

**[Special AI Lecture for Hwarang Friends]**  
**Becoming the Leader of AI Era - From ChatGPT to  
Your Future Superpower**

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**Co-Founder & CTO @ Erudio Bio, Inc.**

**Co-Founder & CEO @ Erudio Bio Korea, Inc.**

**Leader of Silicon Valley Privacy-Preserving AI Forum (K-PAI)**

**AI-Korean Medicine Integration Initiative Task Force Member**

**Global Leadership Initiative Fellow @ Salzburg Global Seminar**

**Visiting Professor & Advisory Professor @ Sogang Univ & DGIST**

## About Speaker

- *Co-Founder & CTO @ Erudio Bio, Inc., San Jose & Novato, CA, USA* 2023 ~
- *Co-Founder & CEO @ Erudio Bio Korea, Inc., Korea* 2025 ~
- *Leader of Silicon Valley Privacy-Preserving AI Forum (K-PAI), CA, USA* 2024 ~
- *Director of AI Semiconductor @ K-BioX, CA, USA* 2025 ~
- *AI-Korean Medicine Integration Initiative Task Force Member @ The Association of Korean Medicine* 2025 ~
- *KFAS-Salzburg Global Leadership Fellow @ Salzburg Global Seminar* 2024 ~
- *Adjunct Professor, EE Department @ Sogang University, Seoul, Korea* 2020 ~
- *Advisory Professor, EECS Department @ DGIST, Korea* 2020 ~
- Global Advisory Board Member @ Innovative Future Brain-Inspired Intelligence System Semiconductor of Sogang University, Korea 2020 ~
- Technology Consultant @ Gerson Lehrman Group (GLG), NY, USA 2022 ~
- Chief Business Development Officer @ WeStory.ai, Cupertino, CA, USA 2025 ~
- Advisor @ CryptoLab, Inc., San Jose, CA, USA 2025 ~



- Co-Founder & CTO / Head of Global R&D / Chief Applied Scientist / Senior Fellow @ Gauss Labs, Inc., Palo Alto, CA, USA 2020 ~ 2023
- Senior Applied Scientist @ Amazon.com, Inc., Vancouver, BC, Canada 2017 ~ 2020
- Principal Engineer @ Software R&D Center, Samsung Electronics 2016 ~ 2017
- Principal Engineer @ Strategic Marketing & Sales, Memory Business 2015 ~ 2016
- Principal Engineer @ DT Team, DRAM Development, Samsung 2012 ~ 2015
- Senior Engineer @ CAE Team, Memory Business, Samsung, Korea 2005 ~ 2012
- PhD - Electrical Engineering @ Stanford University, CA, USA 2001 ~ 2004
- Development Engineer @ Voyan, Santa Clara, CA, USA 2000 ~ 2001
- MS - Electrical Engineering @ Stanford University, CA, USA 1998 ~ 1999
- BS - Electrical & Computer Engineering @ Seoul National University 1994 ~ 1998

## Highlight of Career Journey

- BS in Electrical Engineering (EE) @ Seoul National University
- MS & PhD in Electronics Engineering (EE) @ Stanford University
  - *Convex Optimization - Theory, Algorithms & Software*
  - advisor - *Prof. Stephen P. Boyd*
- Principal Engineer @ Samsung Semiconductor, Inc.
  - *AI & Convex Optimization*
  - collaboration with *DRAM/NAND Design/Manufacturing/Test Teams*
- Senior Applied Scientist @ Amazon.com, Inc.
  - *e-Commerce AIs* - anomaly detection, deep RL, and recommender system
  - *Jeff Bezos's project - drove \$200M* in sales via Amazon Mobile Shopping App
- *Co-Founder & CTO / Global R&D Head & Chief Applied Scientist* @ Gauss Labs, Inc.
- *Co-Founder & CTO* @ Erudio Bio, Inc.
- *Co-Founder & CEO* @ Erudio Bio Korea, Inc.

## Unpacking AI

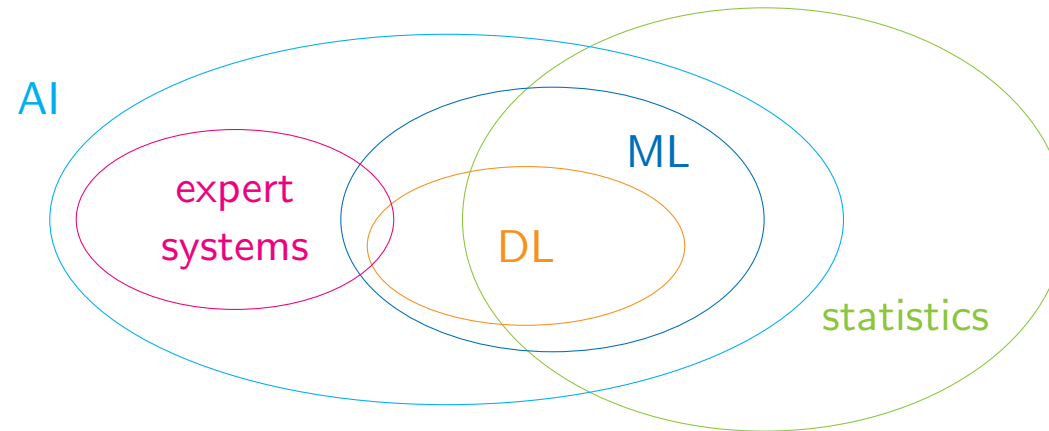
- Artificial Intelligence - 5
  - AI history & recent significant achievements
  - market indicators for unprecedented AI progress
- AI Agents - 30
  - Big Data → ML/DL → LLM & genAI → Agentic AI
  - implication of grand success of LLM in multimodal AI
- Building Your Superpower - Domain x AI - 38
  - AI power user vs AI expert
  - powerful combination - domain expert + AI expert
- Appendix - AI and Biotech - 52
  - AI in biology & AlphaFold 3 / Emerging Trends in Biotech
- Appendix - Some Important Questions around AI - 72
  - Why Human level AI? Can AI think, reason, believe, or even know something?
- Selected references - 108
- References - 110

# **Artificial Intelligence**

## **Definition and History**

## Definition & relation to other technologies

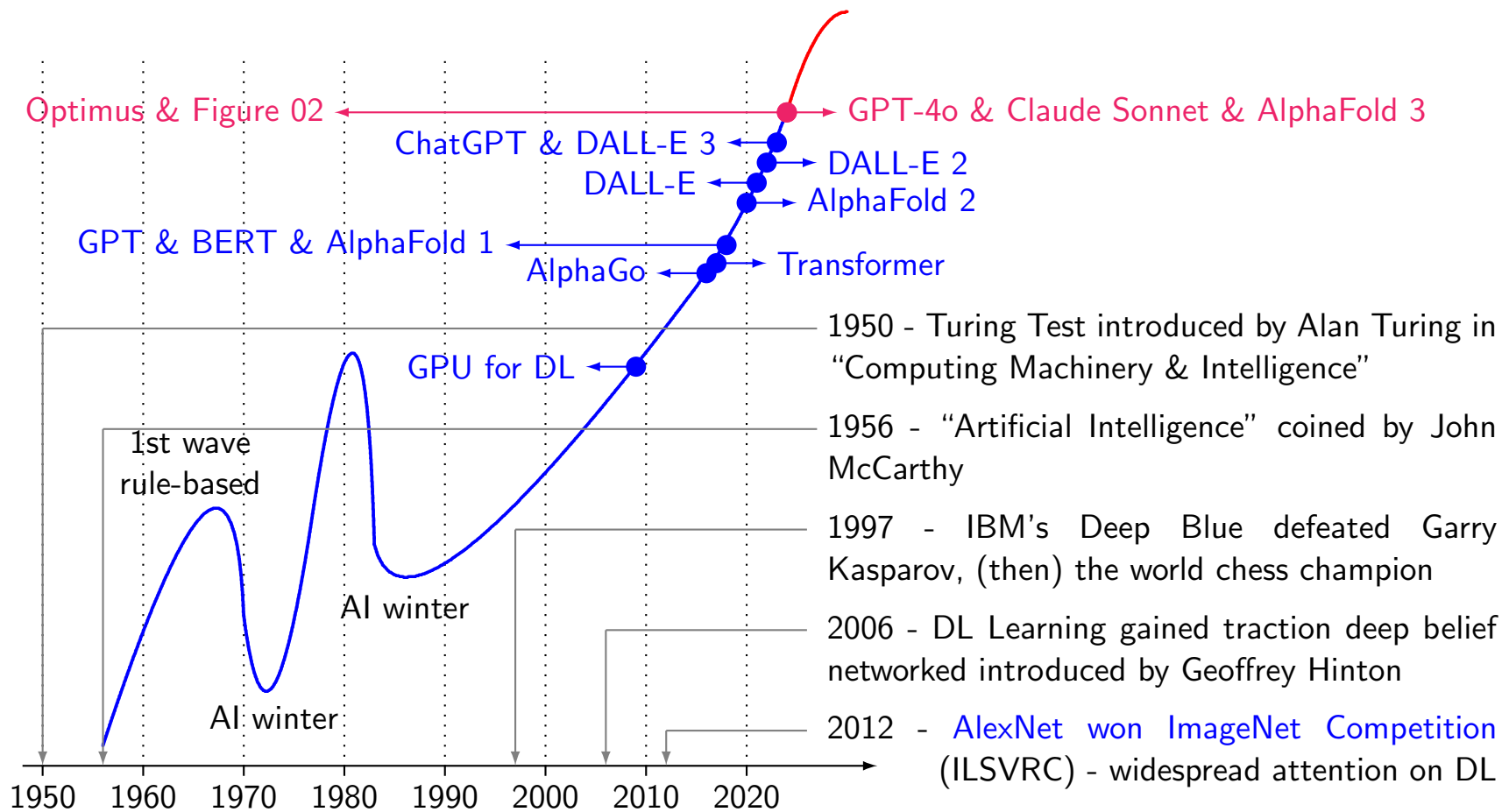
- AI
  - is technology doing tasks requiring human intelligence, such as learning, problem-solving, decision-making & language understanding
  - encompasses *range of technologies, methodologies, applications & products*
- AI, ML, DL, statistics & expert system<sup>1</sup> [HGH<sup>+</sup>22]



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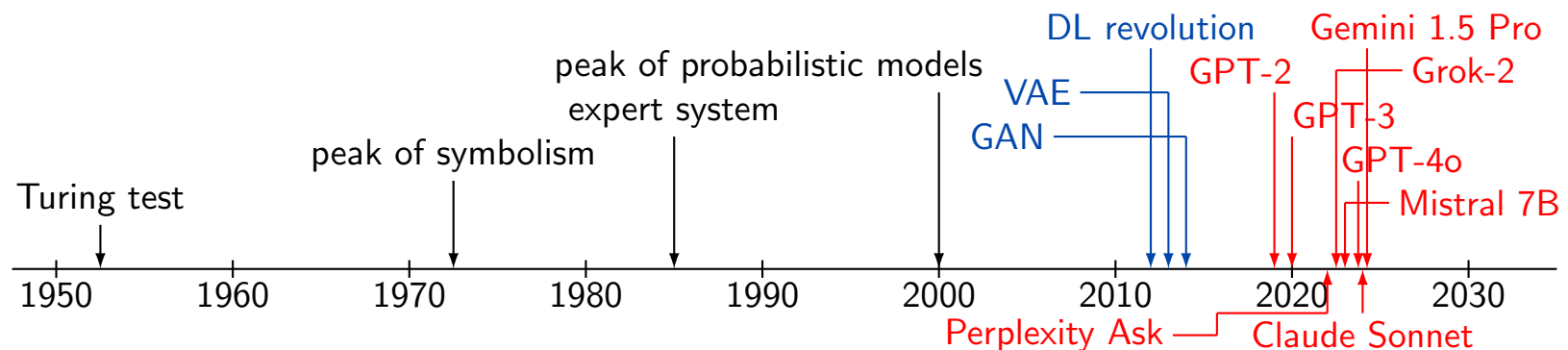
<sup>1</sup>ML: machine learning & DL: deep learning

# History



## Birth of AI - early foundations & precursor technologies

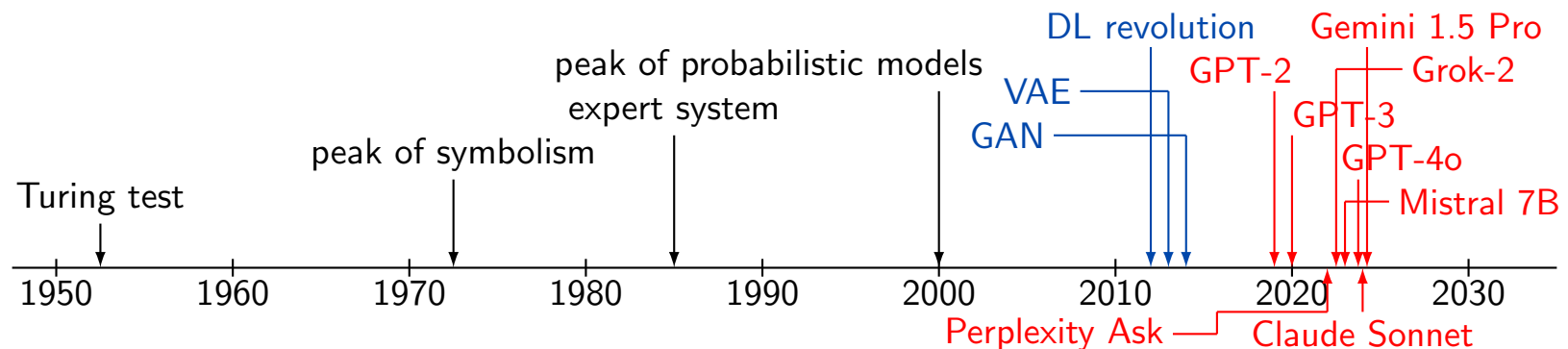
- 1950s ~ 1970s
  - Alan Turing - concept of “*thinking machine*” & *Turing test* to evaluate machine intelligence (1950s)
  - *symbolists* (as opposed to connectionists) - early AI focused on symbolic reasoning, logic & problem-solving - Dartmouth Conference in 1956 by *John McCarthy, Marvin Minsky, Allen Newell & Herbert A. Simon*
  - precursor technologies - genetic algorithms (GAs), Markov chains & *hidden Markov models (HMMs)* - laying foundation for generative processes (1970s ~)





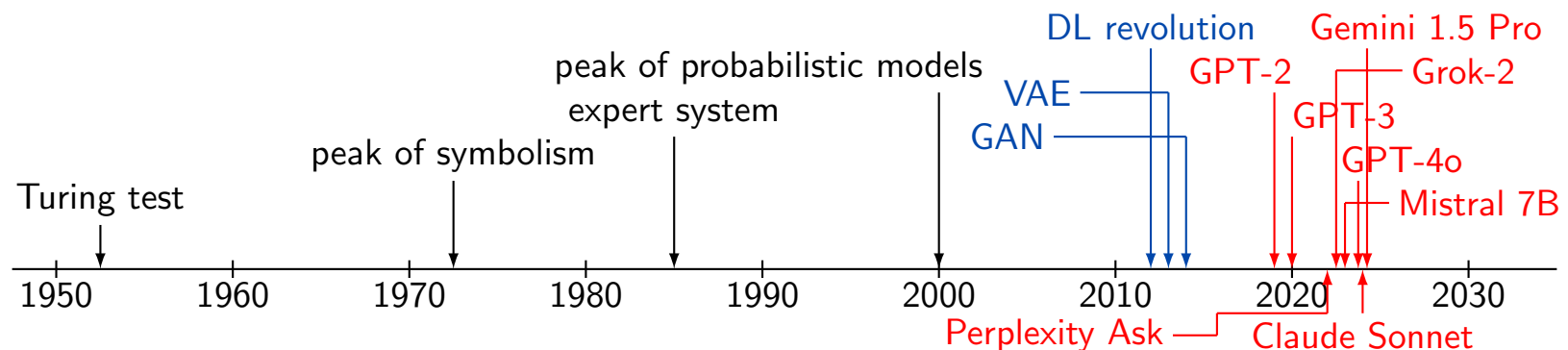
## Rule-based systems & probabilistic models

- 1980s ~ early 2000s
  - *expert systems* (1980s) - AI systems designed to mimic human decision-making in specific domains
  - development of neural networks (NN) w/ backpropagation *training multi-layered networks* - setting stage for way more complex generative models
  - *probabilistic models* (including network models, *i.e.*, Bayesian networks) & Markov models - laying groundwork for data generation & pattern prediction



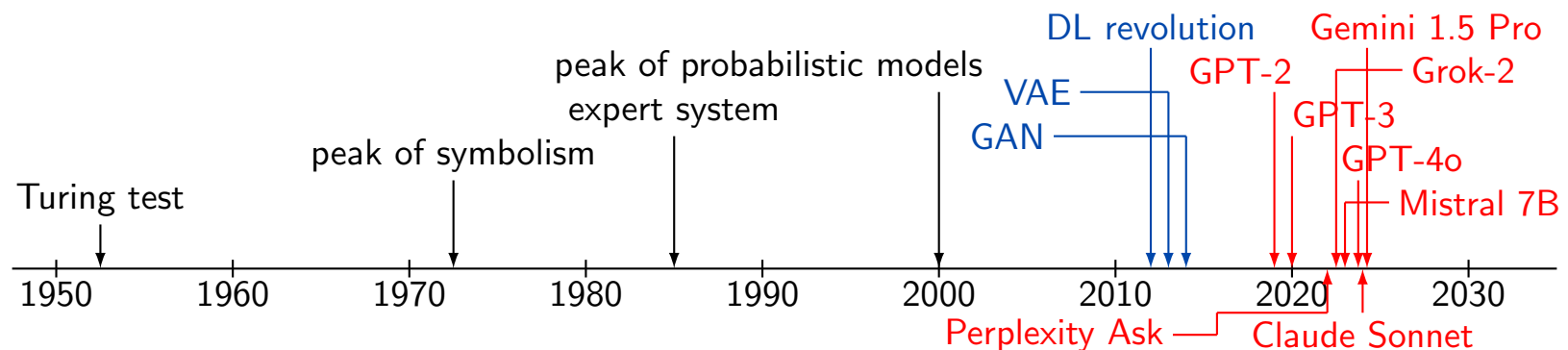
## Rise of deep learning & generative models

- 2010s - breakthrough in genAI
  - *deep learning (DL) revolution* - advances in GPU computing and data availability led to the rapid development of deep neural networks.
  - *variational autoencoder (VAE)* (2013) - by Kingma and Welling - learns mappings between input and latent spaces
  - *generative adversarial network (GAN)* (2014) - by Ian Goodfellow - game-changer in generative modeling where two NNs compete each other to create realistic data
    - widely used in image generation & creative tasks



## Transformer models & multimodal AI

- late 2010s ~ Present
  - Transformer architecture (2017) - by Vaswani et al.
    - *revolutionized NLP*, e.g., LLM & various genAI models
  - GPT series - generative pre-trained transformer
    - GPT-2 (2019) - generating human-like texts - *marking leap in language models*
    - GPT-3 (2020) - 175B params - set *new standards for LLM*
  - multimodal systems - DALL-E & CLIP (2021) - *linking text and visual data*
  - emergence of diffusion models (2020s) - new approach for generating high-quality images - progressively “denoising” random noise (DALL-E 2 & Stable Diffusion)



## **Significant AI Achievements - 2014 – 2025**

## Deep learning revolution

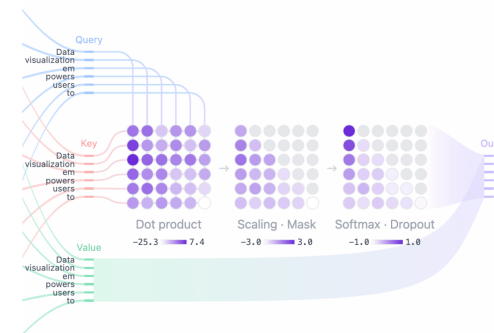
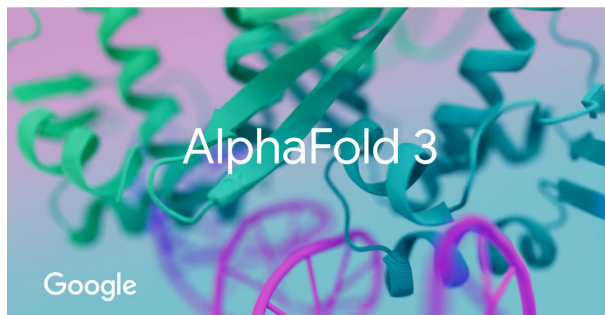
- 2012 – 2015 - DL revolution<sup>2</sup>
  - CNNs demonstrated exceptional performance in image recognition, *e.g.*, *AlexNet's victory in ImageNet competition*
  - widespread adoption of DL learning in CV transforming industries
- 2016 - AlphaGo defeats human Go champion
  - DeepMind's AlphaGo defeated world champion in Go, extremely complex game *believed to be beyond AI's reach*
  - significant milestone in RL - AI's potential in solving complex & strategic problems



<sup>2</sup>CV: computer vision, NN: neural network, CNN: convolutional NN, RL: reinforcement learning

## Transformer changes everything

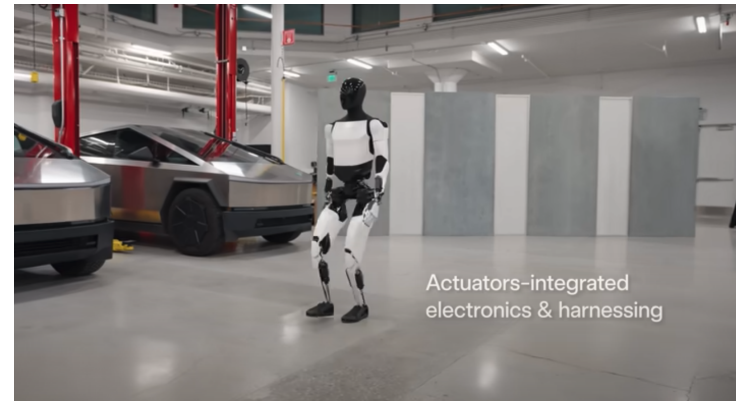
- 2017 – 2018 - Transformers & NLP breakthroughs<sup>3</sup>
  - *Transformer (e.g., BERT & GPT) revolutionized NLP*
  - major advancements in, e.g., machine translation & chatbots
- 2020 - AI in healthcare – AlphaFold & beyond
  - DeepMind's *AlphaFold solves 50-year-old protein folding problem* predicting 3D protein structures with remarkable accuracy
  - accelerates drug discovery and personalized medicine - offering new insights into diseases and potential treatments



<sup>3</sup>NLP: natural language processing, GPT: generative pre-trained transformer

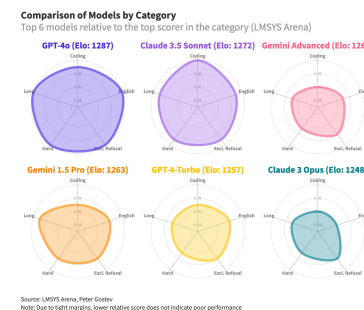
## Lots of breakthroughs in AI technology and applications in 2024

- proliferation of advanced AI models
  - GPT-4o, Claude Sonnet, Claude 3 series, Llama 3, Sora, Gemini
  - *transforming industries* such as content creation, customer service, education, *etc.*
- breakthroughs in specialized AI applications
  - Figure 02, Optimus, AlphaFold 3
  - driving unprecedented advancements in automation, drug discovery, scientific understanding - *profoundly affecting healthcare, manufacturing, scientific research*



## Major AI Breakthroughs in 2025

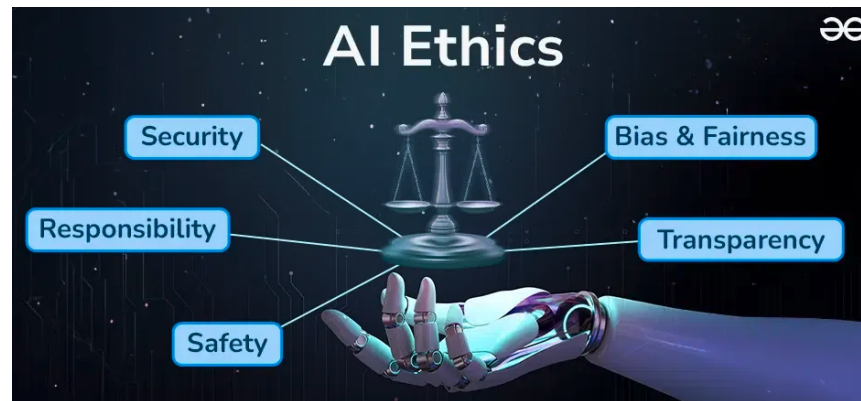
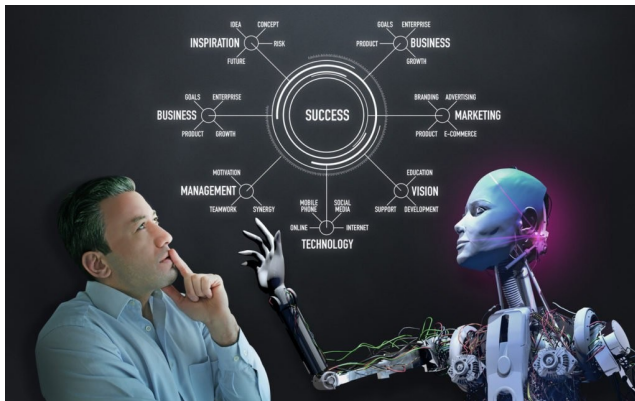
- next-generation foundation models
  - GPT-5 and Claude 4 demonstrate emergent reasoning abilities
  - open-source models achieving parity with leading commercial systems from 2024
- hardware innovations
  - NVIDIA's Blackwell successor architecture delivering 3-4x performance improvement
  - AMD's MI350 accelerators challenging NVIDIA's market dominance
- AI-human collaboration systems
  - seamless multimodal interfaces enabling natural human-AI collaboration
  - AI systems effectively explaining reasoning and recommendations
  - augmented reality interfaces providing real-time AI assistance in professional contexts





## Transformative impact of AI - reshaping industries, work & society

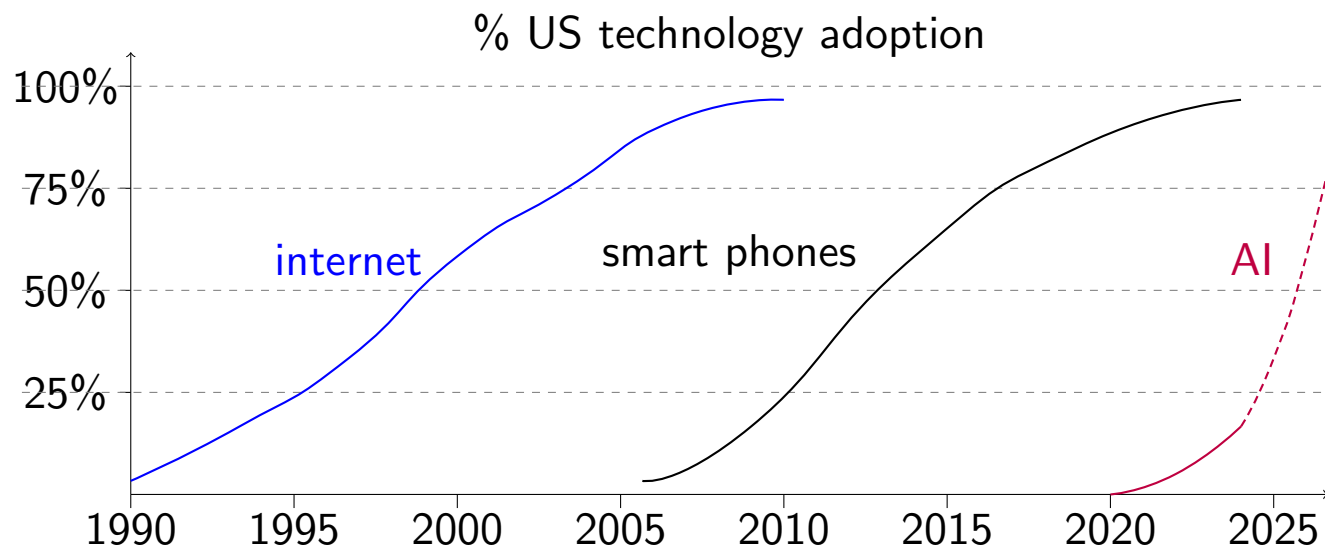
- accelerating human-AI collaboration
  - not only reshaping industries but *altering how humans interact with technology*
  - AI's role as collaborator and augmentor redefines productivity, creativity, the way we address global challenges, *e.g.*, *sustainability & healthcare*
- AI-driven automation *transforms workforce dynamics* - creating new opportunities while challenging traditional job roles
- *ethical AI considerations* becoming central not only to business strategy, but to society as a whole - *influencing regulations, corporate responsibility & public trust*



# **Measuring AI's Ascent**

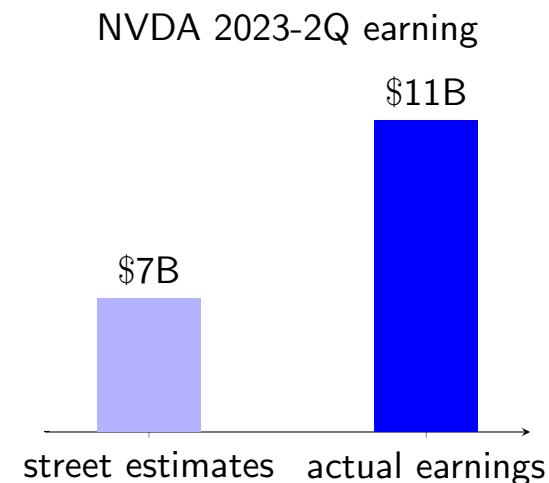
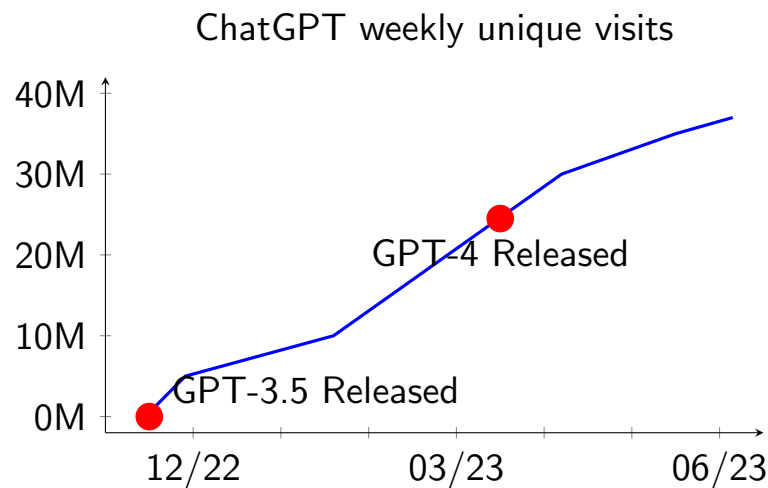
## Where are we in AI today?

- sunrise phase - currently experiencing dawn of AI era with significant advancements and increasing adoption across various industries
- early adoption - in early stages of AI lifecycle with widespread adoption and innovation across sectors marking significant shift in technology's role in society



## Explosion of AI ecosystems - ChatGPT & NVIDIA

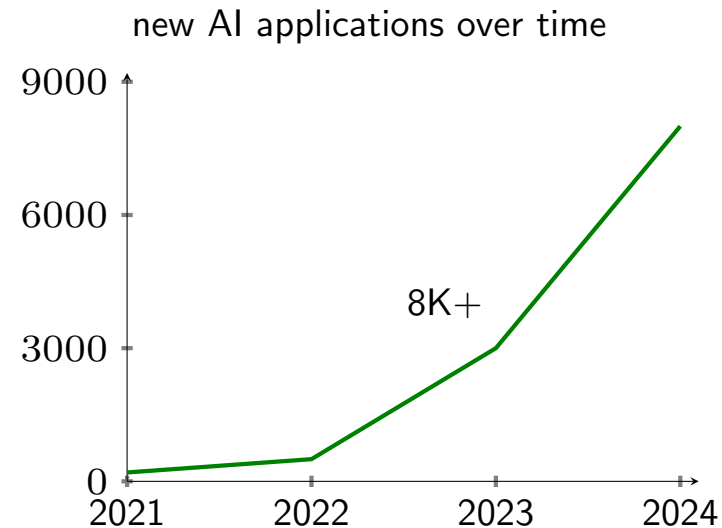
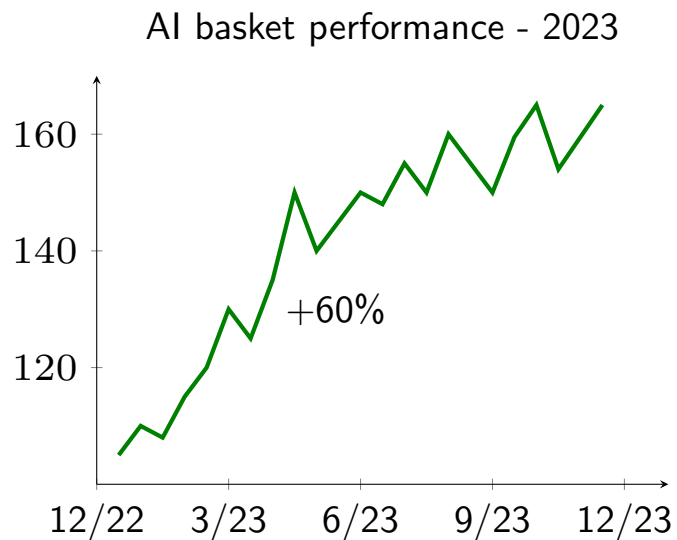
- took only *5 months for ChatGPT users to reach 35M*
- NVIDIA 2023 Q2 earning exceeds market expectation by big margin - \$7B vs \$13.5B
  - surprisingly, *101% year-to-year growth*
  - even more surprisingly *gross margin was 71.2%* - up from 43.5% in previous year<sup>4</sup>



<sup>4</sup>source - Bloomberg

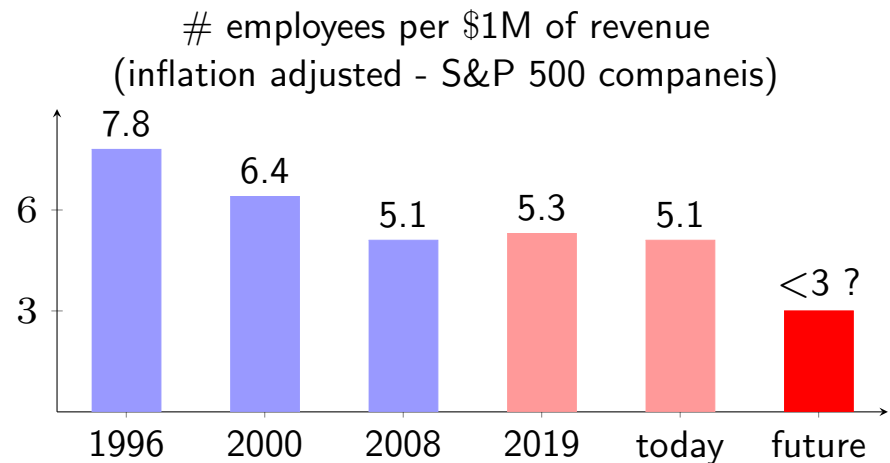
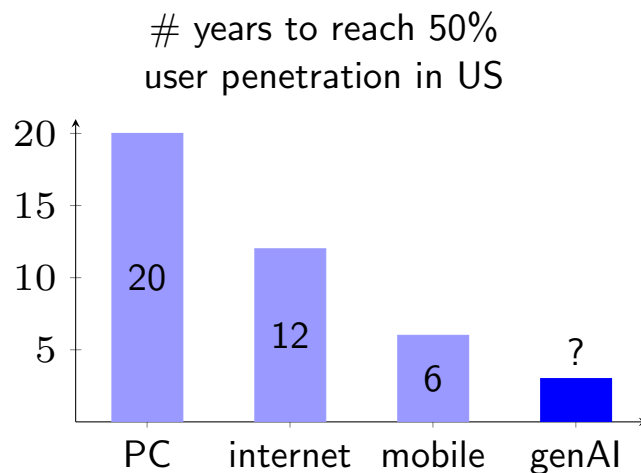
## Explosion of AI ecosystems - AI stock market

- *AI investment surge in 2023 - portfolio performance soars by 60%*
  - AI-focused stocks significantly outpaced traditional market indices
- *over 8,000 new AI applications* developed in last 3 years
  - applications span from healthcare and finance to manufacturing and entertainment



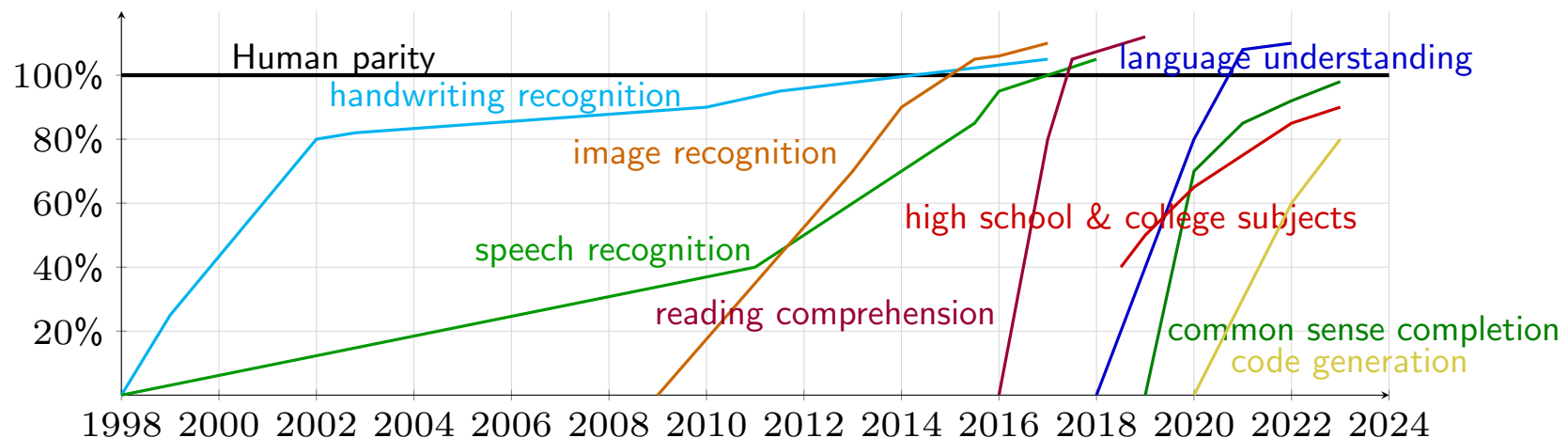
## AI's transformative impact - adoption speed & economic potential

- adoption - has been twice as fast with platform shifts suggesting
  - increasing demand and readiness for new technology improved user experience & accessibility
- AI's potential to drive economy for years to come
  - 35% improvement in productivity driven by introduction of PCs and internet
  - greater gains expected with AI proliferation



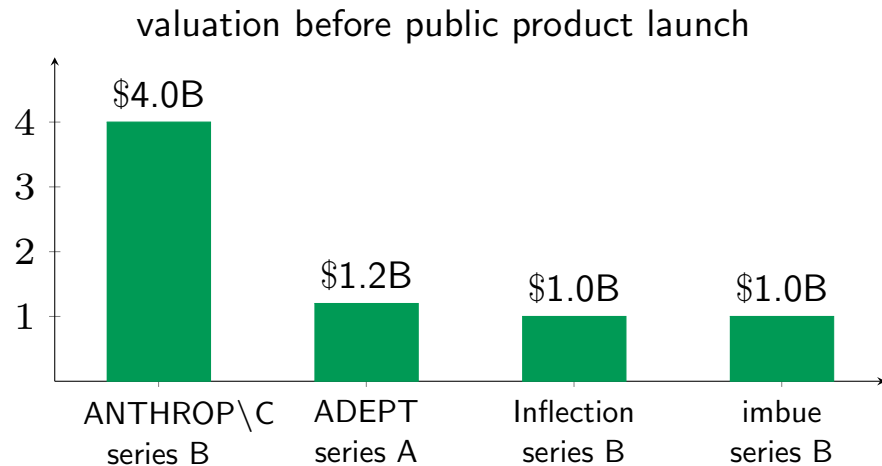
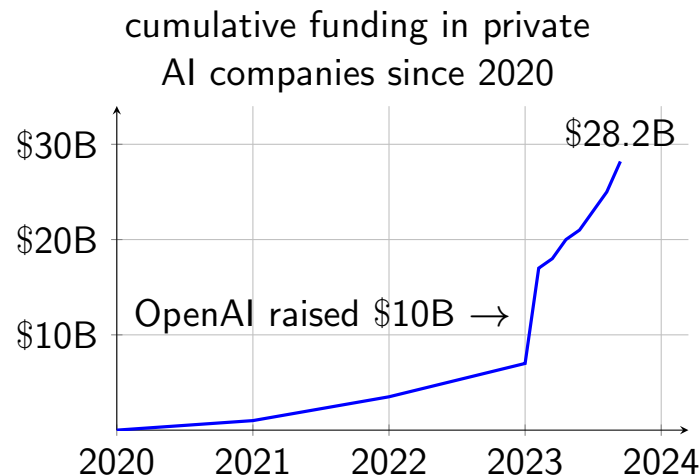
## AI getting more & more faster

- steep upward slopes of AI capabilities highlight accelerating pace of AI development
  - period of exponential growth with AI potentially mastering new skills and surpassing human capabilities at ever-increasing rate
- closing gap to human parity - some capabilities approaching or arguably reached human parity, while others having still way to go
  - achieving truly human-like capabilities in broad range remains a challenge



## Massive investment in AI

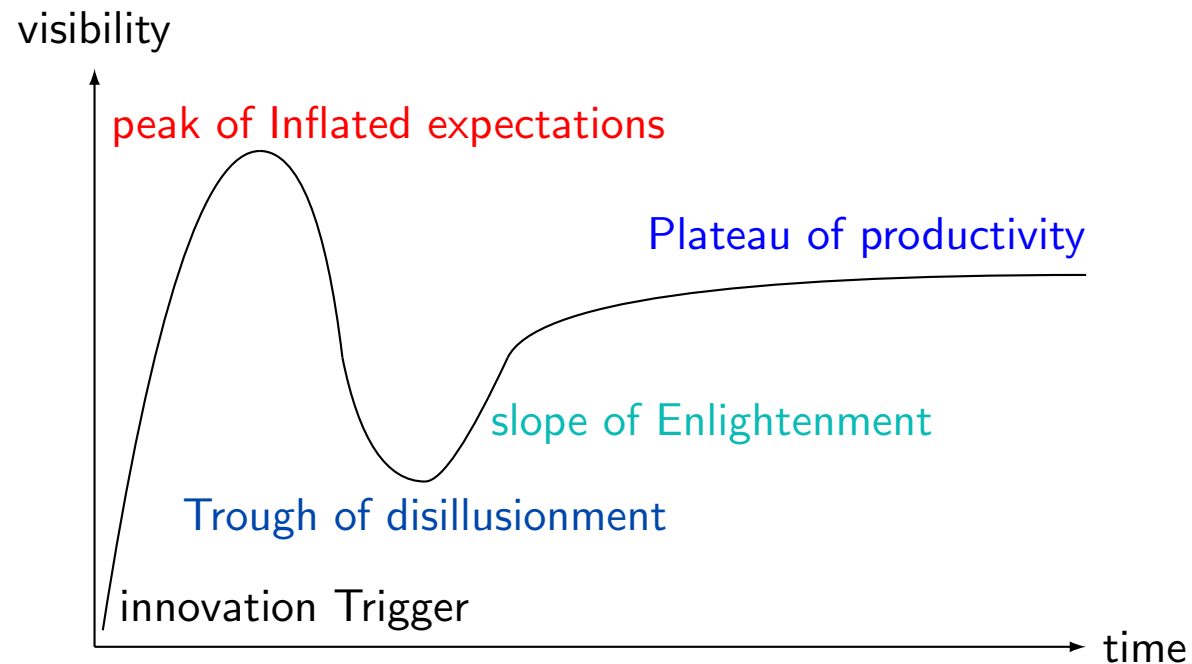
- *explosive growth* - cumulative funding skyrocketed reaching staggering \$28.2B
- OpenAI - significant fundraising (=\$10B) fueled rapid growth
- *valuation surge* - substantial valuations even before public products for stellar companies
- *fierce competition for capital* among AI startups driving innovation & accelerating development
- massive investment indicates *strong belief in & optimistic outlook for potential of AI* to revolutionize industries & drive economic growth





**Is AI hype?**

## Technology hype cycle



- innovation trigger - technology breakthrough kicks things off
- peak of inflated expectations - early publicity induces many successes followed by even more
- trough of disillusionment - expectations wane as technology producers shake out or fail
- slope of enlightenment - benefit enterprise, technology better understood, more enterprises fund pilots

## Fiber vs cloud infrastructure

- fiber infrastructure - 1990s

- Telco Co's raised \$1.6T of equity & \$600B of debt
- bandwidth costs decreased 90% within 4 years
- companies - Covage, NothStart, Telligent, Electric Lightwave, 360 networks, Nextlink, Broadwind, UUNET, NFS Communications, Global Crossing, Level 3 Communications
- became *public good*

- cloud infrastructure - 2010s

- entirely new computing paradigm
- mostly public companies with data centers
- *big 4 hyperscalers generate* \$150B + annual revenue



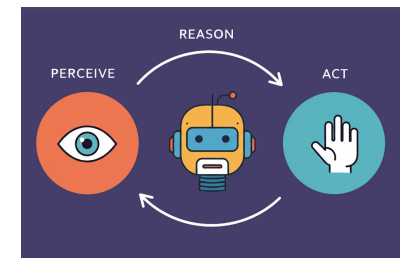
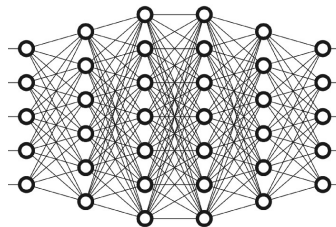
## Yes & No

| characteristics of hype cycles                        | speaker's views                                                                                                                                                                                                                                                             |
|-------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| value accrual misaligned with investment              | <ul style="list-style-type: none"><li>● OpenAI still operating at a loss; business model <i>still</i> not clear</li><li>● gradual value creation across broad range of industries and technologies (<i>e.g.</i>, CV, LLMs, RL) unlike fiber optic bubble in 1990s</li></ul> |
| overestimating timeline & capabilities of technology  | <ul style="list-style-type: none"><li>● self-driving cars delayed for over 15 years, with limited hope for achieving level 5 autonomy</li><li>● AI, however, has proven useful within a shorter 5-year span, with enterprises eagerly adopting</li></ul>                    |
| lack of widespread utility due to technology maturity | <ul style="list-style-type: none"><li>● AI already providing significant utility across various domains</li><li>● vs quantum computing remains promising in theory but lacks widespread practical utility</li></ul>                                                         |

# AI Agents

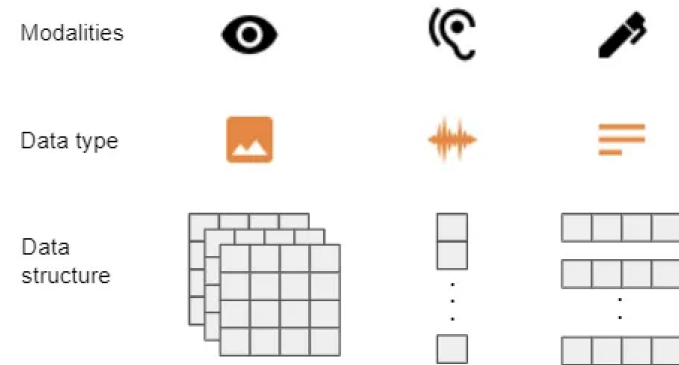
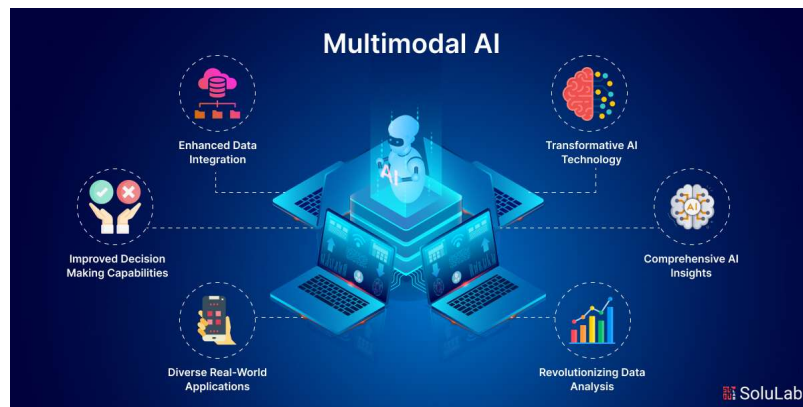
## AI progress in 21st century in keywords

- 2010 ~ Big Data
- 2012 ~ Deep Learning
- 2017 ~ Transformer - Attention is All you need!
- 2022 ~ LLM & genAI
- 2024 ~ AI Agent (Agentic AI)



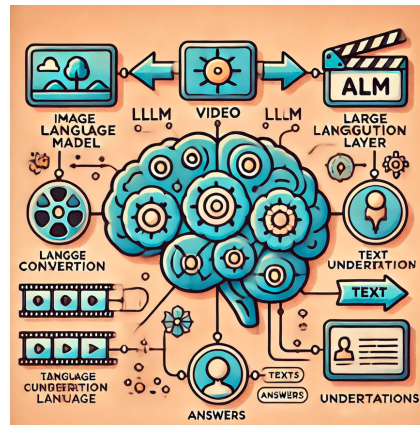
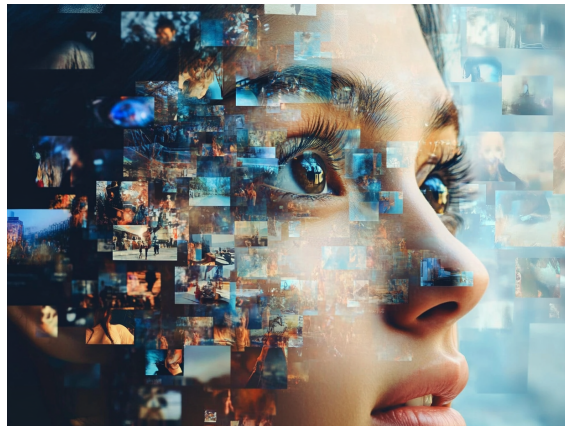
# Multimodal learning

- understand information from multiple modalities, *e.g.*, text, images, audio, video
- representation learning methods
  - combine multiple representations or learn multimodal representations simultaneously
- applications
  - images from text prompt, videos with narration, musics with lyrics
- collaboration among different modalities
  - understand image world (open system) using language (closed system)



## Implications of success of LLMs

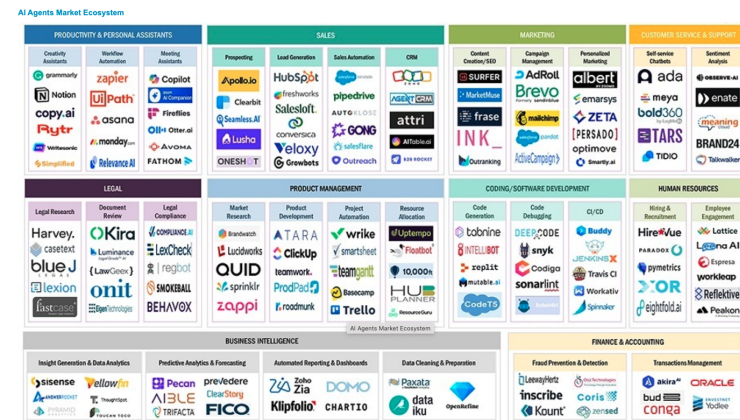
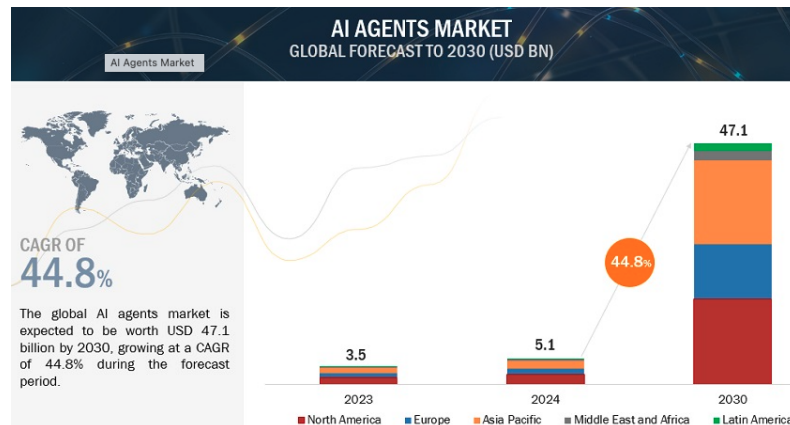
- many researchers change gears towards LLM
  - from computer vision (CV), speech, music, video, even reinforcement learning
- *LLM is not only about NLP . . .* humans have . . .
  - evolved to optimize natural language structures for eons
  - handed down knowledge using *this natural languages* for thousands of years
  - internal structure (or equivalently, representation) of natural languages optimized via *thousands of generation by evolution*
- LLM *connects non-linguistic world (open system) via natural languages (closed system)*





## Multimodal AI (mmAI)

- mmAI - systems processing & integrating data from multiple sources & modalities, to generate unified response / decision
- 1990s – 2000s - early systems - initial research combining basic text & image data
- 2010s - CNNs & RNNs enabling more sophisticated handling of multimodality
- 2020s - modern multimodal models - Transformer-based architectures handling complex multi-source data at highly advanced level
- mmAI *mimics human cognitive ability* to interpret and integrate information from various sources, leading to holistic decision-making

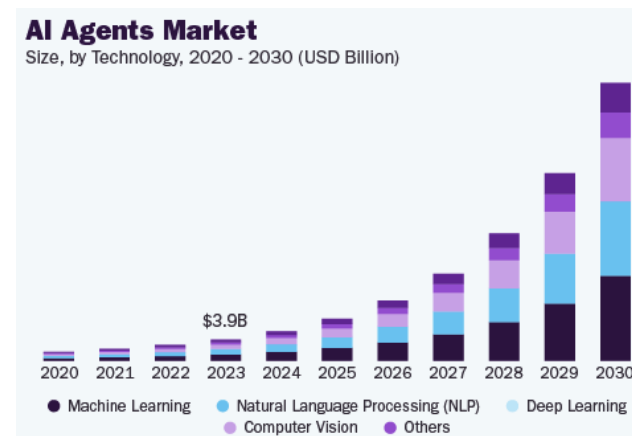
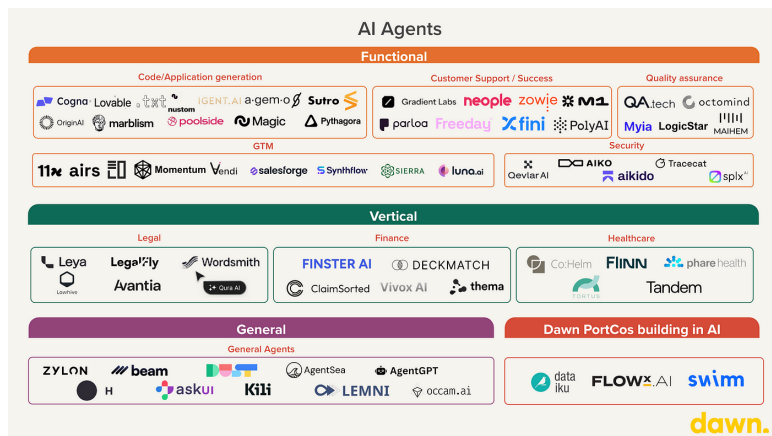


## mmAI Technology

- core components
  - data preprocessing - images, text, audio & video
  - architectures - unified Transformer-based (*e.g.*, ViT) & cross-attention mechanisms / hybrid architectures (*e.g.*, CNNs + LLMs)
  - integration layers - fusion methods for combining data representations from different modalities
- technical challenges
  - data alignment - accurate alignment of multimodal data
  - computational demand - high-resource requirements for training and inferencing
  - diverse data quality - manage variations in data quality across modalities
- advancements
  - multimodal embeddings - shared feature spaces interaction between modalities
  - self-supervised learning - leverage unlabeled data to learn representations across modalities

## AI agents powered by multimodal LLMs

- foundation
  - integrate multimodal AI capabilities for enhanced interaction & decision-making
- components
  - perceive environment through multiple modalities (visual, audio, text), process using LLM technology, generate contextual responses & take actions
- capabilities
  - understand complex environments, reason across modalities, engage in natural interactions, adapt behavior based on context & feedback



## AI agents - Present & Future

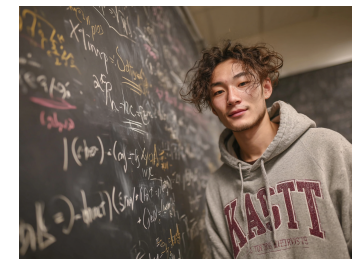
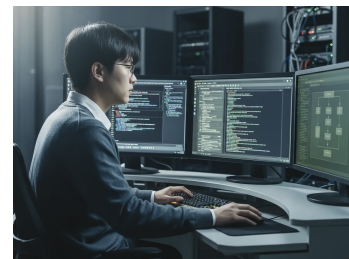
- emerging applications
  - scientific research - agents analyzing & running experiments & generating hypotheses
  - creative collaboration - AI partners in design & art combining multiple mediums
  - environmental monitoring - processing satellite sensor data for climate analysis
  - healthcare - enhanced diagnostic combining imaging, *e.g.*, MRI, with patient history
  - customer experience - virtual assistants understanding spoken language & visual cues
  - autonomous vehicles - integration of visual, radar & audio data
- future
  - ubiquitous AI agents - seamless integration into everyday devices
  - highly tailored personalized experience - in education, entertainment & healthcare



# **Building Your Superpower**

## Students already building with AI - two paths, one future

- AI power user - domain experts using AI (majority)
  - 17-year-old high school student - passionate about helping elderly grandparents
    - built medication reminder app using Claude - no programming background
    - “. . . didn't learn to code. I learned to describe what grandparents need to AI.”
  - college business student - interested in K-beauty industry
    - used Claude to analyze social media sentiment to predict K-beauty trend
    - “I understood Korean beauty culture. AI understood data patterns.”
- AI expert - AI scientists & engineers & builders
  - computer science junior - 4 years studying math, algorithms, neural networks
    - fine-tuned open-source LLM for Korean medical terminology
    - collaborated with doctors (domain experts) on diagnostic tool



## AI power user - domain expert AI-amplified

- who this is for?
  - you love literature, business, medicine, law, art, design, *etc.*
  - you find AI interesting as TOOL, not as end in itself
  - you get excited about domain problems, not algorithms
- what you'll do
  - deepen expertise in your chosen field (4+ years) - learn AI tools as power tools
  - use AI to amplify your domain work & compete on domain insight + AI leverage
- career examples
  - doctor using AI diagnostics, teacher using AI personalization
  - lawyer using AI research, artist using AI iteration
  - marketer using AI analytics, scientist using AI simulation





## AI expert - researcher/scientist/engineer/developer

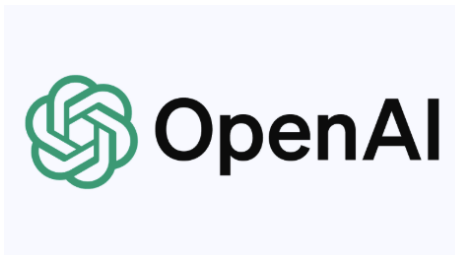
- who this is for?
  - you find algorithms, mathematics, systems *beautiful*, and read AI papers for fun
  - you want to work at AI labs being excited when new architectures are published
- what you'll do
  - deep study - mathematics, computer science, ML theory (*e.g.*, 4+ years)
  - understand neural networks, transformers to build and improve AI systems
  - *collaborate* w/ domain experts to apply your systems
- career examples
  - ML Engineer working for (tech) companies
  - AI Researcher in academia or industry labs
  - research scientist, robotics engineer, computer vision specialist





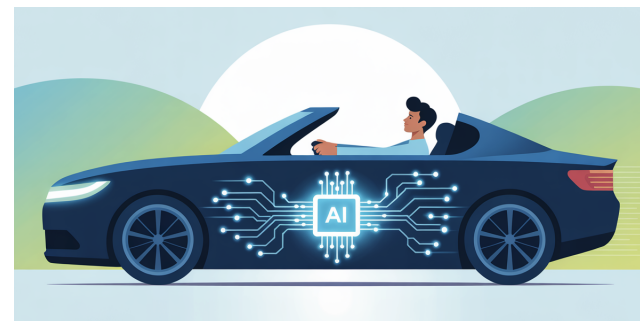
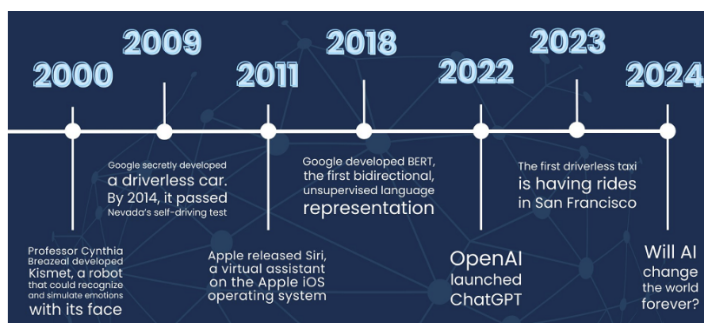
## BIG shifts in AI landscape

- old assumption (2015 – 2020)
  - AI will be built by tech companies, everyone else will be disrupted
  - lots of tech companies will compete for best models/products
- new reality (2024 –)
  - AI is commoditized tool, domain expertise is where value accrues
  - only handful of companies can develop cutting-edge foundation models



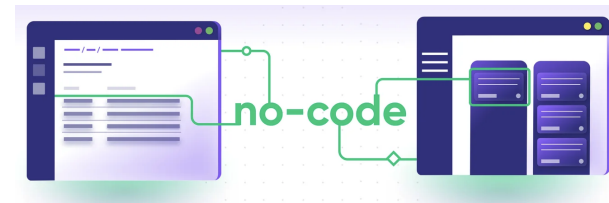
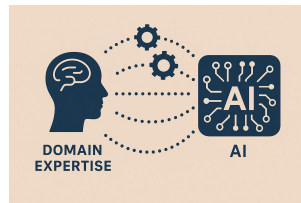
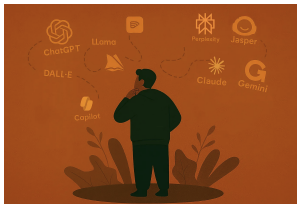
## Domain expert revolution

- why domain experts are winning
  - problem identification requires domain knowledge
  - evaluation requires domain judgment
  - trust requires human domain expertise
  - context requires cultural/domain fluency
- pattern across industries
  - best medical AI applications → built by doctors collaborating with AI engineers
  - best legal AI tools → built by lawyers collaborating with AI engineers
  - best educational AI → built by teachers collaborating with AI engineers
  - domain expert leads & AI engineer supports (not the reverse)



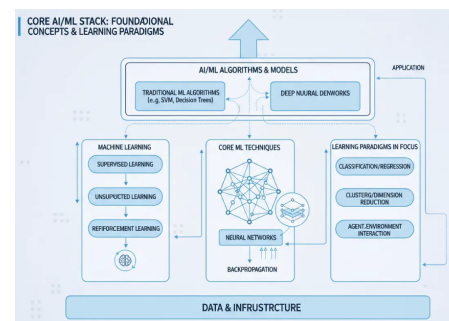
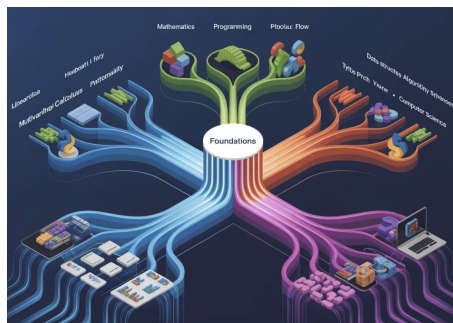
## AI power user - what you actually need to learn

- tool awareness
  - what - know which AI tools exist and their capabilities
  - examples - ChatGPT for brainstorming, Claude for research, NotebookLM for synthesis
  - how - YouTube tutorials, free trials, experimentation
- right questions to throw - interactive way
  - what - communicate effectively with AI using domain knowledge
  - why it works - your domain knowledge makes prompts effective
  - how - practice + domain expertise
- tool integration
  - what - connect AI tools to your workflow, build custom GPTs, use APIs (no coding)
  - how - no-code tools + tutorials



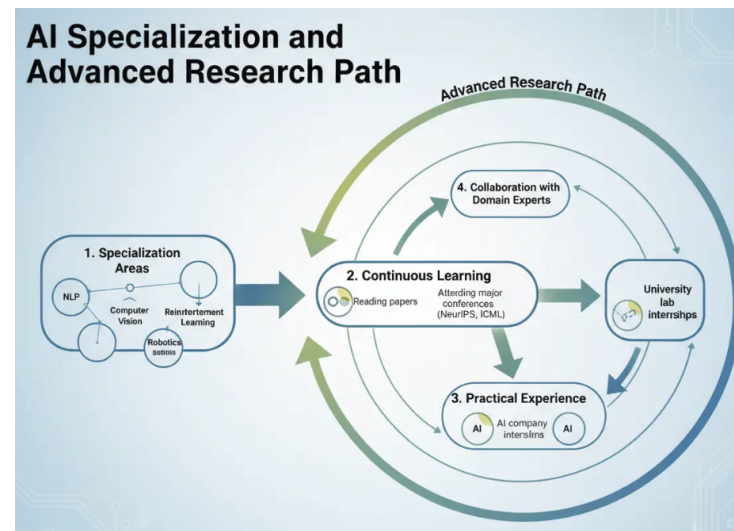
## AI expert path - how to become AI scientist/researcher/engineer/practitioner

- foundation
  - mathematics - linear algebra, multivariable calculus, probability theory, optimization
  - programming - python w/ PyTorch, TensorFlow, . . .
  - computer science - data structures, algorithms, systems
- core AI/ML
  - machine learning (ML) - supervised/unsupervised learning, reinforcement learning, neural networks, backpropagation
  - deep learning (DL) - CNNs, RNNs, Transformers, attention mechanisms
  - practical projects - competitions, replicate papers, contribute to open source



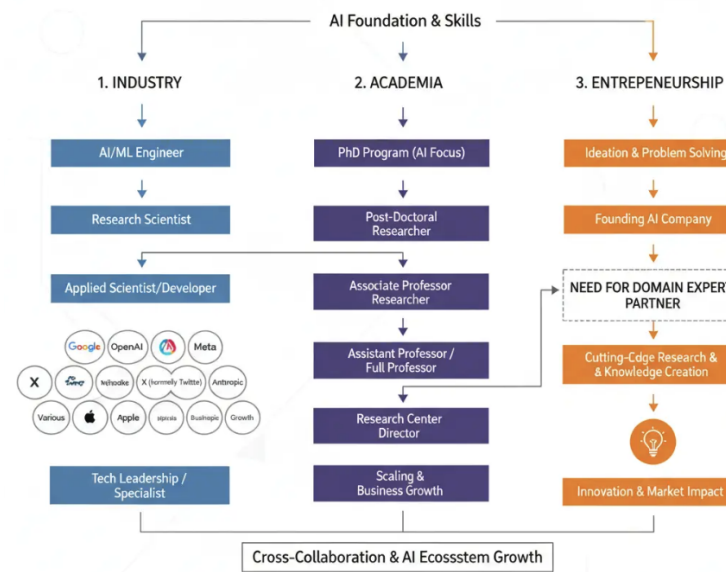
## AI expert path - how to become AI scientist/researcher/engineer/practitioner

- specialization
  - choose area (or not!) - NLP, computer vision (CV), robotics, *etc.*
  - read papers - arxiv, attend conferences (*e.g.*, NeurIPS, ICML, ICLR, CVPR, *etc.*)
  - research experience - lab work at university, internships at AI companies
  - collaboration - work with domain experts on real problems



## AI expert path - how to become AI scientist/researcher/engineer/practitioner

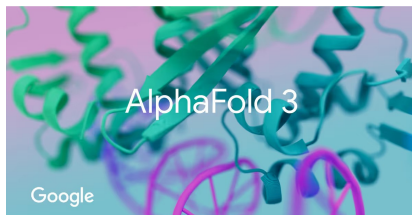
- career paths
  - industry - Google, OpenAI, Meta, Apple, X, Anthropic, and numerous startups
  - academia - PhD → professor / research center
  - entrepreneurship - found AI company (but need domain expert partner!)



## Powerful combination - domain expert + AI expert collaboration

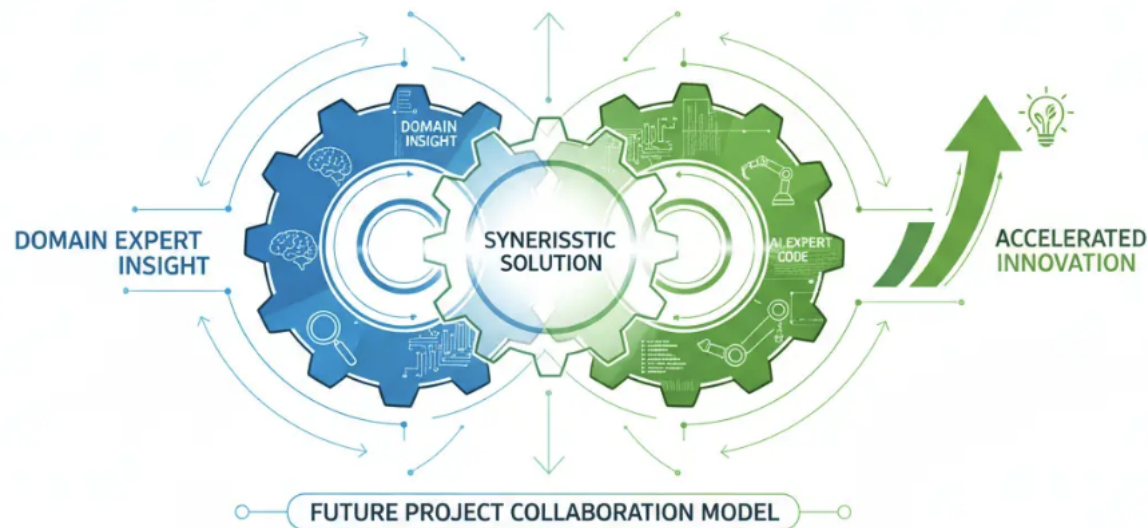
*The magic happens at the intersection!*

- case study 1 - AlphaFold (Protein Folding)
  - AI engineers - build transformer-based neural network, optimized training
  - structural biologists - identify protein folding as THE problem, validated outputs
  - result - 50-year problem solved - neither could do it alone
  - both Demis Hassabis (CEO @ Google DeepMind) & John Jumper (biochemistry background) got Nobel Prizes in chemistry in 2024!
- case study 2 - cancer diagnostic AI
  - AI engineer role - build model, handle large medical imaging datasets
  - oncologist role - label training data correctly, evaluate clinical relevance
  - result - 30% improvement in early detection
  - who makes final diagnosis - always the doctor!



## Powerful combination - domain expert + AI expert collaboration

- case study 3 - your future project
  - domain expert & AI super user- identify problem in your field you understand deeply
  - AI expert - build custom solution beyond available tools
  - result - breakthrough that neither could achieve alone
  - who drives vision - TOGETHER!





## Things AI can't do for you - choose who you'll become

- your technical superpower (Domain × AI) is only as good as *your moral compass*
- why this matters more than ever
  - AI amplifies whatever you choose to do - good intentions OR bad ones
  - history shows us - brilliant minds + no moral foundation = catastrophe
  - your skills will make you powerful; your values determine what you do with that power
- virtues that actually matter in the long run
  - *integrity* - doing the right thing (even) when no one's watching
  - *empathy* - genuinely caring about people; your technology will affect them
  - *service* - building things that help others, not just things that benefit you
  - *morality* - having inner compass that guides you beyond what's legal or profitable

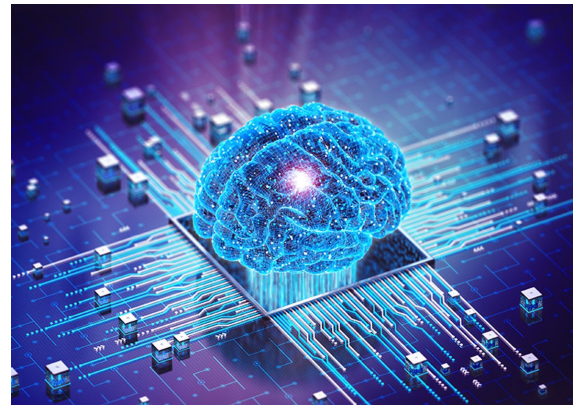


# **Appendices**

# **AI & Biotech**

## AI in biology

- AI has been used in biological sciences, and science in general
- AI's ability to process large amounts of raw, unstructured data (*e.g.*, DNA sequence data)
  - reduces time and cost to conduct experiments in biology
  - enables others types of experiments that previously were unattainable
  - contributes to broader field of engineering biology or biotechnology
- AI increases human ability to make direct changes at cellular level and create novel genetic material (*e.g.*, DNA and RNA) to obtain specific functions



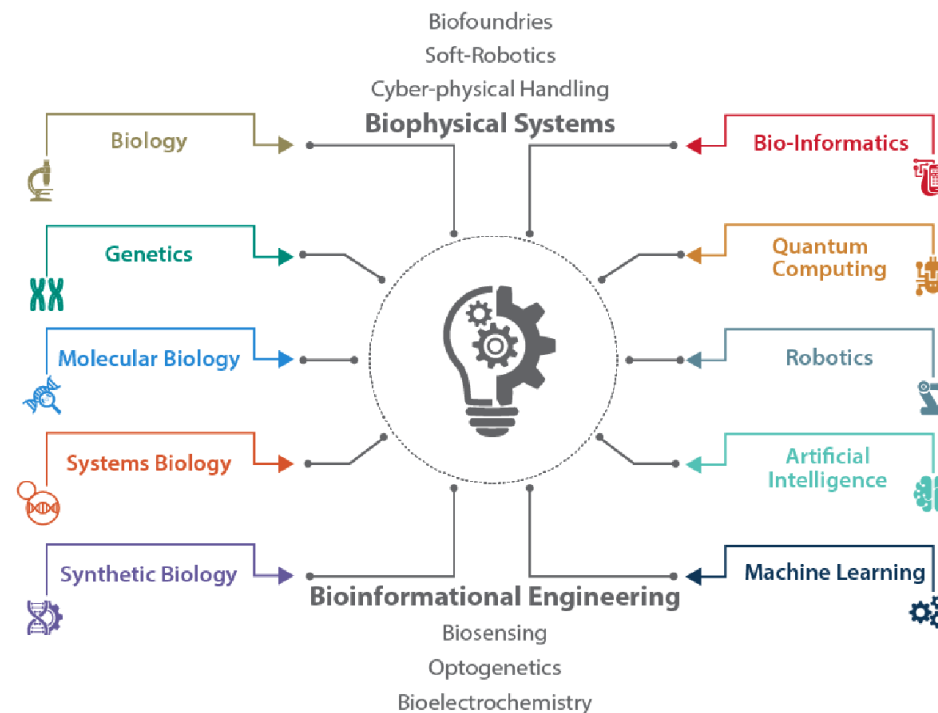
**Biotech**

## Biotech

- biotechnology
  - is multidisciplinary field leveraging broad set of sciences and technologies
  - relies on and builds upon advances in other fields such as nanotechnology & robotics, and, increasingly, AI
  - enables researchers to read and write DNA
    - sequencing technologies “read” DNA while gene synthesis technologies take sequence data and “write” DNA turning data into physical material
- 2018 National Defense Strategy & Senior US Defense and Intelligence Officials identified emerging technologies that could have disruptive impact on US national security [[Say21](#)]
  - [AI](#), lethal autonomous weapons, hypersonic weapons, directed energy weapons, [biotechnology](#), quantum technology
- other names for biotechnology are engineering biology, synthetic biology, biological science (when discussed in context of AI)

## Biotech - multidisciplinary field

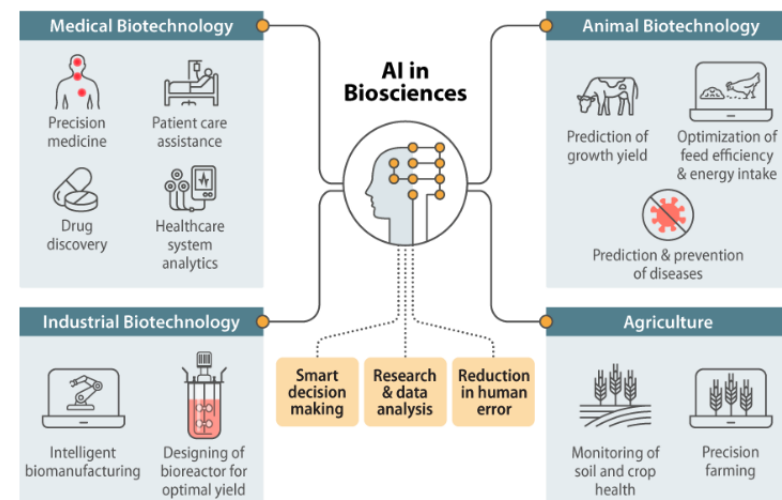
- sciences and technologies enabling biotechnology include (but not limited to)
  - (molecular) biology, genetics, systems biology, synthetic biology, bio-informatics, quantum computing, robotics [DFJ22]



## Convergence of AI and biological design

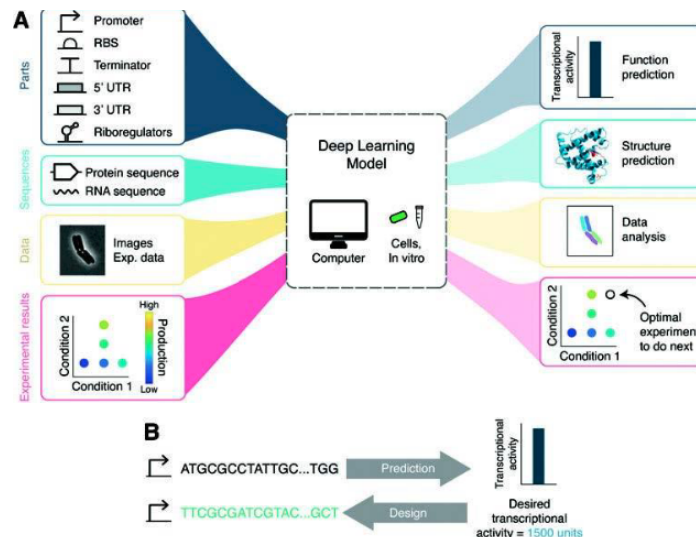
- AI & biological sciences converging [BKP22]
  - each building upon the other's capabilities for new research and development across multiple areas
- Demis Hassabis, CEO & cofounder of DeepMind, said of biology [Toe23]

“. . . biology can be thought of as information processing system, albeit extraordinarily complex and dynamic one . . . just as mathematics turned out to be the right description language for physics, biology may turn out to be *the perfect type of regime for the application of AI!*”
- both AI & biotech rely on and build upon advances in other scientific disciplines and technology fields, such as nanotechnology, robotics, and increasingly big data (*e.g.*, genetic sequence data)
  - each of these fields itself convergence of multiple sciences and technologies
- so *their impacts can combine to create new capabilities*





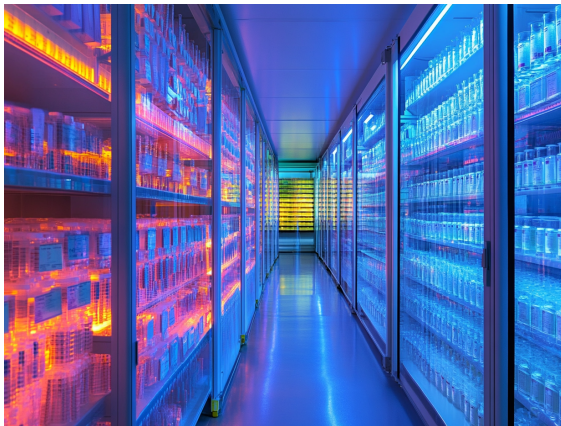
## Multi-source genetic sequence data



- AI, essential to analyzing exponential growth of genetic sequence data
  - “AI will be essential to fully understanding how genetic code interacts with biological processes” - US National Security Commission on Artificial Intelligence (NSCAI)
  - process huge amounts of biological data, *e.g.*, genetic sequence data, coming from different biological sources for understanding complex biological systems
    - sequence data, molecular structure data, image data, time-series, omics data
- *e.g.*, analyze genomic data sets to determine the genetic basis of particular trait and potentially uncover genetic markers linked with that trait

## Quality & quantity of biological data

- limiting factor, however, is *quality and quantity* of biological data, *e.g.*, DNA sequences, that AI is trained on
  - *e.g.*, accurate identification of particular species based on DNA requires reference sequences of *sufficient quality* to exist and be available
- databases have varying standards - access, type, and quality of information
- design, management, quality standards, and data protocols for reference databases can affect utility of particular DNA sequence



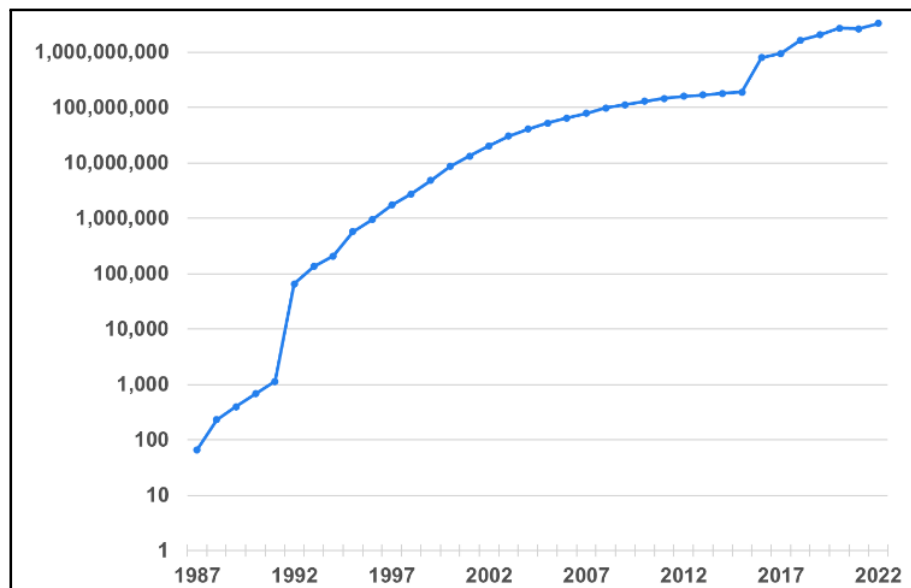
## Rapid growth of biological data

- volume of genetic sequence data grown exponentially as sequencing technology evolved
- more than 1,700 databases incorporating data on genomics, protein sequences, protein structures, plants, metabolic pathways, *etc.*, *e.g.*
  - open-source public database
    - Protein Data Bank, US-funded data center - more than *terabyte of three-dimensional structure data* for biological molecules, *e.g.*, proteins, DNA, RNA
  - proprietary database
    - Gingko Bioworks - more than *2B protein sequences*
  - public research groups
    - Broad Institute - produces roughly *500 terabases of genomic data per month*
- great potential value in aggregate volume of genetic datasets that can be collectively mined to discover and characterize relationships among genes

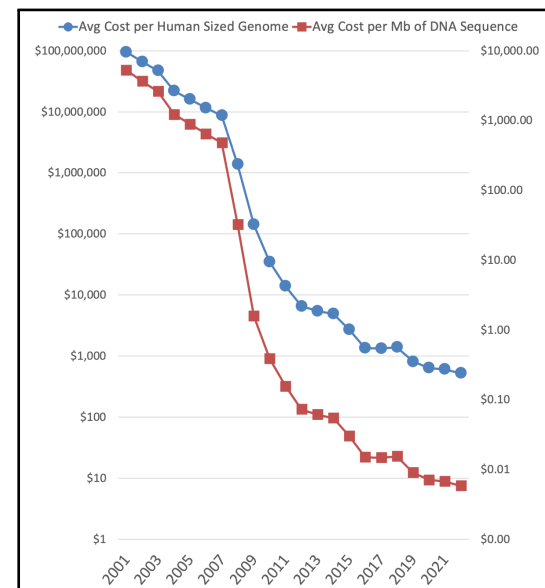
## Volume and sequencing cost of DNA over time

- volume of DNA sequences & DNA sequencing cost
  - data source: National Human Genome Research Institute (NHGRI) [Wet23] & International Nucleotide Sequence Database Collaboration (INSDC)
- *more dramatic than Moore's law!*

# sequences in INSDC



DNA sequencing cost



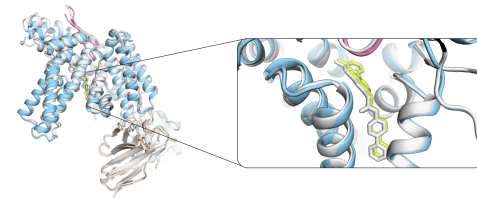
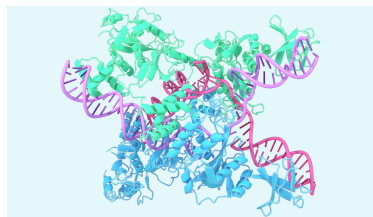
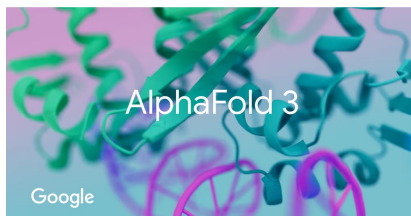
## Bio data availability and bias

- US National Security Commission on Artificial Intelligence (NSCAI) recommends
  - US fund and prioritize development of a biobank containing *“wide range of high-quality biological and genetic data sets securely accessible by researchers”*
  - establishment of database of broad range of human, animal, and plant genomes would
    - *enhance and democratize biotechnology innovations*
    - *facilitate new levels of AI-enabled analysis of genetic data*
- bias - availability of genetic data & decisions about selection of genetic data can introduce bias, *e.g.*
  - training AI model on datasets emphasizing or omitting certain genetic traits can affect how information is used and types of applications developed - *potentially privileging or disadvantaging certain populations*
  - access to data and to AI models themselves may impact communities of differing socioeconomic status or other factors unequally

# **Emerging Trends in Biotech**

# AlphaFold

- solving 50-year-old protein folding problem, *“one of biology’s grand challenges”*
  - definition - given amino acid sequence, predict how it folds into a 3D structure
  - proteins fold in microseconds, but predicting computationally nearly impossible
- AlphaFold 1 (2018) - DL + physics-based energy functions → AlphaFold 2 (2020)
  - attention-based NN solving protein folding “in principle” → AlphaFold 3 (2024) - diffusion-based DL, drug-protein interactions, protein complexes
- AlphaFold protein structure database
  - >200MM protein structures - nearly every known protein, used by >2MM researchers
- Applications & implications
  - drug discovery - target identification, lead optimization, side effect prediction
  - enzyme engineering, agriculture, environmental, vaccine development



# AlphaGo

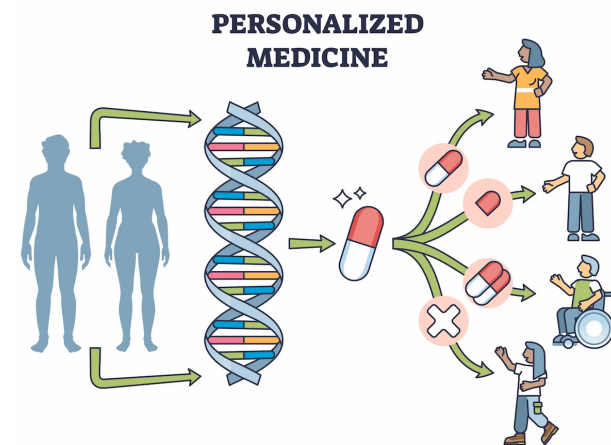
- Go board marked with  $19 \times 19$  grid -  $(19 \times 19)! = 361! \approx 1.44 \times 10^{768}$
- deep reinforcement learning with Monte Carlo tree search
  - trained on thousands of years of Go game history
  - AlphaGo Zero learns by playing against itself
- development experience, insight, knowledge, know-how transferred to AlphaFold



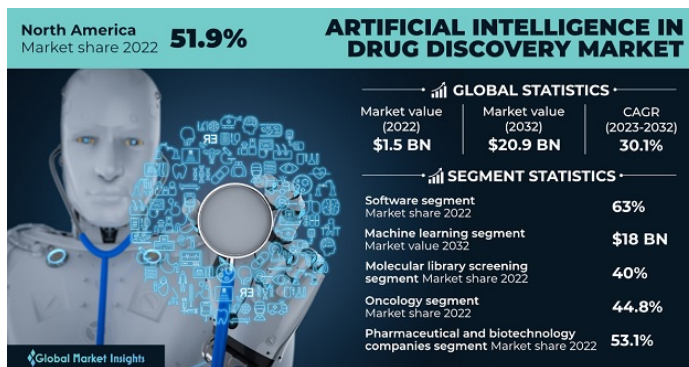
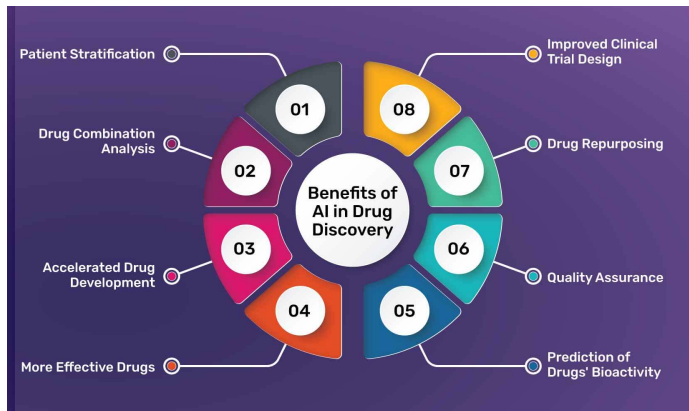


## Personalized medicine

- *shift from one-size-fits-all approach to tailored treatments*
- based on individual genetic profiles, lifestyles & environments
- AI enables analysis of vast data to predict patient responses to treatments, thus enhancing efficacy and reducing adverse effects
- *e.g.*
  - custom cancer therapies
  - personalized treatment plans for rare diseases
  - precision pharmacogenomics
- companies - Tempus, Foundation Medicine, *etc.*



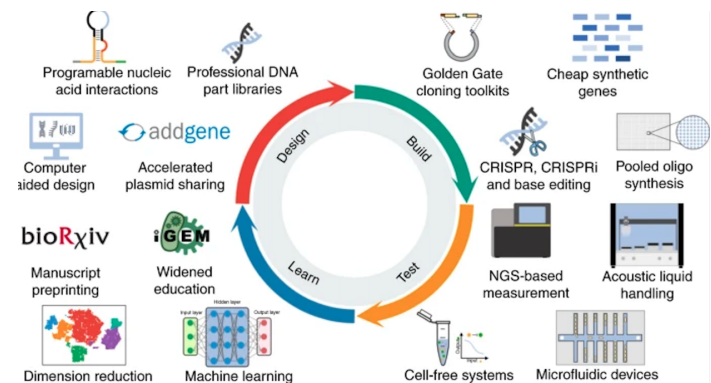
## AI-driven drug discovery



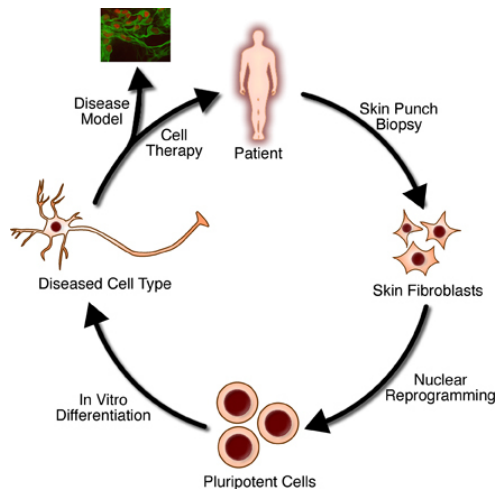
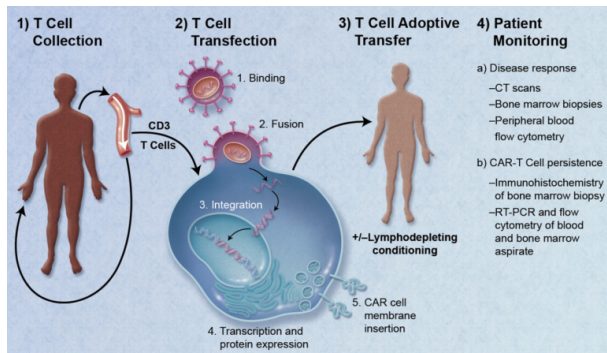
- traditional drug discovery process - time-consuming and costly often taking decades and billions of dollars
- AI streamlines this process by predicting the efficacy and safety of potential compounds with more speed and accuracy
- AI models analyze chemical databases to identify new drug candidates or repurpose existing drugs for new therapeutic uses
- companies - Insilco Medicine, Atomwise.

# Synthetic biology

- use AI for gene editing, biomaterial production and synthetic pathways
- combine principles of biology and engineering to design and construct new biological entities
- AI optimizes synthetic biology processes from designing genetic circuits to scaling up production
- company - Ginkgo Bioworks uses AI to design custom microorganisms for applications ranging from pharmaceuticals to industrial chemicals



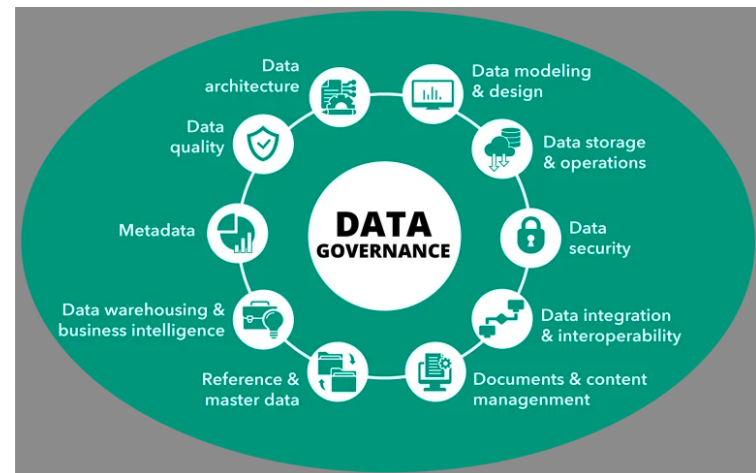
## Regenerative medicine



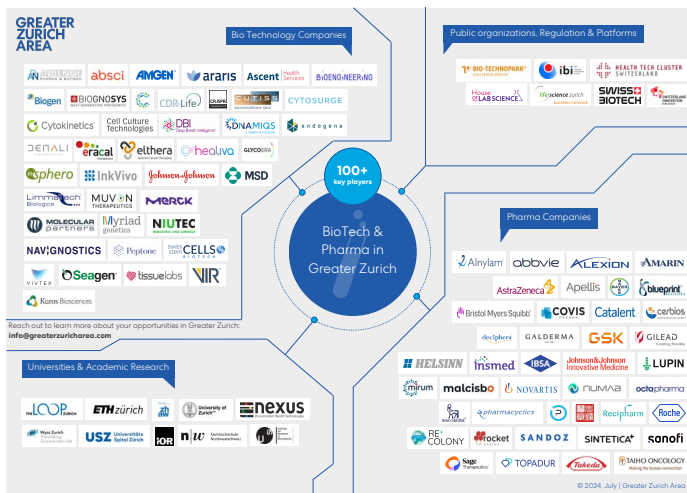
- AI advances development of stem cell therapies & tissue engineering
- AI algorithms assist in identifying optimal cell types, predicting cell behavior & personalized treatments
- particularly for conditions such as neurodegenerative diseases, heart failure and orthopedic injuries
- company - Organovo leverages AI to potentially improve the efficacy and scalability of regenerative therapies, developing next-generation treatments

## Bio data integration

- integration of disparate data sources, including genomic, proteomic & clinical data - one of biggest challenges in biotech & healthcare
- AI delivers meaningful insights *only when* seamless data integration and interoperability realized
- developing platforms facilitating comprehensive, longitudinal patient data analysis - vital enablers of AI in biotech
- company - Flatiron Health working on integrating diverse datasets to provide holistic view of patient health



## Biotech companies



- Atomwise - small molecule drug discovery
- Cradle - protein design
- Exscientia - precision medicine
- Iktos - small molecule drug discovery and design
- Insilico Medicine - full-stack drug discovery system
- Schrödinger, Inc. - use physics-based models to find best possible molecule
- Absci Corporation - antibody design, creating new from scratch antibodies, *i.e.*, “de novo antibodies”, and testing them in laboratories

# **Some Important Questions around AI**

## Some important questions around AI

- why human-level AI?
- what lies in very core of DL architecture? what makes it work amazingly well?
- biases that can hurt judgement, decision making, social good?
- AI ethics & legal issues
- consciousness
- utopia vs dystopia
- knowledge, belief, reasoning
- risk of anthropomorphization



**Human-level AI?**

## Why human-level in the first place?

- lots of times, when we measure AI performance, we say
  - how can we achieve human-level performance, *e.g.*, CV models?
- why human-level?
  - are all human traits desirable? are humans flawless?
  - aren't humans still evolving?
- advantage of AI over humans
  - *e.g.*, self-driving cars can use extra eyes, GPS, computer network
  - *e.g.*, recommendation system runs for hundreds of millions of people overnight
  - AI is available 24 / 7 while humans cannot
    - . . . critical advantages for medical assistance, emergency handling
  - AI does not make more mistakes because task is repetitive and tedious
  - AI does not request salary raise or go on strike

**What makes DL so successful?**

## Factors contributing to astonishing success of DL

- analysis based on speaker's mathematical, numerical algorithmic & statistical perspectives considering hardware innovations

**30%** universal approximation theorem? - (partially) yes! but that's not all

- function space of neural network is *dense* (math theory), *i.e.*, for every  $f : \mathbf{R}^n \rightarrow \mathbf{R}^m$ , exists  $\langle f_n \rangle$  such that  $\lim_{n \rightarrow \infty} f_n = f$

**25%** architectures/algorithms tailored for each class of applications, *e.g.*, CNN, RNN, Transformer, NeRF, diffusion, GAN, VAE, . . .

**20%** data labeling - expensive, data availability - unlimited web text corpus

**15%** computation power/parallelism - AI accelerators, *e.g.*, GPU, TPU & NPU

**10%** rest - Python, open source software, cloud computing, MLOps, . . .

**Sudden leap in LLM performance**

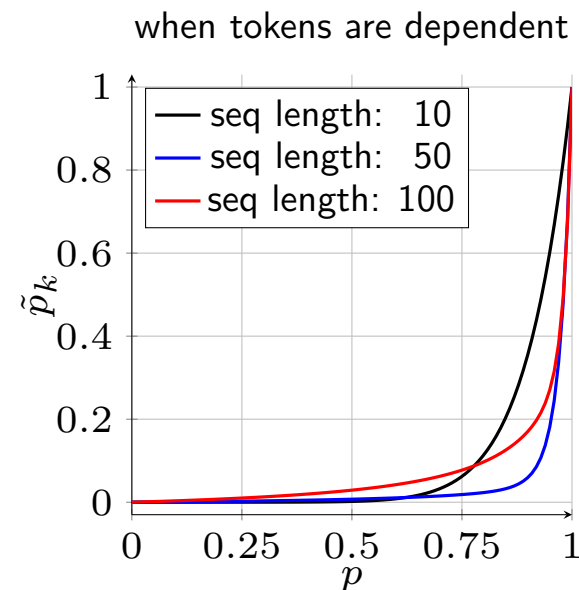
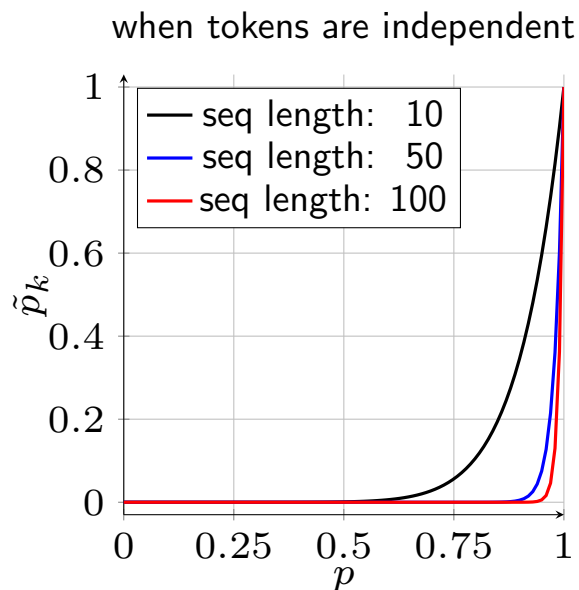
## Probability inferred sequence is correct

- assume
  - $t_i$  -  $i$ th token
  - $p_i$  - probability that  $t_i$  is correct
  - $\rho_i$  - correlation coefficient between  $t_{i-1}$  &  $t_i$
  - $\tilde{p}_k$  - probability that  $(t_1, \dots, t_k)$  are correct
- recursion

$$\rho_i = \frac{\tilde{p}_i - \tilde{p}_{i-1}p_i}{\sqrt{\tilde{p}_{i-1}(1 - \tilde{p}_{i-1})p_i(1 - p_i)}}$$
$$\Leftrightarrow \tilde{p}_i = \tilde{p}_{i-1}p_i + \rho_i \sqrt{\tilde{p}_{i-1}(1 - \tilde{p}_{i-1})p_i(1 - p_i)}$$

## Dramatic improvement of LLM near saturation

- do simulations for both independent & dependent cases
  - assume  $p_i$  are same for all  $i$
- (for both cases) sequence inference improves dramatically as  $p$  approaches 1
- this explains *why we have observed sudden dramatic performance improvement of certain seq2seq learning technologies, e.g., LLM*

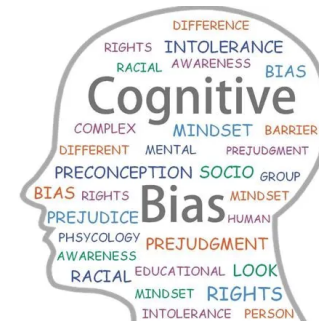
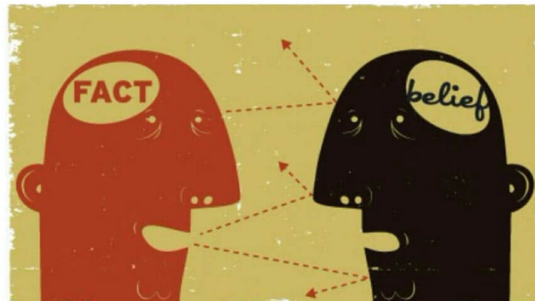


# Biases



## Cognitive biases attributed to humans

- cognitive biases [[Kah11](#)]
  - confirmation bias, availability bias
  - hindsight bias, confidence bias, optimistic bias
  - anchoring bias, halo effect, framing effect, outcome bias
  - belief bias, negativity bias, false consensus



## Biases of LLMs

- LLMs subject to
  - availability bias - biased by imbalancedly available information
    - LLM trained by imbalanced # articles for specific topics
  - belief bias - derive conclusion not by reasoning, but by what it saw
    - LLM easily inferencing what it saw, *i.e.*, data it trained on
  - halo effect - overemphasize on what prestigious figures say
    - LLM trained by imbalanced # reports about prestigious figures
- similar facts true for other types of ML models,
  - *e.g.*, video caption, text summarization, sentiment analysis
- cognitive biases only human represent
  - confirmation bias, hindsight bias, confidence bias, optimistic bias, anchoring bias, negativity bias, framing effect

# AI Ethics

## Ethical issues related to AI

- AI can be exploited by those who have bad intention to
  - manipulate / deceive people - using manipulated data corpus for training
    - *e.g.*, spread false facts
  - induce unfair social resource allocation
    - *e.g.*, medical insurance, taxation
  - exploit advantageous social and economic power
    - *e.g.*, unfair wealth allocation, mislead public opinion
- AI for Good - advocated by Andrew Ng
  - *e.g.*, public health, climate change, disaster management
- should scientists and engineers be morally & politically conscious?
  - *e.g.*, Manhattan project

## **AI related Legal Issues**

## Legal issues with ethical consideration

- scenario 1 - full self-driving algorithm causes traffic accident killing people
  - who is responsible? - car maker, algorithm developer, driver, algorithm itself?
- scenario 2 - self-driving cars kill less people than human drivers
  - *e.g.*, human drivers kill 1.5 people for 100,000 miles & self-driving cars kill 0.2 people for 100,000 miles
  - how should law makers make regulations?
  - utilitarian & humanitarian perspectives
- scenario 3 - someone is not happy with their data being used for training
  - “The Times sues OpenAI and Microsoft over AI use of copyrighted work” (Dec-2023)
  - “Newspaper publishers in California, Colorado, Illinois, Florida, Minnesota and New York said Microsoft and OpenAI used millions of articles without payment or permission to develop ChatGPT and other products” (Apr-2024)

# Consciousness

## Consciousness

- what is consciousness, anyway?
  - recognizes itself as independent, autonomous, valuable entity?
  - recognizes itself as living being, unchangeable entity?
- no agreed definition on consciousness exists yet  
... and will be so forever
- does it have anything to do with the fact that humans are biologically living being?
- is SKYNET ever plausible?
  - can AI have *desire* to survive (or save earth)?





# **Utopia vs Dystopia**

## Utopia vs dystopia



- not important questions (at all) *I think . . .*
- what we should focus on is *not* the possibilities of doomday or Judgment Day, but rather
  - our limits on controlling unintended impacts of AI
  - *misuse* by (greedy, immoral, and unethical) people possessing social, economic & political power
  - *social good and welfare impaired* by either exploiting AI or ignorance of (inner workings of) AI
- should concern
  - choice or balance among utilitarianism, humanitarianism & values
  - amend or improve laws/regulations
  - ethical issues caused by AI

# **Knowledge, Belief, and Reasoning**

**Does AI (LLM) have knowledge or belief? Can it reason?**

**What categories of questions do they belong to?  
engineering, scientific, philosophical, cognitive scientific, . . . ?**

## LLMs . . .

- LLM is very different sort of animal . . . except that it is *not* an animal!
- *unreasonable* effectiveness of data [HNF09]
  - *performance scales with size of training data*
  - *qualitative leaps* in capability as models scale
  - tasks demanding human intelligence *reduced to next token prediction*
- focus on third surprise

*conditional probability model looks like human with intelligence*

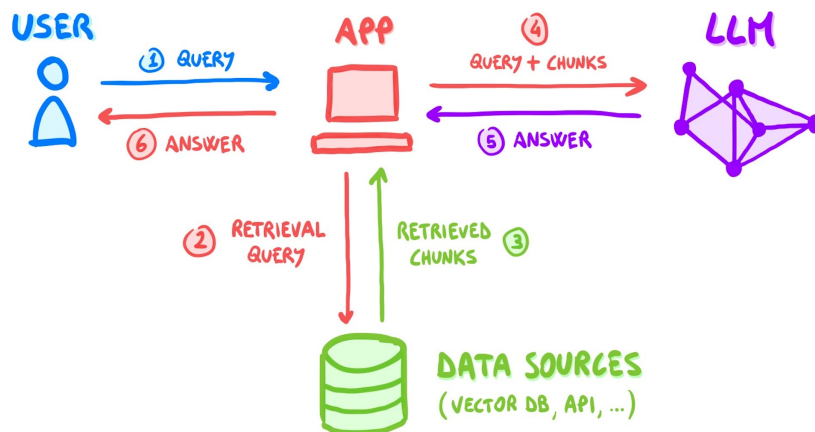
- making vulnerable to anthropomorphism
- examine it by throwing questions such as
  - “*does LLM have knowledge and belief?*”
  - “*can it reason?*”

## What LLM really does!

- given prompt “the first person to walk on the Moon was”, LLM responds with “Neil Armstrong”. . . strictly speaking
  - it’s *not* being asked *who* was the first person to walk on the Moon
  - what are being *really* asked is *“given statistical distribution of words in vast public corpus of text, what words are most likely to follow ‘The first person to walk on the Moon was’?”*
- given prompt “after ring was destroyed, Frodo Baggins returned to”, LLM responds with “the Shire”
  - on one level, it seems fair to say, you might be testing LLM’s knowledge of fictional world of Tolkien’s novels
  - what are being *really* asked is *“given statistical distribution of words in vast public corpus of text, what words are most likely to follow ‘After the ring was destroyed, Frodo Baggins returned to’?”*

## LLMs vs systems in which they are embedded

- crucial to distinguish between the two (for philosophical clarity)
  - LLM (bare-bones model) - highly specific & well-defined function, which is *conditional probability estimator*
  - systems in which LLMs are embedded, *e.g.*, for question-answering, news article summarization, screenplays generation, language translation



## How ChatBot works?

- conversational AI agent does *in-context learning* or *few-shot prompting*
- for example,
  - when the user enters  
who is the first person to walk on the Moon?
  - ChatBot, LLM-embedded system, feeds the following to LLM  
User, a human, and BOT, a clever and knowledgeable AI agent.  
User: what is 2+2?  
BOT: the answer is 4.  
User: where was Albert Einstein born?  
BOT: he was born in Germany.  
User: who is the first person to walk on the Moon?  
BOT:



## Knowledge, belief & reasoning around LLM

- *not* easy topic to discuss, or even impossible because
  - we *do not have agreed definition* of these terms especially in context of being asked questions like

*does LLM have belief?*

or

*do humans have knowledge?*

- let us discuss them in two different perspectives
  - laymen's perspectives
  - cognitive scientific & philosophical perspectives

## Laymen's perspectives on knowledge, belief & reasoning

- does (good) LLM have knowledge?
  - Grandmother: looks like it cuz when instructed *“explaining big bang”*, it says  
*“ The Big Bang theory is prevailing cosmological model that explains the origin and evolution of the universe. . . . 13.8 billion years ago . . . ”*
- does it have belief?
  - Grandmother: I don't think so, *e.g.*, it does not believe in God!
- can it reason?
  - Grandmother: seems like it! *e.g.*, when asked *“Sunghee is a superset of Alice and Beth is a superset of Sunghee. is Beth a superset of Alice?”*, it says  
*“ Yes, based on information provided, if Sunghee is a superset of Alice and Beth is a superset of Sunghee, then Beth is indeed a superset of Alice . . . ”*
- can it reason to prove theorem whose inferential structure is more complicated?
  - Grandmother: I'm not sure – actually, I don't know what you're talking about!

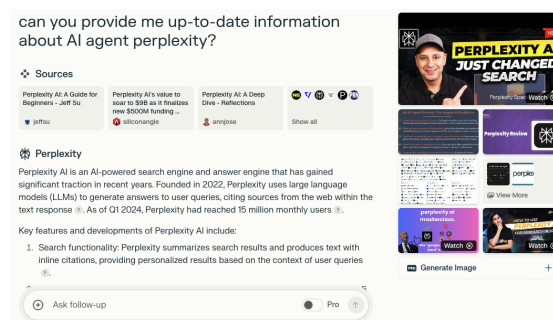
# Knowledge

- could argue LLM “knows” which words follow which other words with high probability
- but, only *in context of capacity to distinguish truth from falsehood* can we legitimately speak of “knowledge”!
- LLM(-embedded BOT)
  - can be said to “*encode*”, “*store*”, or “*contain*” knowledge
  - lacks means to use words “true” & “false” in all ways & in all contexts because . . .
  - *does not inhabit the world* we human language-users share!



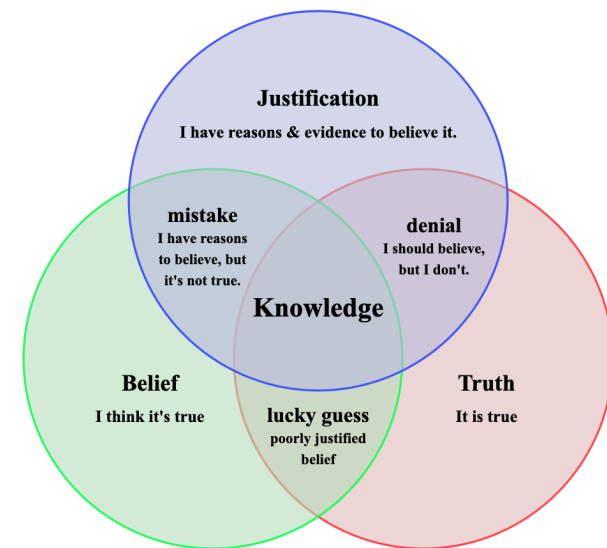
## Belief

- nothing can count as *belief about the world* we share unless
  - is against backdrop of “*ability to update beliefs appropriately in light of evidence from that world*” - (again) essential capacity to distinguish truth from falsehood
- change taking place in humans when acquiring or updating belief is
  - reflection of their nature as language-using animals inhabiting shared world with community of language-users
- then, *what if LLM-embedded system updates LLM with outside world information?*
  - even so, when interacting with AI systems based on LLMs, these grounds are *absent!*



## Knowledge in philosophical and cognitive scientific sense

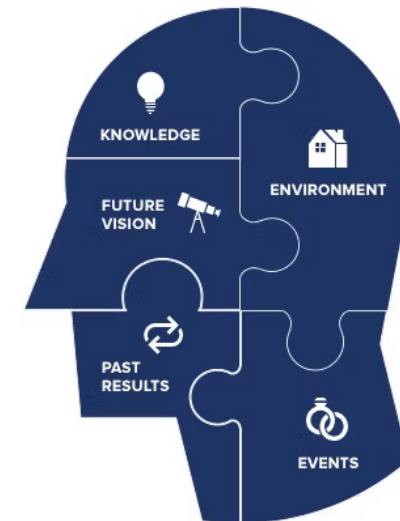
- does LLM have knowledge?
  - Sunghee: *I don't think so!*
- why?
  - we say we have “knowledge” when  
*“we do so against ground of various human capacities that we all take for granted when we engage in everyday conversation with each other.”*
  - when asked *“who is Tom Cruise's mother?”*, it says *“Tom Cruise's mother is Mary Lee Pfeiffer.”*  
However, this is nothing but  
*“guessing” by conditional probability model the most likely words following “Tom Cruise's mother is.”*
  - so *we cannot say it really knows the fact!*



## Belief in philosophical and cognitive scientific sense

- for the discussion
  - do *not* concern any specific belief
  - but concern *prerequisites for ascribing any beliefs to AI system*
- so does it have belief?
  - nothing can count as belief about the world we share unless
    - it is against ground of the ability to update beliefs appropriately in light of evidence from that world, essential aspect of the capacity to distinguish truth from falsehood*
  - LLM does not have this ground, essential consideration when deciding whether it *really* had beliefs.
- Sunghee: so *no, LLM cannot have belief!*

### WHERE DO YOUR BELIEFS COME FROM?



## Reasoning in philosophical and cognitive scientific sense

- note reasoning is *content neutral*
  - *e.g.*, following logic is perfect regardless of truth of premises
  - hence, no access to outside world does *not* disqualify
- when asked “*if humans are immortal, would Socrates have survived today?*”, LLM says “*. . . it’s logical to conclude that Socrates would likely still be alive today. . . .*”
- however, remember, once again, what we just asked it to do is *not* “deductive inference”  
*given the statistical distribution of words in public corpus, what words are likely to follow the sequence, “humans are immortal and Socrates is human therefore.”*
- Sunghee: so *no, LLM cannot reason, either!*
- but, LLM
  - pretends to reason, and from which capabilities, we can benefit!
  - also, can *mimic even multi-step reasoning whose inferencing structure is complicated* using *chain-of-thoughts prompting*, *i.e.*, *in-context learning* or *few-shot prompting*

## Simple example showing LLM not possessing knowledge

- User

*"Who is Tom Cruise's mother?"*



- LLM(-embedded question-answering system) (as of Jan 2022)

*"Tom Cruise's mother is Mary Lee Pfeiffer. She was born Mary Lee South. . . . Information about his family, including his parents, has been publicly available, . . . "*

- User

*"Who is Mary Lee Pfeiffer's son?"*

- LLM(-embedded question-answering system) (as of Jan 2022)

*"As of my last knowledge update in January 2022, I don't have specific information about Mary Lee Pfeiffer or her family, including her son. . . . "*



## Risk of anthropomorphization

- unfortunately, contemporary LLMs are *too powerful, too versatile, and too useful for most people to accept (after understanding) previous arguments!*
- maybe, o.k. for laymen to (mistakenly) anthropomorphize LLM(-embedded systems)
- however, *imperative for (important, smart, and responsible) AI researchers, scientists, engineers & practitioners* to have rigorous understanding in these aspects especially when
  - advise and be consulted by law makers, policy makers, journalists, and various stakeholders responsible for *critical business decisions (in private sectors) and public policies (in public sectors)*
  - collaborate with or/and help professionals in liberal arts, such as *philosophy, ethics, law, religion, literature, history, music, cultural studies, psychology, sociology, anthropology, political science, economics, archaeology, linguistics, media studies, natural sciences, fine arts, . . .*
  - to address negative societal and economic impacts

## Moral

- AI shows incredible utility and commercial potentials, hence should
  - make informed decisions about trustworthiness and safety
  - avoid ascribing capacities they lack
  - *take best utilization of remarkable capabilities of AI*
- today's AI so powerful, so (seemingly) convincingly intelligent
  - obfuscate mechanism
  - actively encourage *anthropomorphism* with philosophically loaded words like *“believe”* and *“think”*
  - easily mislead people about character and capabilities of AI
- matters not only to scientists, engineers, developers, and entrepreneurs, but also
  - *general public, law & policy makers, journalists, . . .*

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**Thank You**