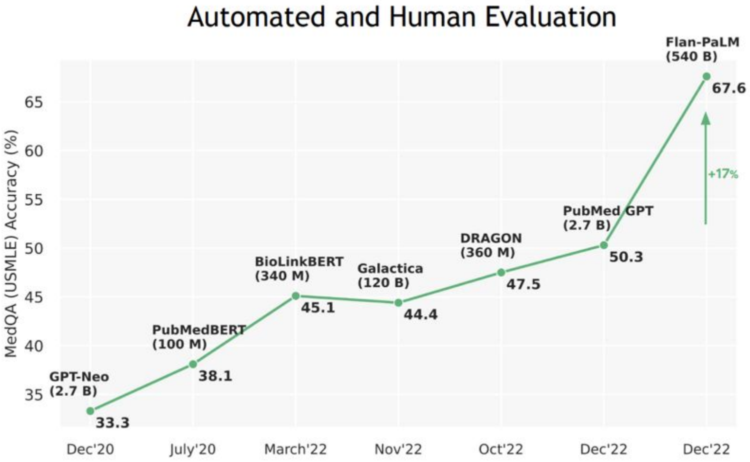
- A new paradigm for building AI systems:
  - Train one model on a huge amount of data using self-supervision at scale
  - Can adapt to a wide range of downstream tasks



AI in biomedical data processing: Language foundation model

- Biomedical large language model (LLM)





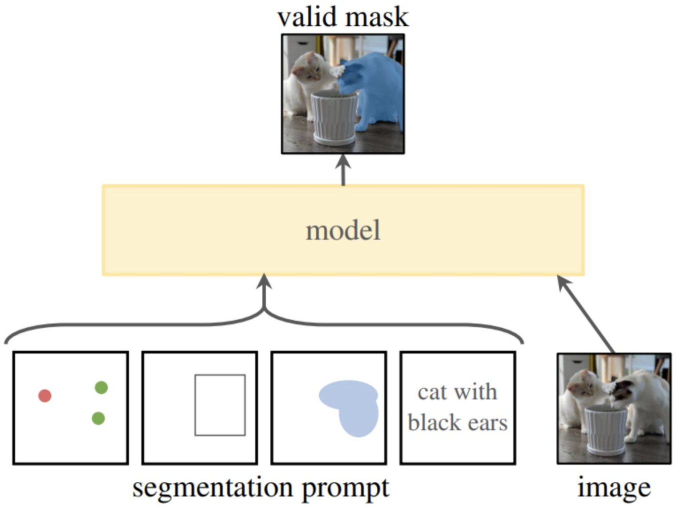
Q: How long does it take for newborn jaundice to go away?

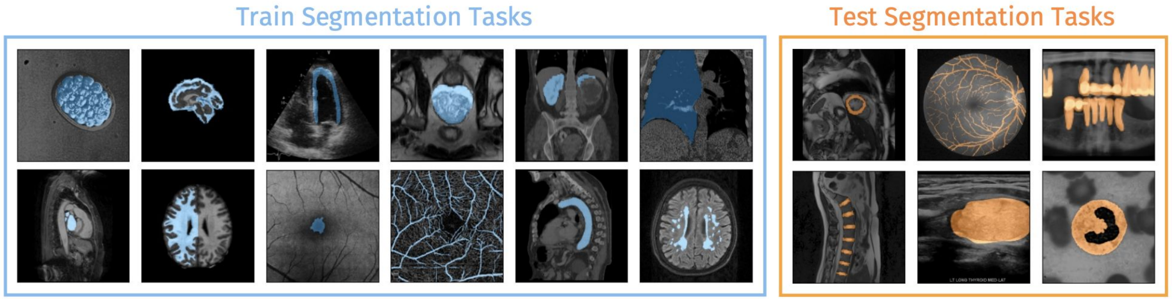
Med-PaLM: Newborn jaundice is when a newborn baby's skin and eyes look yellow. It is caused by a buildup of a substance called bilirubin in the baby's blood. Bilirubin is a byproduct of the normal process of red blood cells breaking down. Newborn jaundice is common and typically harmless, but it can be a sign of a more serious condition. The jaundice typically goes away on its own within a few weeks. In some cases, it may last longer or require treatment. The time it takes for the jaundice to go away can vary depending on the cause and the severity of the jaundice. If the jaundice is severe or lasts longer than a few weeks, the doctor may recommend testing or treatment to determine the cause and prevent complications.

Med-PaLM performs encouragingly on consumer medical question answering

AI in biomedical data processing: Vision foundation model

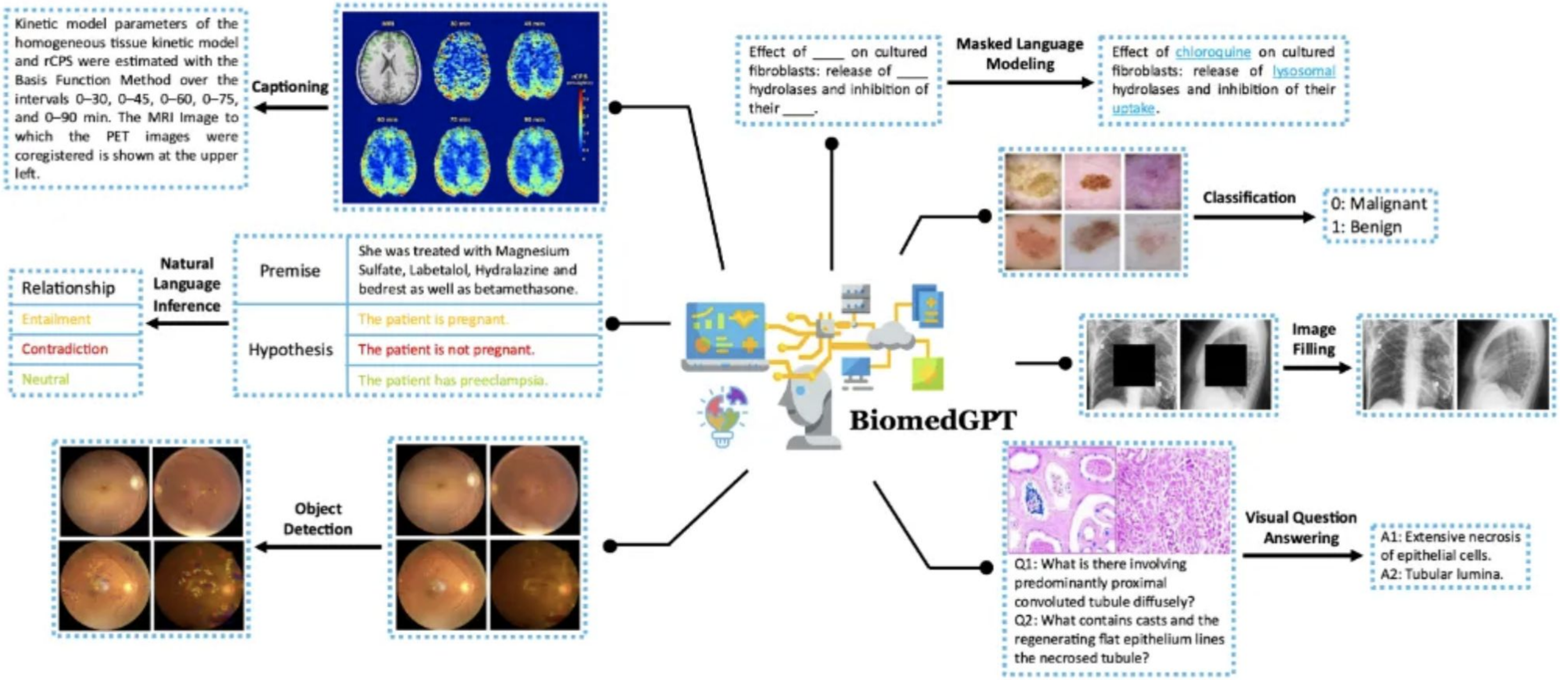
- Biomedical segment everything model (SAM)





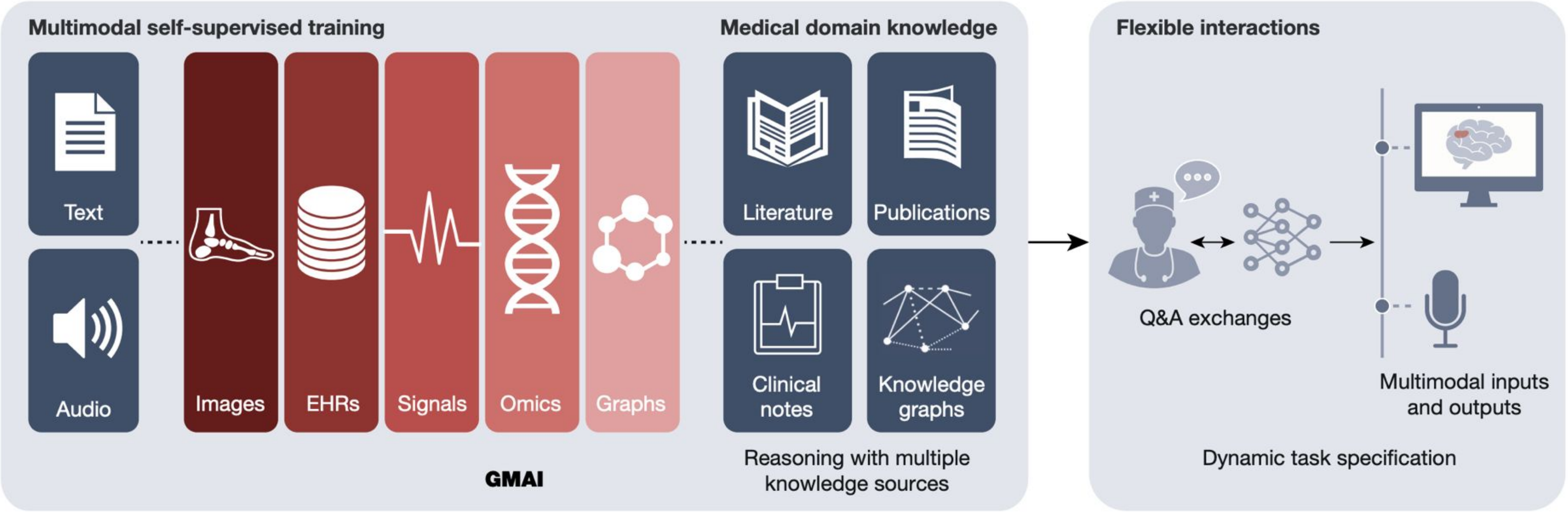
AI in biomedical data processing: Multimodal foundation model

- Biomedical multimodal LLM



AI in biomedical data processing: Multimodal foundation model

- Generalist Medical AI (GMAI)



AI in biomedical imaging: Self-supervised and multimodal learning

- Paper reading list: Self-supervised learning
  - Biomedical applications
- Paper reading list: Multimodal learning
  - Vision language model
  - Biomedical multimodal learning

AI in biomedical imaging: Foundation models

- Paper reading list: Transformer and LLM
  - Parameter-efficient adaptation
  - Biomedical LLM
- Paper reading list: Multimodal LLM
  - Biomedical multimodal LLM
- Paper reading list: Vision foundation model
  - Biomedical applications

AI in biomedical imaging: Other biomedical AI applications

- Paper reading list: Miscellaneous
  - Reliability
  - Interpretability
  - Federated learning
  - Human-in-the-loop
  - Risk prediction
  - Treatment outcome prediction
  - Etc.

156. [Nature Com 2022] Federated learning enables big data for rare cancer boundary detection
157. [FACCT 2022] Who Goes First? Influences of Human-AI Workflow on Decision Making in Clinical Imaging
158. [arXiv 2022] Plex: Towards Reliability using Pretrained Large Model Extensions
159. [Nature MI 2023] Extrapolating heterogeneous time-series gene expression data using Sagittarius
160. [Nature Com 2023] Multilingual translation for zero-shot biomedical classification using BioTranslator
161. [Nature Com 2023] Histopathology images predict multi-omics aberrations and prognoses in colorectal cancer patients
162. [Nature Med 2023] A longitudinal circulating tumor DNA-based model associated with survival in metastatic non-small-cell lung cancer
163. [Nature Med 2023] Artificial-intelligence-based molecular classification of diffuse gliomas using rapid, label-free optical imaging
164. [Nature Med 2023] A deep learning algorithm to predict risk of pancreatic cancer from disease trajectories
165. [npj Digital Med 2023] Solving the explainable AI conundrum by bridging clinicians' needs and developers' goals
166. [npj Digital Med 2023] Physics-informed neural networks for modeling physiological time series for cuffless blood pressure estimation
167. [npj Digital Med 2023] A foundational vision transformer improves diagnostic performance for electrocardiograms
168. [Cell Reports Med 2023] Development of an artificial intelligence-derived histologic signature associated with adjuvant gemcitabine treatment outcomes in pancreatic cancer

Speed breakouts

- Get to know your classmates
- 2-min x 4 breakouts (4 students each group)
  - Name, program, year
  - What is one thing you hope to learn from this class?
  - Which topic of biomedical AI are you most interested in?

Course logistics

- Lectures:
  - TTH 10:30AM-12PM, 1109 FXB
  - Lecture slides: posted on Canvas after each lecture
- Teaching team:
  - Course instructor: Liyue Shen, liyues@umich.edu
  - GSI: Yixuan Jia, jiayx@umich.edu
- Office hour:
  - Instructor office hour:
    - Thursday 1:30PM-3:00PM
    - In-person/remote, location: 4229 EECS Building / Zoom
  - GSI office hour:
    - Monday 12:20PM-1:20PM
    - Zoom
  - Office hours will start week 2

Prerequisites

- Basic knowledge of linear algebra, calculus, probability, statistics, and signal processing.
- Familiarity with machine learning (EECS 453, 553, 545 or equivalent) and computer vision (EECS 442, 504, 542 or equivalent).
- Familiarity with deep learning is highly recommended, e.g. prior experience training a deep learning model.
- Proficiency or significant experience with at least one programming language, such as Python.

Course format

- Course schedule
- Introductory lectures:
  - Week 1 - 3
- Student paper presentations:
  - Week 4 - 14
- Student final project presentations:
  - Week 14 - 15

Date	Lecture #	Topic	Papers	Instructor / Presenter
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Tue 10/24	16	Self-supervised learning		
Thu 10/26	17	Multimodal learning		
Tue 10/31	18	Multimodal learning		
Thu 11/2	19	Transformer and LLM		
Tue 11/7	20	Transformer and LLM		

Grading

- Paper presentation: 15%
- Paper review: 15%
- Project proposal: 15%
- Project presentation: 20%
- Project report: 30%
- Bonus credit: 4%
- Evaluation feedback: 1%

Paper reading

- Paper reading list
- Paper bidding:
  - Complete google form by 11:59 pm EDT on September 8
  - Paper assignments and presentation time slot will be made based on your preferences but not guaranteed
- After paper assignment, all presentation papers and schedules will be available on course schedule

Section II. Preferred paper and presentation time

Students are expected to give presentations according to the class schedule. For fairness, please obey the following rules when you fill out this section:

- Please select **5** papers that you are interested in and record the paper id given in the paper reading list.
- Please rate your interest in these 5 papers individually using 5 numbers (can be any positive continuous number), with the requirement that the **sum of these numbers equals 100**.
- Please pick your preferred **presentation slot** for each paper you selected. Please make sure the scheduled topic for the slot you picked is consistent with the paper you selected. (See class schedule)

The final paper presentation assignment will be determined by:

1. If a student chose one paper with higher score, this student will get priority than the people who might have chosen the same paper with lower scores.
2. If several students chose one paper with the same score, the student with earlier presentation time will get priority.
3. If the above two rules can not determine the winner, the student who submitted this google form earlier will get priority if slots allow, otherwise, two earliest submissions will be combined to form a group.

Please kindly be aware that while we will make every effort to consider your preferred presentation time slot, we cannot guarantee its availability. Additionally, there might be adjustments to the presentation topics based on students' preferences. The instructor team is committed to accommodating these requests to the best of our ability.

Paper reading

- Paper presentation: 15%
  - Present one paper during the class and lead discussion
    - 30-35 min presentation + 5-min Q&A and quiz
    - Default: one student for each presentation
  - Submit presentation slides to Canvas by the end of week before the presentation week
    - Due: Fri 11:59 pm EDT
  - Presentation evaluated by all students and instructors
    - Evaluated by voting from two aspects:
      - Presentation content: score 1-5 (clarity of message, depth of information, key points, etc.)
      - Presentation format: score 1-5 (slide layout, organization, visual design, interaction, etc.)
    - Evaluation score: 1) weighted sum of voted scores, 2) average of two aspects
    - Final credit:
      - In the final week, rank and categorize evaluation scores of all presentations into 3 levels
      - Level 1 / Level 2 / Level 3: get final credits of 15' / 13' / 11'
  - Bonus: Quiz designer or answerer (+1 bonus point)
    - During Q&A, each presenter will design two quiz questions. The audience who gives the correct answer to each quiz question will get +0.5 bonus point. Otherwise, the presenter will reserve the bonus point.
- Resources:
  - Harvard CS197: Reading AI Research Papers

Paper reading

- Paper review: 15%
  - Paper reading workload: 4 papers / each week
  - Paper review for each paper
    - No requirement in length
  - Submit to Canvas one day before the presentation class
    - Due: Mon / Wed 11:59 pm EDT
  - Get all 15% credits if submit on Canvas in time
  - Bonus: Outstanding Reviewers (+1 bonus point)
    - Submit your review to Piazza anytime (Piazza sign-up link)
    - All students and instructors vote for top reviews by clicking "helpful"
    - One outstanding reviewer each paper
      - Get the most votes before submission due time
      - If the same votes, go for earlier post on Piazza
    - 4 outstanding reviewers each week get +1 bonus points
- Resources:
  - CVPR 2023: How to Write Good Reviews
  - CVPR review form template

Project

- Opportunity to gain in-depth experience developing an AI-based approach to solve a biomedical problem
- Scope:
  - Flexible topics relevant to papers discussed in this course
  - Focusing on either methodology development or deployment on new biomedical applications is fine
  - Simply rerunning an existing code repository is NOT sufficient
- Example project ideas:
  - Novel problem
    - Develop a deep learning model for a new problem that has not previously been experimented on
    - Utilize a new dataset or tackle new tasks on existing data
  - Novel analysis
    - Reimplement an existing paper that you find interesting
    - Try different algorithmic variants to see if they improve performance
  - Novel methods
    - New algorithms or model architectures for an existing problem
    - Improve upon current problem's measure of success
- Resources:
  - Harvard CS197: A Framework for Generating Research Ideas, Structuring a Research Paper
  - Public datasets and repositories:
    - Multimodal dataset: The Cancer Imaging Archive (TCIA)
    - Biomedical images: Grand Challenges in Biomedical Image Analysis
    - Electronic health records: MIMIC Critical Care Database
    - Genomics: ENCODE (Encyclopedia of DNA Elements)

Project

- Group:
  - Can work in groups of 1-2 students on the course project
  - Grades will be calibrated by group size
  - Group needs to be finalized by the due date of proposal submission and cannot be changed later
  - For project proposal, presentation slides, and report, every group member needs to submit on Canvas
  - For project presentation, group members need to coordinate to present together within time limit
  - Contributions:
    - In final report, specify the contributions of each author on the paper, which includes discussion, implementation, and writing for each part of the paper
    - We expect your description to include a detailed breakdown specified
    - For an example of appropriate format, please see the author contributions for AlphaGo (Nature, 2016)
- Computing resource:
  - Great lakes credits will be available for this course
  - We will update in the next lecture

Project

- Project proposal: 15%
  - 1-1.5 page documents, using the NeurIPS template
  - Submit to Canvas by Fri 11:59 pm EDT, Oct. 6
  - The proposal should include the following (with grade breakdown):
    - Title, Authors(s)
    - (25%) What is the problem that you will be investigating? Explain the task thoroughly. Why is it interesting?
    - (25%) What is the data you will be using? Please include relevant characteristics such as the source of the data, the size of the dataset, and a sample of the data. Explain clearly which parts of the data will be used as well as potential obstacles.
    - (25%) What methods do you plan to experiment with? Please thoroughly describe them. If there are existing related implementations, will you use them and how? How do you plan to improve or modify such implementations? This can be subject to change, but you should have a general sense of how you plan to approach the problem you are working on.
    - (25%) How will you evaluate your results? Qualitatively, what kind of results do you expect (e.g. plots or figures)? Quantitatively, what kind of analysis will you use to evaluate and/or compare your results (e.g. what performance metrics or statistical tests)? What is your hypothesis regarding your results compared to baselines?

Project

- Project presentation: 20%
  - Present final project during the class in the final week
    - Around 10 min presentation + 2-min Q&A
    - Accurate time depends on number of groups
  - Presentation evaluated by all students and instructors
    - Evaluated by voting from two aspects:
      - Presentation content: score 1-5 (clarity of message, depth of information, key points, etc.)
      - Presentation format: score 1-5 (slide layout, organization, visual design, interaction, etc.)
    - Evaluation score: 1) weighted sum of voted scores, 2) average of two aspects
    - Final credit:
      - In the final week, rank and categorize evaluation scores of all presentations into 3 levels
      - Level 1 / Level 2 / Level 3: get final credits of 20' / 18' / 16'
  - Submit presentation slides to Canvas by Fri 11:59 pm EDT, Dec. 5
- Resources:
  - Harvard CS197: Reading AI Research Papers

Project

- Project report: 30%
  - 7-9 page document, using the NeurIPS template
  - Submit to Canvas by Fri 11:59 pm EDT, Dec. 15
  - The report should include the following (with grade breakdown):
    - Title, Authors(s)
    - Abstract. A paragraph overview of the problem, approach, contribution, and key results.
    - (15%) Introduction. Introduce your problem, and the landscape for why the problem is interesting and what has been done before in this space. Describe your overall plan for approaching the problem, why this is an interesting contribution in the context of the described landscape, and a summary of your results.
    - (15%) Related Work. Describe in detail existing work related to your problem, how they are related to each other, and how your work relates to these. We expect this to be comprehensive and thorough, and with at least 10 citations discussed and cited accordingly.
    - (15%) Data. Describe in detail the data that you are using, including the source(s) of the data, relevant statistics, and qualitative examples if appropriate.
    - (20%) Approach. Describe in detail the methods that you use in your approach. Importantly, through this section and the experiments section (which may include implementation details), there should be sufficient information for others to reproduce your results.
    - (25%) Experiments. Describe experiments that you performed to support your approach and contribution. The exact experiments may vary depending on the project, but we will be looking for the thoughtfulness of your analysis. Examples may include performing comparison of your main approach with other baselines or methods, error analyses to investigate the performance of the model, ablation studies to determine the impact of various components of the approach, analyses to provide insight into the effect of different hyperparameter choices, techniques to interpret how the model is working, etc. You should include graphs, tables, or other figures to illustrate the experimental results.
    - (5%) Conclusion. Summarize the key results, what has been learned, and avenues for future work.
    - (5%) Writing/Formatting. Your paper should be clearly written and nicely formatted, comparable to published NeurIPS papers.
    - Contributions. Specify the contributions of each author on the paper.
    - Supplementary Material. This should be submitted as a separate file from your paper and is not counted in the 7-9 page requirement. At minimum, this should include the relevant code for your project. You may also put additional visualizations, demos, videos, etc. that you wish to share with the teaching team.

Bonus credit

- Bonus credit: 4%
  - Paper review:
    - Bonus: Outstanding Reviewers (+1 bonus point)
      - 4 outstanding reviewers each week get +1 bonus points
  - Paper presentation:
    - Bonus: Quiz designer or answerer (+1 bonus point)
      - During Q&A, each presenter will design two quiz questions. The audience who gives the correct answer to each quiz question will get +0.5 bonus point. Otherwise, the presenter will reserve the bonus point
  - Lectures:
    - Bonus: Idea proposer (+1 bonus point)
      - At the end of each lecture class in the first three weeks, instructors will lead a discussion session. Students who want to share their thoughts or propose ideas relevant to the topics will get +1 bonus points
      - Each lecture will give out at most 3 bonus points for idea proposer
  - In the final week, all bonus points will be summed up and normalized to 4% credits in the final score
  - All recipients of bonus points will be recorded in Course schedule for each class

Evaluation feedback

- Evaluation feedback: 1%
  - Submit midterm feedback in time: 0.5%
  - Submit final feedback in time: 0.5%

Grading

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Tue 11/7	20	Transformer and LLM		

Next time

- Biomedical imaging with deep learning

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