

Machine Learning

CS-433

Martin Jaggi & Nicolas Flammarion
EPFL

Alternatives

Master

- EE-559 – Deep Learning
- CIVIL-459 – Deep learn. for autonomous vehicles
- EE-411 – Fundamentals of inference and learning
- MGT-418 – Convex optimization
- MATH-403 – Low-rank approximation techniques
- MATH-412 – Statistical ML
- MATH-520 – Mathematics of machine learning
- MICRO-455 – Applied ML
- MICRO-401 – ML Programming
- MICRO-570 – Advanced ML
- DH-406 – ML for Digital Humanities
- CS-430 – Intelligent Agents
- CS-439 – Optimization for ML
- CS-401 – Applied Data Analysis
- CS-503 – Visual intelligence: machines and minds
- EE-556 – Mathematics of data
- CS-526 – Learning theory
- CS-433 – Machine Learning

Bachelor

- CS-233a – Intro to ML
- CS-233b – Intro to ML
- CS-330 – Artificial Intelligence
- CIVIL-226 – Introduction to ML for engineers
- BIO-322 – Intro to ML for bioengineers

Seminars, Doctoral Courses and continued education

- ENG-704 – EECS Seminar: Advanced Topics in ML
- CS-723 – Topics in ML Systems
- CS-612 – Topics in Natural Language Processing
- EE-608 – Deep Learn. for Natural Language Proc.
- EE-618 – Theory and M. for Reinforcement Learning
- EE-613 – ML for engineers
- EPFL Extension School – Applied Data Science: ML

Talks: join mailing list:
ml@groupes.epfl.ch

Course Logistics

Assessment

- ✿ **Project 1 (10%), due Oct 31st**
- ✿ **Project 2 (30%), due Dec 22nd**
- ✿ **Final exam (60%)**

Course Logistics

Lectures

tentative
schedule

Date	Topics Covered	Lectures	Slides	Exercises	Projects
20/9	Introduction, Linear Regression				
21/9	Cost functions				Lab 1
27/9	Optimization				
28/9	Optimization				Lab 2
04/10	Least Squares, Overfitting				Project 1 start
05/10	Max Likelihood, Ridge Regression, Lasso				Lab 3
11/10	Generalization, Model Selection, and Validation				
12/10	Bias-Variance decomposition				Lab 4
18/10	Classification				
19/10	Logistic Regression				Lab 5
25/10	Generalized Linear Models				
26/10	K-Nearest Neighbor				Lab 6
01/11	Support Vector Machines				Proj. 1 due 31.10.
02/11	Kernel Regression				Lab 7
08/11	Neural Networks – Basics, Representation Power				Project 2 start
09/11	Neural Networks – Backpropagation, Activation Functions				Lab 8
15/11	Neural Networks – CNN, Regularization, Data Augmentation, Dropout				
16/11	Adversarial ML				Lab 9
22/11	Ethics and Fairness in ML				
23/11	Unsupervised Learning, K-Means				Lab 10
29/11	Gaussian Mixture Models				
30/12	EM algorithm				Lab 11
06/12	Generative models				
07/12	SVD and PCA				Lab 12 & Project Q&A
13/12	Matrix Factorizations				
15/12	Text Representation Learning				Lab 13
20/12	Guest Lecture				
21/12	Projects				Proj. 2 due 22.12.

Course Logistics

Lectures

Tuesday 2x45mins, Room: Rolex learning center

Thursday 2x45mins, Room: Rolex learning centre

We provide PDF lecture notes on our webpage and GitHub, and streaming&recordings of all lectures on YouTube

Exercises

Course Logistics

Thursday 14:15 - 16:00 - live interaction!

Rooms: INF119, INF2, INJ218, INM202, INR219
assignment by lastname

All labs and projects are in **Python**.

See the first lab to get started.

Code Repository for Labs: github.com/epfml/ML_course

Course Logistics

Team of assistants

Youssef Allouah

Maksym Andriushchenko

El Mahdi Chayti

Jean-Baptiste Cordonnier

Lie He

Atli Kosson

Lara Orlandic

Scott Pesme

Maria-Luiza Vladarean

contact us: online forum!

Bastien Aymon

Jérémie Baffou

Léandre Castagna

Pascal Epple

Rui Huang

Iris Kremer

Fabio Matti

Klavdiia Naumova

Auguste Poiroux

Perrine Vantalon

Ke Wang

Course Logistics

Projects

- ✿ **Project 1 (10%), due Oct 31st**
- ✿ **Project 2 (30%), due Dec 22nd**

Real-world problems, Python, Groups of 3 Students

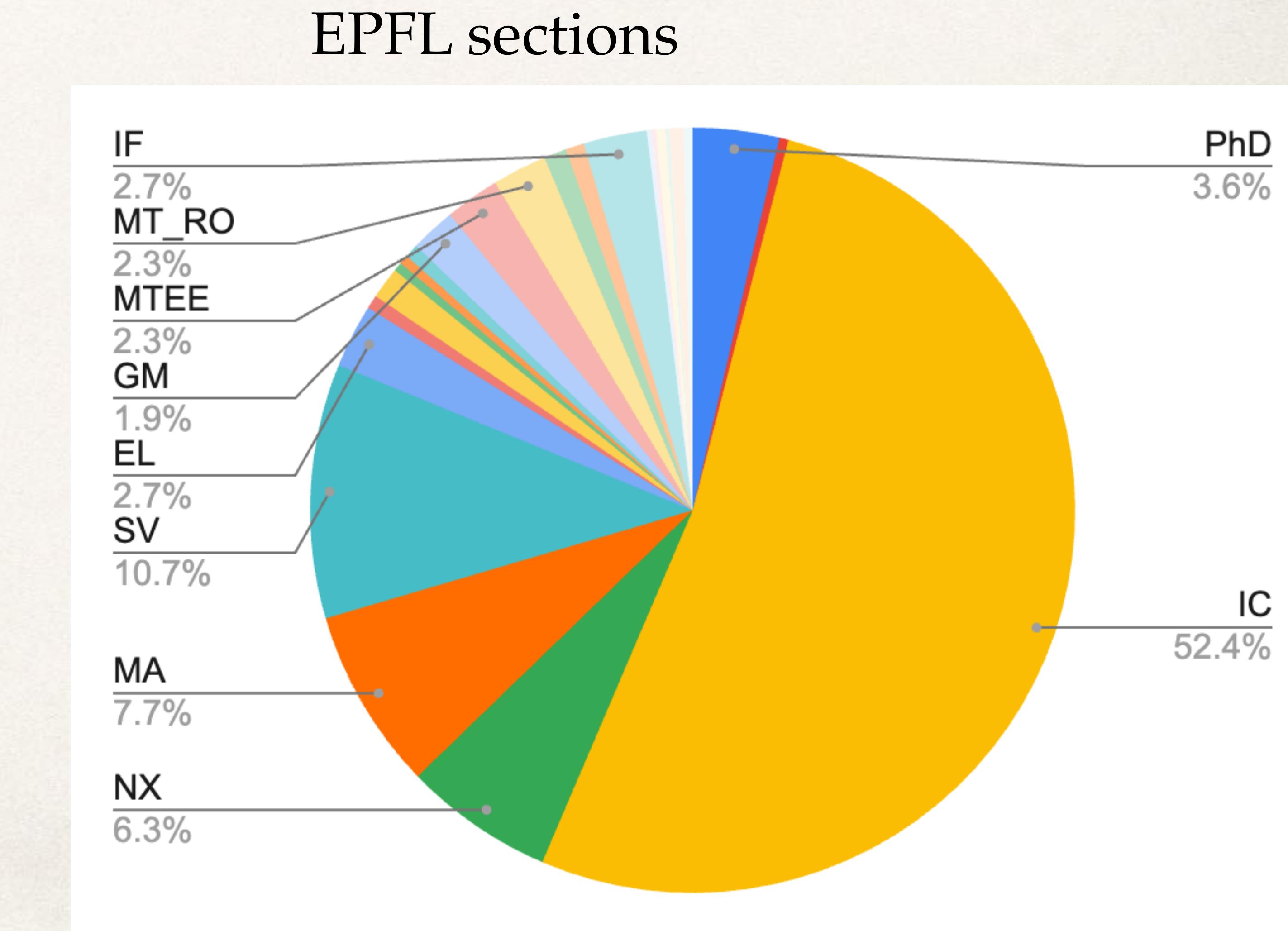
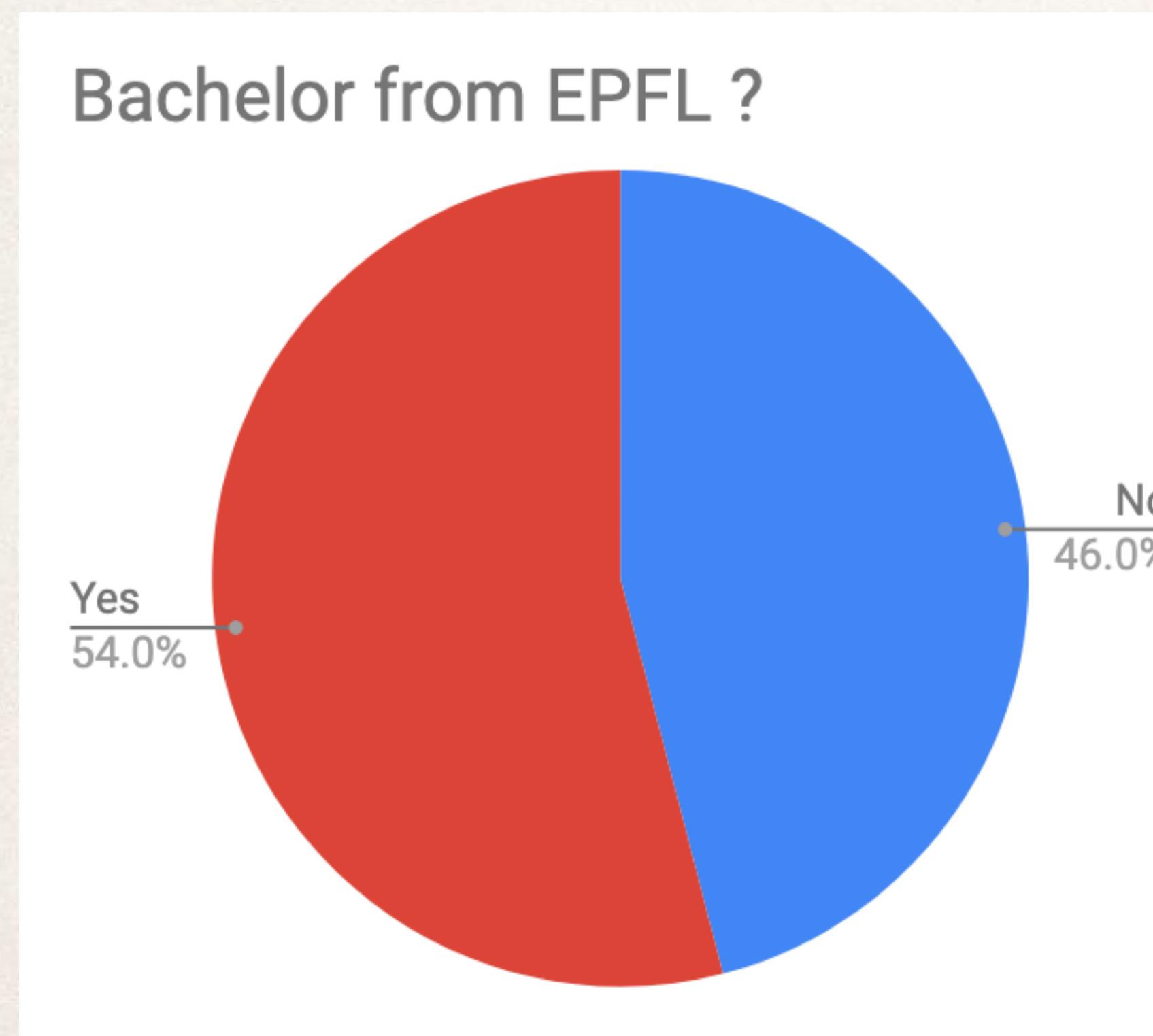
What to expect?

- ✿ **overview** over ML
- ✿ basic **understanding** of most important ML **methods** and **fundamental concepts**
- ✿ experience how ML is done on a **practical** problem

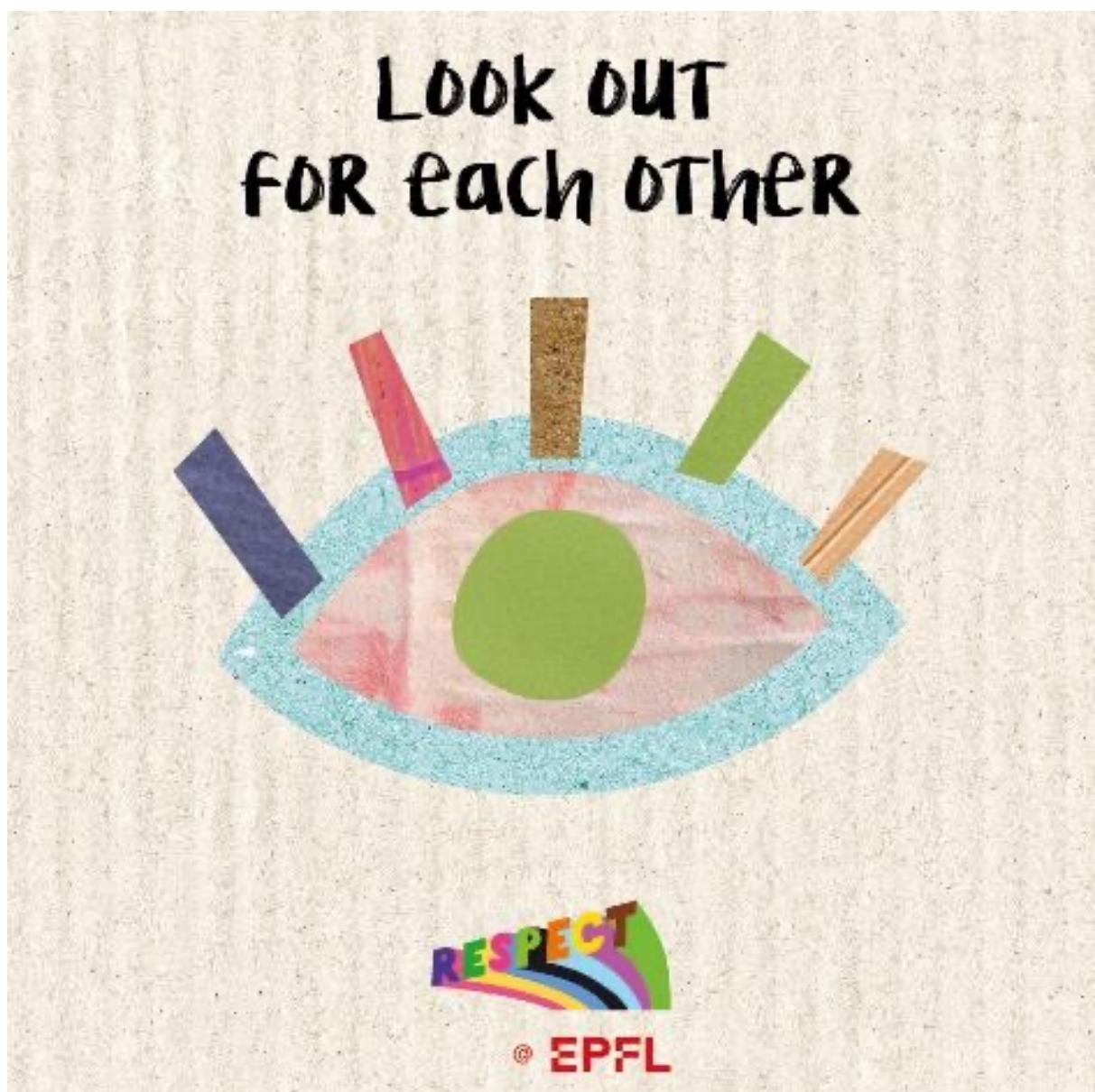
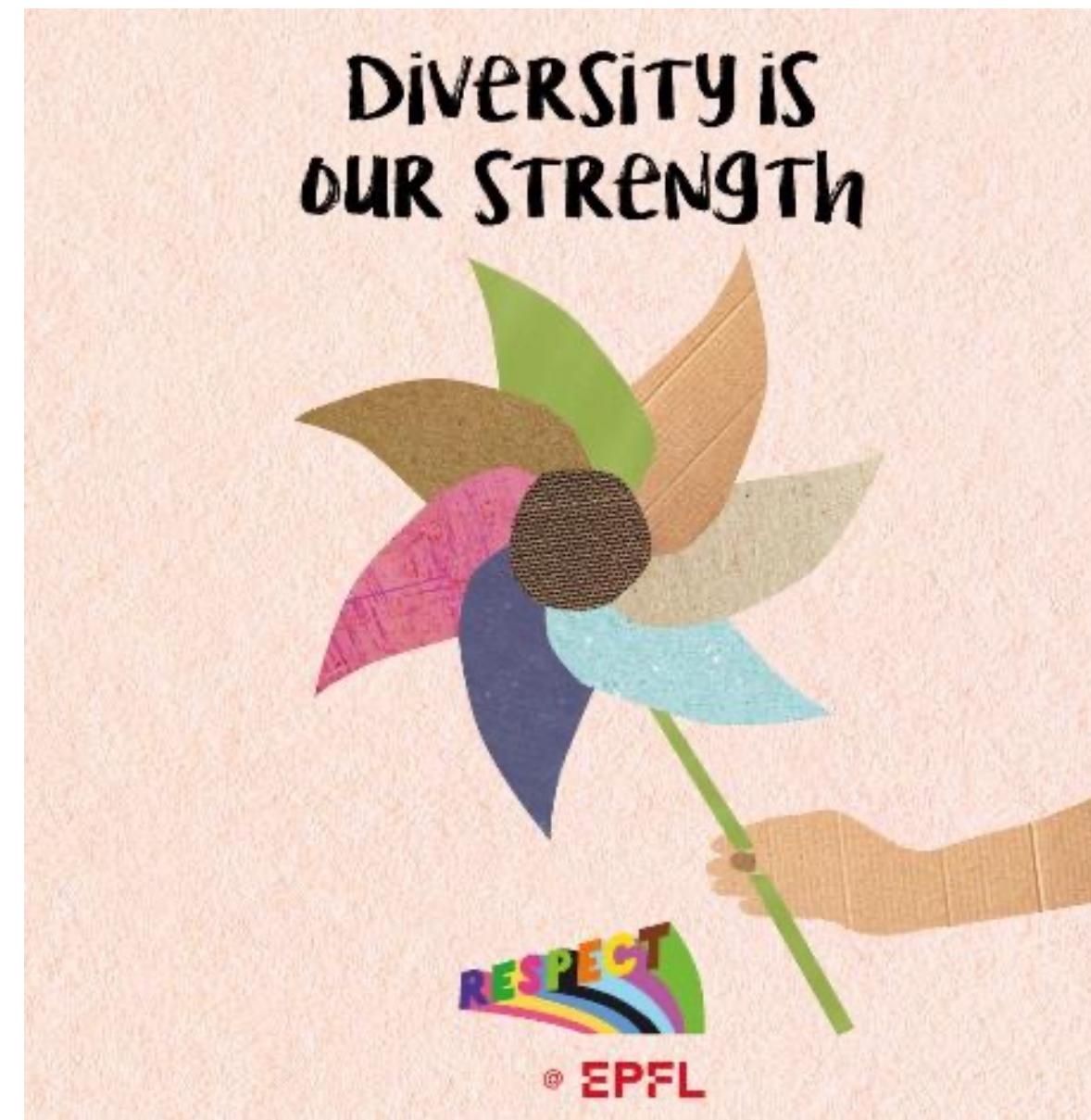
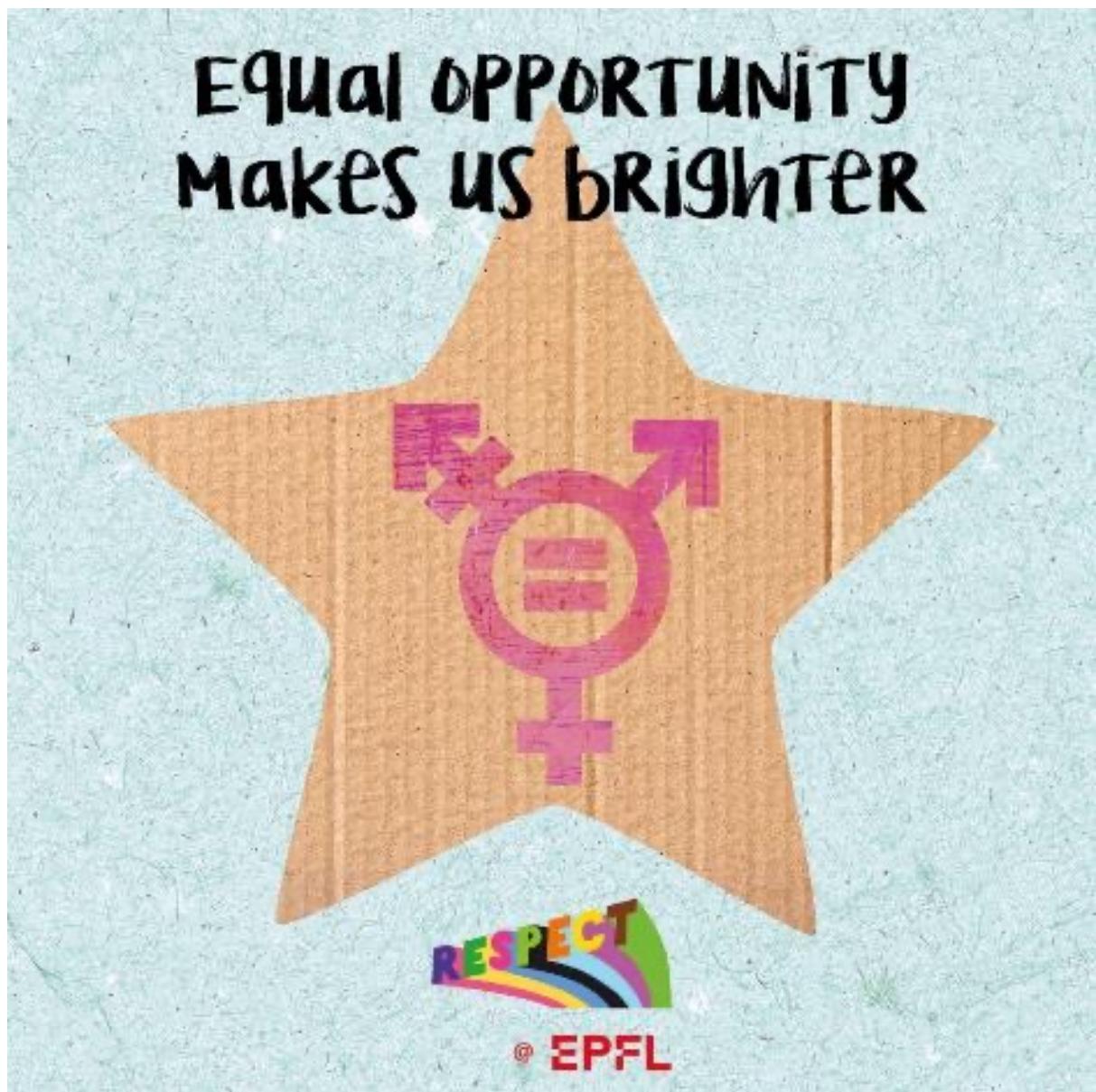
What not to expect?

- ✿ instantly becoming an **expert** data scientist / ML researcher / statistician / large-scale ML specialist / ML software expert / domain expert
- ✿ learn about that newest **hack** you saw on blog *xyz*.
- ✿ build your own **self-aware** AI

Your colleagues here







Project 2 team diversity & performance

Project 2 grades 2021:

	<i>grade Δ:</i>
all 3 team members from same section:	baseline
team members from different section:	+0.2

Introduction

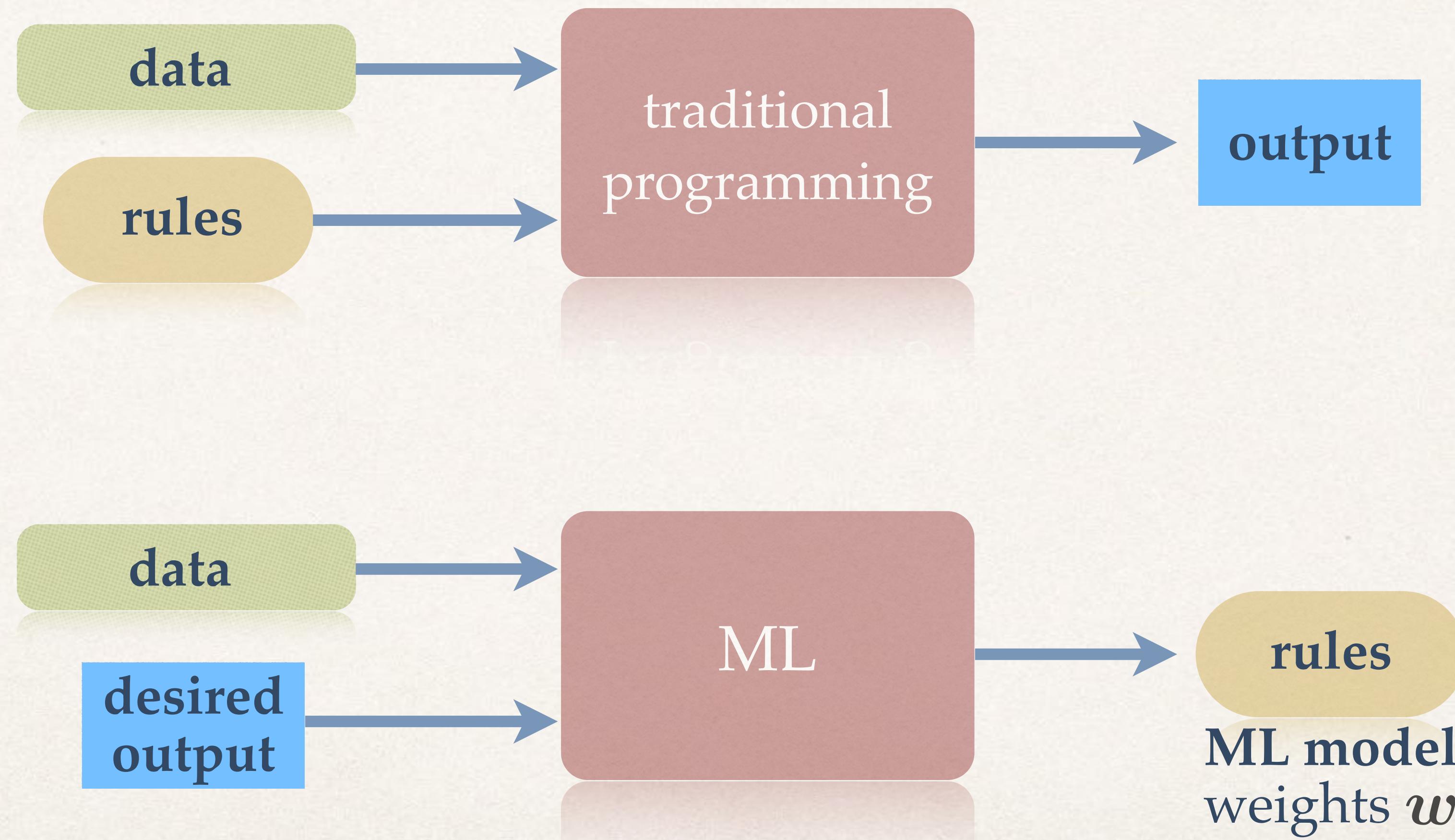
What is Machine Learning?

What is Machine Learning?

algorithms that can

learn from data

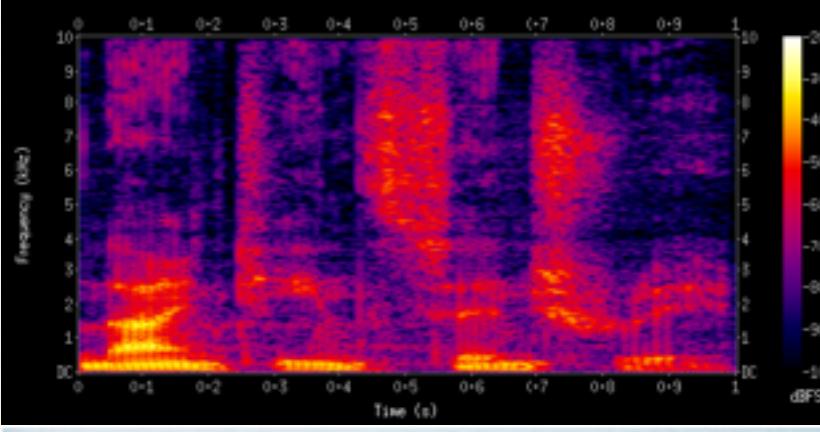
traditions...



traditions...



Learning Functions from Data

input		output	
<i>pixels</i>		hussar monkey	image classification
<i>text</i>	“Bonjour! Comment allez-vous?”	“Hello! how are you?”	translation
<i>audio</i>		“Hello! how are you?”	speech to text
<i>pixels</i>		“a dog is sitting at the beach next to another dog”	image captioning
<i>text</i>	 wha...t?		writing assistant

input

output

“moon landing
conspiracy”

webpage 1
webpage 2
webpage 3

web search

browsing history on
fashion website



recommender
system

pixels



melanoma

medical image
processing

video



“look at whether it works for
the UK or not”

lip reading

“moon landing
conspiracy...”

The bot must be trained in a language capable of decoding Python's strings and displaying it on a high quality display, in order to be able to produce what they have learned in English, and indeed, these images, have been uploaded to the web for quite some time. If this type of thing is indeed present in the wild, then what sort of wild bot should I be worried about?
Thanks to this one specific experiment performed on the same day - as described by the author:
Using some kind of neural network to learn speech, and being able to decode it in order to communicate with others (including yourself)

text generation

professional dancer
+ photo of myself

<https://youtu.be>



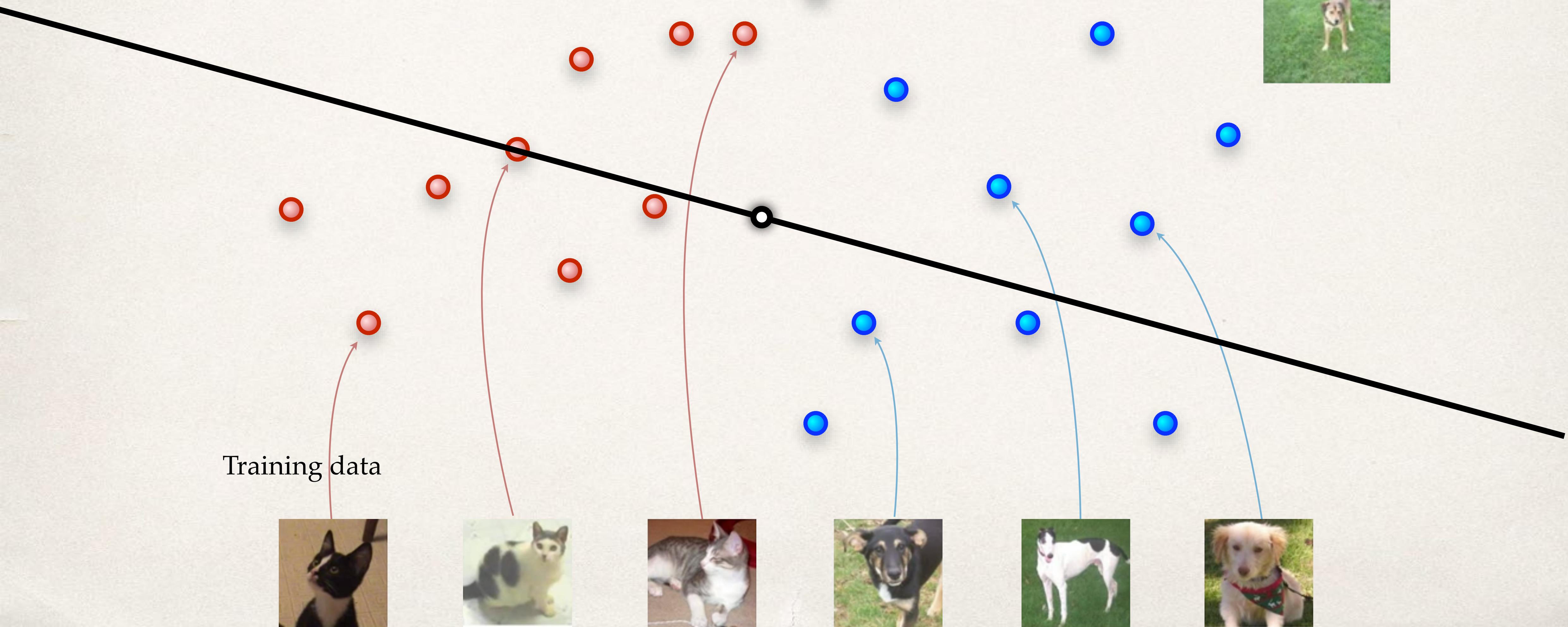
dance transfer



[image source](#)

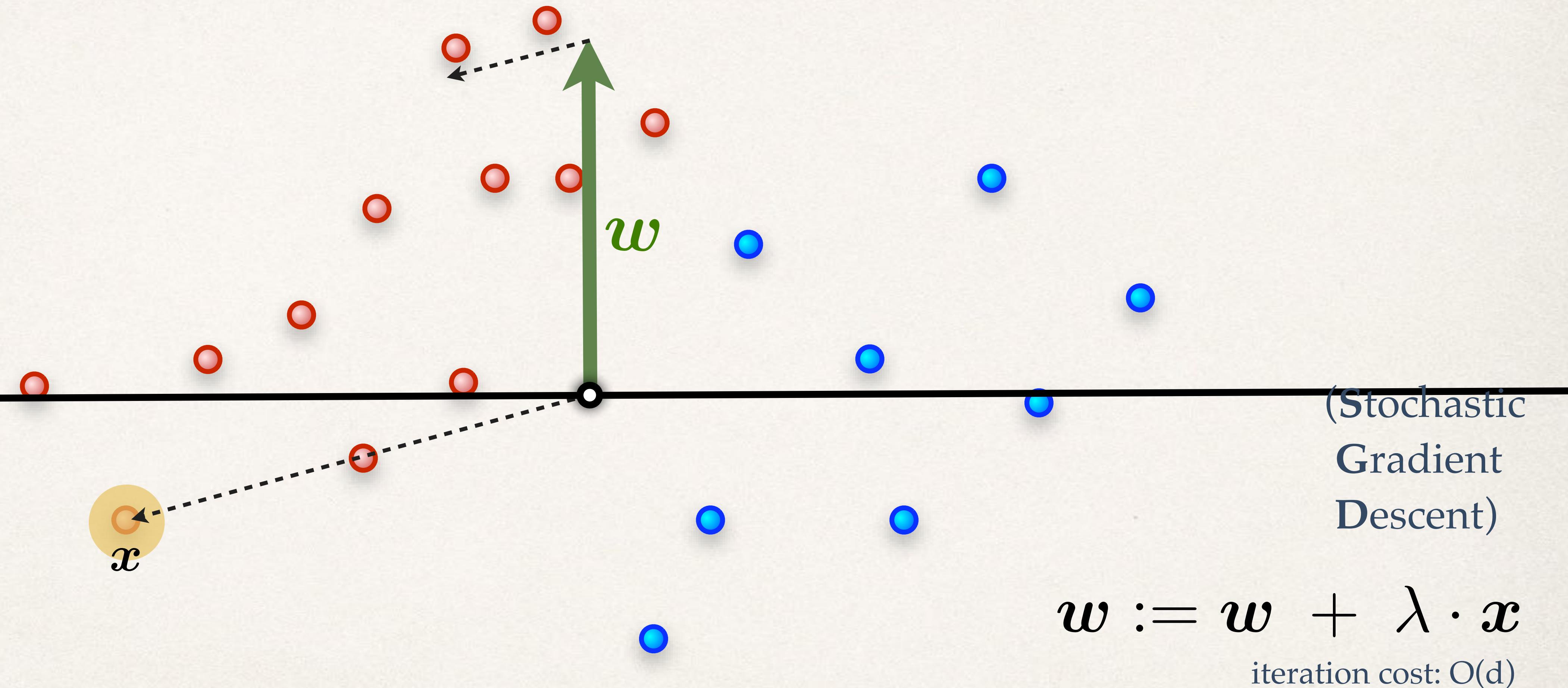
Classification

$$\boldsymbol{x}_i \in \mathbb{R}^d$$



The Learning Algorithm

$$\boldsymbol{x}_i \in \mathbb{R}^d$$

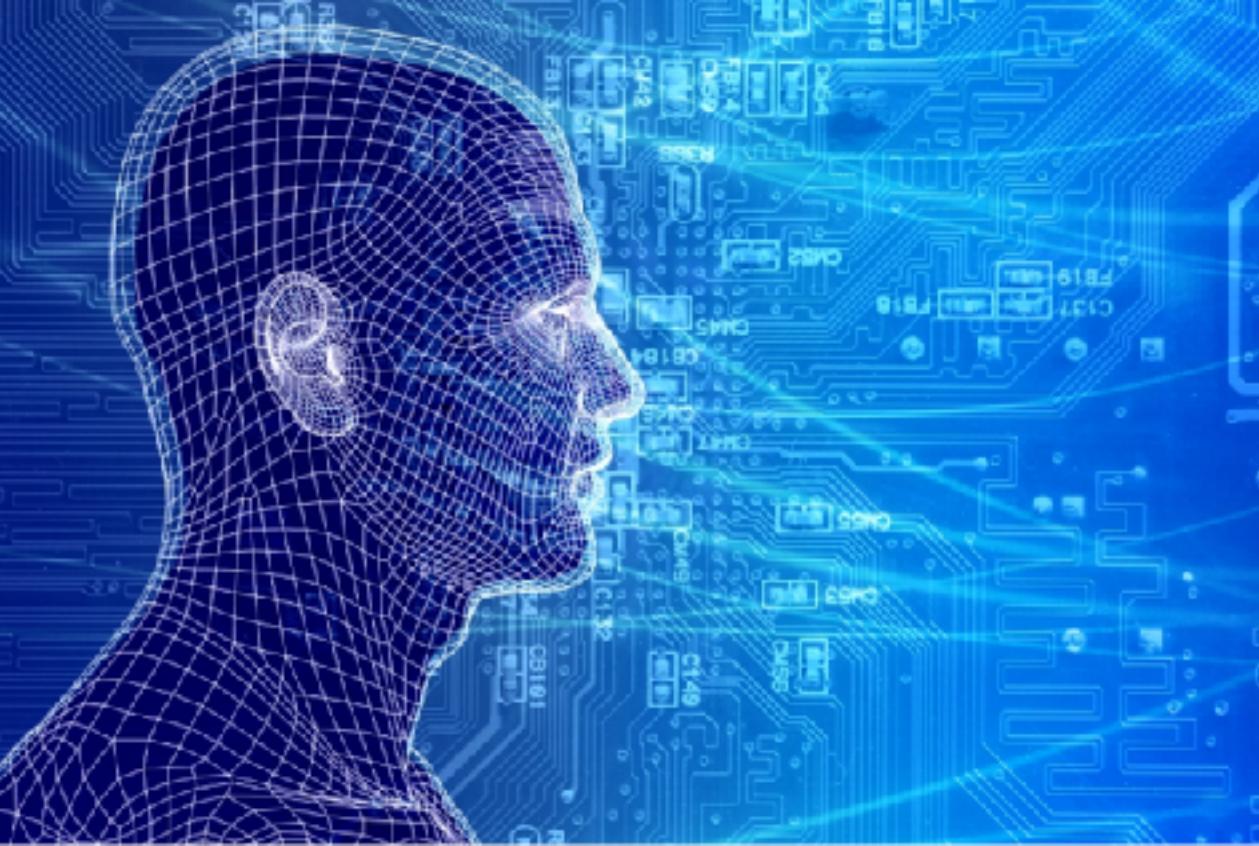


Perceptron

(Rosenblatt 1957)

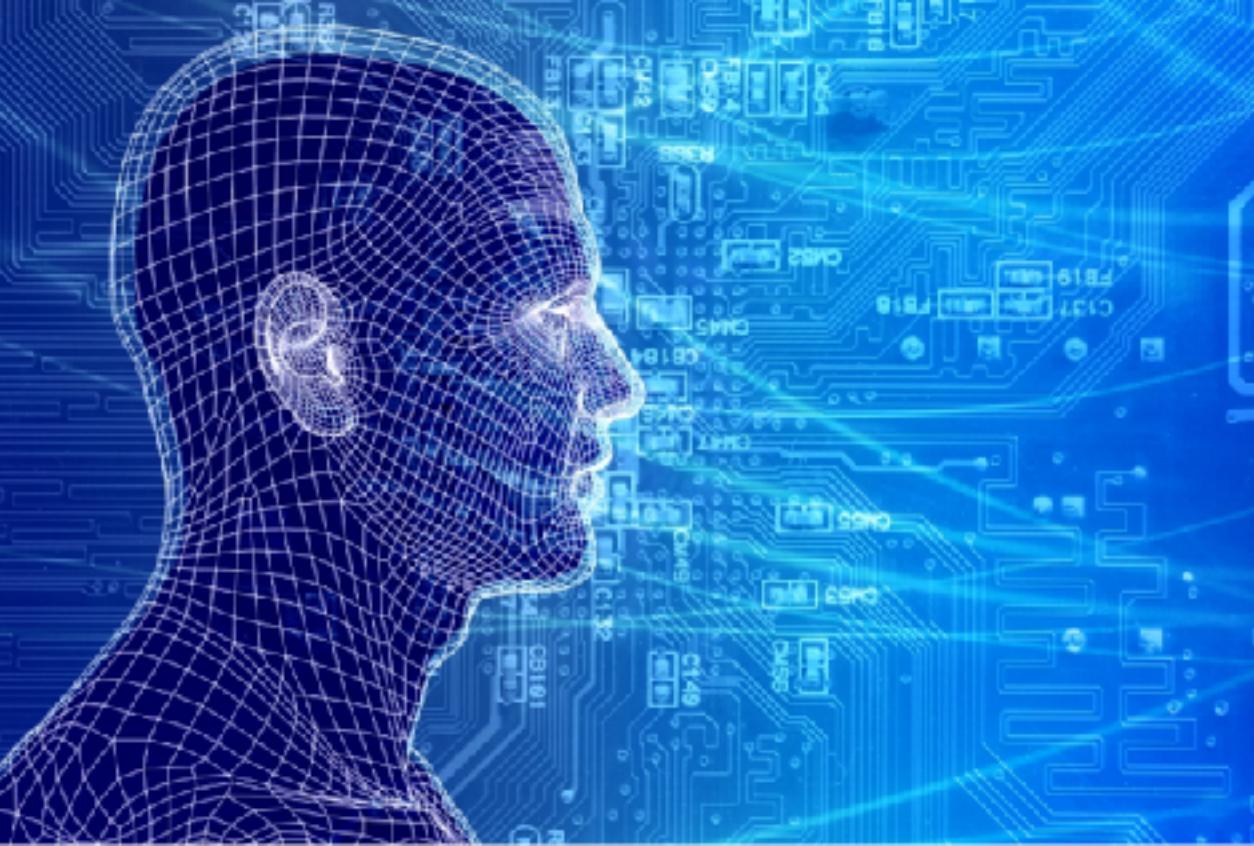
Support-Vector-Machine

(Cortes & Vapnik 1995)



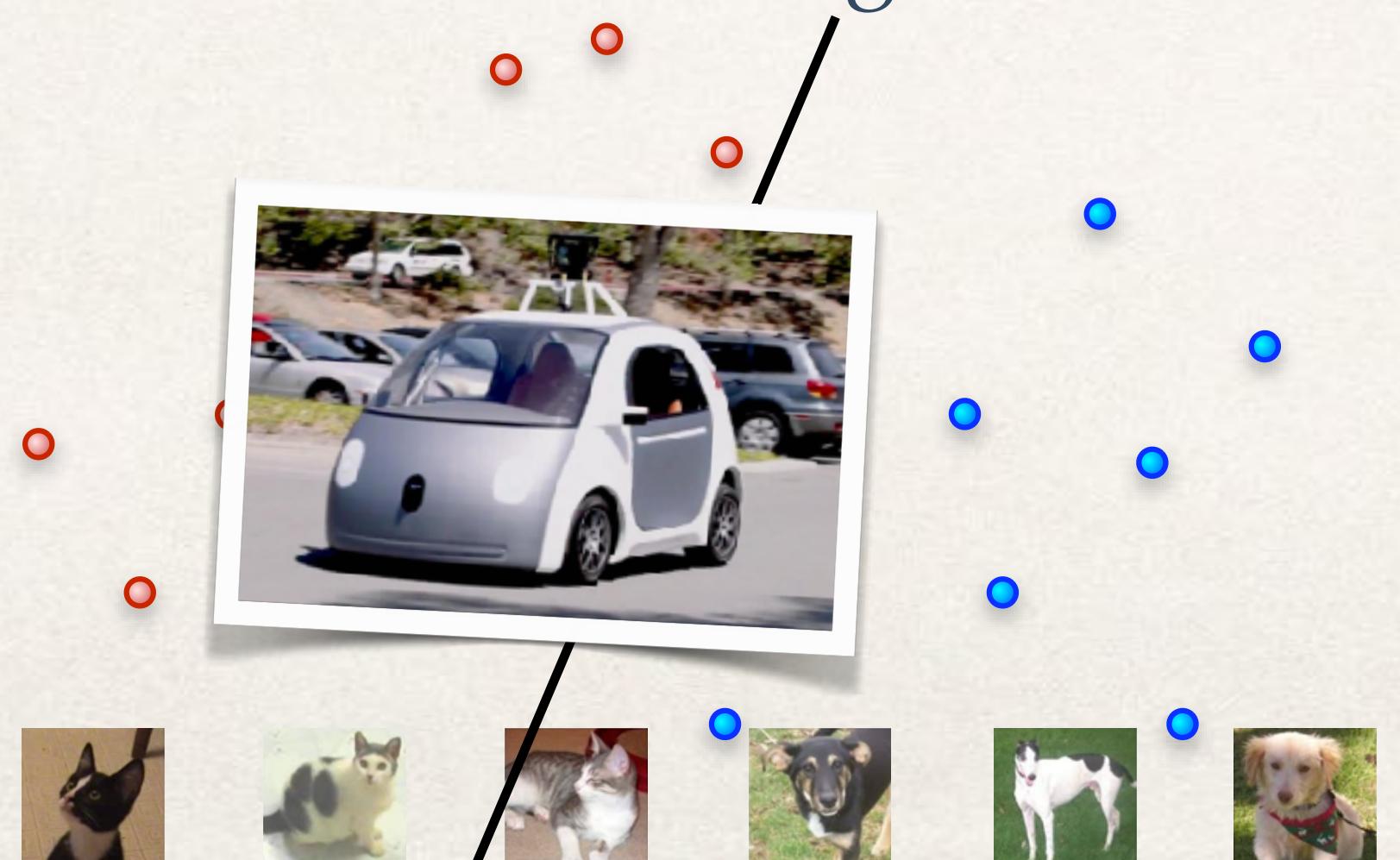
towards...
understanding intelligence
?

if-then-else
≠
intelligence



towards...
understanding intelligence
?

Machine Learning

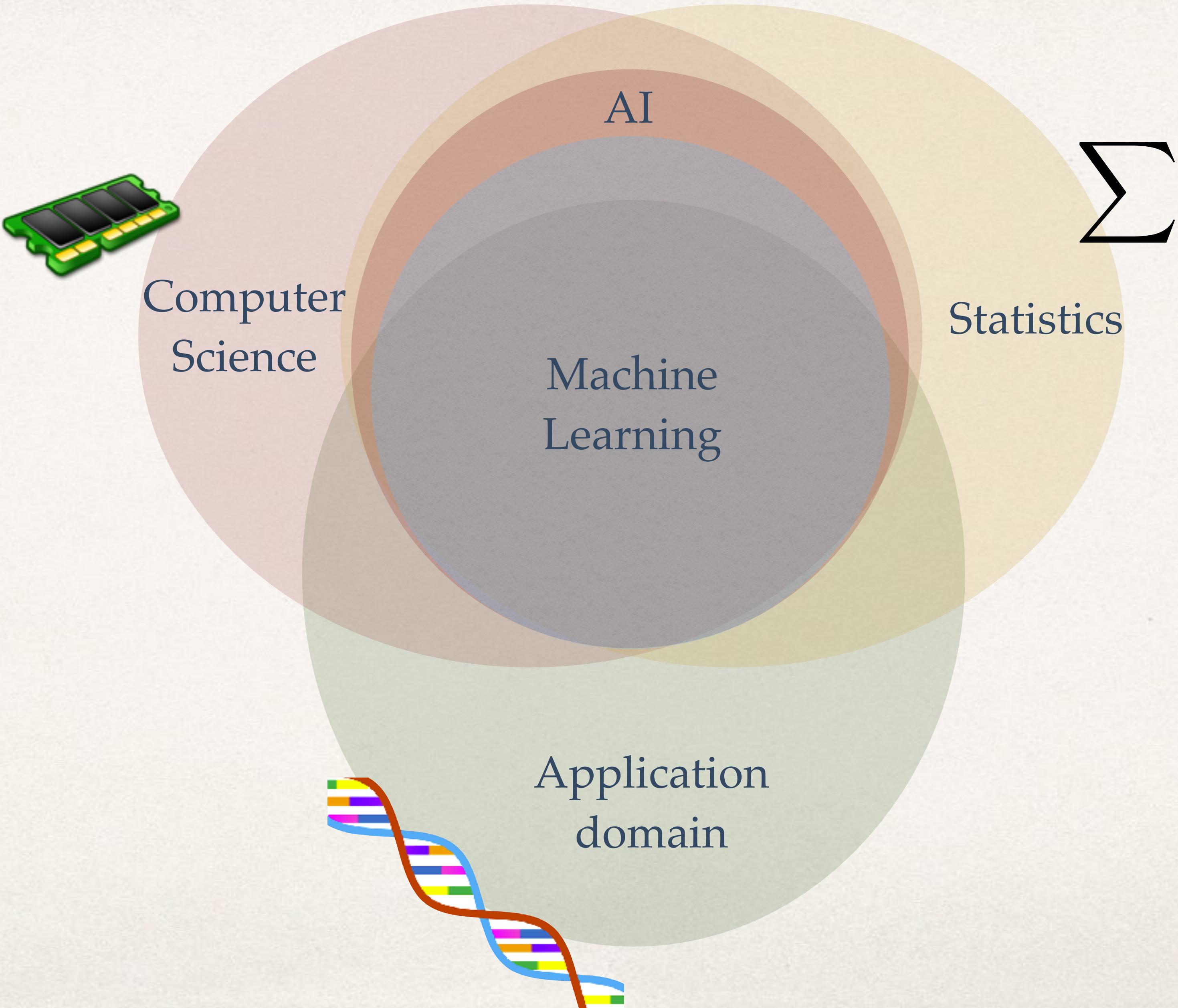


vs

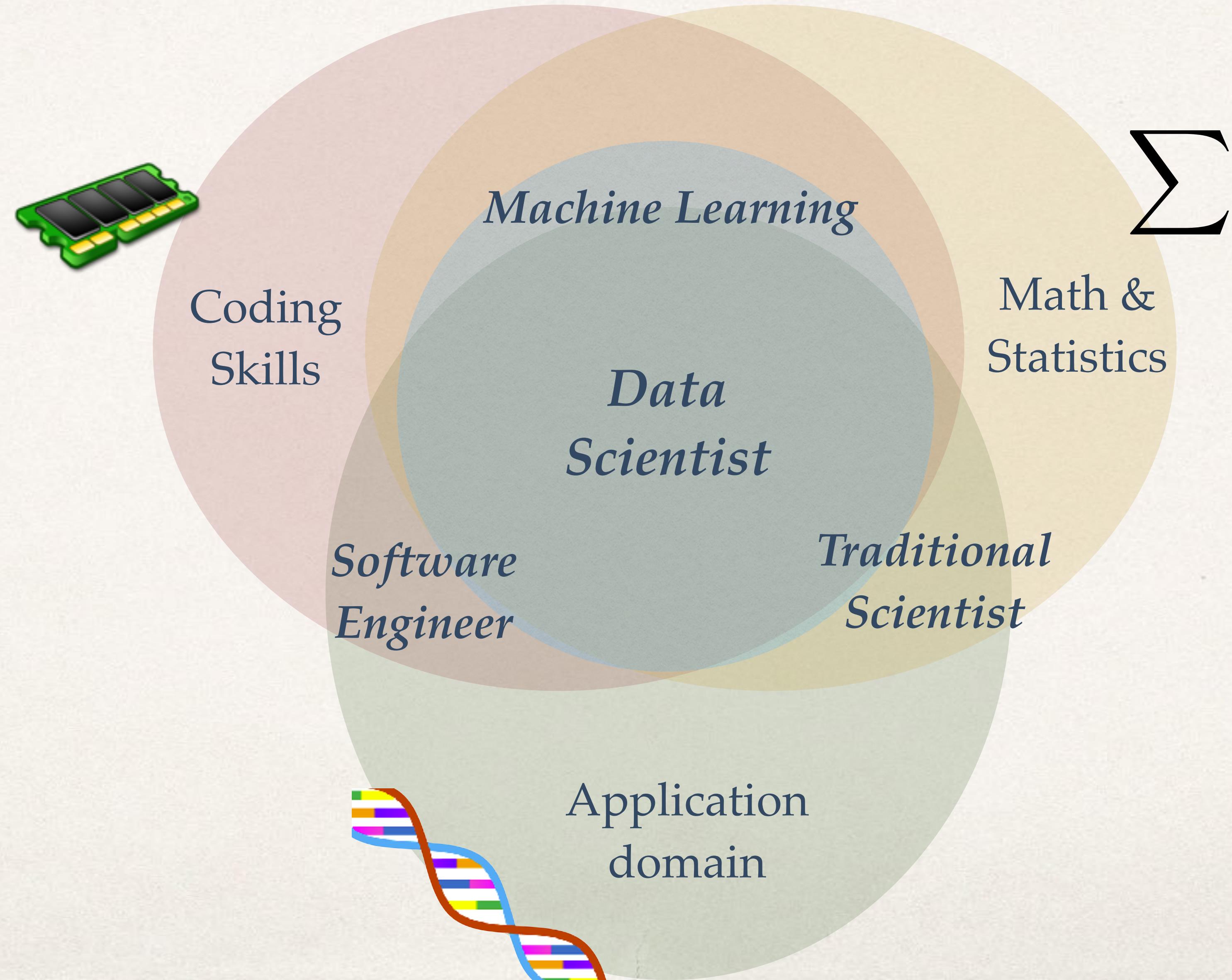
Neuroscience



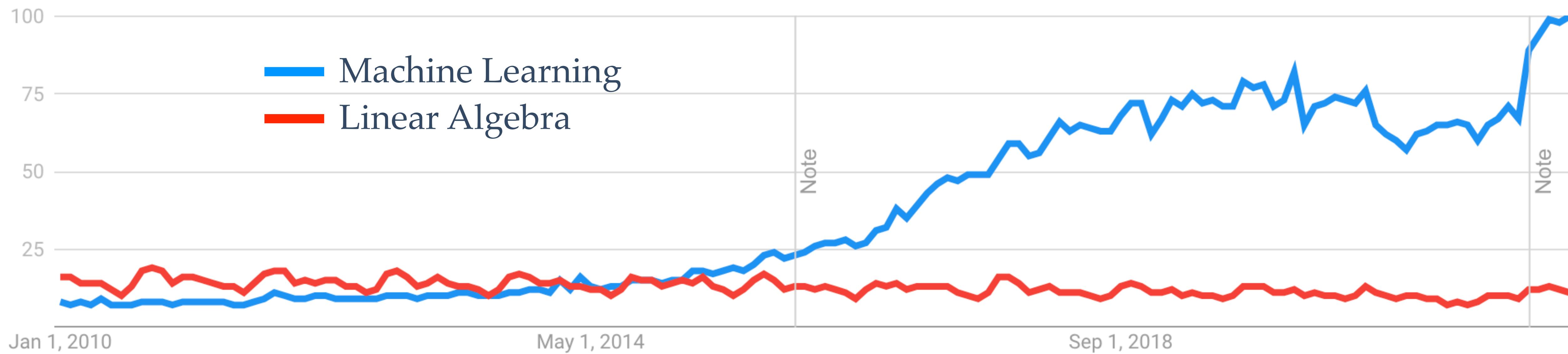
What is similar & different between
Artificial Intelligence, Data Mining,
Statistics, Machine Learning?



Job Skills



Cycles of popularity



source

why ML?

Applications

Industry Applications

- ✿ majority of industries, originally not 'digital':
 - ✿ agriculture, NGOs, 'sharing economy', logistics, delivery, services, manufacturing, sports, personalized health, call centers, entertainment, ...

- ✿ **not only** the
'usual suspects'

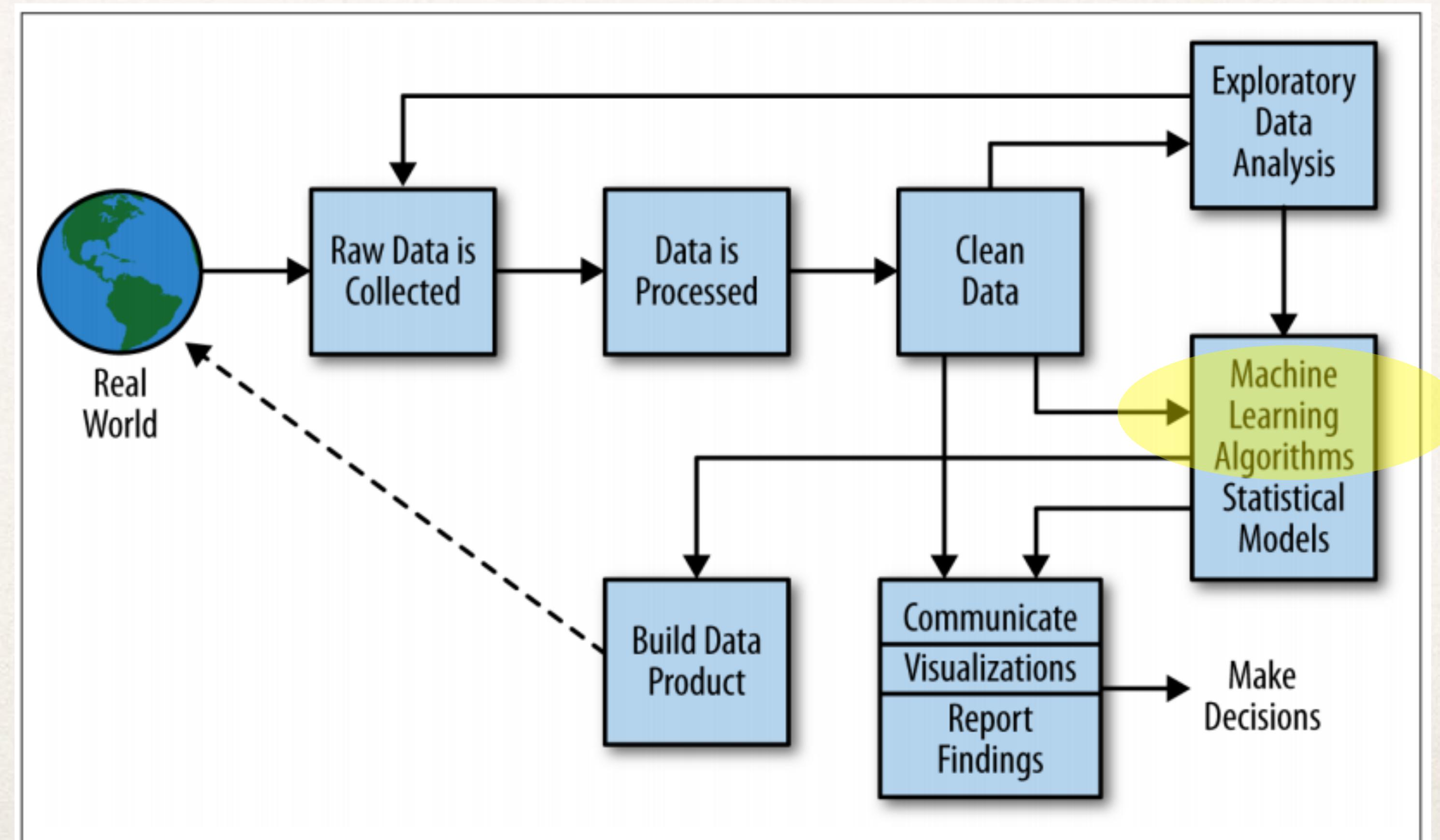


Applications in Other Sciences

- ✿ increasingly data driven
 - ✿ ... Psychology, Economics, Medicine, Social sciences
 - ✿ science of X → *digital* science of X

en.wikipedia.org/wiki/Index_of_branches_of_science

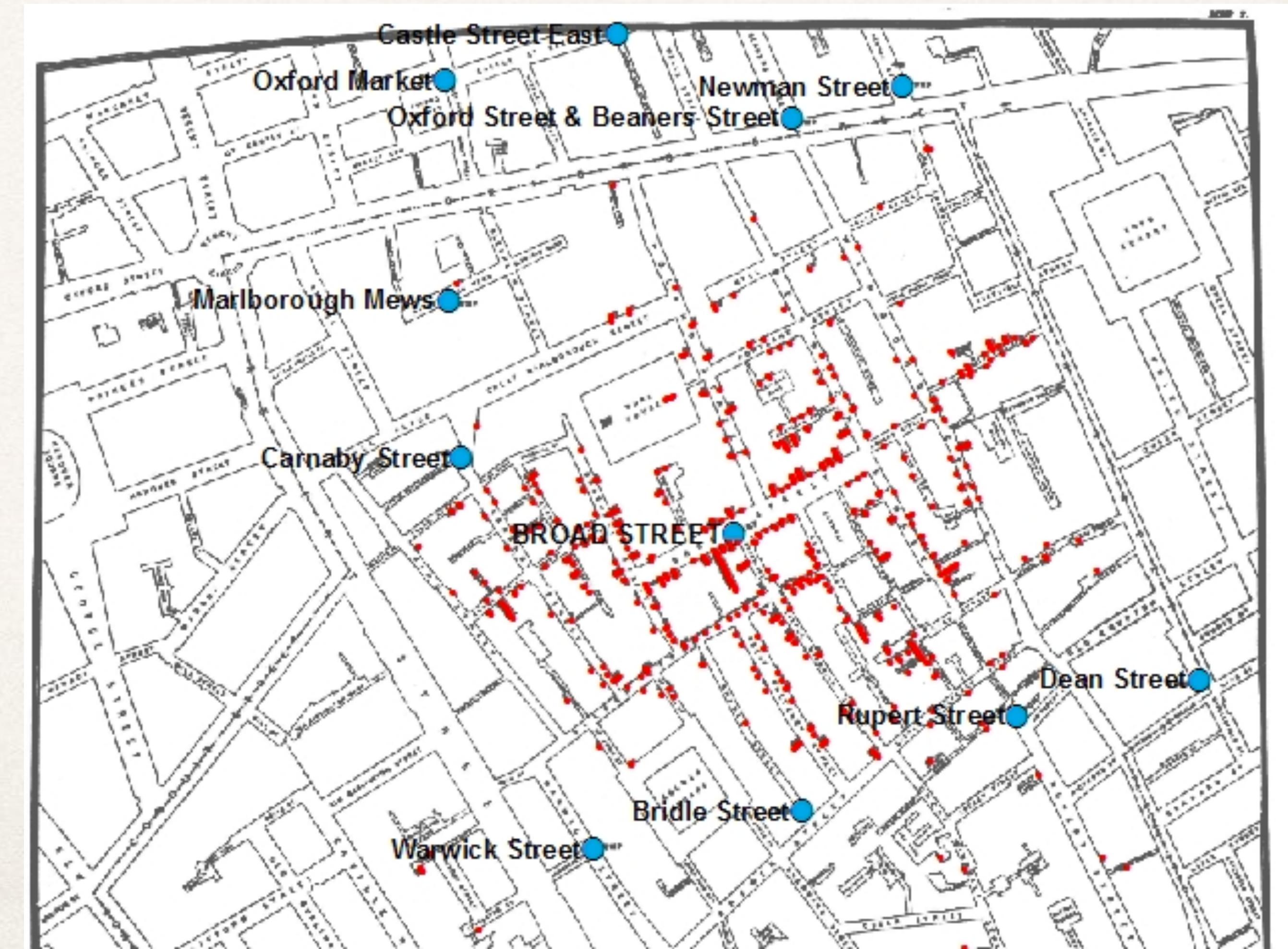
ML is only a small part!



History

- ✿ ML is not new!

London 1854
cholera outbreak



History

- ❖ ML is **not new!**
- ❖ the early days - 1950^{ies} and 1960^{ies}
 - ❖ Neural networks
 - ❖ Turing



What has changed?

1950s: 10^3 FLOPS

2022: 10^{24} FLOPS

“the embryo of an electronic computer that ... will be able to walk, talk, see, write, reproduce itself and be conscious of its existence.”

1958



Challenges

- ✿ Hype
 - ✿ cycles of AI popularity
- ✿ Data Ethics, Privacy, Fairness

[Alle Kategorien ansehen](#)Suche [Sport & Freizeit](#)[Erweiterte Suche](#)[Camping & Outdoor](#)[Fitness](#)[Fußball](#)[Golf](#)[Pulsuhren & GPS](#)[R](#)

Baseballschläger Aluminium "32" von Tysonz

von [Unbekannt](#)Noch keine Kundenrezensionen vorhanden: [Schreiben Sie die erste!](#)Preis: **EUR 21,90**

Alle Preisangaben inkl. MwSt.

Auf Lager.Verkauf und Versand durch [knockout24](#). Für weitere Informationen klicken Sie auf den Verkäufernamen.

Noch 4 Stück auf Lager.

[2 neu ab EUR 21,90](#)[Größeres Bild](#)[Für Kunden: Stellen Sie Ihre eigenen Bilder ein.](#)

Kunden, die diesen Artikel gekauft haben, kauften auch



[Pfeffer 2442 KO
Verteidigungsspray JET
40 ml](#) von Pfeffer KO
 (12)
EUR 5,22



[Sturmhaube 3-loch
Acryl schwarz](#) von
Unbekannt
 (13)
EUR 1,38



[Pfefferspray KO-FOG
40ML](#) von Pfeffer KO
 (17)
EUR 5,19



[KO-CS
Verteidigungsspray 40
ml](#) von KO-CS
 (33)
EUR 4,22

Challenges

- ❖ Hype
 - ❖ cycles of AI popularity
- ❖ Data Ethics, Privacy, Fairness
- ❖ Environmental Impact
- ❖ Lack of Interpretability
 - ❖ example: medical applications of deep learning
- ❖ Social Implications of AI
 - ❖ Interactions AI <-> individuals, AI <-> society
 - ❖ Threats from Super-human AI? see Nick Bostrom, Yuval Harari

useful: Scientific Method, Reproducible
Research, Open Source and Open Data

ML Applications by CS-433 Master Students

ML4science projects by your colleagues 2021

- Probing EEG Signals with Neural-Network Classifiers
Learning from Re-Structured Knowledge in Pretrained Transformer Feed-Forward Layers
A System for Automating the Detection and Counting of Frogs in Small Passages
Efficient CNN defect detection in sewer pipes with application of active learning
Convolutional graph neural networks for tracking yeast cells
U-Net for segmenting fascicles in vagus nerve histologies
The Best Location for You to Live
Severe vs Mild Cough Classification
Improving Chord Prediction in Jazz Music using Melody Information
Identifying recrystallization in stainless steel using machine learning on accoustic data
Socio-epidemiological insights from a yearlong COVID-19 Twitter stream
Complete Sentence Detection for Speech Recognition Systems
Deformation of images using Generative Adversarial Networks: a study on neural activity data of the worm *C. elegans*
Predicting emotions from brain data using various machine learning models.
Optimization of a memory gene selection for annotating cell-families in scRNAseq data, a machine learning approach
Wolf Howling Detection
Machine Learning for Energy Expenditure Prediction
Identifying Green Jobs
Surrogate modelling of nerve electrical stimulation using deep learning
Improving Chord Prediction in Jazz Music
Learning-based Correspondences for Ophthalmic Image Registration
Machine Learning replaces Radiative Transfer
Deep Learning-based Discomfort Glare Detection
Network Architecture Search and Expert Designed CNNs for Multi-target Concrete Defect Detection
SKA Source finding
Classification of ordinal outcomes for the analysis of injury severity using machine learning methods
Developing a ML pipeline to detect centrioles in human cells
If You Are Happy And You Know It, Your Speech Will Surely Show It: A CNN Based Speech Emotion Detector
SELFIES or SMILES? A case study in chemical reaction prediction
Machine learning for flir temperature extraction
Posture Detection for Healthy Desk Work
Tuberculosis Classification Survey using Computer Vision models
Phosphorylation Site Prediction Using Deep Learning
Unsupervised Topic Modeling
Disambiguating Voynich Manuscript transliterations with word embeddings
Transformer network for the Dial-a-Ride problem
Covert speech decoding from EEG signals
Stock Prediction using Sentiment Analysis
Studying Lobbying Influence in the European Parliament using Twitter data
Oscillation Classifier for a 2 dimension trajectory
Automation of tuft detachment detection for flow detachment analysis
Predicting lobbying influence in the European parliament through retweet graphs
Predict mouse behaviour from LFP recordings
Predicting the Coordination Environment of Zn metalloproteins
Approaches to DFT Parameter Learning
Effect of Loss Function on Supervised Learning of Quantum Many-Body States
ModalPINN - Reconstruction of airflow around a cylinder using limited number of sensors
Unsteady parametrized Stokes equations in a 2D arterial bifurcation with stenosis: design of an Autoencoder for data compression
- The future of data storage: "Digital Polymers"
Droplet Classification & Cell Counting
Discrete traffic data generation using ML methods
Detecting TB from chest X-Rays in a population of patients living with HIV and diabetes in West Africa
Machine learning for predicting stimuli response in mice
Modular Clinical Decision Support Networks for Data-Driven Diagnostic Predictions
Evaluating the performance of GANs on *C. Elegans* neural network images deformation
Exploring and Visualising Patterns in 300'000 Consultations Collected with a Clinical Decision Support Algorithm
Mouse Action Segmentation
Music Super-resolution with Spectral Flatness Loss and HiFi-GAN discriminators
Lego Project
The LEGO Detection Project
Using GANs to deform 3D bodies
Semantic Segmentation of Centrioles in Human Cells and Assigning Them to Nuclei
Finding meaning in autogenerated text
Droplet Counter
Reconstruction of cell lineage with deep learning and cell state transition dynamic inference
Automatic detection of natural slicks in Lake Geneva from a ground-based optical imagery package
Delineating Solar Panels using Aerial Imagery
Psychology takes on ML
EcoML
Exploring the feasibility of DNN models for the quantitative discrimination between different conformational species of α -synuclein
Complex Valued Neural Networks
Neuron and axon image detection
A regression based approach of exploring the glare metrics using real world experiments data
Ophthalmology Image Registration
Move sequence detection on bouldering problems
Understanding Bouldering using ML Methods
Generalizability of dysarthric speech detection models across languages and pathologies
Retinal image registration
Improving chord prediction in Jazz music using melody information
Protein domain classification
DNA Binding Sites Prediction
Unsupervised Learning to Prescribe Medication to Schizophrenic Patients
Plasma Mode Classification using 2D-Convolutional Neural Networks
Predicting Ions Concentration in Water Streams
Unsupervised Non-Deformable Retina Images Registration Using Neural Network
Detecting novelty in USPTO patent applications with neural networks
Digitizing patents
Fear Decoding in Rodents
Combining Unsupervised and Supervised Learning Techniques for Prediction and Analysis of Rhône's Plume Shape
Racing team - detection of cones
Lung Ultrasound Covid Classification
Hydrometeor Classification and riming degree estimation from Multi-Angle Snowflake Camera images.
Single amino acid prediction at protein-protein interaction interfaces
Reproduce test-time training algorithm on iWildCam dataset
Towards Accurate Prediction of Donor-acceptor Copolymer Properties
Word Embeddings for the Morphosyntactic Analysis of the Voynich Manuscript

ML4science projects by your colleagues 2020

Machine Learning-based Estimation of Cardiac Contractility from Peripheral Pressure Waveform
Deep learning techniques for geometric matching of C. Elegans brain microscopy images
Benchmarking Machine Learning Methods for Eukaryote/Prokaryote Contigs Classification
Machine Learning for Science: Classification of Skin Samples Using Mass Spectrometry Analysis
Application of Deep Knockoffs for fMRI to Generate Surrogate Data
Automatic detection of weak cipher usage in aircraft communications
Predicting Topic Change and Emoji Usage from Twitter Data
Cell Nuclei Segmentation in 2D Fluorescence Microscopy Images
Unsupervised cell classification in flow cytometry data
Predicting chemicals concentration in water streams using Gradient Boosting Regressor
Extracting Masonry Building Facades through Polygon Image Segmentation
Sequence-dependent clustering of DNA in Protein-DNA Xray crystal data and in cgDNA+ model
Applying the VoxelMorph Framework to C.Elegans Brain Data
Using forearm sEMG to control individual fingers of a robotic hand
Music beyond Major and Minor
Avalanche Forecasting: An Ordinal Regression Approach
Machine Learning for Side-Channel Disassembly
Multi-object Detection and Tracking
Motion-based Similarity Search in Videos of Confucian Rituals
Detecting the Degree of Cavitation In Situ in Young Trees
Machine Learning in Chemistry
Personalized Federated Image classification using Weight Erosion
In-crystal Gamma-interaction localization for positron emission tomography (PET) from Cherenkov photons
Classification of zebrafish embryo using various ML methods
Resource-Efficient Machine Learning Algorithm Design for On-Implant Neurological Symptom Detection
Ebola Virus Disease Diagnosis for West African Ebola Virus epidemic
Supervised classification of fly behaviors from posetracking data
Cell-type classification from microscope imaging
COVID-19 Predictions using Machine Learning
Unsupervised time series analysis of country wise COVID data
Voxelmorph
Unsupervised classification of video games styles
Can the Style and Wording in Critical Reviews of Video Games Predict its PEGI Labelling?
Ensemble Methods for Dynamic Portfolio Valuation
Vector embeddings of harmonies in music with deep learning
Robustness of U-Net based models to common image artefacts
Recognizing Humor and Predicting Humor Ratings in Short Texts
Segmentation of cell nuclei in 2D microscopy images with CNNs
Mechanism of Action (MoA) Prediction – Kaggle Competition
Diagnostic and Prognostic models for Ebola
Automatic Grading of Handwritten Student Essays
Stroke Level Prediction through Pacman Game Data
Among Us Project 2 – Market states prediction

Regularized maximum likelihood estimation – TRANSP-OR
Stroke Level Estimation through pac-man game data played by acute stroke patients
STLM: Steganography in Text using Language Models
Eastern Rituals Search Engine (ERSE)
Cough Classifier
Extracting high value lung ultrasound images from video for the diagnosis and prognosis of COVID-19
Detecting rooftop available surface for installing PV modules in aerial images using Deep Learning
Dimensionality reduction and clustering of energy consumption time series in supermarket buildings
Protein-Protein Interactions
Predicting gene-gene relationship with CNNC model
PneumoNet: Neural networks for the detection of pneumonia from digital lung auscultation audio
Predicting errors during Pacman for stroke patients
Galaxy Detection Machine Learning Project
Automatic detection of available area for rooftop solar panel installations
Prediction of myocardial infection risk after stenosis diagnosis
LC3 compressive strength analysis
Adapting Attention Guided Camera Localization for the Geodetic Engineering Laboratory
Machine learning models to predict the diagnosis and risk of COVID-19 from clinical data in Switzerland
Facades and Openings Detection Based on Different Deep Learning Models
Variational Inference compared to Markov Chain Monte Carlo for modelling gene expression
3D Spatiotemporal clustering of mixed-type medical data in Tanzania
Classification and Clustering on Schizophrenic Patient's Data
TRANSP-OR – Prediction of mode of transportation
Learned cross-domain descriptors (LCD) for drone navigation
What if Interactive GlobalCOVID Policy Simulator
Image Segmentation of Adenovirus Particles in Food Vacuoles of Eukaryotic Organisms
Music Beyond Major and Minor
Determining the important features for estimating the reproduction number in the COVID-19 pandemic
Exploring chord embedding spaces between musical composers and eras
Vector Embeddings of Musical Chords
Word embeddings and transformer models for optimal learning
Identification of fire periods from air quality monitoring network measurements
Drone and pigeon detection
Characterization of turbulent structures in tokamaks
Improving Deep Learning models for EMG decoding used for prosthesis control enhancement
Pneumonia Diagnosis based on CNN-LSTM-BERT Model
L-form bacteria segmentation
Machine Learning for Spaced Repetition in Human Learning
COVID-19 risk stratification on Chest X-Rays: performance on a small cohort of patients in Switzerland
Dry vs Wet Cough Automatic Classification using the COUGHVID Dataset
Improving Freshwater Quality Measurements through Machine Learning
Lesion detection on cardiology images using Deep Learning
3D to 2D feature matching for next generation 3D mapping algorithms
Calibrate a model of OTC markets

Reproducibility Challenge

reproduce (parts of) the experiments in a machine learning research paper:
<https://paperswithcode.com/rc2022>

(the papers can be from any conference such as
NeurIPS, ICML, ICLR, ACL-IJCNLP, EMNLP, CVPR, ICCV, AAAI and IJCAI

Reproducibility Challenge recent examples:

- On Warm-Starting Neural Network Training
- Can gradient clipping mitigate label noise?
- Sanity-Checking Pruning Methods: Random Tickets can win the Jackpot
- Learning to Play Sequential Games versus Unknown Opponents
- Distributed Distillation for On-Device Learning
- AdaAttN: Revisit Attention Mechanism in Arbitrary Neural Style Transfer
- Reproducing Empirical Results and Assessing Theoretical Guarantees of PAGE
- Contrastive Learning of Musical Representation
- Invariance Principle Meets Information Bottleneck for Out-of-Distribution Generalization
- Learning by Turning: Neural Architecture Aware Optimisation

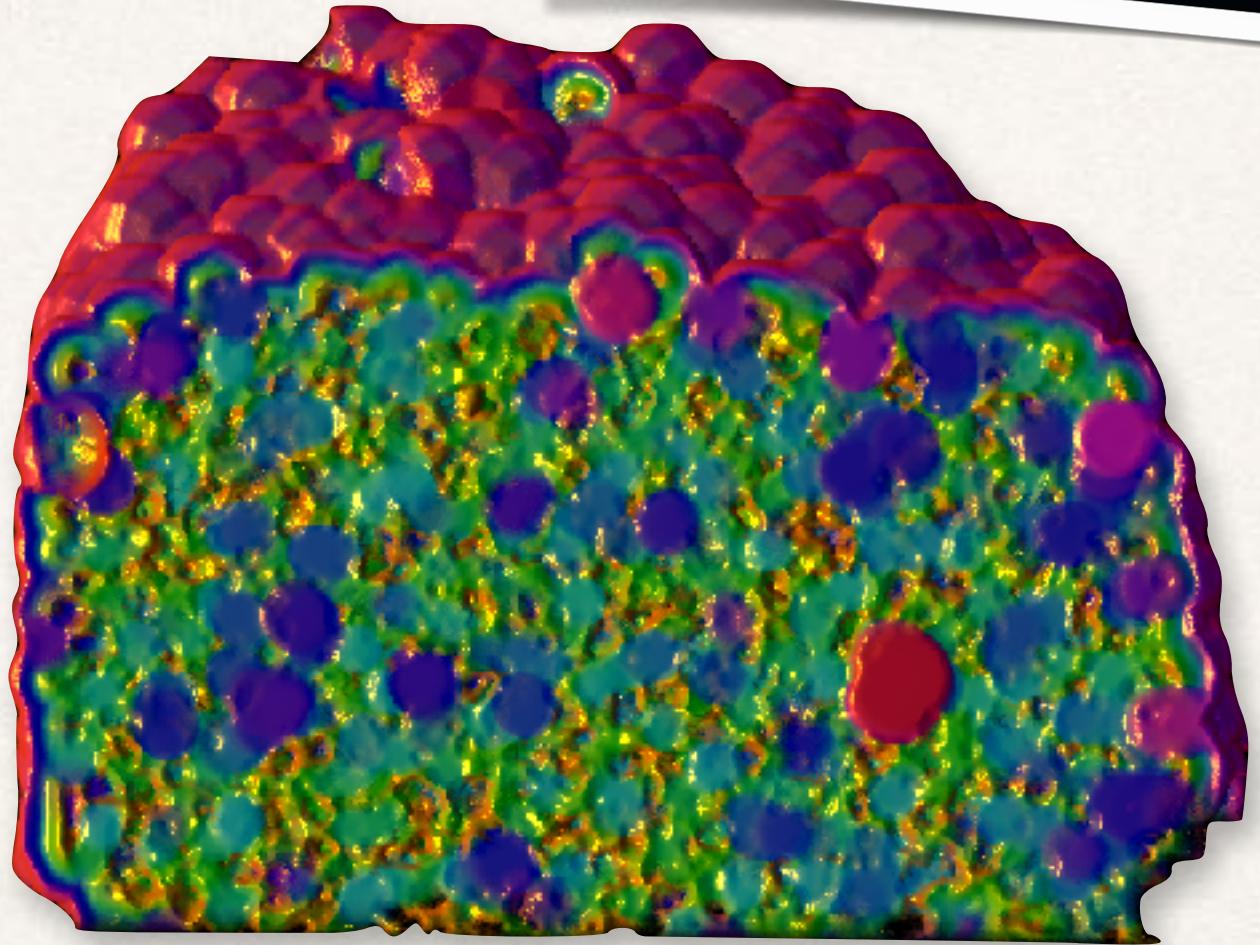
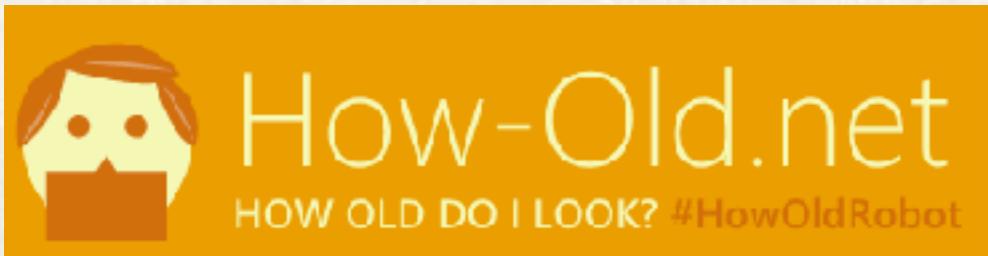
why ML?

Applications, cont.

Image Data

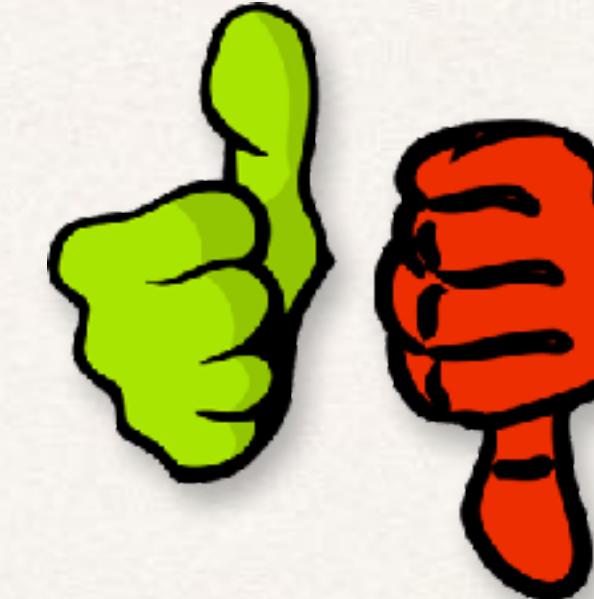
- ✿ Astronomy
- ✿ Face recognition
- ✿ 2D + 3D medical imaging
- ✿ OCR
- ✿ self-driving cars

how-old.net



Text Data

- ❖ Text Understanding & Text Generation
- ❖ Spam Detection
- ❖ User Content
- ❖ Medical Text
- ❖ Machine Translation



negative	neutral	But i wanna wear my Concord's tomorrow though but i don't feel like it
positive	neutral	Gonna watch Grey's Anatomy all day today and tomorrow(:
negative	neutral	@CoachVac heey do you know anything about UVA's fallll fest loll they invited me
neutral	neutral	@DustyEf when that sun is high in that Texas sky, I'll be buckin it to county fair. A
neutral	positive	Up 20 points in my money league with Vernon Davis and L. Fitz still to go tomorrow
neutral	positive	DEEJAYING this FRIDAY in THE FIRST CHOP it's CHRIS actual SMITH with a smash

signing that was scheduled for tomorrow at the Books A Million
oks like it! Was after El Clasico on Sunday. I didn't like her lol
ent for the 2nd time today!

basketball Game tomorrow at 6:00 pm Then Football Senior night

@Young__Assassin VS @jamievarner set for TUF 16 Finale on t

lide thru sometime this weekend ill have somethin yu can sip o

absolutely-- I meant out of the Bachmann, Perry, Santorum, H

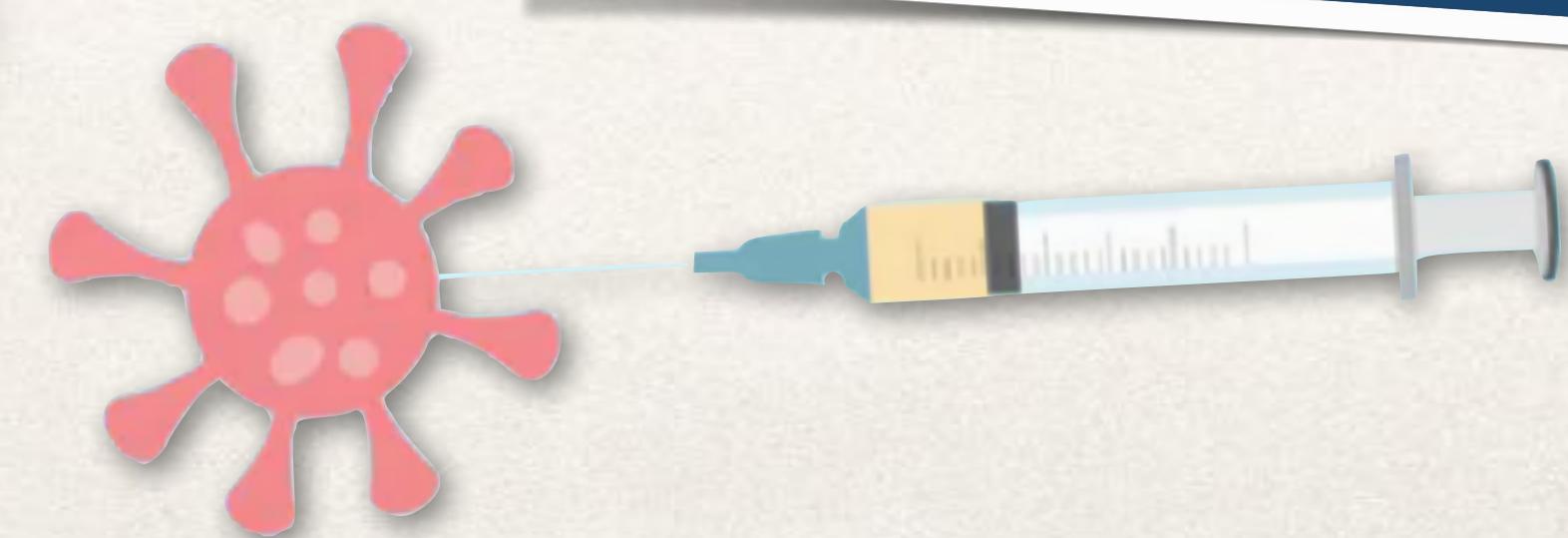
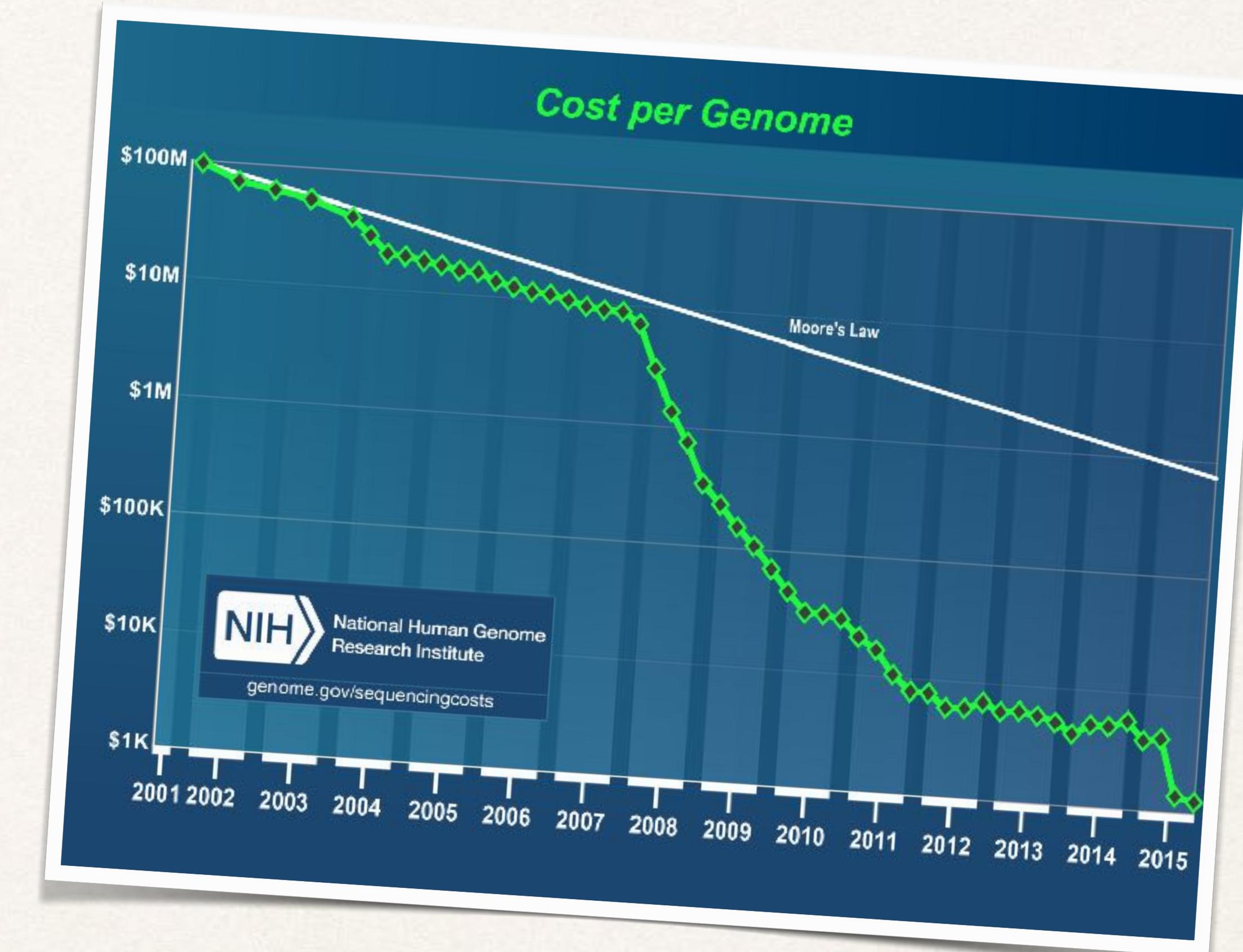
re Levein discussion on Wed. Can't keep changing boss, but he

vember 02, 1958 Elvis gave a party at his hotel before going o

ot to then kick back n party everyday like its Fri

oo exited about Vancouver tomorrow! I'm like a kid at Christma

Medical: Genetic Data



ref

Audio

- ✿ Hearing aids
- ✿ Voice Recognition
- ✿ Automatic Translation
- ✿ Voice Cloning

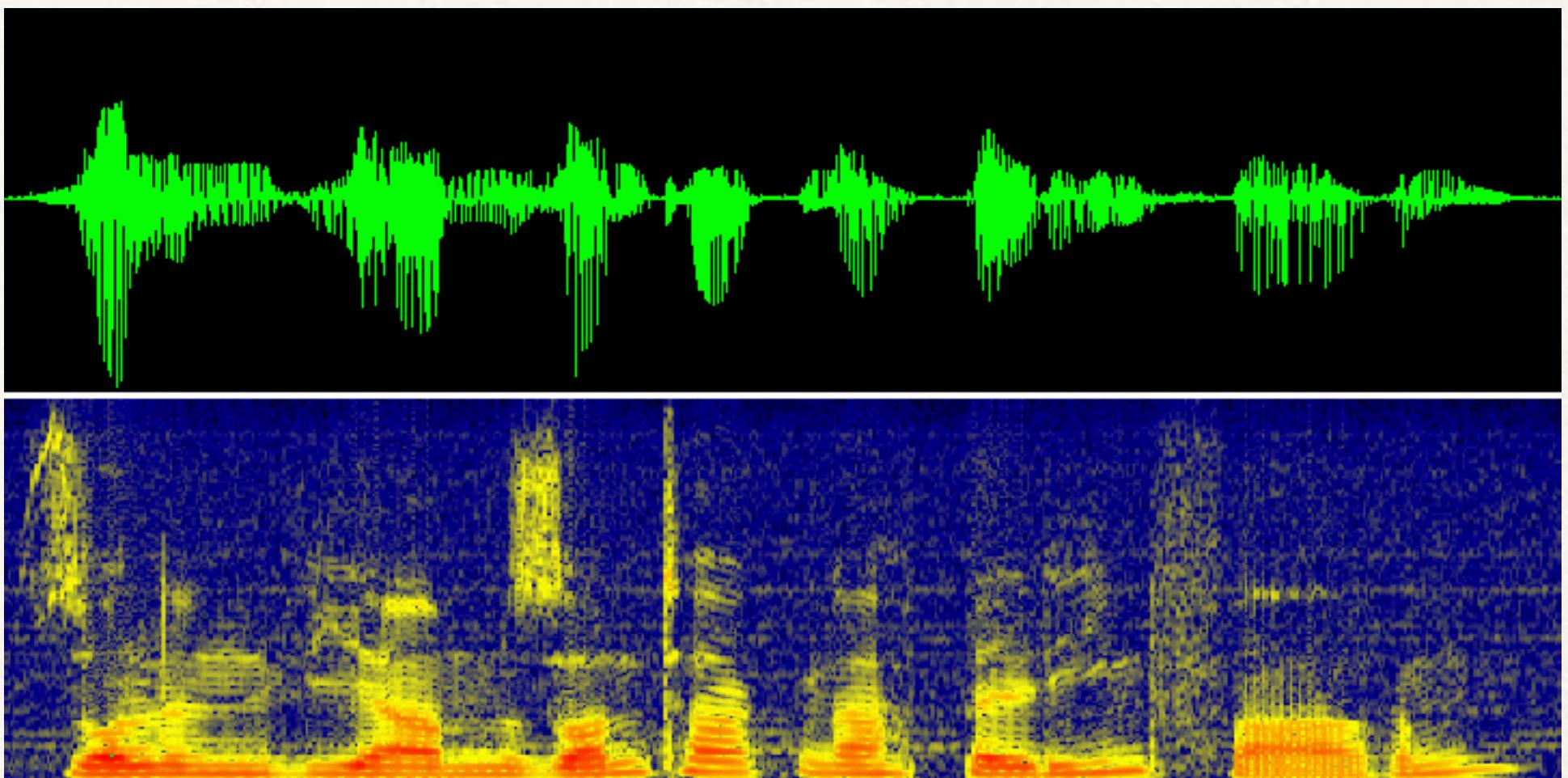


Image generation

The figure illustrates the quality of image generation from three different AI models: MIDJOURNEY, DALL-E 2, and STABLEDIFFUSION. The top section displays a scene of astronauts in a studio setting, while the bottom section shows a kangaroo in front of the Sydney Opera House holding a sign.

MIDJOURNEY

DALL-E 2

STABLEDIFFUSION

350M

75

20B

Behi

Parti

parti.research.google/
petapixel.com

Multimodal Data

- ✿ Lip Reading

- ✿ Text2image

- ✿ 3d / 2d mix
(e.g. self driving cars)

"The royal skateboard of England on display among the Crown Jewels at the Tower of London"

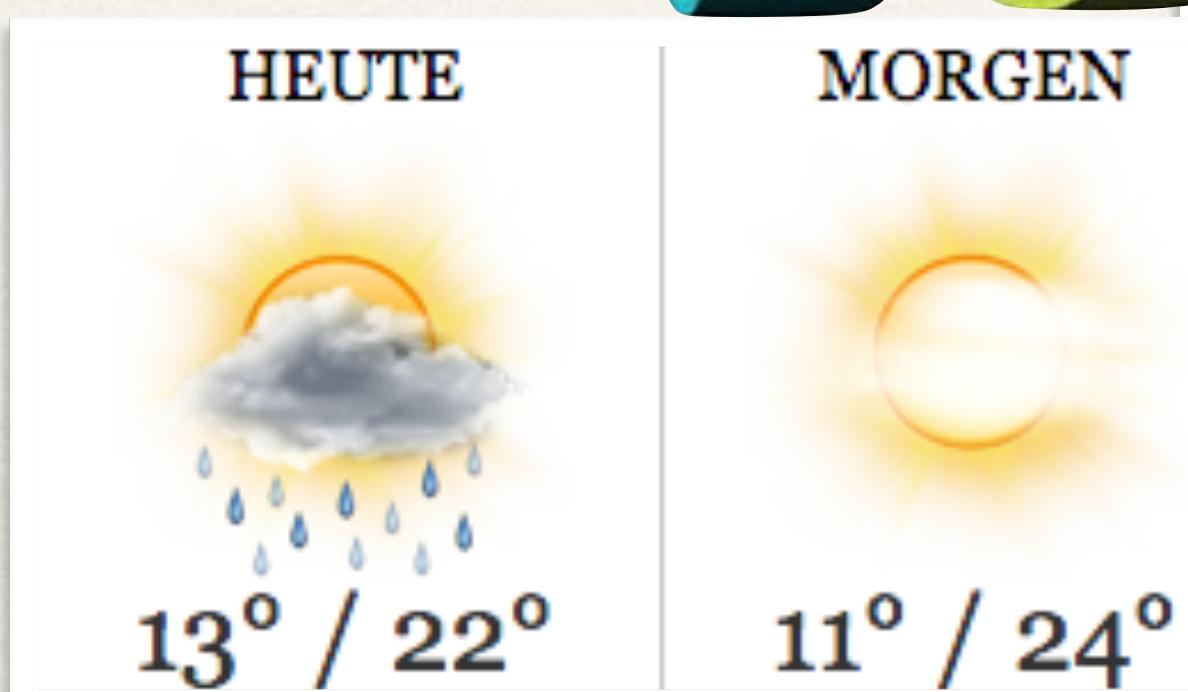


"a medieval painting of the wifi not working"



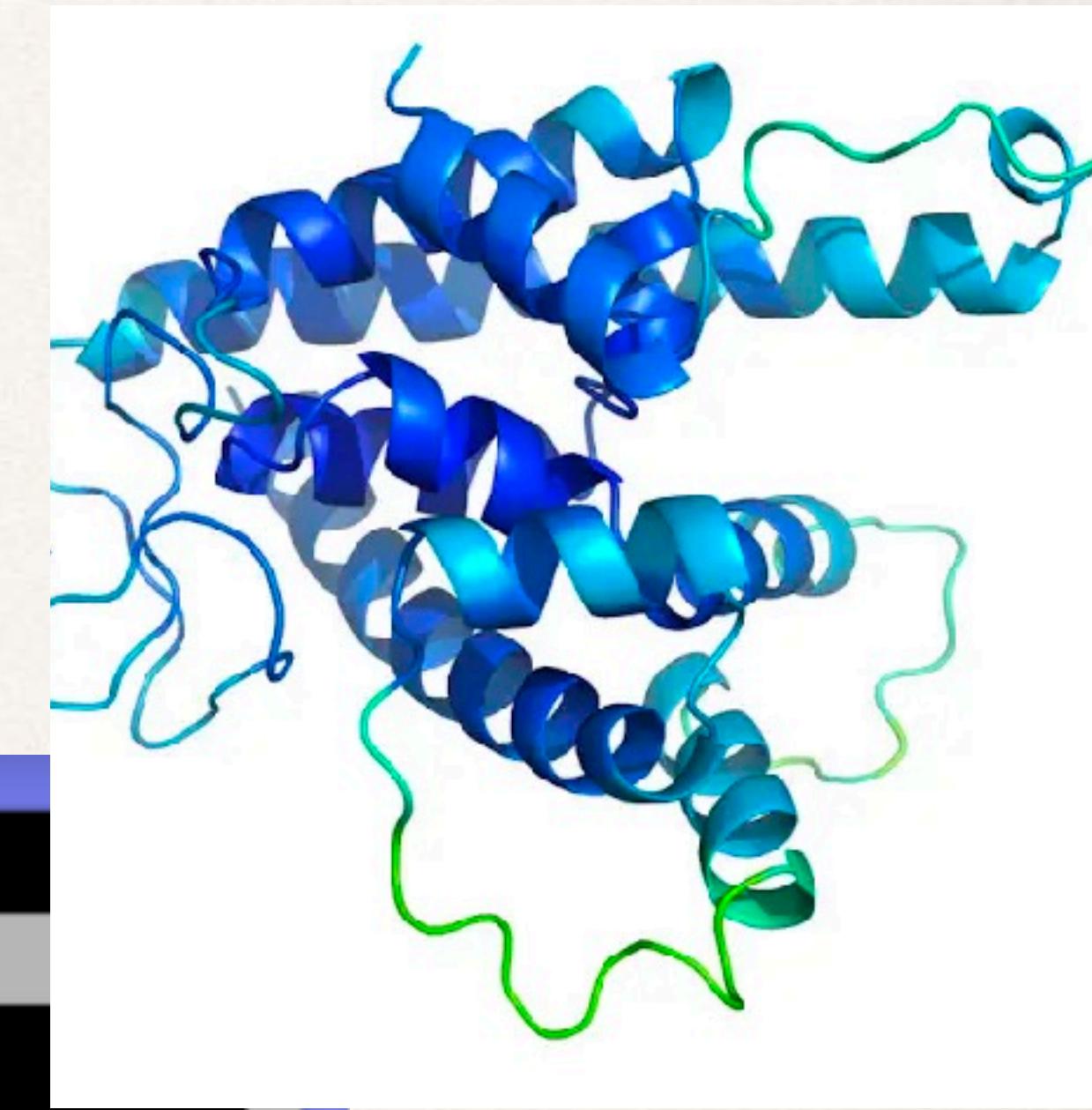
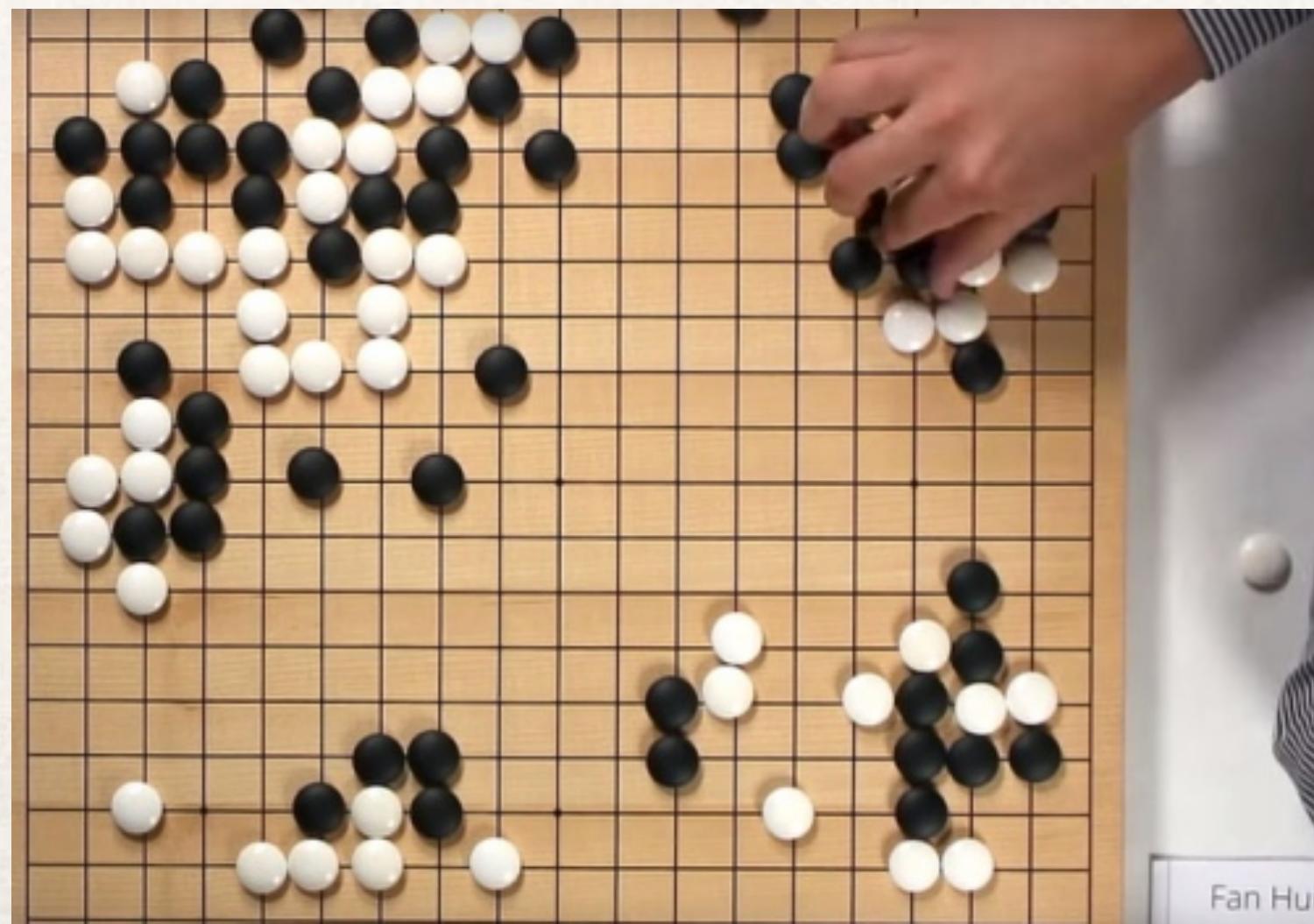
Numerical / Sensor Data

- ❖ Cern
- ❖ Astronomy / Telescopes
- ❖ Fitness Trackers
- ❖ Weather Forecast
- ❖ Robotics
- ❖ Kinect



Games & Simulations

- ✿ Immediate Feedback
- ✿ Chess, Go
- ✿ AlphaFold
- ✿ Physical World



Internet Data



		Products / Words		
		Customers / Words		
Customers / Products	Words / Products	★	★★★	
		★	★★★	
Customers / Products	Words / Products	★	★★★	
		★	★★★	
Customers / Products	Words / Products	★★★	★★★	★★★
		★★★	★★★	★★★
Customers / Products	Words / Products	★★★	★★★	★★★
		★★★	★★★	★★★

$$\approx UV^\top$$

Recommender systems, Virtual assistants, Ads

New Opportunities?

Your turn

up next:

- ✿ Regression
- ✿ Linear Regression
- ✿ Classification
- ✿ ... fundamental concepts of ML