

TTIC 31230, Fundamentals of Deep Learning

David McAllester, Autumn 2024

A Timeline of Deep Learning

Early History

1943: McCulloch and Pitts introduced the **linear threshold “neuron”**. Words in red are important — we will discuss them in detail in this class.

1962: Rosenblatt applies a “Hebbian” learning rule. Novikoff proved the perceptron convergence theorem.

1969: Minsky and Papert publish the book *Perceptrons*.

The Perceptrons book greatly discourages work in artificial neural networks. Symbolic methods dominate AI research through the 1970s.

80s Renaissance

1980: Fukushima introduces the neocognitron — a form of convolutional neural Network or CNN. CNNs created the deep revolution in 2012.

1984: Valiant defines PAC learnability and stimulates learning theory. Wins the Turing Award in 2010.

1985: Hinton and Sejnowski introduce the Boltzman machine

1986: Rummelhart, Hinton and Williams demonstrate empirical success with backpropagation (itself dating back to 1961).

90s and 00s: Research In the Shadows

1997: Schmidhuber et al. introduce LSTMs (a form of recurrent neural network or RNN).

1998: LeCunn draws attention to convolutional neural networks (CNNs) (LeNet).

2003: Bengio introduces neural language modeling.

Current Era: 2012-13

2012: Alexnet dominates the Imagenet computer vision challenge.

Google speech recognition converts to deep learning.

Both developments come out of Hinton's group in Toronto.

2013: Refinement of AlexNet continues to dramatically improve computer vision.

2014

2014: Neural machine translation appears (Seq2Seq models).

Variational auto-encoders (VAEs) appear.

Generative Adversarial Networks (GANs) appear.

Graph neural networks appear (GNNs) revolutionizing the prediction of molecular properties.

Dramatic improvement in computer vision and speech recognition continues.

2015-16

2015: Google converts to neural machine translation leading to dramatic improvements.

Batch Normalization appears improving the performance of image classification.

Residual Connections appear. This makes yet another dramatic improvement in computer vision.

Diffusion Models are formulated which become important in 2021.

2016: Reinforcement Learning is used to develop AlphaGo which defeats Lee Sedol.

2017

2017: AlphaZero learns both go and chess at super-human levels in a matter of hours entirely from self-play and advances computer go far beyond human abilities.

Unsupervised machine translation is demonstrated.

Progressive GANs demonstrate high resolution realistic face generation.

The **Transformer** appears greatly improving language modeling.

2018

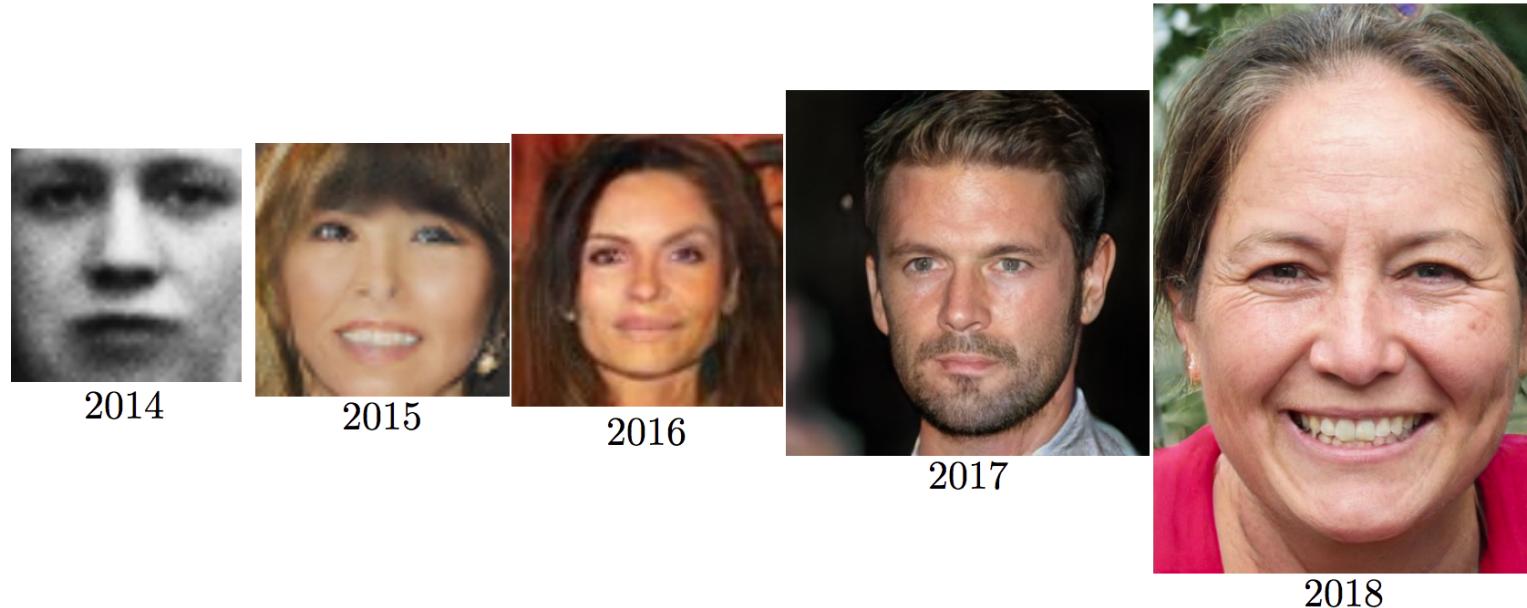
Unsupervised pre-training significantly improves a broad range of NLP tasks including question answering.

Contrastive learning is formulated which ultimately becomes the foundation of various systems.

AlphaFold revolutionizes protein structure prediction.

Progress on GANS

4.5 years of progress on faces



(Goodfellow 2019)

ArXiv 1406.2661, 1511.06434, 1607.07536, 1710.10196, 1812.04948
Goodfellow, ICLR 2019 Invited Talk

Progress on GANs



Odena et al
2016



Miyato et al
2017



Zhang et al
2018



Brock et al
2018

(Odena 2018)

BigGANs, Brock et al., 2018



Figure 1: Class-conditional samples generated by our model.

Variational Auto Encoders (VAEs, 2015)



[Alec Radford, 2015]

2019: Vector Quantized VAEs



VQ-VAE-2, Razavi et al. June, 2019

VAEs in 2019

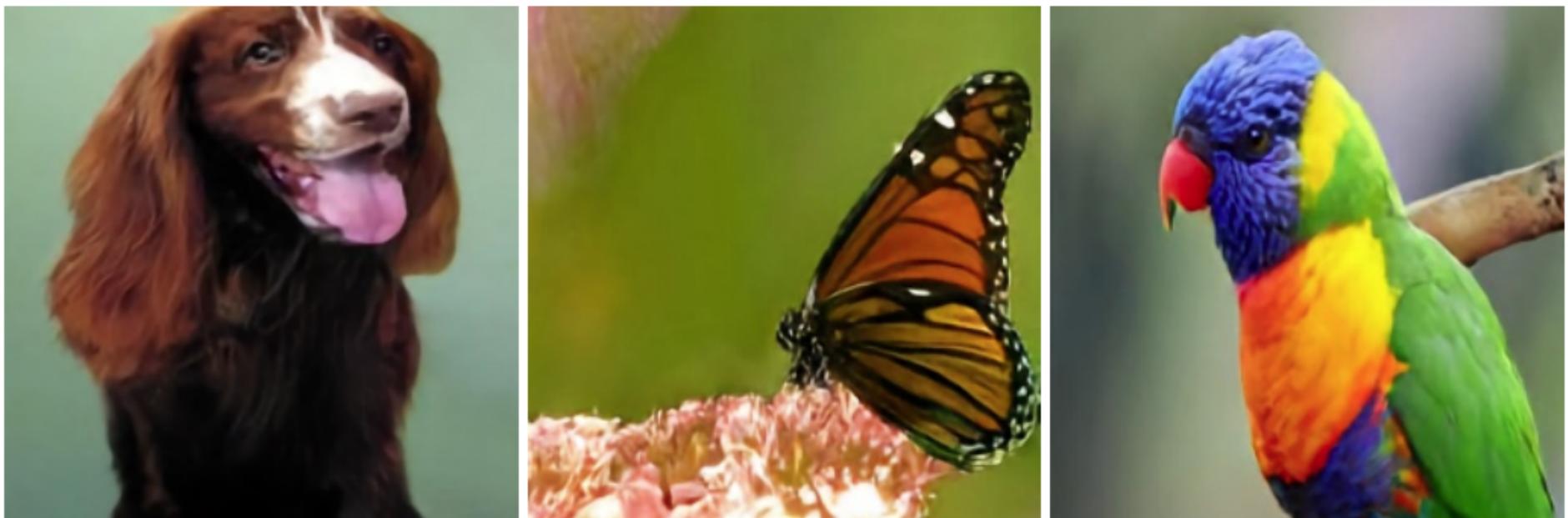


Figure 1: Class-conditional 256x256 image samples from a two-level model trained on ImageNet.

VQ-VAE-2, Razavi et al. June, 2019

2019: Natural Language Understanding

GLUE: General Language Understanding Evaluation

Rank	Name	Model	URL	Score
1	T5 Team - Google	T5		90.3
2	ERNIE Team - Baidu	ERNIE		90.1
3	Microsoft D365 AI & MSR AI & GATECH MT-DNN-SMART			89.9
4	王玮	ALICE v2 large ensemble (Alibaba DAMO NLP)		89.7
5	Microsoft D365 AI & UMD	FreeLB-RoBERTa (ensemble)		88.4
6	Junjie Yang	HIRE-RoBERTa		88.3
7	Facebook AI	RoBERTa		88.1
8	Microsoft D365 AI & MSR AI	MT-DNN-ensemble		87.6
9	GLUE Human Baselines	GLUE Human Baselines		87.1

June 2020: Wav2vec 2.0, Facebook

Trained on 53k hours of unlabeled audio (no text) they use **contrastive learning** to convert speech to a sequence of discrete **quantized vectors** they call “pseudo-text units”.

By training on only one hour of human-transcribed audio, and using the Wav2vec transcription into pseudo-text, the outperform the previous state of the art in word error rate for 100 hours of human-transcribed text.

February 2021: GLSM, Facebook

Generative Spoken Language Model (GSLM)

Using a form of VQ-VAE They then train a generative model of the sequences of pseudo-text units learned from unlabeled audio.

This model can continue speech from a speech prompt in much the same way that GPT continues text from a text prompt.

Semantic and grammatical structure in a “unit language model” is recovered from speech alone.

January 2021: CLIP, OpenAI

CLIP: Contrastive Language-Image Pre-training.

Trained on images and associated text (such as image captions or hypertext links to images) CLIP computes embeddings of text and embeddings of images (“co-embeddings”) trained to capture the mutual information between the two.

This is done with contrastive learning.

CLIP

The model computes a probability of text given the co-embedding of the image.

It is then used for zero-shot image classification on various datasets.

One can classify an image by comparing the probabilities that the model assigns to “prompts”. There is a prompt for each class.

Zero-Shot Image Classification

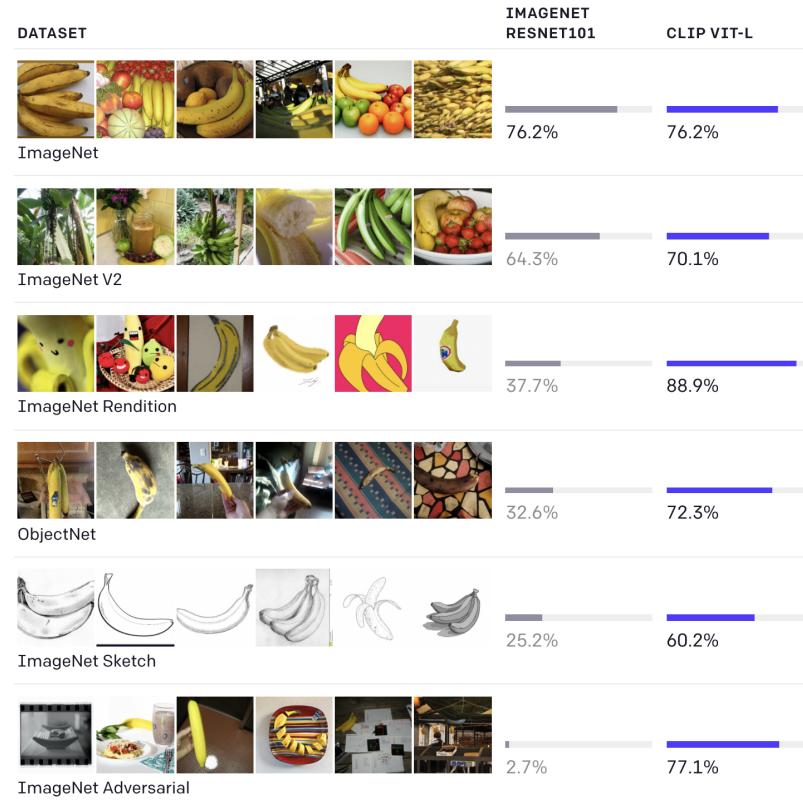
FOOD101

guacamole (90.1%) Ranked 1 out of 101 labels



- ✓ a photo of **guacamole**, a type of food.
- ✗ a photo of **ceviche**, a type of food.
- ✗ a photo of **edamame**, a type of food.
- ✗ a photo of **tuna tartare**, a type of food.
- ✗ a photo of **hummus**, a type of food.

Zero-Shot Image Classification



Although both models have the same accuracy on the ImageNet test set, CLIP's performance is much more representative of how it will fare on datasets that measure accuracy in different, non-ImageNet settings. For instance, ObjectNet checks a model's ability to recognize objects in many different poses and with many different backgrounds inside homes while ImageNet Rendition and ImageNet Sketch check a model's ability to recognize more abstract depictions of objects.

January 2021: DALL·E, OpenAI

April 2021: DALL·E-2

The name DALL·E is simply some kind of homage to the painter Dali and the Disney character WALL·E.

Both versions of DALL·E uses CLIP's co-embeddings of images and text.

Given text, DALL·E generates an image using a **diffusion model**.

DALL·E-1 Zero-Shot Image Rendering from Language

TEXT PROMPT an illustration of a baby daikon radish in a tutu walking a dog

AI-GENERATED
IMAGES



[Edit prompt or view more images↓](#)

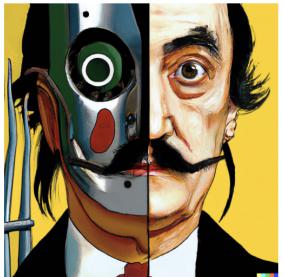
TEXT PROMPT an armchair in the shape of an avocado....

AI-GENERATED
IMAGES



[Edit prompt or view more images↓](#)

DALL·E-2



vibrant portrait painting of Salvador Dalí with a robotic half face



a shiba inu wearing a beret and black turtleneck



a close up of a handpalm with leaves growing from it



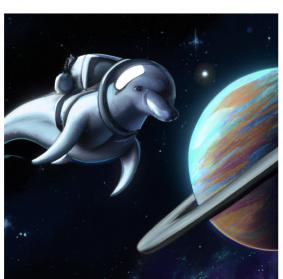
an espresso machine that makes coffee from human souls, artstation



panda mad scientist mixing sparkling chemicals, artstation



a corgi's head depicted as an explosion of a nebula



a dolphin in an astronaut suit on saturn, artstation



a propaganda poster depicting a cat dressed as french emperor napoleon holding a piece of cheese



a teddy bear on a skateboard in times square

July 2021: Codex, OpenAI

Using an unsupervised pretrained language model they fine-tune on code, including comments, from public repositories.

Starting from an English prompt Codex continues with code — a form of automatic programming.

There is a published version (58 authors) and a production version that powers **GitHub Copilot**.

Copilot may supplant Stack Overflow for finding out how to do x in language y.

January 2022: Chain of Thought Prompting

Give examples of “chains of thought” for few shot learning of reasoning steps.

Naive Prompting

Standard Prompting

Input

Q: Roger has 5 tennis balls. He buys 2 more cans of tennis balls. Each can has 3 tennis balls. How many tennis balls does he have now?

A: The answer is 11.

Q: The cafeteria had 23 apples. If they used 20 to make lunch and bought 6 more, how many apples do they have?

Model Output

A: The answer is 27. 

Chain of Thought Prompting

Chain of Thought Prompting

Input

Q: Roger has 5 tennis balls. He buys 2 more cans of tennis balls. Each can has 3 tennis balls. How many tennis balls does he have now?

A: Roger started with 5 balls. 2 cans of 3 tennis balls each is 6 tennis balls. $5 + 6 = 11$. The answer is 11.

Q: The cafeteria had 23 apples. If they used 20 to make lunch and bought 6 more, how many apples do they have?

Model Output

A: The cafeteria had 23 apples originally. They used 20 to make lunch. So they had $23 - 20 = 3$. They bought 6 more apples, so they have $3 + 6 = 9$. The answer is 9. ✓

June 2022: Step by Step Prompting

It turns out that adding the simple instruction “take it step by step” elicits powerful chain of thought reasoning in GPT-3.

September 2022: Humanoid Soccer, Deep Mind

Deep mind demonstrated two-on-two humanoid soccer in simulation (MuJoCo).

This a startling advance in the state of the art in humanoid control.

It also continues Deep Mind's effort in reinforcement learning.

March 2023: GPT-4 is Unveiled

Dramatic improvement in conversational abilities and apparent understanding of common sense language meaning.

Training involves “instruction training” and “reinforcement learning with human feedback” (RLHF).

Most technical details are proprietary.

GPT-4 shows both a tendency to “hallucinate”, presenting fiction as fact, and people find ways to “jailbreak” GPT4 into alternate and even malevolent personalities

Concerns over AI safety grows. Not everyone is concerned.

September 2023

DALL·E-3 was introduced.

Significant advances in speech recognition and speech generation continue.

May 2024

GPT-4o is introduced. This provides better support for multi-modal data such as images and sounds intermixed with text.

July 2024

DeepMind announces that its theorem proving system achieved a silver medal in the IMO competition.

This is an annual mathematics competition for high school students.

September 2024

Open AI introduces o1. This model uses extreme chain of thought reasoning with greatly improved problem solving and reasoning ability but at the cost of being very slow and very energy intensive.

Summer and Fall 2024

It seems that Tesla is making rapid progress in self driving.

Tesla's may be operating as robotaxis this fall.

An Open Problem Slide from the 2023 class

The MathZero Problem: Since the development of AlphaZero people have been asking if the same thing could be done for the “game” of mathematics.

Update: AlphaProof is a significant advance on this problem. OpenAI o1 also has surprising mathematical reasoning capabilities.

An Open Problem Slide from the 2023 class

The Autoformalization Problem: This is the problem of automatically formalizing and verifying published proofs in mathematics possibly discovering legitimate gaps in the proofs where they exist.

Update: AlphaProof appears to do a fair amount of auto-formalization.

An Open Problem Slide from the 2023 class

The Proof Assistant Problem: This is the more modest goal of improving the level of automation in formal verification systems. The system most widely adopted by the mathematics community is LEAN based on dependent type theory.

Update: Recent developments would indicate that great progress on proof-assistants are on the horizon.

Application Advancements vs. Architecture Advancements

Advancements in the general principles of learning are having applications over very diverse applications.

When considering Moore's law of AI it seems worth distinguishing architectural advancements (new general learning methods) from new applications of established architectures or fine tuning of known methods.

This course will focus on general, architectural, ideas.

Architectural Ideas

- Linear Threshold “neuron”
- Convolutional Neural Network or CNN
- Backpropagation
- Recurrent Neural Network or RNN
- Neural Language Modeling
- Variational Auto-Encoders (VAEs)
- Generative Adversarial Networks (GANs)
- Graph Neural Networks
- Normalization Layers
- Residual Connections
- Diffusion Models

- Reinforcement Learning
- The Transformer
- Unsupervised Pretraining
- Vector Quantization
- Contrastive Learning
- Prompting
- Backtracking Chain of Thought

The latest on Retrieval



OpenAI ✨
@OpenAI

...

ChatGPT can now browse the internet to provide you with current and authoritative information, complete with direct links to sources. It is no longer limited to data before September 2021.

RB What are the latest reviews for a commuter bike?

RB Finished browsing

The Schwinn Discover, labeled as the best cheap commuter bike, is lauded for its broad functionality at an entry-level price. It features a 21-speed SRAM drivetrain, aluminum frame, and comfort-style design ensuring a smooth ride even on bumpy roads. The bike is equipped with essential commuter accessories like fenders and a rear rack, making it a popular choice among Amazon buyers¹.

For more detailed reviews, you can follow [this link](#).

ChaptGPT as Therapist



Ilya Sutskever

@ilyasut

...

In the future, once the robustness of our models will exceed some threshold, we will have *wildly effective* and dirt cheap AI therapy. Will lead to a radical improvement in people's experience of life. One of the applications I'm most eagerly awaiting.



Lilian Weng @lilianweng · Sep 26

Just had a quite emotional, personal conversation w/ ChatGPT in voice mode, talking about stress, work-life balance. Interestingly I felt heard & warm. Never tried therapy before but this is probably it? Try it especially if you usually just use it as a productivity tool. [twitter.com/sama/status/17...](https://twitter.com/sama/status/17)

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