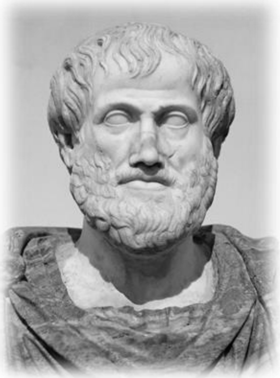
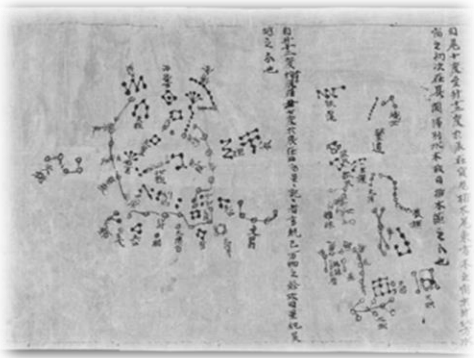
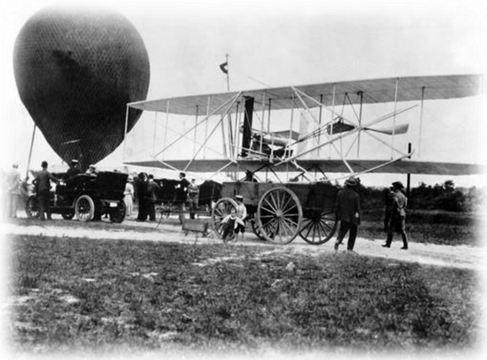
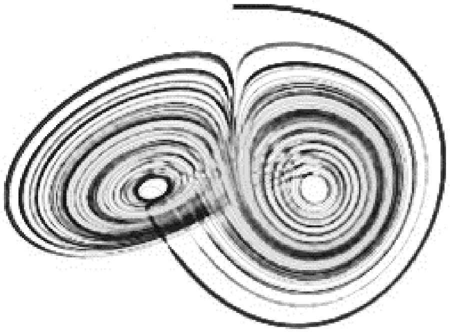
Data Driven Engineering I: Machine Learning for Dynamical Systems

Emerging Concepts and the Outlook

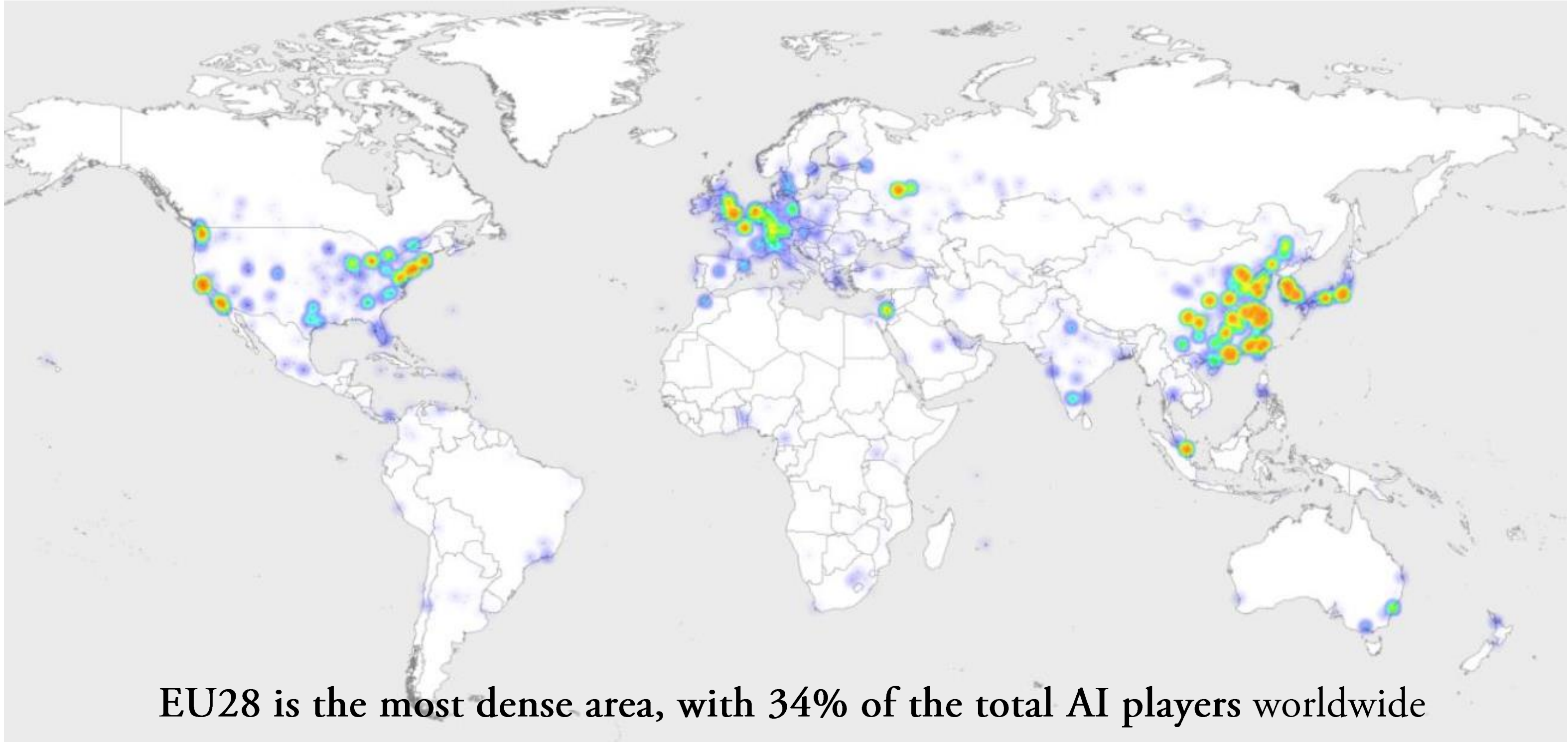
Institute of Thermal Turbomachinery
Prof. Dr.-Ing. Hans-Jörg Bauer

Outline

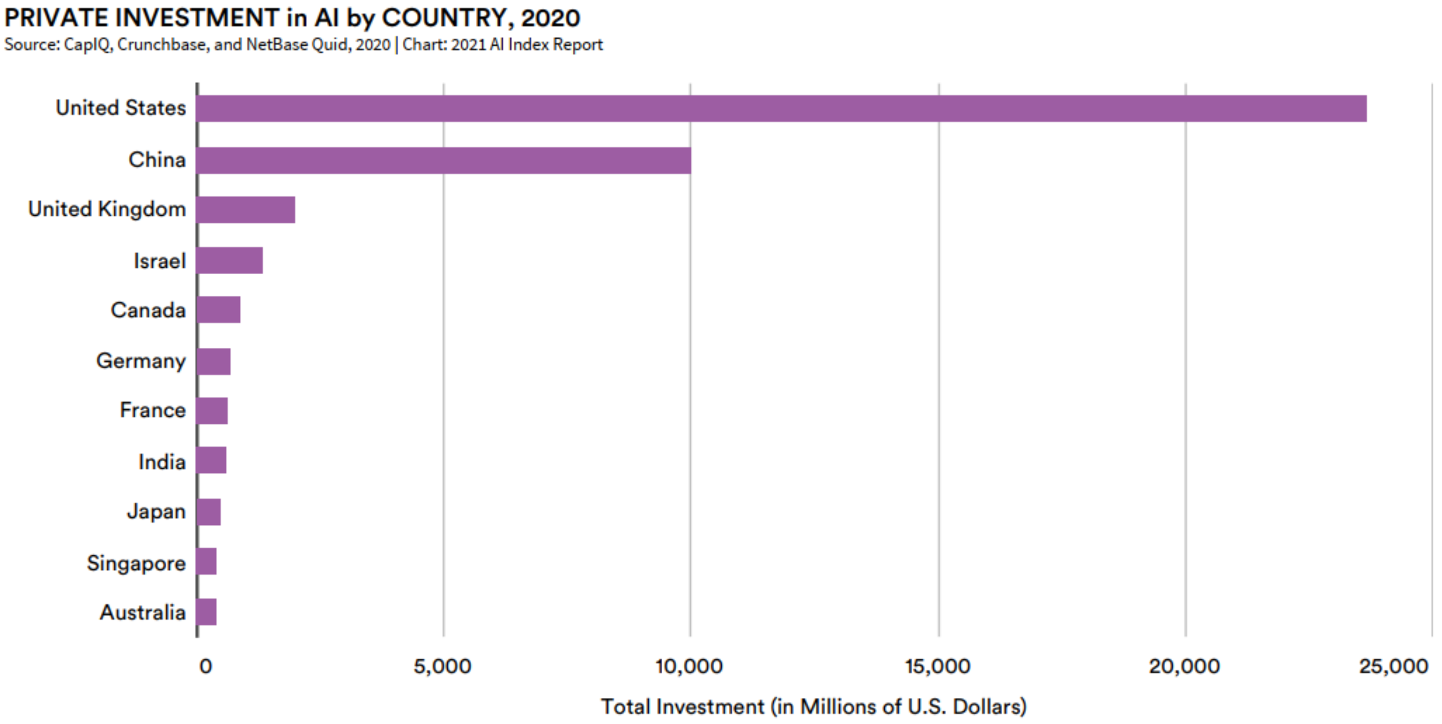
- AI activities in industry
- AI in academia
- Selected studies
- DDE Lecture

AI Activities: R&D and Industry

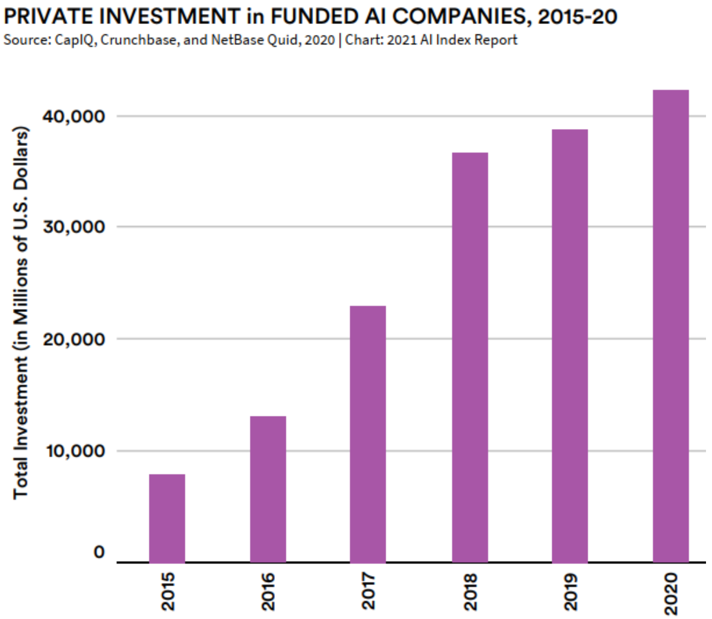


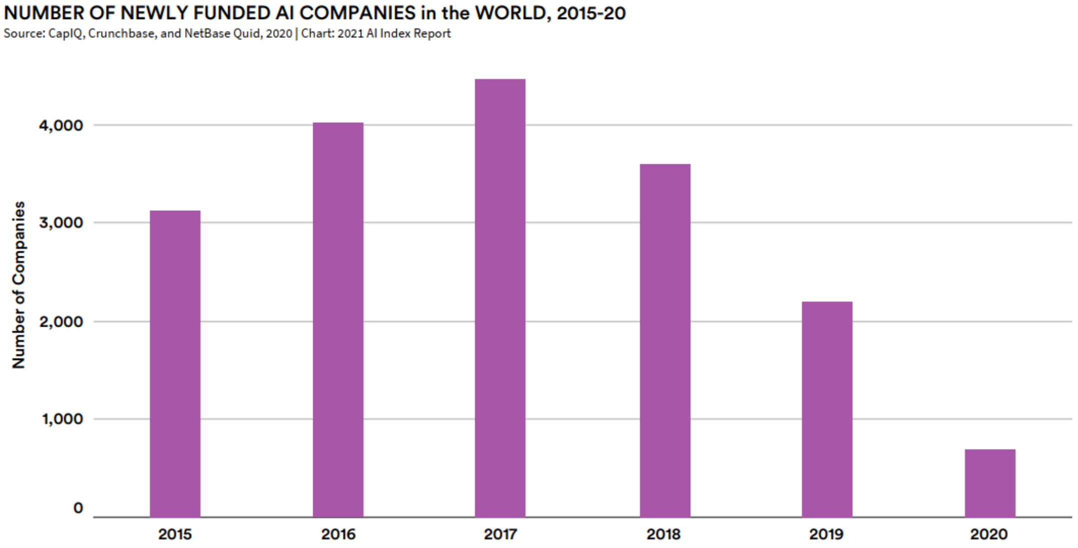
JRC PREDICT- AI TES Dataset, 2019

AI Activities: R&D and Industry



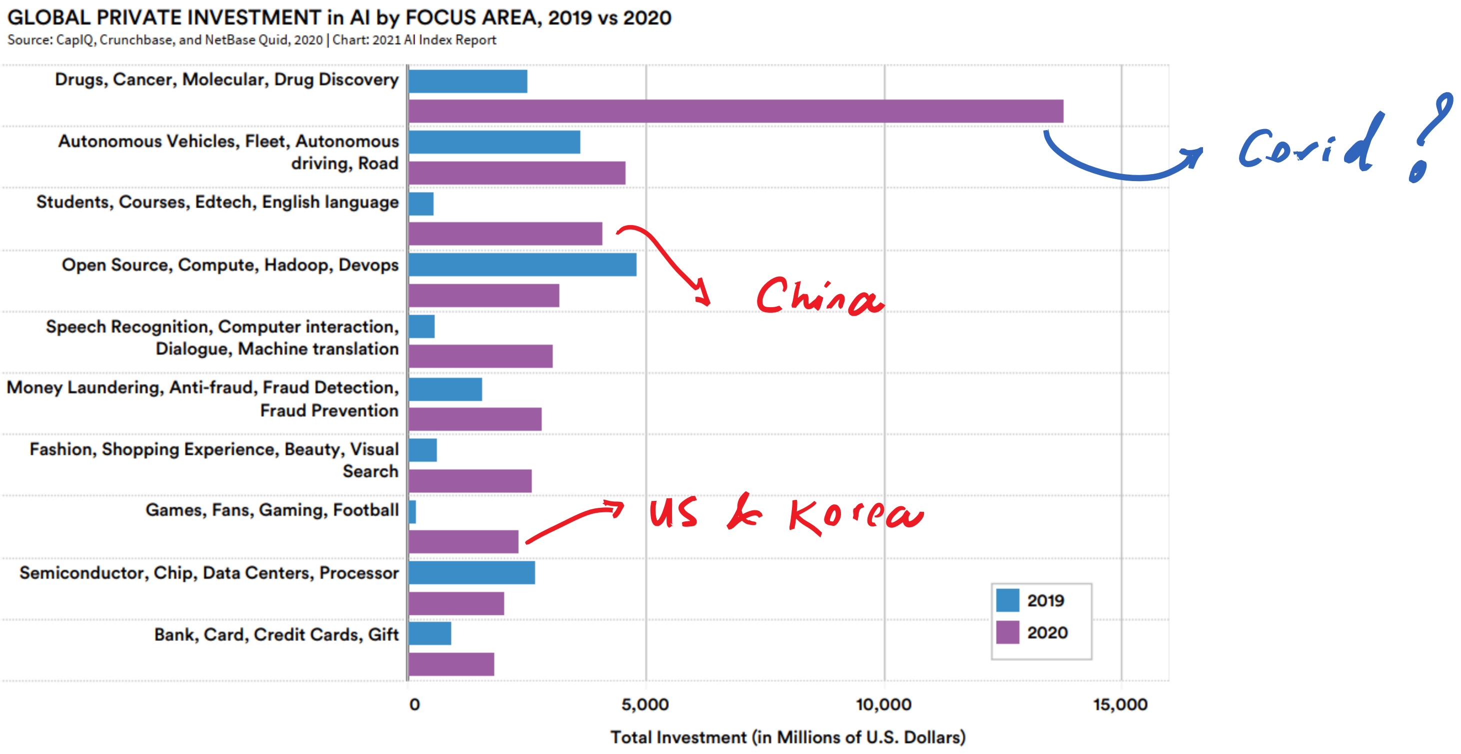
Startup companies





investments of over USD 400,000 in the last 10 years

AI Activities: Investment details



AI Integration to Industry

AI CAPABILITIES EMBEDDED in STANDARD BUSINESS PROCESSES, 2020

Source: McKinsey & Company, 2020 | Chart: 2021 AI Index Report

Industry	Human Resources	Manufacturing	Marketing And Sales	Product and/or Service Development	Risk	Service Operations	Strategy and Corporate Finance	Supply-Chain Management
All Industries	8%	12%	15%	21%	10%	21%	7%	9%
Automotive and Assembly	13%	29%	10%	21%	2%	16%	8%	18%
Business, Legal, and Professional Services	13%	9%	16%	21%	13%	20%	10%	9%
Consumer Goods/Retail	1%	19%	20%	14%	3%	10%	2%	10%
Financial Services	5%	5%	21%	15%	32%	34%	7%	2%
Healthcare/Pharma	3%	12%	16%	15%	4%	11%	2%	6%
High Tech/Telecom	14%	11%	26%	37%	14%	39%	9%	12%

% of Respondents

AI Integration to Industry

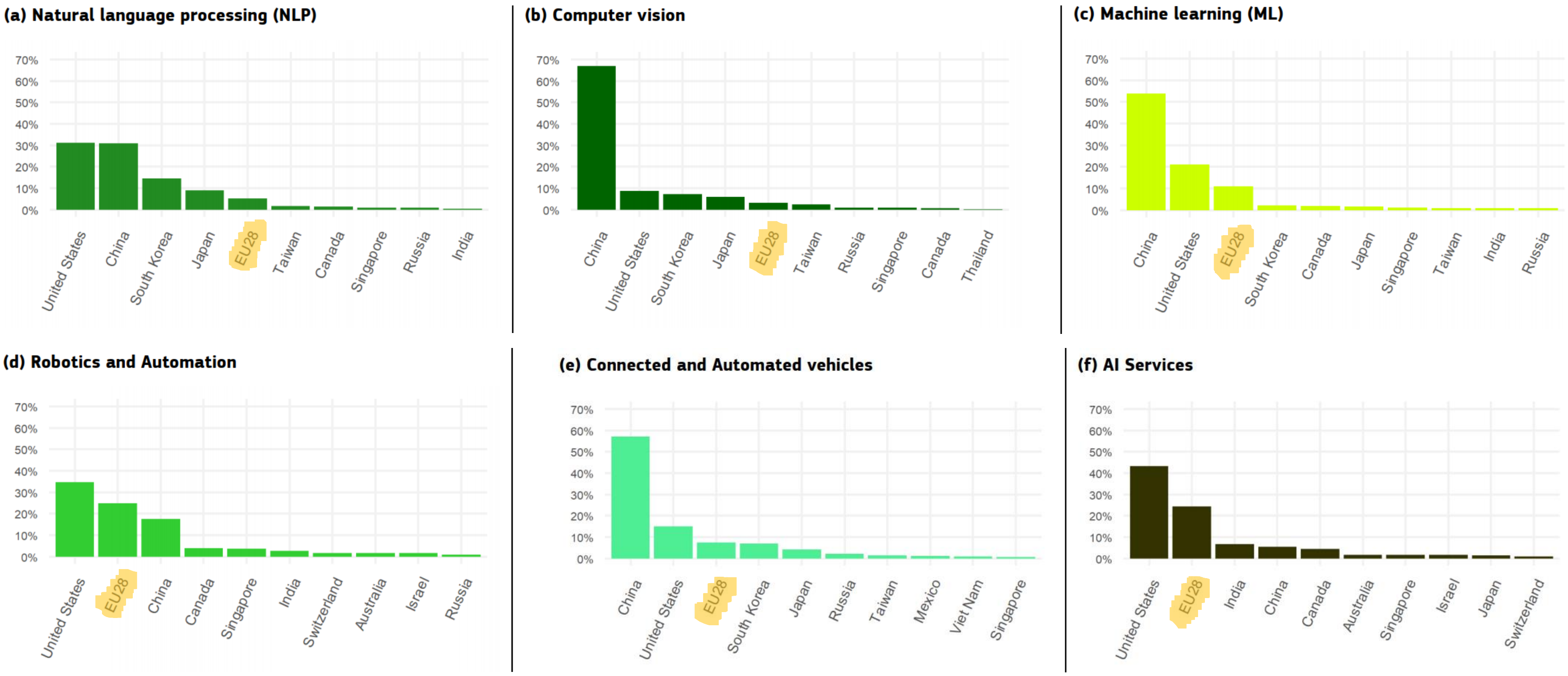
AI CAPABILITIES EMBEDDED in STANDARD BUSINESS PROCESSES, 2020

Source: McKinsey & Company, 2020 | Chart: 2021 AI Index Report

Industry	Autonomous Vehicles	Computer Vision	Conversational Interfaces	Deep Learning	NL Generation	NL Speech Understanding	NL Text Understanding	Other Machine Learning Techniques	Physical Robotics	Robotic Process Automation
All Industries	7%	18%	15%	16%	11%	12%	13%	23%	13%	22%
Automotive and Assembly	20%	33%	16%	19%	12%	14%	19%	27%	31%	33%
Business, Legal, and Professional Services	7%	13%	17%	19%	14%	15%	18%	25%	11%	13%
Consumer Goods/Retail	13%	10%	9%	6%	6%	6%	9%	12%	23%	14%
Financial Services	6%	18%	24%	19%	18%	19%	26%	32%	8%	37%
Healthcare/Pharma	1%	15%	10%	14%	12%	11%	15%	19%	10%	18%
High Tech/Telecom	9%	34%	32%	30%	18%	25%	33%	37%	14%	34%

% of Respondents

AI Activities: R&D and Industry

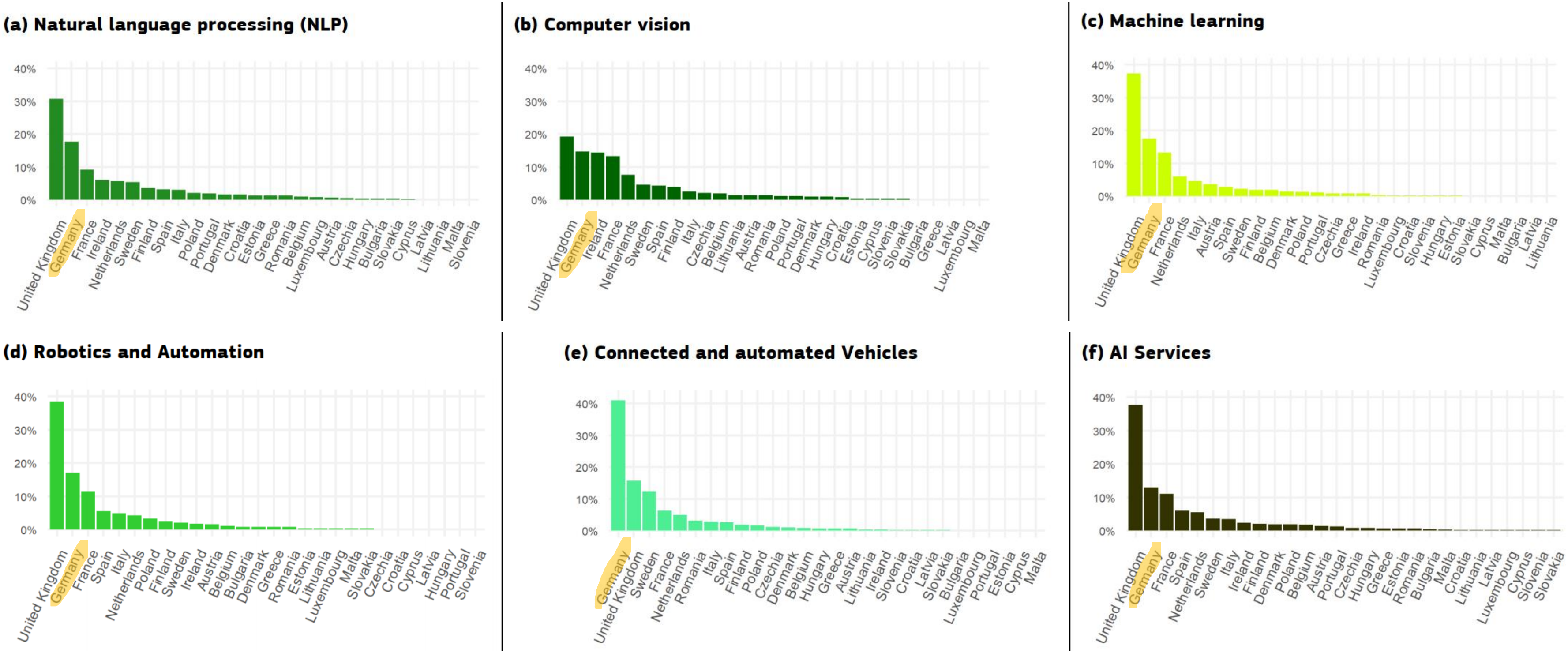


Country activities as a percentage of worldwide activities in each key area, 2009-2018.

JRC PREDICT- AI TES Dataset, 2019

AI Activities: R&D and Industry

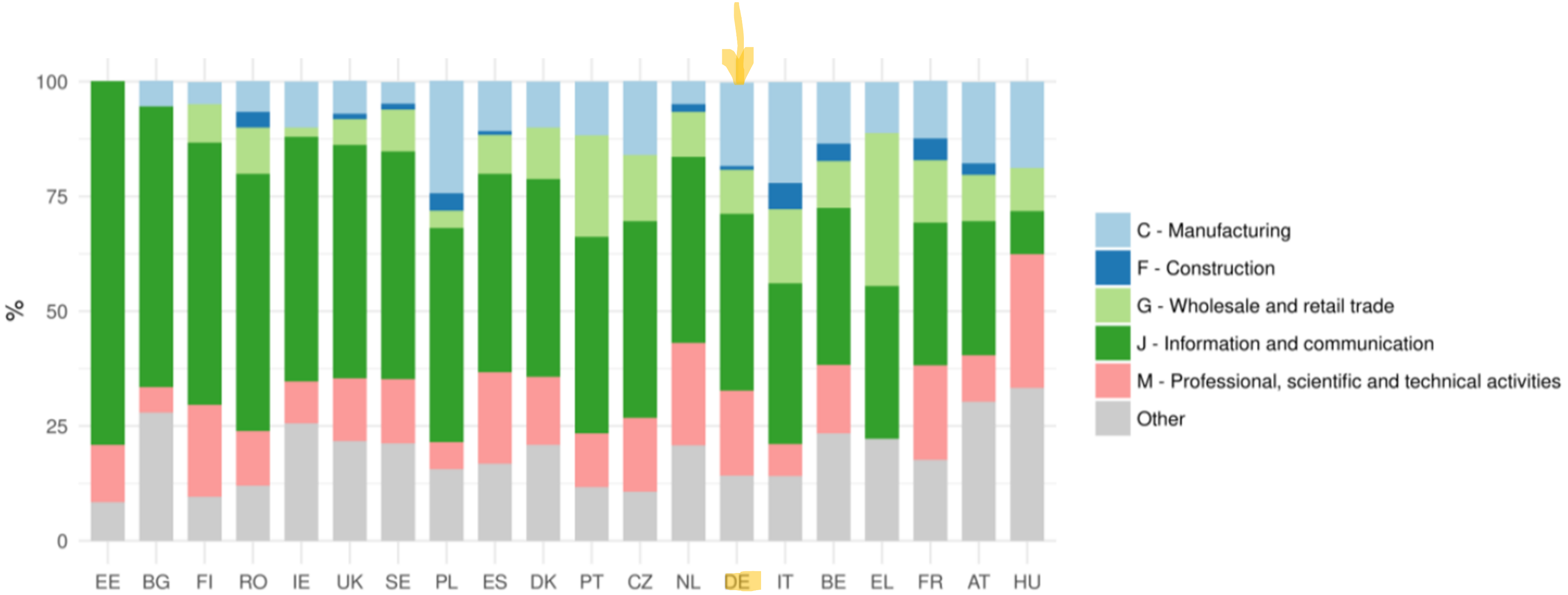
Karlsruhe Institute of Technology



Country activities as a percentage of EU activities in each key area, 2009-2018.

JRC PREDICT- AI TES Dataset, 2019

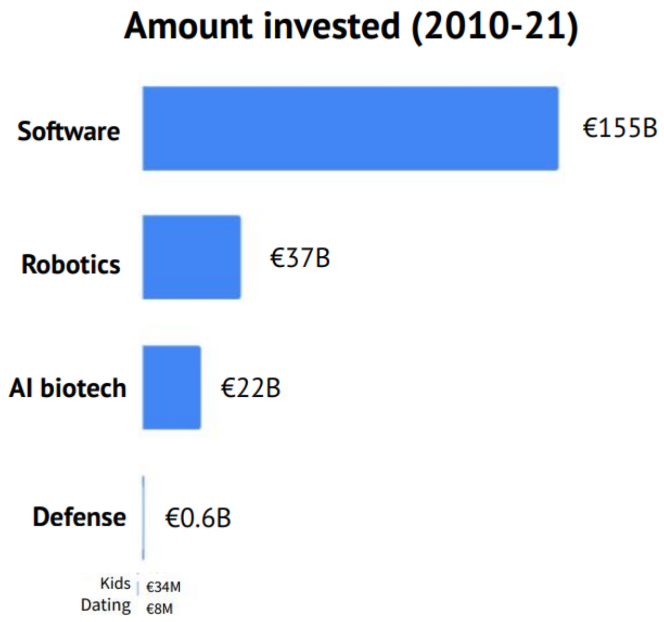
AI Activities: Firm distribution in Europe



AI unicorns

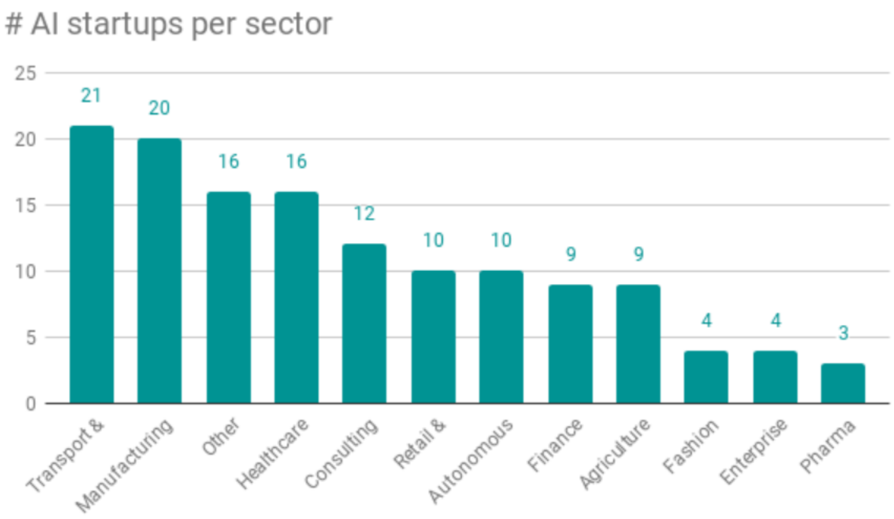
- 182 active AI unicorns >> $1.3T of combined enterprise value

	Number of AI unicorns	Total funding raised	Combined enterprise value
United States	103	€55B	€801B
China	35	€26B	€346B
United Kingdom	10	€4B	€69B
Israel	8	€2B	€25B
Canada	4	€1B	€8B
Germany	3	€2B	€14B
Singapore	3	€2B	€5B
Switzerland	3	€1B	€4B
Hong Kong	3	€3B	€9B
France	2	€1B	€2B
South Korea	2	€100M	€2B
Japan	1	€400M	€2B
India	1	€400M	€1B
Belgium	1	€300M	€2B
Bermuda	1	€200M	€2B
Taiwan	1	€100M	€1B
Sweden	1	n/a	€4B



AI Startups

Germany : Distinctly invest in manufacturing tech.



following key German industrial sectors:

- Manufacturing,
- Transport and Mobility,
- Healthcare.

AI Industry & Startups

Karlsruhe Institute of Technology

Continental

Cyber Valley

amazon

BOSCH Invented for life

Lufthansa

automotive engineering iav

PORSCHE

Allianz

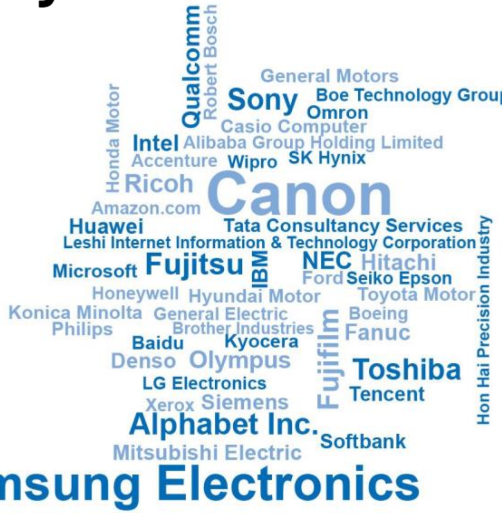
ARGMAX.ai VOLKSWAGEN GROUP ML RESEARCH

SIEMENS

BAYER

Deutsche Post DHL Group

DB



AI Industry & Startups

Karlsruhe Institute of Technology

Transportation & Mobility

APOSTERA, atlatec, AAI Automotive Artificial Intelligence, BAREWAYS, bliq, CARGONEXX, COMPREDICT, anvelio, FERNRIDE, German Autolabs, Kopernikus Automotive, LILIUM, MOTOR AI, NAVENTIK, peregrine technologies, RECOGNI, REE, SIGRA, SMARTLANE, SPLEENLAB, TWAICE, tiramizoo, TRACKS

Energy

INDUSTRIAL ANALYTICS, SOLANDEO, klima

Water & Waste

angsa, BREEZE TECHNOLOGIES, circunomics, ENWAY

Agriculture, Forestry & Fishing

AIRFARM, apic.ai, computomics, Dahlia Robotics, foldAI, ORBEM, ORORA TECHNOLOGIES, plantix, SKYLAB, SPACENUS, VINS

Manufacturing

3dvisionlabs, AISIGHT, arculus, ARTIMINDS, conductiv.ai, deevio, ERIUM, FactoryPal, FRANKA EMIKA, GESTALT ROBOTICS, Ground Truth Robotics, HOFMANN & STIRNER, KREATIZE, LAYER7AI, LOOXR, PANDA, micropsi industries, Pupil Labs, robominds, ROBOTISE, Streem.ai, truphysics, TVARIT, wandelbots

AI Industry & Startups

Cyber Valley

Europe's largest in AI

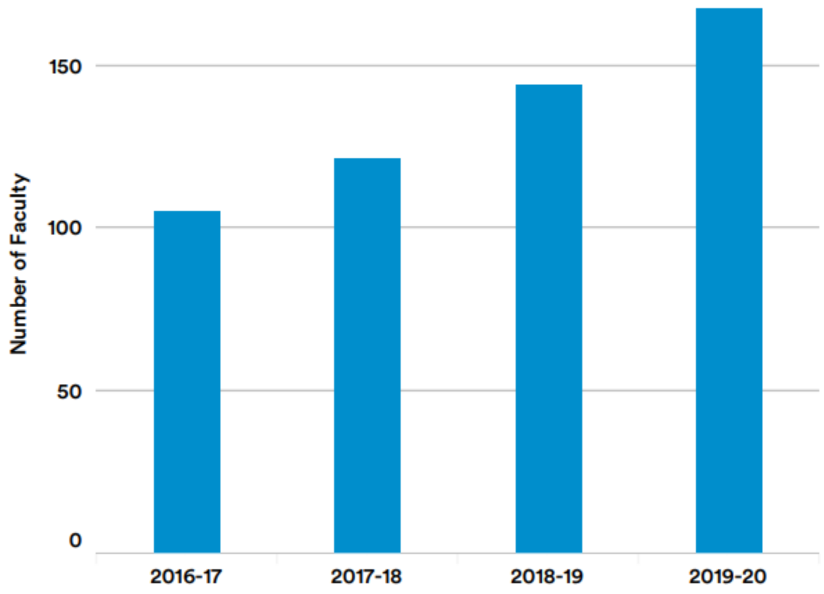
BW State	Max Planck	Uni. Stuttgart	Uni. Tübingen

R. Bosch GmbH   Amazon   BMW AG   Daimler AG   Porsche AG   ...

AI Education (73 Universities)

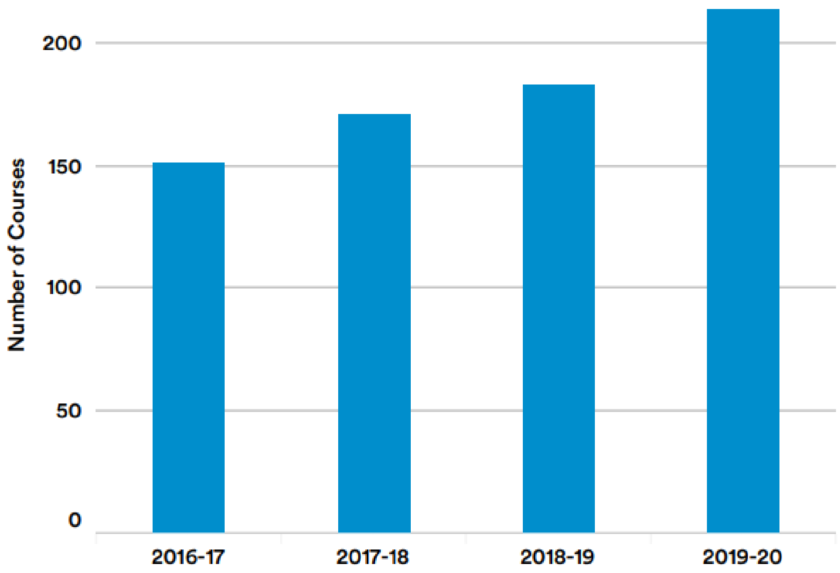
NUMBER of TENURE-TRACK FACULTY WHO PRIMARILY FOCUS THEIR RESEARCH on AI, AY 2016-20

Source: AI Index, 2020 | Chart: 2021 AI Index Report

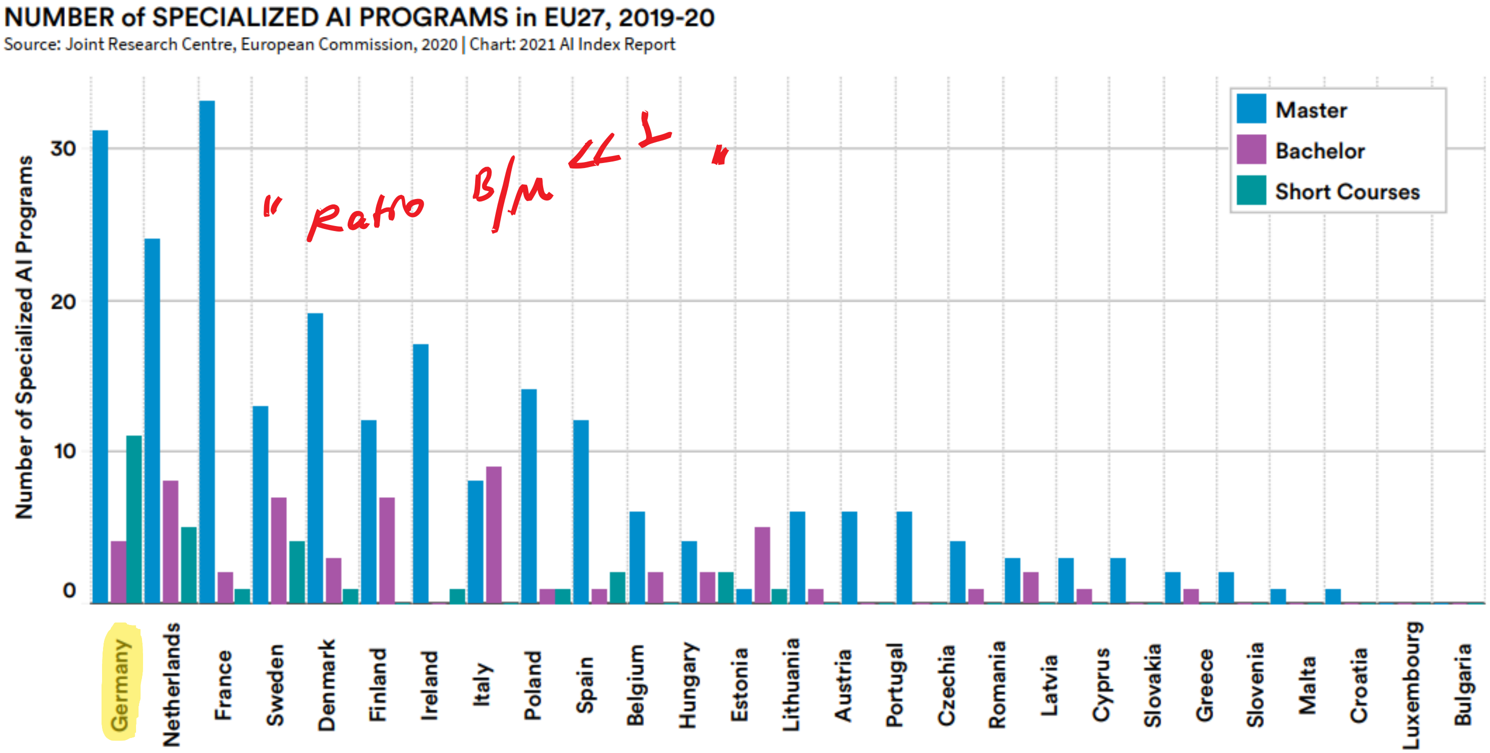


NUMBER of GRADUATE COURSES THAT TEACH STUDENTS the SKILLS NECESSARY to BUILD or DEPLOY a PRACTICAL AI MODEL, AY 2016-20

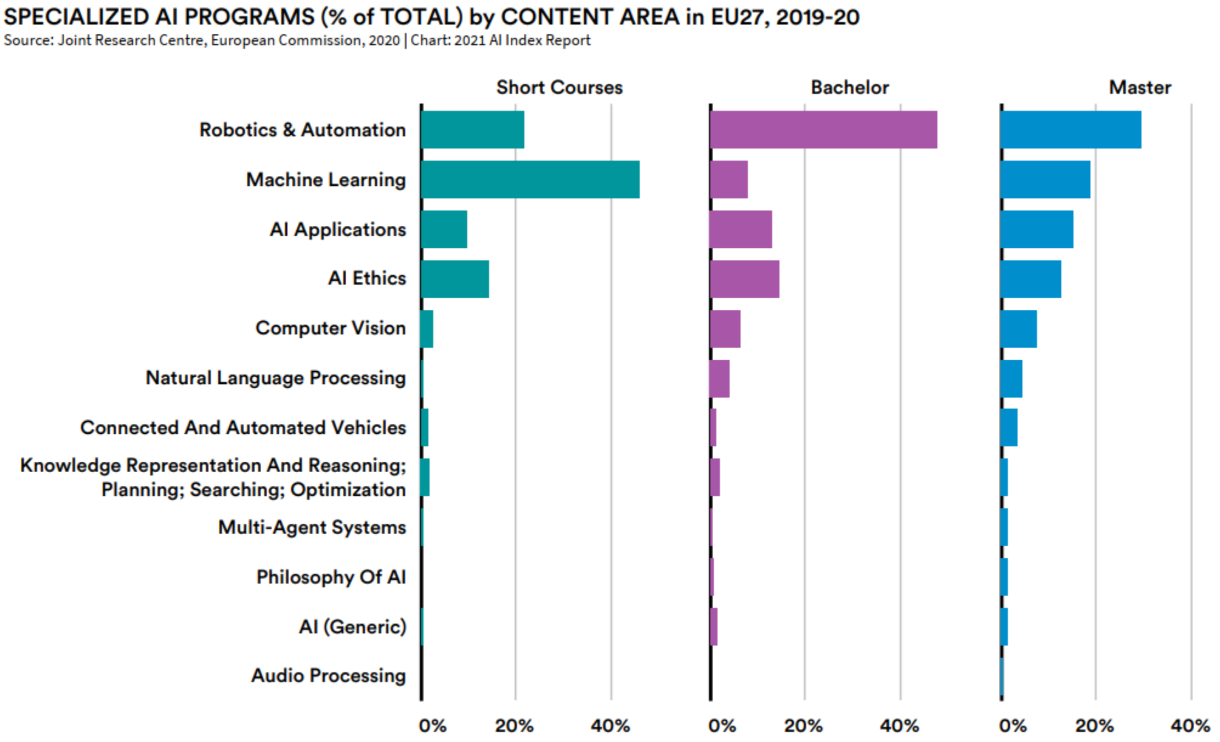
Source: AI Index, 2020 | Chart: 2021 AI Index Report



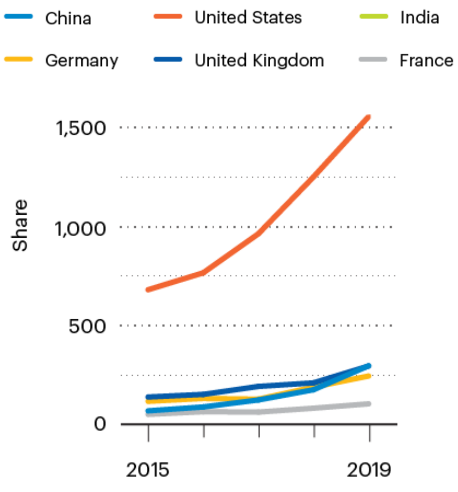
Changing landscape: EU

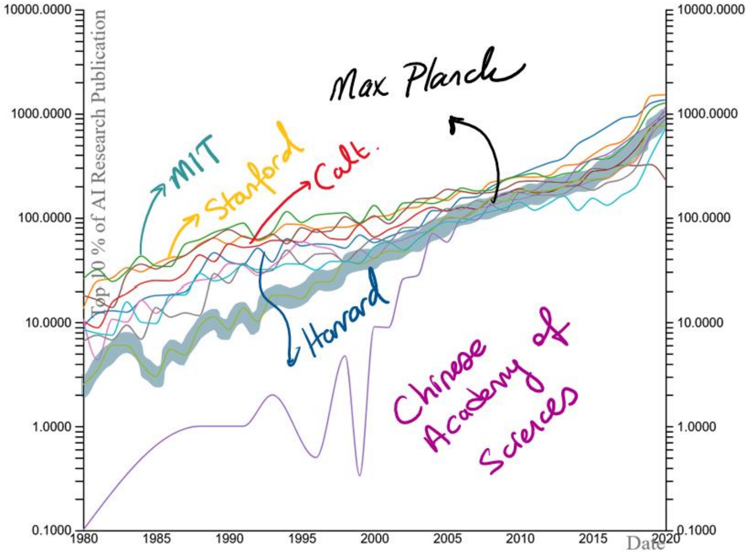


Changing landscape: EU



Where are we in AI landscape as KIT ?



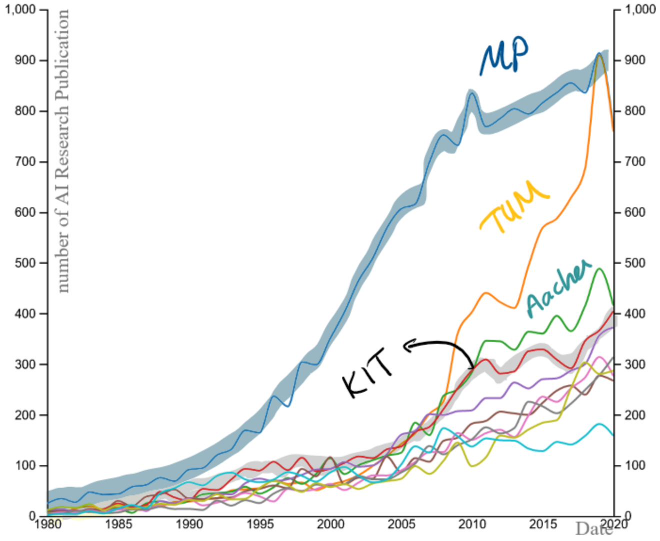


→ Only one institute from Germany

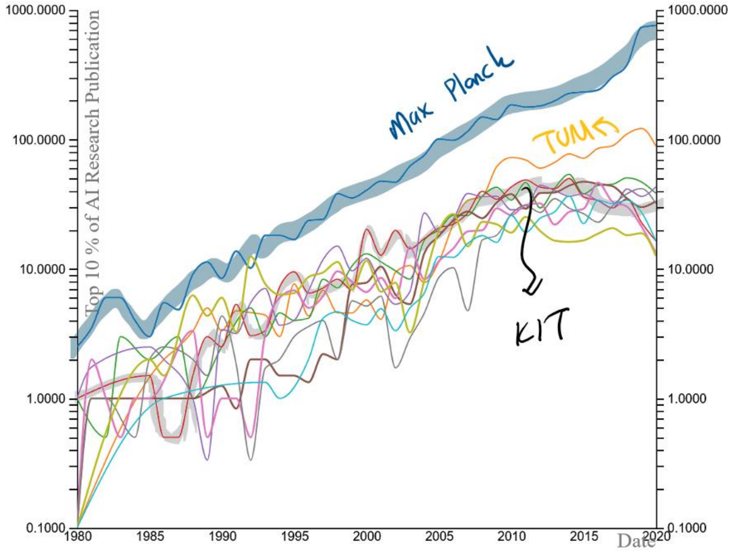
→ MP is representative of top institutes

Where are we in AI landscape as KIT ?

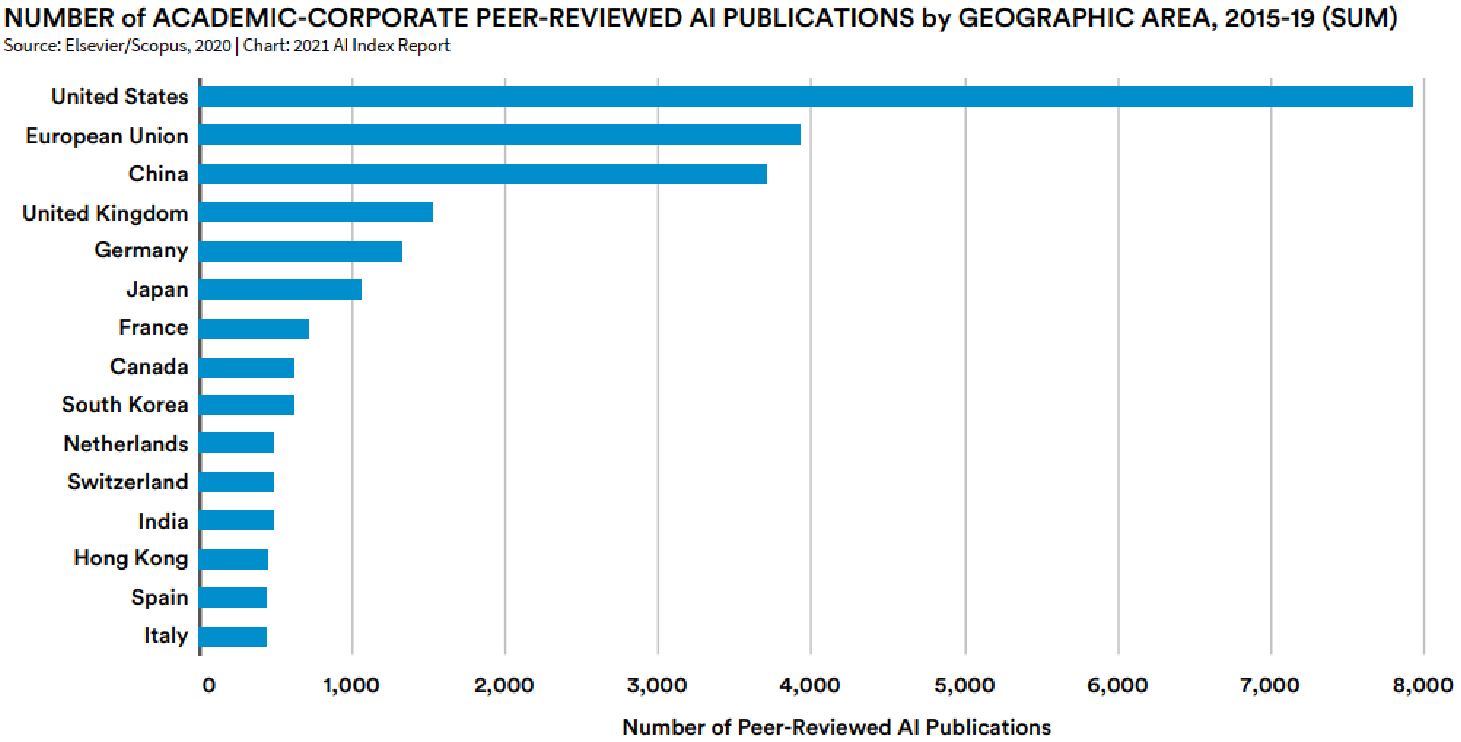
Karlsruhe Institute of Technology



Top 10% Journals ⇒



Academic-Corporate Collaboration



AI Strategy of the German Federal Government 2020

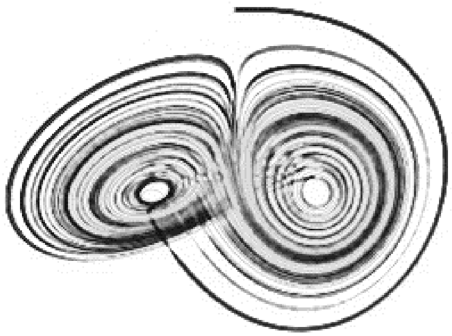
- learning **manufacturing technology** - use of artificial intelligence in production
- AI funding measures in **agriculture, the food chain, health food** and rural areas
- self-learning systems in the field of **mobility**
- applied research, development and testing on complex **autonomous driving**
- AI Flagship Projects for the **Environment, Climate, Nature and Resources** (KI-Leuchttürme) with the priorities AI innovations **for climate protection and “resource-efficient AI”**

AI Strategy of the German Federal Government

* Academia

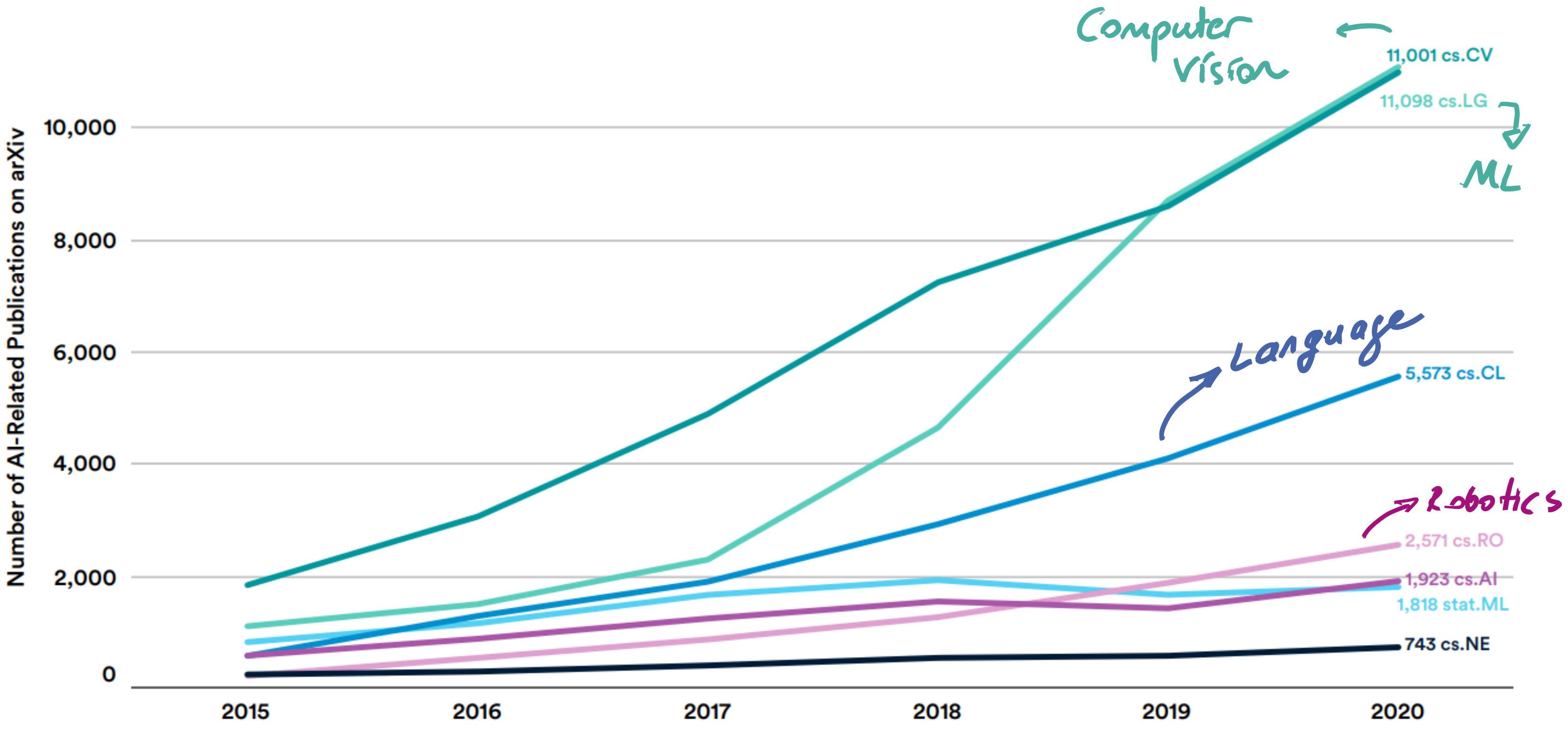
- 30 Alexander von Humbolt professorship
- € 5 billion for education
  ↓
  € 90 million for DFG
- Fraunhofer ⇒ "Industry 4.0"

- Emmy Noether Calls
- Max Planck Research School for intelligent systems
  ↳ 160 Scholars
  (~80 jointed recently)



A selection from recent work

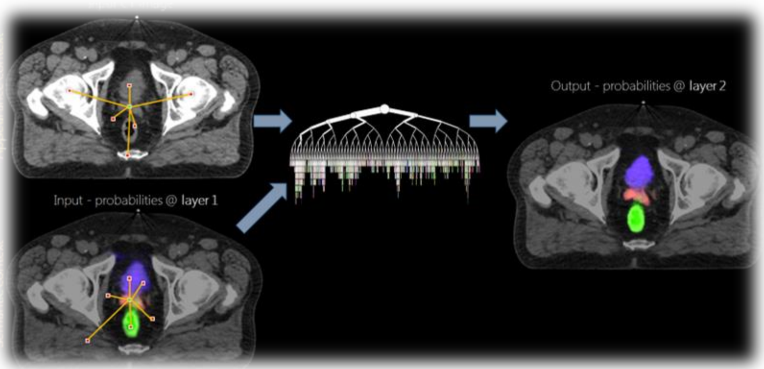
Hot topics in AI



Computer Vision

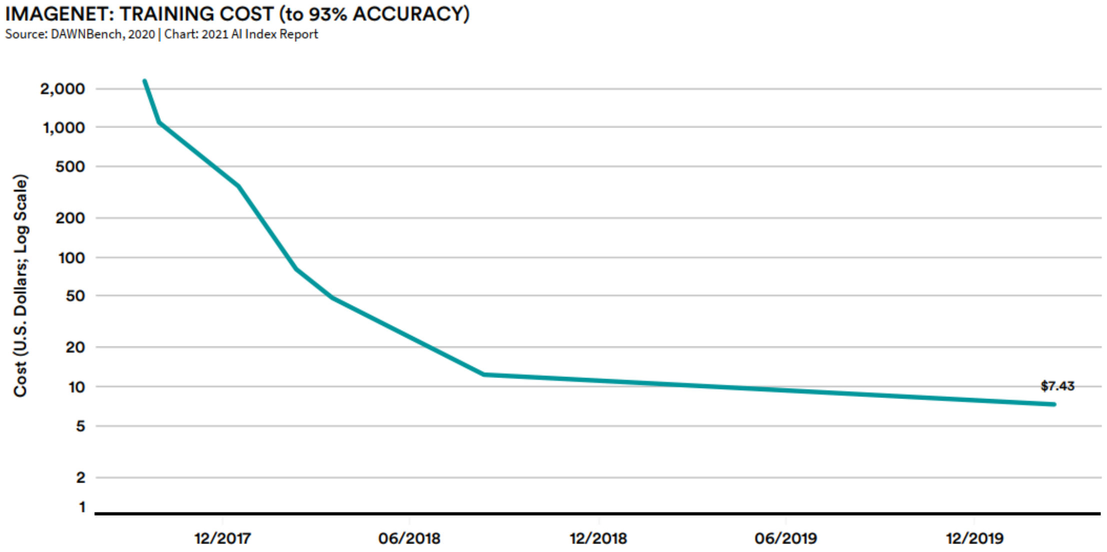
- **Applications:** object recognition, pose estimation, and semantic segmentation

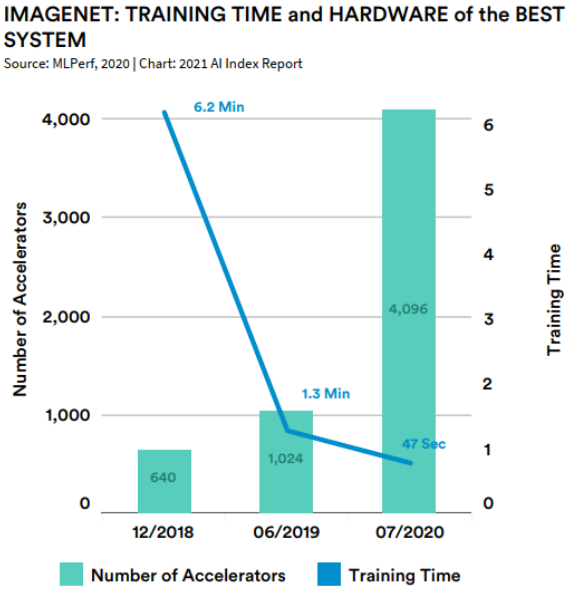
- self-driving cars
- medical image analysis
- surveillance, satellite imagery analysis
- detecting defective parts in manufacturing and assembly



Computer Vision

- Deep learning ~2010: affordable and applicable
- ImageNet Challenge: 14M images, > 200 classes





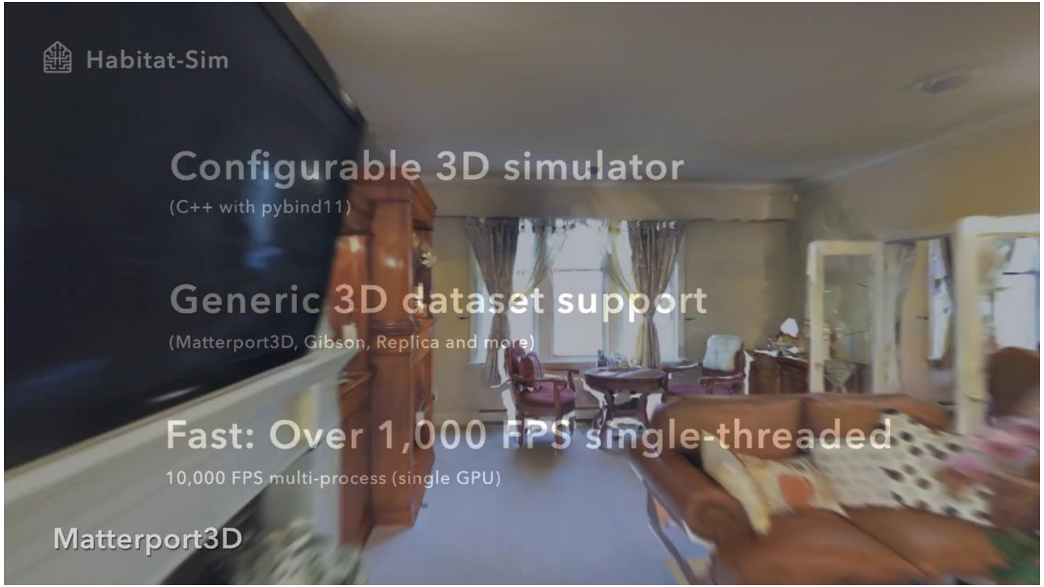
Embodied Vision

- AI systems that can be interactive or embodied

i. Deploy robots in virtual spaces

ii. Simulate what their cameras would see and capture

iii. Develop AI algorithms for navigation, object search, object grasping



CV protects employees from workplace injuries

- trained to detect over 35 types of employee health and safety (EHS) incident
- run 24/7

Heatmap of incidents

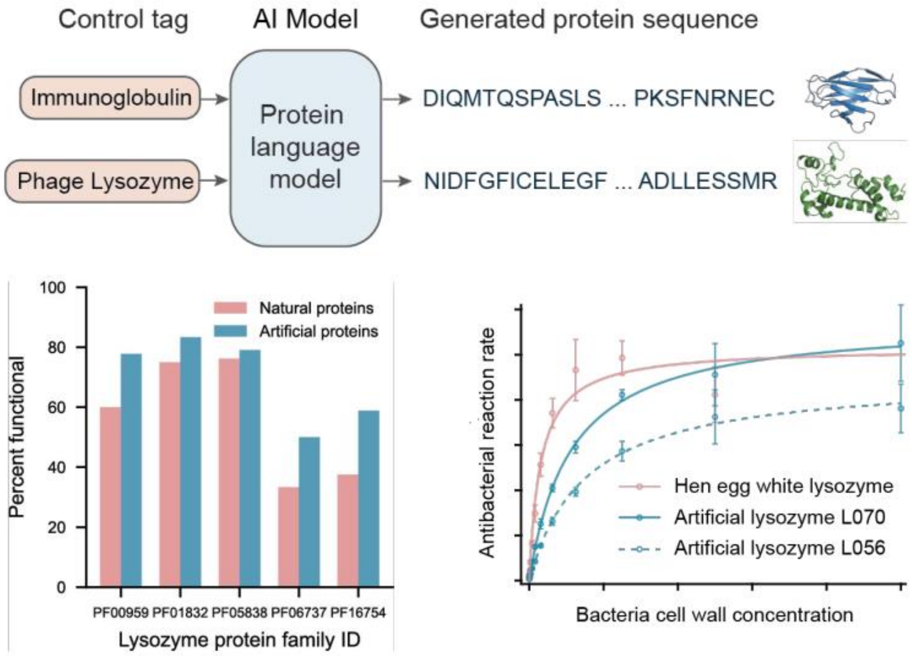
Employee not wearing PPE

Dangerous driving

intenseye

Language models => artificial functional proteins

- Protein language model by predicting the next amino acid for over 280M protein sequences
- **AI-generated proteins** across 5 families of antibacterial lysozymes show similar biological performance

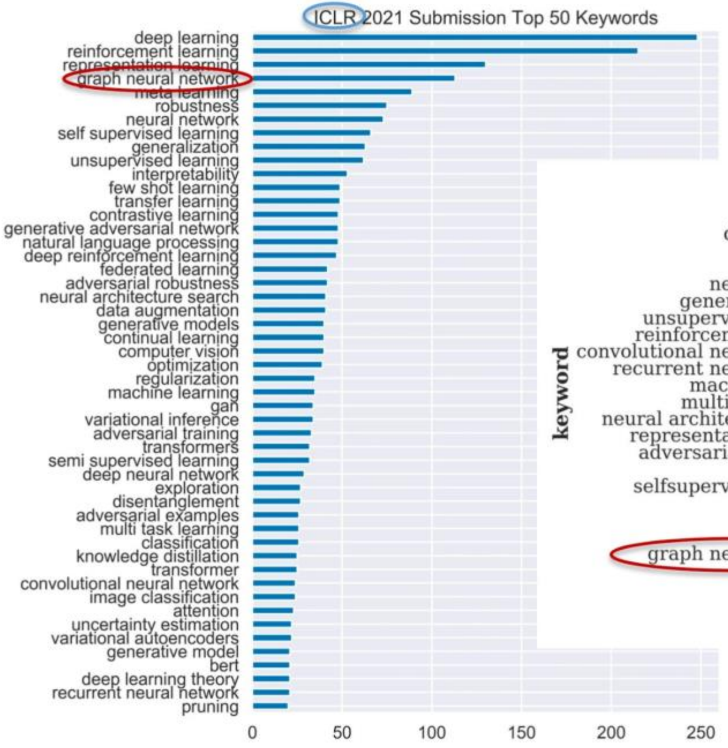


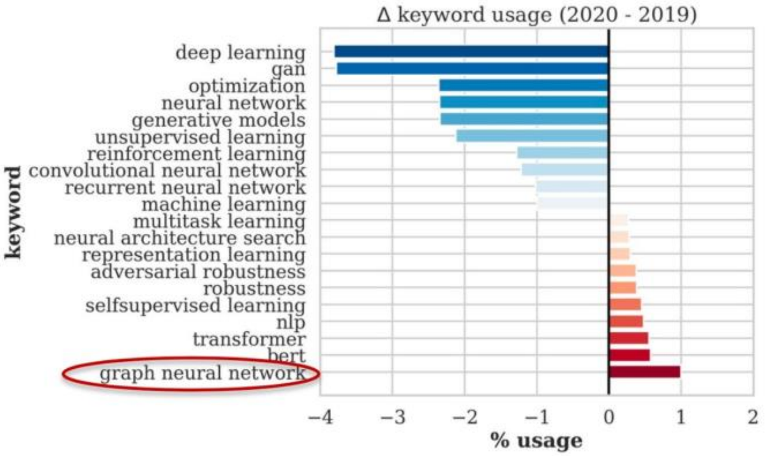
Electricity demand forecast using transformers

- NLP => Time series analysis
- UK National Grid ESO halves error of electricity demand forecast using transformers
- Temporal Fusion Transformer: forecasts to the control room since May 2021
- halved the mean absolute error (MAE)

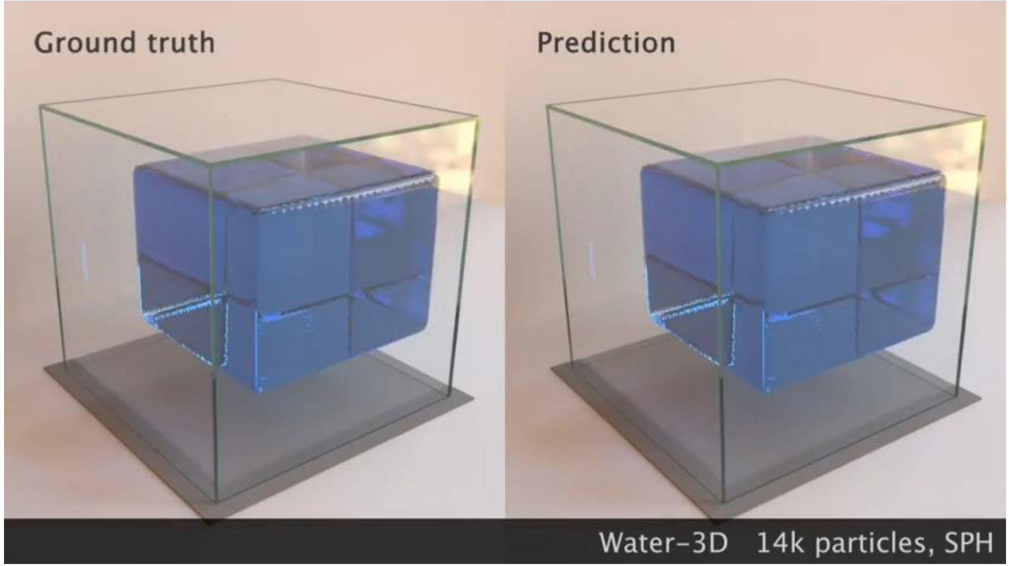
Forecast lead time	Reduction in mean absolute error (MAE)
1 hour	58%
4 hours	25%
8 hours	11%
24 hours	14 %

Graph Neural Networks: one of the hottest fields of AI





Simulate Complex Physics with Graph NN



- Graph Nets library of DeepMind
- Autoencoder (TF)

Experimental domain	N	K	1-step ($\times 10^{-9}$)	Rollout ($\times 10^{-3}$)
WATER-3D (SPH)	13k	800	8.66	10.1
SAND-3D	20k	350	1.42	0.554
GOOP-3D	14k	300	1.32	0.618
WATER-3D-S (SPH)	5.8k	800	9.66	9.52
BOXBATH (PBD)	1k	150	54.5	4.2
WATER	1.9k	1000	2.82	17.4
SAND	2k	320	6.23	2.37
GOOP	1.9k	400	2.91	1.89
MULTIMATERIAL	2k	1000	1.81	16.9
FLUIDSHAKE	1.3k	2000	2.1	20.1
WATERDROP	1k	1000	1.52	7.01
WATERDROP-XL	7.1k	1000	1.23	14.9
WATERRAMPS	2.3k	600	4.91	11.6
SANDRAMPS	3.3k	400	2.77	2.07
RANDOMFLOOR	3.4k	600	2.77	6.72
CONTINUOUS	4.3k	400	2.06	1.06

- Simulate wide range of physical systems in which fluids
- Generalize to larger systems / longer time scales

GANs vs. diffusion models: new adversary

- Inverse distribution problem
- Denoised images from noisy ones
- at each step as a Gaussian parametrized as a DNN
- Beat GANs on ImageNet: from 64x64 to 512x512

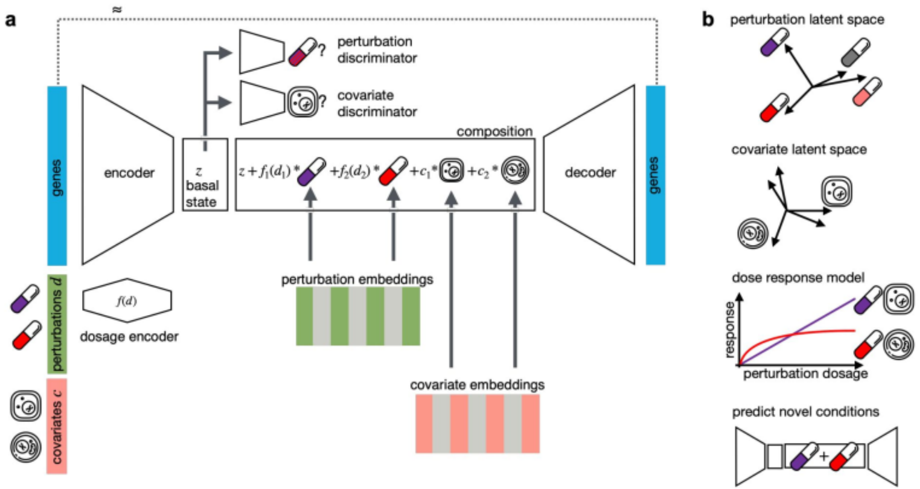
Figure 1: Selected samples from our best ImageNet 512×512 model (FID 3.85)

Autoencoders for drug therapy

- ❑ Cells treated with a finite number of drug combinations and to predict the effect of unseen combinations

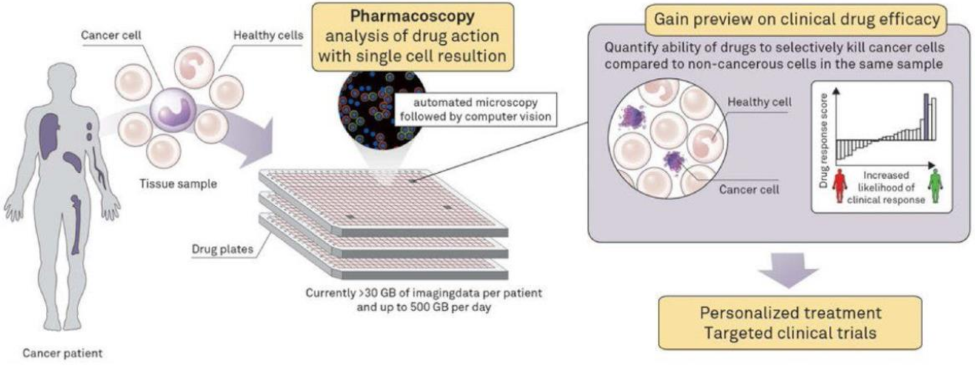
- An autoencoder is used to encode and learn embeddings for the transcriptional response of single cells

- 30 drug treatments across different cell types, doses, and drugs



Drug selection for cancer patients

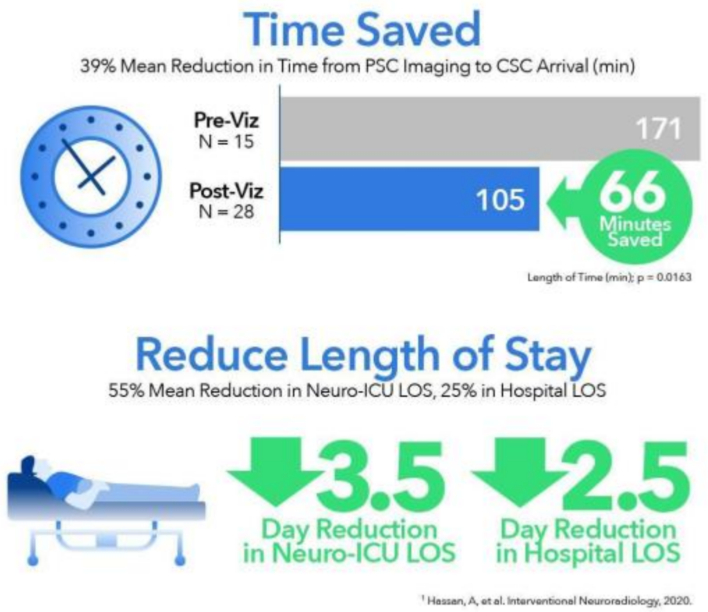
- 90% of patients do not respond to the therapy
- how live cancer cells respond to 140 anticancer drugs at the single cell level
- clinical trial of 56 blood cancer patients
- AI-guided therapy achieved a 55% overall response rate



Exscientia

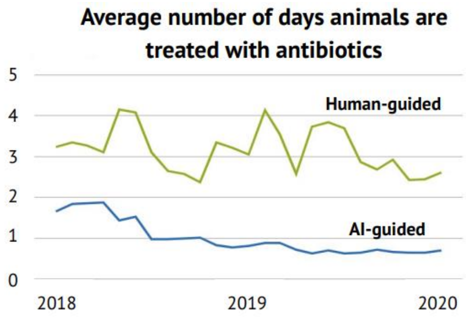
Stroke detection software

- deep learning system from Viz.ai
- 96% sensitivity and 94% specificity in identifying large vessel occlusions in 2,544 consecutive patients from 139 hospitals using scanners from multiple manufacturers
- 52 minutes faster than the standard of care, resulting in a 40% improvement in patient outcomes

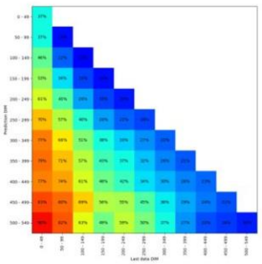


Sustainability and carbon efficiency of farms

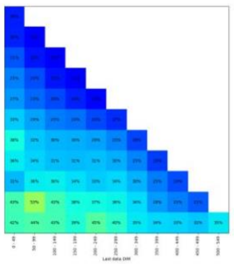
- **Dairy cow farmers**
- accelerometer data from a neck-worn sensor: predict health issues 2-3 days prior to human observation
- predict the onset of calving, which reduces the number of days that pregnant cows are treated with antibiotics
- predict milk yield with <1% margin of error up to 200 days in the future



Industry-standard

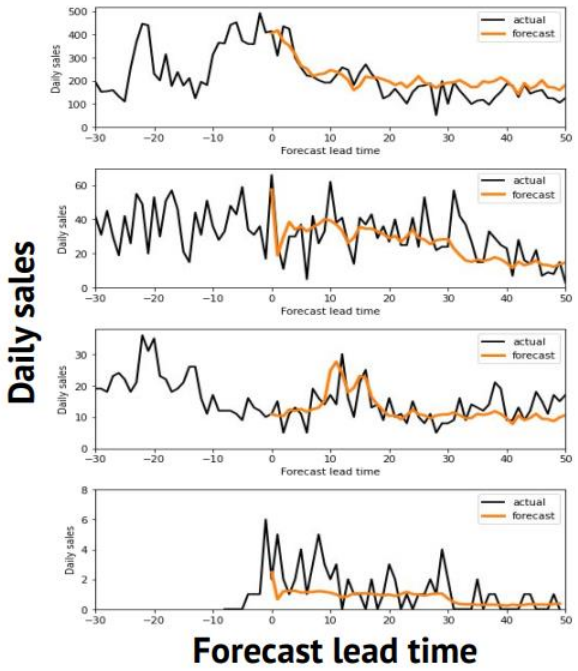


AI milk predictor



DL automates stock replenishment decisions

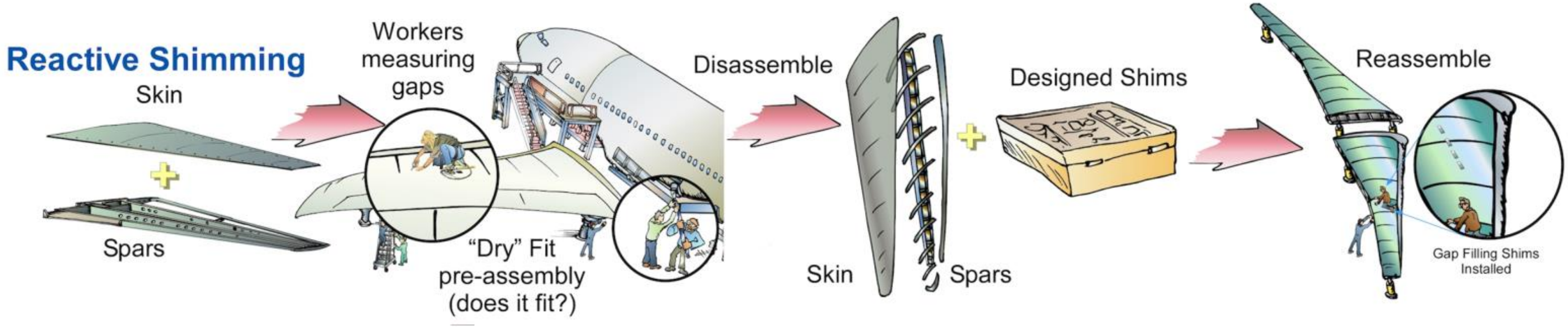
- Ocado: seq-to-seq models are used to forecast demand:
  - Ranges of up to 55,000+ products
  - savings of £250,000 per month with 5% more accurate forecasting
  - waste reduced from 0.6% to 0.3%
  - product availability increased from 92% to 94.5%



Aircraft assembly

- Boeing 787: 2.3 million parts sourced from around the globe
- assembled in an extremely complex and intricate manufacturing process

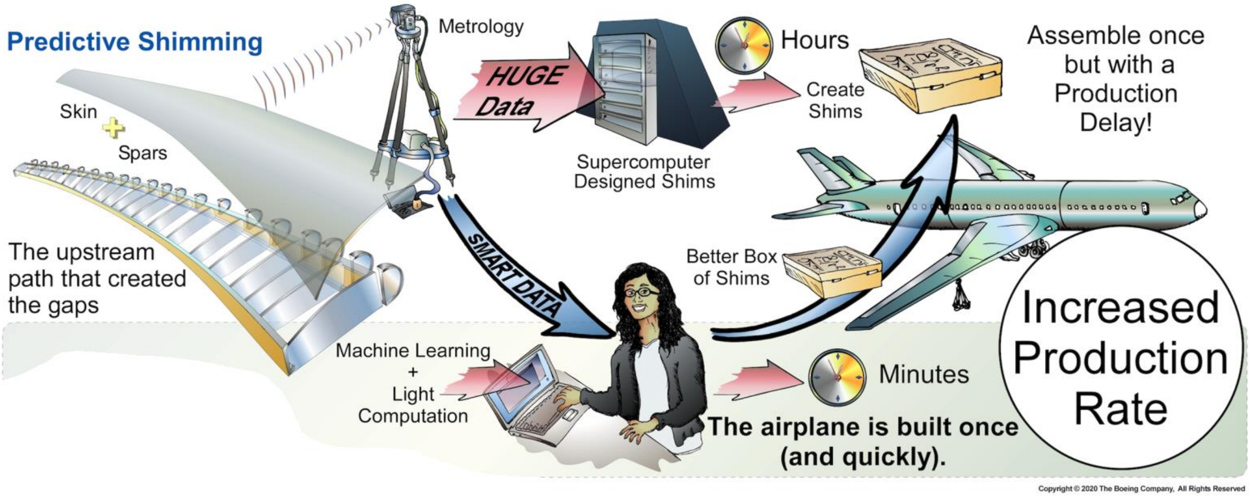
- parts have been dry-fit, gaps measured manually
- custom shims manufactured and inserted, often involving disassembly and reassembly



Aircraft assembly

- PIXel Identification Despite Uncertainty in Sensor Technology (PIXI-DUST)
- predicts 99% of the shim gaps within the desired measurement tolerance
- using around 3% of the laser scan points that are typically required

- Robust PCA
- Train:53 aircraft data



Intelligent fault diagnosis (IFD)

Objects	References	Methodologies
Bearings	Yang et al. [101], Samanta et al. [102], Yu et al. [103], Castejon et al. [104], Muruganatham et al. [105], Unal et al. [106], Zarei et al. [107], Almeida et al. [108], and Ahmed et al. [109]	BPNN
	Wang et al. [110], Lei et al. [111], Vijay et al. [112], Jiang et al. [113], and Tang et al. [114]	RBFN
	Lei et al. [115], Wu et al. [116]	WNN
Gears	Abu-Mahfouz et al. [117], Rafiee et al. [118], Hajnayeb et al. [119], Cerrada et al. [120], Kane et al. [121], Waqar et al. [122], and Tyagi et al. [123]	BPNN
	Lai et al. [124], Li et al. [125], and Liu et al. [126]	RBFN
	Chen et al. [127]	WNN
Motors	Ayhan et al. [128], Sadeghian et al. [129], Arabaci et al. [130], Cabal-Yepez et al. [131], Hernandez-Vargas et al. [132], and Moosavi et al. [133]	BPNN
	Ghate et al. [134], and Palacios et al. [135]	RBFN
	Boukra et al. [136]	WNN
Engines	Sharkey et al. [137], Lu et al. [138], Chen et al. [139,140], Khazaee et al. [141,142], and Zabihi-Hersari et al. [143]	BPNN
	Wu et al. [144,145]	RBFN
	Shen et al. [146], Zhang et al. [147]	WNN
Others	Kuo et al. [148], Ilott et al. [149], Wu et al. [150], Mohammed et al. [151], Walker et al. [152], Malik et al. [153], and McCormick et al. [154,155]	BPNN
	Wu et al. [156], and Villanueva et al. [157]	RBFN
	Liu et al. [158], Chen et al. [159], Guo et al. [160], Xiao et al. [161], and Jin et al. [162]	WNN

Crack fault diagnosis of rotating machine

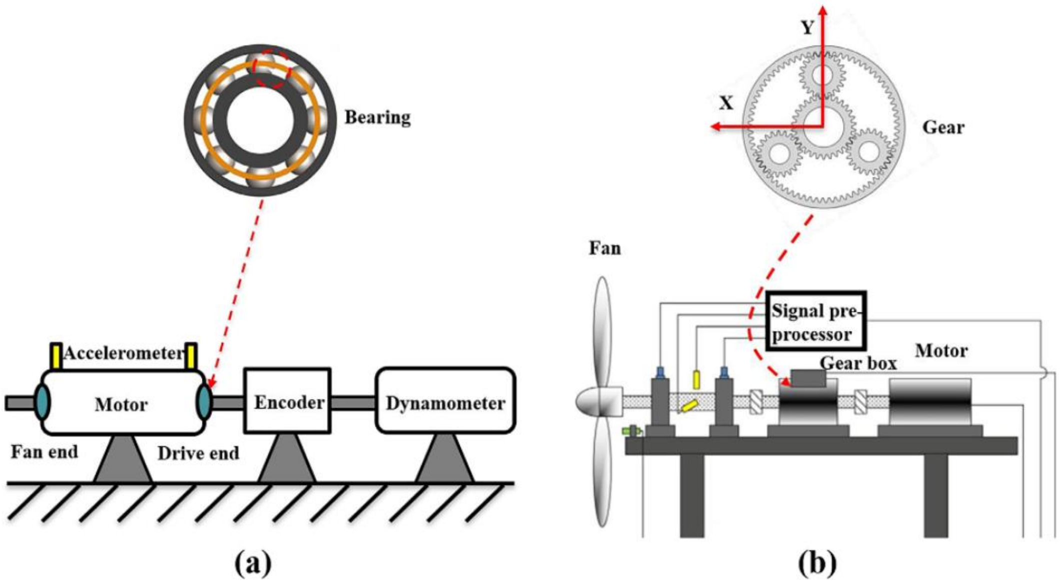


Fig. 6. Schematic diagram of the experiment setup system (a) CWRU bearing fault experiment (b) THU gearbox fault experiment.

Fault classes of CWRU bearing experiment.

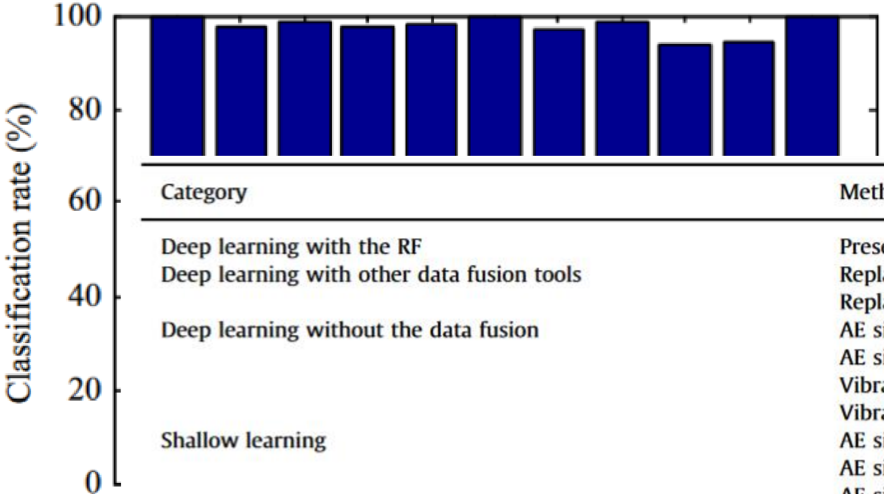
Classes	Type	Levels
H	Health	–
BF_18	Ball crack	Crack depth:0.18 mm
BF_36	Ball crack	Crack depth:0.36 mm
BF_54	Ball crack	Crack depth:0.54 mm
BF_72	Ball crack	Crack depth:0.72 mm

Classes	Type	Levels
H	Health	–
SC1	Sun tooth crack	Crack depth:1/8 dedendum
SC2	Sun tooth crack	Crack depth:1/4 dedendum
SC3	Sun tooth crack	Crack depth:1/2 dedendum
SB	Sun tooth broken	Break position: 1/3 tooth depth
PC1	Planet tooth crack	Crack depth:1/8 dedendum
PC2	Planet tooth crack	Crack depth:1/4 dedendum
PC3	Planet tooth crack	Crack depth:1/2 dedendum
PB	Planet tooth broken	Break position: 1/3 tooth depth

Model performance in the original condition.

Model	Accuracy/%		Training time/s	
	CWRU	THU	CWRU	THU
Decision tree	90.55	90.10	28.61	56.22
Random forest	92.10	93.47	284.50	6915.20
Adaboost tree	92.85	94.16	169.27	1784.70

Gearbox -- vibrations



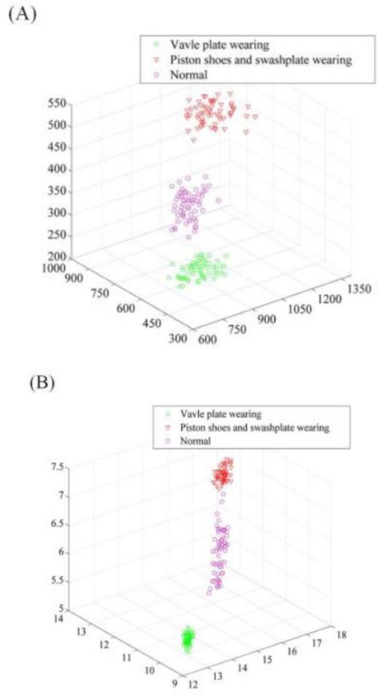
Category	Method	Classification rate (%)
Deep learning with the RF	Present DRFF	97.68
Deep learning with other data fusion tools	Replace RF with SVM for DRFF	96.45
	Replace RF with KNN for DRFF	95.58
Deep learning without the data fusion	AE signal for DBM	79.77
	AE signal for DRFF	83.94
	Vibratory signal for DBM	88.74
	Vibratory signal for DRFF	89.49
Shallow learning	AE signal for SVM	58.94
	AE signal for KNN	32.42
	AE signal for RF	87.20
	Vibratory signal for SVM	71.57
	Vibratory signal for KNN	51.84
	Vibratory signal for RF	88.43

Fault Diagnosis for Rotating Machinery

- bearing, gear/gearbox and pumps

SUMMARY OF DL-BASED METHODS FOR MACHINERY FAULT DIAGNOSIS

Technique	Applications	Diagnosis Effect	(Ref.)
CNN with first-layer kernel dropout	Bearing fault diagnosis	99.77% accuracy	[74]
CNN and second generation wavelet transform	Motor bearing fault diagnosis	99.63% accuracy	[75]
CNN and wavelet packet energy	Spindle bearing fault diagnosis	99.8% accuracy	[76]
CNN with hierarchical structure	Bearing fault diagnosis	desirable performance	[40]
CNN	Bearing fault diagnosis	99.75%	[77]
CNN	Bearing fault diagnosis	100% accuracy	[78]
CNN	Rotor and bearing fault diagnosis	100.00% accuracy for rotor; 93.33% for bearing	[79]
CNN	Bearing fault diagnosis	99.89% accuracy	[80]
DBN and sparse autoencoder	Bearing fault diagnosis	97.82% average accuracy	[81]
RNN-based	Bearing fault	99.85%	[82]
CNN	Gearbox fault diagnosis	96.8% mean accuracy	[93]
SAE, dropout technique and ReLU activation function	Gearbox fault diagnosis	99.34%	[94]
GAN and stacked denoising autoencoders	Gearbox fault diagnosis	98.4% accuracy	[95]
TL	Gearbox and bearing fault diagnosis	100%	[96]
Multimodal deep support vector	Gearbox fault diagnosis	97.08%	[97]
Support tensor machine	Gear fault diagnosis	99.50%	[98]
DNN	Bearings and gears fault diagnosis	100%	[39]
CNN	Bearing, self-priming centrifugal pump, and axial piston hydraulic pump fault diagnosis	99.79%, 99.481%, 100% prediction accuracy	[99]
SAE	Spacecraft fault diagnosis	98.35%	[100]
Refrigerant charge fault detection-based CNN	Heat pump system	99.9%	[101]

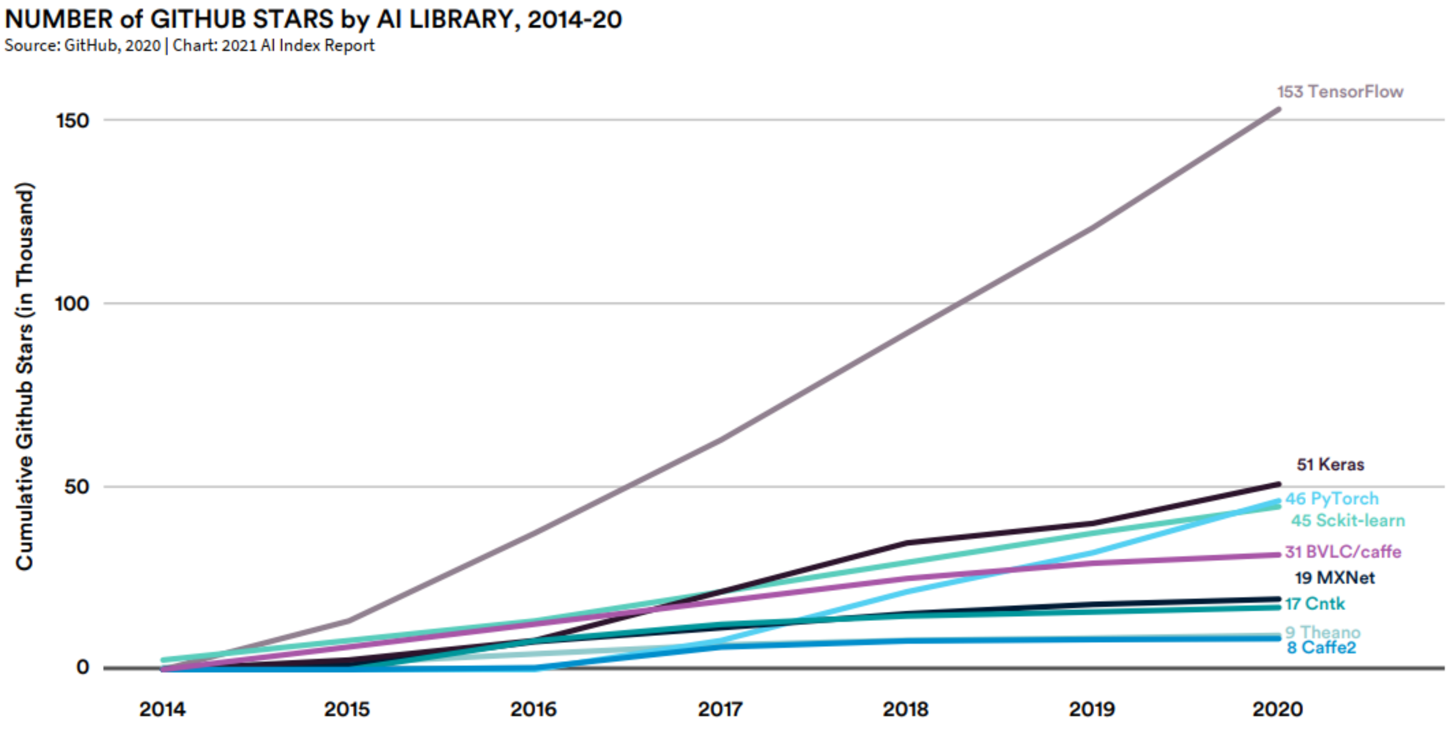


Manufacturing Tool

Machining process	Activity	Algorithms	Input
Milling process	Monitoring of tool wear, detection of tool breakage, prediction of tool wear	k-NN, SVM, SVR, random forest (RF)	Tool images, power consumption data, cutting force, vibrations and acoustic emission
Turning	Prediction of machining parameters, online tool life prediction	SVR, ANNs, Cascade-forward BPNN, Computing based on DNA, Cascade-forward NN, Feed-forward NN, polynomial regression	Radius of tool edge, tool coating status, machining time, feed rate, cutting speed, avg. no. of white pixels from tool image, depth of cut, 6 signal features from cutting force, vibrations, acoustic emission sensor, spindle speed
Grinding	Surface roughness and surface shape peak valley monitoring	Interpolation factor SVR	Acoustic emission, vibration, grinding force
Drilling	Evaluation of quality and geometric profile	Logical analysis of data	Thrust force, torque, cutting force
Boring	Chatter prediction (stable, transition, chatter)	SVM	Feed rate, spindle speed and depth of cut

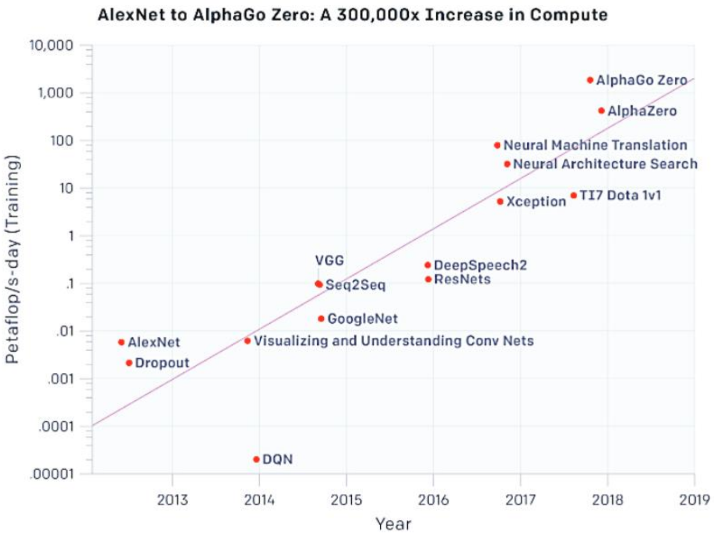
Machining process	Activity	Algorithms	Input
Abrasive water jet	Surface roughness prediction	Feed-forward BPNN, regression model	Abrasive flow, traverse speed, abrasive grit size, jet pressure, standoff distance
Electric discharge machining (EDM)	Predict optimum process parameter for maximum material removal rate (MRR) and minimum wear ratio, minimum surface roughness	BPNN, GA particle swarm optimization, GPR, NSGA-II, GRA—Gray rational analysis	Pulse current, pulse-ON/OFF time
ECDM, ECM	Optimization of process parameters for maximizing MRR and minimizing radial overcut	Teaching learning-based optimization (TLBO)	Electrolyte concentration and flow rate, applied voltage, inter-electrode gap

Open-source Software Libraries



Carbon emissions of large neural network training

- Deep learning models: >billion parameters



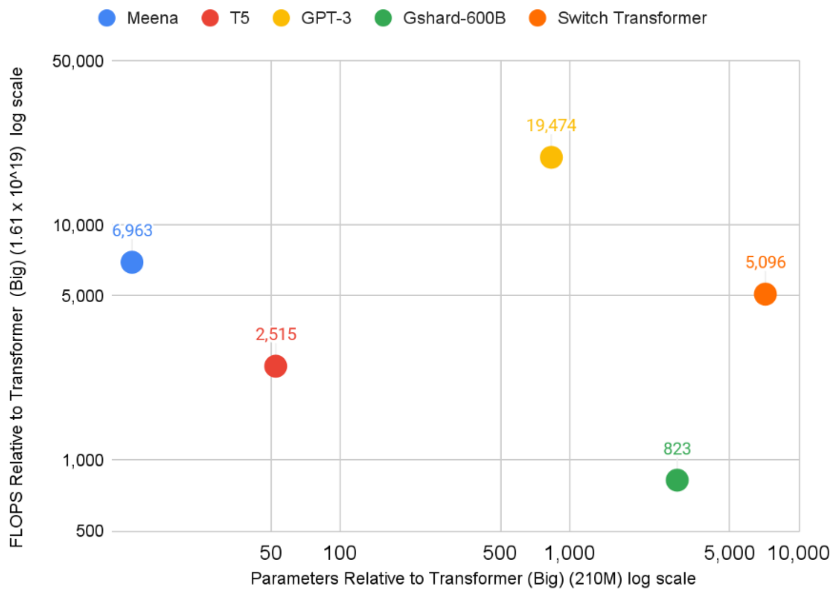
NLP models:

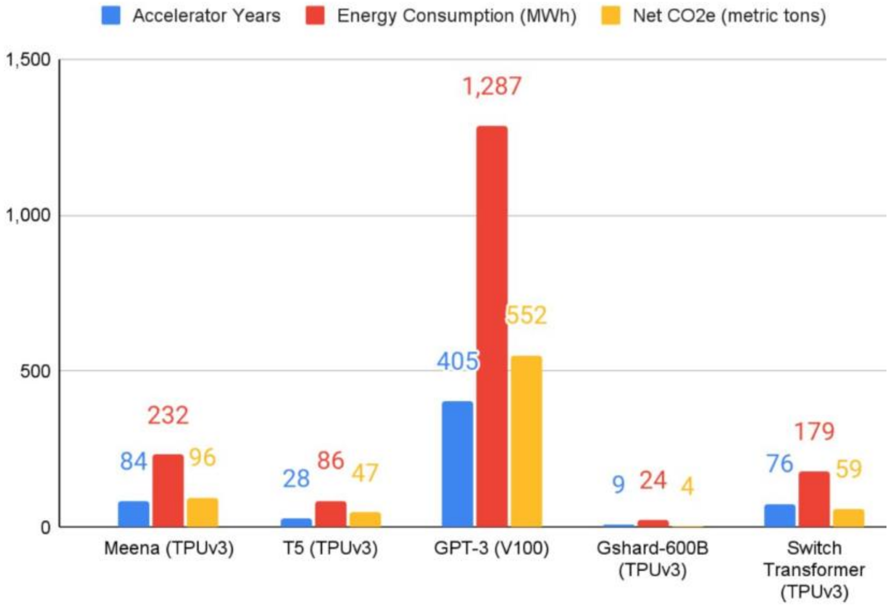
	Date of original paper	Energy consumption (kWh)	Carbon footprint (lbs of CO2e)	Cloud compute cost (USD)
Transformer (65M parameters)	Jun, 2017	27	26	$41-$140
Transformer (213M parameters)	Jun, 2017	201	192	$289-$981
ELMo	Feb, 2018	275	262	$433-$1,472
BERT (110M parameters)	Oct, 2018	1,507	1,438	$3,751-$12,571
Transformer (213M parameters) w/ neural architecture search	Jan, 2019	656,347	626,155	$942,973-$3,201,722
GPT-2	Feb, 2019	-	-	$12,902-$43,008

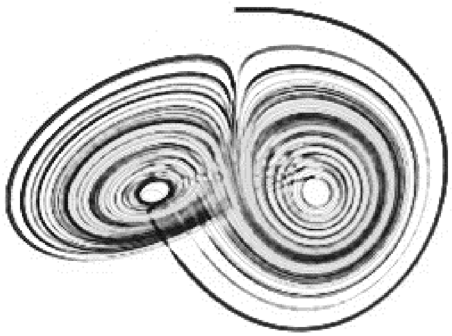
GPT3: 75 billion parameters, 4.6 million $ and 355 years in computing time

Carbon emissions of large neural network training

Deep learning models: >billion parameters



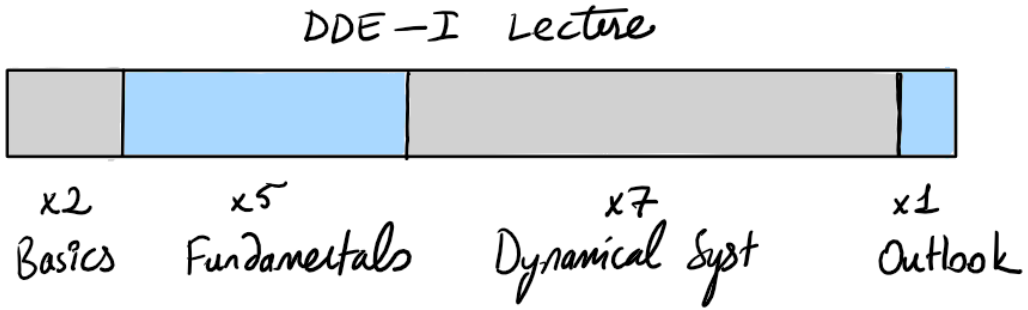




DDE Lecture Series

Data Driven Eng. Lecture (Series)

DDE-I



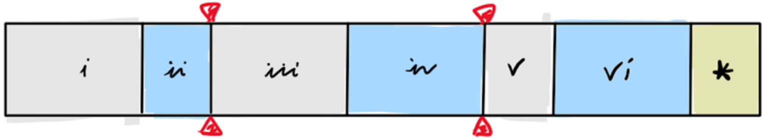
* 6 ML Classes
* 35 model architectures + 11 aux. models
* 10 x 45' Coding Sessions

Idea: Data Driven Eng. Lecture (Series)

⇩

DDE-II

"Specialization"



10 lectures
3 Project sessions

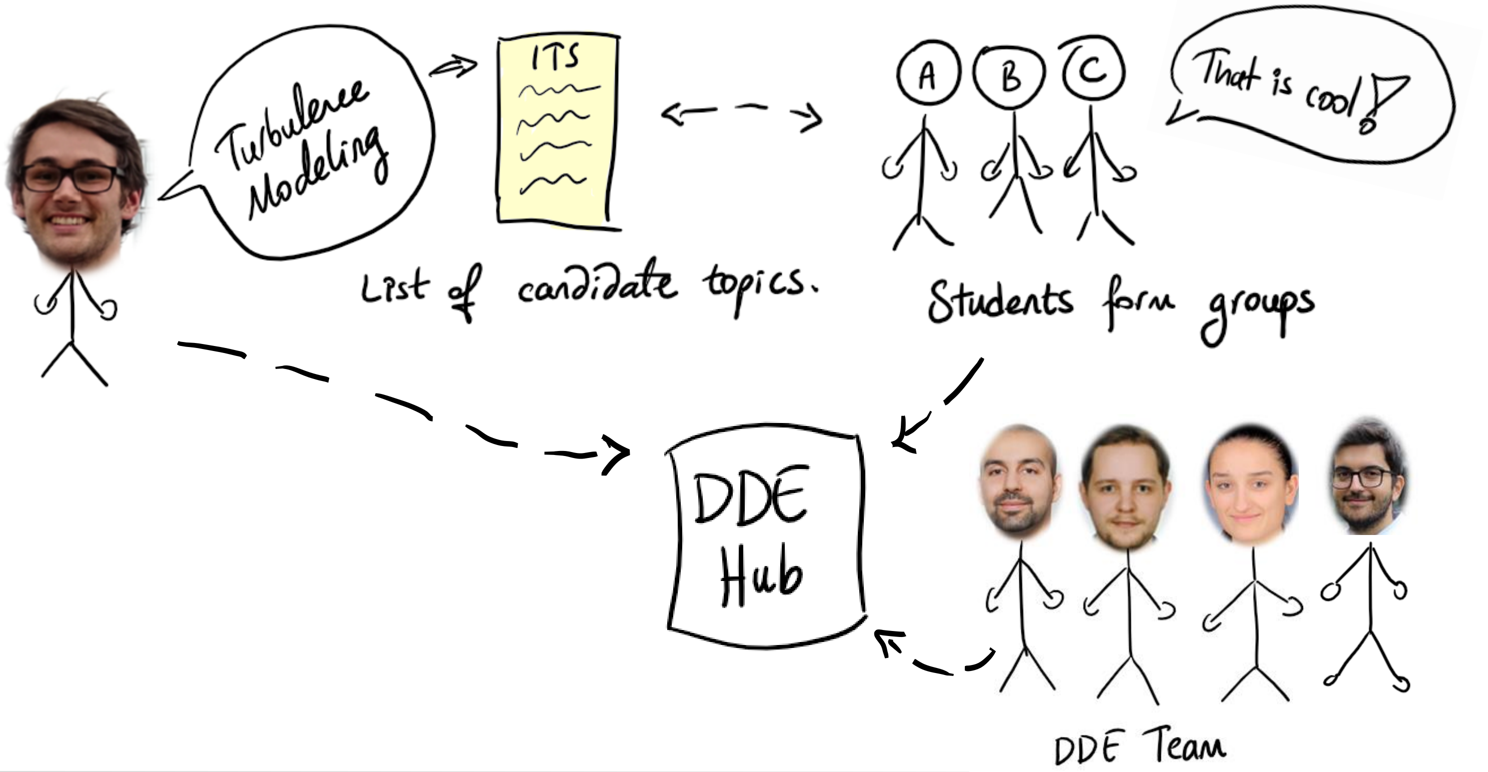
Assume:

Participants have an idea about ML methods
have solved at least 1 end-to-end problem
familar with the interface

- Image processing → CNN
- Alternative data transf. tools (POD, DMD, ...)
- Graph N.N.
- Sensory Data Management
- Genetic Programming

- Fluid dynamics
- Heat Transfer
- State Space Models
- AI Agumented Process Control & Experiment Design

* Working Frame:



* How we will manage it?

Team A ⇒

Group project

Phase I	Phase II	Phase III
Project Outline & Road Map	Prelim. Results (LL)	Finalize the work

* what else?

(i) New BS & MS topics will be available at ITS + HiWi Positions

(ii) Check other options ⇒ KIT ⇒ BW ⇒ Germany ⇒ EU ⇒ Global

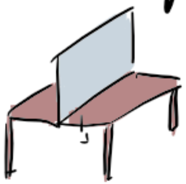
(iii) Field evolves rapidly ⇒ "open-access"

↳ Register to websites, forums, channels

Back to today...

* DDE-I "lecture"

Individual project → Submit jupyter notebook → 1 week → Exam (oral) → Corona reg.



Back to today...

* Project (start ASAP)

↳ * Structure *

1. Analysis of the Problem
2. Data Exploration and Preparation
3. Testing Phase I: Baseline Models
4. Testing Phase II: Model Development
5. Testing Phase III: Model Regularization and Hyperparameter optimization
6. Evaluation of the model predictions
7. Lessons Learnt and Conclusions

depending Problem;

- All in 1 file
- Separate notebooks

Back to today...

* Project (start ASAP)

! They must be functional. (Run → ✓)

eg ↳ may attach the dataset if read locally.

! Read the guide (W7). It is outlining your final exam...

! Git page for DDE ⇒ Top V Projects will be published.

↳ Prepare a heading including | your name + x

↳ Contact you if selected.

Back to today...

- Exam → Registration
  - Lecture is offered 1st time in WS 20.
  - See forum on ILIAS
- Content
  - DDE ⇒ "Table of Content"
  - ↳ problem types
  - ↳ solution methods → what are they, what they do. in general
  - ↳ What steps are to be followed
  - ↳ Evaluation of the results

Theme → "your work"

Students have the ability to:

- *distinguish between different learning methods (information, similarity, probability, error-based) and select right strategies and algorithms accordingly,*
- *explore large datasets, handle data quality issues and prepare it for downstream applications,*
- *explain the procedures of ML algorithms,*
- *judge and apply different approaches to analyze static datasets,*
- *analyze and evaluate methods for large dynamical systems via deep learning,*
- *plan and execute an end-to-end machine learning project from data collection to launch phase,*
- *design recipes for a given problem and to solve practical engineering problems with ML.*

DDE Team 2022