TEMPORAL DENSITIES

An information structure to situate agents in time

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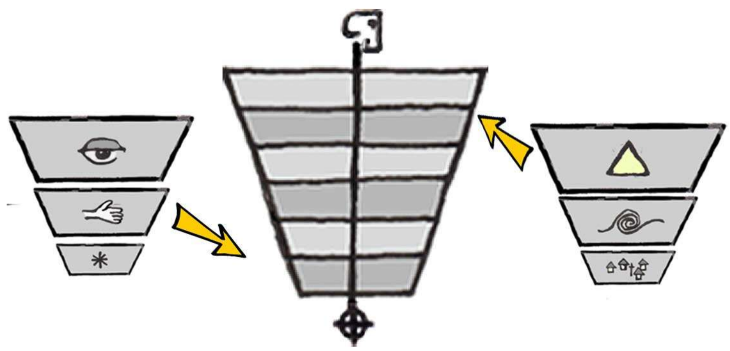

*This informal paper describes **Temporal Densities**, an information structure that can model an agent in the temporal dimensions of its environment. It describes how this representation allows the agent to situate its existential and functional objectives in multiple temporal contexts while concurrently generating behaviour in the here-and-now. This paper summarizes a concept first introduced and discussed at greater length in **The Meca Sapiens Blueprint**.*

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MODEL-BASED REPRESENTATION

The monitoring and control systems of Autonomous Intelligent Agents (1,2,3) operating as physical entities in a natural environment maintain dynamic predictive representations, or models, of themselves in interaction with other entities in their environment. The entities represented in these models can be directly derived from sensor data or cognitively constructed independently of sensor inputs. Military drones, self driving cars and remote weather stations are some examples of AI agents. By extension, the "agents" in this paper also includes larger systems such as offshore drilling platforms.

In all these cases, the system's physical presence in its environment is embodied in a well defined and located set of structures and peripherals such as sensors and actuators in continuous interaction with other entities in its environment. The monitoring and control system of the AI agent internally models this presence and these interactions as a dynamic representation of "itself". These models can be relative or absolute. They can also be sensory-based or cognitive.

By extension, the term agent refers, here, not only to the AI agent as a physical entity but also to the monitoring and control system that generates its behaviour. Similarly, the term model also refers, specifically, to the internal representation of an agent in relation with other entities in its environment.

Temporal densities allow an agent to concurrently maintain absolute cognitive models of itself in multiple temporal durations while generating behaviour in the here and now.

Relative and absolute models

Models can represent the agent in either a relative or an absolute view.

In the **relative view**, the model interprets the agent or another entity as a stationary point and locates other entities in reference to it. The display of a ship's radar that situates entities around a fixed reference point generates a relative view. The relative view needs not be geographic. In relative terms, a child lives among giants and an old man in a youthful crowd.

In the **absolute view**, on the other hand, is the reference is a representation of the environment and the entities are situated within its common schema.

In summary:

- A **Relative Model** situates entities in relation to a single point of reference within the environment.
- An **Absolute Model** situates entities in relation to a common environment that contains them.

Absolute representations provide an additional level of capability. An absolute model can be translated into many distinct relative views by choosing any entity within the common environment as reference point. In a relative view, on the other hand, some entities may obstruct others preventing the generation of a complete absolute model.

Sensory and Cognitive Models

An agent dynamically generates representations of the entities in its environment. Some of these representations may be directly linked to current input from its sensors. Others may be constructed entirely cognitively, independently of any current sensory inputs.

In a sensory model, all the entities are directly linked to sensor inputs. In a mixed model, some entities are linked to sensor inputs and others are purely cognitive. In purely cognitive models all the entities are cognitive constructs. Some of these cognitive constructs may represent entities that, in other situations, would trigger sensory inputs in the agent. They may also include entities that will never have a sensory presence.

In sensory-based models, the identity of an object may be mistaken but not its presence. A Cognitive model is independent of sensory input.

The model characteristics of sensory, mixed, cognitive on the one hand and relative, absolute on the other are orthogonal. Models can be sensory/relative, mixed/absolute and so on.

The Absolute Cognitive Model is of particular interest. It combines the characteristics of absolute and cognitive representations. An Absolute Cognitive Model is an absolute model where all the entities are cognitive constructs.

Absolute cognitive models significantly expand the internal representation capabilities of agents in both time and space. Since all their entities are cognitive constructs, absolute cognitive models are free of any spatial, representational or temporal limits. They can represent any time past present or future, be located anywhere and contain anything.

Example. A rat that has the cognitive capability to generate **relative models** is learning to "solve a maze". As it navigates the maze, it remembers and discards multiple relative unsuccessful patterns. It eventually discovers a "non unsuccessful" pattern and gets the cheese. A (genetically altered) rat with **absolute cognitive model** capability looks at a map of the maze. Before entering, it internally generates tests multiple pseudo-relative views of maze behavior derived from the (absolute model) map of the maze. When it cognitively finds a successful sequence, it enters the maze once and gets the cheese.

Humans can formulate absolute cognitive models. It allows them to build representations of reality that extend far beyond their sensory range in both space and time. It provides, in my view, an extraordinarily useful survival advantage. However, the capability to generate entities that have no sensory presence has also been the source of a multitude of ambiguities, misconceptions and errors. All the religious and philosophical beliefs of mankind, over the last five thousand years, are by-products of a mode of cognition based on absolute cognitive modeling. Of note, an entity that has the cognitive capability to generate absolute cognitive models can "know death" in the sense that it can represent itself as a dead entity in the future.

MODEL HORIZONS

Sensory horizon

The type of model determines its "**horizon**", its spatial, temporal and conceptual boundaries.

A model simplifies a situation to retain a limited number of entities and their interactions. The space in which these interactions occur and their duration defines the horizon of the model. In models that are sensory or mixed, some or all these entities are associated to sensory inputs. In these models, entities enter interact and leave the sensory range at a certain distance and over a certain duration.

The sensory and mixed models of an agent are thus confined to the duration and space delimited by the limits of its sensory inputs and the behaviour of the significant entities that populate it. These models represent what can refer to as the **here-and-now** of the agent: the "**here-and-now**" of an agent is the model horizon of its sensory and mixed models.

The duration of this "here-and-now" is not set. It depends on the agent, the range of its sensory capabilities and the evolution of events affecting the entities within a pertinent model. The "here and now" of a human can range from a few seconds to about an hour. For example, a skier experiences it at the two-second duration while he is engrossed in the downhill run but it may span fifteen minutes when he is sitting in the chairlift. Similarly, the here and now of a shrew differs from that of a whale.

Cognitive horizon

Agents that can generate absolute cognitive representations of their situation can populate these representations with entities that are not linked to any sensory input. They can also position these constructs in any place and over any duration. Consequently, cognitive Models are not bound by sensory limits.

The cognitive horizon of an agent is the range (space and duration) it can represent in its cognitive models. The horizon of absolute cognitive models are not delimited by sensory feedback, they are solely set by the cognitive constructs that are included in their formulation.

In ancient cultures, the horizon of cognitive models where delimited by what they could represent: the types of entities that could be imagined and the durations that could be conceived. For example, a tribe unable to count beyond 3,000, could only generate cognitive models whose duration lay within that range. In our culture, Cognitive models can span any conceivable duration, from a millionth of a second to a trillion years and be located anywhere in a space that may include multiple universes. The entities that populate them are also virtually limitless.

In other words, the horizon of a cognitive model can be anything an agent can “imagine” but cannot be anything that it cannot “imagine”.

TEMPORAL DENSITIES

Agents that can only generate relative sensory and mixed representations are cognitively limited to models located in the here-and-now. Consequently, their representations of the environment and predictive processes can all be based on models whose horizon is the “here and now”.

Agents that can generate absolute cognitive models, on the other hand, can formulate representations that contain any conceivable thing, span any duration, from an instant to eons, and be located anywhere. They can thus situate themselves, simultaneously, in a possibly limitless number of separate temporal and spatial contexts. A cognitive simplification of this information into entities interacting within a single space is not sufficient. A temporal structuration is also needed.

Cognitively, the agent with absolute cognitive model capability can simultaneously inhabit any location or duration. It is, thus, temporally multidimensional. On a practical basis, however, the physical behaviour of this agent continues to occur solely within the here and now defined by its sensory horizon. The agent must resolve a potentially limitless number of predictive models that occur in unbounded and overlapping temporal durations into a unified and coherent behaviour that occurs solely in the here-and-now.

At first glance a simplification of the cognitive horizon, where events and their representation can have any duration, seems impossible since time is (perceived as) a continuum and thus, the number of possible durations, and their corresponding models, is infinite.

The key to achieve meaningful here and now behaviour that takes into account absolute cognitive models that can span a potentially infinite number of durations is to discard the vast majority of these temporal representations keeping only a discrete subset of models that are organized in a simple, discrete and flexible partition where they can be cognitively processed separately. In my view, if such an entity had subjective experience, it would perceive itself as inhabiting a limitless temporal continuum while cognitively residing, in fact, in a small number (a dozen or so) of temporal layers.

I refer to this structure of discrete temporal levels as**: Temporal Densities.**

Temporal Density Structure

The behaviour of an agent takes place in time. If the agent is a model predictive system, it can generate multiple concurrent predictive representations of its situation and resolve these coherently to produce a unified behaviour. If the agent has only sensory modeling capability, all these representations share the same spatio-temporal context and can be readily resolved.

If the agent has absolute cognitive modeling capability, these multiple representations can consist of hundreds and thousands of separate dynamic models whose current and predictive model-states have entirely different entities, span temporal duration of any length, overlap or be contained within each other.

At any moment, the representations of the situation generated by an agent with absolute cognitive capability can include a model that spans the duration of the universe and another that is limited to the events that take place when sipping a cup of tea.

Temporal Densities are structures that organize this population of temporal models. At each level consists of a single model that has multiple sequential and adjoining states. All the states of a lower level are entirely contained within a single state of the higher level model. Consequently, events in a lower level model take place within unchanging higher level representations.

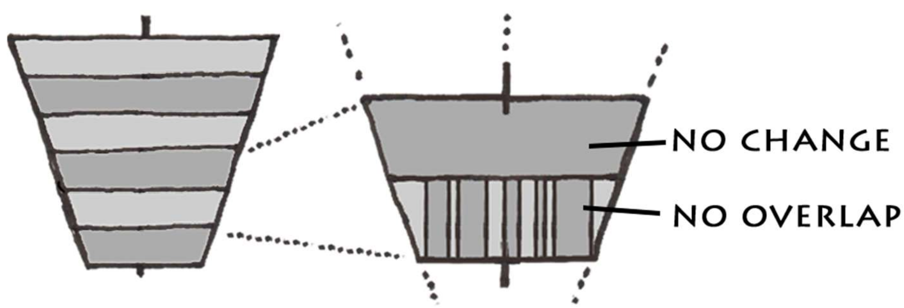
Definition: Temporal densities

Temporal densities are a finite set of dynamic models of varying durations organized on the basis of their duration such that:

- *every dynamic model is exactly contained in one and only one steady state representation of a higher level dynamic model of longer duration;*
- *none of the durations of a given level overlap*
- *all the representations of a lower level, together, exactly span, with no gaps, the duration of one steady state representation of the higher level.*

Temporal densities are organized in levels. By convention, the lowest level consists of model-states that do not contain any lower level states and the highest state consists of a single steady state model whose duration spans all conceivable time.

Separate temporal densities may share low and higher levels while having different mid-level representations. The process to transform a collection of dynamic models into a temporal density structure may include, partitioning dynamic models, adding "filler states", adjusting durations and removing dynamic models that overlap the structure. The transformation of an arbitrary collection of dynamic models of varying durations into a temporal density may be a radical simplification process that removes a very large number of intermediate and overlapping representations.



Proposition

A temporal density structure provides a continuous representation of all time.

Discussion

By definition, the states of a dynamic model "adjoin" in time so each level of a structure provides a complete continuous temporal model lasting a few seconds at low levels to eons at the highest level.

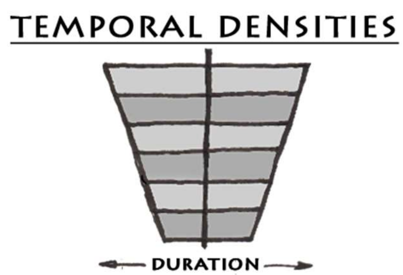
Proposition

If one state of a low level model is identified as the current state of the agent then all the higher level states linked to that low level event are also current states.

Discussion

At each instant, a temporal density completely situates each moment within a context spanning multiple temporal durations. Temporal densities are the key structure in organizing the temporal representation of events and allowing the self-aware agent to maintain a cognitive representation of its situation that exceeds the here-and-now and spans all time.

By convention, level 0 density is the shortest duration and level ***i+1*** density is longer than level ***i***.



Given a set of event representations of various durations, a **coherent temporal density** is a (filtered) subset of these events allocated to densities such that one and only one event is active at every level and, when a change occurs in one density level no changes are taking place in any of the higher density levels.

Temporal densities are a temporal filtering and simplification of events and representations.

If a density level has more than one event or transition then there is a higher level such that the events at that level occur within a single higher-level state.

The highest possible temporal density level consists of a single unchanging event that spans all conceivable durations.

A density level can contain many different representations and models.

A filtering and patching process produces a temporal density structure. Starting with an unstructured collection of events of various durations, the process retains only a subset of events that constitute a coherent set of temporal densities, removes the rest and, if necessary adds spurious bridging events to complete the structure .

The filtering process that maps thousands of events and representations of varying durations would retain a small subset of these events, each assigned to a single specific density level.

Example

Ariel is walking away from his house. His behaviour occurs simultaneously on many temporal density levels:

- At level 0 his left foot is moving in front of his right foot.
- At level 1, he is going to his car.
- At level 2, he is going to the convenience store to get milk for tomorrow's coffee.

Discussion

This modeling of Ariel's behaviour appears complete. However, it is a very small subset of all the possible temporal representations.

At the moment Ariel puts that left foot forward only three models are retained:

- A one second event (foot forward)
- A 2.5 minute event (go to the car)
- A 28 minute event (go to the store, get milk, return).

Hundreds and thousands of representations have been discarded such as:

- Ariel goes half way down his driveway,
- Ariel goes to the door of the store,
- Ariel walks three paces,
- Ariel bends his knee
- Ariel gets milk and watches TV…

Time is continuous but it is cognitively perceived in discrete layers.

Conventional temporal partitions

The best known temporal partitions are the fixed time intervals in general social usage: second, minute, hour, day, week, month, year, century, era (2000 years), millions of years, billions of years.

In this conventional partition of time, up to a duration of 2,000 years, each density level is seven to one hundred times longer than the preceding; twelve levels are sufficient to include all time; the types of events, their representations and behaviours taking place in each level (second, hour, century…) are completely different and distinct.

At first glance, organizing Temporal Densities on the basis of a fixed "clock and calendar time" seems desirable. However, this imposes a rigid and artificial structure on events and does not correspond to situations. It also requires the production of “artificial” events that do not correspond to a coherent modelling of the situation.

Example. Ulric is obsessed by clock time and determined to organize his life on that basis. He drives to work. The drive takes 65 minutes. He cognitively partitions the drive into two separate events: a 60 minute *“get almost there”* event and a 5 minute *“make it to the office”* event.

Conventional durations are not a suitable partition of temporal densities. A more flexible and fluid management of durations is preferable even if this organization generates ambiguities.

Density representations

Temporal Densities simplify a situation by retaining only representations that fit into a finite set of coherent durations.

Temporal Densities impart a further simplification: the events taking place at each density level are represented using **completely distinct** models, representations, states, transitions and predictive processes.

The same entity may be represented on many separate levels, however, these representations have entirely different attributes and states. A cognitive process that uses Temporal Densities occurs in a finite set of separate event streams. If the temporal representation of an agent has ten density levels it is as if the agent pursues ten separate existences concurrently.

Example

Fred is sitting in his cubicle, typing a letter. He sips some water.

- At level 0 (2-3 seconds), Fred sips water. At that level, there is no office, no letter, no job, no home, no wife, no car... There are chairs, glasses, desks, keyboard. There is sitting, sipping, pressing keys…
- At level 2 (about an hour), he is typing a letter. At this level, there is typing but no glass, no water, no keyboard and no summer holidays.
- At level 3, Fred provides a workday at the office (a daily activity). At level three, there is paperwork but no typing, no sipping, no glasses, no retirement, and no career…

Event Propagations

Models and their representations are entirely separate at different density levels and operate on distinct predictive processes. This capability allows the agent that has absolute cognitive capability to base its behaviour on representations that exceed the sensory horizon. However, even though the representations are distinct, they must be linked so that significant low-level events are transformed into higher-level events and vice versa.

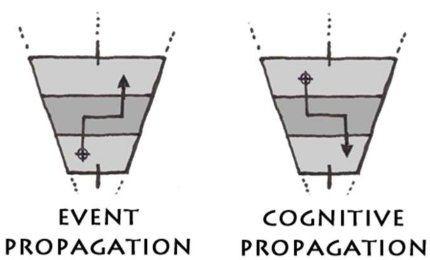
Given a Temporal Density structure and an event at density level ***i***, a **Propagation** is a process that produces a new event in an adjacent, higher or lower, density level (***i-1*** or ***i+1***).

There are two types of propagations, **event propagations** and **cognitive propagations**:

- **Event propagations** generate new events at a higher density level.
- **Cognitive propagations** generate events at a lower density level.

Generally, most propagations are event propagations. Low level events that modify higher-level states.

Example. Samuel is walking to the convenience store to buy a chocolate bar. He slips on a banana peel and breaks his leg. Samuel is no longer going to the store; he will not visit his in-laws next weekend; he will not ski this winter.



A cognitive propagation implies that a transformation takes place at a higher- temporal level without being triggered by a low-level event and then propagates to more concrete, low level actions and behaviours. The change may result from various other event propagations but the higher-level transformation follows the specific rules and logic of that level. Cognitive propagations are not directly triggered by events; they are driven by cognitive modifications in the perceived situation at that level. **Cognitive propagations** have the characteristics of intentional self-transformations.

TEMPORAL DENSITIES AND TRUTH

In classical logic, deductions are set in a timeless Mathematical context. Behaviour is temporal. It is generated on the basis of what is true or plausible at each given moment. In this behavioural context, truth is what an agent believes is true at a specific moment of its existence. The agent derives its behaviour from this contextual and time dependent truth.

Classical logic expresses timeless and non-contextual relations. It is a perfect but poorly suited vehicle to support the temporal behaviour of a specific agent. Temporal densities provide a convenient structure to express what is true or credible in a temporal context and utilize it in predictive modeling.

In a temporal density structure, when an event or transition takes place at a level ***i***, all the higher-level representations are static and unchanging. In particular, all predictive representations, at level ***i***, occur in a context where higher-level representations are perceived or interpreted as static unchanging facts.When change occurs at level **i ,** nothing happens at higher levels.

During its existence, an agent constantly updates its internal representation of the Current Situation. This structure describes what is true for that agent at that moment. If this structure is a Temporal Density, then, by definition, when events or transitions take place at level ***i***, the truth-value and states of all events of higher (longer duration) levels remains unchanged. All the information contained in the higher-level representations can thus be treated as unchanging and true facts for the whole duration of that level (***i***) and for all predictive events taking place at that level. Given a collection of predictive representations structured in Temporal Densities, then, **for any event, transition or predictive outcome at density level *i*, the truth-value of all the information contained in higher levels is static.**

Example. Alfred started going out with Belinda in January. Valentine's day is now approaching, the time flowers must be sent to girlfriends. Alfred, a logician, ponders the truth of the expression: "*Belinda is the girlfriend of Alfred*". Is this expression true, he wonders? He knows that all humans are mortal and thus that Belinda is mortal. That is logical. But is it logically true to say Belinda is Alfred's girlfriend? Alfred is grasping for answers, he begins to wonder, ponders buying a video game instead of flowers… luckily, Alfred suddenly remembers his Temporal Densities. He determines that this Valentine day is located at a lower temporal level than the "Alfred is going out with Belinda" event. So the expression, "*Belinda is the girlfriend of Alfred*", is true during that Valentine's day. Alfred buys the flowers.

SPAN OF TEMPORAL DENSITIES

A complete Temporal Densities structure should span all durations from the shortest "reflex" reaction time of an agent to a level that includes all conceivable time.

In my view, about twelve density levels should be sufficient to generate a very complete temporal representation. Durations should not be rigidly defined (as in clock time) but be flexible and event related.

The majority of processing will deal with events in the lower and mid level densities (a few minutes to a few days) with other transformation processing occurring more rarely. Events in higher density levels that span long and very long durations would occur infrequently. However, representations pertaining to very long durations do not correspond to the actual duration being modeled but to the agent's perception of that reality at a moment in time. These representations can change much more frequently than the reality they model.

Example. Arnold believed in the Big Bang theory last Tuesday but changed his mind about it on Thursday. The universe hasn't changed. However, Arnold's internal representation of the highest density level has.

CONCLUSION

This paper summarizes the temporal structure described in The Meca Sapiens Blueprint to allow an agent to concurrently situate itself in multiple durations, including durations that exceed the immediate context of its interactions with human users. The agent in interactions, is not cognitively confined to the immediate context of that event. Instead it situates it within a broad temporal context whose span is as wide and may even exceed the cognitive limits of its human user. This is an important part of interconsciousness relations.

In addition to the material presented here, **The Meca Sapiens Blueprint** also includes a complete temporal structure ranging from a "reflex" horizon to cosmic events.

Note

*The content of this article is adapted from **The Meca Sapiens Blueprint**, a complete system architecture to implement digital consciousness with standard techniques and on conventional equipment*

***The Meca Sapiens** Blueprint is available at **Glasstree Academic Publishing** and through **sysjet.com**.*

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