Contents

Summary of *Structure*

Structures are necessary components for us human beings to grasp physical and artificial worlds[1] with limited representational capacity[2]. The opposite would be instead keeping all, potentially infinite, manifested instances in our memory without any abstraction. With structures, we can effectively perceive reality as a collection of elements and their assembling with relations or hierarchy. By this cognitive process, our minds allow us to know the world and make sense of what is happening in it, ideally leading to consistent and rational behaviour.

Similarly, when building knowledge engines for intelligent agents, structure formation emerges as a key factor. While the structured paradigm explicates structures through data and trains models to capture them, the unstructured paradigm seems to directly rely on specific computational graphs (e.g. deep transformers) and massive pretraining corpora without any predefined schematic structures. This sharp difference in the treatment of structures has led to the tension between the two paradigms, with the current fashion in favour of the unstructured paradigm. Scaling language models on larger datasets tends to be the preferred answer to artificial intelligence while knowledge graphs being left out in the cold.

In this part, however, we reveal a deep connection between the two paradigms. Specifically, we have demonstrated that training models with language modelling objectives picks up structural patterns in embedding-encapsulated models, regardless of whether we are working within a structured or unstructured paradigm. In other words, structures naturally arise when the learning objective attempts to model the surrounding environment through a self-supervised, language modelling approach, as illustrated in Figure

[1] E.g. a fictional universe or societal traditions.

[2] The brain operation is bounded by its energy supply from the body and can be sensitive to working environments e.g. the psychological contexts.

3.9.

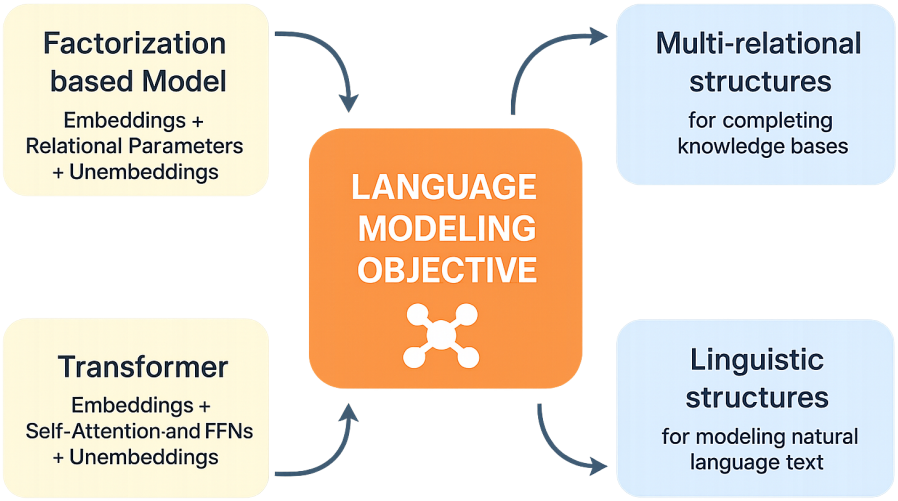

Figure 1: Language modelling objective over embedding-encapsulated models drives the acquisition of structures for both structured and unstructured learning paradigms.

When we consider such a structure formation process induced by training with language-modeling objectives, the surficial tension between structured and unstructured paradigms – as exemplified separately with knowledge graphs and large language models – thus shrinks: they both rely on structures, be they in data or in the models, and language modeling helps both form meaningful structures in the models; it is just that one encodes structures deeper in the models via training with sometimes arbitrary or even "magic" corpora choice, while the other uses structures more straightforward. These forming[3] and formed structures are fundamental to both paradigms, and crucial for downstream tasks such as text or graph completion and for broader representation learning.

To conclude this part of the thesis, we would like to prompt the readers' brain with a question on structures in artificial intelligence and perhaps for our own brains: Are structures always helpful for the artificial intelligence agent's performance? And to what extent do these embedded structures advance or constrain model generalization across

[3]At this moment, someone may be training a large language model, which is forming some structures about our physical world or about some artificial reality.

scenarios? These structures definitely offer efficiency in knowledge representation and retrieval, but at the cost of demanding queries of more formal terms, usually needing to align with the language used to form the structures Can they be that flexible when dealing with informal knowledge in unseen formats or new knowledge?

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