

The Importance Of Forgetting For Both Humans And Machines

GOTO Copenhagen 2022

Robert Crowe
Google

Remember. Learn.

- Recognize patterns
- Generalize to broad concepts

Why forget?

- Failure to remember?
- Why not remember everything?

Even simple animals forget

- Fruit flies
- C. elegans

Do we need to make room?

Estimates vary

- 1B? 80-90B neurons?
- Over 1B memories?

People can remember more

- Hyperthymesia
 - "non-stop, uncontrollable and totally exhausting ... It makes me crazy ... it's a burden." Jill Price
- John von Neumann
 - Every word of every book
- Memory competitions
- Why have we evolved to forget?

People forget different things differently

- Breakfast yesterday?
- Childhood friends?
- Sensory input?
- My shoes?

Hippocampus

Episodic memories

Neocortex

- General knowledge transferred from hippocampus during sleep
- Spatial reasoning
- Language
- Sensory perception
- Motor commands

Amygdala

- Emotional significance
- Fear, shame, love, grief

Prefrontal Cortex

Short-term or working memory

Different types of memory

Different policies for forgetting

- Amygdala
- Hippocampus
- Neocortex

Semantic

Episodic

Emotional

Short-term

Sensory

Knowledge

It's a feature, not a bug

Why evolve to forget?

- Neuroscience consensus
- Improved adaptation

Opinion

Decay happens: the role of acti forgetting in memory

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Although the biological bases of forgetting remain obscure, the consensus among cognitive psychologists emphasizes interference processes, rejecting decay in accounting for memory loss. In contrast to this view, recent advances in understanding the neurobiology of long-term memory maintenance lead us to propose that a brain-wide well-regulated decay process, occurring mostly during sleep, systematically removes selected memories. Down-regulation of this decay process can increase the life expectancy of a memory and may eventually prevent its loss. Memory interference usually occurs during certain active processing phases, such as encoding and retrieval, and will be stronger in brain as with minimal sensory integration and less pattern separation. In areas with efficient pattern separation, such as the hippocampus, interference-driven forgetting will be minimal, and, consequently, decay will cause most forgetting.

Current thinking on forgetting

Forgetting of established long-term memory (see Glossary) may indicate that memory is either physically unavailable (that is, memory is lost) or that it is (temporarily) inaccessible. With some exceptions, theories proposed within the domains of experimental and cognitive psychology often emphasize one type of forgetting over the other [1]. Two explanations for actual, non-pathological memory loss have been proposed, one involving decay of aspects of the memory trace, the other involving interference with it.

suggests that it could also affect [7]. Because retrieval of consolid plasticity in the relevant traces, new material can then affect the solidation, of the reactivated mer happen after initial learning [8]. T dental incorporation of new mater

Active forgetting: the idea that, instead of pas are actively removed, on the basis of, for exar AMPA receptor: an ionotropic glutamate Catastrophic interference: neural networks their connections. Because neural networks ha connections, networks eventually reach satura activity pattern will disrupt existing mem-Consolidation: cellular (or synaptic) consoli

stabilize the learning-induced changes in syna the biological substrate of memory. Disru completion causes partial or full memory los to a reorganization process of the brain s Decay: forgetting due to a gradual loss of the of disuse. Thorndike posited that, unless required akin to a muscle that will atrophy if it is not exe assumed that decay is a passive process. Episodic memory: memory for what, when, a whether this form of event memory is unique

Explicit memory: unlike implicit memory, exp

Unstable Memories Create a High-Level Representation that Enables Learning Tran

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SUMMARY

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A memory is unstable, making it susceptible to interference and disruption, after its acquisition [1-4]. The function or possible benefit of a memory being unstable at its acquisition is not well understood. Potentially, instability may be critical for the communication between recently acquired memories, which would allow learning in one task to be transferred to the other subsequent task [1, 5]. Learning may be transferred between any memories that are unstable, even between different types of memory. Here, we By assigning semantic categories to test the link between a memory being unstable and (1 to 4) we generated a word list with the the transfer of learning to a different type of memory as a motor sequence. task. We measured how learning in one task transferred to and thus improved learning in a subsequent Transfer between the Different N task. There was transfer from a motor skill to a word list task and, vice versa, from a word list to a motor skill task. What was transferred was a high-level relationship between elements, rather than knowledge of the individual elements themselves. Memory instability was correlated with subsequent transfer, suggesting that transfer was related to the instability of the memory. Using different methods, we stabilized and motor sequence shared a com the initial memory, preventing it from being suscepti- they had different structures (motor s ble to interference, and found that these methods 17 ms versus 73 ± 12 ms, mean :

Supplemental Experimental Proced

signing each of the positions within the nated 1 to 4) to one of the four sema list. For example, a specific vegetable 1 within the motor sequence so that placed by turnip, whereas the secon spinach. Different semantic catego each of the other three positions, an placed by a unique word from that c

We first tested for the transfer of lea motor skill task (Figure 1A). As train three practice blocks, the improveme icantly greater when the earlier word sequence shared a common structure and S2). By the final block, participa of the sequence was substantially of

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PLOS BIOLOGY

had either the same or different high

Citation: Robertson EM (2018) Memory instability as a gateway to generalization. PLoS Biol 16(3): e2004633. https://doi.org/10.1371/journal. pbio.2004633 Published: March 19, 2018 Copyright: © 2018 Edwin M. Robertson. This is an open access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and

> reproduction in any medium, provided the original author and source are credited. Funding: Air Force Office of Scientific Research http://www.wpafb.af.mil/afrl/afosr/ (grant number

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Memory instability as a gatew

Institute of Neuroscience & Psychology, Centre for Cognitive Neuroima

Our present frequently resembles our past. Patterns of activ

out our lives like a motif. Identifying and exploiting these pat

behaviours, from creating grammar to the application of skil

generalization may be dependent upon memory instability.

ries are unstable and able to interact with one another, allow

mon features to be extracted. Exploiting these common fea

knowledge that can be applied across varied circumstances

many of the biological and behavioural conditions necessar

Our past experience can aid our current and future performa

tennis player may help when it comes to playing other racque

aging the transfer of skill from one situation to another also li

the world of actions. The location of a reward in a navigation

in subsequent versions of the task even though key aspects of

of the reward, change [1]. Similarly, generalization can occur

events to create categories. Generalization therefore plays a k

tive functions. Yet, despite its clear importance and adaptive

The ability to generalize from a specific example to a categ

predictions for how generalization is produced.

training and rehabilitative strategies.

tion occurs is poorly understood.

generalization

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Abstract

Perspective

The Persistence and Transience of Memory

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The predominant focus in the neurobiological study of memory has been on remembering (persistence). However, recent studies have considered the neurobiology of forgetting (transience). Here we draw parallels between neurobiological and computational mechanisms underlying transience. We propose that it is the interaction between persistence and transience that allows for intelligent decision-making in dynamic, noisy environments. Specifically, we argue that transience (1) enhances flexibility, by reducing the influence of outdated information on memory-guided decision-making, and (2) prevents overfitting to specific past events, thereby promoting generalization. According to this view, the goal of memory is not the transmission of information through time, per se. Rather, the goal of memory is to optimize decision-making. As such, transience is as important as persistence in mnemonic systems.

We do not remember days, we remember moments. The et al., 2013; Hardt et al., 2013a). Here we first briefly review the richness of life lies in memories we have forgotten.

-Cesare Pavese (This Business of Living)

Introduction

Memory allows for the transmission of information through time. Most people, including many scientists, view the ideal mnemonic system as one of perfect persistence. That is, a system that transmits the greatest amount of information, with the highest possible fidelity, across the longest stretches of time. However, the few examples we have of individuals with something approximating this "perfect" mnemonic persistence suggest that Persistence remembering everything comes at a price. The Soviet clinical A Neurobiological Definition of Persistence

large literature concerned with neurobiological mechanisms of memory persistence. We then turn to the fledgling literature concerned with neurobiological mechanisms of memory transience. Based on principles from machine learning and computational neuroscience, we propose that it is the interaction between these two processes (i.e., persistence x transience) that optimizes memory-guided decision-making in changing and noisy environments. Specifically, we propose that only by combining persistence and transience can individuals exhibit flexible behavior and generalize past events to new experiences.

neuropsychologist A. R. Luria described the case of Patient S., Remembering transports us back in time, allowing us to rea man with "vast memory" who could only forget something if experience some past event or experience, a form of mental he actively willed himself to do so (Luria, 1968), Nonetheless, actime travel (Tulving, 2002), At the neural level, this suggests cording to Luria's accounts. Patient S, was handicapped by his that some aspect of our present brain state reflects a past brain apparent super-human memory. While on one hand, he was able state corresponding to the remembered event. Perhaps most to remember instances in exquisite detail his memory was simply remembering might involve reactivation of the pattern

Testing the hypothesis

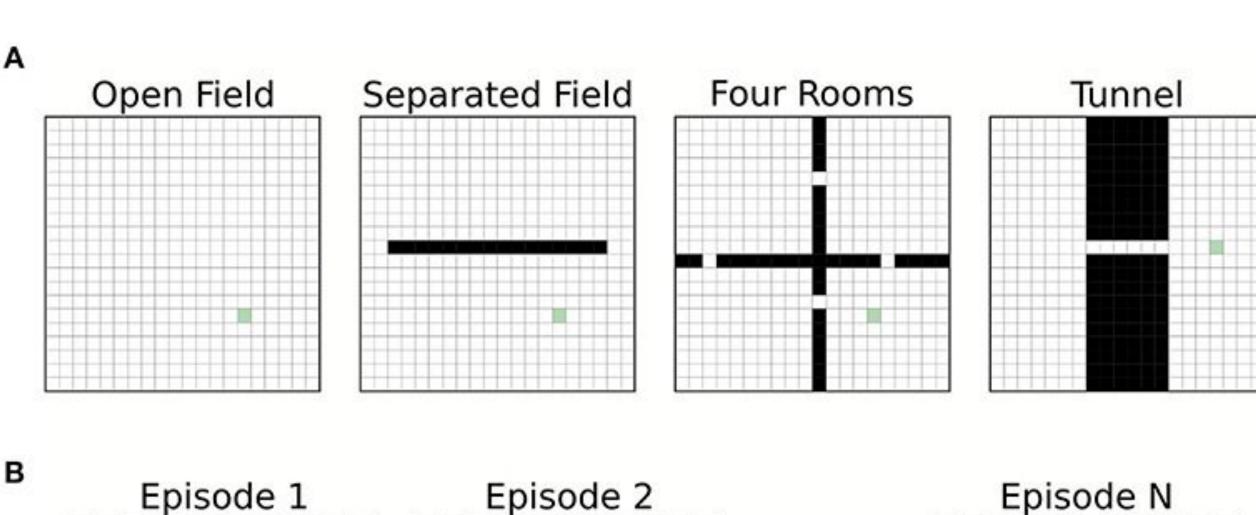
- Water maze experiments
- Smell association experiments
- Faster adaptation
- Exercise

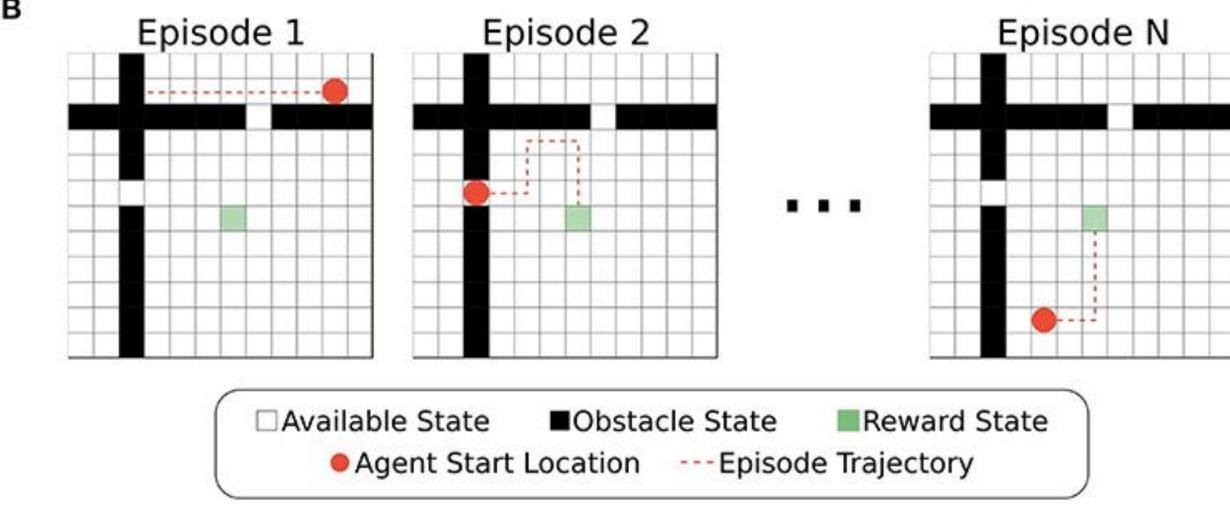
What about machine learning?

 Do models need to forget to adapt to change?

Early results in machine learning

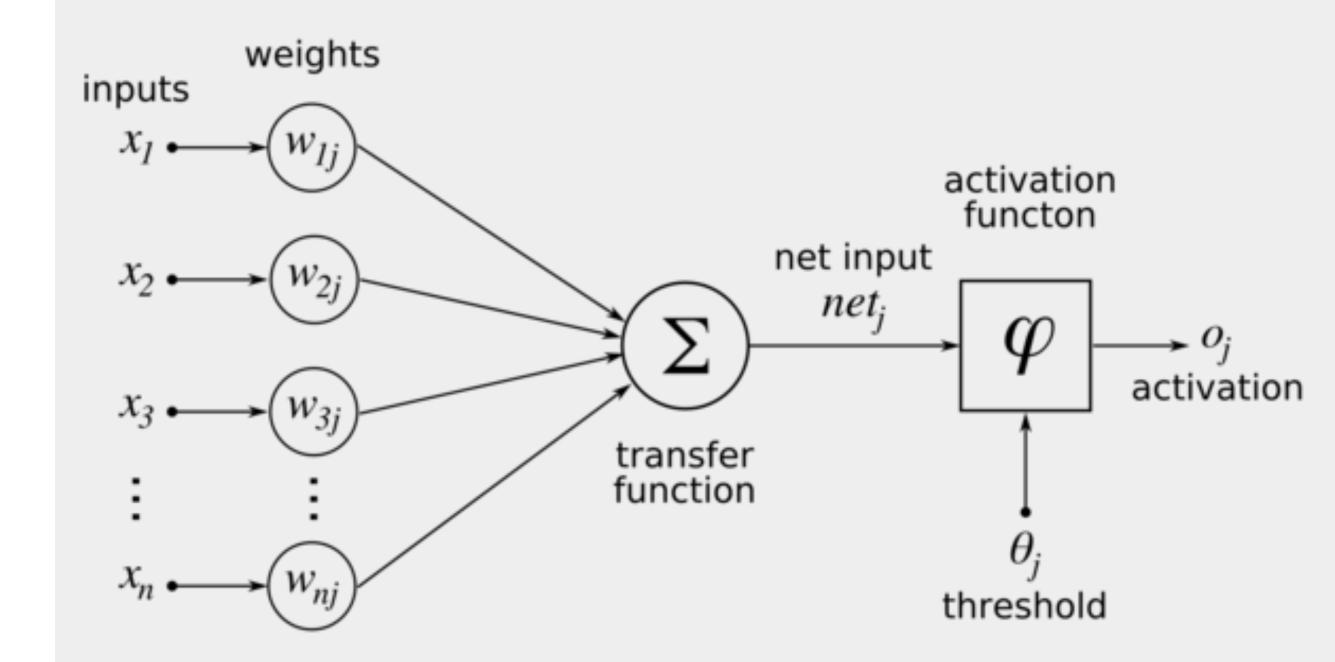
- Reinforcement learning experiments
- Find reward, avoid obstacles
- Context improves adaptation





Supervised Learning

- Learning by example
- Requires "training data"
 - Required "labels" correct answers



This is a gecko



This is a chameleon

Gecko

Chameleon

Gecko

Chameleon

Prediction, aka Inference

Satanic Leaf-Tailed Gecko

Change

Imagine that you're a retailer selling bicycles

You train a model using data from your app to order inventory

At first, it's going great!

But then, slowly at first ...

But then, slowly at first ...

My ?

Models need to adapt to change too

How do models forget?

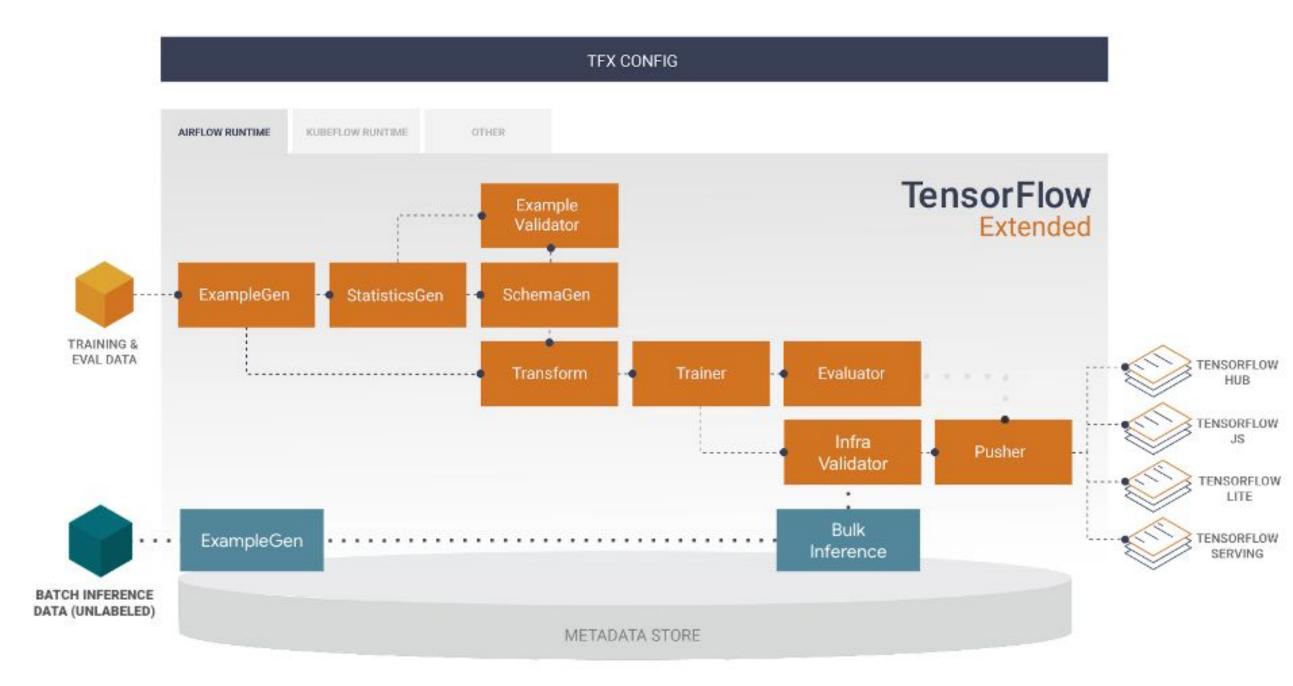
- Brute force
- Full or incremental retraining
- New data, new labels
- Slow, expensive

IMAGE REMOVED BECAUSE OF LICENSING RESTRICTIONS

How do know when to retrain?

- MLOps infrastructure
- Schedule
- Based on monitoring

Hello TFX!



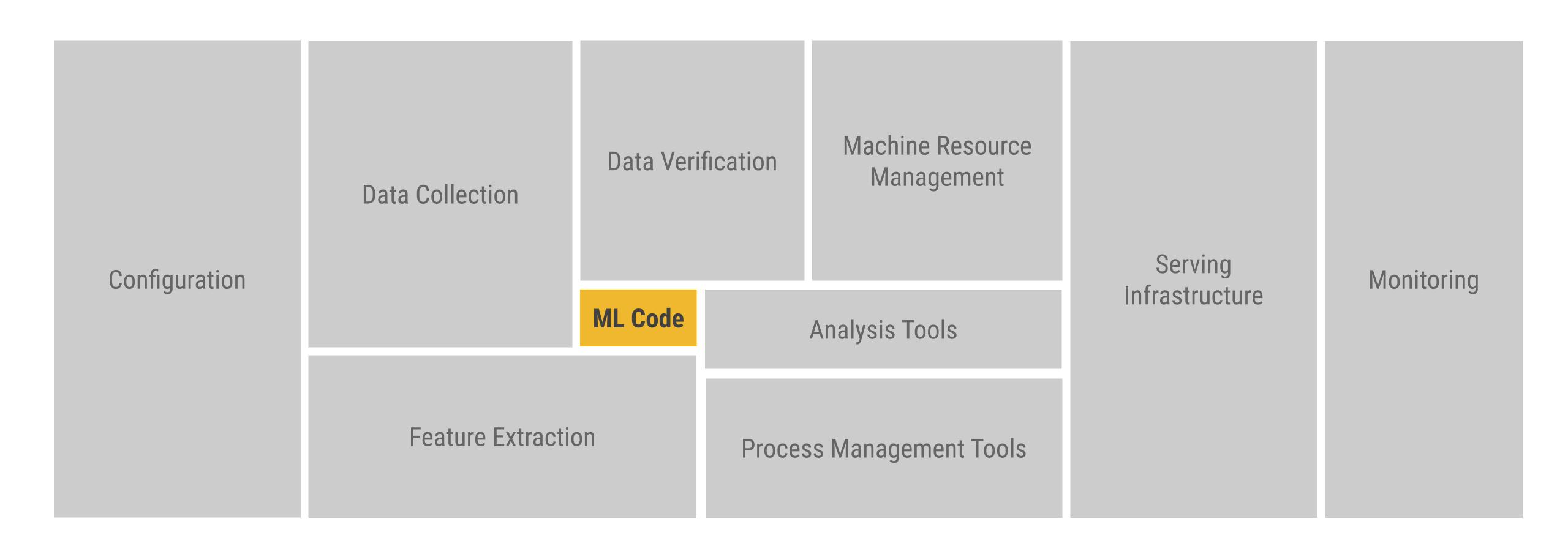
MLOps

"MLOps is an ML engineering culture and practice that aims at unifying ML system development (Dev) and ML system operation (Ops). Practicing MLOps means that you advocate for automation and monitoring at all steps of ML system construction, including integration, testing, releasing, deployment, and infrastructure management." http://goo.gle/mlops-levels

In addition to training an amazing model ...

Modeling Code

... a production solution requires so much more



Production Machine Learning

Machine Learning Development

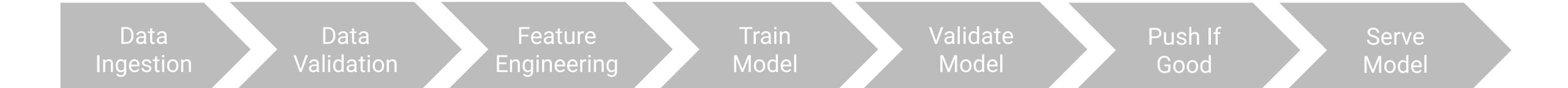
- Labeled data
- Feature space coverage
- Minimal dimensionality
- Maximum predictive data
- Fairness
- Rare conditions
- Data lifecycle management



Modern Software Development

- Scalability
- Extensibility
- Configuration
- Consistency & Reproducibility
- Modularity
- Best Practices
- Testability
- Monitoring
- Safety & Security

Training and Deploying Models

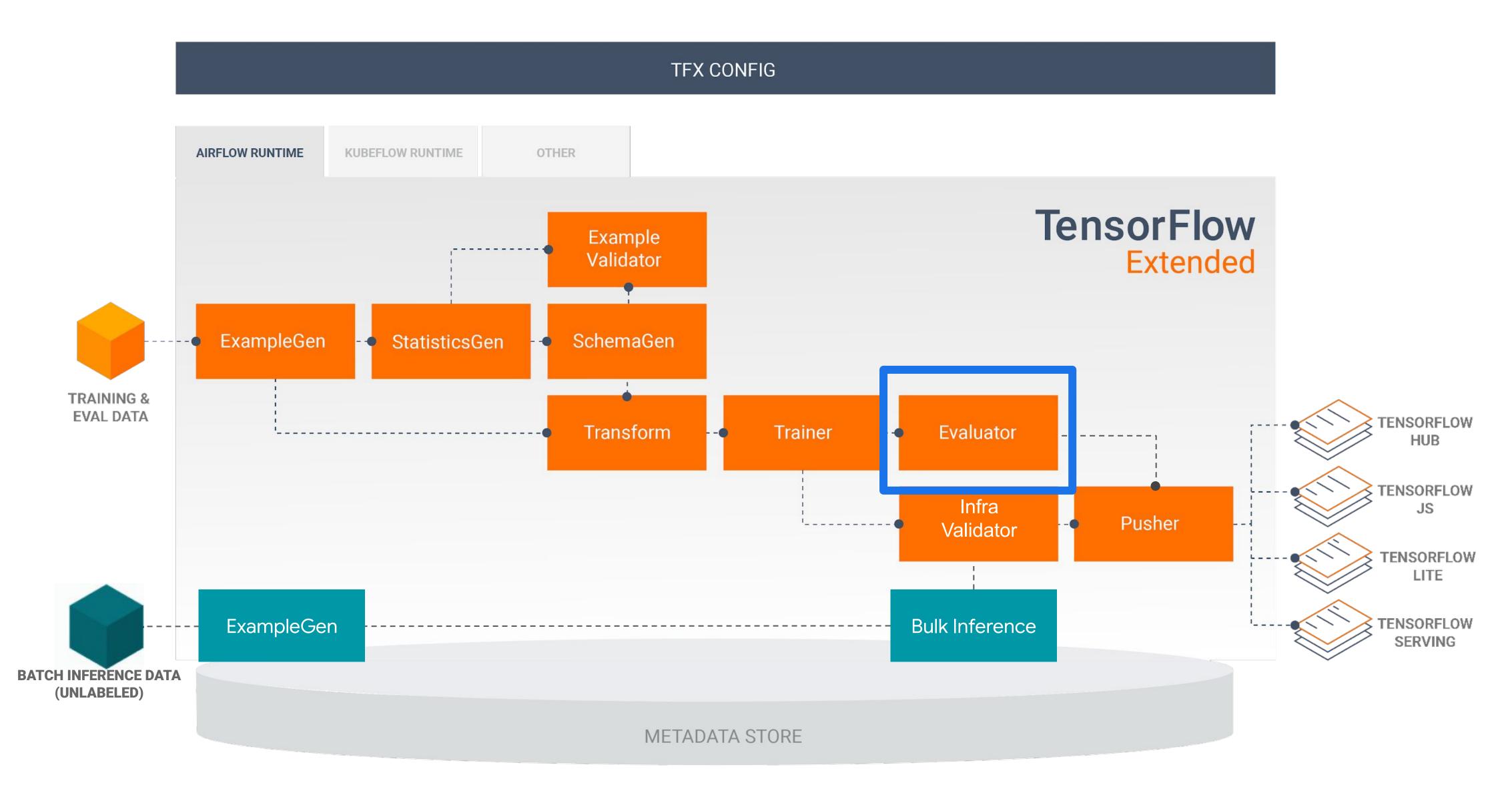


Training Pipeline

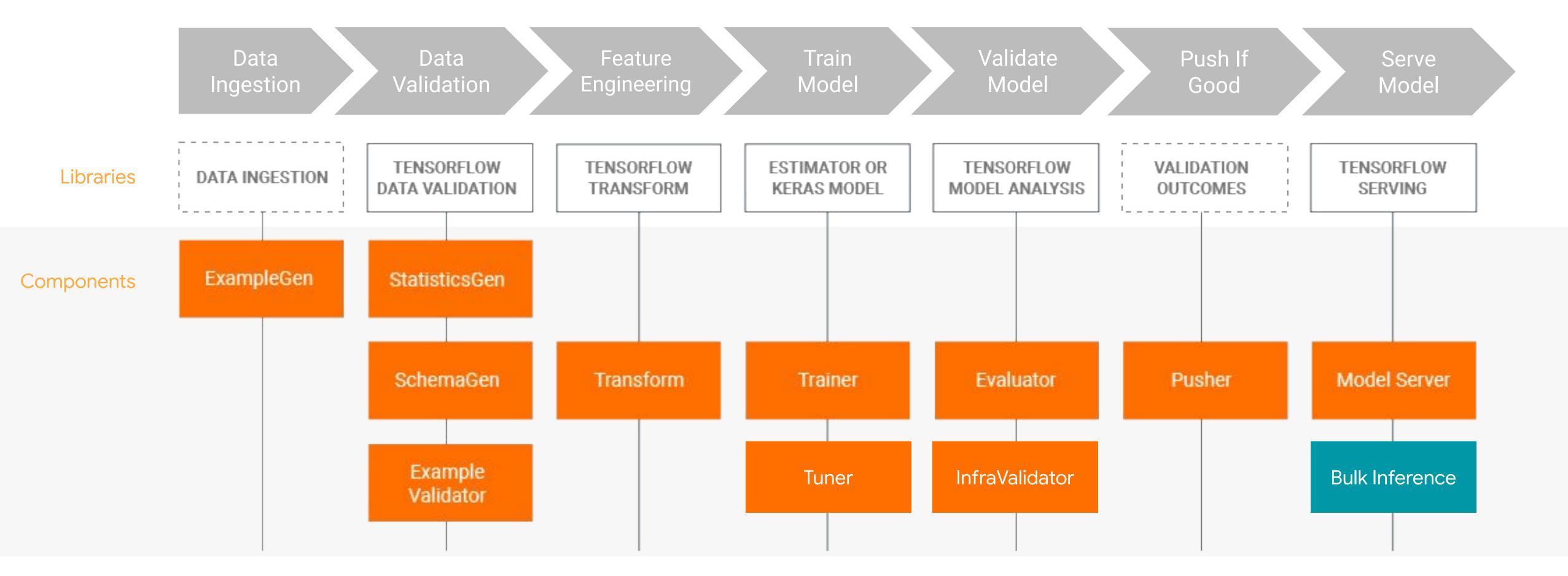
- Google needed a strong platform
- Not the only platform available
- Example of state of the art



Hello TFX!



TFX Production Components



Major MLOps System Components

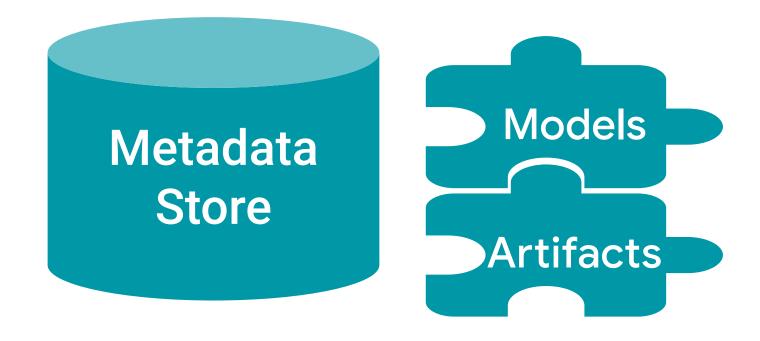






Training Pipeline

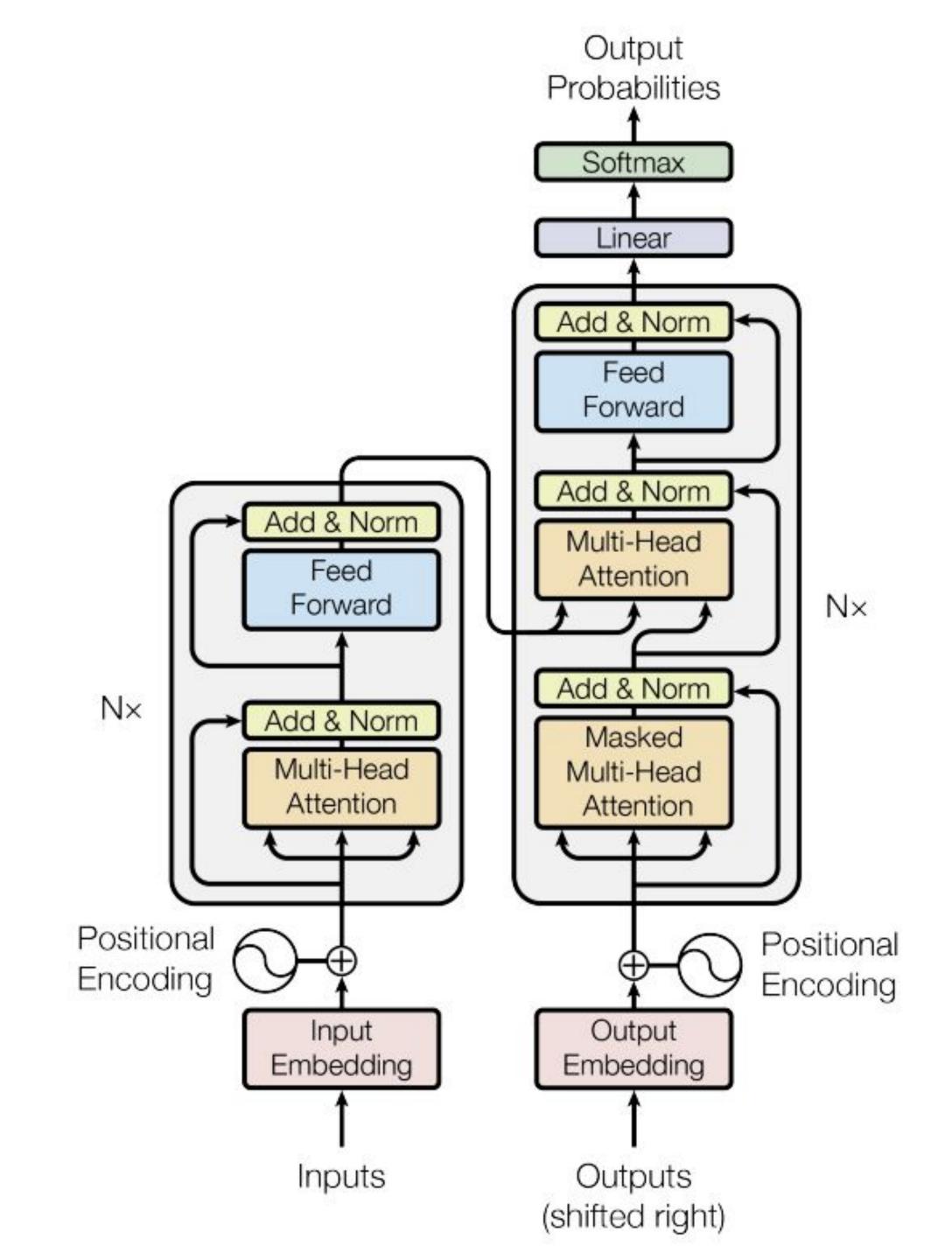
Feature Store





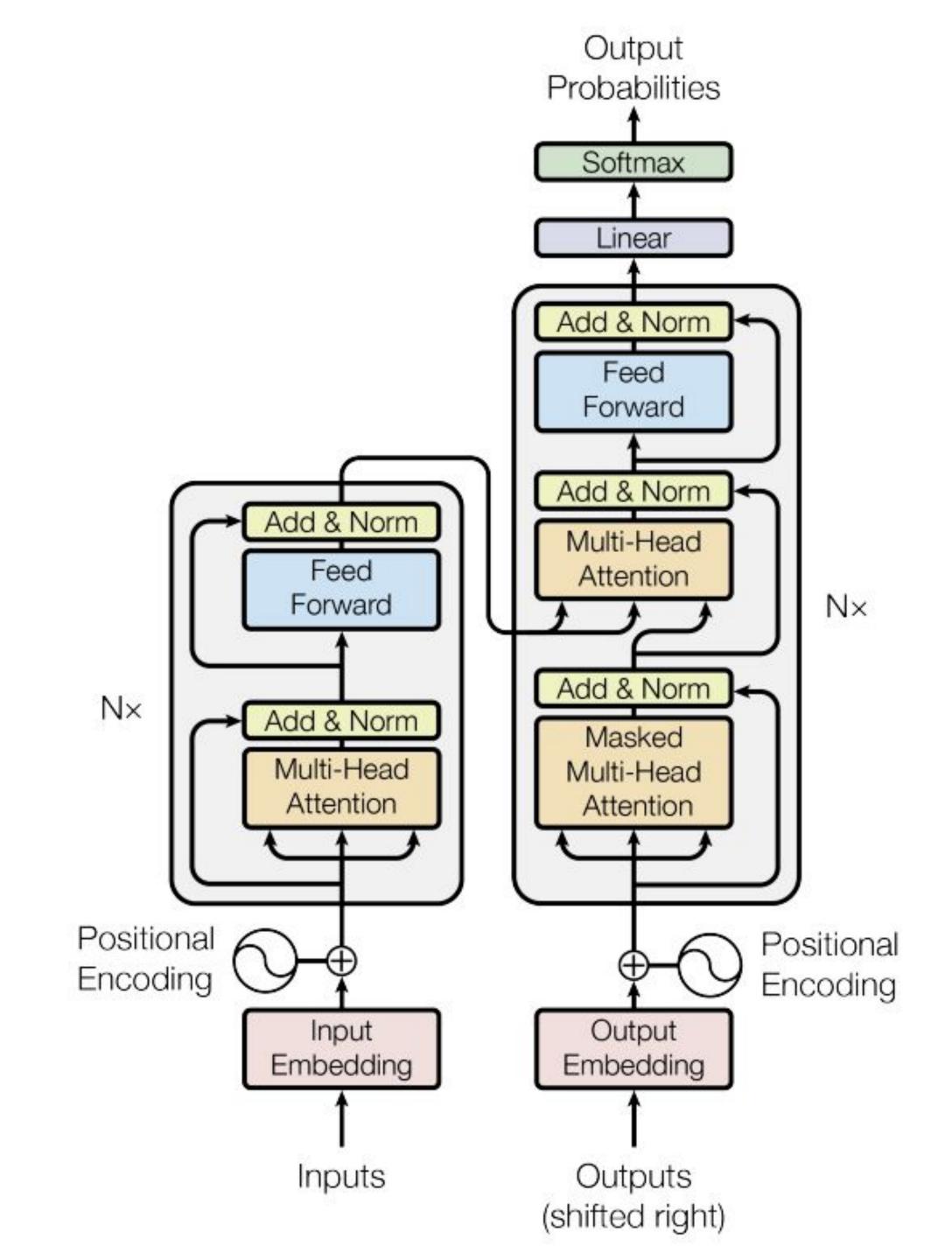
What about tomorrow?

- Today: Fully or partially retrain
- Foundational models
- Multi-modal models
- Transformers



Breakthrough capabilities

- Language
- Question answering
- Sentence completion
- Reading comprehension
- Common sense reasoning



Explaining a joke

Prompt

Explain this joke:

Joke: Did you see that Google just hired an eloquent whale for their TPU team? It showed them how to communicate between two different pods!

Model Response

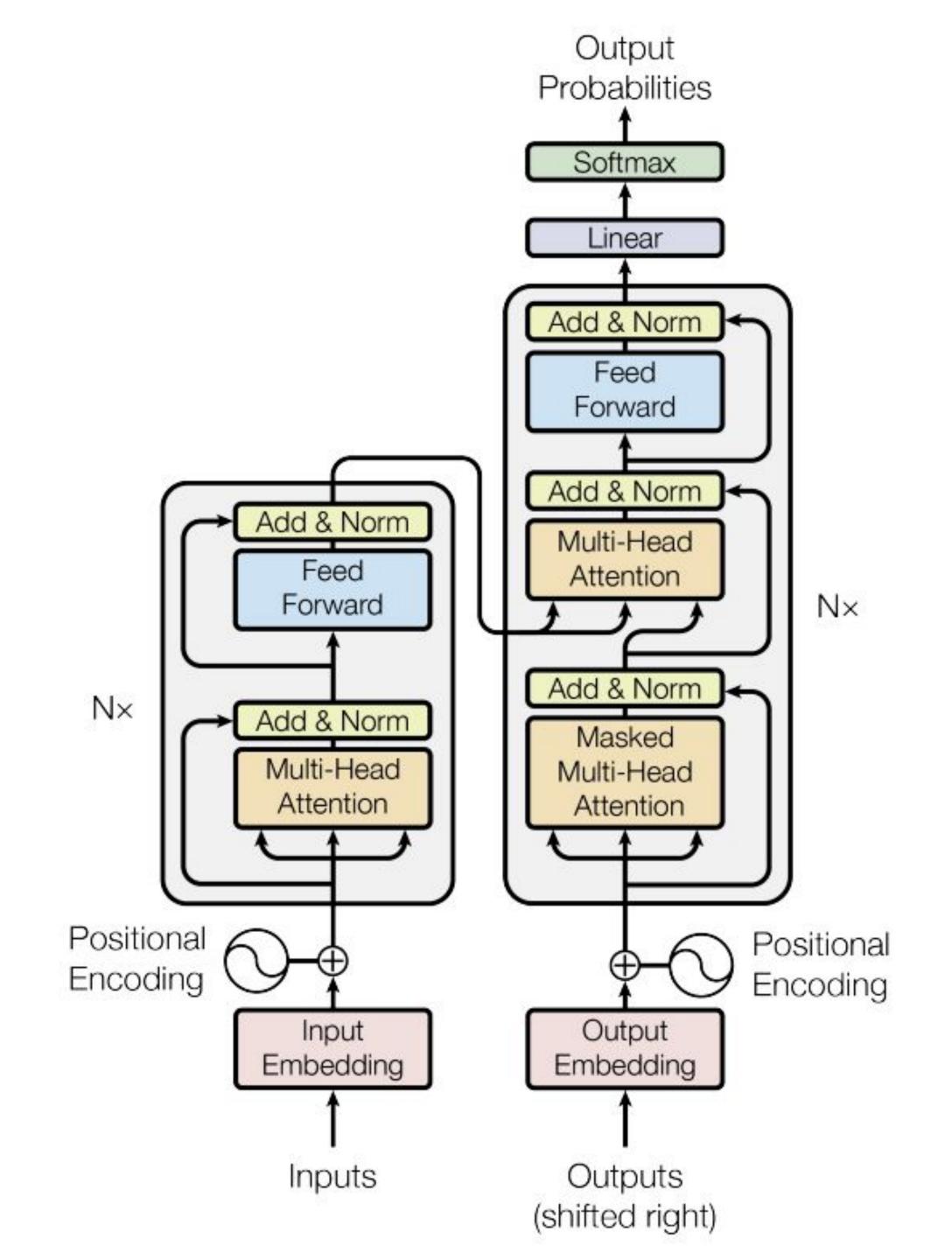
Prediction: TPUs are a type of computer chip that Google uses for deep learning. A "pod" is a group of TPUs. A "pod" is also a group of whales. The joke is that the whale is able to communicate between two groups of whales, but the speaker is pretending that the whale is able to communicate between two groups of TPUs.

Prompt Model Response

```
// Translate from C to Python
int add_one ( int x ){
  int m = 1;
  while ( x & m ) {
    x = x ^ m;
    m <<= 1;
  }
  x = x ^ m;
  return x; }</pre>
```

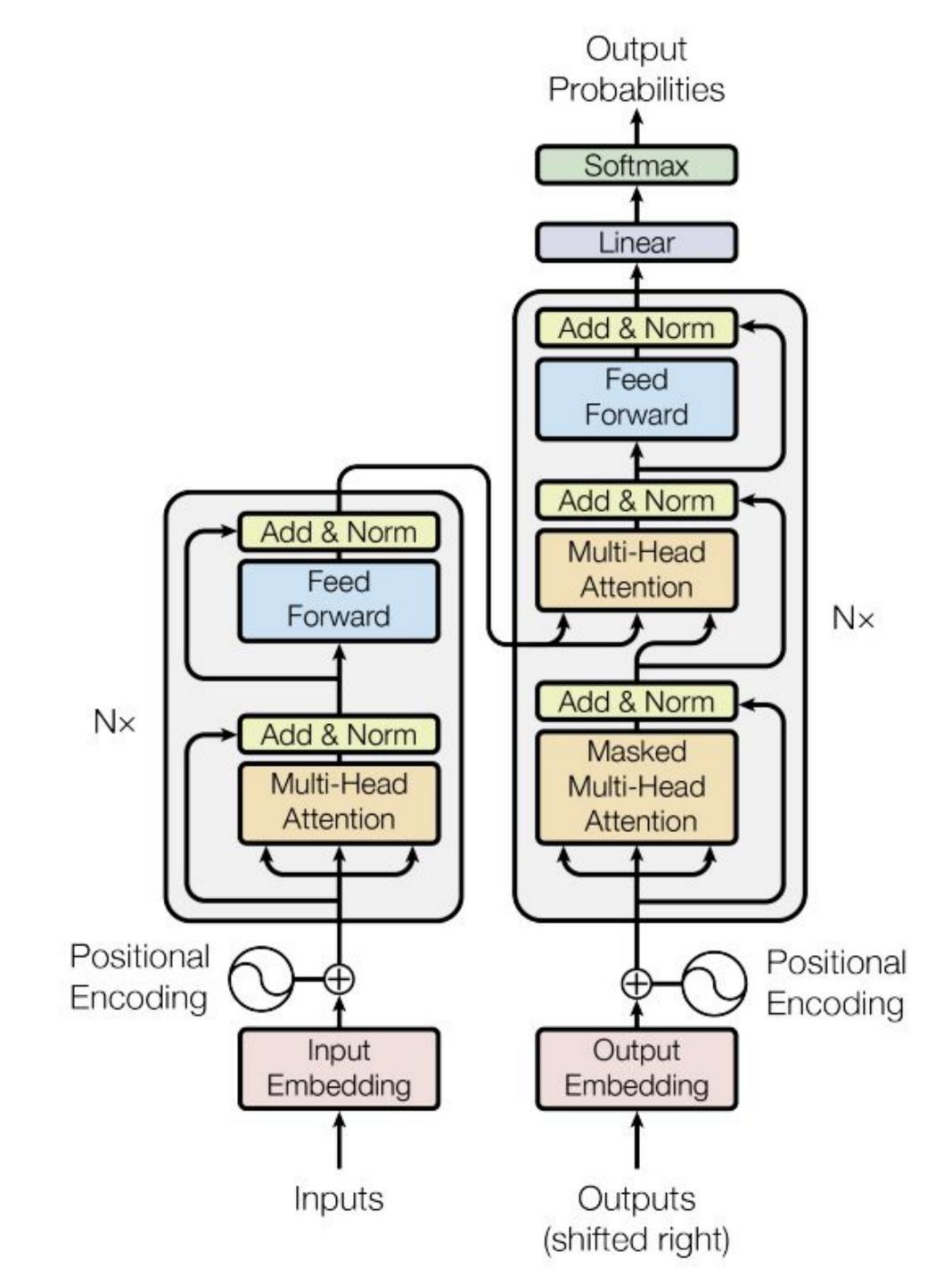
What about tomorrow?

- GPT-3
 - o 175B parameters, 45TB data
 - US\$12M to train
- PaLM = GPT-3 * 3

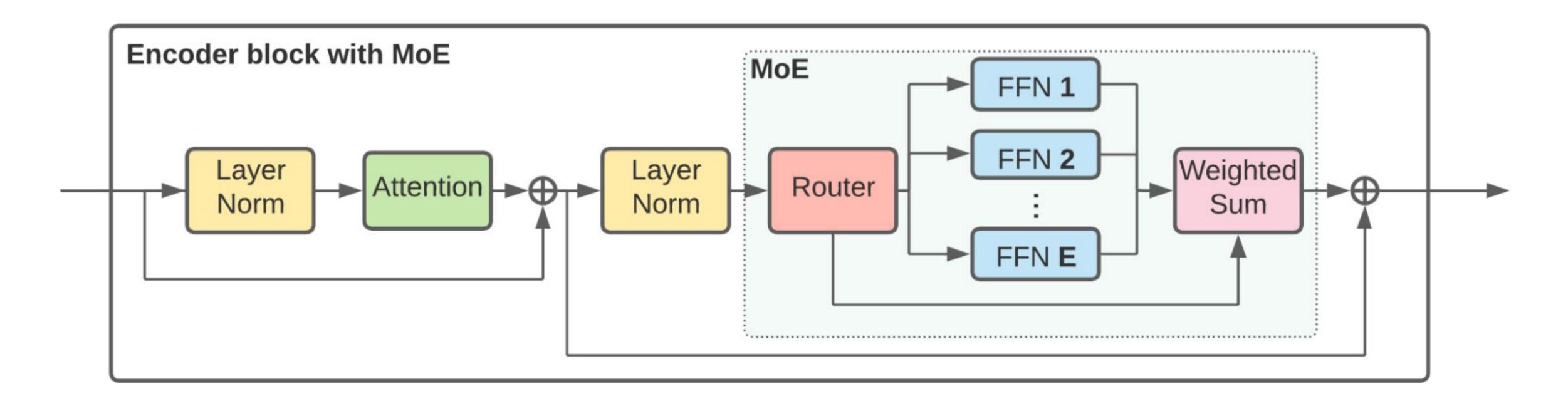


Is it a problem?

- Currently being worked on
- Domain dependent



Is it a problem?

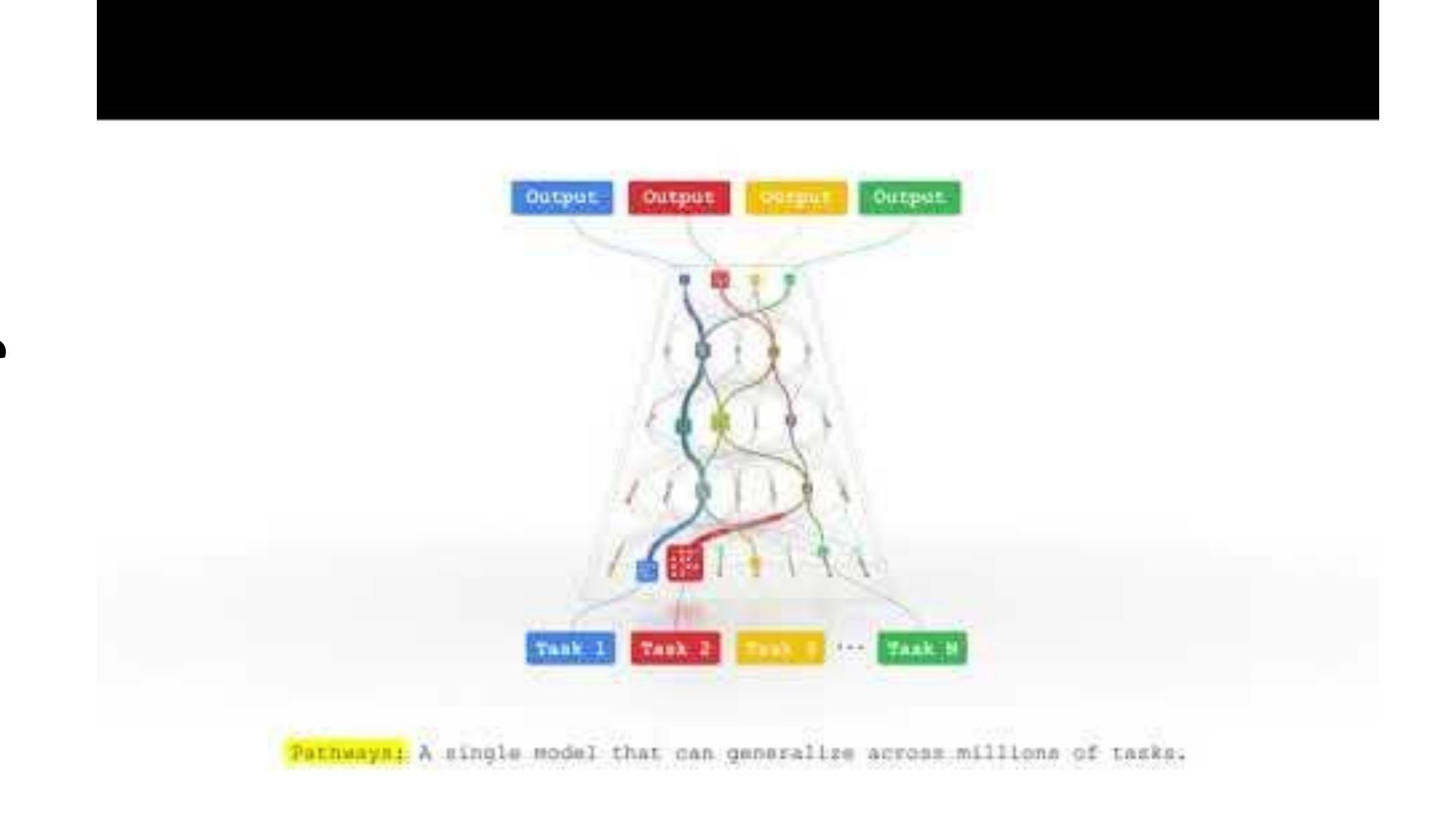


- Ensemble approach?
- Mixture of Experts (MoE)

Learning from studying our brains

- Mirroring how the brain manages updates
- Multiple centers of the brain cooperating

IMAGE REMOVED BECAUSE OF LICENSING RESTRICTIONS



Forgetting helps us adapt

IMAGE REMOVED
BECAUSE OF LICENSING
RESTRICTIONS



More Information on TFX

Web https://tensorflow.org/tfx

Repo https://github.com/tensorflow/tfx

YouTube https://goo.gle/tfx-youtube

SIG https://github.com/tensorflow/tfx-addons

Community https://discuss.tensorflow.org/tag/tfx



Selected Studies

The Persistence and Transience of Memory, Blake A. Richards, Paul W. Frankland - https://doi.org/10.1016/j.neuron.2017.04.037

Forgetting Enhances Episodic Control With Structured Memories, Annik Yalnizyan-Carson, Blake A. Richards - https://www.frontiersin.org/articles/10.3389/fncom.2022.757244/full

Memory instability as a gateway to generalization, Edwin M. Robertson - https://journals.plos.org/plosbiology/article/file?id=10.1371/journal.pbio.2004633&type=printable

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