

Deep Learning

Learning to learn within
the bigger picture



Durham
University

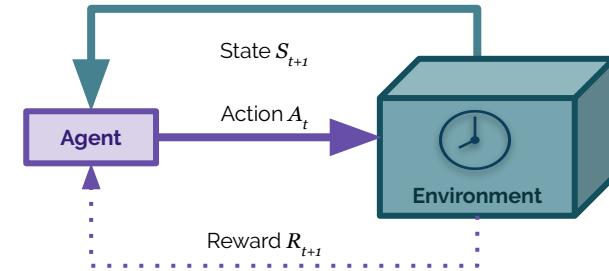
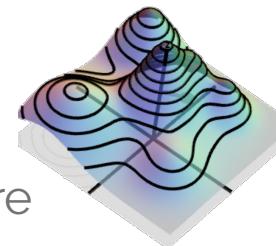
Dr Chris Willcocks

Department of Computer Science

Lecture Overview

Recap

- Manifold Learning
- Reinforcement learning
-all the way back to learning in nature



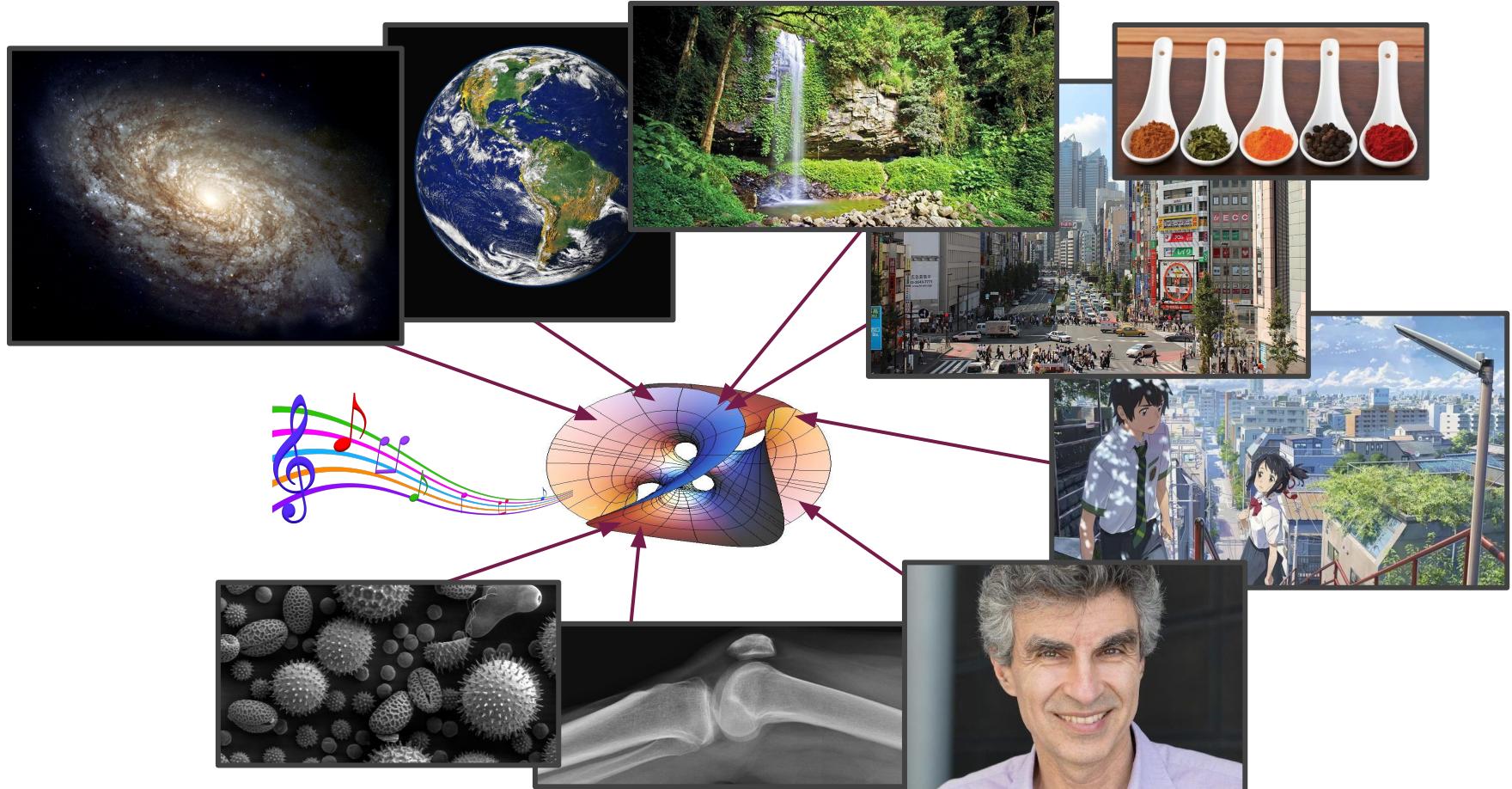
Aims of today's lecture

- Taking a step back
 - Reflect and speculate
- Meta-learning (or learning to learn)
 - A field of machine learning still in its infancy
- Approaches and recent algorithms

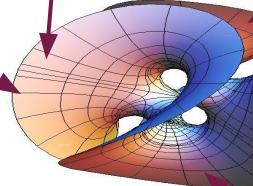
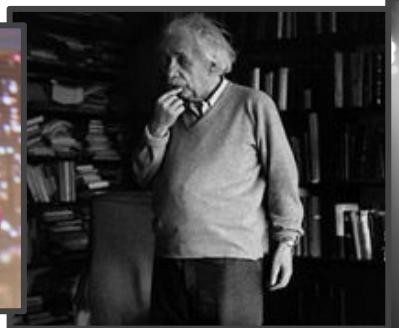
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A Big Distribution of Data



A Big Distribution of Tasks



Learning to learn to...

- move our fingers
- play music, type
- sing, talk
- ...
- think like Einstein & Hinton

A Big Distribution of Tasks

- What is this?
- What do you do with it?

} *Can we generalise to unseen tasks and unseen data?*



Solve,
admire

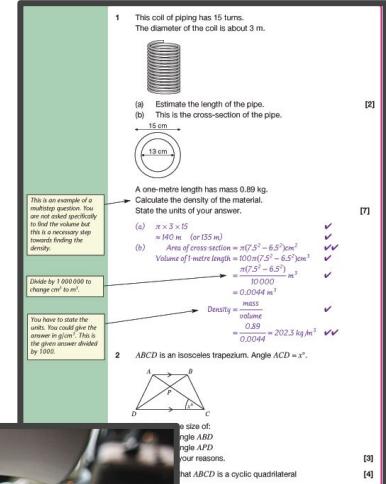
Play, complete, improvise...

A large bracket groups two musical score snippets. The top one shows a treble clef staff with various notes and rests. The bottom one shows a bass clef staff with similar musical elements. Both snippets include measure numbers and some markings like '3' over notes.

Play, measure,

Eat, taste, smell...

Solve, comprehend, ...

A scanned document containing two math problems. Problem 1 asks about a coil of piping with 15 turns and a diameter of about 3 m, asking for the length of the pipe. Problem 2 asks about a one-metre length of material with a mass of 0.89 kg, calculating density. The page includes handwritten student work with step-by-step calculations and a final boxed answer.

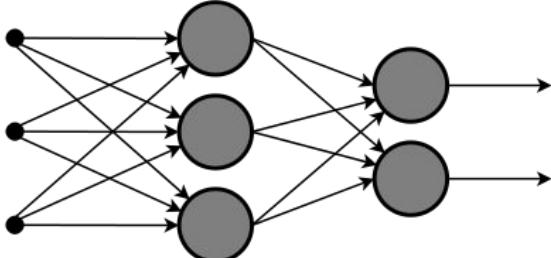
A Big Space of Programs

- Fact (from a provable theory):

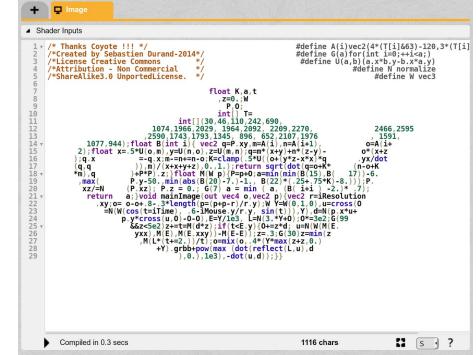
"The smallest possible program that fits to your training data will achieve the best generalisation possible."

- We know how, but the search space is too large.

What about smallest possible constrained circuits?



...and we arrive at backpropagation (searching for smallest circuit).



```
Shader Inputs
float k, t
vec3 N
vec3 P
vec3 T
int i
int j
int k
int l
int m
int n
int o
int p
int q
int r
int s
int t
int u
int v
int w
int x
int y
int z
float a, b, c, d, e, f, g, h, i, j, k, l, m, n, o, p, q, r, s, t, u, v, w, x, y, z
vec3 A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, P, Q, R, S, T, U, V, W, X, Y, Z
vec3 A1, B1, C1, D1, E1, F1, G1, H1, I1, J1, K1, L1, M1, N1, O1, P1, Q1, R1, S1, T1, U1, V1, W1, X1, Y1, Z1
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vec3 A84, B84, C84, D84, E84, F84, G84, H84, I84, J84, K84, L84, M84, N84, O84, P84, Q84, R84, S84, T84, U84, V84, W84, X84, Y84, Z84
vec3 A85, B85, C85, D85, E85, F85, G85, H85, I85, J85, K85, L85, M85, N85, O85, P85, Q85, R85, S85, T85, U85, V85, W85, X85, Y85, Z85
vec3 A86, B86, C86, D86, E86, F86, G86, H86, I86, J86, K86, L86, M86, N86, O86, P86, Q86, R86, S86, T86, U86, V86, W86, X86, Y86, Z86
vec3 A87, B87, C87, D87, E87, F87, G87, H87, I87, J87, K87, L87, M87, N87, O87, P87, Q87, R87, S87, T87, U87, V87, W87, X87, Y87, Z87
vec3 A88, B88, C88, D88, E88, F88, G88, H88, I88, J88, K88, L88, M88, N88, O88, P88, Q88, R88, S88, T88, U88, V88, W88, X88, Y88, Z88
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vec3 A92, B92, C92, D92, E92, F92, G92, H92, I92, J92, K92, L92, M92, N92, O92, P92, Q92, R92, S92, T92, U92, V92, W92, X92, Y92, Z92
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vec3 A96, B96, C96, D96, E96, F96, G96, H96, I96, J96, K96, L96, M96, N96, O96, P96, Q96, R96, S96, T96, U96, V96, W96, X96, Y96, Z96
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vec3 A98, B98, C98, D98, E98, F98, G98, H98, I98, J98, K98, L98, M98, N98, O98, P98, Q98, R98, S98, T98, U98, V98, W98, X98, Y98, Z98
vec3 A99, B99, C99, D99, E99, F99, G99, H99, I99, J99, K99, L99, M99, N99, O99, P99, Q99, R99, S99, T99, U99, V99, W99, X99, Y99, Z99
vec3 A100, B100, C100, D100, E100, F100, G100, H100, I100, J100, K100, L100, M100, N100, O100, P100, Q100, R100, S100, T100, U100, V100, W100, X100, Y100, Z100
```

Replies to @ChombaBupe

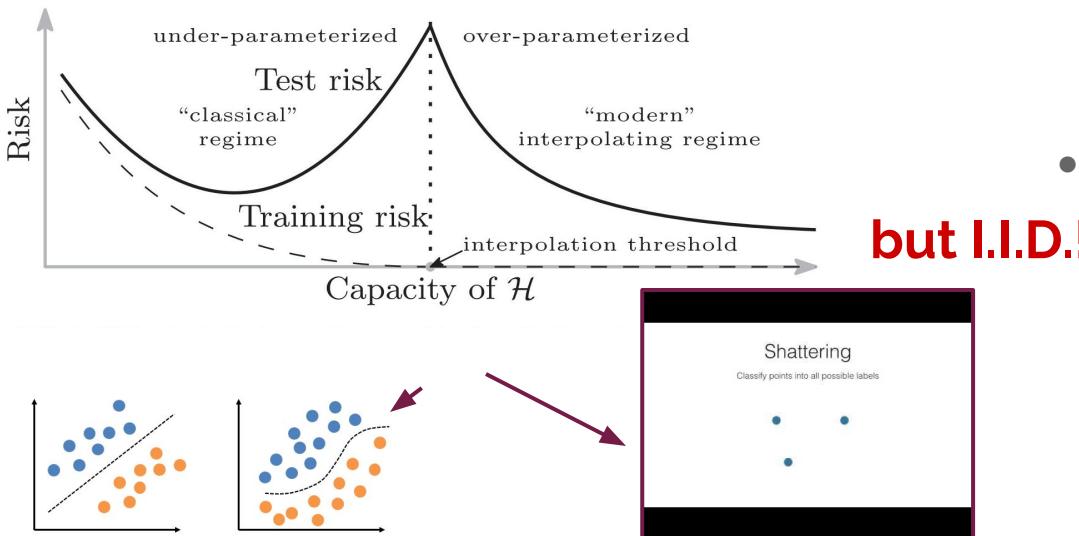
In situations where you can't use backprop, there are other methods you can fall back to. In situations where you can use backprop, I can't think of a situation where it would make sense to choose not to

11:27 PM - 15 Jan 2018

Statistical Learning Theory

if... not I.I.D:

"The discrepancy between training error and generalization error is bounded from above by a quantity that grows as the model capacity grows, but shrinks as the number of training examples increase."



- So how do we collect the dataset?
 - Close to real I.I.D. train/test/val
 - Get varied data
 - Varied photos
 - Varied camera types
 - Varied locations, views, scales, orientations, weather conditions, seasons, ...
 - Balanced classes
 - Carefully augmented data
 - ...
- And how to we build the model?
 - Dropout, L1/L2 regularisation
 - Tune layers/parameters
 - Weight sharing (convolutions)
 - Residual blocks
 - Transfer learning
 - Weight loss terms by imbalance
 - Early stopping...

Thinking with Distributions

Task dataset conditions are rarely IID to training conditions



!=

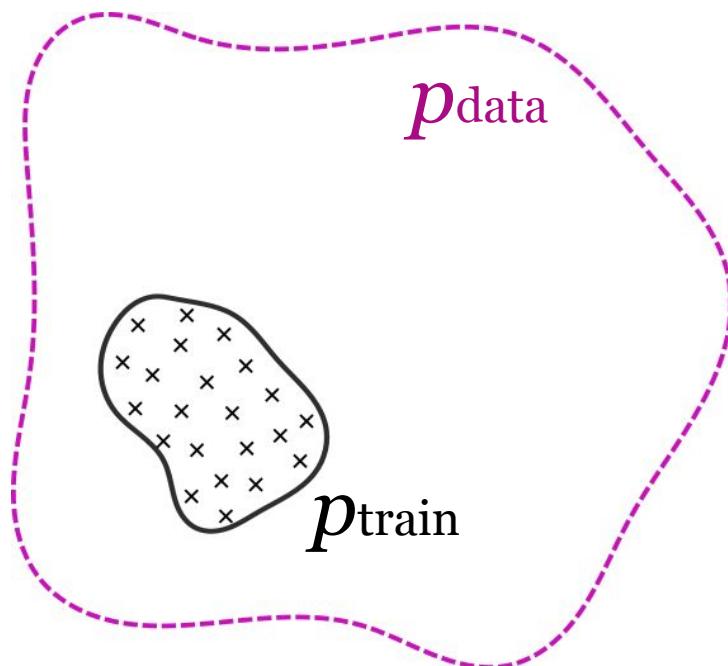


100,000 images
Samsung camera / mostly Android
Held in one orientation

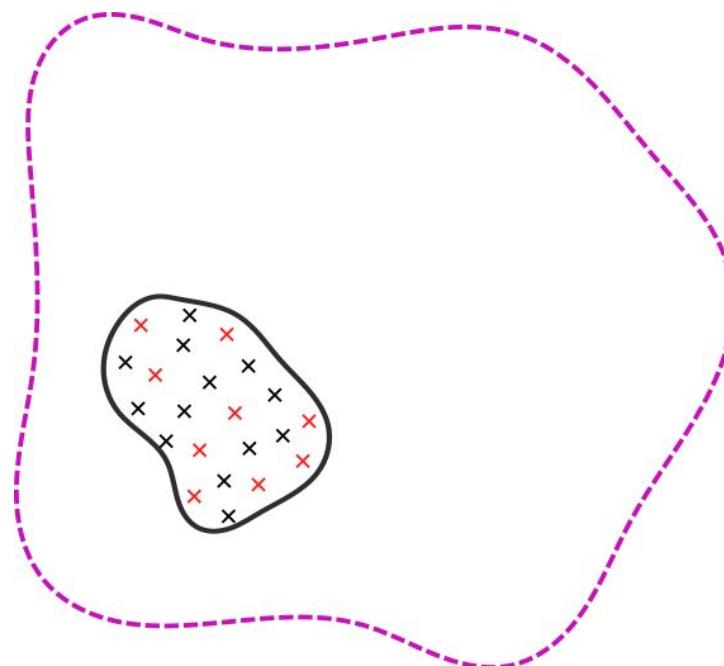
Different/future product line
Different brands
Different expected cameras (mostly iPhone)
Different orientations
Different expected lighting, weather, ...
Different user interests, ...

Thinking with Distributions

A common lie...

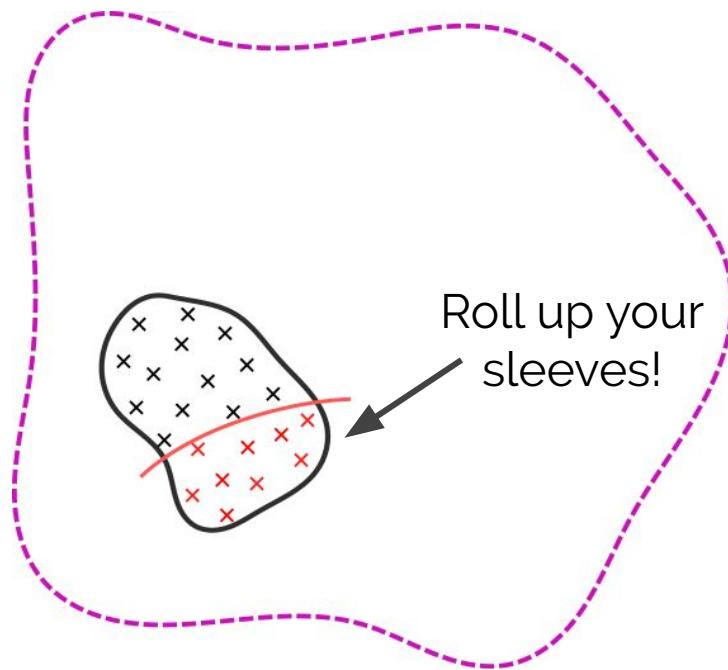


99.7% “test” accuracy!

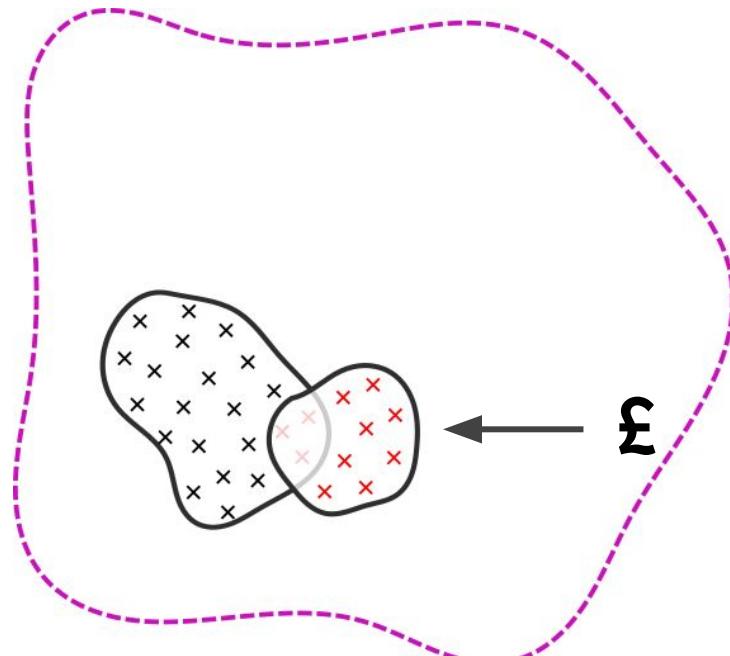


Thinking with Distributions

62% “test” accuracy
(but closer to the truth)

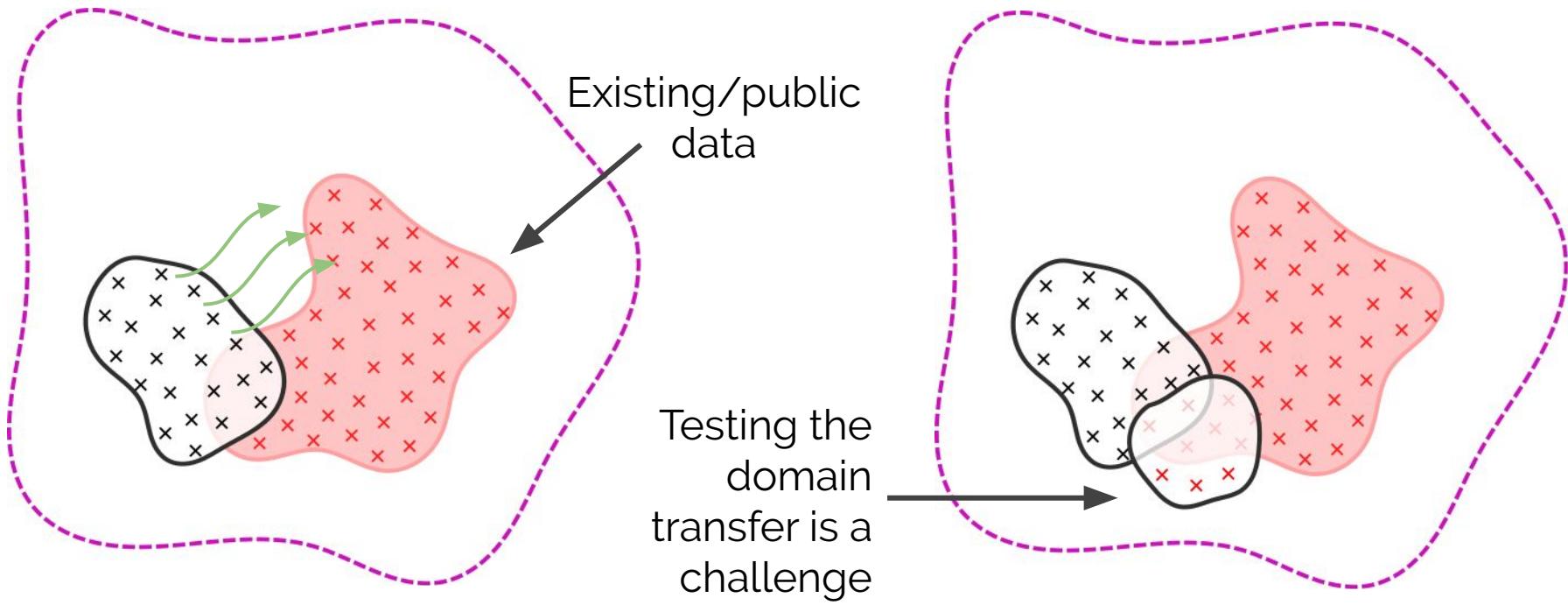


51% “test” accuracy
(even closer to the truth)



Thinking with Distributions

Generative models (e.g. Domain Adaptation)



Meta Learning

The goal:

- Learn to learn:



$$\theta^* = \arg \min_{\theta} \mathbb{E}_{\mathcal{D} \sim p(\mathcal{D})} [\mathcal{L}_{\theta}(\mathcal{D})]$$

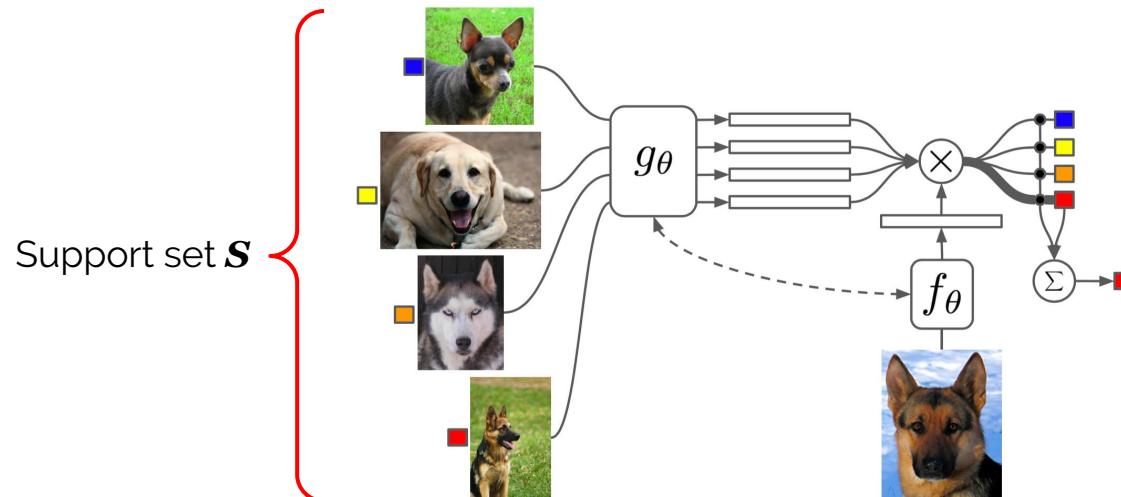
How?

- Don't just train on one task, but train on many tasks
- So we "*simply*" replace training examples with training tasks, and pretend that's normal learning

Meta Learning & Supervised Learning

Traditional Supervised Learning, **Meta Learning**

$$\theta = \arg \max_{\theta} \mathbb{E}_{L \sim \mathcal{T}} [\mathbb{E}_{S^L \sim \mathcal{D}, B^L \sim \mathcal{D}} [\sum_{(x,y) \in B^L} P_{\theta}(y|x, S^L)]]$$



Meta Learning Approaches

Categories

- Metric-based
- Model-based
- Optim-based

$$P_{\theta}(y|\mathbf{x}, S) = \sum_{(\mathbf{x}_i, y_i) \in S} k_{\theta}(\mathbf{x}, \mathbf{x}_i) y_i$$

$$P_{\theta}(y|\mathbf{x}, S) = f_{\theta}(\mathbf{x}, S)$$

$$P_{\theta}(y|\mathbf{x}, S) = P_{g_{\phi}(\theta, S^L)}(y|\mathbf{x})$$

They all have this in common (S = a support set)

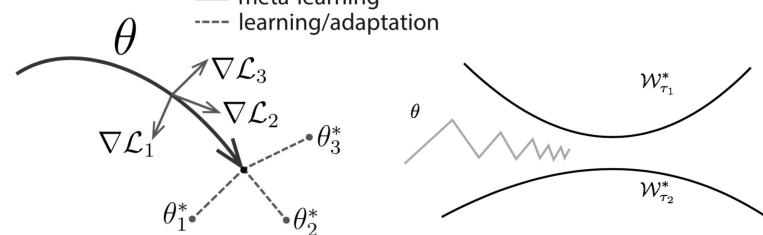
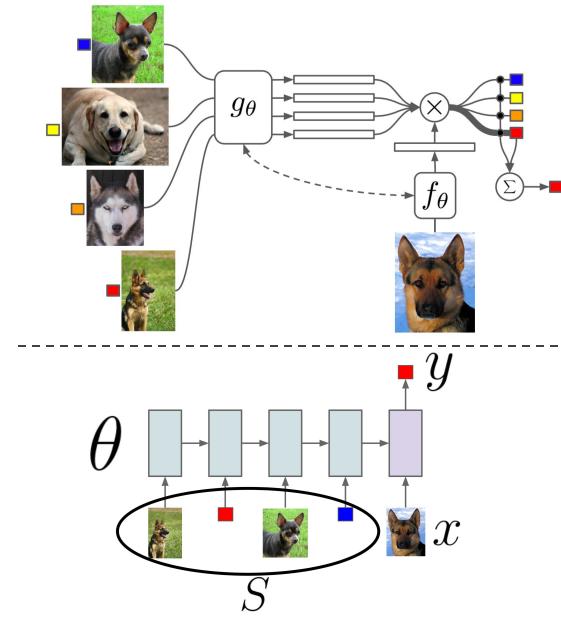
Research advances

- Few-shot datasets
- Simulation with error
- Self-play
- Interactive learning
- Curiosity-driven learning

Algorithm 2 Reptile, batched version

```

Initialize  $\theta$ 
for iteration = 1, 2, ... do
    Sample tasks  $\tau_1, \tau_2, \dots, \tau_n$ 
    for  $i = 1, 2, \dots, n$  do
        Compute  $W_i = \text{SGD}(L_{\tau_i}, \theta, k)$ 
    end for
    Update  $\theta \leftarrow \theta + \beta \frac{1}{n} \sum_{i=1}^n (W_i - \theta)$ 
end for
  
```



Few-shot Learning Datasets

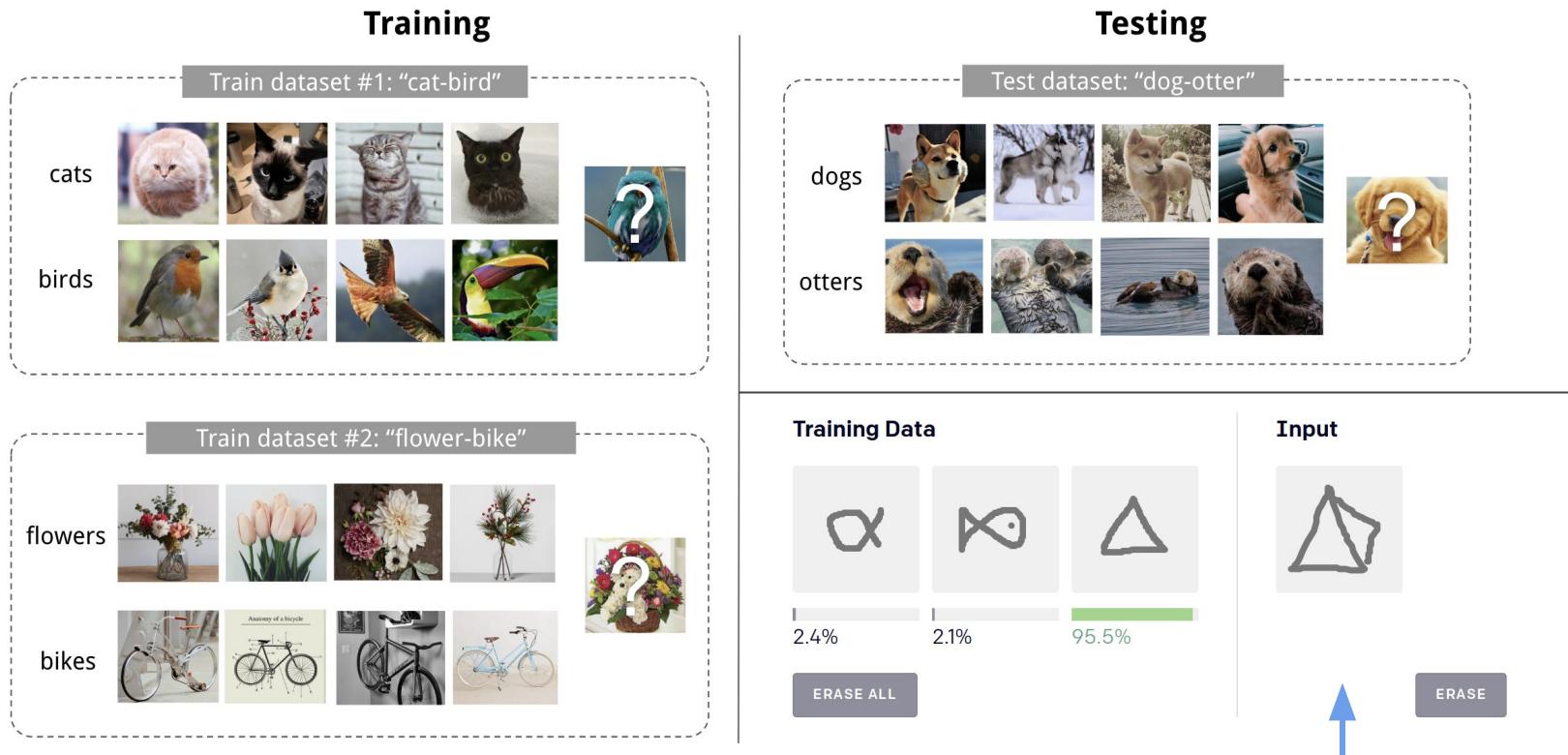


Omniglot

Mini-Imagenet



Few-shot Learning Examples



Model-based

$x, S = \text{“The cat sat on the”}$

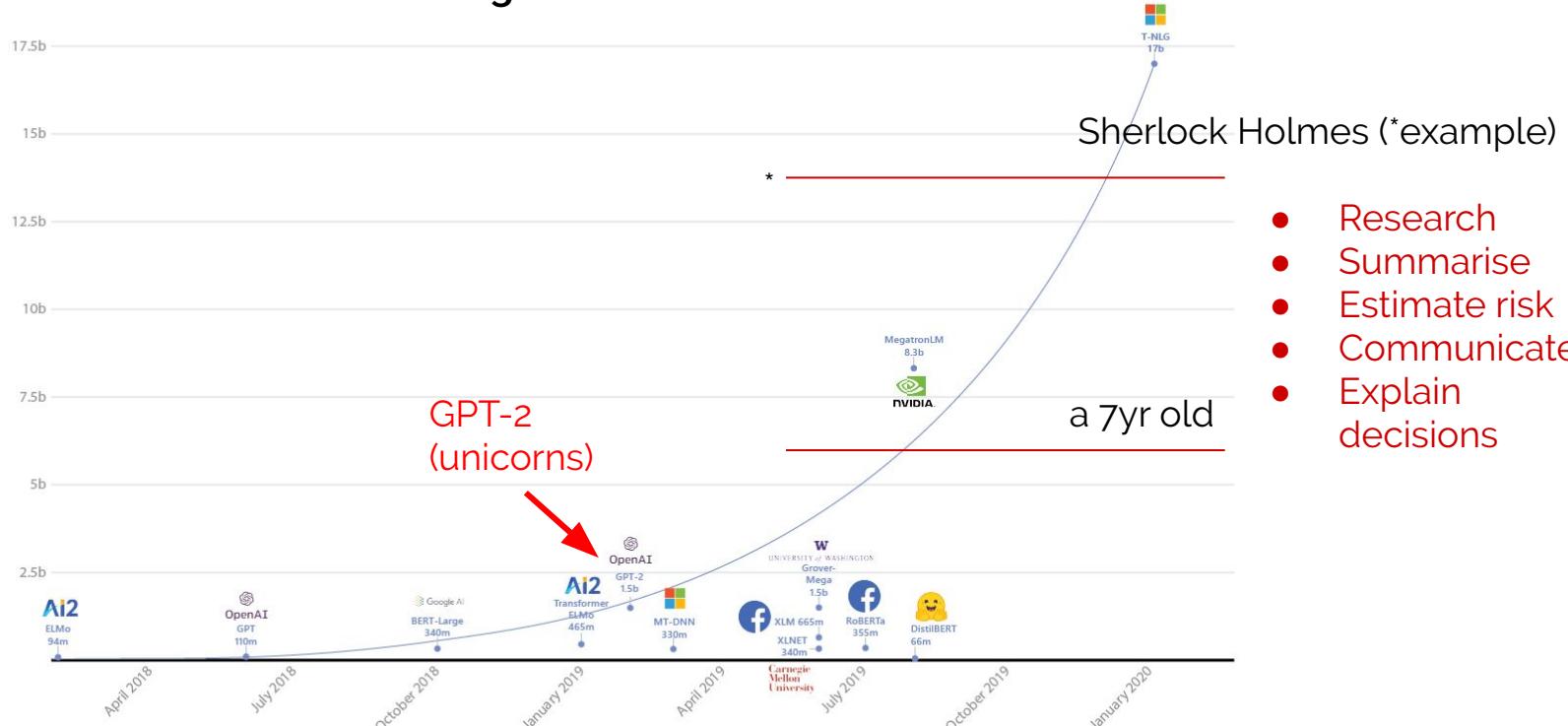
$$p(x) = \prod_{i=1}^n p(s_n | \overbrace{s_1, \dots, s_{n-1}})$$



Trained on the internet... “**mat.**”

Recap: The *Meta* Learning Race

Do a Google Search for “Microsoft Turing NLG”



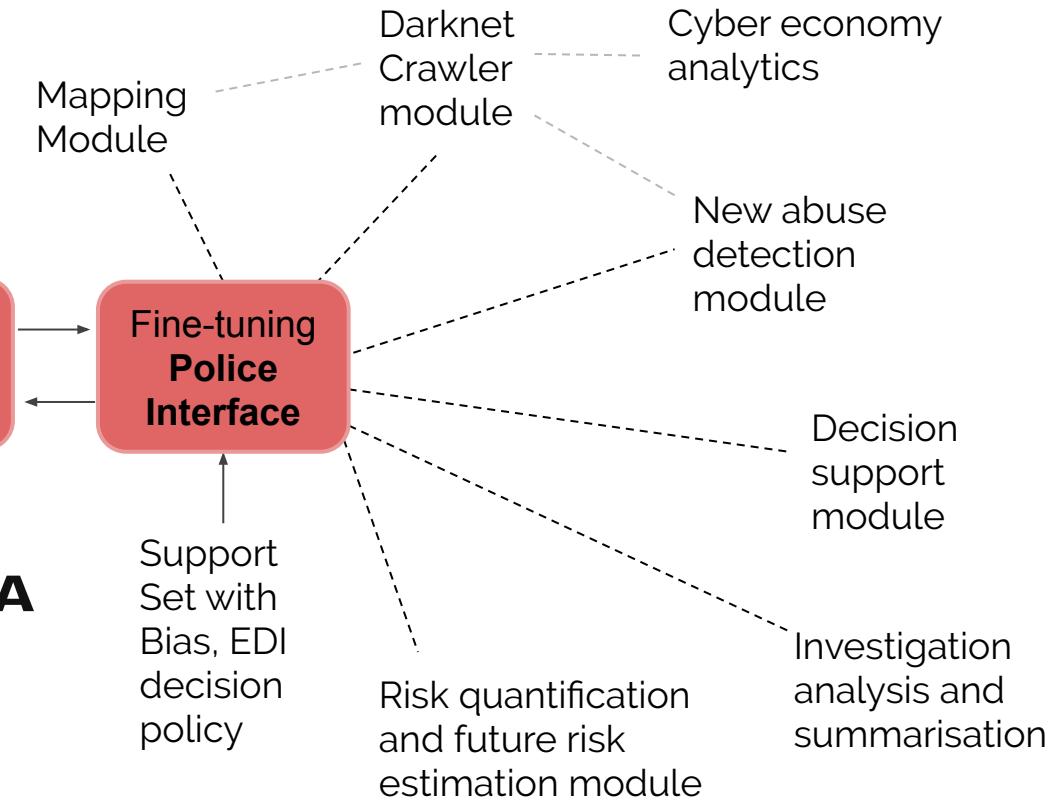
Released **February 10th**, 2020 - Microsoft Research

Interfacing

Small websites interfacing to the market-leading always-improving big backbone model



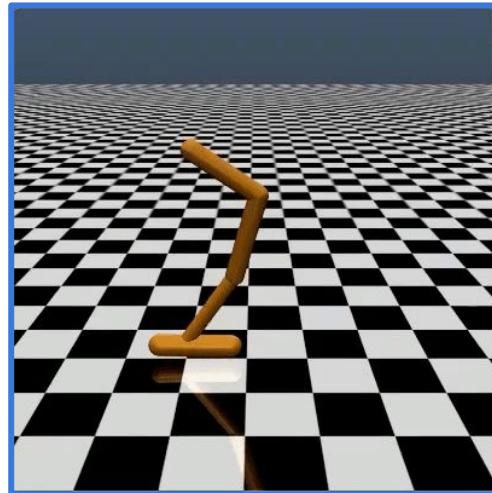
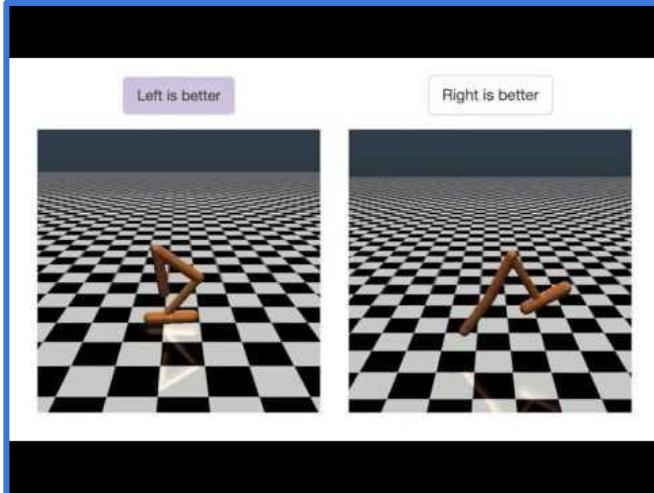
Example: Policing



Interfacing

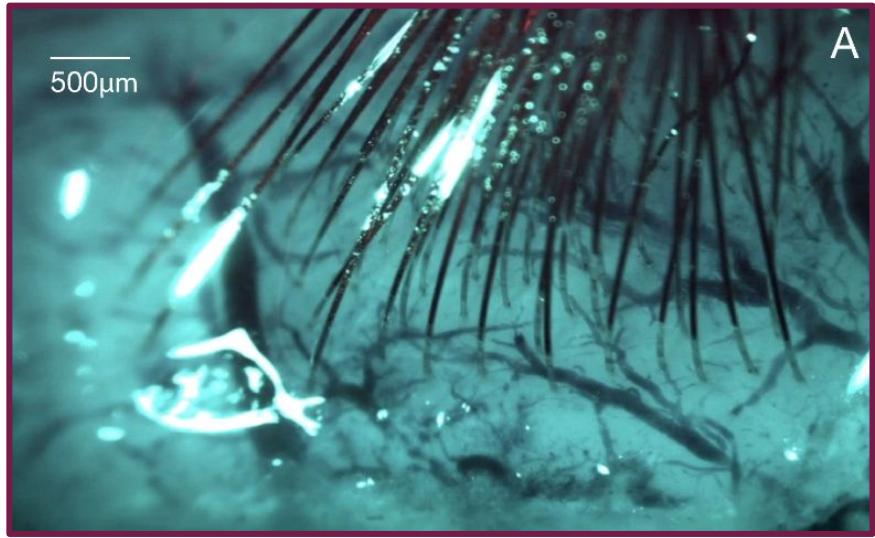
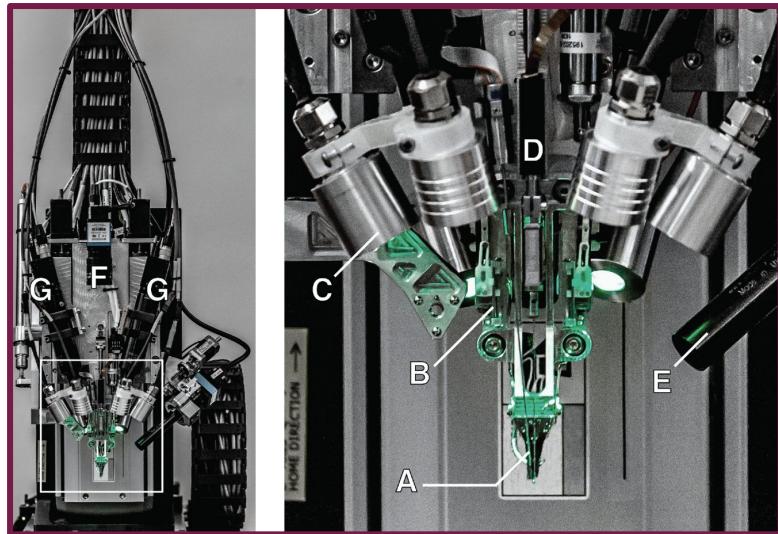
Data efficient rewards: about 500 clicks to make a leg that backflips

A few clicks to get an atari game that does something totally unique (follow another car).



<https://openai.com/blog/deep-reinforcement-learning-from-human-preferences/>

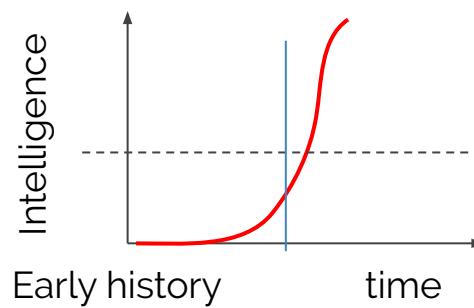
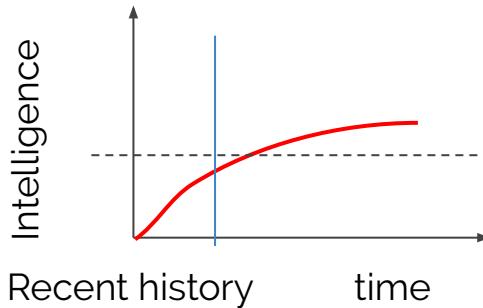
Brain Machine Interfaces (BMI)



<https://www.neuralink.com/>

Reflections

- Big diverse datasets learning \mathbf{p}_{data}
- Vision and text starting to align
- Staying in-the-loop
 - Natural dialogue/smart interfacing
 - Reinforcement learning to communicate goals
 - BMI
- Reasoning - is there more than imitation?



We still don't know the future,
but (from security)...

- low immediate threat,
but high risk
- $\text{risk} = \text{impact} * \text{probability}/\text{cost}$