# AI - Industry & Society

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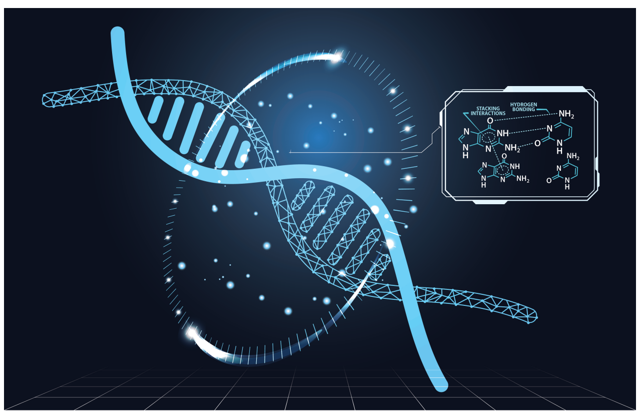
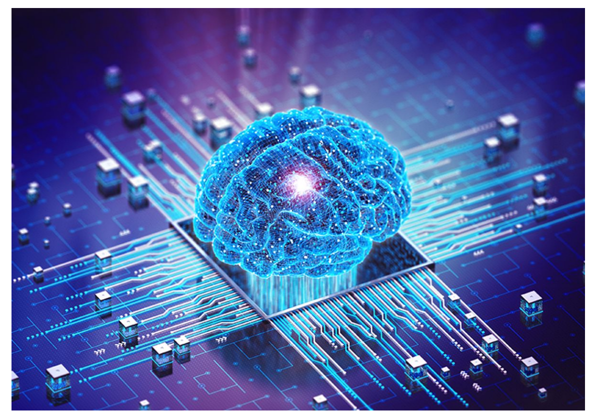
# AI & Biotech

# 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





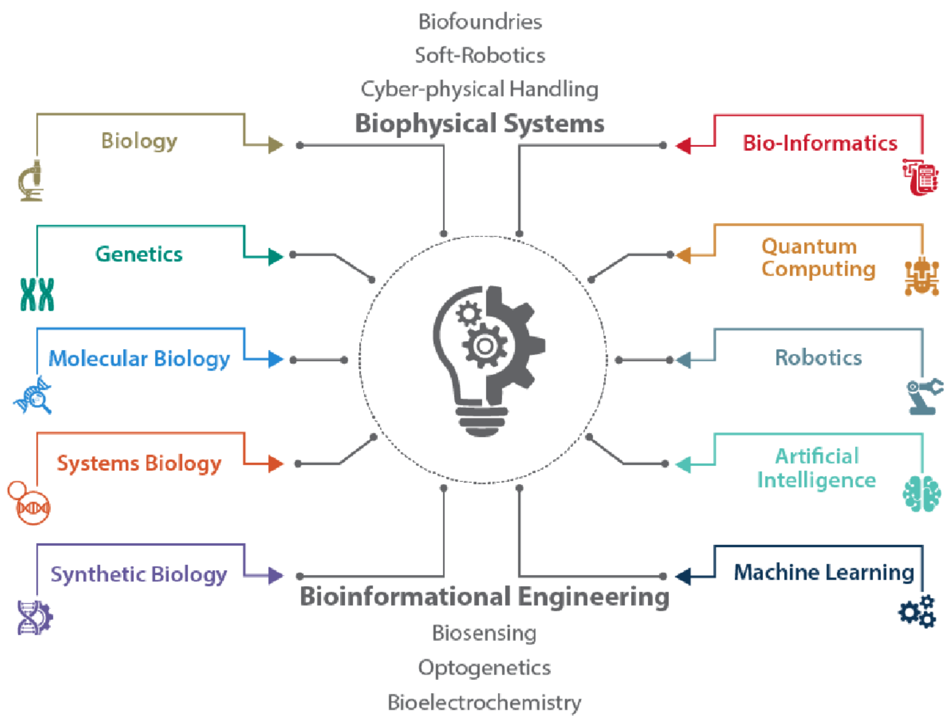
# Biotech

# 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]

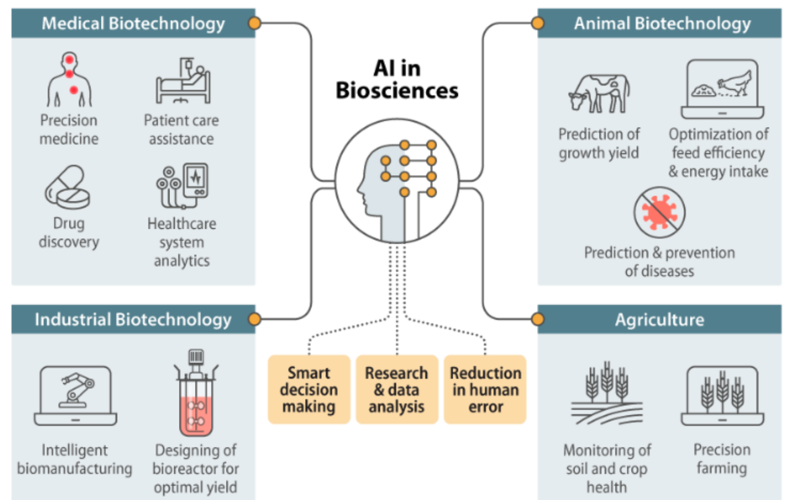


# Convergence of AI and biological design

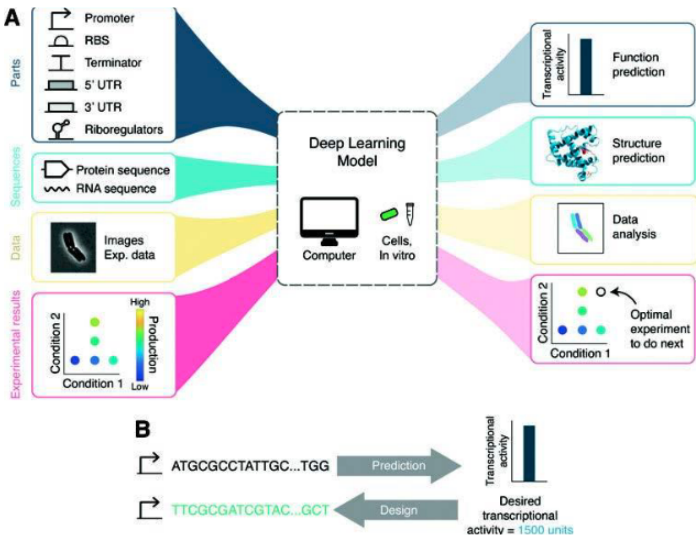
- AI & biological sciences converging [BKP22]
  - each building upon the other's capabilities for new research and development across multiple areas
- Demis Hassabis, CEO & cofounder of DeepMind, said of biology [Toe23]

  > ". . . 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



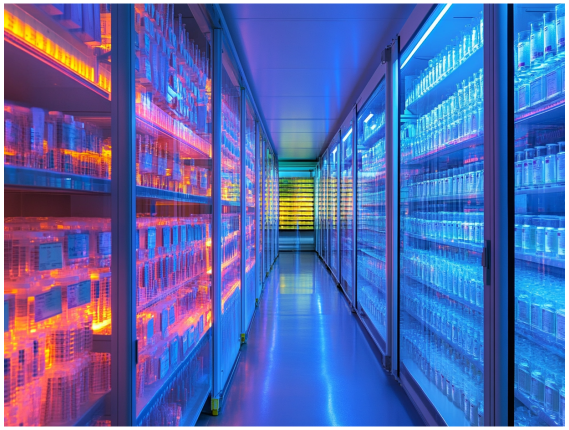

- AI, essential to analyzing exponential growth of genetic sequence data

  "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



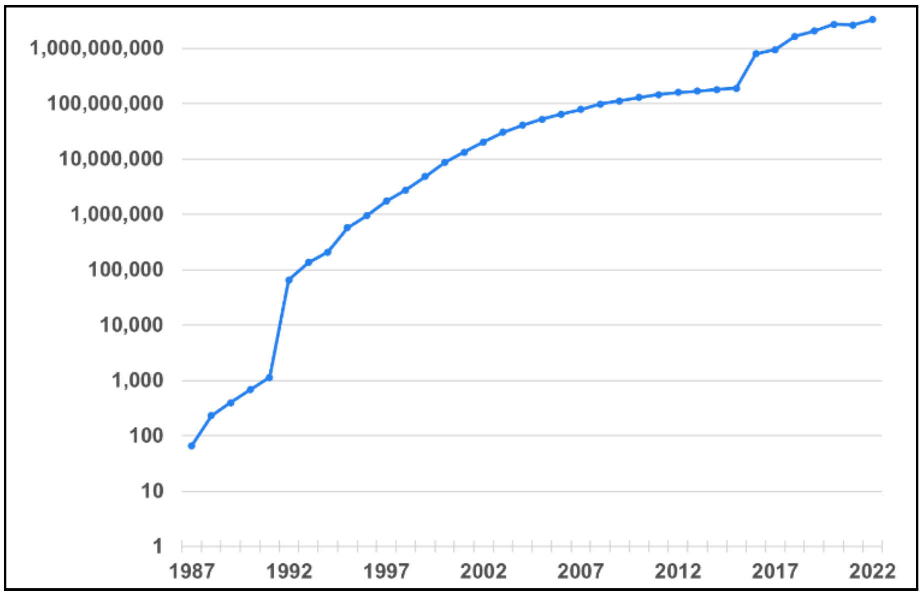
# Rapid growth of biological data

- 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

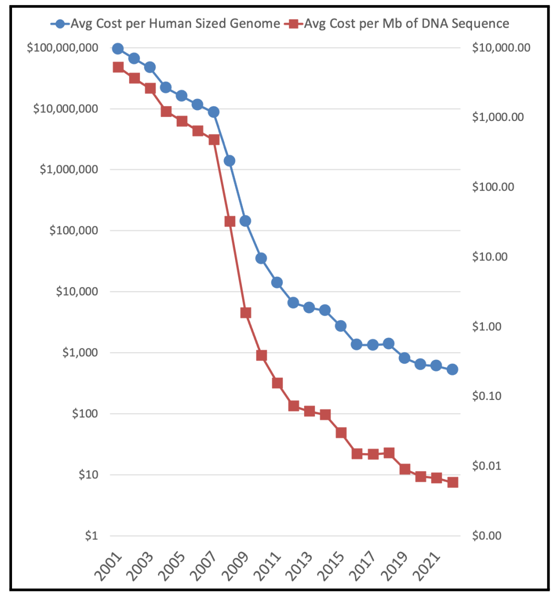
# Volume and sequencing cost of DNA over time

- 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



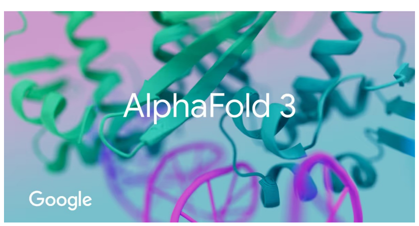
## Bio data availability and bias

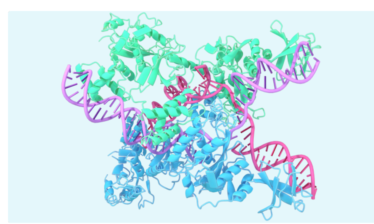
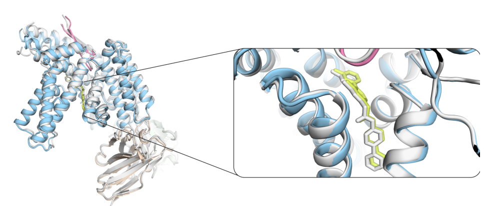
- US National Security Commission on Artificial Intelligence (NSCAI) recommends
  - US fund and prioritize development of a biobank containing *"wide range of high-quality biological and genetic data sets securely accessible by researchers"*
  - establishment of database of broad range of human, animal, 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 $\rightarrow$ AlphaFold 2 (2020) - attention-based NN solving protein folding "in principle" $\rightarrow$ 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 19×19 grid - $(19 \times 19)! = 361! \approx 1.44 \times 10^{768}$
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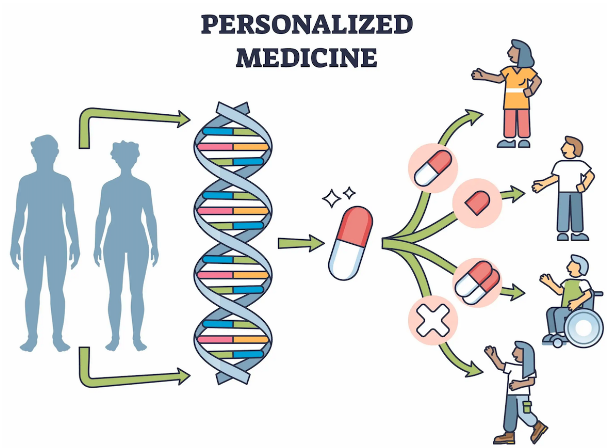
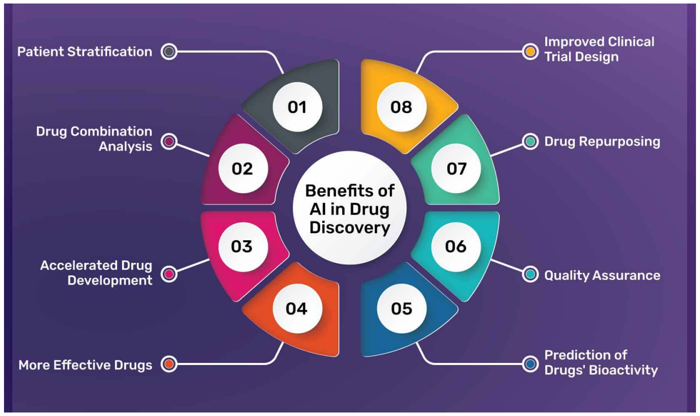
- deep reinforcement learning with Monte Carlo tree search
  - trained on thousands of years of Go game history
  - AlphaGo Zero learns by playing against itself
- development experience, insight, knowledge, know-how transferred to AlphaFold

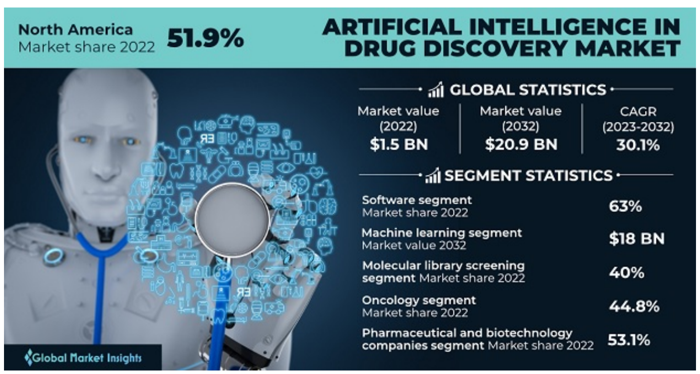

# Personalized medicine

- *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

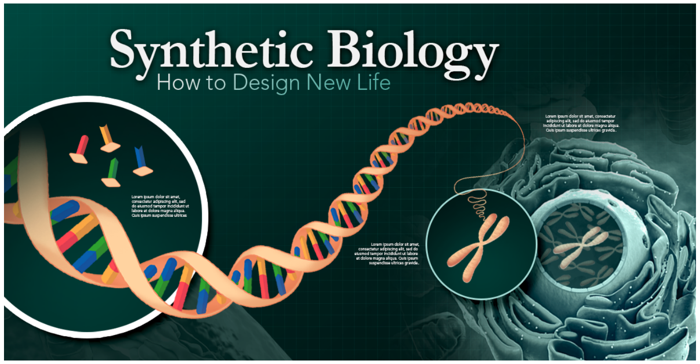


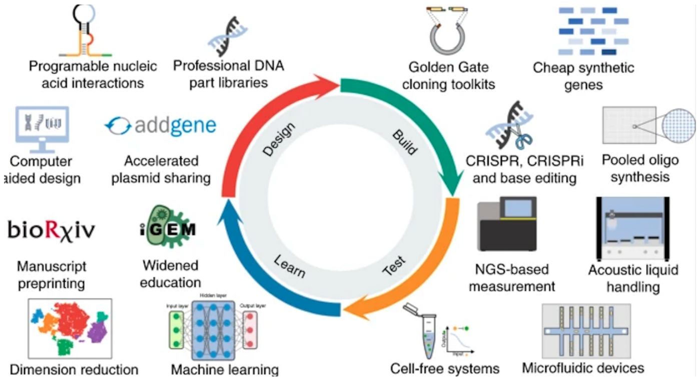




- traditional drug discovery process - time-consuming and costly often taking decades and billions of dollars
- AI streamlines this process by predicting the efficacy and safety of potential compounds with more speed and accuracy
- AI models analyze chemical databases to identify new drug candidates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

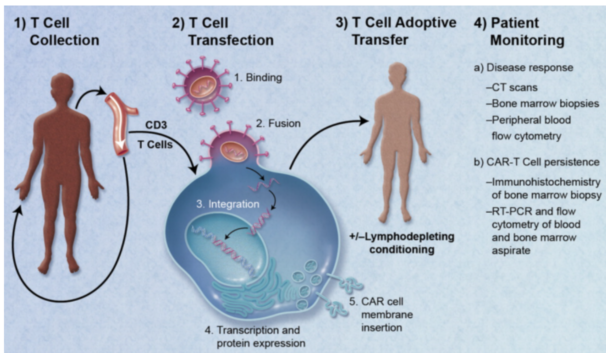
# Synthetic biology

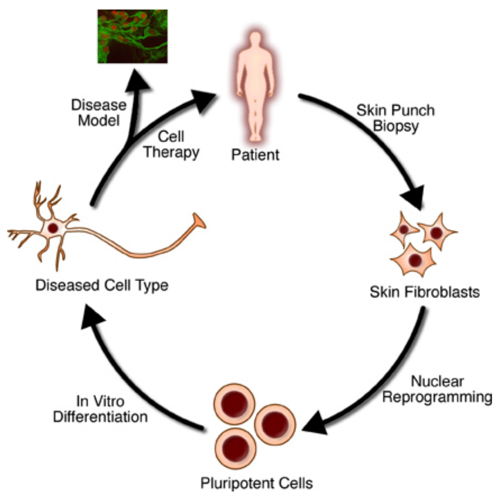
- use AI for gene editing, biomaterial production and synthetic pathways
- combine principles of biology and engineering to design and construct new biological entities
- AI optimizes synthetic biology processes from designing genetic circuits to scaling up production
- company - Ginkgo Bioworks uses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



# Regenerative medicine

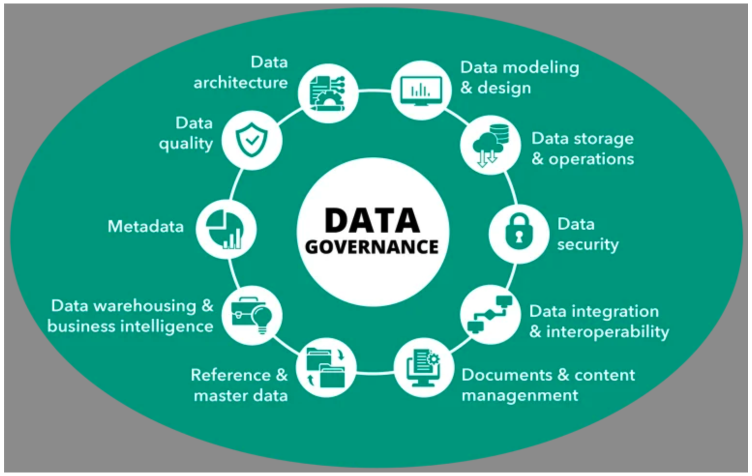


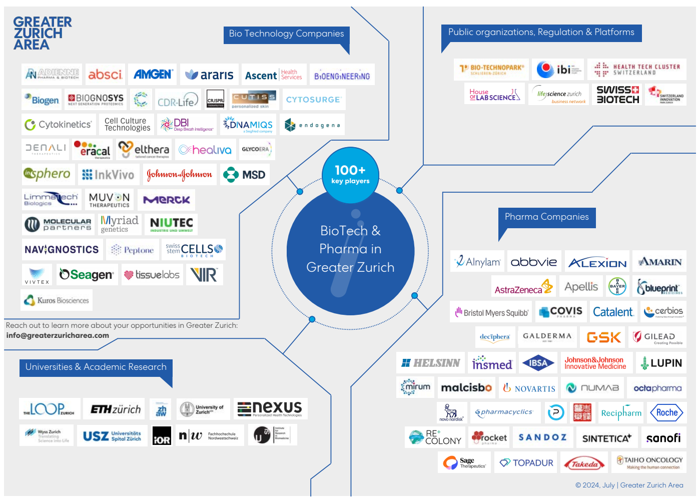

- AI advances development of stem cell therapies & tissue engineering
- AI algorithms assist in identifying optimal cell types, predicting cell behavior & personalized treatments
- particularly for conditions such as neurodegenerative diseases, heart failure and orthopedic injuries
- company - Organovo 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



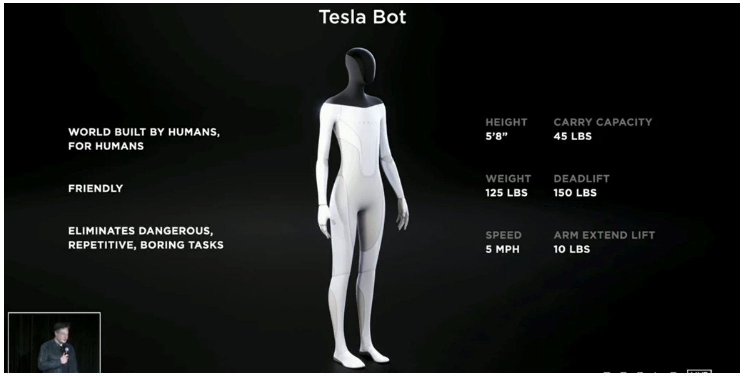

- Atomwise - small molecule drug discovery
- Cradle - protein design
- Exscientia - precision medicine
- Iktos - small molecule drug discovery and design
- Insilico Medicine - full-stack drug discovery system
- Schrödinger, Inc. - use physics-based models to find best possible molecule
- Absci Corporation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

# AI-powered Humanoid Robots

# Tesla Optimus

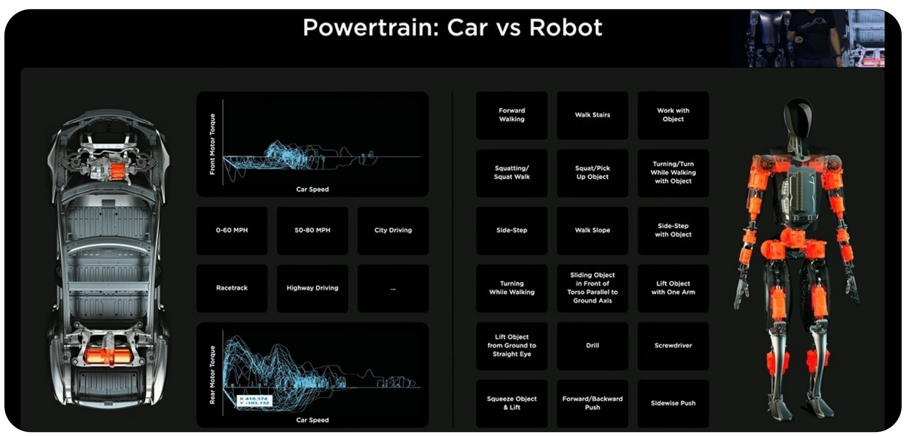
# Tesla Optimus

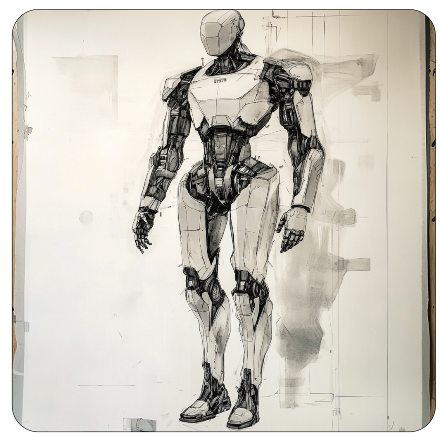
- humanoid robot developed by Tesla intended to handle repetitive & dangerous tasks
- objective - *revolutionize automation* & assist in human labor across various industries
- features - YouTube - Optimus - Gen 2
  - dimensions - 5'8" tall & 125 lbs
  - capabilities - lifting weights, walking at 5 MPH & performing everyday tasks
  - AI-powered - runs on Tesla's AI leveraging same technology used in self-driving cars
  - power source - 2.3 KWH battery designed for efficient power management
  - launch year - announced by Elon Musk during Tesla AI Day in 2021
  - *price - $25,000~$30,000* expected to decrease over time




# History of Tesla Optimus

- inception - first conceptualized as extension of Tesla's AI & robotics capabilities
- AI day 2021 - *officially announced by Elon Musk* w/ vision to solve labor shortages & improve productivity
- Sep 2022 - prototype unveiled
- gen 2 introduced in 2023 - improved capabilities
- Jun 2024 w/ more advanced tasks - *towards mass production for commercial applications*

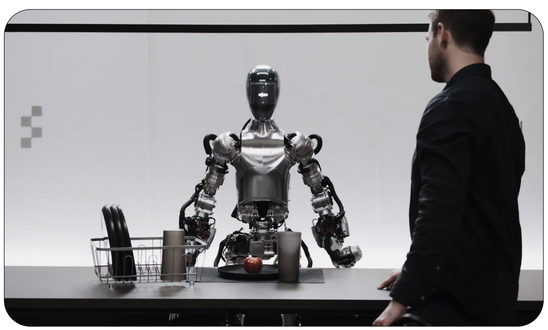
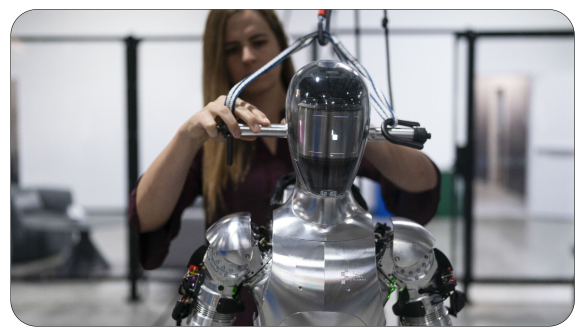


# Figure AI

# Figure AI robots

- Figure AI
  - founded in 2022 as Silicon Valley startup company by Brett Adcock - serial entrepreneur with successful Archer Aviation & Vettery
  - vision of enhancing productivity by integrating AI and robotics into both industrial & personal spaces
- Figure 02
  - 5'6" tall, 154 lbs, payload of 44 lbs, 5 hr runtime, 1.2 m/s speed
  - imitation learning
  - capabilities - advanced cognition, STS task, dexterous hands w/ 16 degrees of freedom

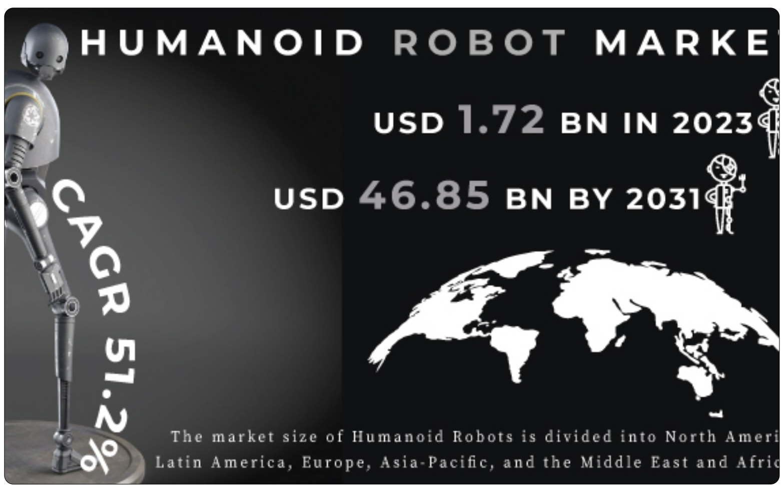
# History of Figure AI

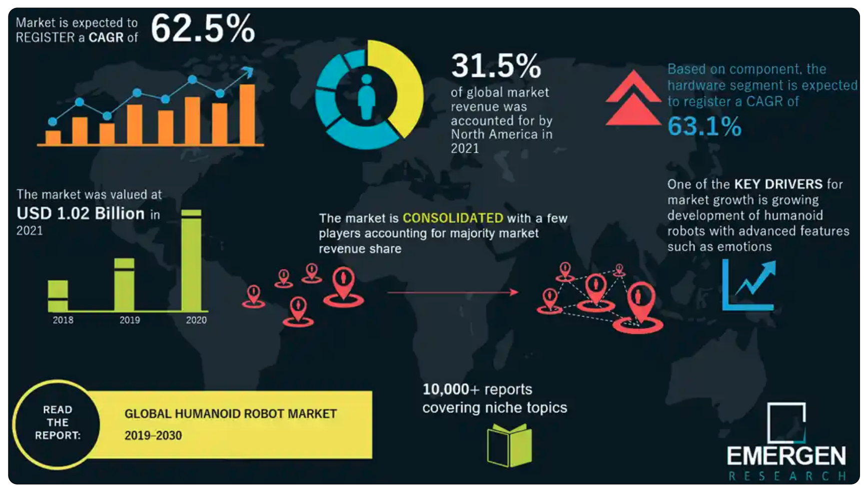
- 2022 - founded by Brett Adcock - previously co-founded Archer Aviation & Vettery
- 2022-2023 - early development - stealth mode focusing on developing their own technology
- May 2023 - public announcement - officially announces mission to develop general-purpose humanoid robots - already raised \$70M @ announcement
- Aug 2023 - unveils Figure 01, first prototype w/ basic mobility & manipulation capabilities
- Oct 2023 - series B funding - raised \$675M beyond initial goal of \$500M - Jeff Bezos, Microsoft, OpenAI - valuation of $\sim$ \$2.6B
- late 2023 $\sim$ early 2024 - partnership announcements - refines humanoid robot technology in locomotion, object manipulation & human-robot interaction
- 2024 - significant strides in robot control & decision-making

# Impacts & Future

# Impacts on industries & markets

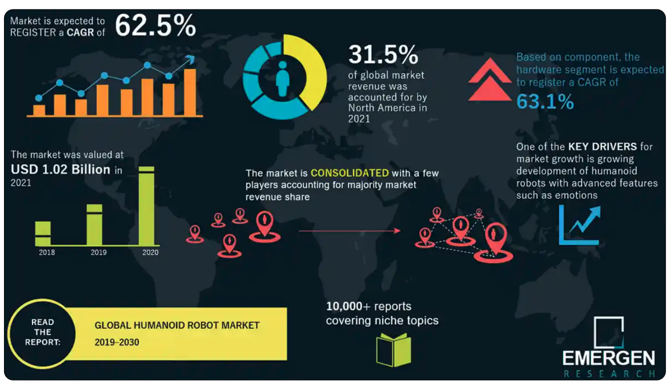
- impacts on robotics history
  - competitor benchmark - competes with robotics giants such as Boston dynamics
  - affordability & scale - predict to lead to *lower costs & higher adoption*
- impacts on labor market
  - task automation - replace human labor in *high-risk & repetitive roles*
  - *job displacement vs creation* - new roles in AI, robot maintenance & oversight
- impacts on consumer market - home automation



# Future outlook & predictions

- widespread industrial adoption - expected to become common tool in factories by 2030
- market valued @ *$1.02B in 2021* - expected *CAGR of 62.5%, 63.1% in hardware segment by 2030* - *31.5% revenue increase in 2021* North America - *10,000 humanoid robots* will be shipped worldwide each year by 2027
- AI evolution - continuous learning and AI enhancements will lead to greater efficiency & adaptability
- consumer integration - long-term vision includes personal assistant
- societal impact - could redefine human roles in industries & homes *raising philosophical & ethical questions on human-robot collaboration*




# Industrial AI

# Industrial AI (inAI)

- inAI (collectively) refers to AI technology & software and their products developed for
  - *customer values creation, productivity improvement, cost reduction, production optimization, predictive analysis, insight discovery*

  in industries such as
  - *semiconductor, steel, oil & gas, cement, and other various manufacturing industries*

  (unlike general AI, which is frontier research discipline striving to achieve human-level intelligence)

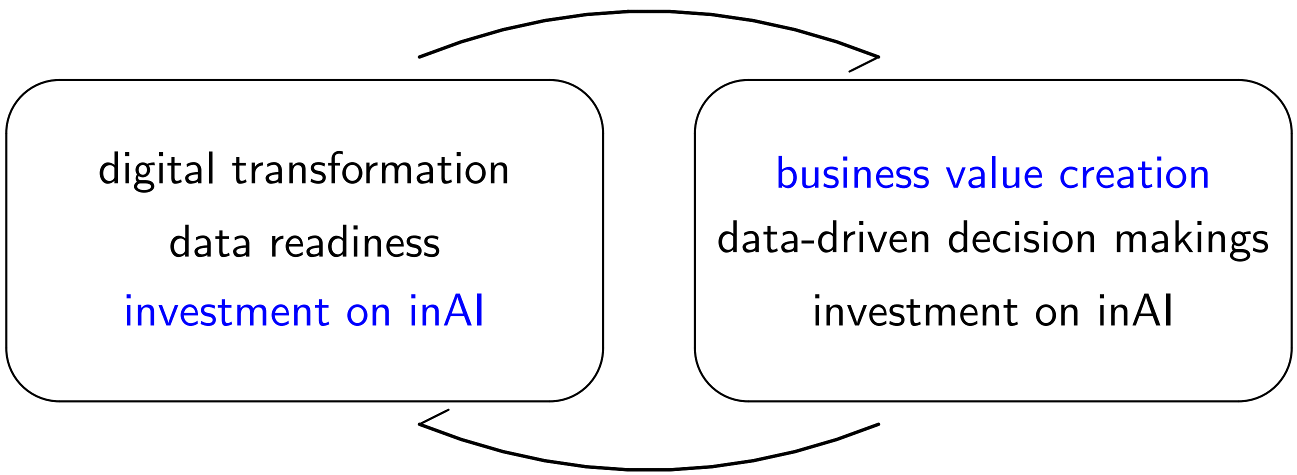
# inAI fields

- product
  - product design & innovation, adaptability & advancement, product quality & validation, design for reusability & recyclability, performance optimization
- production process
  - *production quality,* process management, inter-process relations, process routing & scheduling, process design & innovation, *traceability, predictive process control*
- machinery & equipment
  - *predictive maintenance, monitoring & diagnosis,* component development, *ramp-up optimization,* material consumption prediction
- supply chain
  - supply chain monitoring, material requirements planning, customer management, supplier management, logistics, reusability & recyclability

# Characteristics of inAI

# Vicious (or virtuous) cycle

- integration of inAI with customers' business creates monetary values and encourages data-driven decisions
- however, to do so, digital transformation with data-readiness is MUST-have
- created values, in turn, can be invested into infrastructure required for digital transformation and success of inAI!

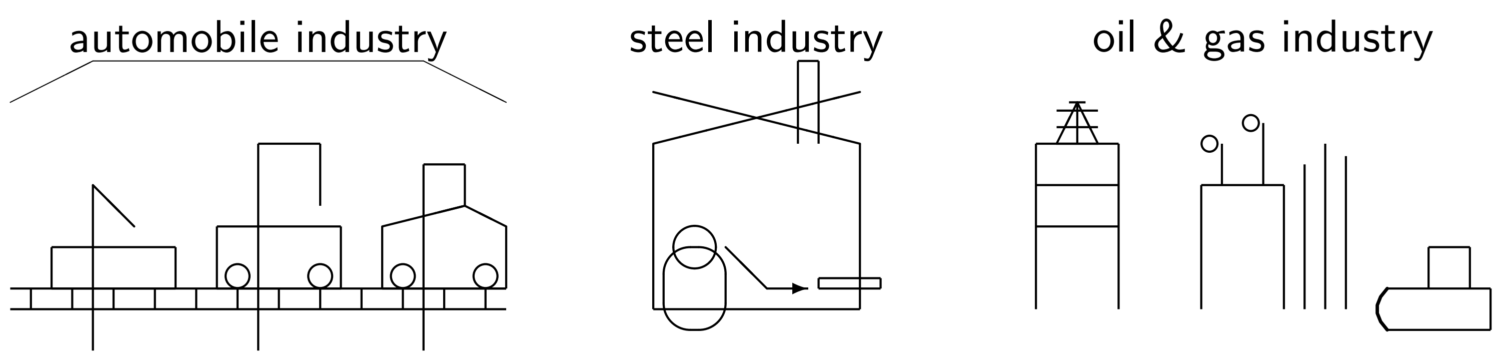


# Data-centric AI

- unlike many ML disciplines where foundation models do generic representation learning, $i.e.$, learn universal features
- each equipment has (gradually) different data characteristics, hence need data-centric AI

  ". . . need 1,000 models for 1,000 problems" - Andrew Ng

  - data-centric AI - discipline of systematically engineering the data used to build AI system



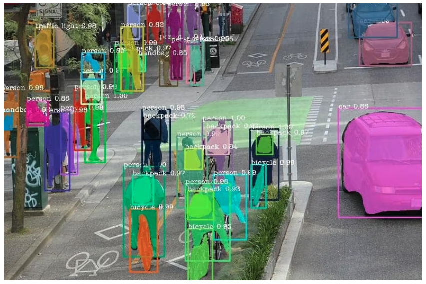
# Challenging data characteristics

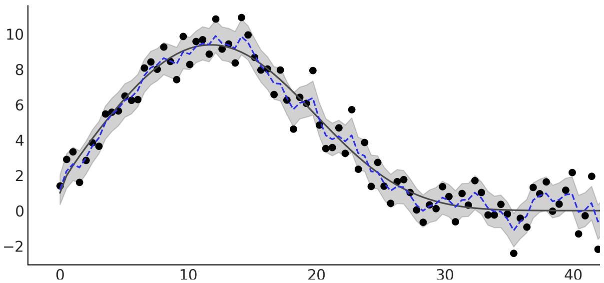
- huge volume
- data multi-modality
- high velocity requirement
- very fat data
- sever data shift & drift (in many cases)
- label imbalance
- data quality

# Manufacturing AI

# MLs in manufacturing AI (manAI)

- *image data* - huge amount of image data measured and inspected
  - SEM/TEM images, wafer defect maps, test failure pattern maps [1]
  
  → semantic segmentation, defect inspection, anomaly detection
- *time-series (TS) data* - *all the data* coming out of manufacturing is TS
  - equipment sensor data, process times, various measurements, MES data [2]
  
  → regression, anomaly detection, semi-supervised learning, Bayesian inference






[1] SEM: scanning electron miscroscope, TEM: transmission electron miscroscope

[2] MES: manufacturing execution system

# CV ML in manAI

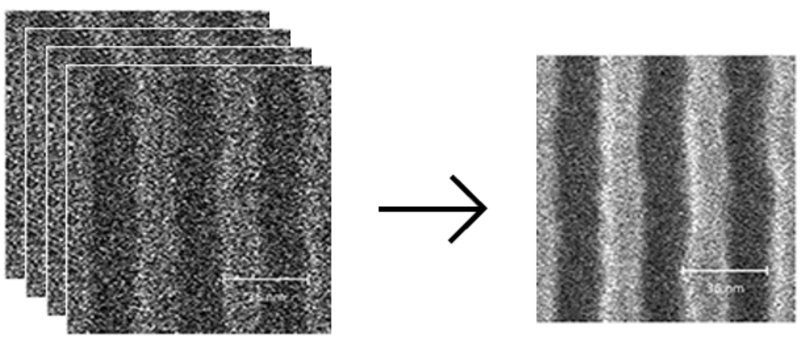
# Computer vision ML in manAI

- measurement and inspection (MI)
  - metrology - measurement of critical features
  - inspection - defect inspection, defect localization, defect classification
  - failure pattern analysis
- applications
  - automatic feature measurement
  - anomaly detection
  - defect inspection

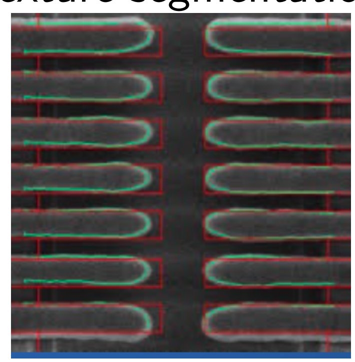
# Automatic feature measurement

- ML techniques
  - image enhancement (denoising)
  - texture segmentation
  - repetitive pattern recognition
  - automatic measurement

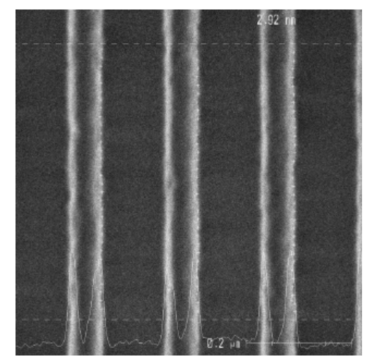
image enhancement



texture segmentation

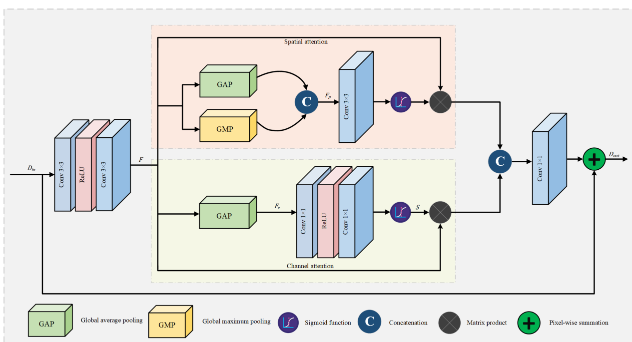


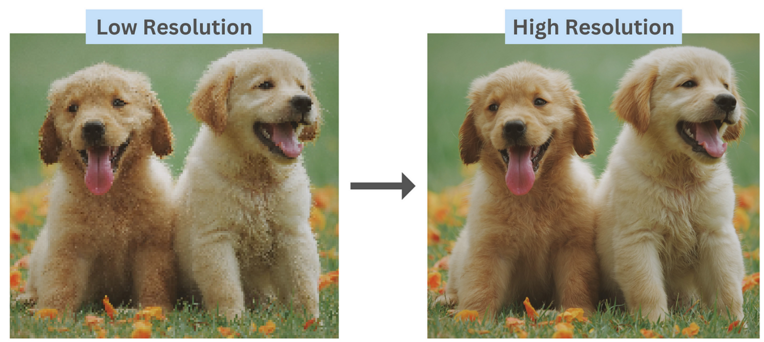
auto-measurement



# Image enhancement

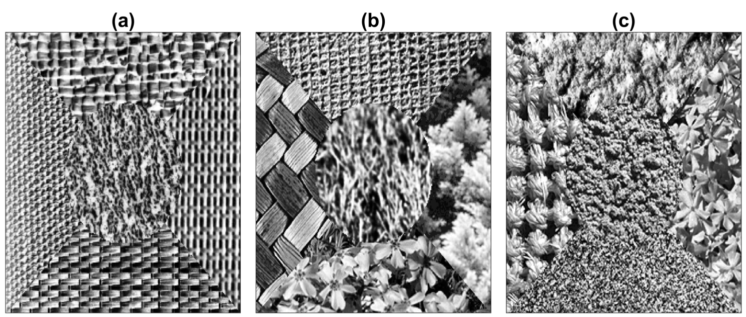
- image enhancement techniques
  - general supervised denoising using DL
  - blind denoising using DL - remove noise without prior knowledge of noise adapting to various noise types
  - super-resolution - upscale low-resolution images, add realistic details for sharper & higher-quality images



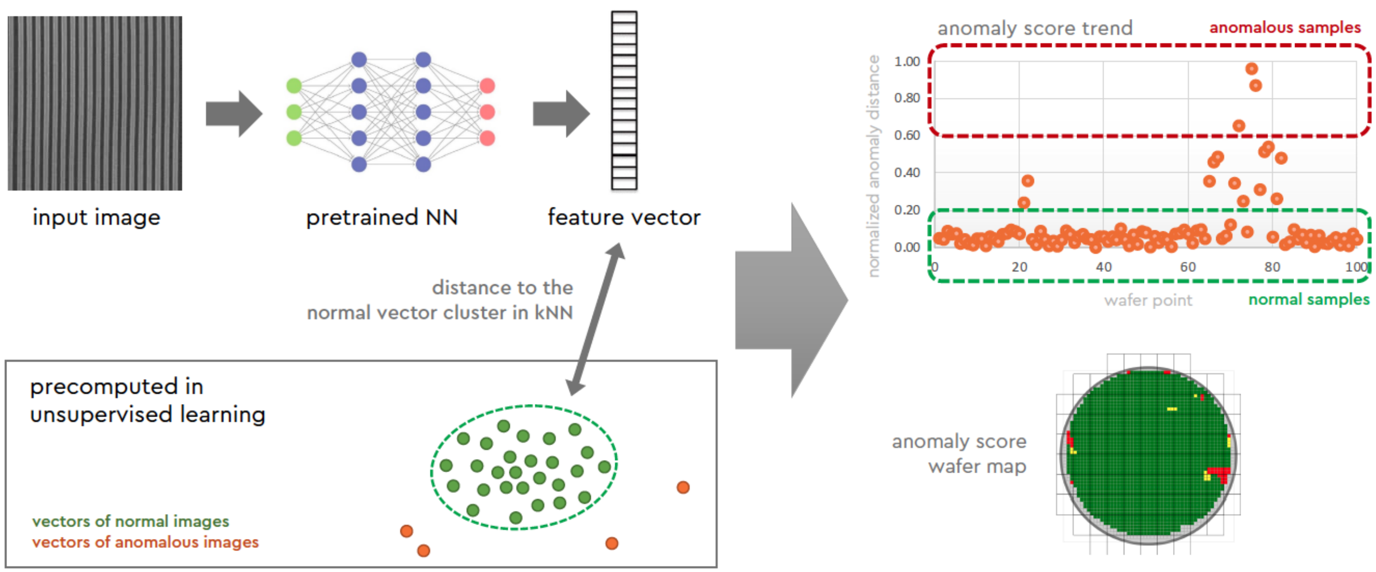
# Image segmentation

- texture segmentation
  - distinguish areas based on texture patterns - identifying regions with similar textural features - used for material classification, surface defect detection, medical imaging
  - methods - Gabor filters, wavelet transforms, DL
- semantic segmentation
  - assign class labels to every pixel - enabling precise object and region identification - used for autonomous driving, scene understanding, medical diagnostics
  - methods - fully convolutional network (FCN), U-net, DeepLab



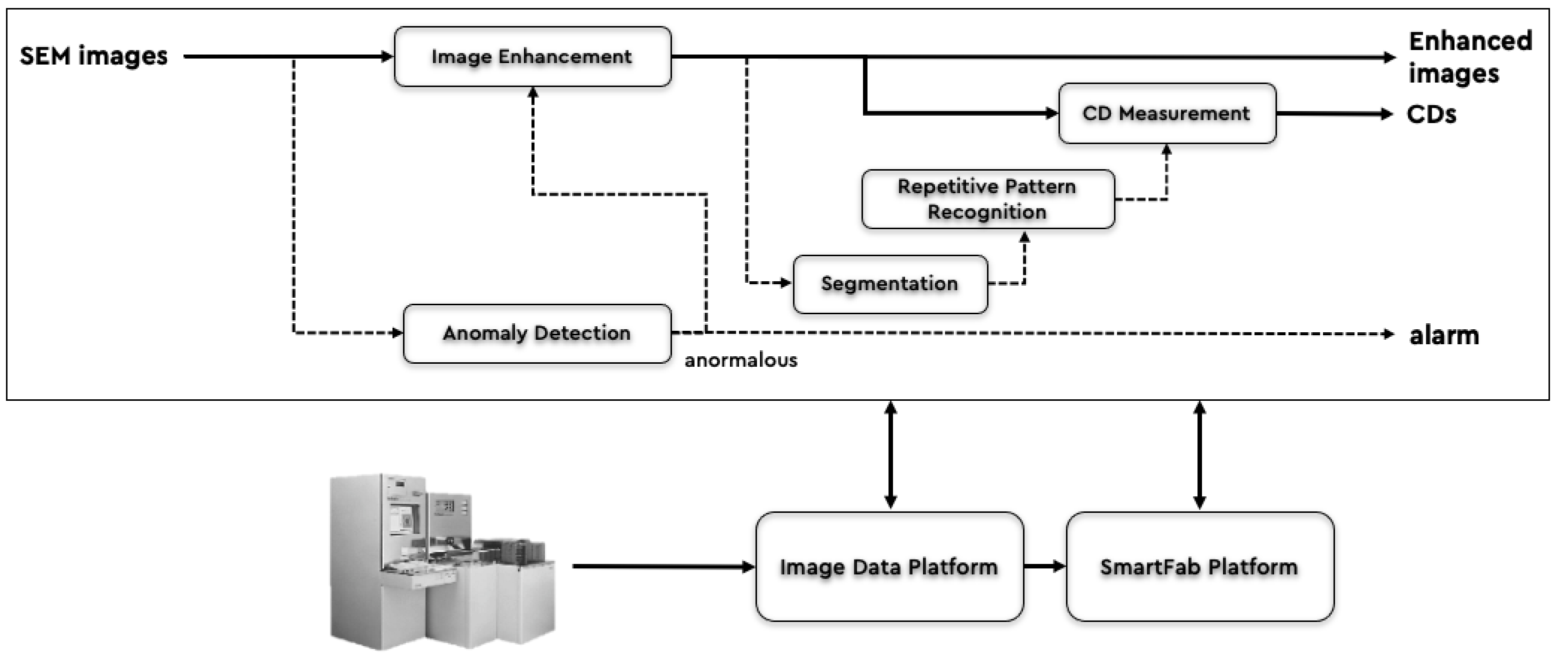

# Anomaly detection using side product

- representation in embedding space obtained as side product from previous processes
- distance from normal clusters used for anomaly detection
- can be used for yield drop prediction and analysis



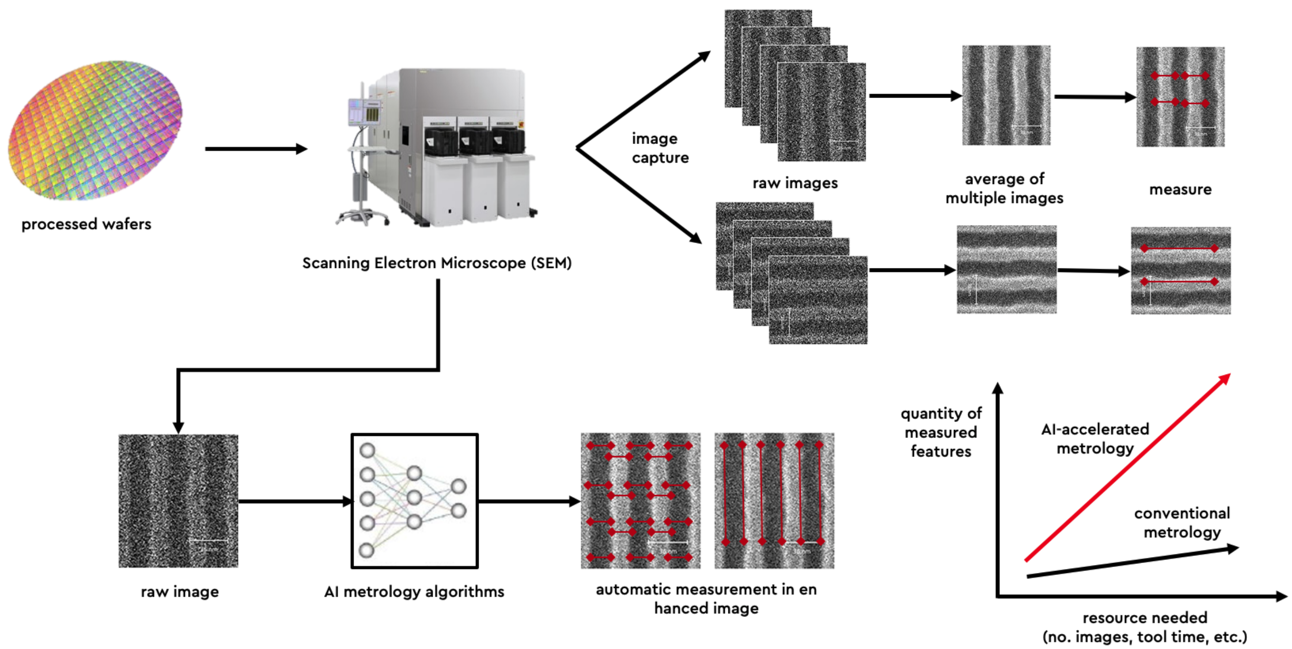
# AI-enabled metrology system

- integration of separate components creates AI-enabled metrology system



# Benefits of new system

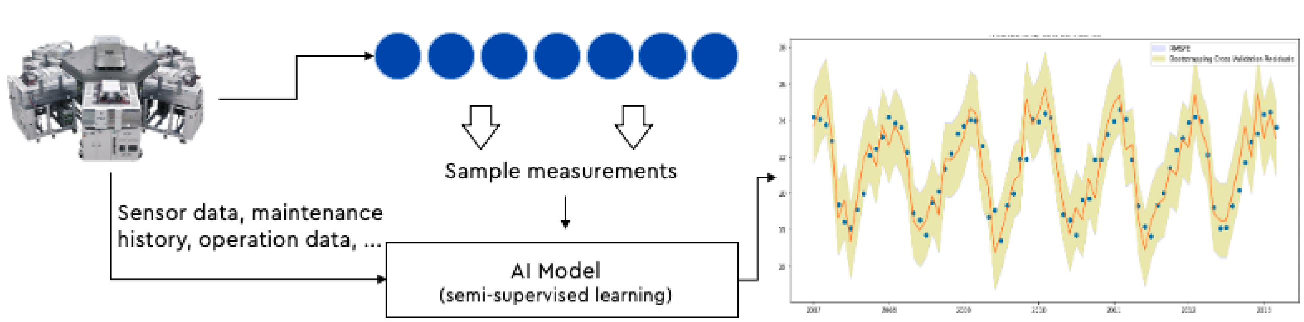
- new system provides
  - improved accuracy and reliability
  - improved throughput
  - savings on investment on measurement equipment



# TS ML in manAI

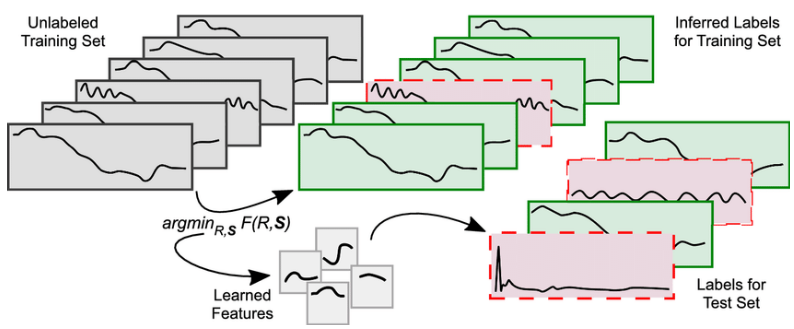
# Time-series ML applications in manAI

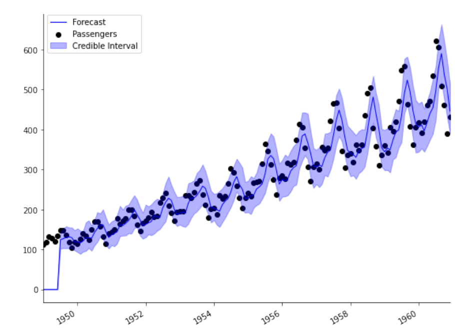
- estimation of TS values
  - virtual metrology - estimate measurement without physically measuring things
- anomaly detection on TS
  - predictive maintenance - predict maintenance times ahead
- multi-modal ML using LLM & genAI
  - root cause analysis and recommendation system




# TS MLs in manAI

- TS regression/prediction/estimation
  - LSTM, GRU, attention-based models, Transformer-based architecture for capturing long-term dependencies and patterns
- anomaly detection
  - isolation forest, autoencoders, one-class SVM
- TS regression providing credibility intervals
  - Bayesian-based approaches offering uncertainty estimation alongside predictions



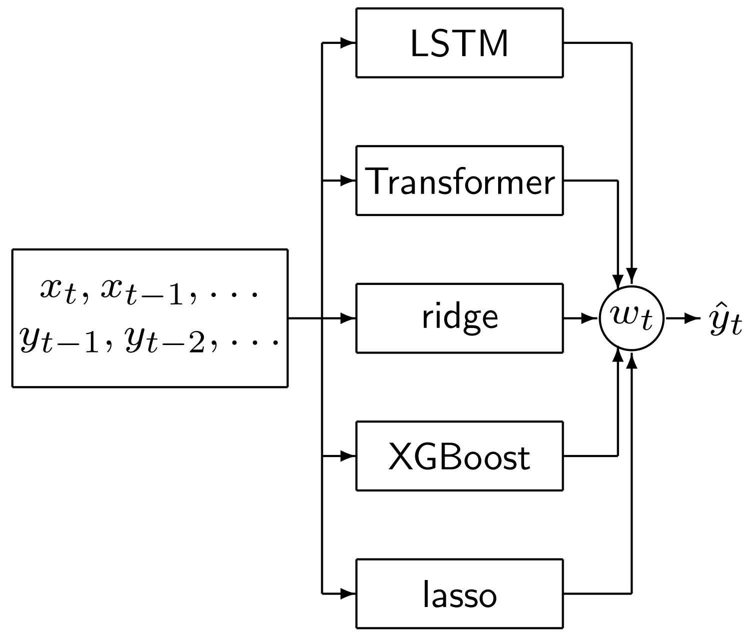



# Difficulties with TS ML

- no definition exists for general TS data
- data drift & shift
  - $p(x_{t_k}, x_{t_{k-1}}, \ldots)$ changes over time
  - $p(y_{t_k} | x_{t_k}, x_{t_{k-1}}, \ldots, y_{t_{k-1}}, y_{t_{k-2}}, \ldots)$ changes over time
- (extremely) fat data, poor data quality, huge volume of data to process
- not many research results available
- none of algorithms in academic papers work / no off-the-shelf algorithms work

# Online learning for TS regression

- use multiplie experts - $f_{1,k}, \ldots, f_{p_k,k}$ for each time step $t = t_k$ where $f_{i,k}$ can be any of following
  - seq2seq models ($e.g.$, LSTM, Transformer-based models)
  - non-DL statistical learning models ($e.g.$, online ridge regression)
- model predictor for $t_k$, $g_k : \mathbf{R}^n \to \mathbf{R}^m$ as weighted sum of experts



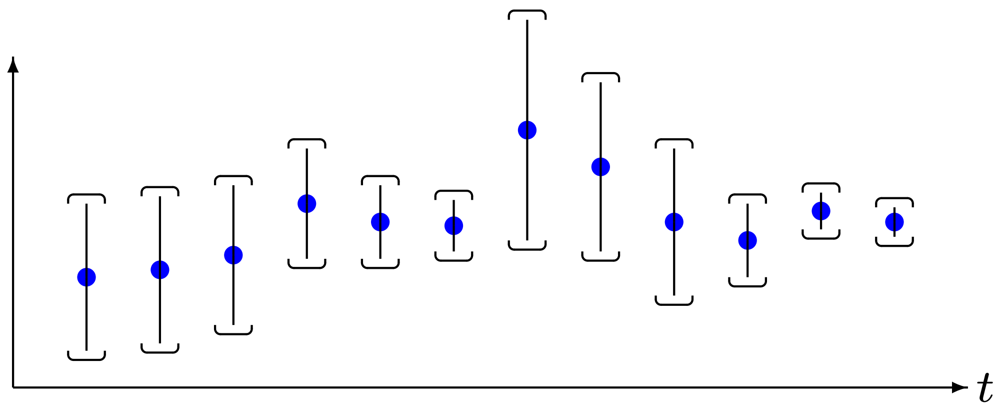

$$g_k = w_{1,k} f_{1,k} + w_{2,k} f_{2,k} + \cdots + w_{p_k,k} f_{p_k,k} = \sum_{i=1}^{p_k} w_{i,k} f_{i,k}$$

# Credibility intervals

- every point prediction is wrong, $i.e.$

$$\mathbf{Prob}(\hat{y}_t = y_t) = 0$$

- reliability of prediction matters, however, *none* literature deals with this (properly)
- critical for our customers, $i.e.$, *such information is critical for downstream applications*
  - $e.g.$, when used for feedback control, need to know how reliable prediction resuilts are
  - sometimes *more crucial than algorithm accuracy*



# Bayesian approach for credibility interval evaluation

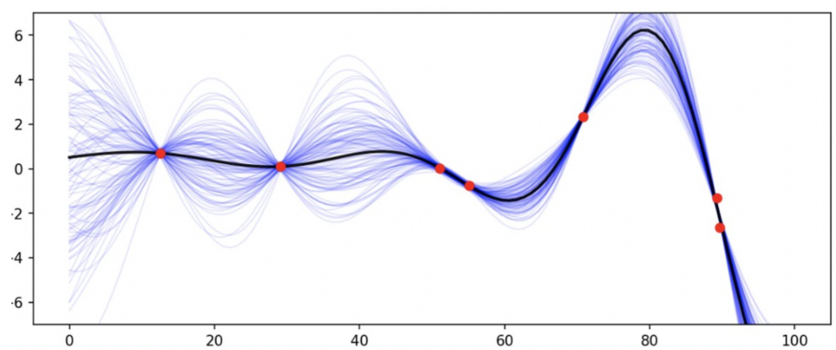
- assume conditional distribution $i$th predictor parameterized by $\theta_{i,k} \in \Theta$

$$p_{i,k}(y(t_k)|x_{t_k}, x_{t_{k-1}}, \ldots, y(t_{k-1}), y(t_{k-2}), \ldots) = p_{i,k}(y(t_k); x_{t_k}, \theta_{i,k})$$

  – depends on prior & current input, *i.e.*, $\theta_{i,k}$ & $x_{t_k}$

- update $\theta_{i,k+1}$ from $\theta_{i,k}$ after observing true $y(t_k)$ using Bayesian rule

$$p(w; \theta_{i,k+1}) := p(w|y(t_k); x_{t_k}, \theta_{i,k}) = \frac{p(y(t_k)|w, x_{t_k})p(w; \theta_{i,k})}{\int p(y(t_k)|w, x_{t_k})p(w; \theta_{i,k})dw}$$



# Virtual Metrology

# VM

- background
  - every process engineer wants to (so badly) measure every material processed - make sure process done as desired
    - $e.g.$, in semiconductor manufacturing, photolithography engineer wants to make sure diameter of holes or line spacing on wafers done correctly to satisfy specification for GPU or memory chips
  - however, various constraints prevent them from doing it, $e.g.$, in semiconductor manufacturing
    - measurement equipment requires investment
    - incur intolerable throughput
    - fab space does not allow
- GOAL - *measure every processed material without physically measuring them*

# VM - problem formulation

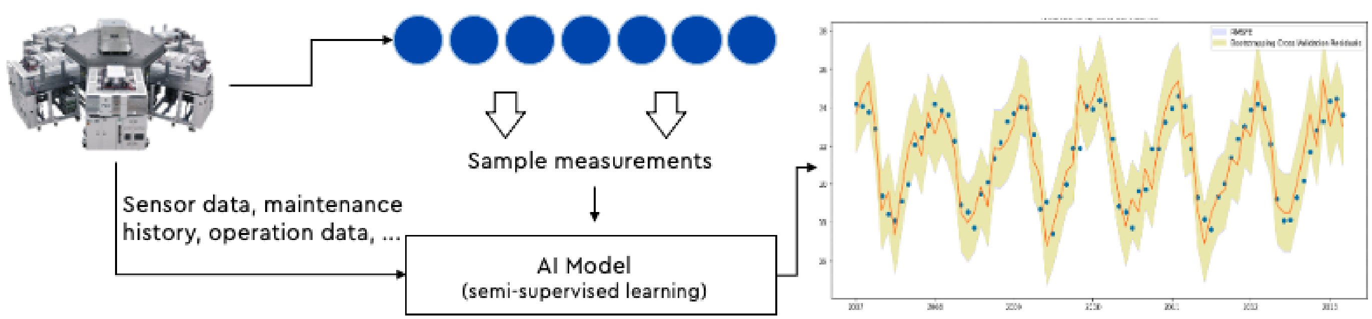
- problem description

$$\begin{array}{rl} \text{(stochastically) predict} & y_{t_k} \\ \text{given} & x_{t_k}, x_{t_{k-1}}, \ldots, y_{t_{k-1}}, y_{t_{k-2}}, \ldots \end{array}$$

- our problem formulation

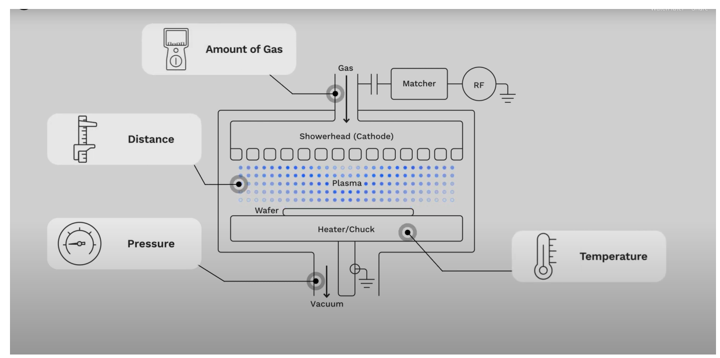
$$\begin{array}{ll} \text{minimize} & \sum_{k=1}^{K} w_{k,K-k}\, l(y_{t_k}, \hat{y}_{t_k}) \\ \text{subject to} & \hat{y}_{t_k} = g_k(x_{t_k}, x_{t_{k-1}}, \ldots, y_{t_{k-1}}, y_{t_{k-2}}, \ldots) \end{array}$$

where optimization variables - $g_1, g_2, \ldots : \mathcal{D} \to \mathbf{R}^m$



# VM - Gauss Labs' inAI success story

- Gauss Labs' ML solution & AI product
  - fully home-grown online TS adpative ensemble learning method
  - outperform competitors and customer inhouse tools, *e.g.*, *Samsung, Intel, Lam Research*
  - published & patented in US, Europe, and Korea
- business impacts
  - improve process quality - reduction of process variation by tens of percents
  - (indirectly) contribute to better product quality and yield
  - Gauss Labs' main revenue source



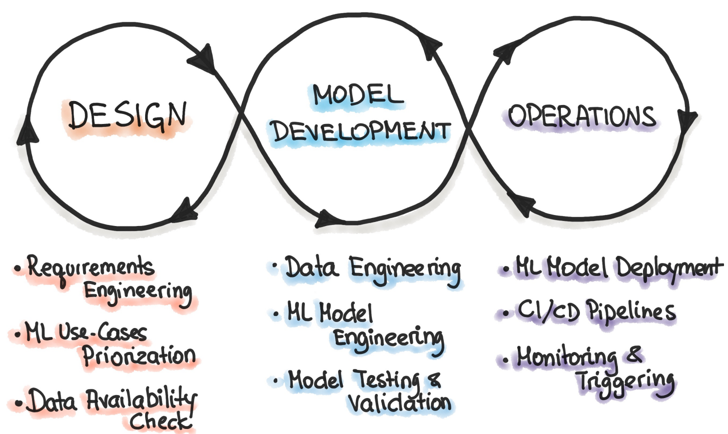
# Manufacturing AI Productionization

# Minimally required efforts for manAI

- MLOps - for CI/CD
- data preprocessing - missing values, inconsistent names, difference among different systems
- feature extraction & selection
- monitoring & retraining
- notification, via messengers or emails
- mainline merge approvals by humans
- data latency, data reliability, & data availability

# MLOps for manAI

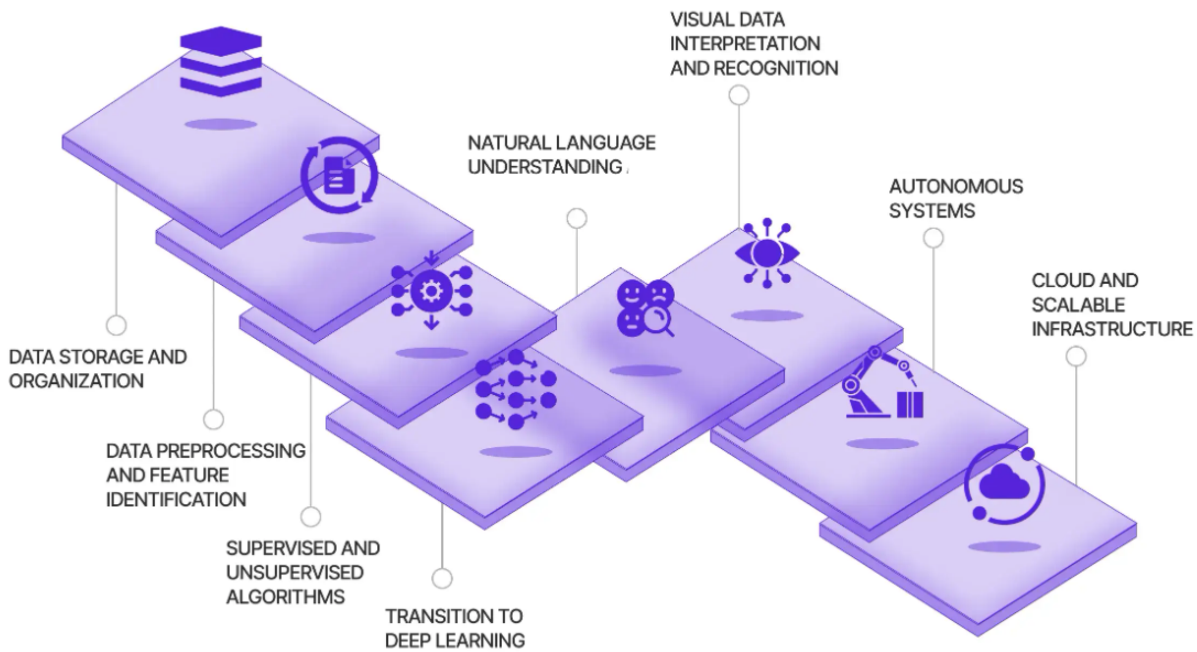
- environment for flexible and agile exploration - EDA[3]
- fast & efficient iteration of algorithm selection, experiements, & analysis
- correct training / validation / test data sets critical!
- seamless productionization from, *e.g.*, Jupyter notebook to production-ready code
- monitorning, *right* metrics, notification, re-training




[3] EDA - exploratory data analysis

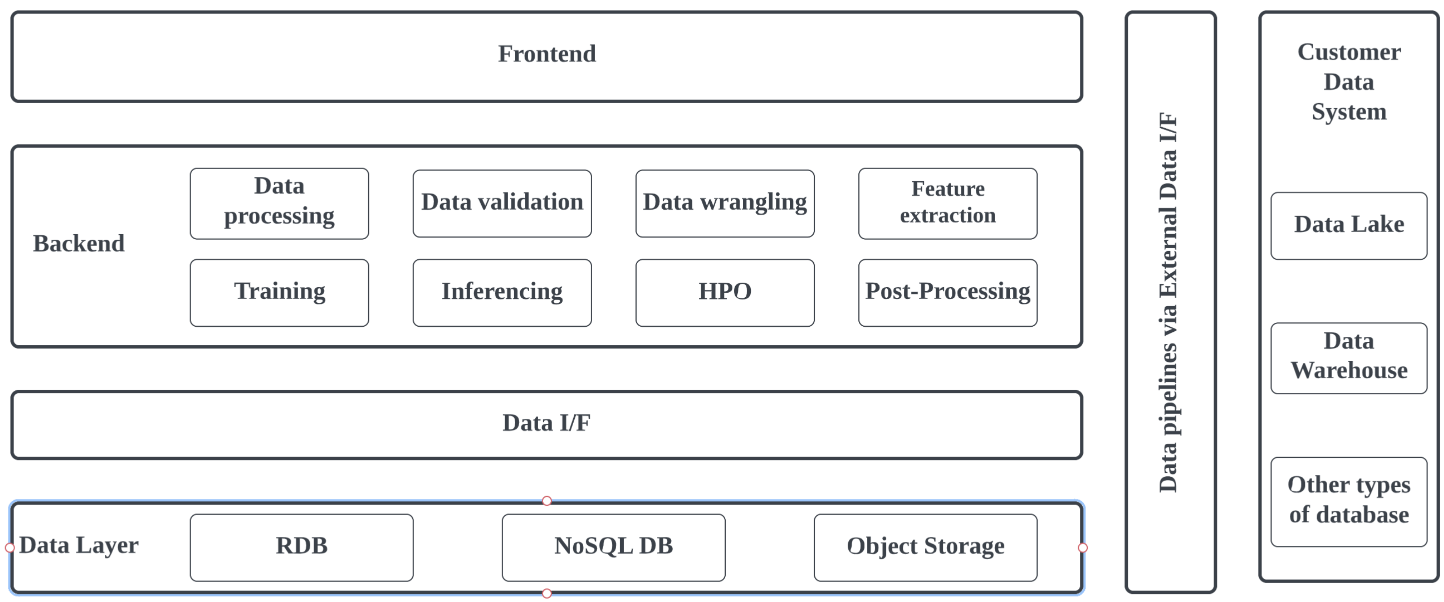
# manAI software system

- data, data, data! – store, persist, retrieve, data quality
- seamless pipeline for development, testing, running deployed services
- development envinroment should be built separately



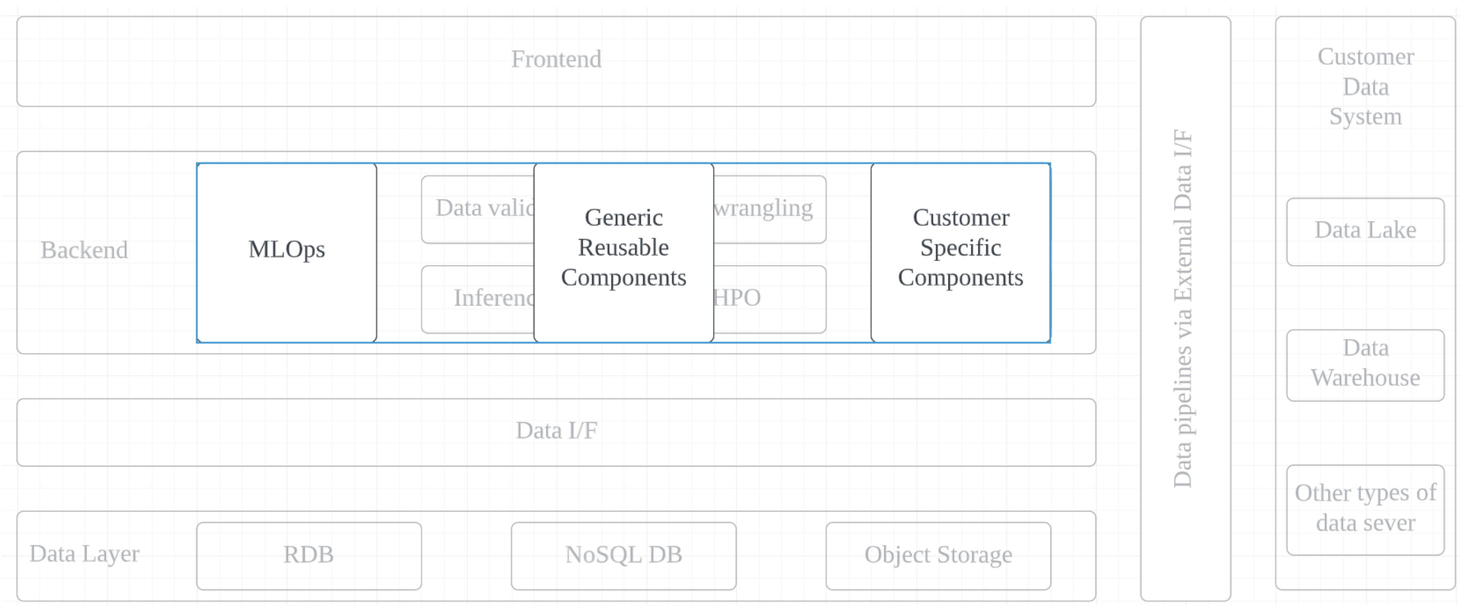
# manAI system architecture

- frontend / backend / data I/F / data layer
- efficient and effective MLOps in backend or development environment



# Reusuable components vs customer specific components

- make sure to build two components separate - generic reusable and customer specific
- generic models should be tuned for each use case
- generic model library grows as interacting with more and more customers



# My Two Cents

# Recommendations for maximum impact via inAI

- concrete goals of projects
  - north star – yield improvement, process quality, making engineers' lives easier
  - hard problem – scheduling and optimization
- be strategic!
  - learn from others – lots of successes & failures of inAI
  - ball park estimation for ROI cricial – efforts, time, expertise, data
  - utilities vs technical excellency / uniqueness vs common technology
  - home-grown vs off-the-shelf

# Remember . . .

- data, data, data! – readiness, quality, procurement, pre-processing, DB
- *never* underestimate domain knowledge & expertise – data do NOT tell you everything
- EDA
- do *not* over-optimize your algorithms – ML is all about trials-&-errors
- overfitting, generalization, concept drift/shift - way more important than you could ever imagine
- devOps, MLOps, agile dev, software development & engineering

# Conclusion

# Conclusion

- various CV MLs used for inAI applications
- TS ML applications found in every place in manufacturing
- drift/shift & data noise make TS MLs very challenging, but working solutions found
- in reality, crucial bottlenecks are
  - data quality, prepocessing, monitoring, notification, and retraining
  - data latency, avaiability, and reliability
  - excellency in software platform design and development using cloud services

# Global Semiconductor Industry

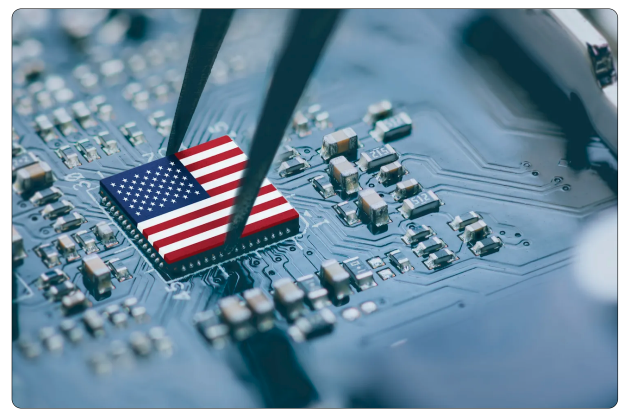
# Hard-to-predict AI hardware markets

- US
  - birthplace for modern semiconductor chips driving PC market, internet, multi-media, mobile phones, and AI . . .
    - Intel, Texas Instrument (TI), Global Foundry
  - traditionally strong with design houses - NVIDIA, AMD, Broadcom, Apple, . . .
  - threatened experiencing global chip shortage & vulnerable supply chain via COVID
  - national security concerns & economic competitiveness
- China
  - strong fast followers - SMIC[4], Huawei, Hua Hong Semiconductor (foundry)
- South Korea
  - best memory chip makers - Samsung, SK hynix
  - struggling with LSI and foundry business

[4]SMIC - Semiconductor Manufacturing International Corporation

# Reshoring semiconductor manufacturing industry

- trade & semiconductor WAR between US & China
  - export controls on advanced chips and equipment
- CHIPS & Science Act (Aug, 2022)
  - $52B in subsidies for domestic production, 25% investment tax credit for chip plants
  - (coerce) world-best semiconductor manufacturers build factories in US with support
    - GlobalFoundries - $1.5B @ Feb-2024
    - Intel - $8.5B @ Apr-2024 - Ohio - two fabs expandable to $100B
    - Samsung - $6.4B @ Apr-2024 - Talor, Texas
    - TSMC - $6.6B @ Apr-2024 - Phoenix, Arizona - two foundry fabs (3nm & 4nm)



## Turmoils in global semiconductor business

- global context
  - EU Chips Act - €43B to boost European chip production
  - Japan & South Korea - significant investments in domestic capacity
- industry dynamics
  - Intel's foundry ambitions - targeting 50% global market share by 2030
  - TSMC expanding global footprint (US, Japan, possibly Germany)
- future outlook
  - projected shift in global semiconductor manufacturing landscape
  - increased geographical diversification of chip production

# Export controls on US chip technology to China


- goal - limit China's access to advanced semiconductor tech to maintain US strategic advantage
- impacts on
  - China - advanced chips and equipment not allowed, domestic innovation increased
  - US - short-term - US lose market share and revenue in China
  - US - long-term - potential decline in US global competitiveness
- Chinese response - circumvent controls and adapt supply chains
- conclusion
  - US-China chip rivalry transforms global supply chains with deep implications for *security & industry*
  - US success hinges on better coordination and policy analysis

- reference - Balancing the Ledger - Center for Strategic & International Studies (CSIS)

# China strikes back on US sanction

- Huawei's launch of Mate 60 Pro smartphone
  - these domestically produced chips represent major breakthrough against US sanctions
  - its success with *advanced 7nm Kirin 9000S chip* demonstrates significant progress in China's self-reliance in high-tech manufacturing - narrowing the technological gap with global leaders
- Huawei case highlights potential failure of US sanctions potentially leading to more aggressive US measures
  - US export controls on China's semiconductor industry are effective in the short term but insufficient to halt China's progress especially in legacy chip manufacturing
  - to maintain technological edge, US must balance further restrictions with supporting its semiconductor industry to avoid overreliance on export controls

# Chinese semiconductor companies

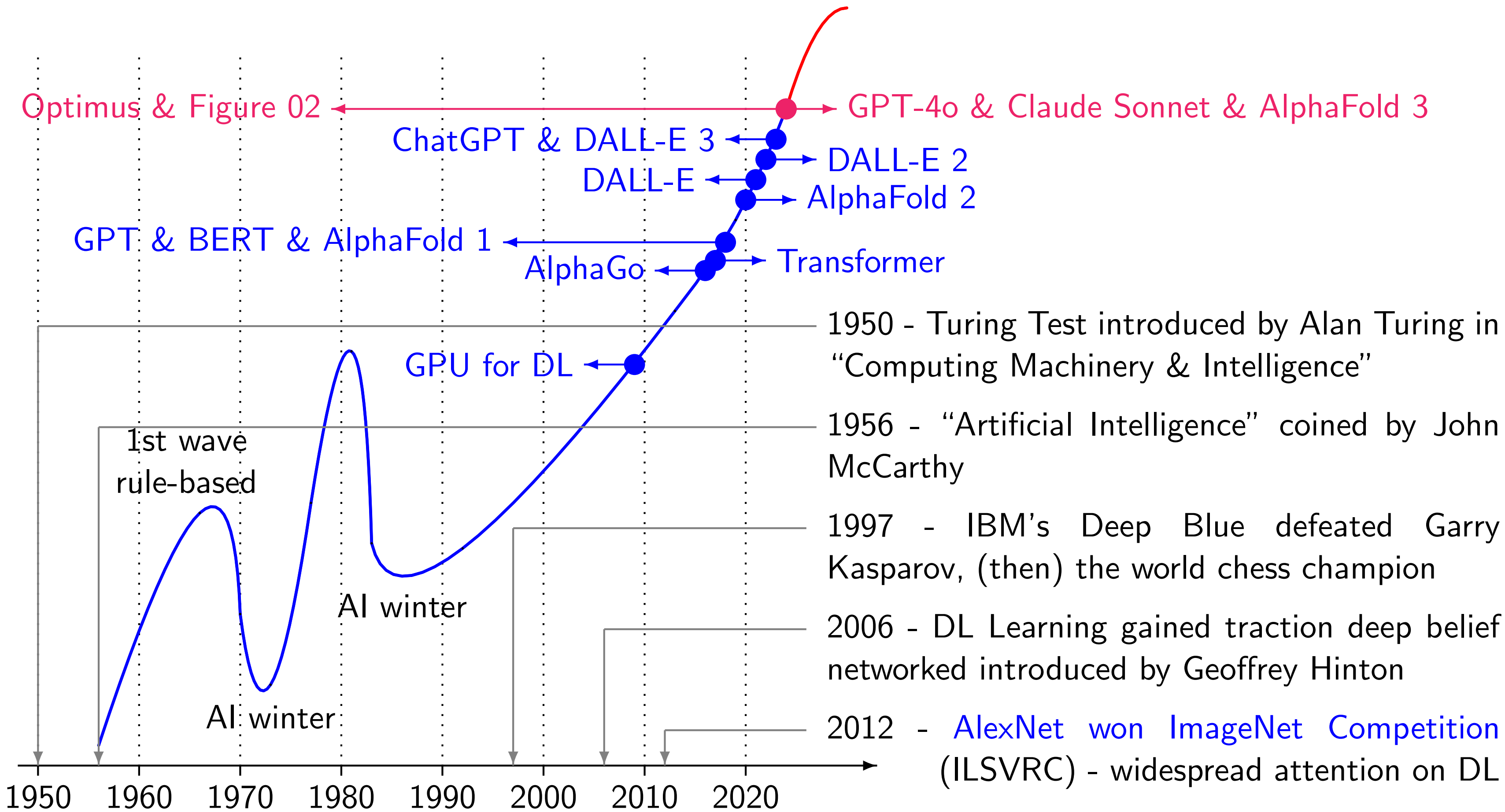
- Chinese major semiconductor companies
  - SMIC - China's largest chip foundry, advancing 7nm technology
  - HiSilicon - Huawei's chip design arm, crucial for the Kirin processors
  - YMTC - leader in 3D NAND memory chip production
  - Huahong Group, CXMT, SMEE, GigaDevice, UnilC Semiconductors, ASMC, *etc.*
- *SMIC shows significant progress in producing 7nm chips* & YMTC leads memory chip manufacturer - both face challenges from US export controls
- industry faces internal challenges, *e.g.*, corruption & misallocation of resources
- but remains crucial to China's goal of technological self-reliance

# Silicon Valley's Cultural Engine of Innovation and Disruption

# My journey from Samsung & Amazon to Gauss Labs & Erudio Bio

- Samsung Semiconductor, Inc.
  - inception into industry from academia, the world's best memory chip maker!
- Amazon.com, Inc.
  - experience so-called Silicon Valley big tech culture and technology
  - set tone for my future career trajectory!
- Gauss Labs, Inc.
  - found & operate AI startup, shaping corporate culture & spearheading R&D as CTO
  - inherent challenges of Korean conglomerate spin-off startup - cultural constraints, over-capitalization, and leadership limitations
- Erudio Bio, Inc.
  - concrete & tangible bio-technology in addition to AI
  - great decisions regarding business development; business models, market fit, go-to-market (GTM) strategies based on lessons learned *in a hard way* ☺

# Joining Amazon.com, Inc. at the inflection point of AI

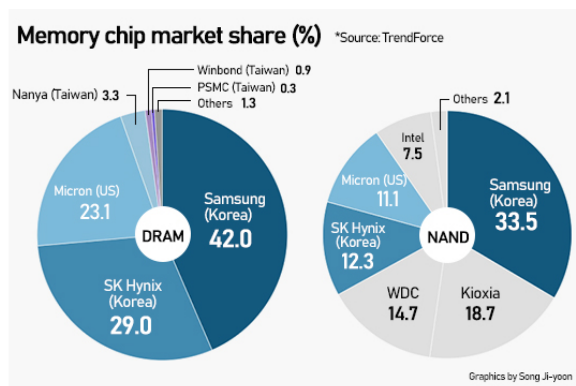


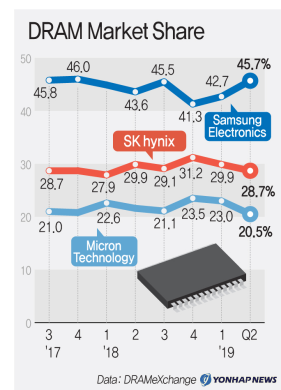
# Innovation ecosystem of Silicon Valley

- key characteristics
  - risk-taking culture, *trust* in technology → *genuine* respect for engineers and scientists
  - easy access to huge capital - VCs, angel investors alike
  - talent density - engineers, researchers, scientists, entrepreneurs, PMs, TPMs, . . .
  - diversity, "collision density" of ideas
  - ecosystem of collaboration and competition - startups, academia, industry leaders
- what they mean for global big tech
  - set trends in AI, software & hardware (and or hence) product & industry innovation
  - act as testing ground for disruptive ideas


# Case study: Amazon - amazing differentiators of big techs

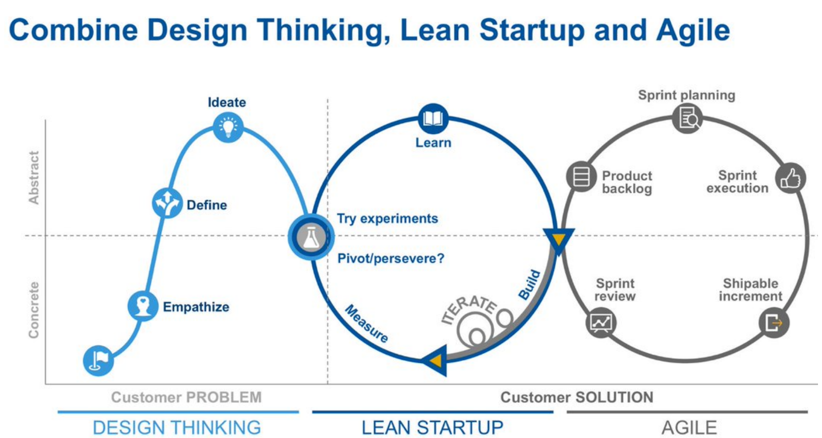
- Amazon's culture & leadership principles
  - customer obsession as driver of innovation
  - high standards & ownership culture, disagree & commit
  - bias for action and long-term thinking - sounds contradictory?
  - mechanisms like "two-pizza teams" & "Day One" for (or rather despite) scalability
- lessons for Korean corporations
  - applying customer-centric innovation in hardware & AI, *e.g.*, on-device AI
  - balancing agility with long-term R&D
  - *build / adapt / apply on the core strength of Samsung that no other company has!*

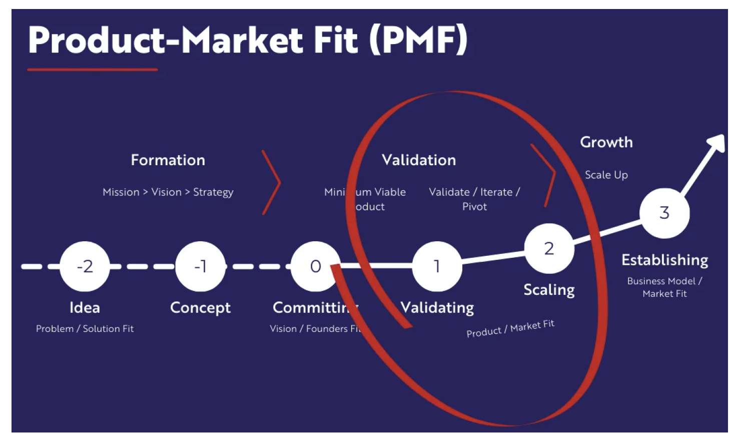



# Founding and scaling startups

- challenges
  - competence of and chemistry among co-founders crucial
  - technology & great team are *necessary*, but *not sufficient (at all!)* for success
  - business models, market fit, timing, agility, flexibility for pivoting / perseverance
- insight
  - importance of domain expertise in addition to AI
  - balancing innovation with good business decisions



# Bridging Silicon Valley & Korea

- cultural differences
  - risk appetite & failure tolerance
  - decision-making speed vs hierarchy
  - innovation vs execution focus
- opportunities for collaboration
  - leveraging Korea's manufacturing expertise with Silicon Valley's software/AI strengths
  - building global teams with diverse perspectives

# To be successful . . .

- embrace customer/market-centric mindset in innovation and for business decisions
- balance agility with long-term vision
- foster cross-cultural collaboration for global impact
- ((very) strategically and carefully) leverage AI to solve real-world industrial challenges


# 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 advanages for medical assitance, emergency handling
  - AI does not make more mistakes because task is repetative and tedius
  - AI does not request salary raise or go on strike

## What makes DL so successful?

## Factors constributing 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 $f : \mathbf{R}^n \to \mathbf{R}^m$, exists $\langle f_n \rangle$ such that $\lim_{n\to\infty} f_n = f$

**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 inferenced 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 $(t_1, \ldots, t_k)$ are correct
- recursion

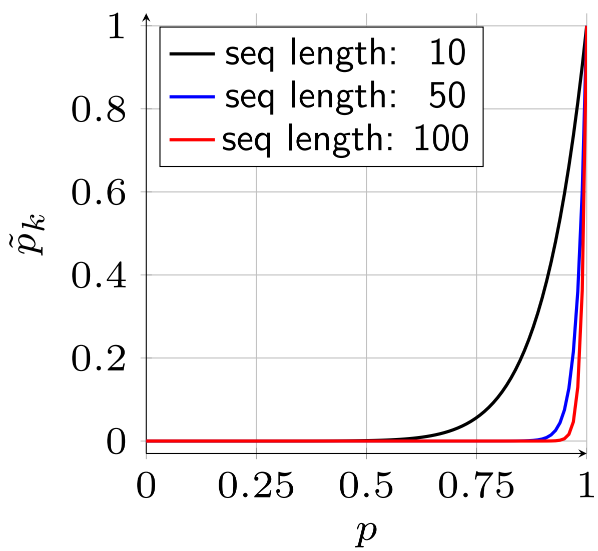
$$\rho_i = \frac{\tilde{p}_i - \tilde{p}_{i-1} p_i}{\sqrt{\tilde{p}_{i-1}(1-\tilde{p}_{i-1}) p_i (1-p_i)}}$$

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

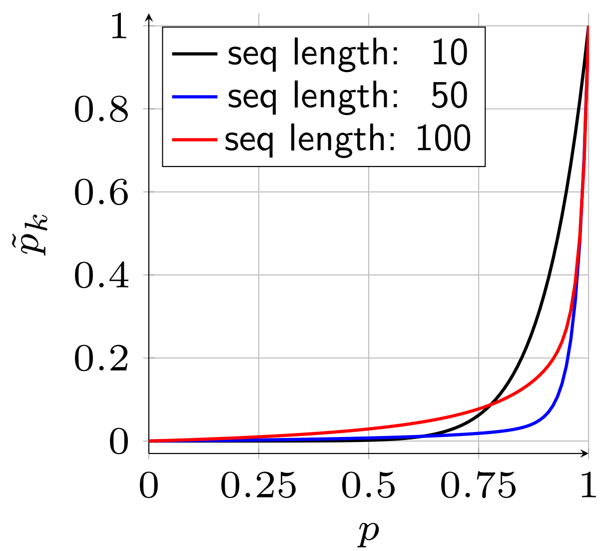
# Dramatic improvement of LLM near saturation

- 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

when tokens are independent



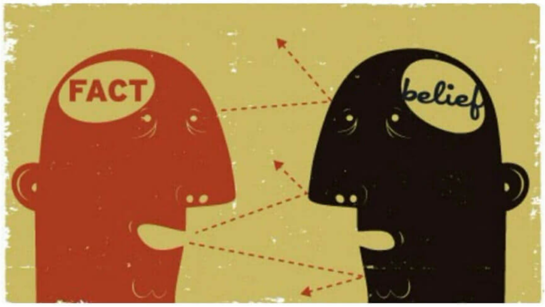

when tokens are dependent

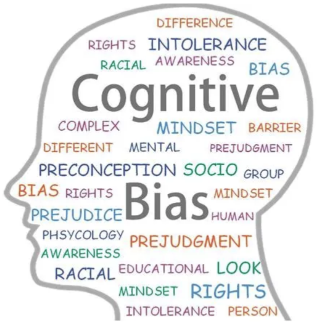


# Biases

# 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 subjec to
  - availability bias - baised 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 eaisly 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
  - manupilate / deceive people - using manupilated 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*

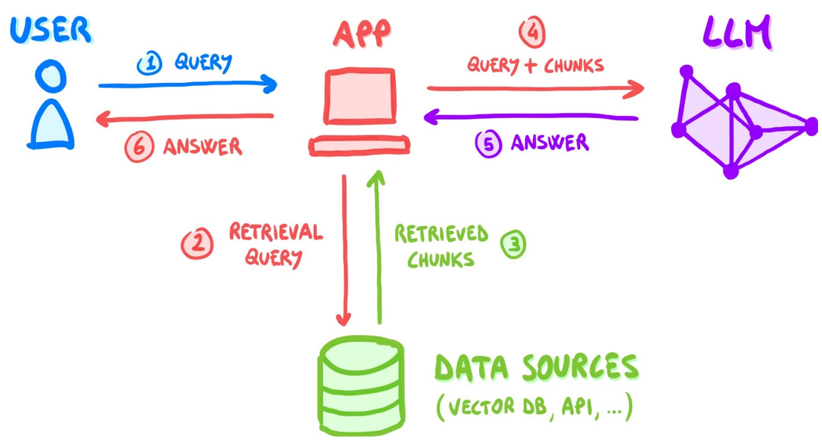
  - making vulnerable to anthropomorphism
- examine it by throwing questions such as
  - *"does LLM have knowledge and belief?"*
  - *"can it reason?"*

# 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

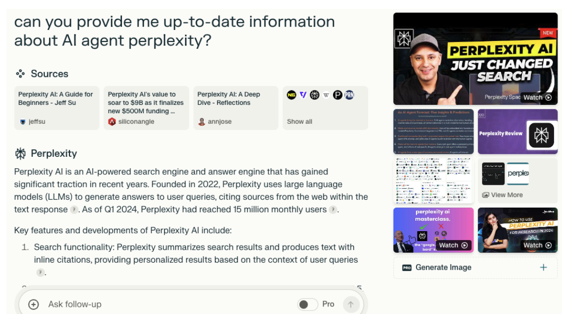
- does (good) LLM have knowledge?
  - Grandmother: looks like it cuz when instructed *"explaing big bang"*, it says
    *" The Big Bang theory is prevailing cosmological model that explains the origin and evolution of the universe. . . . 13.8 billion years ago . . . "*
- does it have belief?
  - Grandmother: 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*!

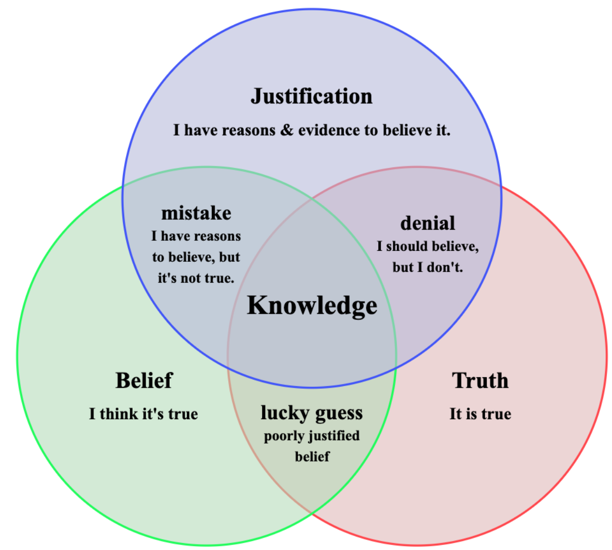



# Knowledge in philosophical and cognitive scientific sense

- 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

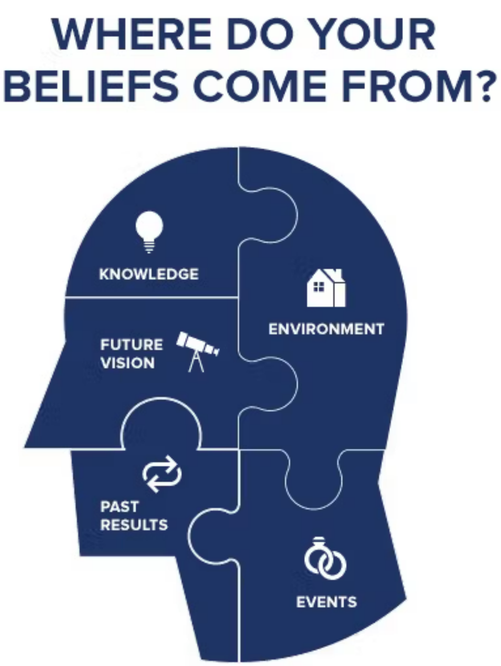
    *"guessing" by conditional probability model the most likely words following "Tom Cruise's mother is."*
  - so *we cannot say it really knows the fact!*



# 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!*



# 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 Socreates 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-short 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 soceital and economic impacts

# Moral

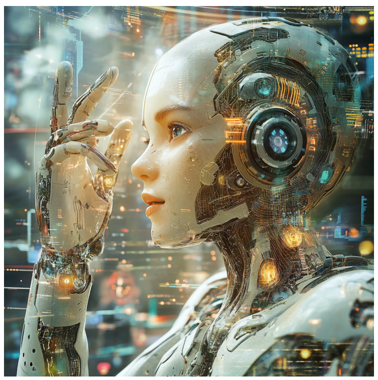
- AI shows incredible utility and commercial potentials, hence should
  - make informed decisions about trustworthiness and safety
  - avoid ascribing capacities they lack
  - *take best utilization of remarkable capabilities of AI*
- today's AI so powerful, so (seemingly) convincingly intelligent
  - 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, . . .*

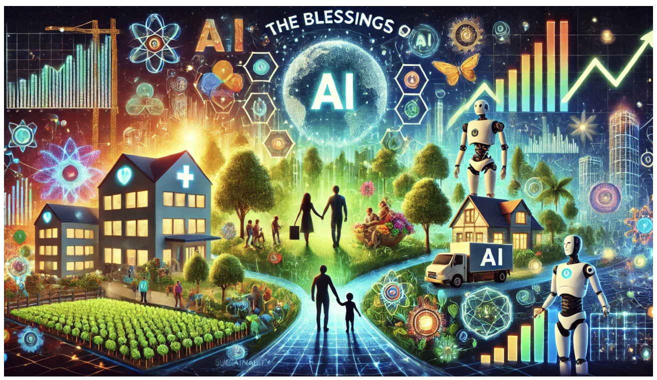
# Empowering Humanity for Future Enriched by AI

# Blessings & Curses of AI

# Blessings

- advancements in healthcare & improved quality of life
  - much faster & more accurate diagnosis, far superior personalized medicine, accelerated drug discovery, assistive technologies
- economic growth & efficiency
  - automation to increase productivity and reduce cost, far superior decision-making
- environmental solutions
  - climate change prediction, global warming effect mitigation, solutions for sustainability
- safety & security
  - natural disaster prediction & relief, cybersecurity






## Curses

- job displacement & overall impacts on labor market
  - millions of jobs threatened, wealth gap widened
- bias & inequality, misinformation & manipulation
  - existing human biases, both conscious and unconscious, perpetuated through AIs, asymmetric accessibility to advanced AI technologies by nations & corporations
- ethical dilemmas
  - infringing privacy & human rights, accountability for weapon uses and damages by AI
- environmental costs
  - significant energy for training AI models, waste generated by obsolescent AI hardware

# Salzburg Global Seminar

# KFAS-Salzburg Global Leadership Initiative

- "Uncertain Futures and Connections Reimagined: Connecting Technologies" - 41 global leaders convened from 4-Dec to 8-Dec, 2024 @ Schloss Leopoldskron in Salzburg, Austria
- My working group was "Technology, Growth, and Inequality: The Case of AI"
  - International Cooperation Officer (Portugal)
  - Gender Equality, Disability Inclusion Consultant, UN Women (Lithuania)
  - Assistant Professor @ Lincoln Alexander School of Law (Canada)
  - Research Associate @ Luxembourg Institute of Socio-Economic Research
  - Policy Officer & Delegation of the EU Union (India)
- blog: Bridging Technology & Humanity - Reflections from Lyon, Salzburg, and München


# KFAS-Salzburg Global Leadership Initiative

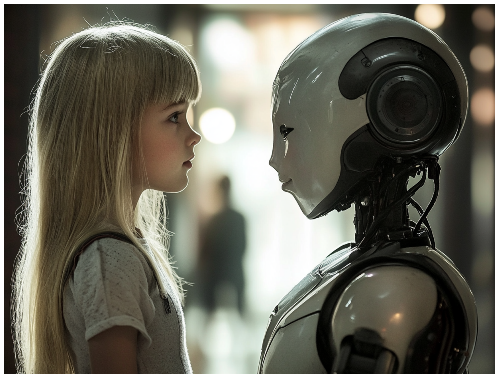
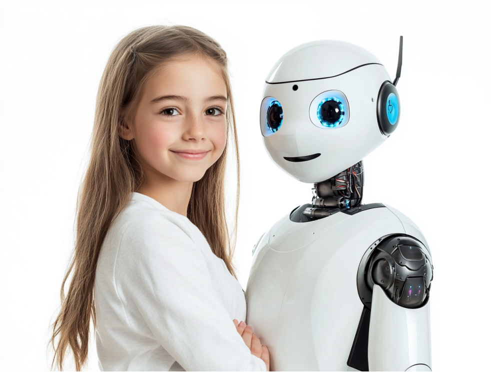
Salzburg Global photo collections




# Empowering Humanity

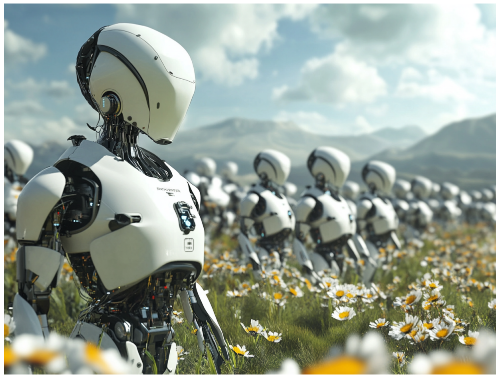
# AI capacity building - scientists, engineers & practitioners

- ethics and responsible AI education or campaign via interdisciplinary collaboration
  - foster continuous learning programs on AI risks, bias & societal impacts
- bias detection & mitigation
  - bias-detection tools to identify & reduce discrimination in data & models
  - regular fairness audits
- transparency & explainability
  - explainable AI (xAI) techniques, frameworks like Model Cards for transparency
- environmental impact awareness
  - reduce AI's carbon footprint, advocate for sustainable AI development practices

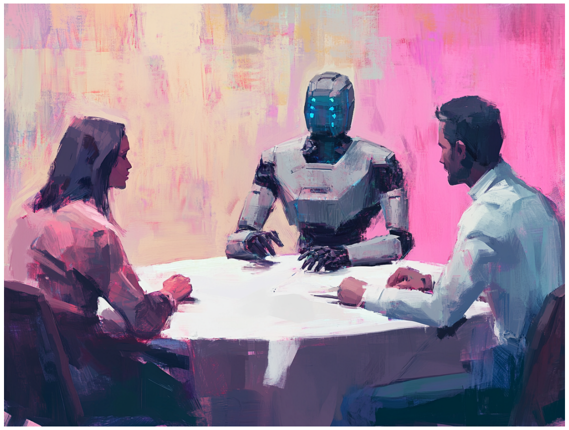
# AI capacity building - lawmakers & policy makers

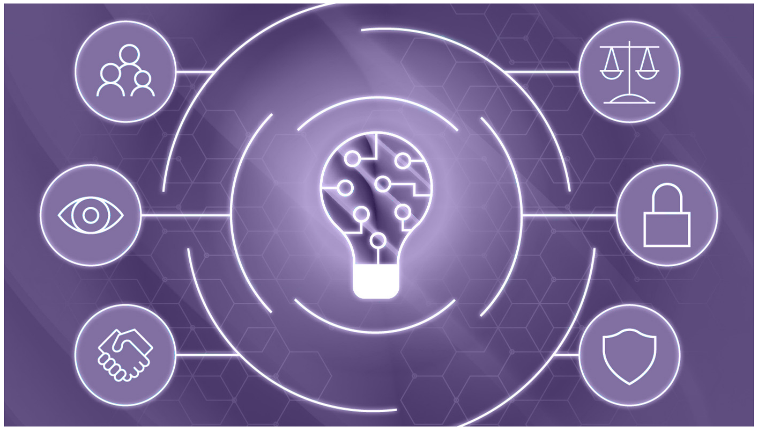
- problems
  - difficulties in understanding of rapidly evolving AI technologies
  - lead to reactive or insufficient regulation
- proposed solutions
  - develop comprehensive regulatory frameworks addressing transparency, bias & privacy concerns
    - gender bias, racial bias, hallucinations
  - foster public debates on ethical AI use & societal implications
  - introduce policies to limit spread of AI-generated misinformation,



# Participatory social agreements

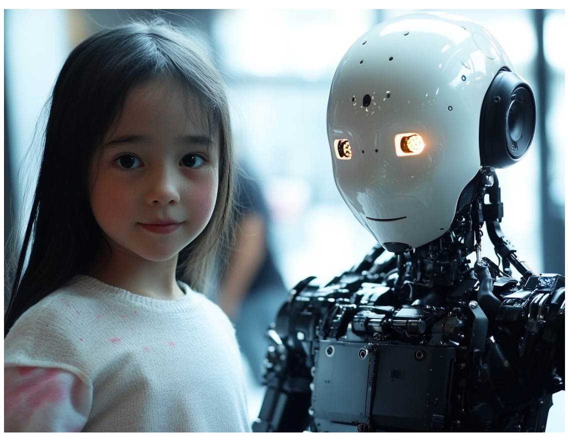
- open data frameworks including data sovereignty, regulation of data transfer, storage & localization
- corporate social responsibility, extra-territorial obligations & environmental protection
  - including outside the jurisdiction of the country
- labour and employment displacements, tax cuts & algorithmic impact assessments
  - including remedies for AI harms and enforcements





# Reclaiming technology for Humanity

- strategic approach to AI development
  - *leverage very technologies alienating humans to strengthen human connection*
  - transform automation from replacement to *enhancement of human capabilities*
  - leverage technological scale to address fundamental human needs
- *paradigm shift* in technological implementation
  - recognize the duality of advanced technologies
  - *systematically channel AI capabilities toward human-centric solutions*
  - convert technological challenges into opportunities for human advancement



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