BERT

The Architecture

Learning goals

- Understand the use of the transformer encoder in this model
- Understand the architectural components

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An embedding layer at the bottom of the network was complemented by three AWD-LSTM layers (Merity et al., 2017) and a softmax layer for pre-training.

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Compared to ELMo it is just **unidirectionally contextual**, since it uses only the decoder side of the Transformer. On the other hand it is **end-to-end trainable** (cf. ULMFiT) and embeddings do not have to be extracted like in the case of ELMo.

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October 2018 - BERT

BERT (**Devlin et al., 2018**) is a bidirectional contextual embedding model purely relying on Self-Attention by using multiple **Transformer encoder** blocks.

BERT (and its successors) rely on the **Masked Language Modelling objective** during pre-training on huge unlabelled corpora of text.

CONTEXT: ULMFIT AND GPT

Shortcomings of ELMo:

- No adaption of the Embeddings to target domain/task
- Sequential nature of LSTMs: Not fully parallelizable

Alleviations/Alternatives:

- ULMFiT ▸ Howard and Ruder, 2018 is a uni-directional LSTM which is fine-tuned as a whole model on data from the target domain/task.
- GPT ▸ Radford et al., 2018 is a Transformer decoder which is fine-tuned as a whole model on data from the target domain/task.

All three still not sufficient:

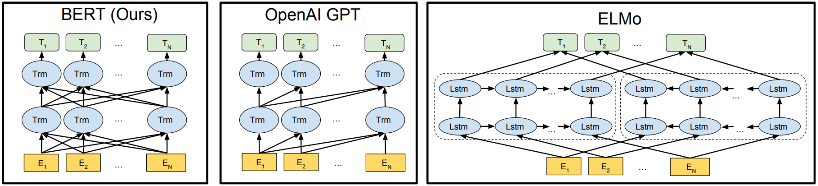
- *Bidirectionally contextual:* Only ELMo
- *Parallelizable:* Only GPT
- *Fine-tune whole model:* Only ULMFiT & GPT

BERT: KEY FACTS

***B**idirectional **E**ncoder **R**epresentations from **T**ransformers:*

- Bidirectionally contextual model
  $\rightarrow$ The embeddings of a single token depend on its left- and on its right-side context (similar to ELMo, but better)
- Completely replaces recurrent architectures by Self-Attention
  $\rightarrow$ parallelizable
- Model can fine-tuned as a whole

ELMO VS. GPT VS. BERT



Source: Devlin et al., 2019

Major architectural differences:

- ELMo uses two separate unidirectional models to achieve bidirectionality $\rightarrow$ Only "*shallow*" bidirectionality
- GPT is not bidirectional, thus no issues concerning causality
- BERT combines the best of both worlds:

$$\textit{Self-Attention} + (\textit{Deep})\ \textit{Bidirectionality}$$

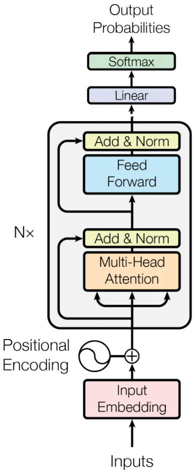
BERT: KEY FACTS

- New self-supervised objective(s)

  $\rightarrow$ MLM as *necessity* for the architecture to work

  $\rightarrow$ Next-Sentence-Prediction as complementary objective (cf. next section)
- Transformer *encoder* as backbone of the architecture
- 110M (340M) parameters in total for $BERT_{Base}$ ($BERT_{Large}$)
  - 12 (24) Transformer encoder blocks
  - Embedding size of $E = 768$ (1024)
  - Hidden layer size $H = E$
  - $A = H/64 = 12$ (16) attention heads
  - Feed-forward size is set to $4H$

CORE OF BERT – TRANSFORMER ENCODER



▸ Vaswani et al. (2017)

A REMARK ON "CAUSALITY"

Causality is an issue!

- Goal: Learn contextual representations for words/tokens
- *Self-Supervision:* Input and target sequence are the same
  $\rightarrow$ We modify the input to create a meaningful task
- ⚠ Unconstrained Self-Attention makes using the LM objective infeasible
- **Question:** Why is this the case?

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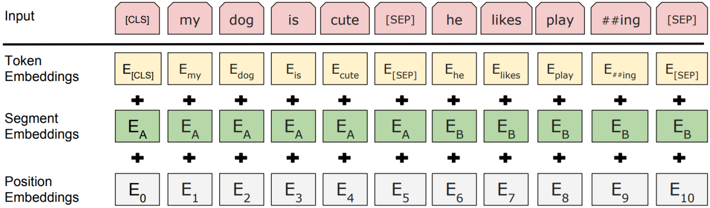
  Bidirectionality at a lower layer would allow a word to see itself at later hidden layers
  $\rightarrow$ The model would be allowed to cheat!
  $\rightarrow$ This would not lead to meaningful internal representations

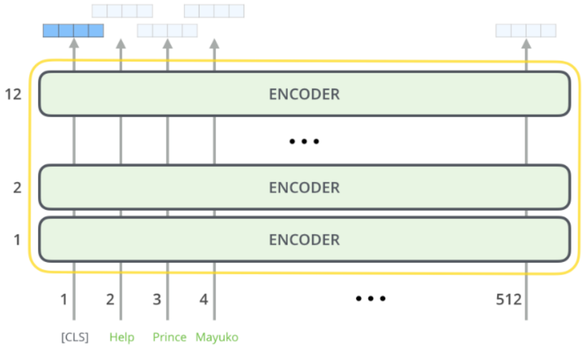
BERT – INPUT EMBEDDINGS



Source: Devlin et al., 2019

- Two concatenated sentences as input
- WordPiece tokenization Wu et al., 2016 for the inputs
  $\rightarrow$ Vocabulary of 30.000 tokens
- *Learned* segment + position embeddings
- Special `[CLS]` and `[SEP]` tokens

BERT – ALL EMBEDDINGS



Source: Jay Alammar

- One embedding per token per layer
- Non-contextual embeddings in the very first embedding layer
- More contextualization deeper into the model

BERT – THE ROLE OF [CLS] AND [SEP]

Why deliberately include extra "words"?

- The `[CLS]` token serves as an overall embedding for representing the whole sequence
  $\rightarrow$ Later on (cf. next chapter) BERT can thus used for classifying whole sequences
  $\rightarrow$ Can be extracted and used for clustering or similar
- The `[SEP]` (short for "'separator') token serves as a "signal" for the model when used for taks on pairs of sequences

Note:

- One further "special" token: `[UNK]` for representing unknown tokens or symbols (so the don't "break" the model)