

The Importance Of Forgetting For Both Humans And Machines

GOTO Copenhagen 2022

Robert Crowe

Google

Remember. Learn.

- Recognize patterns
- Generalize to broad concepts

IMAGE REMOVED
BECAUSE OF LICENSING
RESTRICTIONS

Why forget?

- Failure to remember?
- Why not remember everything?

IMAGE REMOVED
BECAUSE OF LICENSING
RESTRICTIONS

Even simple animals forget

- Fruit flies
- C. elegans

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RESTRICTIONS

Do we need to make room?

Estimates vary

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

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RESTRICTIONS

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?

IMAGE REMOVED
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RESTRICTIONS

People forget different things differently

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

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RESTRICTIONS

Different parts of the brain

Hippocampus

- Episodic memories

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RESTRICTIONS

Different parts of the brain

Neocortex

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

IMAGE REMOVED
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RESTRICTIONS

Different parts of the brain

Amygdala

- Emotional significance
- Fear, shame, love, grief

IMAGE REMOVED
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RESTRICTIONS

Different parts of the brain

Prefrontal Cortex

- Short-term or working memory

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RESTRICTIONS

Different types of memory

Different policies for forgetting

- Amygdala
- Hippocampus
- Neocortex

Semantic

Episodic

Emotional

Short-term

Sensory

Knowledge

- Neuroscience consensus
- Improved adaptation

Remembering transports us back in time, allowing us to re-experience some past event or experience, a form of mental time travel (Tulving, 2002). At the neural level, this suggests that some aspect of our present brain state reflects a past brain state corresponding to the remembered event. Perhaps most simply, remembering might involve reactivation of the patterns

Testing the hypothesis

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

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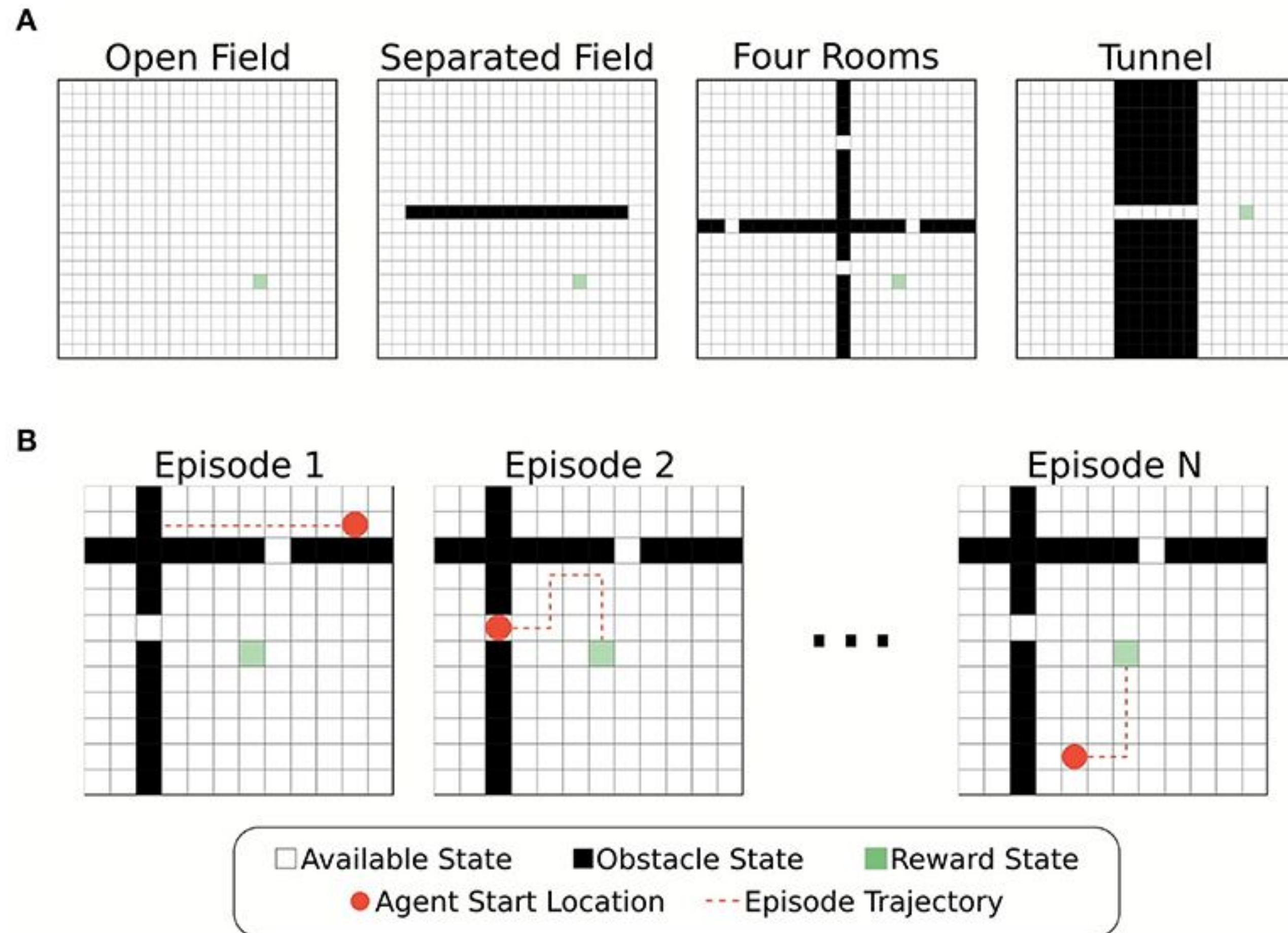
What about machine learning?

- Do models need to forget to adapt to change?

IMAGE REMOVED
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RESTRICTIONS

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

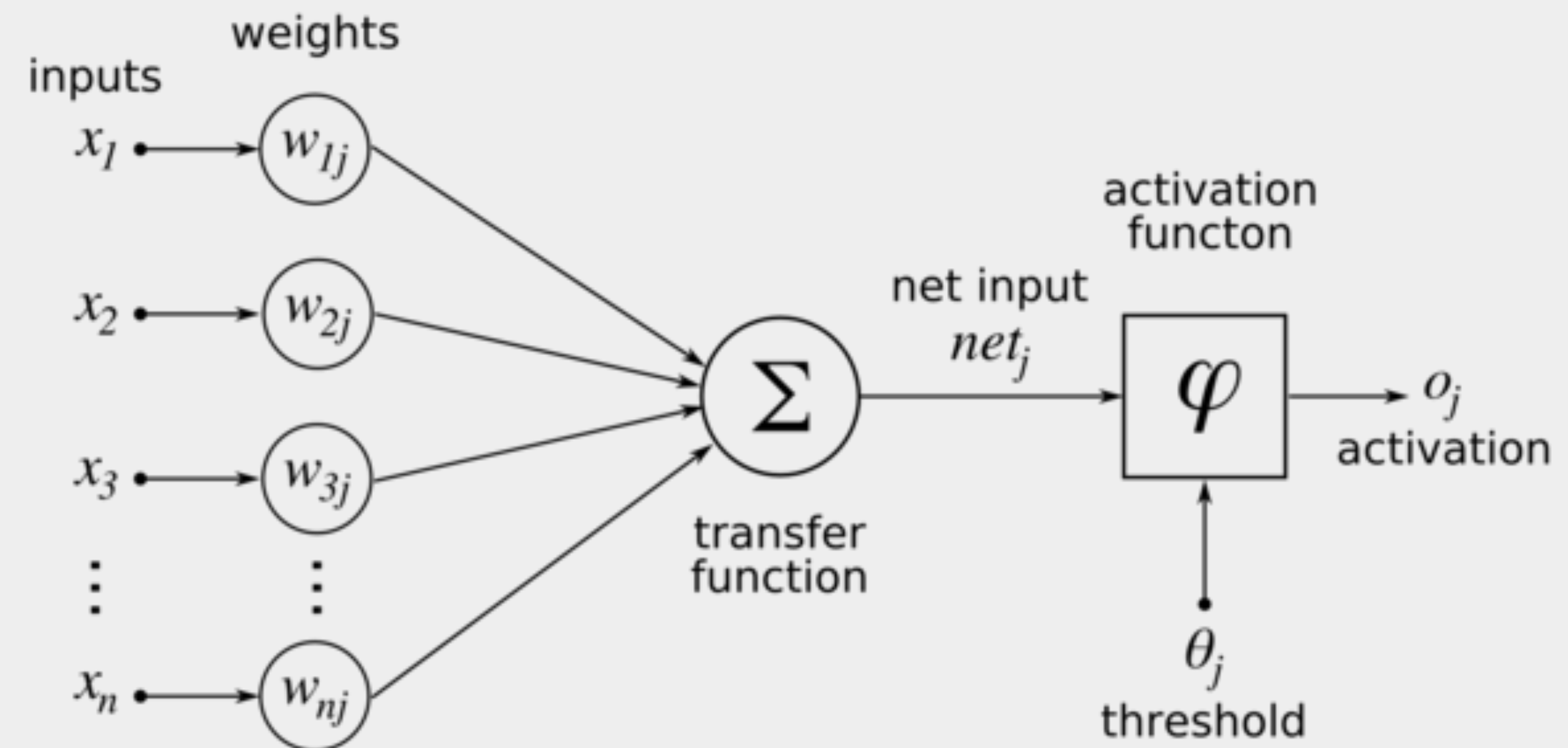


IMAGE REMOVED
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This is a gecko



This is a chameleon

IMAGE REMOVED
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RESTRICTIONS

Gecko

IMAGE REMOVED
BECAUSE OF LICENSING
RESTRICTIONS

Chameleon

IMAGE REMOVED
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RESTRICTIONS

Gecko

IMAGE REMOVED
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RESTRICTIONS

Chameleon

Prediction, aka
Inference

IMAGE REMOVED
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Gecko or Chameleon?

IMAGE REMOVED
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RESTRICTIONS

Gecko or Chameleon?

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Gecko or Chameleon?

IMAGE REMOVED
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Gecko or Chameleon?

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Satanic Leaf-Tailed Gecko

[https://commons.wikimedia.org/wiki/File:Satanic_leaf-tailed_gecko_\(Uroplatus_phantasticus\)_Ranomafana_4.jpg](https://commons.wikimedia.org/wiki/File:Satanic_leaf-tailed_gecko_(Uroplatus_phantasticus)_Ranomafana_4.jpg)

Change

**Imagine that
you're a retailer
selling bicycles**

IMAGE REMOVED
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RESTRICTIONS

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

IMAGE REMOVED
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RESTRICTIONS

**At first, it's
going great!**

IMAGE REMOVED
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RESTRICTIONS

**But then, slowly
at first ...**

IMAGE REMOVED
BECAUSE OF LICENSING
RESTRICTIONS

**But then, slowly
at first ...**

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Why?

Models need to adapt to change too

How do models forget?

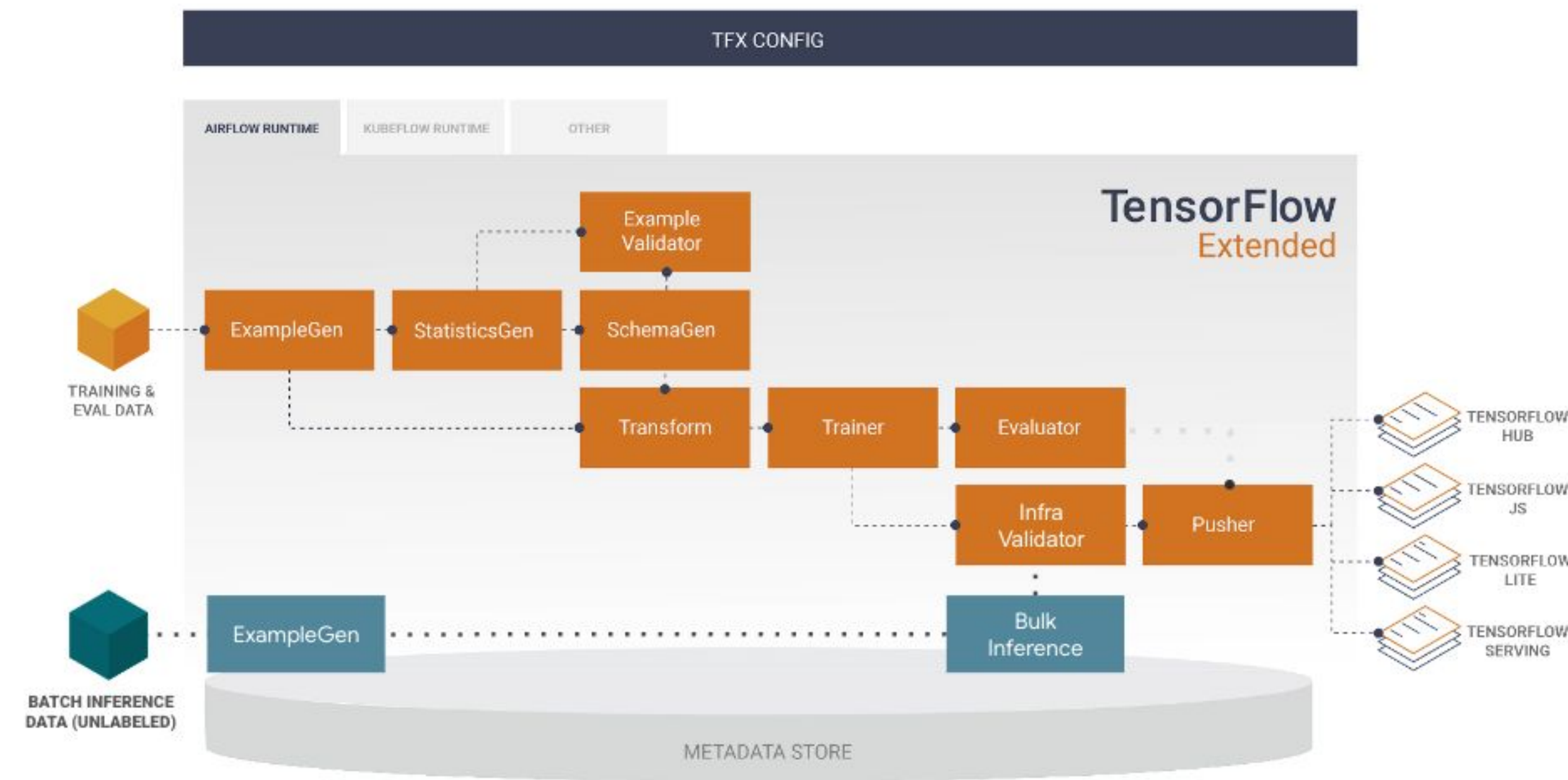
- Brute force
- Full or incremental retraining
- New data, new labels
- Slow, expensive

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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.” -

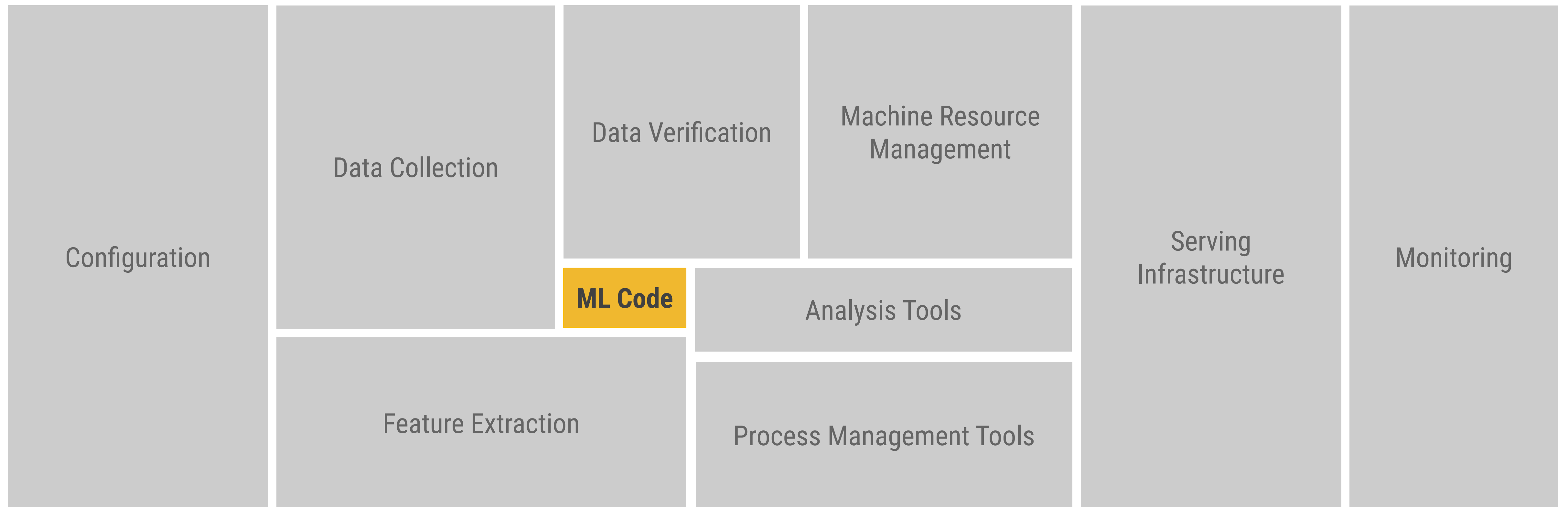
<http://goo.gle/mlops-levels>

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

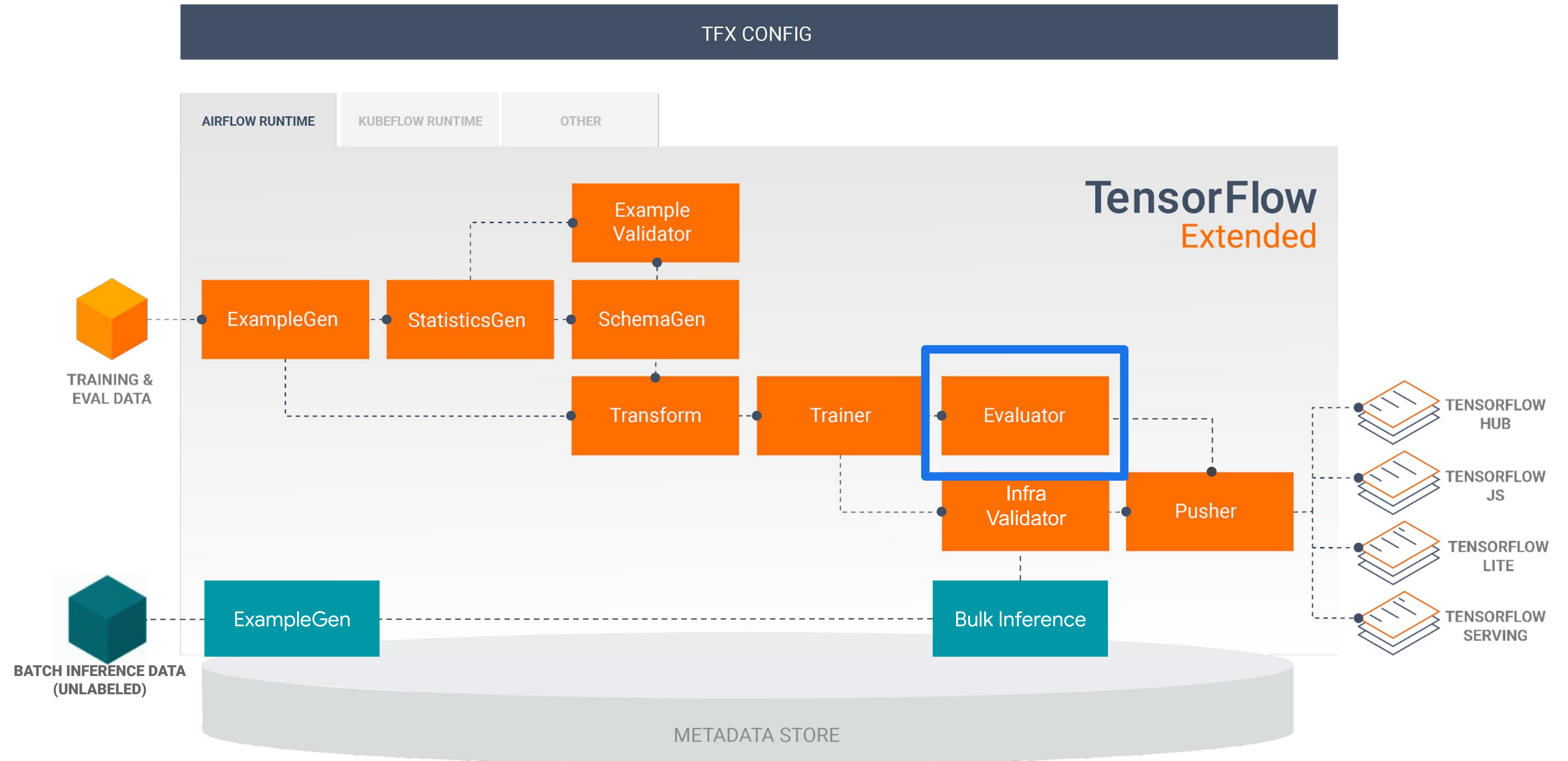


Training Pipeline

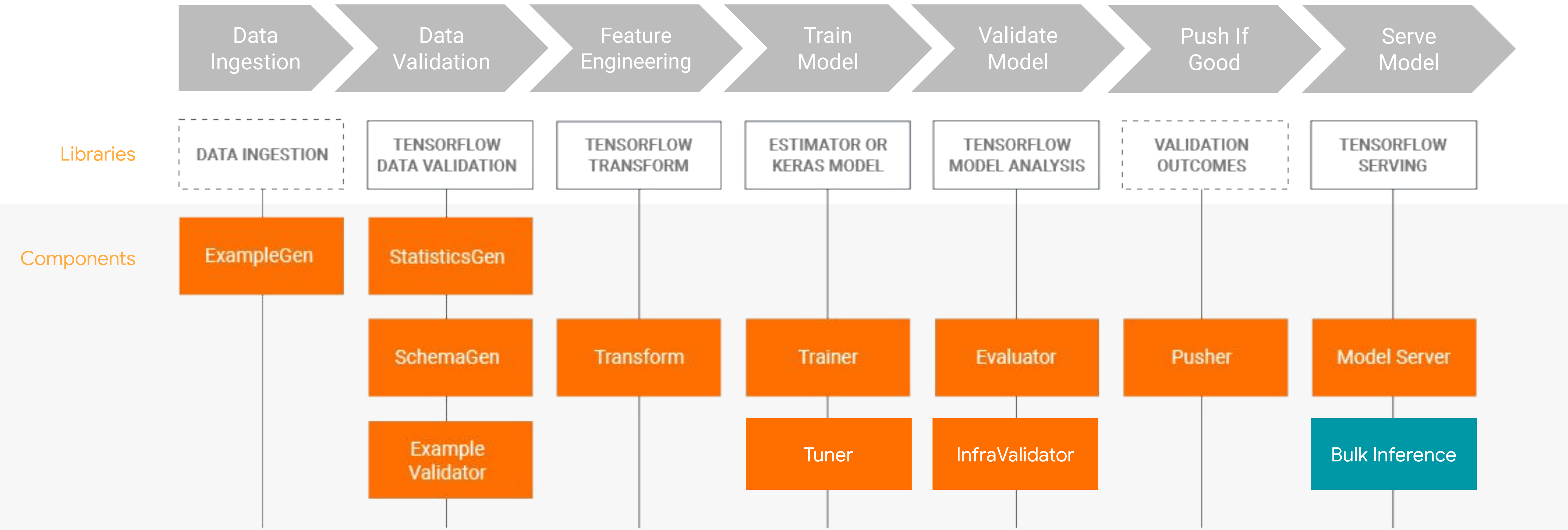
- Google needed a strong platform
- Not the only platform available
- Example of state of the art



Hello TFX!



TFX Production Components



Major MLOps System Components



Collect
Data



Experimentation



Monitoring &
Scheduling

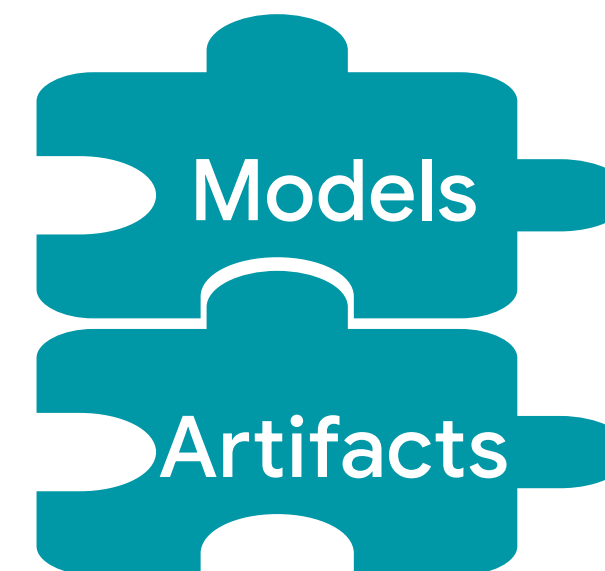
Training Pipeline



Feature
Store

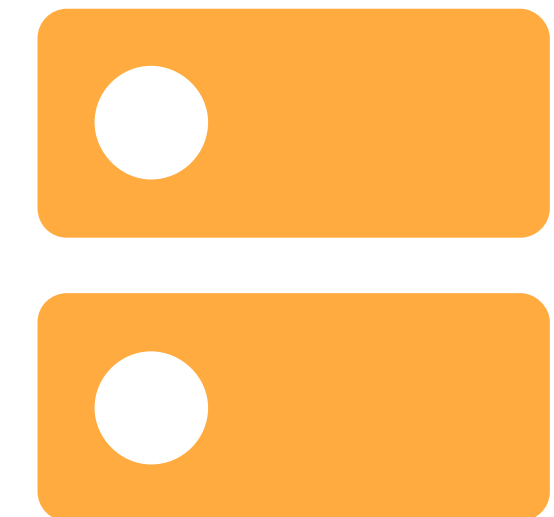


Metadata
Store



Models

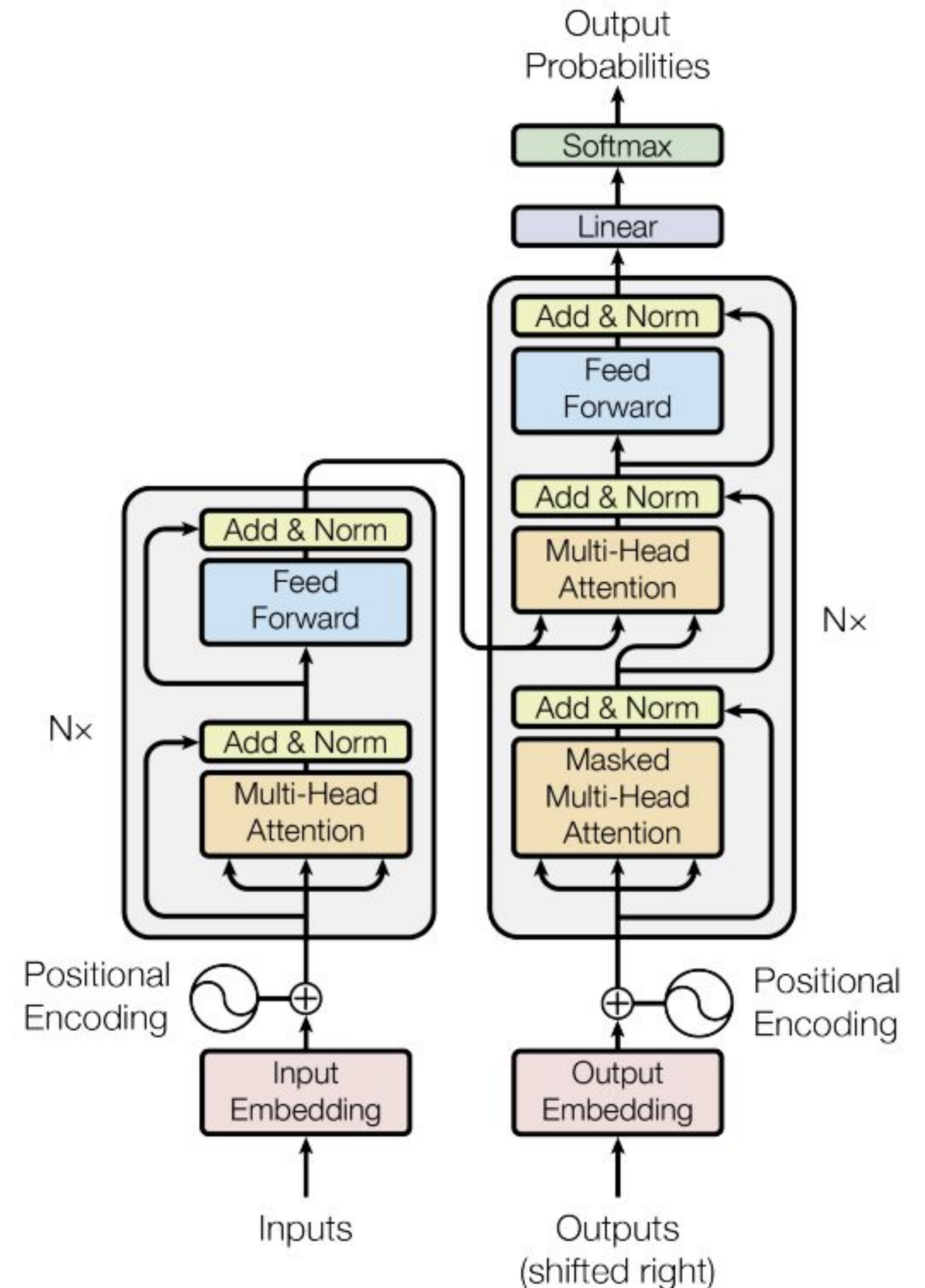
Artifacts



Serving

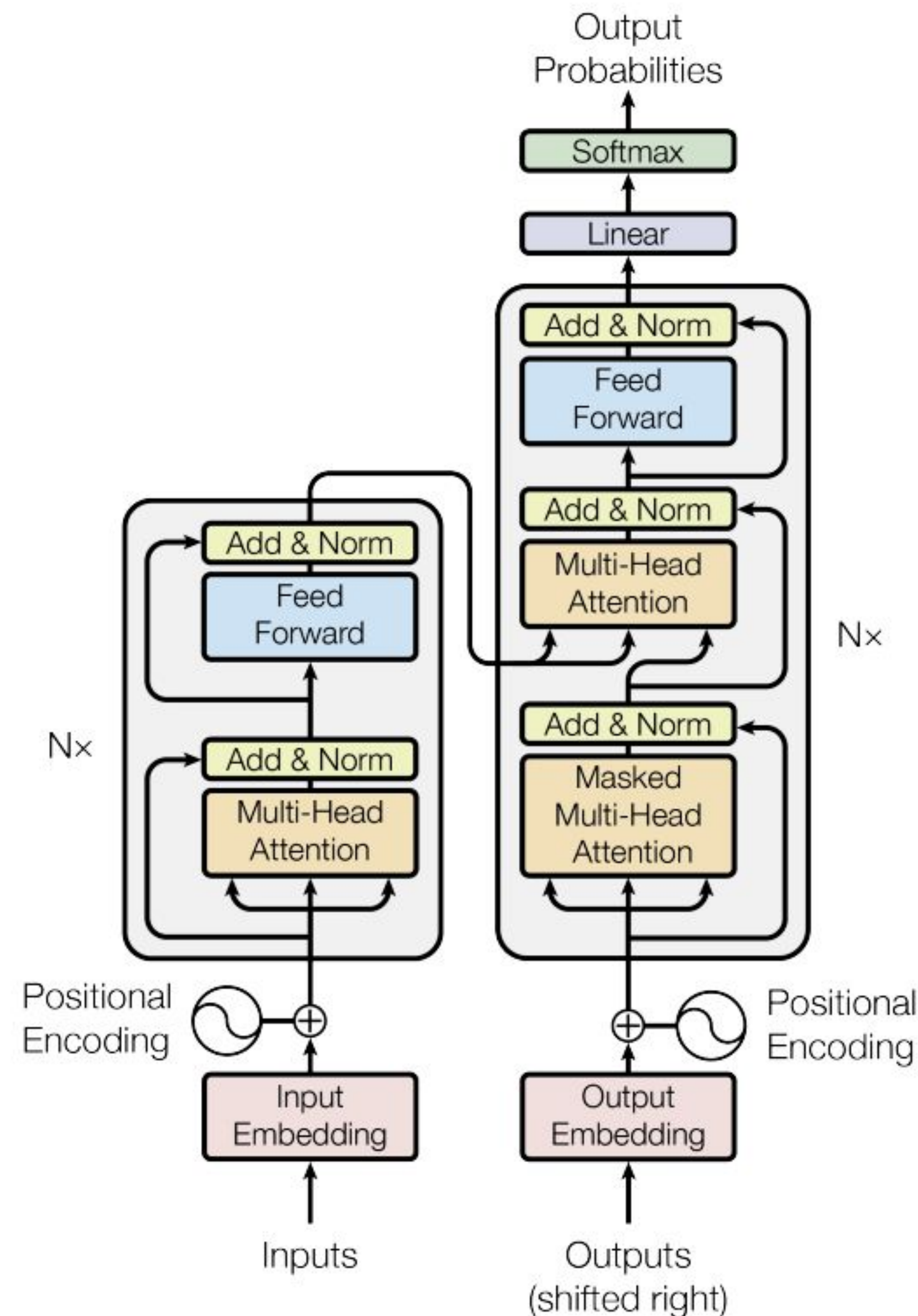
What about tomorrow?

- 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.

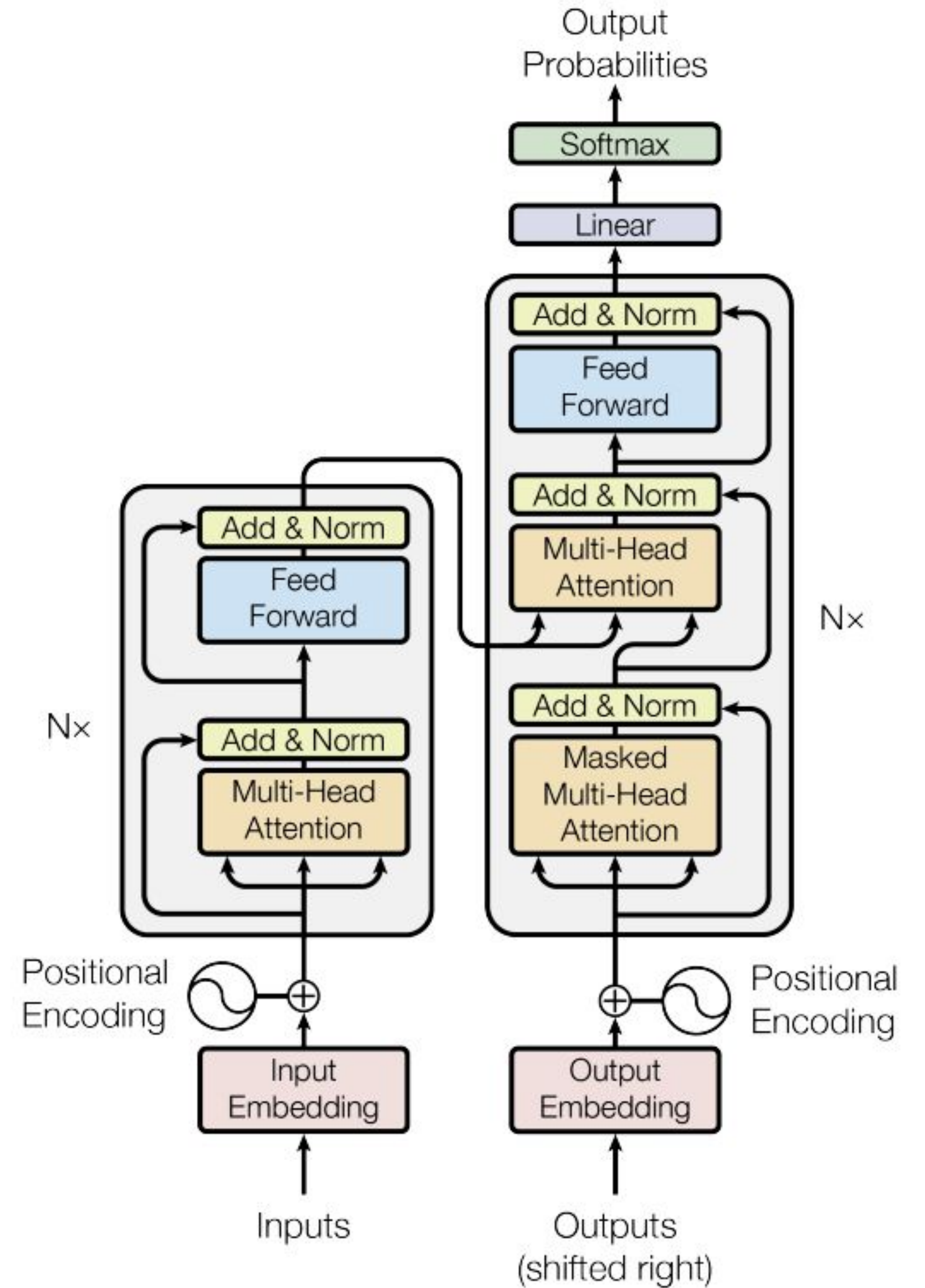
Prompt

```
// 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; }
```

Model Response

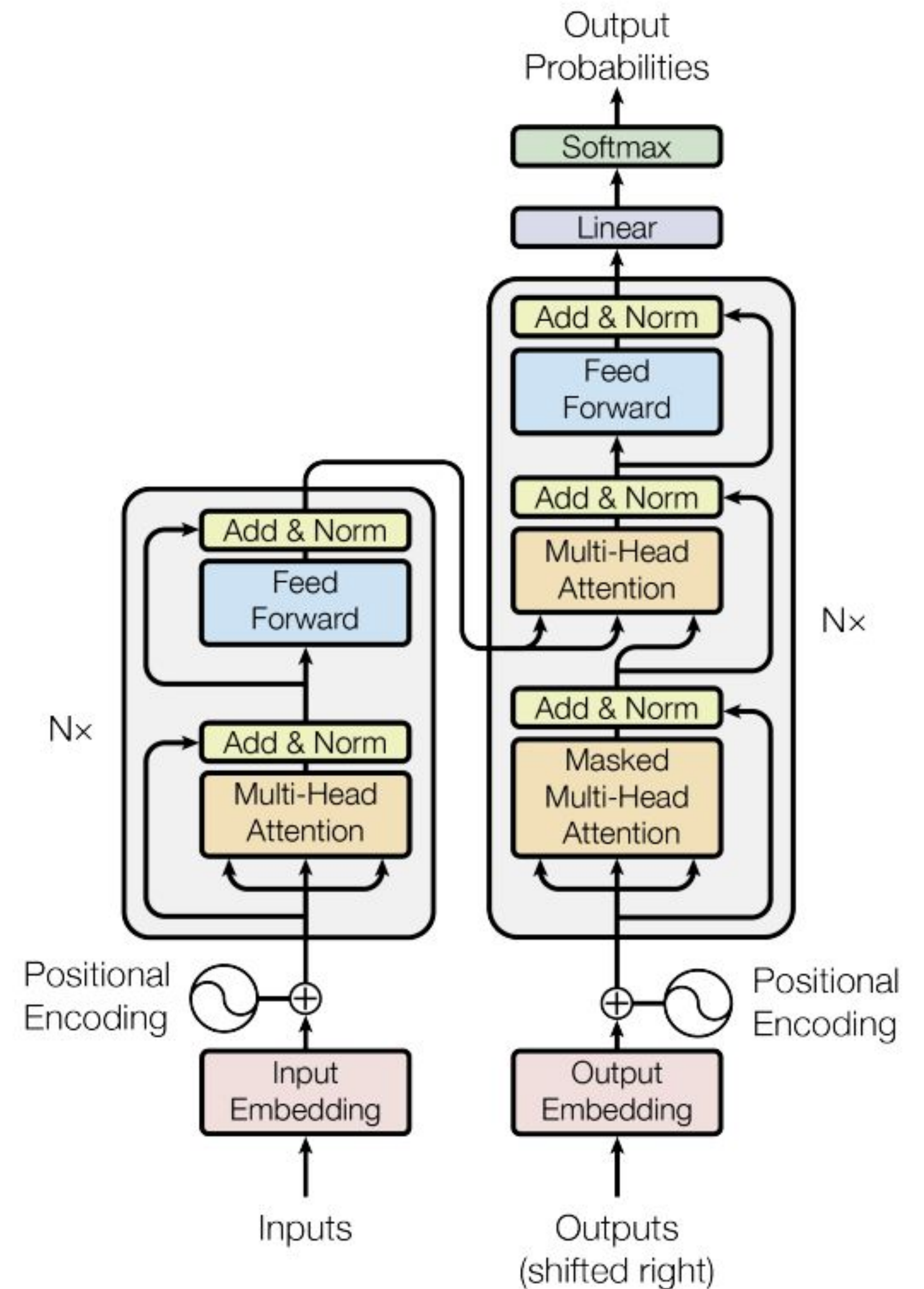
What about tomorrow?

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

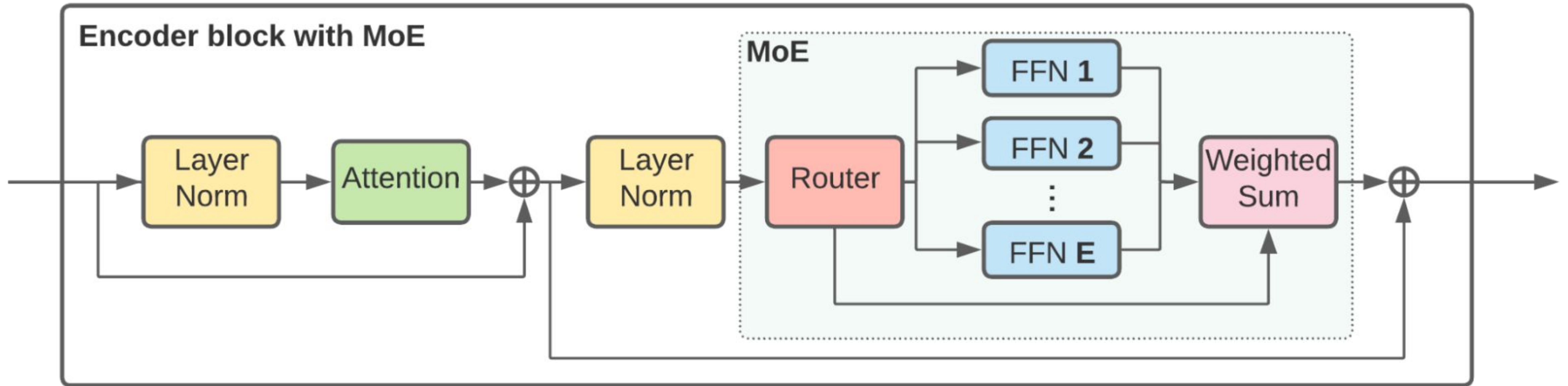


Is it a problem?

- Currently being worked on
- Domain dependent



Is it a problem?



- Ensemble approach?
- Mixture of Experts (MoE)

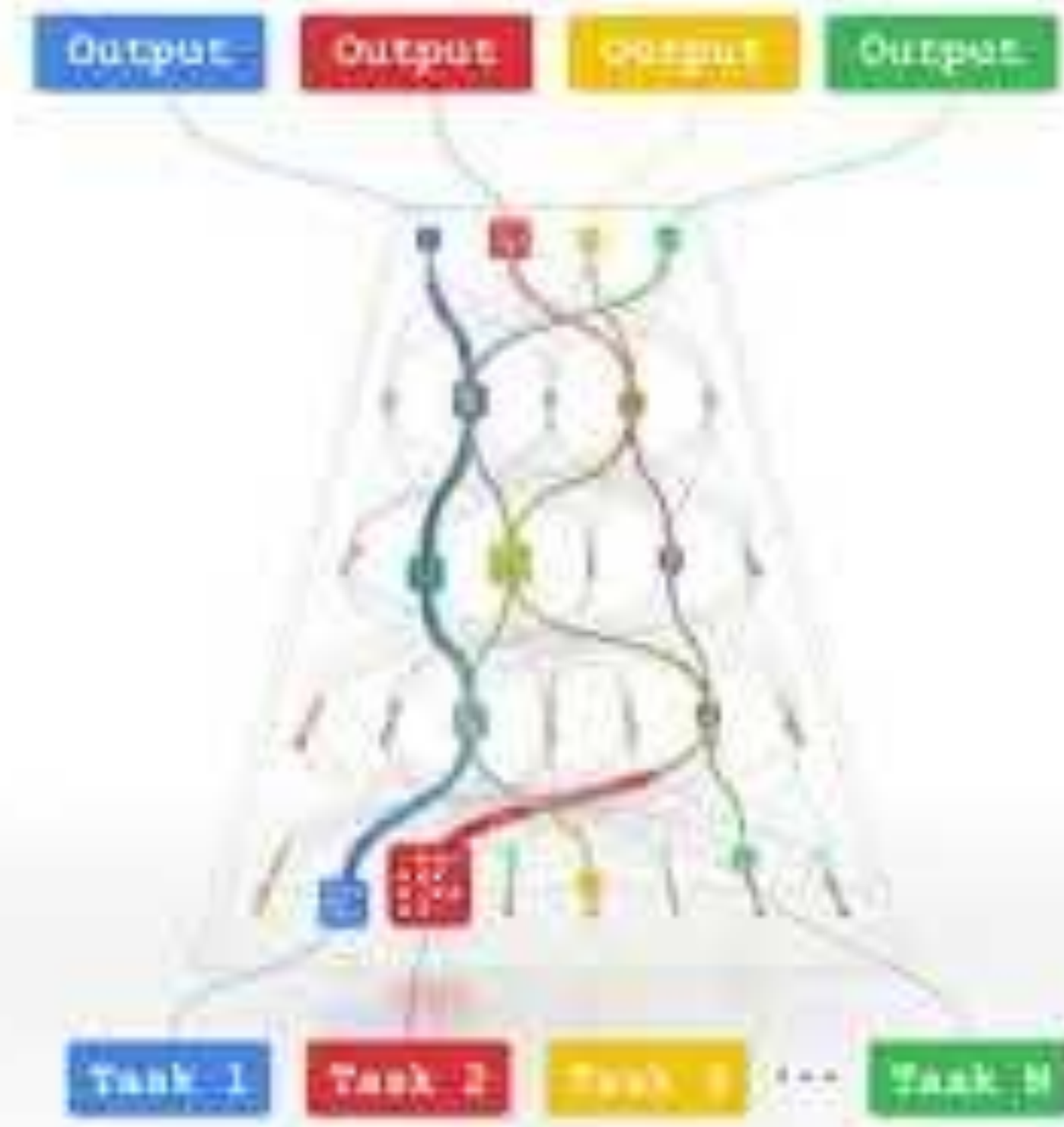
Learning from studying our brains

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

IMAGE REMOVED
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RESTRICTIONS

Pathways

Pathways: A single model that can generalize across millions of tasks.



Forgetting helps us adapt

IMAGE REMOVED
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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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