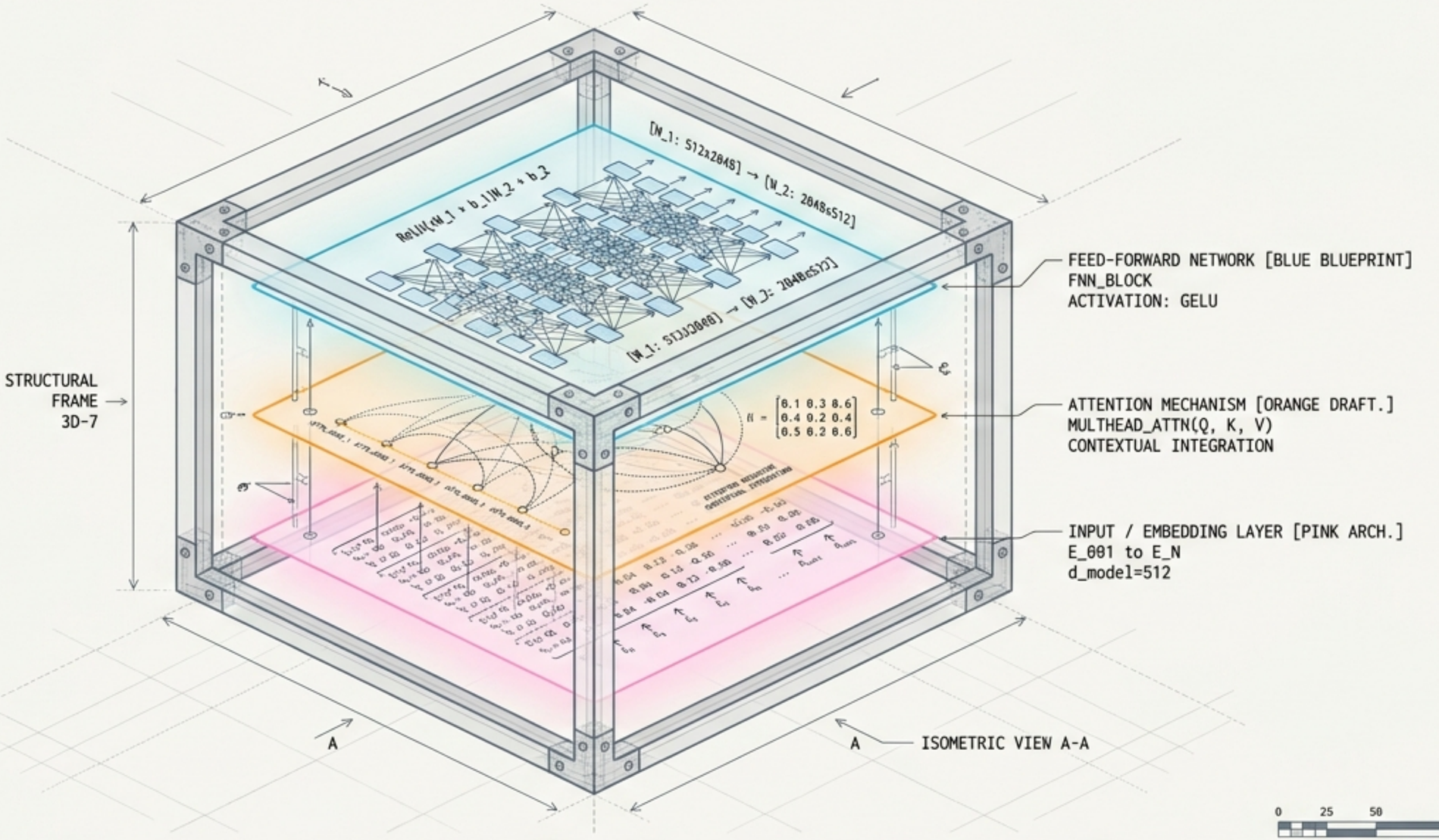

Anatomy of the AI Mind

An engineering blueprint of Large Language Models and the Transformer architecture.

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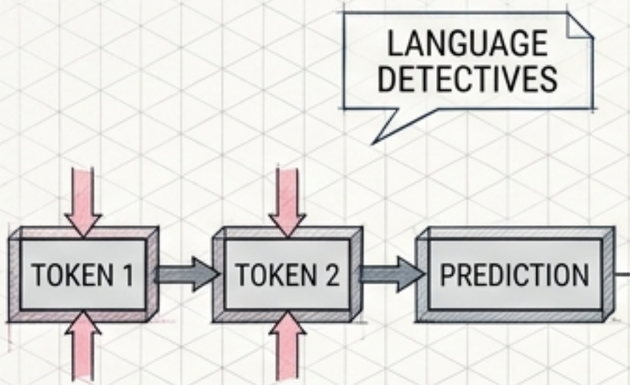
DRAWN BY: AI ARCHITECT	SHEET NO: 001

THE EVOLUTION OF NATURAL LANGUAGE PROCESSING

1. TRADITIONAL NLP (RULES & N-GRAMS)

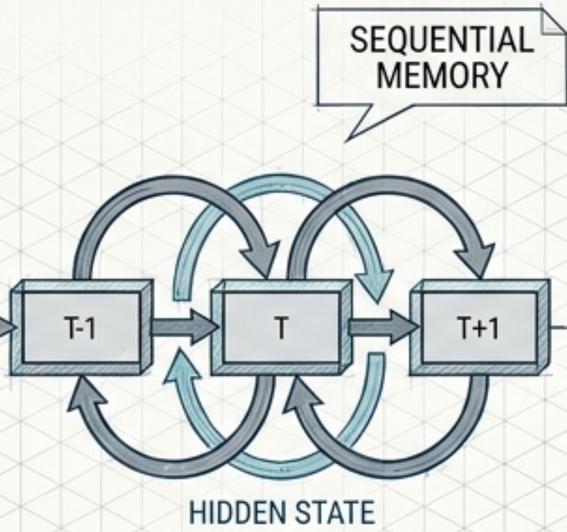


Predicts next words based on immediate predecessors.

Uses Naïve Bayes or Rules-based systems.

"The sky is" -> "blue"

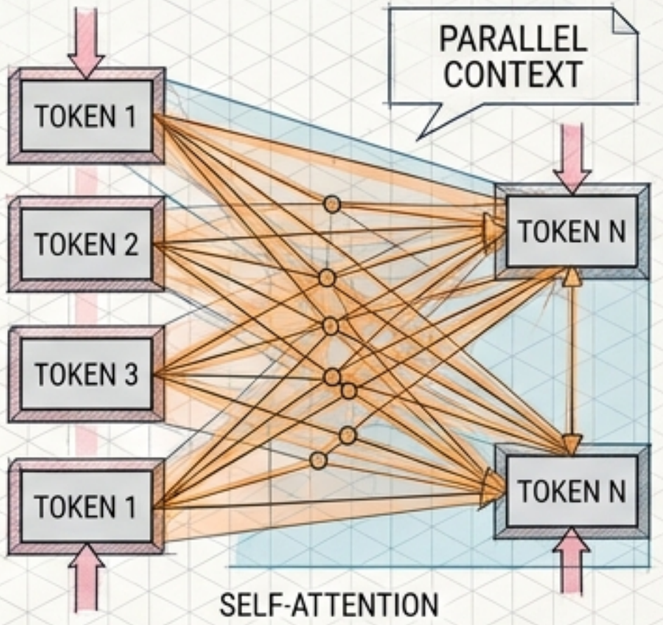
2. RECURRENT NEURAL NETWORKS (RNN/LSTM)



Handles sequential data using loops to maintain a hidden state.

Processes words one at a time. Struggles with long-range context.

3. TRANSFORMER-BASED LLMS



Uses self-attention to process entire sequences at once.

BERT, GPT, LLaMA, T5

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DATE: OCT 26, 2024

The 2017 Paradigm Shift: Attention Is All You Need

The Breakthrough

Proposed by Vaswani et al. at Google.

The Core Innovation

Replaced sequential processing (RNNs) entirely with highly parallelized processing.

Attention Is All You Need

Ashish Vaswani
Noam Shazeer
Niki Parmar
Jakob Uszkoreit
Llion Jones
Aidan N. Gomez
Łukasz Kaiser
Illia Polosukhin

The Mechanism

Introduced “Self-Attention,” allowing models to capture contextual information across extremely long sequences simultaneously.

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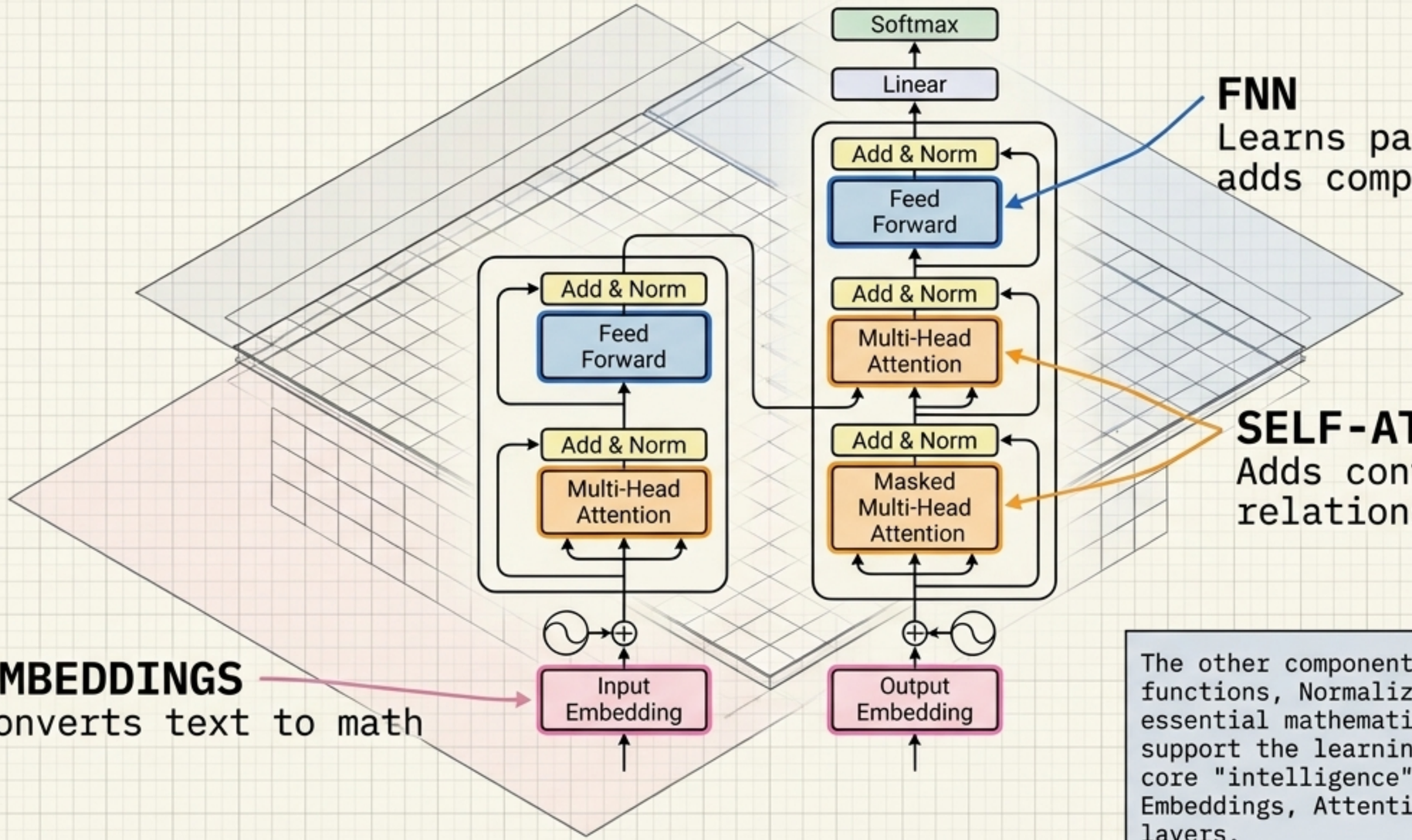
DATE: OCT 26, 2024

Deconstructing the Transformer Architecture



FNN
Learns patterns and adds complexity

SELF-ATTENTION
Adds context and relationships

EMBEDDINGS
Converts text to math

The other components (Sine/Cosine functions, Normalization) are essential mathematical operations that support the learning process, but the core "intelligence" resides in the Embeddings, Attention, and FNN layers.

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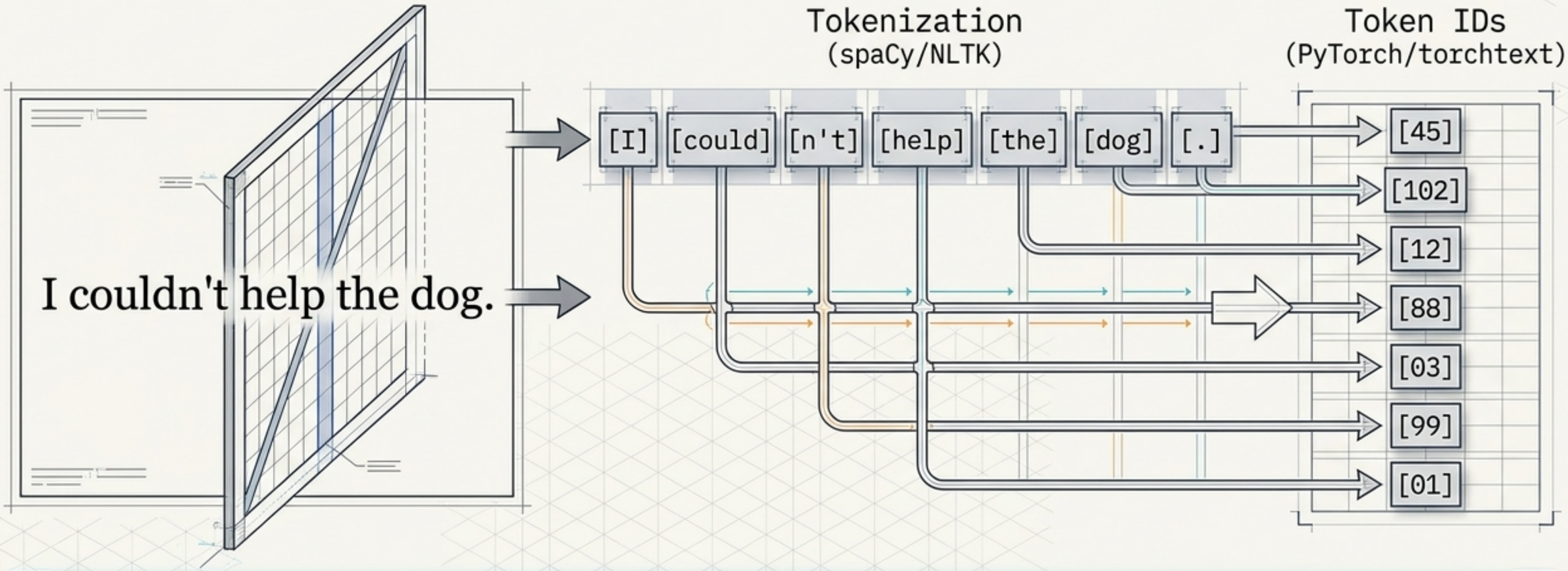
Bridging Human Language and Machine Logic



Deep learning models operate exclusively on numerical data. Tokenizers bridge this gap by breaking text into smaller units and assigning unique integers (Token IDs). Special tokens like **<unk>** (unknown), **<bos>** (beginning), and **<eos>** (end) manage sequence structure.

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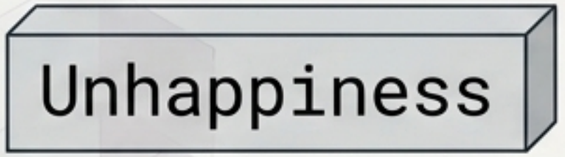
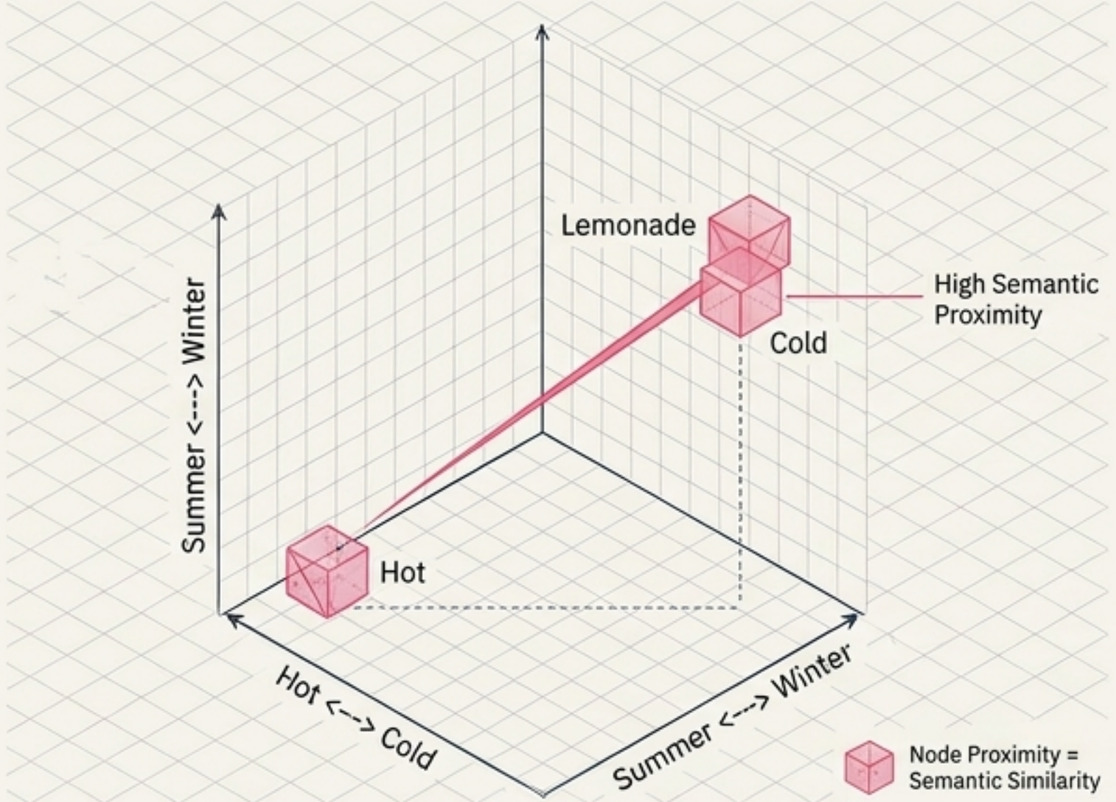
The Tokenization Matrix

Word-Based (nltk/spaCy)	Character-Based	Subword-Based (Transformers Default)
Mechanism Splits based on spaces/punctuation.	**Mechanism** Splits into individual letters.	**Mechanism** WordPiece / SentencePiece. Keeps frequent words whole, splits infrequent words into meaningful roots.
Vocabulary Size Massive.	**Vocabulary Size** Very small.	**Advantage** Balances vocabulary size with semantic preservation.
Limitation Treats "Unicorn" and "Unicorns" as completely unrelated concepts.	**Limitation** Single characters lack meaning; sequence length explodes, hurting performance.	
Visual Example 	**Visual Example** 	**Visual Example** 

Mapping Meaning into High-Dimensional Space

Semantic Space Visualization



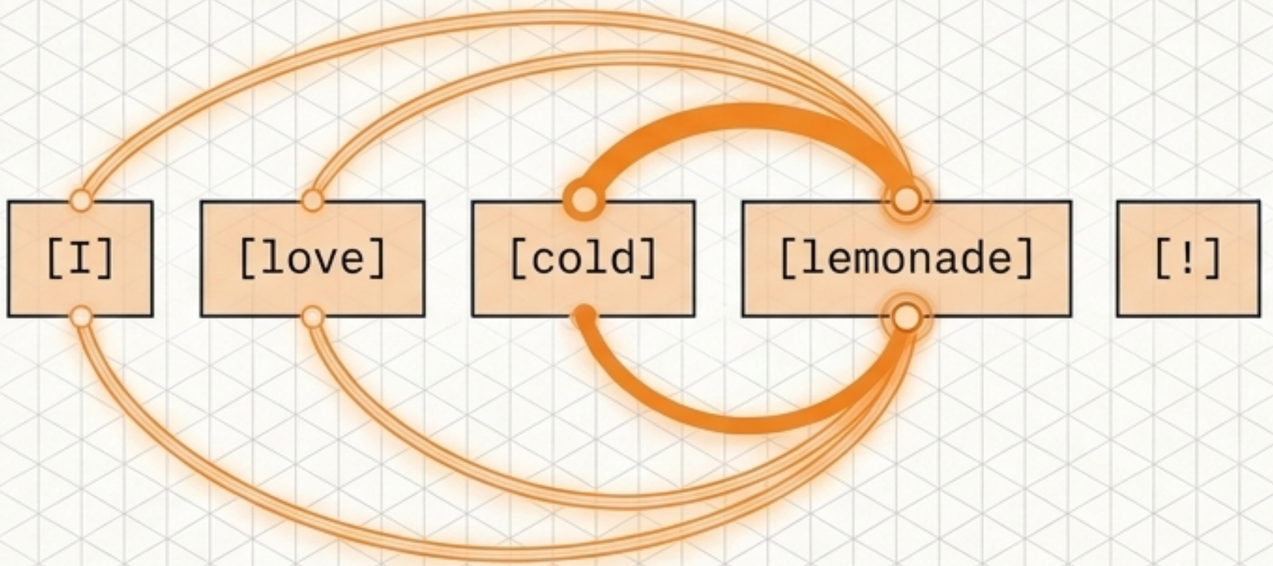
The 768-Dimension Vector Representation

token	dim1	dim2	...	dim768
I	0.16	-0.04	...	0.67
love	-0.21	0.59	...	0.33
lemonade	-0.11	0.35	...	-0.15

Given a vocabulary of 50k and 768 dimensions per token, the embedding matrix alone contains 38 million parameters. These parameters are randomly initialized and slowly updated during training until their locations in space represent true semantic meaning.

Self-Attention: The Web of Context

Without attention, the word 'lemonade' has the exact same mathematical location in "I love cold lemonade!" and 'I love Beyonce's Lemonade album."



The attention layer adjusts the meaning of each word based on context from surrounding words. It computes scores determining the importance of every other word in the sequence simultaneously.

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Calculating Attention: Queries, Keys, and Scores

Matrix 1: Queries (The Questions)

What a token is looking for.

	q1	q2	...	q768
Token 1	0.45	-0.12	...	0.45
Token 2	0.45	-0.12	...	0.26
...	...	...	...	...
Token n	0.23	-0.18	...	0.45
Token n	0.31	-0.29	...	0.75

Matrix 2: Keys (The Identities)

What a token actually is.

	k1	k2	...	k768
Token 1	0.16	0.13	...	0.26
Token 2	0.79	0.33	...	0.18
...	...	...	...	...
Token n	0.17	0.22	...	0.40
Token n	0.32	0.18	...	0.53

Attention Scores

	k1	k2	...	k768
...	0.26	0.88	...	0.89
...	0.17	0.34	...	0.41
...	0.36	0.92	...	0.97
...	0.21	0.47	...	0.01
...	0.12	1.06	...	0.02

Synthesis: When a Query matches a Key, an Attention Score is generated. This highly parallelized matrix multiplication is why Transformers can train on petabytes of data across multiple GPUs, completely outperforming older sequential models.

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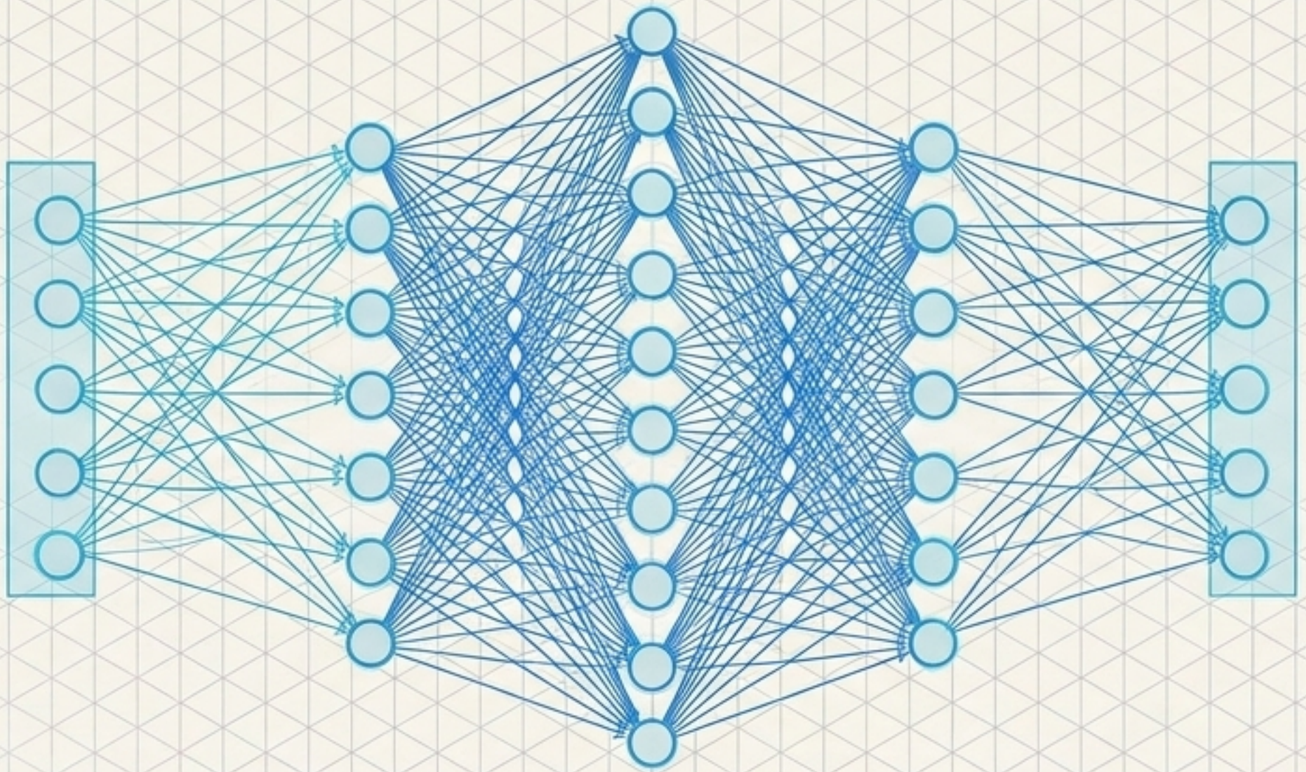
Feed-Forward Networks: Capturing Deep Complexity

Input Layer
768 nodes
(from Attention layer)



Output Layer
Contracts back
to 768 nodes

After attention is calculated, each position passes through this network separately.

While Attention learns **CONTEXT** (how words relate to each other), the FNN learns **CONCEPTS** (capturing complex patterns like noun-adjective relationships or abstract ideas).

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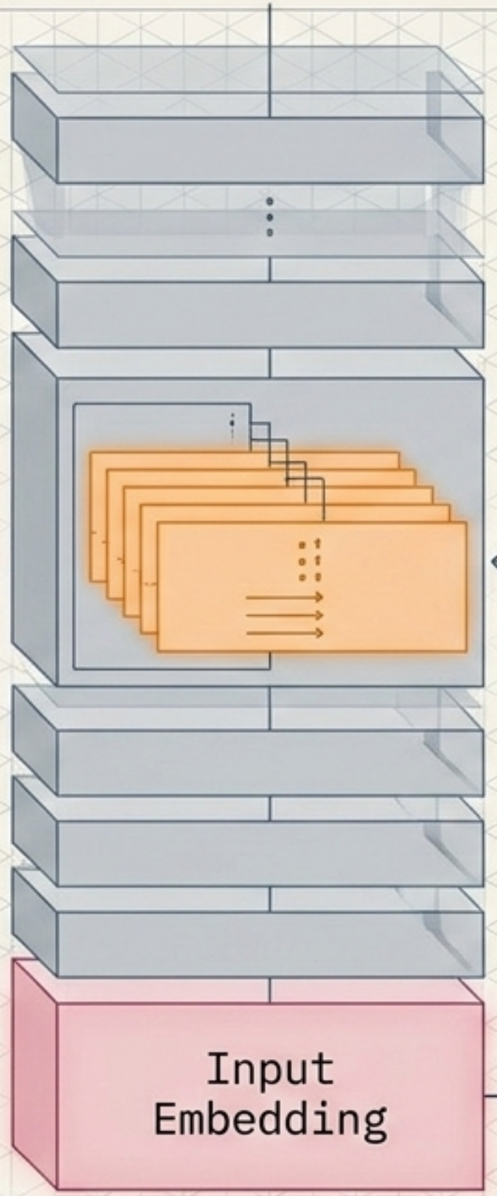
Stacking the Blocks: Multi-Head Attention



Multiple attention layers running in parallel (Multi-Headed Attention).

This entire Transformer Block is repeated 12+ times (or 24+ times for larger LLMs).

Positional Encoding: Because everything is processed in parallel, a sine/cosine function is injected at the base so the model remembers the sequential order of words.

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The Transformer Trinity

	Core Function	Training	Famous Model
Encoder-Only	Understands text. CONTEXT UNDERSTANDING	Masked → words. Masked Language Modeling (Predicting obscured words). **INPUT:** [CLS] The [MASK] sat on the mat. [SEP] **OUTPUT:** cat	BERT.
Decoder-Only	Generates text. GENERATION PROCESS	Autoregressive (Predicting the next token). **INPUT:** The quick brown fox... **OUTPUT:** ...jumps	GPT, LLaMA.
Encoder-Decoder	Translates/Transforms text. TRANSFORMATION FLOW	Sequence-to-Sequence. **INPUT:** Hello, how are you? **OUTPUT:** Hola, ¿cómo estás?	T5, BART.

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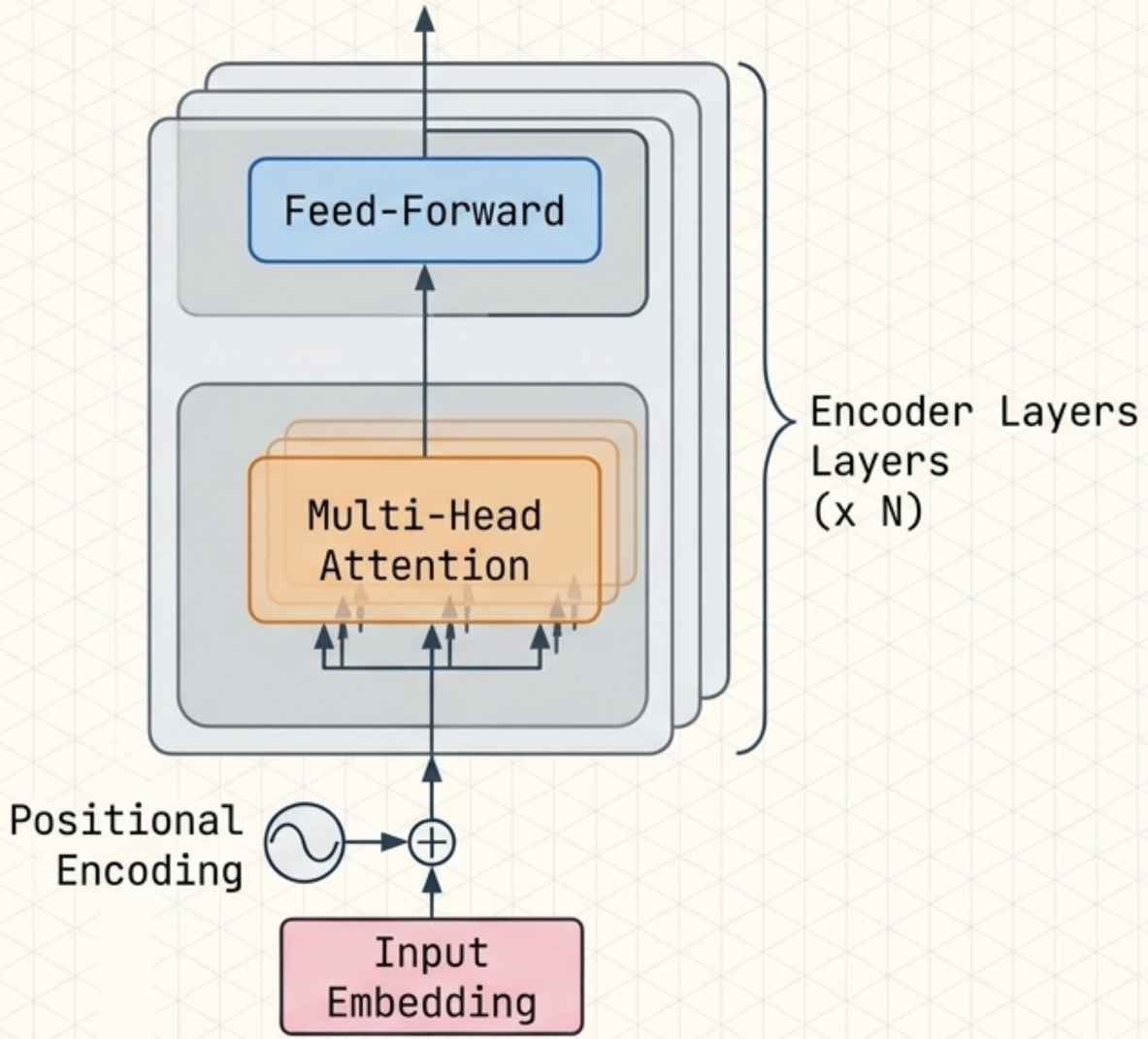
Encoders: Masters of Understanding



Mechanism

Takes raw text and encodes it into a rich embedding representation. It uses bidirectional self-attention to see the entire context of a sentence at once.

Practical Application

Sentiment Analysis, Text Classification.

Data

Input: "I love cold lemonade!"
Output: "[Positive]"

Training Method

Masked Language Modeling (MLM). The model is given "I love {MASK} lemonade" and must learn to output "cold".

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Decoders: Masters of Generation

Mechanism

Takes an input text sequence and uses a linear layer (lm_head) with softmax to output probabilities, inferring the very next word in a sequence.

Practical Application

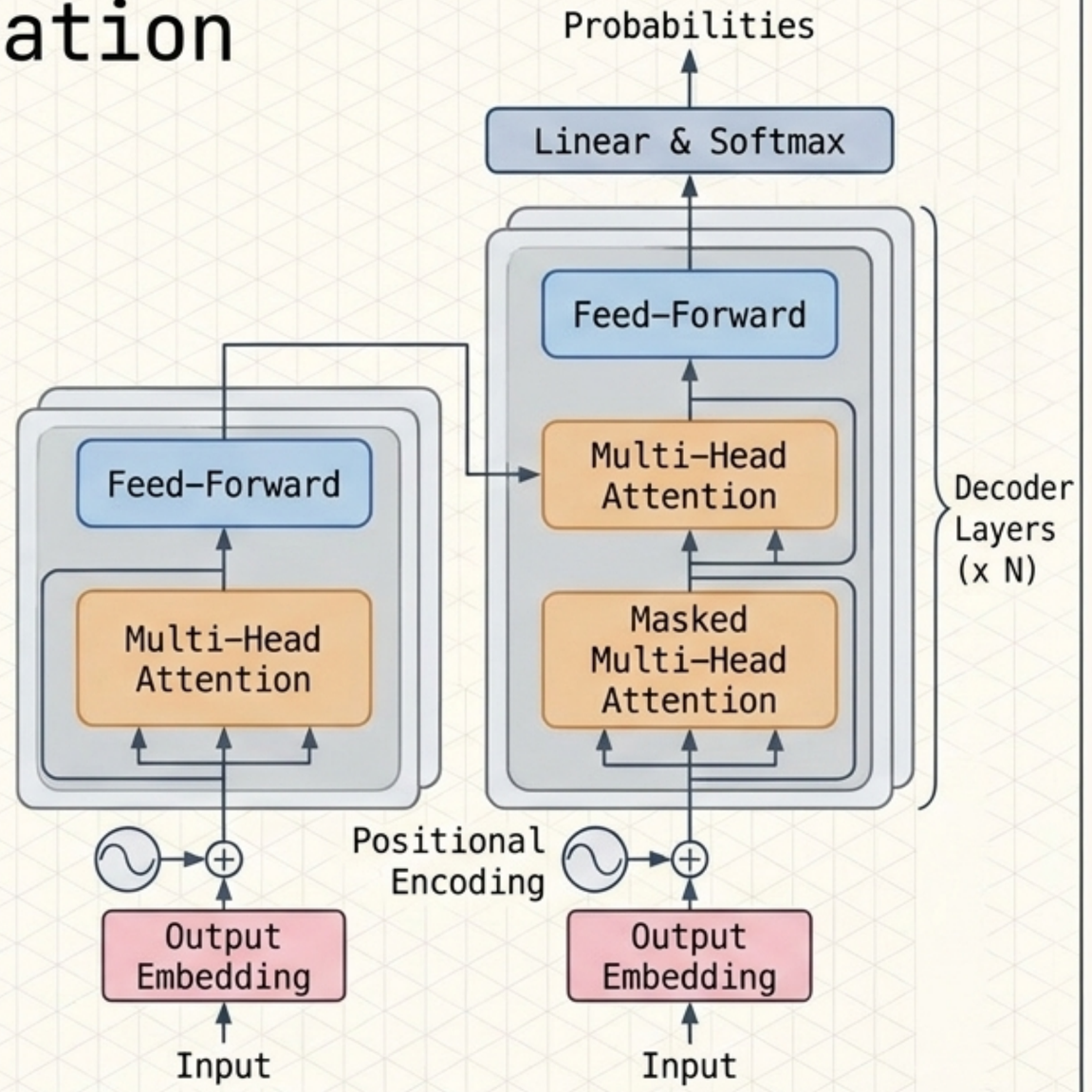
Text Generation, Chatbots.

Data

Input: "I love cold lemonade! It's the perfect..."
Output: "...drink!"

Training Method

Autoregressive Language Modeling. It learns by constantly predicting the subsequent token.



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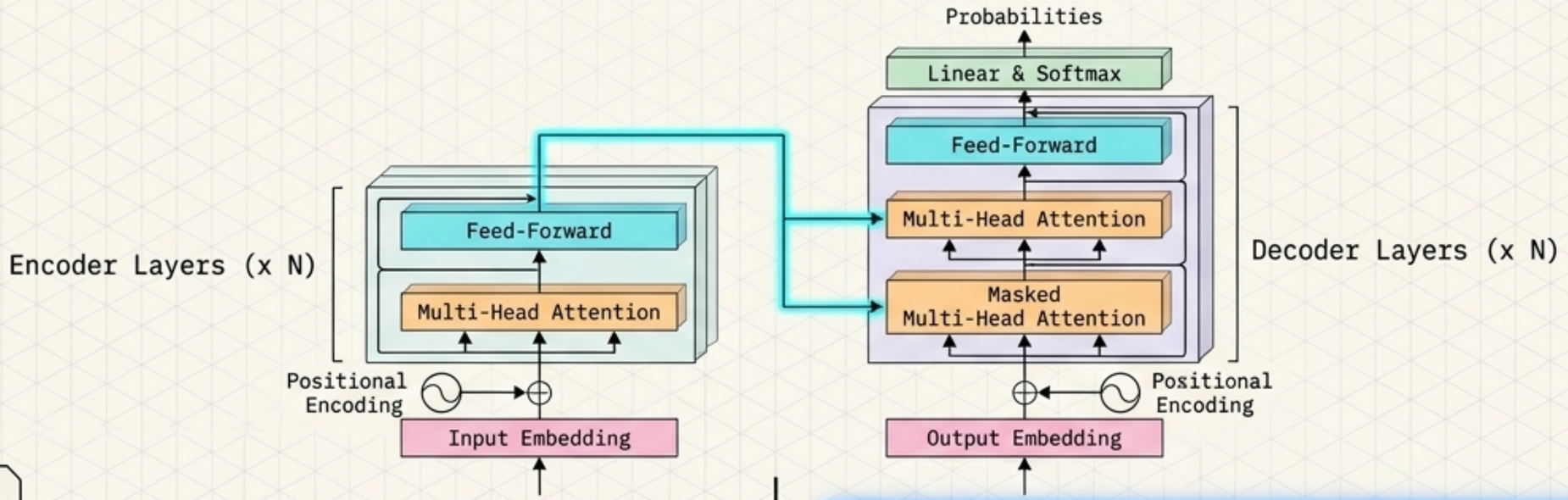
Encoder-Decoder: The Universal Translators



Mechanism

Takes two inputs: A source text sequence (fed to Encoder) and a shifted target sequence (fed to Decoder). The Encoder's fixed-dimensional memory representation is passed across to the Decoder's attention mechanism to guide generation.

Application

Machine Translation, Summarization.

Input: "I love cold lemonade!"
Output: "¡Me encanta la limonada fría!"

Conclusion

Whether predicting code, classifying legal documents, or translating languages, modern AI relies on the exact same fundamental blueprint: turning text into math, building webs of context, and stacking the layers deep. It is not magic; it is exceptional architecture.

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