# The Notion of Semantic Simulation

D. Gueorguiev ~~2/11/2023~~ 3/10/2024

I am personally interested in LLMs and the problem of modeling human-like reasoning in general. Related to this is my interest in tackling in a coherent way the problem of modeling of semantic inferences as well as causal inferences and counterfactual logic.

Specifically, I am looking into a semantic simulation model which will be capable of *semantic inference* in which semantic structures, loosely representing parts of thoughts, are governed by *equations of evolution* in a *dynamical system*. Let me expound on the latter. I believe that in order to model human-like reasoning we need to pose the problem of extracting semantic meaning and generating semantic inferences in a different way than the existing methods adopted in LLMs. That is – we will define a *semantic simulation* as a process in which appropriately defined laws are governing the evolution through time of semantic structures populating the *semantic space* (or *simulation space*)*.* Here *semantic space* is defined as a metric space with *N* dimensions. The chosen metric in that space is *the semantic distance*. Let us assume that this semantic environment accepts textual input which is partitioned into *text quanta*. A *text quantum* represents a portion of the textual information with inherent semantic meaning. Each new set of quanta introduced to the environment will result in creating a new *semantic structure* in the metric space. Think of this structure as a collection of *semantic particles* in this space. This collection of particles evolves using some laws of attraction and conservation of certain quantities defined in that metric space. Each semantic particle has intrinsic properties which characterize it. One intrinsic property to every semantic particle is its *semantic mass*. Another intrinsic property to each semantic particle or *an ensemble of particles* is its *semantic energy*. Semantic energy is acquired by a particle or an ensemble of particles while the latter are travelling through semantic space which is permeated by the *semantic energy field*. The semantic energy acquired by a particle or ensemble of particles depends on the *semantic signature* of the later. The propensity of semantic structures and particles to combine together in larger semantic structures is modeled via *semantic attractive / repulsive forces*. Introducing new structures (corresponding to new textual input in the environment) in this space will alter the position, the movement and the composition of the existing structures. The distance (the metric) between two structures in that space will correspond to their semantic similarity. The closer semantically are two structures the smaller the distance between their centers.

~~Reinforcement learning in this environment is implemented via the mediation of particle properties such as the semantic energy of the particle. Specifically, the acquired semantic energy of a semantic particle depends on its trajectory before the present moment and past trajectories of other particles. In turn the current position and the future movement of the semantic particle will depend on its semantic mass and acquired semantic energy.~~

Reinforcement Learning in the semantic simulation environment is implemented via the mediation of the *semantic energy field* which permeates semantic space. The trajectory of the semantic particles in an ensemble will depend on the current semantic energy of the ensemble and the *semantic signatures* of the particles in the ensemble. While each particle in an ensemble moves through semantic space toward the *true semantic in-situ position* of the ensemble an additional semantic energy is acquired by the particle in the process. The final position at true semantic position of the ensemble will depend on the semantic signatures, the masses, and the energies of its constituents. As each ensemble moves through specific location in Semantic Space it leaves a mark on the energy field in that location. In other words, the energy field is *altered* (appropriately small delta by magnitude) in each location on the trajectory of the ensemble towards its true semantic in-situ position. The way the energy field is *altered* by the passing ensemble is subtle and signature dependent. If another ensemble of particles approaches the same location it will be more likely to pass through that location if it has *relevant combined (ensemble) semantic signature* and it will be less likely to pass through that location if it has *adverse ensemble semantic signature*. That is, the energy alteration in specific region of semantic space would be *conducive* for an ensemble with relevant *semantic signature* and would be *repelling* an ensemble with adverse semantic signature.

Additionally the duration for which those alterations (or disturbances) of the semantic energy field last depends on how much the semantic structure which caused them has been used in inferences.

Thus the described alterations of the energy field in semantic space introduce a feedback mechanism to tune the trajectories of ensembles which will be entering the system in the future based on the current state of the system.

The idea here is to combine the effect of the semantic attractive / repulsive forces mentioned in the first paragraph with the effect of the altered semantic energy field to guide the semantic ensembles entering the system toward their true semantic position. The important thing to recognize in order to make this mechanism work is that the semantic attractive and repulsive forces cause deviations in the ensemble trajectory on a smaller scale than the scale at which the altered semantic energy field acts over the ensemble trajectory. That is, the semantic attractive and repulsive forces will start affecting the trajectory of a semantic ensemble travelling toward its true semantic position only if it is close enough to the particles or structures which exert the aforementioned forces. That is, the semantic forces are local in nature while the alterations in the semantic energy field have global effect since semantic energy can be carried by the ensemble in semantic space.

*Inference in semantic space* is done by recognizing patterns in the created structures and their trajectories. Matching the recognized patterns will lead to creating new structures. The inherent semantic properties of the newly created (inferred) structures will determine the motion and trajectories of the latter which in turn will influence the already existing semantic structures. Hence semantic inference will alter the semantic distances and composition of the structures in proximity of the newly inferred structures. Thus, semantic Inference will alter the semantic meaning assigned to the points in the region of interest.

For the purpose of understanding and modeling semantic Inference it is defined a new construct *Semantic Template*.

Each semantic template is a composite structure which exists in a different than Semantic Space metric space which will be denoted as *Template Space*. Each *Semantic Template* is composed of two types of template structures – *Pattern Matching Structure* and *Inference Structure*. The *Pattern Matching Structure* is *bound to* specific region of *Semantic Space* which it tracks for certain patterns. The patterns of interest are the presence of certain semantic signatures with certain trajectories. As soon as it detects a pattern which it is tuned to recognize the *Pattern Matching Structure* activates the *Inference Structure* of the same template. In result, the Inference Structure produces an Inferred Semantic Structure in specific place and time in Semantic Space. In effect the Inference Structure is also bound to a region in Semantic Space in which it creates the newly inferred structure. Thus, we say that the Semantic Template has been *triggered* and has *produced an inference*.

Further study on semantic templates and their desired properties is required. However, certain desired properties and behavior of the Semantic Templates are obvious even at this moment.

~~The semantic templates will behave as a special kind of semantic structures confined to their own region of Template Space.~~ Each semantic template will be bound to а region in Semantic Space (not necessarily *simply connected*) which will track for patterns it is tuned to recognize and in which it will create inferences. Each Semantic Template will follow certain equations of evolution in Template Space which will govern its motion and the aggregation with other Semantic Template structures to produce more complex Template Structures. The simplest possible way to aggregate semantic templates is via chaining.

A simple example of *chained templates* is discussed in [the document](https://github.com/dimitarpg13/aiconcepts/blob/master/docs/SemanticStructures/PracticalExamplesUsingSemanticSimulationWithRL.docx). (**TODO**: this document needs to be revised heavily).

More on the aggregation of Semantic Templates-

Similarly to the regular semantic structures template structures can be attracted to or repelled from each other.

//TODO: finish this paragraph

We need to understand the meaning of the metric *distance* in Template Space – what does it mean for two Template Structures to be close to each other in Template Space? Does it mean that regions in Semantic Space they are bound to will be close? Or it means that the kind of patterns they are going to recognize will be somewhat similar? How does the Inference Structures factor in the definition of a distance between two Semantic Templates? So the completion of the Semantic Template concept will depend on finding meaningful answers to these questions.

## What's Next?

There are three topics in Semantic Structures which need to be completed as I feel those are of importance to the whole idea of semantic simulation by using a dynamical system. Those topics are:

1. Modeling of the aggregation of Semantic Structures via attractive / repulsive forces acting on the former and via their interaction with the semantic energy field: The idea is to combine the effect of the semantic attractive / repulsive forces with the effect of the altered semantic energy field to guide the semantic ensembles entering the system toward their true semantic position. The important thing to recognize in order to make this mechanism work is that the semantic attractive and repulsive forces cause deviations in the ensemble trajectory on a smaller scale than the scale at which the altered semantic energy field acts over the ensemble trajectory. That is, the semantic attractive and repulsive forces will start affecting the trajectory of a semantic ensemble travelling toward its true semantic position only if it is close enough to the particles or structures which exert the aforementioned forces. That is, the semantic forces are local in nature while the alterations in the semantic energy field have global effect since semantic energy can be carried by the ensemble in semantic space. Need more work on the energy field based mechanism of guiding semantic structures toward their true semantic in-situ position.  
   Need more work on the model of attraction / repulsion of semantic structures via semantic associations / disassociations. Need to clarify how this mechanism will work together with the energy field based mechanism to synthesize the correct semantic structure after some evolution and how the newly formed semantic structure will eventually reach its true semantic in-situ position.
2. Completing the modeling of Semantic Inference via Semantic Templates: We need to understand the meaning of the metric distance in Template Space – what does it mean for two Template Structures to be close to each other in Template Space? Does it mean that regions in Semantic Space they are bound to will be close? Or it means that the kind of patterns they are going to recognize will be somewhat similar? How does the Inference Structures factor in the definition of a distance between two Semantic Templates? So the completion of the Semantic Template concept will depend on finding meaningful answers to these questions.
3. Elaborate how exactly Reinforcement Learning would be applied to variety of concepts in Semantic Space:

a) for Semantic Energy: through alteration of the semantic energy field to find the true semantic in-situ positions of semantic structures.

b) for Association / Disassociation Links: recall those are the mediators of the attractive/repulsive forces between particle ensembles in Semantic Space. Strengthening / weakening those should happen based on previously made connections and resulting inferences.

c) for Semantic Templates: through modifying templates parameters, such as the bound region of the template, based on past inferences.

d) for Semantic Templates: through modifying the laws of aggregation of Semantic Templates (need to work first on the laws of aggregation of the latter)

Hint: pose each of those problems as online optimization problems which can be solved with appropriately chosen policy-based or value-based RL formalism.

There is a more advanced topic which I would like to gain better understanding and have clearer idea in my mind about. This is topic of Hierarchical Semantic Template Spaces.

## Hierarchical Semantic Template Spaces

//TODO: finish this topic overview

More details on this simulation environment as well as key definitions and formulations can be found in the links below:

<https://github.com/dimitarpg13/aiconcepts/blob/master/docs/SemanticStructures/OnTheNeedofDynamicSimulationWhenModelingInteractionsOfSemanticStructures.docx>

<https://github.com/dimitarpg13/aiconcepts/blob/master/docs/SemanticStructures/ModelingAttractiveRepulsiveForcesInSemanticProperties.docx>

<https://github.com/dimitarpg13/aiconcepts/blob/master/docs/SemanticStructures/ReinforcementMechanismInSemanticStructureModels.docx>

<https://github.com/dimitarpg13/aiconcepts/blob/master/docs/SemanticStructures/SemanticTemplates.docx>

<https://github.com/dimitarpg13/aiconcepts/blob/master/docs/SemanticStructures/PracticalExamplesUsingSemanticSimulationWithRL.docx>