The XLNet was an autoregressive Transformer designed as an improvement over BERT , with 340M parameters and trained on 33 billion words. It was released on 19 June 2019, under the Apache 2.0 license. [1] It achieved state-of-the-art results on a variety of natural language processing tasks, including language modeling, question answering, and natural language inference.

Architecture

The main idea of XLNet is to model language autoregressively like the GPT models , but allow for all possible permutations of a sentence. [2] Concretely, consider the following sentence:

My dog is cute.

In standard autoregressive language modeling, the model would be tasked with predicting the probability of each word, conditioned on the previous words as its context:

We factorize the joint probability of a sequence of words x 1 , … , x T $\displaystyle x_{1},\ldots ,x_{T}$ using the chain rule: Pr (x 1 , … , x T) = Pr (x 1) Pr (x 2 | x 1) Pr (x 3 | x 1 , x 2) … Pr (x T | x 1 , … , x T − 1) . $\displaystyle \Pr(x_{1},\ldots ,x_{T})=\Pr(x_{1})\Pr(x_{2}|x_{1})\Pr(x_{3}|x_{1},x_{2})\ldots \Pr(x_{T}|x_{1},\ldots ,x_{T-1}).$

For example, the sentence "My dog is cute" is factorized as:

Pr (My , dog , is , cute) = Pr (My) Pr (dog | My) Pr (is | My , dog) Pr (cute | My , dog , is) . $\displaystyle \Pr({\text{My}},{\text{dog}},{\text{is}},{\text{cute}})=\Pr({\text{My}})\Pr({\text{dog}}|{\text{My}})\Pr({\text{is}}|{\text{My}},{\text{dog}})\Pr({\text{cute}}|{\text{My}},{\text{dog}},{\text{is}}).$

Schematically, we can write it as

→ My → My dog → My dog is → My dog is cute . $\displaystyle {\texttt {}}{\texttt {}}{\texttt {}}{\texttt {}}\to {\text{My }}{\texttt {}}{\texttt {}}{\texttt {}}\to {\text{My dog }}{\texttt {}}{\texttt {}}\to {\text{My dog is }}{\texttt {}}\to {\text{My dog is cute}}.$

However, for XLNet, the model is required to predict the words in a randomly generated order. Suppose we have sampled a randomly generated order 3241, then schematically, the model is required to perform the following prediction task:

→ is → dog is → dog is cute → My dog is cute $\displaystyle {\texttt {}}{\texttt {}}{\texttt {}}{\texttt {}}\to {\texttt {}}{\texttt {}}{\text{is }}{\texttt {}}\to {\texttt {}}{\text{dog is }}{\texttt {}}\to {\texttt {}}{\text{dog is cute}}\to {\text{My dog is cute}}$

By considering all permutations, XLNet is able to capture longer-range dependencies and better model the bidirectional context of words.

Two-Stream Self-Attention

To implement permutation language modeling, XLNet uses a two-stream self-attention mechanism. The two streams are:

Content stream: This stream encodes the content of each word, as in standard causally masked self-attention.

Query stream: This stream encodes the content of each word in the context of what has gone before. In more detail, it is a masked cross-attention mechanism , where the queries are from the

query stream, and the key-value pairs are from the content stream.

The content stream uses the causal mask $M_{\text{causal}} = \begin{bmatrix} 0 & -\infty & -\infty & \dots & -\infty \\ 0 & 0 & -\infty & \dots & -\infty \\ 0 & 0 & 0 & \dots & -\infty \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \dots & 0 \end{bmatrix}$ ${\displaystyle M_{\text{causal}}={\begin{bmatrix}0&-\infty &-\infty &\dots &-\infty \\0&0&-\infty &\dots &-\infty \\0&0&0&\dots &-\infty \\\vdots &\vdots &\vdots &\ddots &\vdots \\0&0&0&\dots &0\end{bmatrix}}}$ permuted by a random permutation matrix to $PM_{\text{causal}}P^{-1}$ ${\displaystyle PM_{\text{causal}}P^{-1}}$.

The query stream uses the cross-attention mask $P(M_{\text{causal}}-\infty I)P^{-1}$ ${\displaystyle P(M_{\text{causal}}-\infty I)P^{-1}}$, where the diagonal is subtracted away specifically to avoid the model "cheating" by looking at the content stream for what the current masked token is.

Like the causal masking for GPT models, this two-stream masked architecture allows the model to train on all tokens in one forward pass.

Training

Two models were released: [1] [2]

XLNet-Large, cased: 110M parameters, 24-layer, 1024-hidden, 16-heads

XLNet-Base, cased: 340M parameters, 12-layer, 768-hidden, 12-heads.

It was trained on a dataset that amounted to 32.89 billion tokens after tokenization with SentencePiece. The dataset was composed of BooksCorpus , and English Wikipedia, Giga5, ClueWeb 2012-B, and Common Crawl .

It was trained on 512 TPU v3 chips, for 5.5 days. At the end of training, it still under-fitted the data, meaning it could have achieved lower loss with more training. It took 0.5 million steps with an Adam optimizer , linear learning rate decay, and a batch size of 8192. [3]

See also

BERT (language model)

Transformer (machine learning model)

Generative pre-trained transformer

References

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t

e

Google

Google Brain

Google DeepMind

AlphaGo (2015)

Master (2016)

AlphaGo Zero (2017)

AlphaZero (2017)

MuZero (2019)

Fan Hui (2015)

Lee Sedol (2016)

Ke Jie (2017)

AlphaGo (2017)

The MANIAC (2023)

AlphaFold (2018)

AlphaStar (2019)

AlphaDev (2023)

AlphaGeometry (2024)

AlphaGenome (2025)

Inception (2014)

WaveNet (2016)

MobileNet (2017)

Transformer (2017)

EfficientNet (2019)

Gato (2022)

Quantum Artificial Intelligence Lab

TensorFlow

Tensor Processing Unit

Assistant (2016)

Sparrow (2022)

Gemini (2023)

BERT (2018)

XLNet (2019)

T5 (2019)

LaMDA (2021)

Chinchilla (2022)

PaLM (2022)

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Gemma (2024)

Veo (2024)

DreamBooth (2022)

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Vids (2024)

Gemini Robotics (2025)

" Attention Is All You Need "

Future of Go Summit

Generative pre-trained transformer

Google Labs

Google Pixel

Google Workspace

Robot Constitution

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Quest Visual

Reqwireless

RightsFlow

Sidewalk Labs

SlickLogin

Titan Aerospace

Typhoon Studios

Urban Engines

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YouTube Next Lab and Audience Development Group

Business Groups

Computing University Initiative

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CrossCheck

Data Liberation Front

Data Transfer Project

Developer Expert

DigiKavach

DigiPivot

Digital Garage

Digital News Initiative

Digital Unlocked

Dragonfly

Founders' Award

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Get Your Business Online

Google for Education

Google for Startups

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Quantum Artificial Intelligence Lab

RechargeIT

Sensorvault

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YouTube Creator Awards

YouTube Select

YouTube Original Channel Initiative

Year in Search

YouTube Rewind 2018 2019

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2019

AlphaGo versus Fan Hui

AlphaGo versus Lee Sedol

AlphaGo versus Ke Jie

Android Developer Challenge

Android Developer Day

Android Developer Lab

CNN/YouTube presidential debates

Code-in

Code Jam

Developer Day

Developers Live

Doodle4Google

Future of Go Summit

G-Day

Hash Code

I/O

Lunar X Prize

Mapathon

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Summer of Code

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YouTube Space

YouTube Theater

Krishna Bharat

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Jeff Dean

John Doerr

Sanjay Ghemawat

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Larry Page (co-founder)

Patrick Pichette

Eric Schmidt

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Shirley M. Tilghman

Rachel Whetstone

Susan Wojcicki

Censorship

DeGoogle

FairSearch

" Google's Ideological Echo Chamber "

No Tech for Apartheid

Privacy concerns Street View YouTube

Street View

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Trade unions Alphabet Workers Union

Alphabet Workers Union

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Keyhole Markup Language

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Programmable Search Engine

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RenderScript

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SageTV

Schema.org

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Translator Toolkit

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Web Accelerator

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.app

.dev

.google

.zip

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BeatThatQuote.com

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e

Feldman v. Google, Inc. (2007)

Rescuecom Corp. v. Google Inc. (2009)

Goddard v. Google, Inc. (2009)

Rosetta Stone Ltd. v. Google, Inc. (2012)

Google, Inc. v. American Blind & Wallpaper Factory, Inc. (2017)

Jedi Blue

European Union (2010–present)

United States v. Adobe Systems, Inc., Apple Inc., Google Inc., Intel Corporation, Intuit, Inc., and Pixar (2011)

Umar Javeed, Sukarma Thapar, Aaqib Javeed vs. Google LLC and Ors. (2019)

United States v. Google LLC (2020)

United States v. Google LLC (2023)

Perfect 10, Inc. v. Amazon.com, Inc. (2007)

Viacom International, Inc. v. YouTube, Inc. (2010)

Lenz v. Universal Music Corp. (2015)

Authors Guild, Inc. v. Google, Inc. (2015)

Field v. Google, Inc. (2016)

Google LLC v. Oracle America, Inc. (2021)

Smartphone patent wars

Rocky Mountain Bank v. Google, Inc. (2009)

Hibnick v. Google, Inc. (2010)

United States v. Google Inc. (2012)

Judgement of the German Federal Court of Justice on Google's autocomplete function (2013)

Joffe v. Google, Inc. (2013)

Mosley v SARL Google (2013)

Google Spain v AEPD and Mario Costeja González (2014)

Frank v. Gaos (2019)

Garcia v. Google, Inc. (2015)

Google LLC v Defteros (2020)

Epic Games v. Google (2021)

Gonzalez v. Google LLC (2022)

Beauty YouTuber

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Google and the World Brain

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The Google Story

Googled: The End of the World as We Know It

How Google Works

I'm Feeling Lucky

In the Plex

The MANIAC

Google Feud

Google Me (film)

" Google Me " (Kim Zolciak song)

" Google Me " (Teyana Taylor song)

Is Google Making Us Stupid?

Proceratium google

Matt Nathanson: Live at Google

The Billion Dollar Code

The Internship

Where on Google Earth is Carmen Sandiego?

" Attention Is All You Need "

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SpiNNaker

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Theano

JAX

Flux.jl

MindSpore

Portals Computer programming Technology

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Technology