

Machine Learning Frontiers

Review of what we've covered

Challenges and open questions

Exciting applications

Where to go from here?

Supervised Learning

K-Nearest Neighbors

Linear regression

Perceptron

Logistic regression

Linear Discriminant Analysis (LDA)

Quadratic Discriminant Analysis

Naïve Bayes

Classification and Regression Trees

Random Forests

Neural Networks, backpropagation, CNNs

Kernel Methods / Support Vector Machines

Ensemble methods

Bagging, boosting, stacking

Regularization (ridge and lasso), feature selection, cost functions, and norms

Decision theory

Gradient descent and stochastic gradient descent

Performance Evaluation

Cross validation

Bootstrap sampling

Confusion Matrices

ROC curves

Precision/Recall/Error Types

Bias-variance tradeoff

Curse of Dimensionality

Unsupervised Learning

Clustering

K-Means

Gaussian mixture model

Agglomerative clustering

DBSCAN

Spectral clustering

Density Estimation

Gaussian mixture models

Dimensionality Reduction

Principal Components

Analysis, LDA

Markov Models

Markov chains

Hidden Markov Models

Markov reward processes

Markov Decision Processes

Reinforcement Learning

Dynamic Programming

Policy Evaluation

Policy Improvement

Policy Iteration

Value Iteration

Generalized policy iteration

Monte Carlo Control

Model free learning

Semi-supervised learning

Self-supervised learning

Topics we covered

Machine Learning is **NOT** magic

It's **one tool of many** to assist us in making better, faster decisions

It is not a substitute for critical thinking and domain expertise – they go together

Practical Considerations for Machine Learning

1. Let your **problem/question** drive your design choices
 2. Set a reasonable goal and clear metric of success
 3. Ask yourself if there are **non-ML approaches that would work?**
 4. Develop an **end-to-end pipeline** as soon as you're able and keep it maintained (data preparation & preprocessing, analysis, and performance evaluation)
 5. Start with the **simplest solution** you can and layer on complexity as needed
-
- **Features / representations** are often more important than algorithms
 - **Experimental design** is often more important than algorithms

Adapted from Google: <https://developers.google.com/machine-learning/guides/rules-of-ml>

More advice

- ALWAYS look at your data – before you begin, the inputs/outputs, etc.
 - Check your distributions
 - Explore outliers to get insights on the model
- Report confidence intervals whenever possible (make sure your “better” model is not just a noisy aberration)
- When comparing supervised models, make sure you’re comparing on the same validation set
- Make sure you NEVER mix training and validation information

Adapted from <https://www.unofficialgoogledatascience.com/2016/10/practical-advice-for-analysis-of-large.html>

Challenges and Open Questions

Unsolved challenges in machine learning

Generalizing from **small numbers of examples** (few-shot learning)

Adapting to **new environments** and non-stationary problems

Transferring knowledge between tasks (transfer learning)

Combining **heterogeneous data sources** into a model

Interpretability for confidence in algorithms

Ethics, fairness, and privacy (asks the question: should we?)

Greenwald and Oertel, 2017, Future Directions in Machine Learning
Jeannette Wing, 2020, Ten Research Challenge Areas in Data Science

Types of Biases

- Historical bias
- **Representation bias**
- Measurement bias
- Evaluation bias
- Aggregation bias
- Population bias
- Simpson's paradox
- Longitudinal data fallacy
- **Sampling bias**
- Behavioral bias
- Content production bias
- Linking bias
- Temporal bias
- Popularity bias
- Algorithmic bias
- User interaction bias
- Presentation bias
- Ranking bias
- Social bias
- Emergent bias
- Self-selection bias
- Omitted variable bias
- Cause-effect bias
- Observer bias
- Funding bias

Bold indicates those biases we've discussed through the semester – there are MANY more

Mehrabi, N., Morstatter, F., Saxena, N., Lerman, K. and Galstyan, A., 2019. A survey on bias and fairness in machine learning. arXiv preprint arXiv:1908.09635.

Interpretability

Transparency (can I tell how the model works)

- **Simulability:** can I contemplate the whole model at once?
- **Decomposability:** is there an intuitive explanation for each part of the model?
(e.g. all patients with diastolic blood pressure over 150)

Explainability (post-hoc explanations)

Visualization, local explanations, explanations by example

(e.g. this tumor is classified as malignant because to the model it looks a lot like these other tumors)

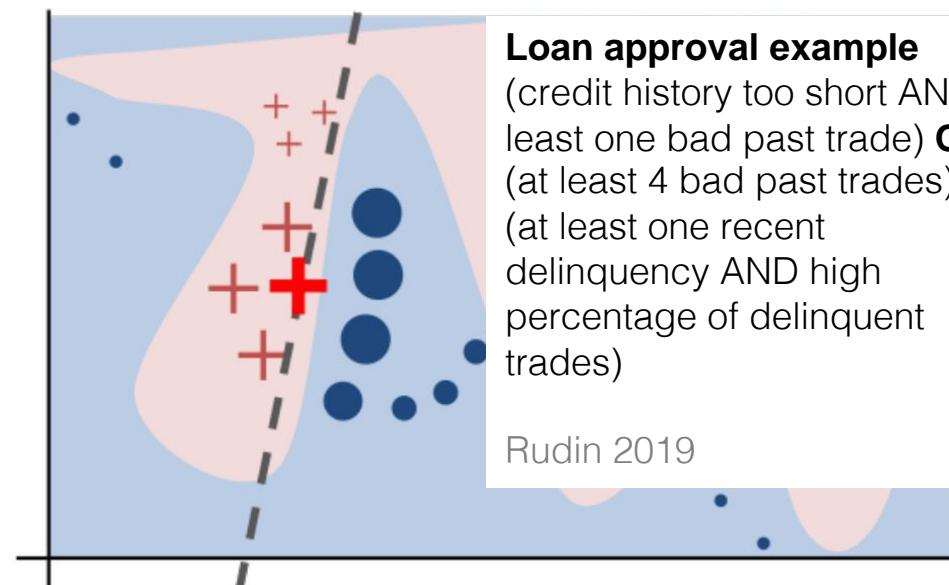
Lipton, Zachary C. "The Mythos of Model Interpretability: In Machine Learning, the Concept of Interpretability Is Both Important and Slippery." *Queue* 16, no. 3 (2018): 31–57.

Recidivism prediction algorithm

Performance as good as a black box model with 130+ factors; might include socio-economic info; expensive (software license); within software used in US justice system

IF	age between 18-20 and sex is male	THEN predict arrest (within 2 years)
ELSE IF	age between 21-23 and 2-3 prior offences	THEN predict arrest
ELSE IF	more than three priors	THEN predict arrest
ELSE	predict no arrest	

Rudin, Cynthia. "Stop Explaining Black Box Machine Learning Models for High Stakes Decisions and Use Interpretable Models Instead." *Nature Machine Intelligence* 1, no. 5 (2019): 206–15.



Loan approval example
(credit history too short AND at least one bad past trade) **OR**
(at least 4 bad past trades) **OR**
(at least one recent delinquency AND high percentage of delinquent trades)

Rudin 2019

Ribeiro, Marco Tulio, Sameer Singh, and Carlos Guestrin. "Model-Agnostic Interpretability of Machine Learning." ArXiv Preprint ArXiv:1606.05386, 2016.

Ethical Considerations

- Privacy and surveillance
- Manipulation of behavior
- Transparency in machine learning systems
- Decision system biases
- Automation and employment
- Autonomous systems and responsibility
- Machine ethics (e.g. Isaac Asimov's 3 laws)
- Artificial moral agents
- Singularity

Müller, V.C., 2020. Ethics of artificial intelligence and robotics.

The Bitter Lesson ([link](#),[video](#))

Richard Sutton

“The biggest lesson that can be read from 70 years of AI research is that general methods that leverage computation are ultimately the most effective, and by a large margin.”

Computation

NVIDIA
Graphics Processing Units (GPU)



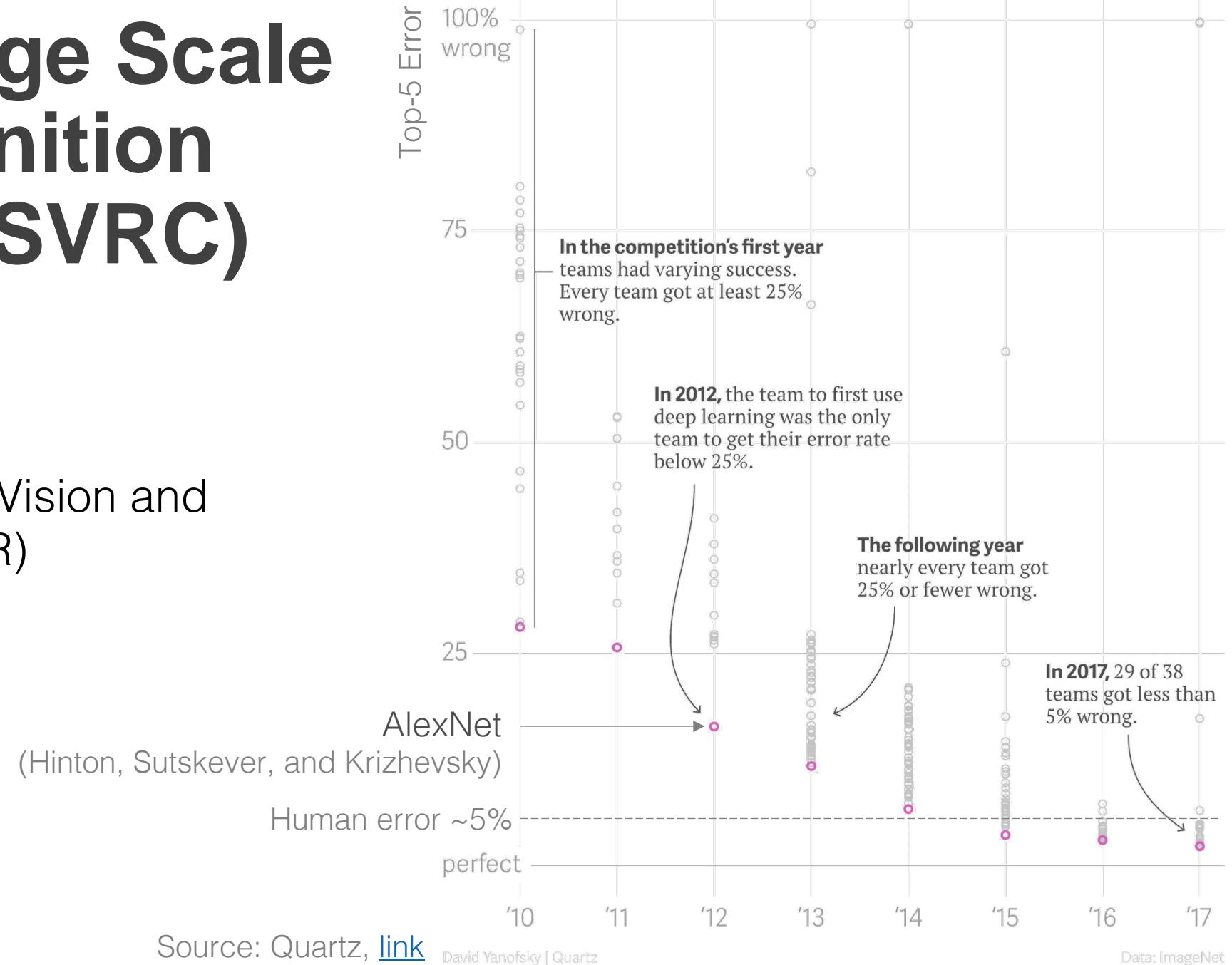
Google
Tensor Processing Unit (TPU)



ImageNet Large Scale Visual Recognition Challenge (ILSVRC)

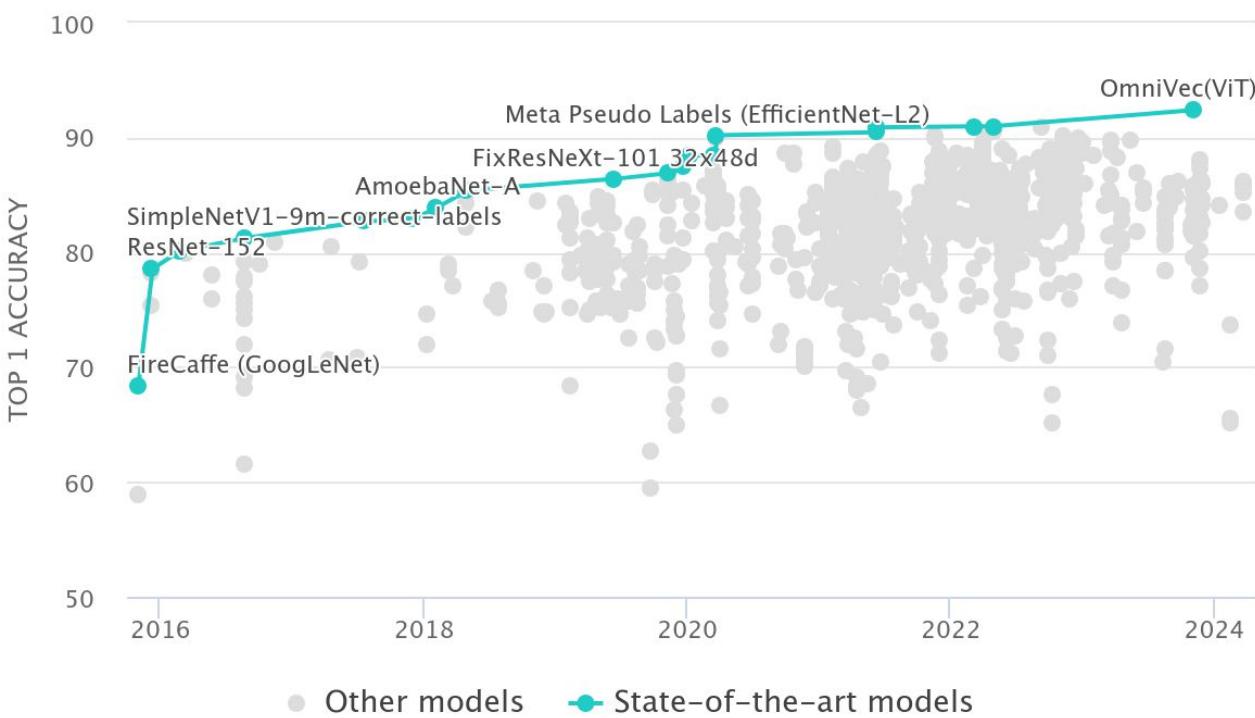
Fei-Fei Li et al. 2010 ([link](#))

Competition at:
Conference on Computer Vision and
Pattern Recognition (CVPR)

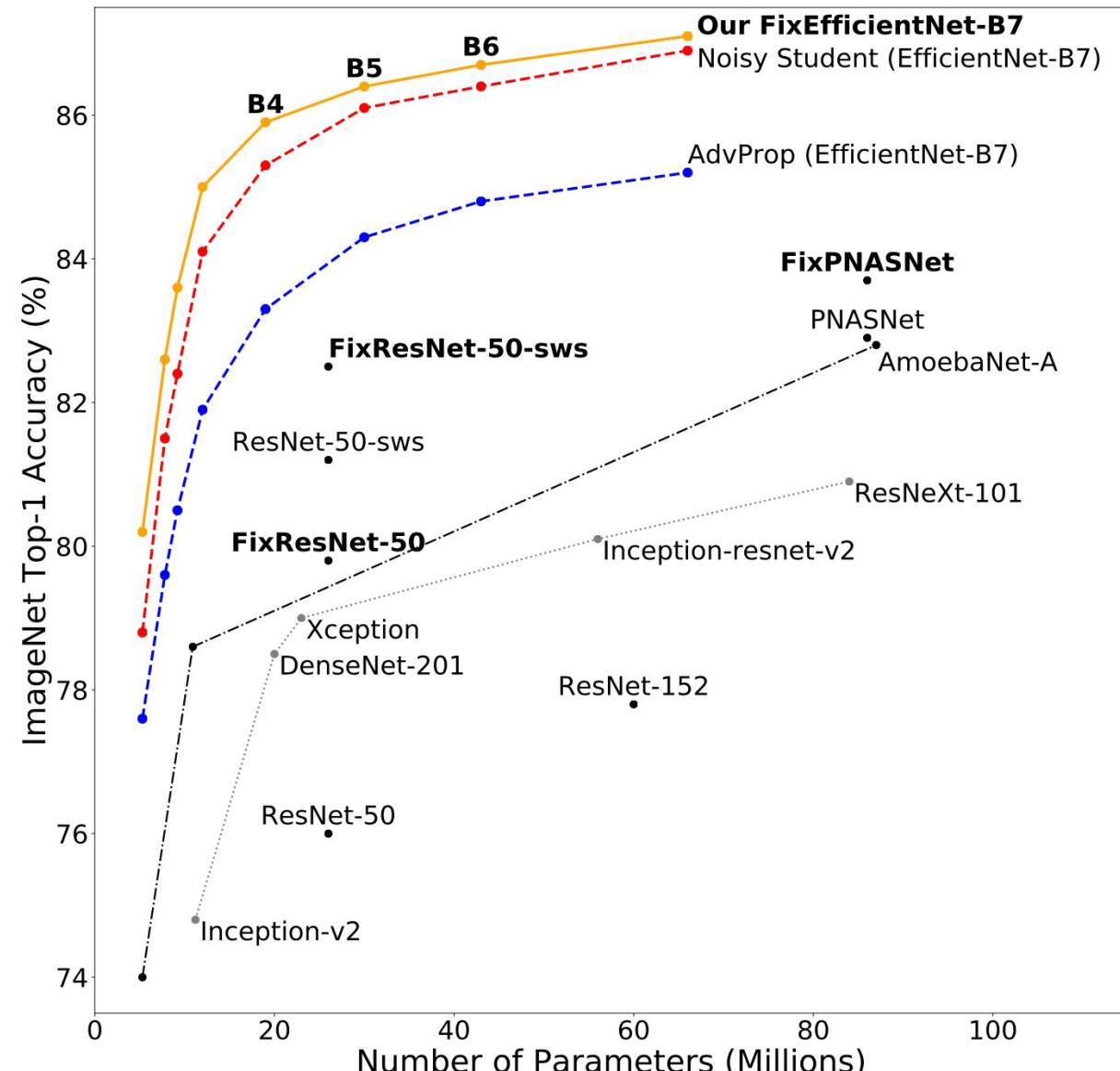


Latest Advances with Image Recognition

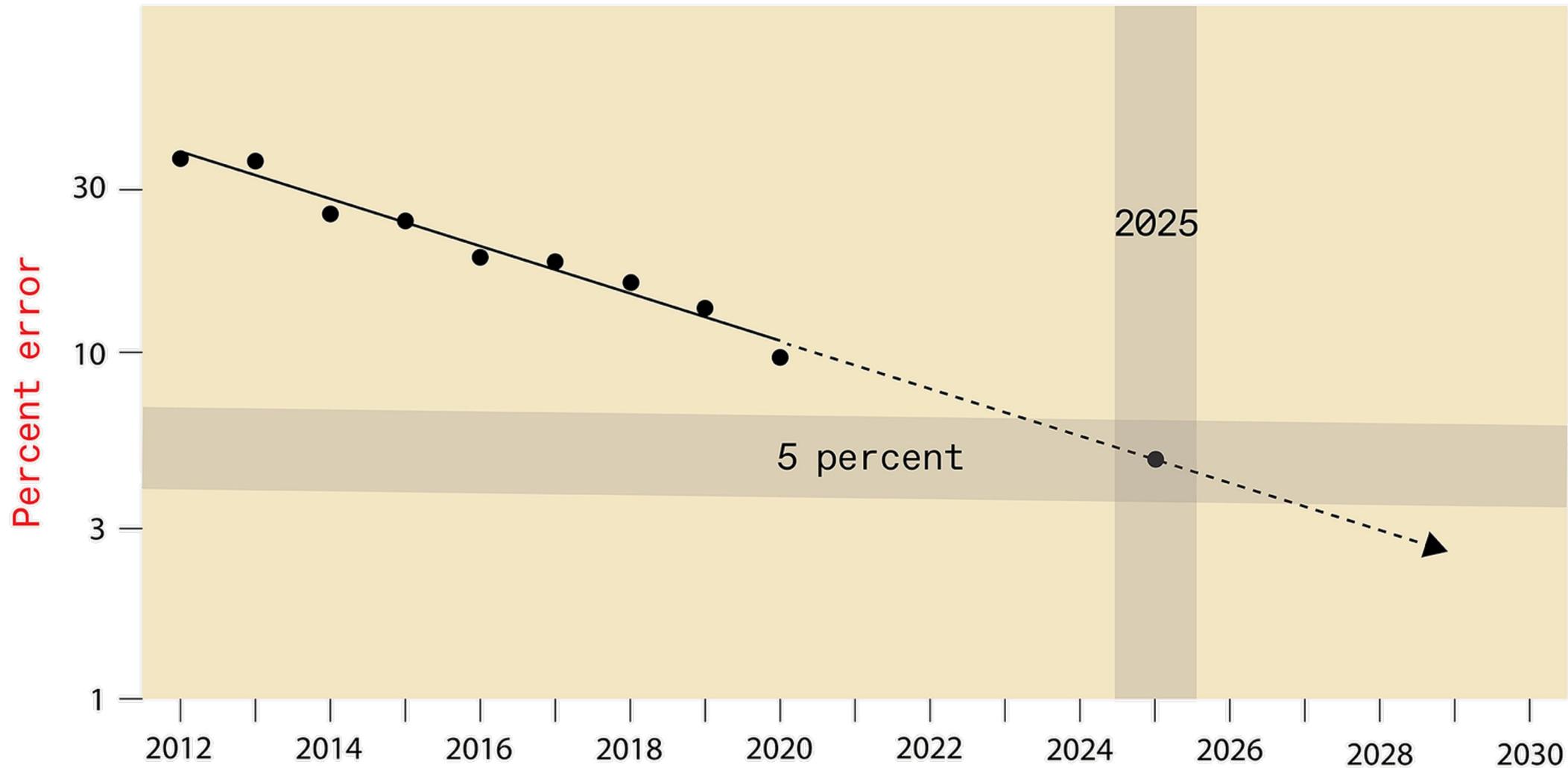
Touvron, H., Vedaldi, A., Douze, M. and Jégou, H., 2020.
Fixing the train-test resolution discrepancy:
FixEfficientNet. arXiv preprint arXiv:2003.08237.



Source: <https://paperswithcode.com/sota/image-classification-on-imagenet>

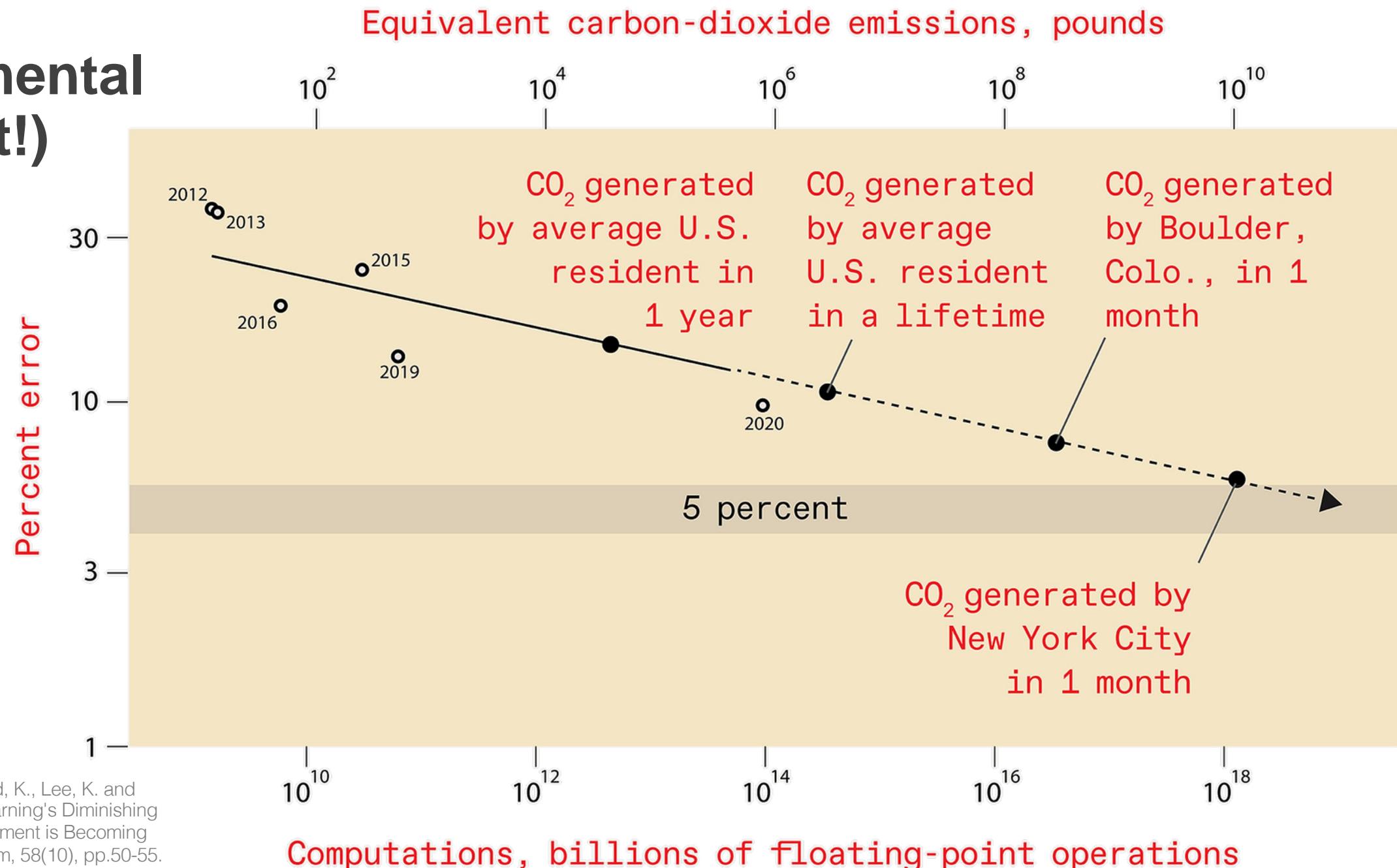


Trend in ImageNet performance



Thompson, N.C., Greenwald, K., Lee, K. and Manso, G.F., 2021. Deep Learning's Diminishing Returns: The Cost of Improvement is Becoming Unsustainable. IEEE Spectrum, 58(10), pp.50-55.

Potential environmental (and cost!) impacts



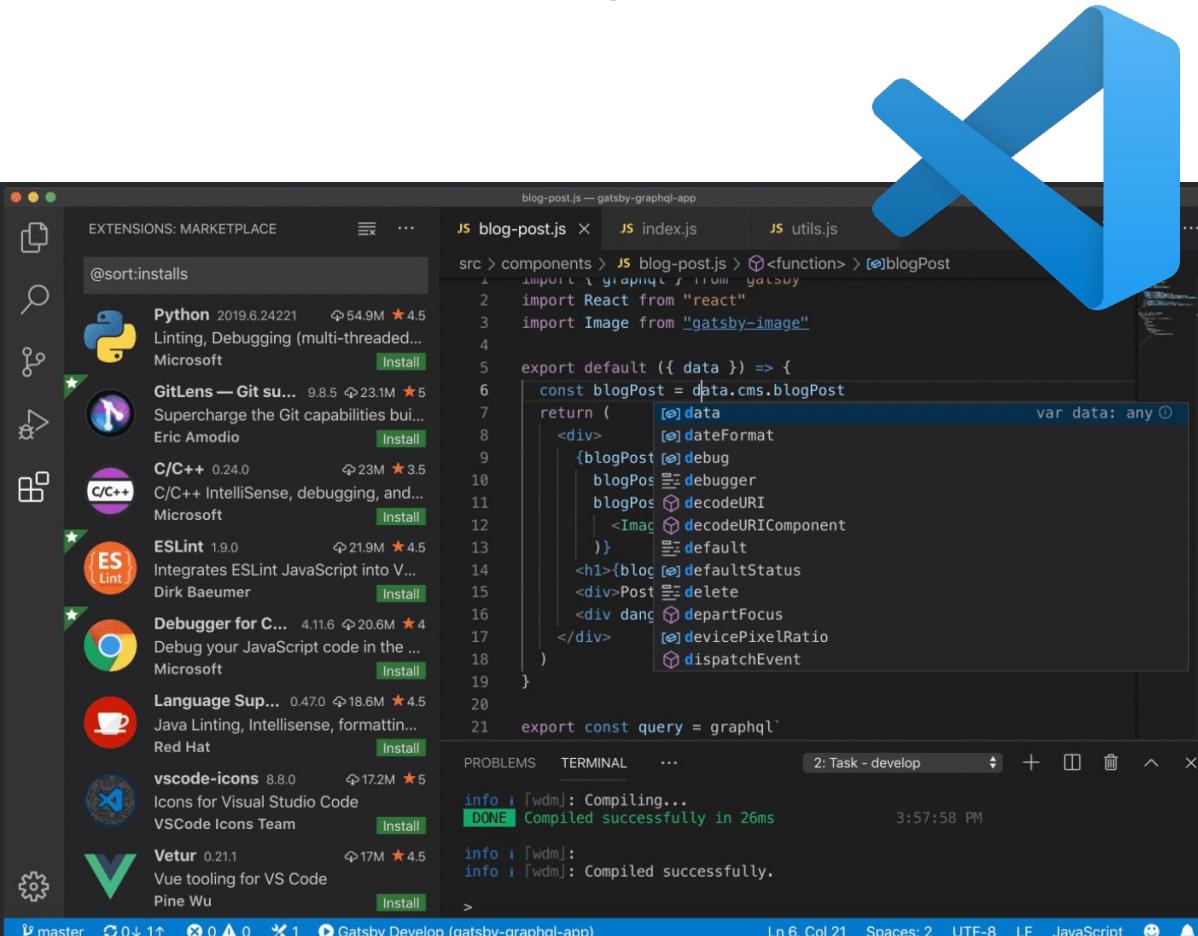
How to deal with increasing complexity?

More code

More machine learning experiments to keep track of

Tools: Development Environments

Use the best coding tools for the job: VS Code, Jupyter, etc.



For additional practical considerations, explore Berkeley's [Full Stack Deep Learning](#)

Organization: Experiment Tracking

Track your experiments in an organized way. If it helps, use Comet.ml, Weights and Biases, MLFlow, Neptune, etc.

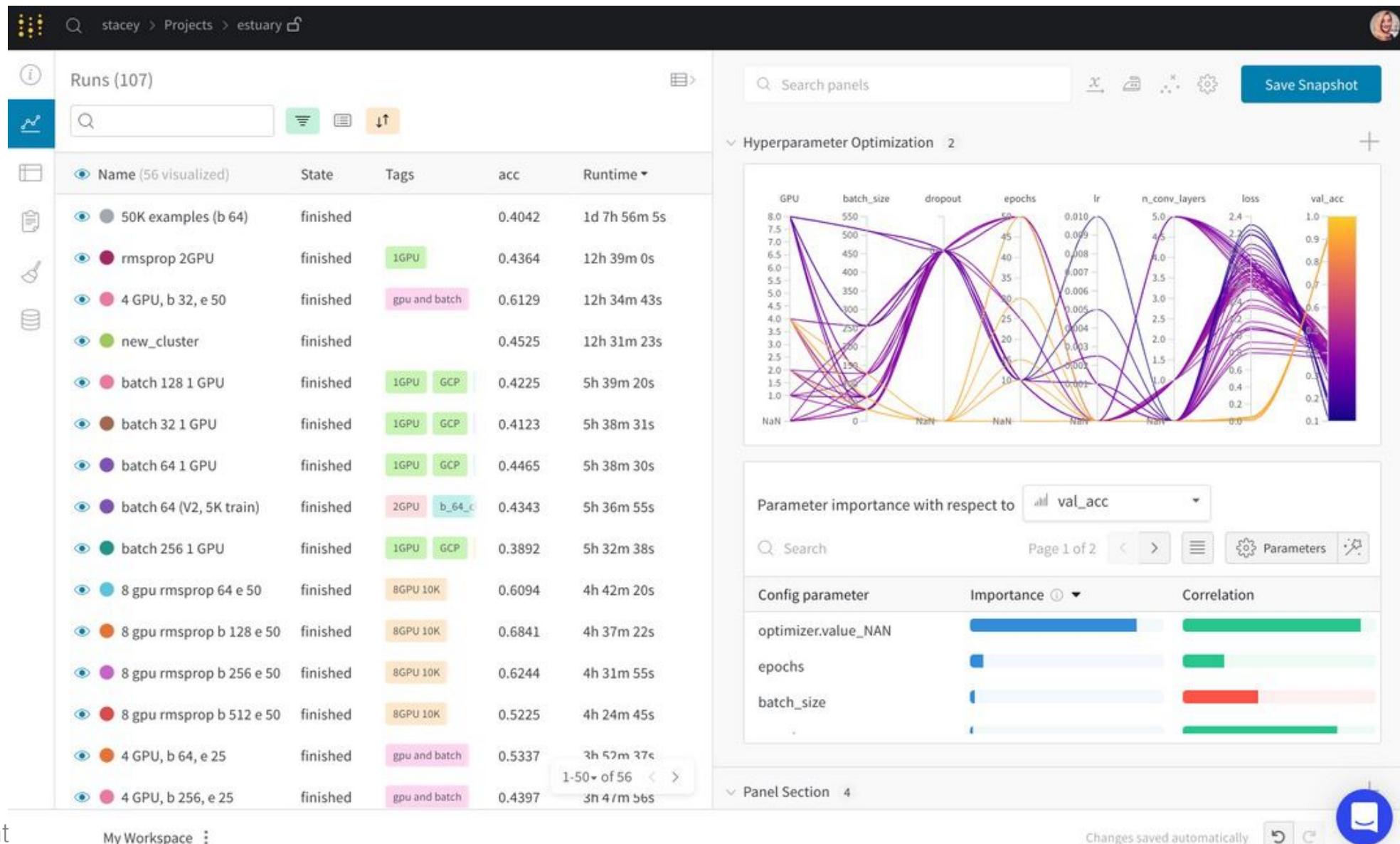
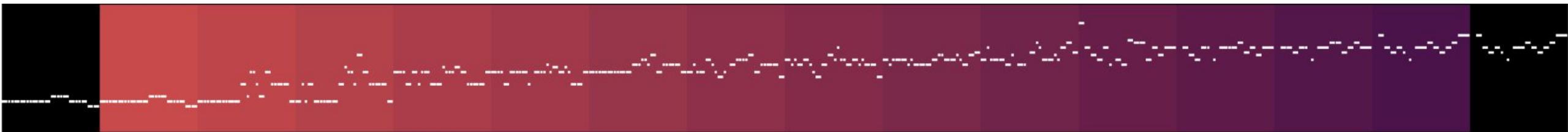


Image from:
<https://github.com/wandb/client>

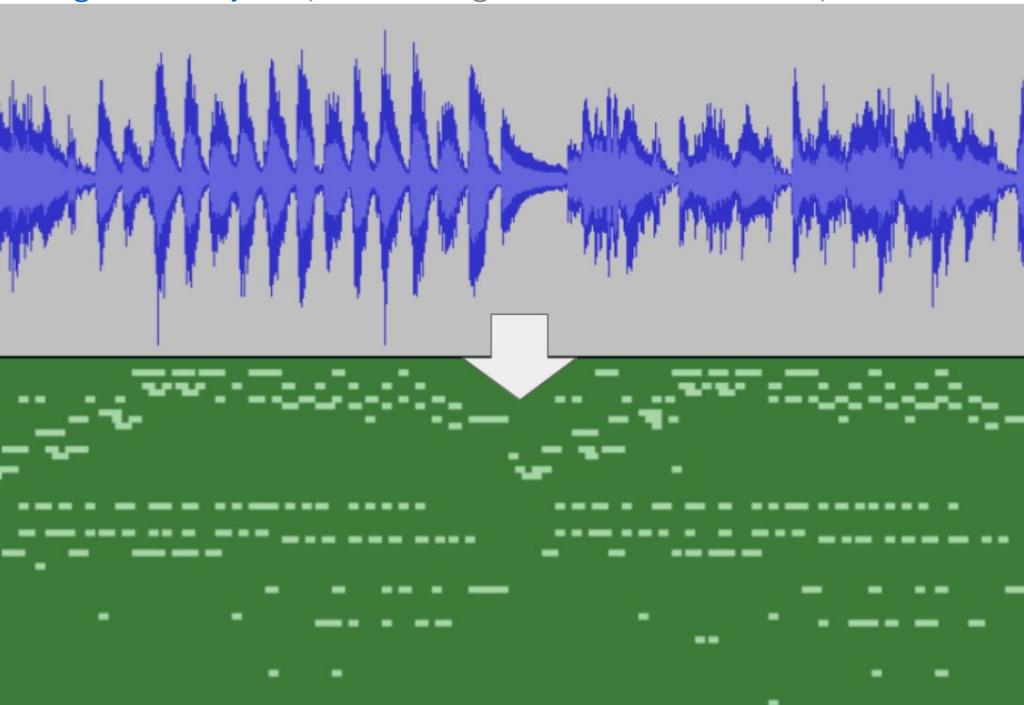
Machine Learning Applications

Music

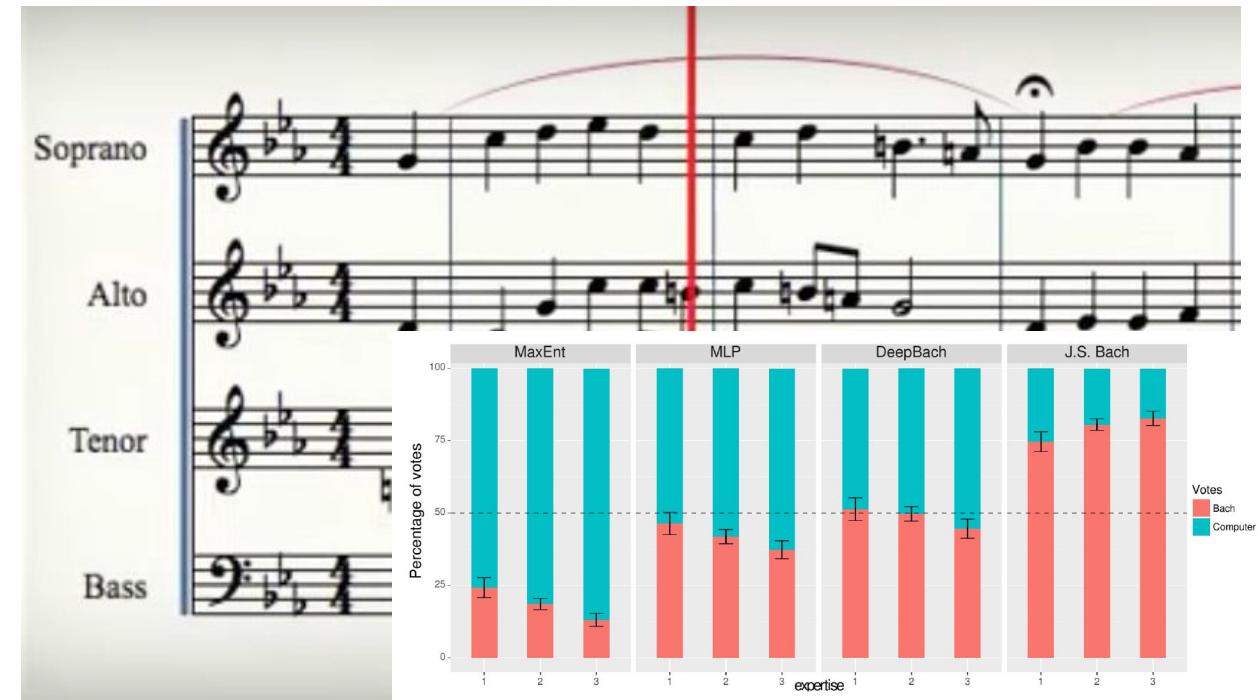
MusicVAE (Magenta):
Blending musical scores ([link](#))
[Magenta Project](#) (from Google Brain / tensorflow)



Onsets and Frames:
Automated transcription ([link](#))
[Magenta Project](#) (from Google Brain / tensorflow)

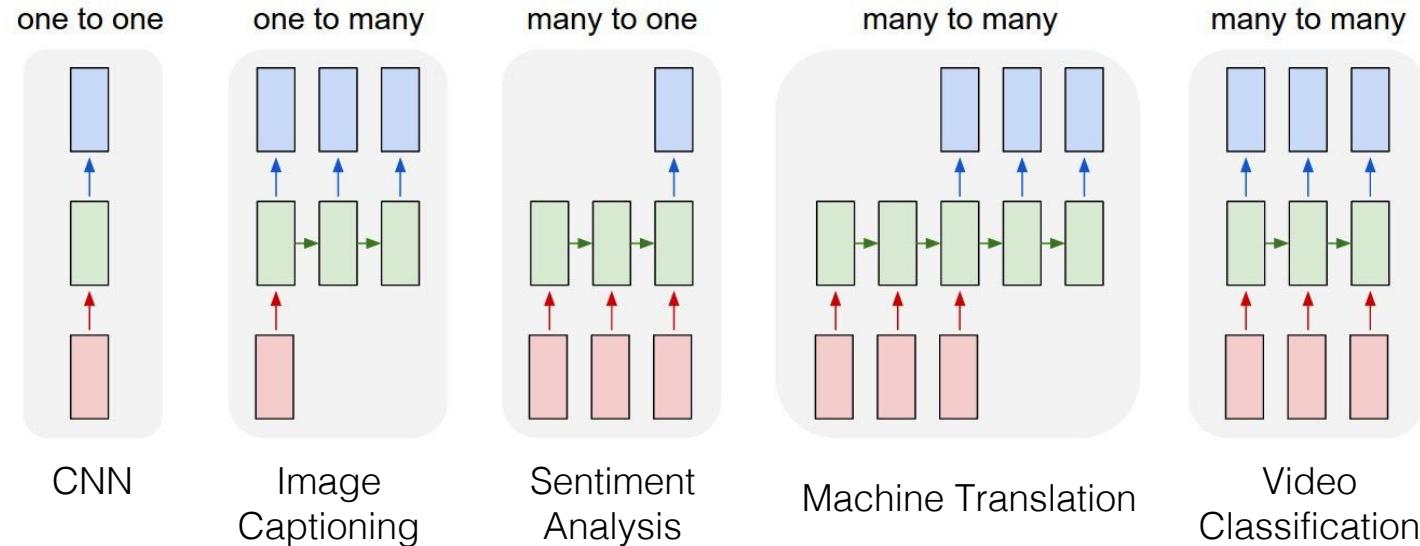


Deep Bach:
Automated harmonization ([link](#))
Paper available here: <https://arxiv.org/abs/1612.01010>



Natural Language Processing

Recurrent Neural Networks



Transformers

Do not process sequentially,
enables parallelization

Use an attention mechanism
E.g. a way of indicating which words in a
sentence are most relevant to a specific word

Examples: BERT, Transformer XL

Example architecture: Long short-term memory (LSTM)

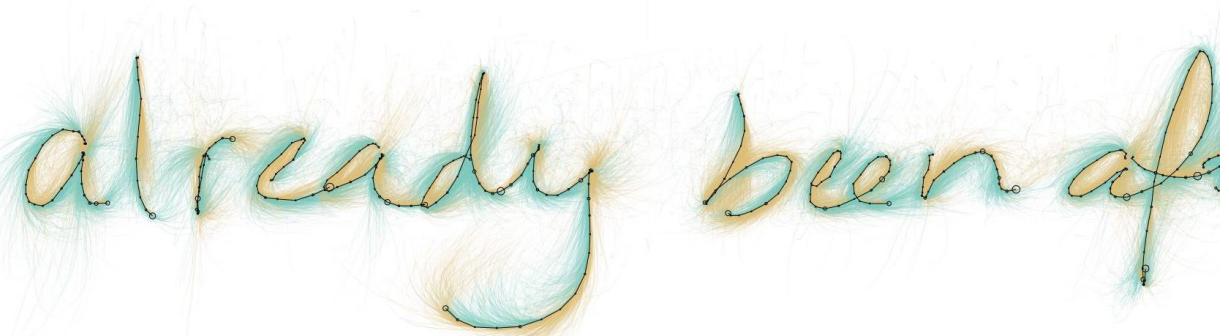
Drawbacks: Sequential data processing (slow)

Computer Vision

Handwriting completion:
...with Neural Networks ([link](#))

Carter et al. 2016, our Experiments in Handwriting with a Neural Network
(Google Brain)

SketchRNN:
Automated sketching ([link](#))
[Magenta Project](#) (from Google Brain / tensorflow)



Computer Vision & Visual Arts

Deep Dream: Style Transfer and Abstract Art ([link](#))

Originally developed by Alexander Mordvintsev from Google

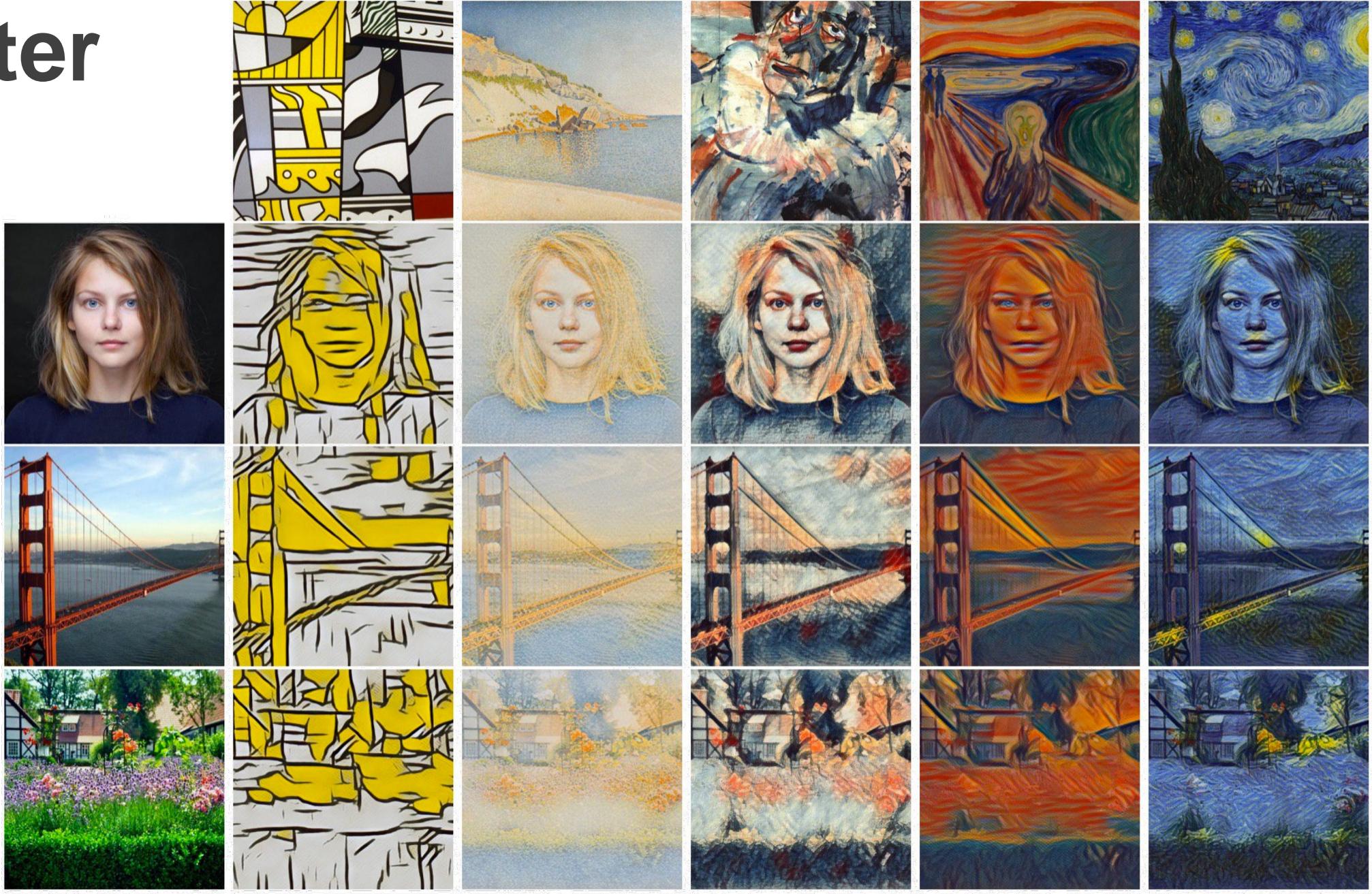
There are now websites for DIY deep art: <https://deeprart.io/>



Computer Vision

Style Transfer
([link](#))

Dumoulin et al. 2016, A learned representation for artistic style



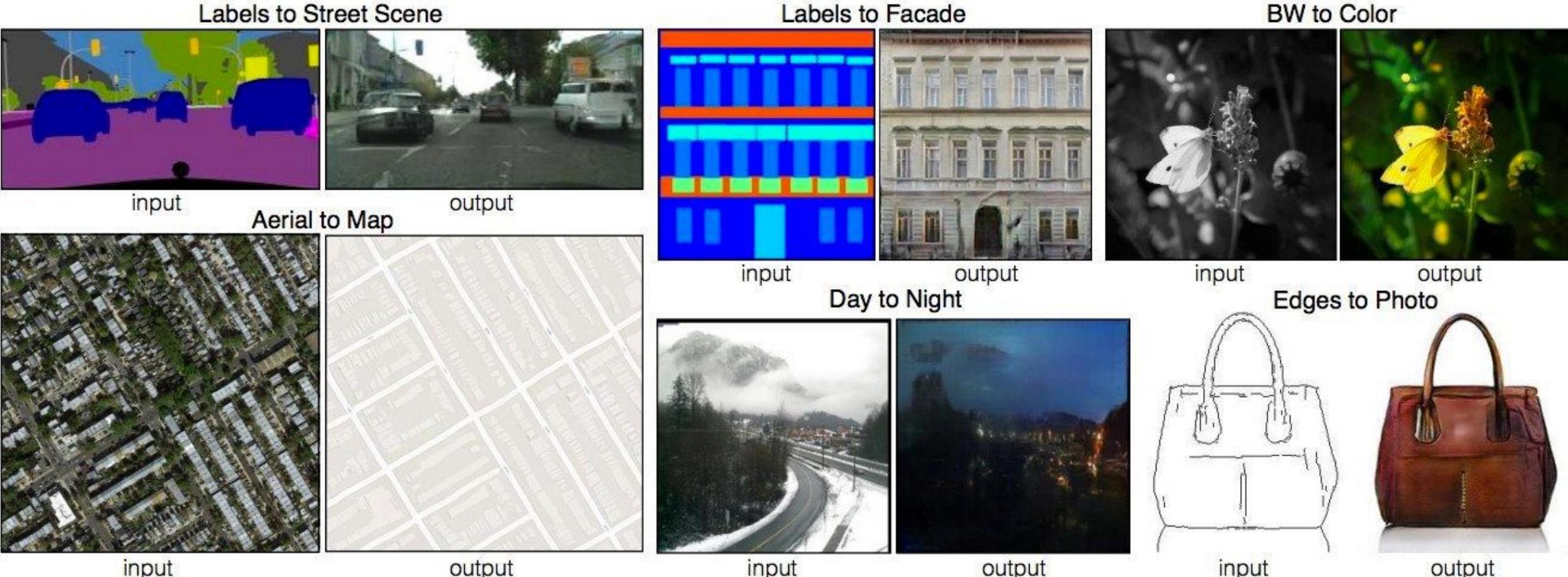
There are now websites for DIY deep art: <https://deepart.io/> and where you can purchase it, like this one:



Computer Vision

Image-to-Image Translation ([link](#))

Isola et al. 2017, Image-to-image translation with conditional adversarial networks



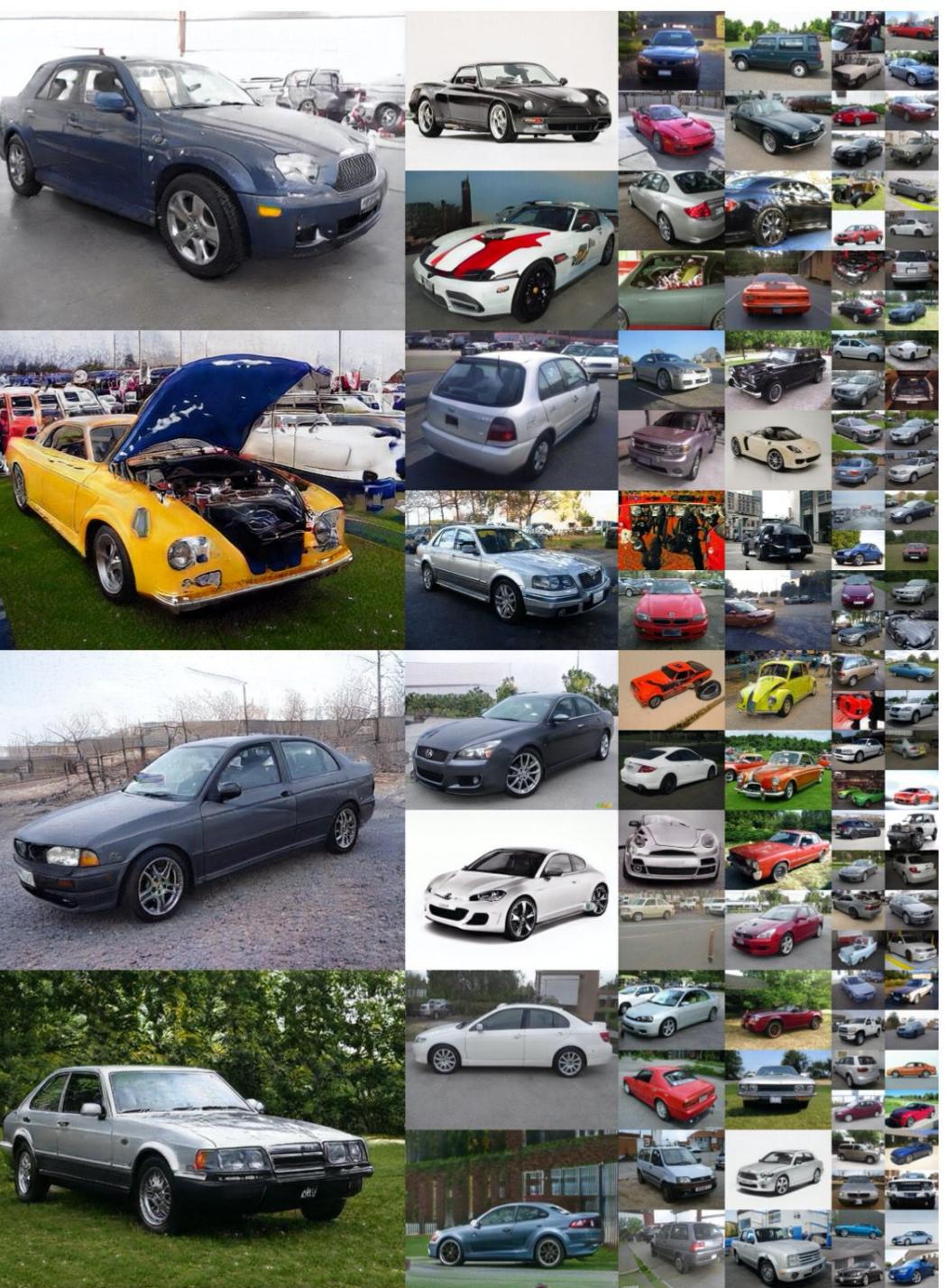
Computer Vision

StackGAN: Image Synthesis from Text Descriptions ([link](#))

Zhang et al. 2017, StackGAN: Text to Photo-realistic Image Synthesis with Stacked Generative Adversarial Networks

Text description	This flower has a lot of small purple petals in a dome-like configuration	This flower is pink, white, and yellow in color, and has petals that are striped	This flower has petals that are dark pink with white edges and pink stamen	This flower is white and yellow in color, with petals that are wavy and smooth	A picture of a very clean living room	A group of people on skis stand in the snow	Eggs fruit candy nuts and meat served on white dish	A street sign on a stoplight pole in the middle of a day
64x64 GAN-INT-CLS								
256x256 StackGAN								

Karras, T., Laine, S.
and Aila, T., 2019. A
style-based generator
architecture for
generative adversarial
networks.
In Proceedings of the
IEEE Conference on
Computer Vision and
Pattern
Recognition (pp.
4401-4410).



Synthetic
images

Face Synthesis

These images are all synthetic

Image Synthesis ([link](#))

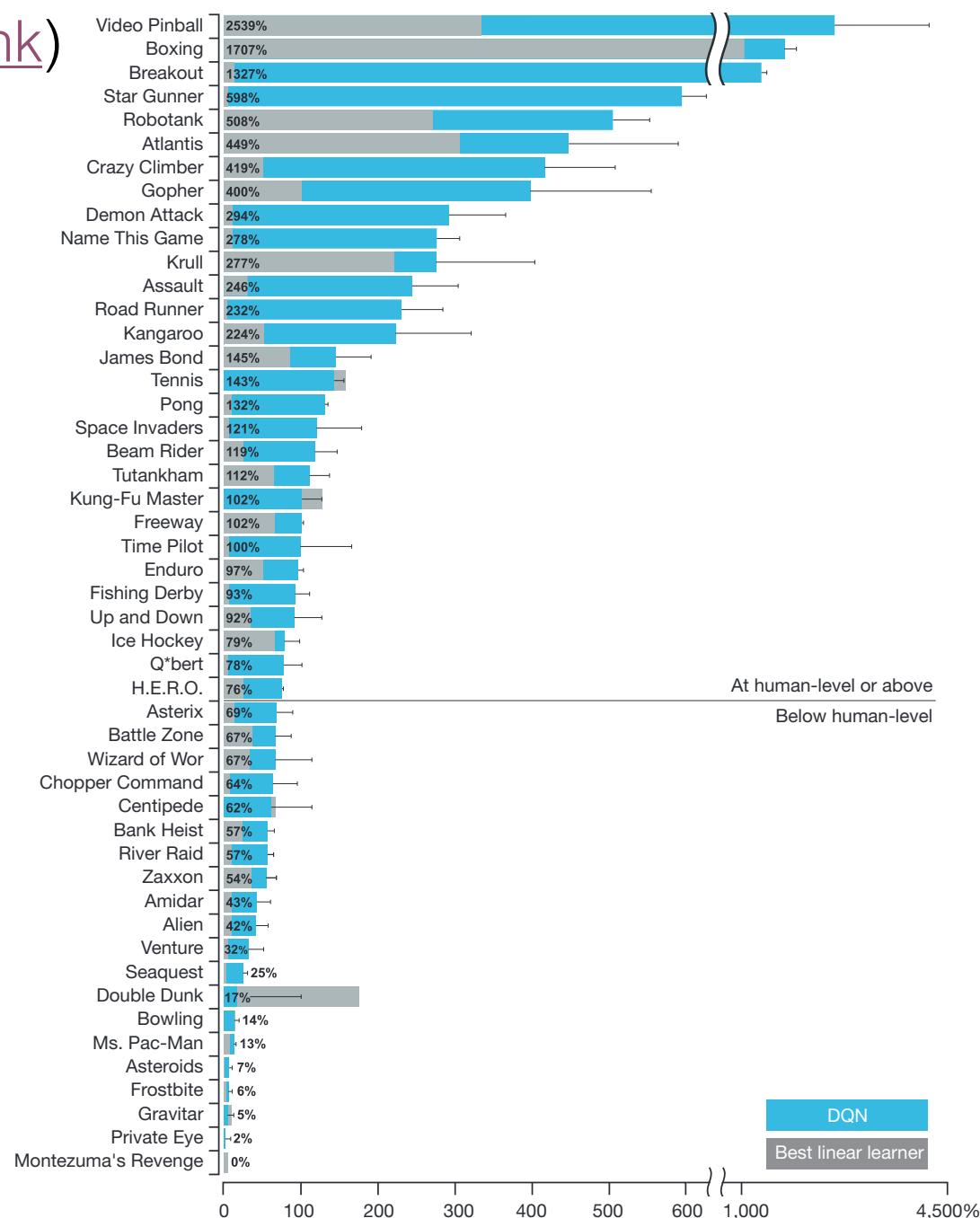
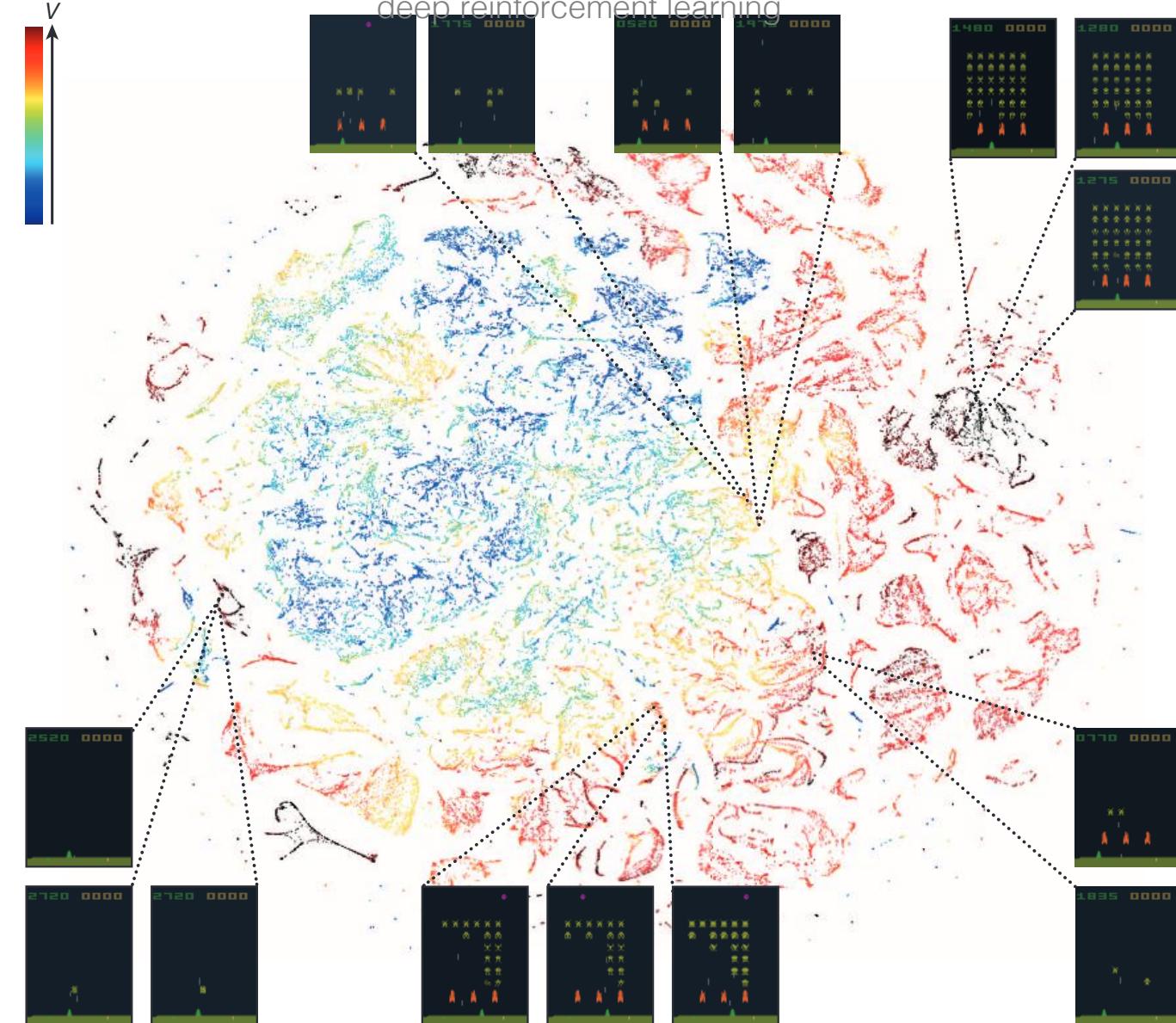
Karras et al. 2018, NVIDIA: Progressive growing of GANS for improved quality, stability, and variation



Games

Reinforcement Learning for Atari ([link](#))

Mnih et al. 2015 (DeepMind), Human-level control through deep reinforcement learning



Games & Reinforcement Learning

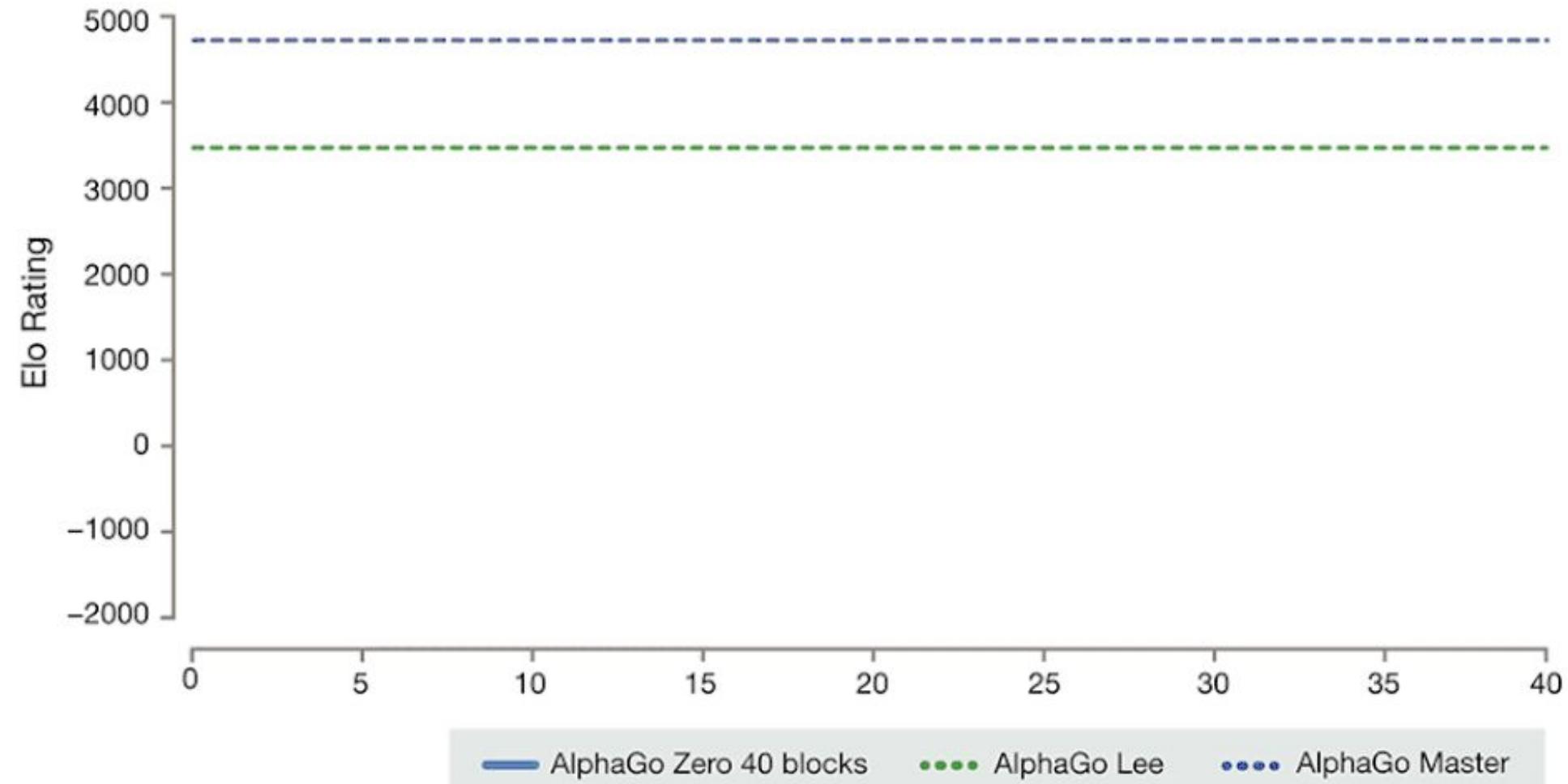
Learning Go starting from random play

Mastered in 24 hours

Did the same with Chess

AlphaZero ([link](#))

Silver et al. 2017 (DeepMind), Mastering Chess and Shogi by Self-Play with a General Reinforcement Learning Algorithm



AlphaStar: Learning to Play StarCraft II

Vinyals, O., Babuschkin, I., Czarnecki, W.M., Mathieu, M., Dudzik, A., Chung, J., Choi, D.H., Powell, R., Ewalds, T., Georgiev, P. and Oh, J., 2019. Grandmaster level in StarCraft II using multi-agent reinforcement learning. *Nature*, 575(7782), pp.350-354.

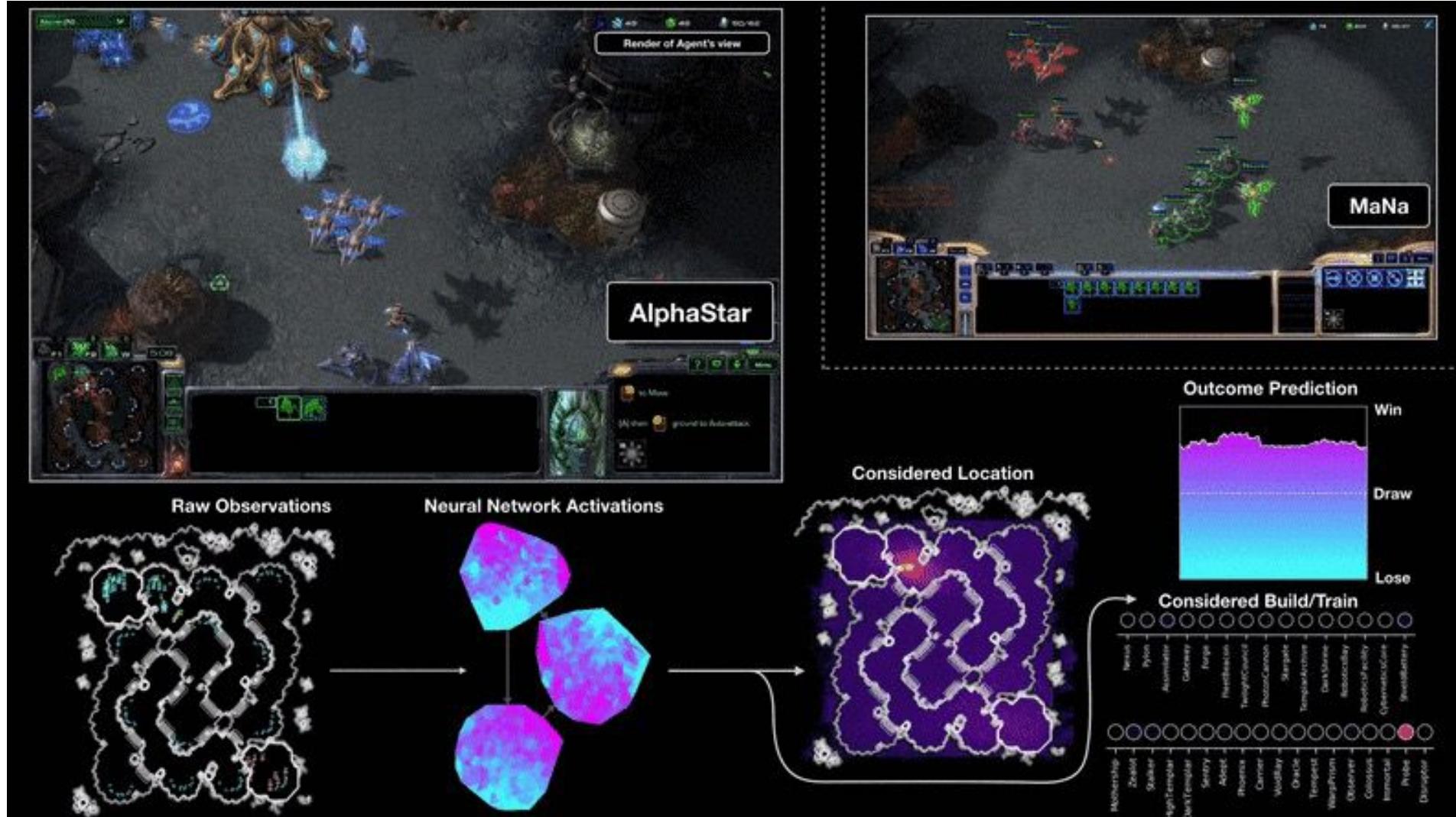


Image from
<https://deepmind.com/blog/article/alphastar-mastering-real-time-strategy-game-starcraft-ii>

AlphaStar: Learning to Play StarCraft II

Vinyals, O., Babuschkin, I., Czarnecki, W.M., Mathieu, M., Dudzik, A., Chung, J., Choi, D.H., Powell, R., Ewalds, T., Georgiev, P. and Oh, J., 2019. Grandmaster level in StarCraft II using multi-agent reinforcement learning. *Nature*, 575(7782), pp.350-354.

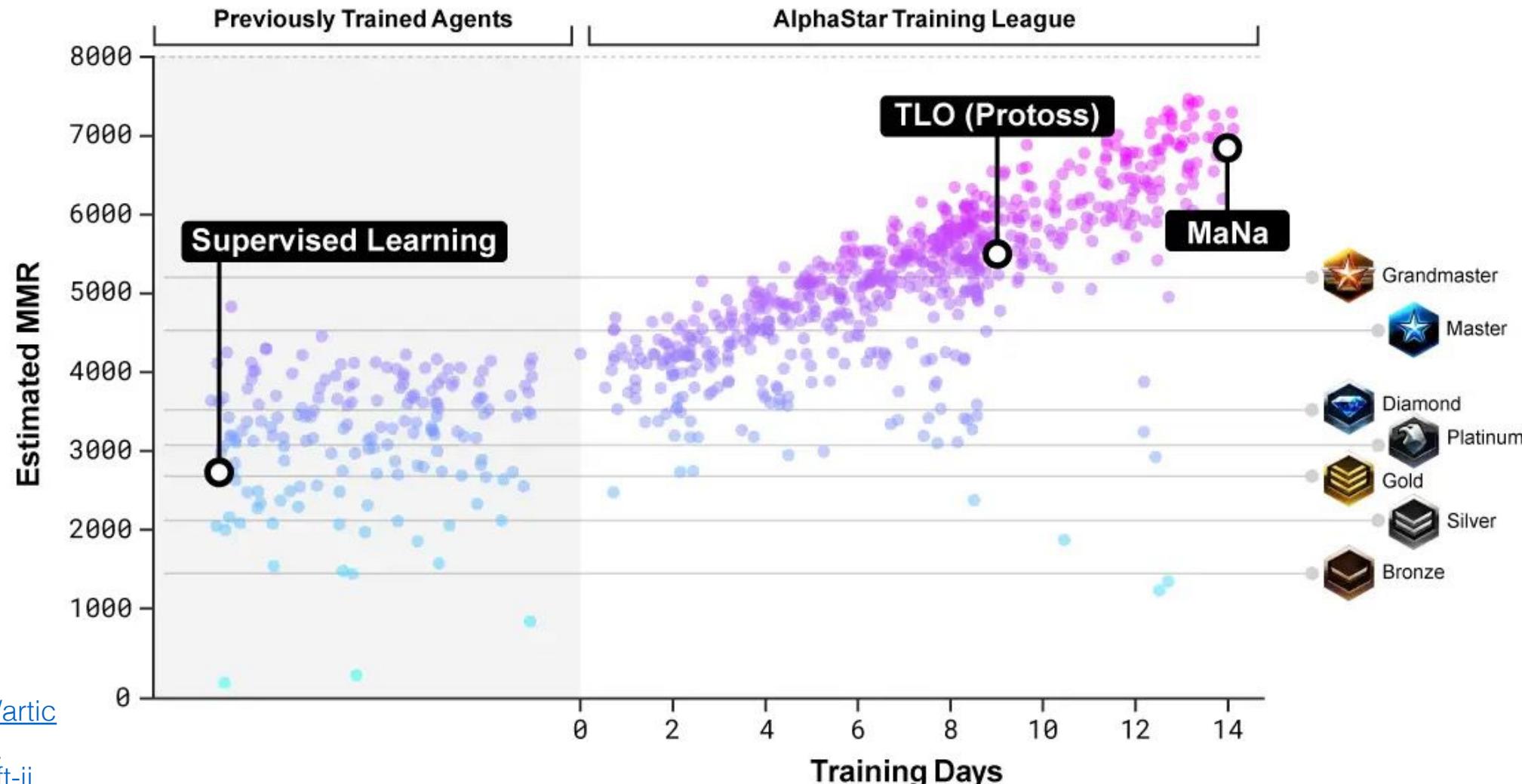


Image from
<https://deepmind.com/blog/article/alphastar-mastering-real-time-strategy-game-starcraft-ii>

Other applications

Forecasting Chaos ([link](#))

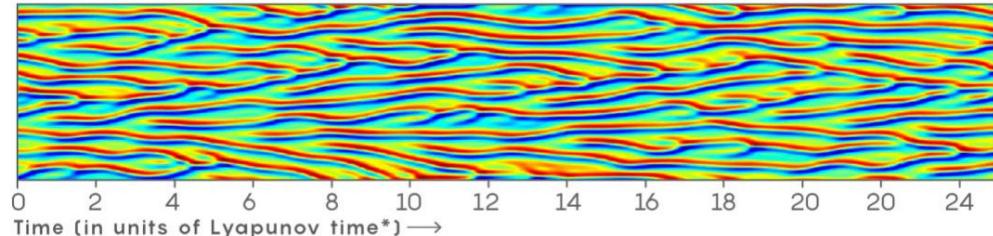
Pathak et al. 2017, Model-Free Prediction of Large Spatiotemporally Chaotic Systems from Data: A Reservoir Computing Approach

Figure (right) from Quanta Magazine ([link](#))

- Weather prediction
- Heart attack prediction
(monitoring cardiac arrhythmias)
- Monitoring neuronal firing patterns for signs of neuron spikes
- Predicting solar flares

A Chaos Model

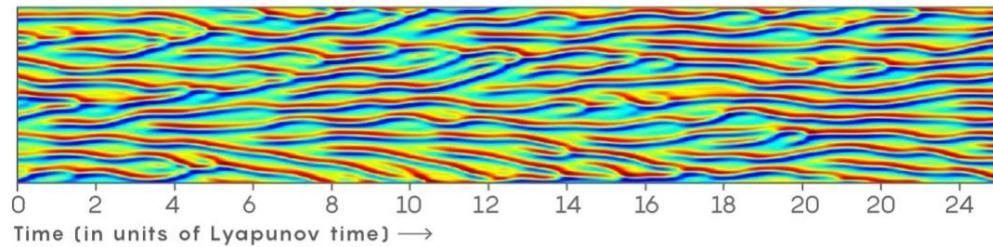
Researchers started with the evolving solution to the Kuramoto-Sivashinsky equation, which models propagating flames:



* Lyapunov time = Length of time before a small difference in the system's initial state begins to diverge exponentially. It typically sets the horizon of predictability, which varies from system to system.

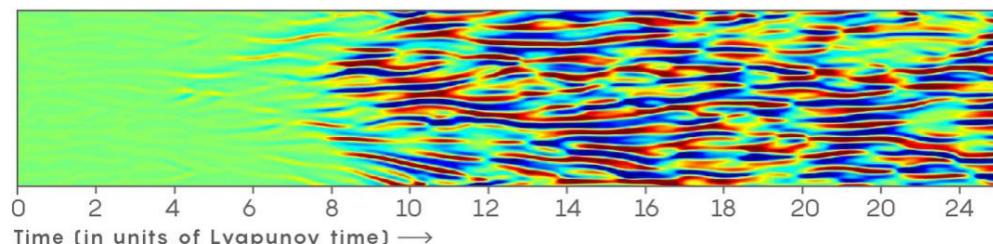
B Machine Learning

After training itself on data from the past evolution of the Kuramoto-Sivashinsky system, the "reservoir computing" algorithm predicts its future evolution:



A – B Do They Match?

Subtracting B from A shows that the algorithm accurately predicts the model out to an impressive 8 Lyapunov times, before chaos ultimately prevails:



Other applications

Self-driving cars ([link](#))

Lee et al. 2017, DESIRE: Distant Future Prediction in Dynamic Scenes with Interacting Agents

Automated medical diagnostics

Drug development & chemical synthesis

Brain-computer interfaces

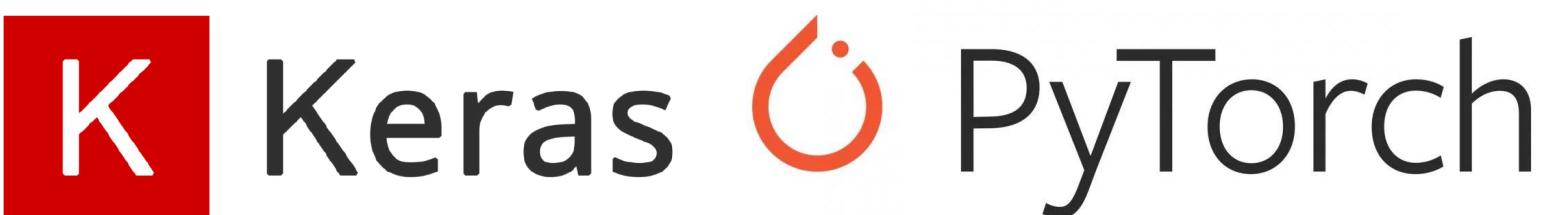
3D Shape detection and tracking

Energy demand forecasting

Open source frameworks

Keras ([link](#))

Wrapper for PyTorch and
Tensorflow making coding
easier



PyTorch ([link](#))

Framework for implementing
graphical models, such as
neural networks

OpenAI ([link](#))

OpenAi Gym is a toolkit for developing
and comparing reinforcement learning
algorithms



Where to go from here?

Courses at Duke

ECE 585: Signal Detection and Extraction Theory

ECE 586: Vector Space Methods with Applications

ECE 588: Image & Video Processing

ECE 684: Natural Language Processing

ECE 685D: Deep Learning

AIPI 531 - Reinforcement Learning

CompSci 527: Computer Vision

Math 412: Topological Data Analysis

Math 465/CompSci 445: Introduction to High Dimensional Data Analysis

Stat 601: Bayesian and Modern Statistical Methods

Stat 623: Statistical Decision Theory

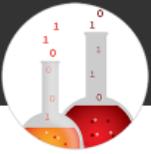
Stat 571: Advanced Probabilistic Machine Learning

ECE 590: Special Topics courses on machine learning and artificial intelligence topics

Courses on foundational concepts: Probability, Statistics, Linear Algebra, Mathematics, Programming and Software Development

Staying up-to-date

Data Elixir



ISSUE 202 Oct 2nd 2018

— In the News —

One Small Step for the Web...

Tim Berners-Lee announced a new platform that gives users complete control over their data. The platform works on the existing web but within its ecosystem, you decide where you store your data. Partly because of the people involved, this project is worth paying attention to.

inrupt.com

AI Could Provide Moment-by-Moment Nursing for a Hospital's Sickest Patients

ICUs are one of the most expensive parts of the medical system. The sickest patients often receive round-the-clock care and are typically attached to multiple machines and monitors. There's also vast amounts of data, which makes ICUs a prime target for AI disruption. In this article, the founders of Autonomous Healthcare explore the problems and opportunities.

ieee.org

— Sponsored Link —

Try Mode Studio: a complete toolkit for every analyst

Mode Studio combines a SQL editor, Python & R notebooks, and a visualization builder in one platform. And it's free forever. Connect data from anywhere and analyze with the best language for the job, without having to jump between tools. Build custom visualizations or use our out-of-the-box charts. Share your analysis with a click—every report lives at a URL.

modeanalytics.com

Data Science Roundup

Scaling Knowledge. 5 Tips for Better DS Writing. Infrastructure @ Stitch Fix. New Data o...

Scaling Knowledge. 5 Tips for Better DS Writing. Infrastructure @ Stitch Fix. New Data on DS Jobs. [DSR #152]

By Tristan Handy • Issue #152 • [View online](#)

Special thanks to Domino Data Lab for sponsoring this week's Roundup. I've actually jumped on the "Sponsored Content" bandwagon—you'll see a post from Domino below with a "Sponsored" callout in the title. We'll only accept sponsorships like this from organizations we think highly of and—of course—will always prioritize your reading experience.

Enjoy this week's issue :)

- Tristan

♥ Want to support us? Forward this email to three friends!

✉ Forwarded this from a friend? Sign up to the Data Science Roundup [here](#).

This Week's Most Useful Posts

Scaling Knowledge

Data scientists, analysts, and engineers are ultimately employed by companies for the single purpose of producing and disseminating

Kaggle Newsletter



Hey there!

This month's newsletter is sure to inspire those new to Kaggle (like me 🎉) and experts alike. See a motivational [interview with our first-ever Kernels Grandmaster](#), Martin Henze (AKA "Heads or Tails") as he shares his tips and tricks for getting to the next level. You're still getting your feet wet, start with [this video discussion with our own Meg Risdal](#), who breaks down the basic steps to beginning a project.

Speaking of videos... Did you tune in for the [43-minute livestream](#) of Siraj Raval competing in our [Taxi Duration Challenge](#)?

Read on for more of the month's data science notes, highlights and competitions. And, of course, we're hiring, too!

Have a great one,
Rachel

TALKING DATA SCIENCE

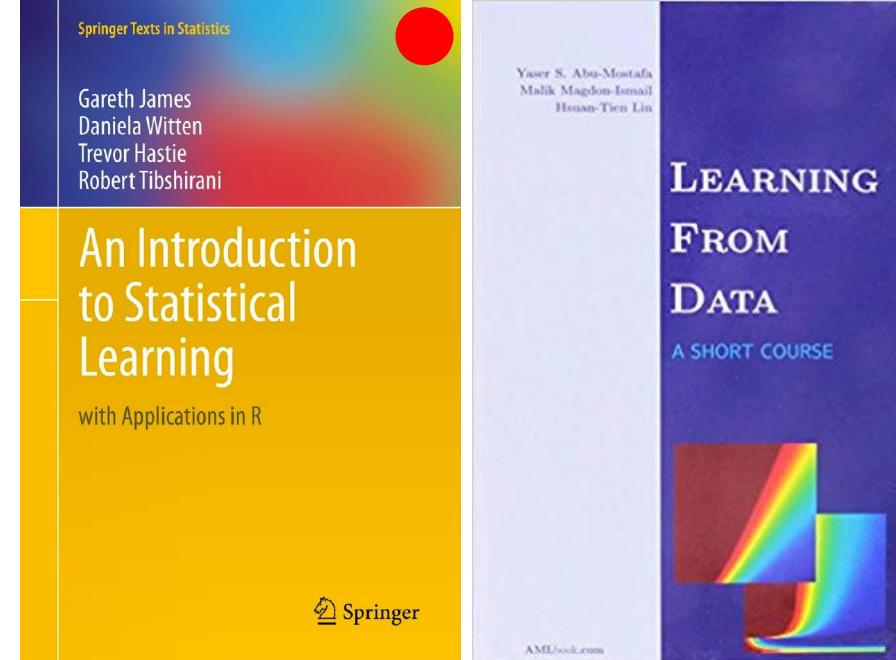


Profiling Top Kagglers: Martin Henze, World's First Kernels Grandmaster

Data Science Books

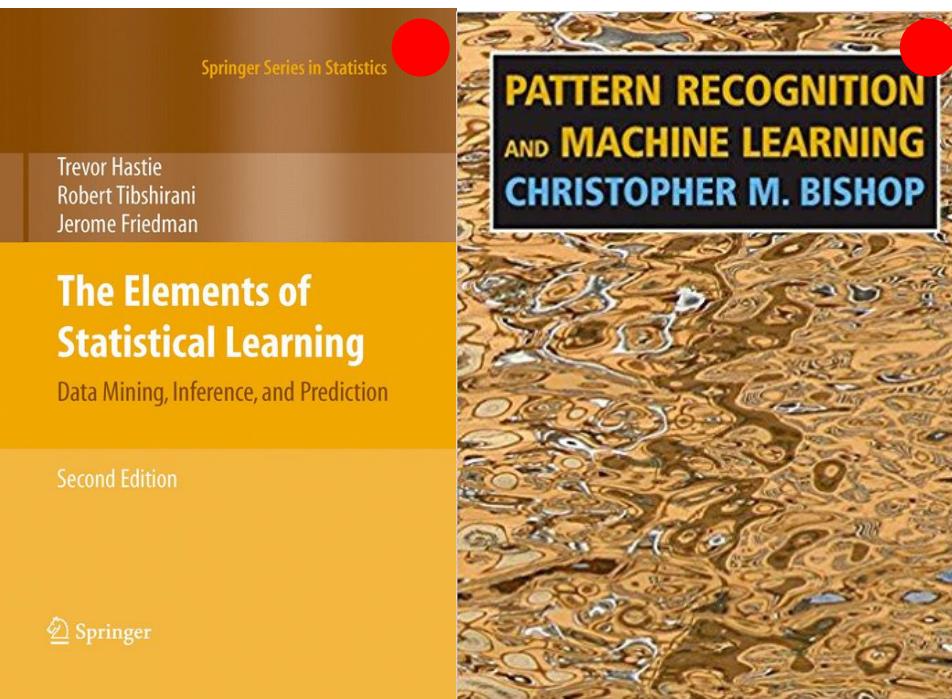
Additional Resources Available at:
<https://kylebradbury.org/datascience.html>

Introductory Texts



Free online

Advanced Texts



Applied Texts



Staying up-to-date

Blogs:

Google Research ([link](#))

Microsoft Research ([link](#))

DeepMind Research ([link](#))

Kaggle ([link](#))

Arxiv ([link](#)) (Arxiv sanity-preserved)

The screenshot shows the homepage of the Arxiv Sanity Preserver. At the top, there is a red header bar with fields for 'User' and 'Pass', a 'Login or Create' button, and a 'Fork me on GitHub' link. Below the header is a green bar with the text 'New to arxiv-sanity? Check out the [introduction video](#)'. The main area has a search bar and a navigation bar with buttons for 'most recent', 'top recent', 'top hype', 'friends', 'discussions', 'recommended', and 'library'. A button labeled 'Only show v1' is also present. A message 'Showing most recent Arxiv papers:' is displayed above a list of papers. The first paper shown is titled 'Automatic Prediction of Building Age from Photographs' by Matthias Zeppelzauer, Miroslav Despotovic, Muntaha Sakeena, David Koch, and Mario Döller. It was posted on 4/19/2018 (v1: 4/6/2018) and is categorized under cs.CV. The abstract and several thumbnail images of the paper are visible.

Conferences:

ICML: International Conference on Machine Learning ([link](#))

NeurIPS (formerly NIPS): Neural Information Processing Systems ([link](#))

ICLR: International Conference on Learning Representations ([link](#))

CVPR: IEEE Conference on Computer Vision and Pattern Recognition ([link](#))

SIGKDD: ACM International Conference on Knowledge Discovery & Data Mining ([link](#))



TWO MINUTE PAPERS

by Károly Zsolnai-Fehér

Summaries of latest
ML research

[\(link\)](#)

The image displays a grid of 24 thumbnail images from the 'TWO MINUTE PAPERS' YouTube channel, arranged in four rows of six. Each thumbnail includes a video duration indicator in the bottom right corner.

- Row 1:**
 - What's So Hard About Cloth Simulations? (3:15)
 - The Bitter Lesson - Compute Reigns Supreme (9:11)
 - Beautiful Gooey Simulations, Now 10 Times Faster (3:07)
 - NeuroSAT: An AI That Learned Solving Logic... (5:00)
 - This AI Learned to "Photoshop" Human Faces (3:12)
 - Google's PlaNet AI Learns Planning from Pixels (3:22)
- Row 2:**
 - DeepMind: The Hanabi Card Game Is the Next Frontier fo... (3:55)
 - Liquid Splash Modeling With Neural Networks (3:44)
 - GANPaint: An Extraordinary Image Editor AI (3:36)
 - This Experiment Questions Some Recent AI Results (5:09)
 - Do Neural Networks Need To Think Like Humans? (5:14)
 - Google AI's Take on How To Fix Peer Review (5:50)
- Row 3:**
 - AlphaZero: DeepMind's AI Works Smarter, not Harder (4:27)
 - AI-Based 3D Pose Estimation: Almost Real... (2:56)
 - This AI Learned Image Decolorization..and More (4:38)
 - Extracting Rotations The Right Way (3:36)
 - OpenAI - Learning Dexterous In-Hand Manipulation (5:13)
 - DeepMind's AlphaStar Beats Humans 10-0 (or 1) (13:42)
- Row 4:**
 - AI Learns Real-Time Defocus Effects in VR (4:20)
 - None of These Faces Are Real (4:37)
 - What Makes a Good Image Generator AI? (5:41)
 - This AI Produces Binaural (2.5D) Audio (3:58)
 - 6 Life Lessons I Learned From AI Research (7:37)
 - This AI Learns From Humans...and Exceeds Them (4:15)

Jeffrey Hinton
Google &
U. of Toronto



Backpropagation for
neural nets. Won
ImageNet
Competition in 2012.

Yann LeCunn
Facebook & NYU



Creator of the LeNet,
Optical Character
Recognition, and
CNNs

Fei-Fei Li
Stanford Artificial
Intelligence Lab



Creator of ImageNet,
computer vision

Andrew Ng
Baidu & Stanford

Founder of Google
Brain, co-founder of
Coursera



Image: Twitter

Andrej Karpathy
Tesla (formerly
OpenAI)

CNNs for computer
vision and natural
language processing



Image: Stanford

Yoshua Bengio
Université de
Montréal

Deep learning



Image: Université de Montréal

David Silver
DeepMind

Deep reinforcement
learning



Image: Business Insider UK

Ian Goodfellow
Google Brain

Creator of generative
adversarial networks



Image: Michael Dukakis Institute

**People to know &
read about in
Machine Learning**

Parting Thoughts

Hinton's Hints

Hinton is now “**deeply suspicious**” of backpropagation

“...‘Science progresses **one funeral at a time.**’ The future depends on some graduate student who is deeply suspicious of everything I have said.”

“...I suspect that means getting rid of back-propagation. I don't think it's how the brain works,” he said. “We clearly **don't need all the labeled data.**”

Interview with Axios ([link](#))

Parting advice

Baby steps: start small and with a simple model, add complexity as needed

Be prepared to iterate

Treat your data as a precious resource

Consider the consequences of your choices for others

No approach is perfect

Educating the **mind** without
educating the **heart** is no
education at all.

Aristotle