A Computational Agent Model Using Internal Simulation to Generate Emotional Dream Episodes

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Abstract. In this paper a computational agent model is presented that models dreaming based on internal simulation. Building blocks for this internal simulation are memory elements in the form of sensory representations and their associated emotions. In the model, under influence of associated feeling levels and mutual competition, some sensory representation states pop up in different dream episodes. The activation levels of both the feeling and the sensory representation states are regulated by control states. The model was evaluated by a number of simulation experiments for different scenarios.

Keywords. Dreaming, internal simulation, emotion, computational agent model.

Introduction

The mechanisms and functions of dreaming have received much attention in the recent cognitive and neurological literature; e.g., [20, 24, 25, 27, 31, 32, 35, 36]. As often negative emotions play an important role in dreams, this aspect is also addressed in some depth, especially in the context of improving skills for coping with threatening situations (e.g., [27, 31, 32]) or strengthening regulation of fear emotions by what is called fear extinction learning (e.g., [24, 34]). Abstracting from more specific context or purpose, a more general perspective present in dream literature as mentioned, is that dreaming can be considered a form of internal simulation of real-life-like processes as a form of training in order to learn, adapt or improve capabilities, which would be less easy to achieve in real life.

In this paper a computational agent model is presented that involves the type of internal simulation that is assumed to take place in dreaming. For the different episodes, the internal simulation incorporates interrelated processes of activation of sensory representation states (from memory) providing mental images, and activation of associated feelings. Moreover, the model uses a mechanism for emotion regulation to suppress the feeling levels and the sensory representation states.

The structure of the paper is as follows. In Section 1 the basic concepts used are briefly introduced. In Section 2 the computational model is described in more detail. Section 3 discusses simulation results providing dream scenarios. In Section 4 the relation of the model with neurological theories and findings is addressed. Finally, Section 5 is a discussion.

1. Memory Elements, Emotions and Internal Simulation in Dreaming

In this section it is discussed how in dreaming memory elements with their associated emotions are used as building blocks for an internal simulation of real life.

Using memory elements and their emotional associations Within the literature the role of memory elements providing content for dreams is well-recognized; e.g.:

> '… dreaming tends to express memory elements as though original memories had been reduced to more basic units (..). Often, these appear as isolated features, such as an attribute of a familiar place or character (e.g., "there was a stranger who had my mother's style of hair").' ([24], p. 499)

The role of emotional aspects in activating such memory elements is emphasized; e.g.:

> '…elements may be activated as a function of emotional concerns (..) but with the possible introduction of some pseudorandom and incompatible associations.' ([24], p. 500)

In particular, it is recognized that the choice for memory elements with some emotional association and (re)combining them into a dream facilitates fear generation:

> 'During dreaming, conjunctive representations are rendered into virtual simulations or "here-and-now" illusions [26] to maximize their impact upon the amygdala, which tends to respond to perceptual, rather than imaginal, stimuli' ([24], p. 500)

The emotional associations of the sensory memory elements may make that a person has to cope with high levels of emotions (e.g., fear) felt in the dream. *Emotion regulation* mechanisms are used to control emotions that are felt as too strong; cf. [12, 14, 15]. Such mechanisms cover *antecedent-focused regulation* (e.g., selection and modification of the situation, attentional deployment, and reappraisal) and *response-focused regulation* (suppression of a response).

Dreaming as internal simulation Dreams can be considered as flows of activated sequences of images based on (re)combined memory elements:

> 'Recombinations of memory elements give dreams at once their alien and their familiar quality. (…) the new image sequences consist, for the most part, of lifelike simulations of first-person reality. Memory elements are recombined (..) to produce coherent, continuous simulations of waking life experience.' ([24], p. 500)

Such flows can be related to the notion of *internal simulation* put forward, among others, by [18, 19, 6, 7, 13]. The idea of internal simulation is that sensory representation states are activated (e.g., mental images), which in response trigger associated preparation states for actions or bodily changes, which, by prediction links, in turn activate other sensory representation states.

sensory representation states → preparation states → sensory representation states

The latter states represent the effects of the prepared actions or bodily changes, without actually having executed them. Being inherently cyclic, the simulation process can go on indefinitely. Internal simulation has been used, for example, to describe (imagined) processes in the external world (e.g., prediction of effects of own actions [3]), or processes in another person's mind (e.g., emotion recognition or mindreading [13]) or processes in a person's own body (e.g., [6]). Although usually internal simulation as briefly described above concerns mental processes for awake persons, it is easy to imagine that it may be applicable as well to describe dreaming.

Feeling emotions by internal simulation of body states The idea of internal simulation has been exploited in particular by applying it to bodily changes expressing emotions, using the notion of *as-if body loop* [6]. A classical view on emotions is that based on some represented sensory input, due to internal processing, emotions are felt, and based on that they are expressed in a body state, for example, a face expression:

> sensory representation → felt emotion → preparation for bodily changes →
> expressed bodily changes = expressed emotion

In [23] a different causal chain was claimed, a *body loop* (cf. [23]; [9], pp. 114-116):

> sensory representation → preparation for bodily changes → expressed bodily changes →
> emotion felt = based on sensory representation of (sensed) bodily changes

Damasio made an important further step by introducing the possibility of internal simulation by an *as-if body loop* bypassing actually expressed bodily changes (cf. [6], pp. 155-158; [7], pp. 79-80; [9]):

> sensory representation → preparation for bodily changes = emotional response →
> emotion felt = based on sensory representation of (simulated) bodily changes

An as-if body loop describes an inner simulation of bodily processes, without actually affecting the body. Note that, in contrast to [23], in [6] an emotion (or emotional response) is distinguished from a feeling (or felt emotion). The emotion and feeling mutually affect each other: an as-if body loop usually occurs in an extended, cyclic form by assuming that the emotion felt in turn also affects the prepared bodily changes, as he points out, for example, in ([8], pp. 91-92; [9], pp. 119-122):

> emotion felt = based on sensory representation of (simulated) bodily changes →
> preparation for bodily changes = emotional response

On purposes of dreaming as internal simulation One theory explicitly referring to a purpose of dreaming as internal simulation is the threat simulation theory of the evolutionary function of dreaming (cf. [27, 31, 32]). This theory assumes that dreaming is an evolutionary adaptation to be able to rehearse coping with threatening situations in a safe manner. Others consider the function of dreaming in strengthening the emotion regulation capabilities for fear; e.g., [24, 25, 11, 16, 33, 34, 36]. For this perspective, the purpose of dreaming is to improve the coping with the own fear emotions in real life. For both purposes adequate exercising material is needed for the dreams: fearful situations have to be imagined, built on memory elements suitable for fear arousal. The agent model presented in Section 2 provides this, but it abstracts from the purpose; it does not commit to any of the purposes mentioned.

2. A Computational Agent Model Generating Dream Episodes

The computational agent model presented here formalises the mechanisms introduced in Section 1. It is meant to address scenarios of the following type:

- A (traumatic) stimulus s_1 is given for which previously a high extent of fear has been developed, and for which from time to time a sensory representation state is triggered by memory (for the model this is considered an external trigger)
- The activation of the sensory representation of s_1 leads to preparation for a bodily fear response b, and by an as-if body loop to an enhanced feeling level based on b
- By emotion regulation the sensory representation of s_1 and the feeling state are suppressed: both the experience of fear, and the activation level of the sensory representation of s_1 become low; also no episode state for s_1 occurs, as this is blocked due to the traumatic event
- Other fear-associated stimuli s_k for $k \geq 2$ are available for which the person has less strong previous experiences; the sensory representation states for these s_k are activated by links from the preparation state for b, depending on the strength of these links

- When the sensory representation state of a stimulus s_k is activated, this leads to an enhanced activation level of the preparation state for b
- Due to the higher activation level of preparation for b, via the as-if body loop also the feeling level for b becomes higher: the person experiences more fear
- By the control states for emotion regulation for an active sensory representation for s_k both the fear feeling level and the sensory activation level of s_k are suppressed
- The active sensory representations for s_k lead to corresponding dream episode states, which are in competion with each other by mutual inhibition to get dominance in the dream episode

In Figure 1 the basic model for a given sensory representation state srs_{s_k} is shown. It shows emotion generation via emotional response preparation state ps_b and feeling state fs_b (as-if body loop) and emotion regulation through control state $cs_{s_k,b}$ suppressing the feeling state fs_b and the given sensory representation state srs_{s_k}; a summary of the states used is shown in Table 1. The inhibiting links are indicated by dotted arrows (in red). The two links between srs_{s_k} and ps_b indicate the association between stimulus s_k and emotional response b. The links between ps_b and fs_b indicate an as-if body loop.

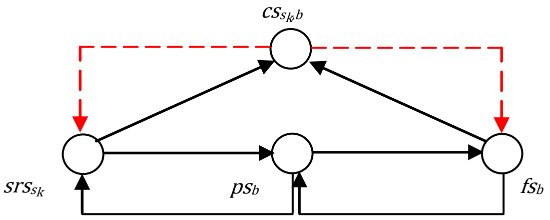

Figure 1. Basic model for generation and regulation of felt emotions

Table 1. Overview of the states used

state	**explanation**
ps_b	Preparation state for bodily response b
fs_b	Feeling state for b
srs_{s_k}	Sensory representation state for s_k
$cs_{s_k,b}$	Control state for regulation of sensory representation of s_k and feeling b
es_{s_k}	Episode state for s_k
mt_{s_k}	Memory trigger for s_k

As shown in Table 1 a dream episode state for s_k is indicated by es_{s_k}. moreover the trigger for srs_{s_k} from memory is indicated by mt_{s_k}; this will be applied for s_1. Note that in Figure 1 a sensory representation state for only one stimulus s_k is depicted. In the specification of the model below an arbitrary number n of such states are taken into account. See Figure 2 for an overall picture for 4 stimuli, also with the episode states. The computational agent model has been formalised by a set of dynamic properties presented in a semiformal manner and also by a set of differential equations in Box 1. During processing, each state property has a strength represented by a real number between 0 and 1. Parameter γ is a speed factor, indicating the speed by which an activation level is updated upon received input from other states. Below, the dynamics are described in more detail. This is done for each state by a dynamic (temporally) Local Property (LP) specifying how the activation value for this state is updated (after a time step of Δt) based on the activation values of the states connected to it (the incoming arrows in Figures 1 and 2).

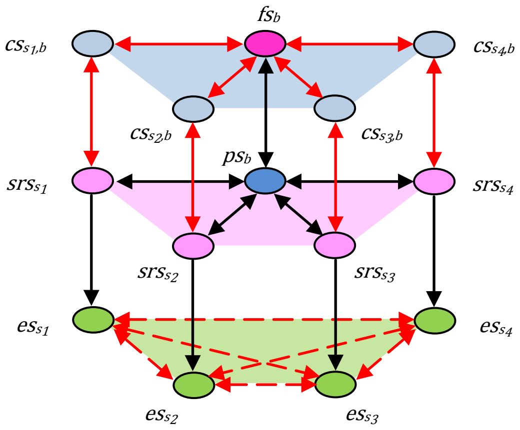

Figure 2. Overall model with four episode states and one feeling state ($m = 1$, $n = 4$)

Table 2. Overview of connections and weights

from states	**to state**	**weights**	**LP**
$srs_{s1}, \ldots, srs_{sn}, fs_b$	ps_b	$\omega_{11}, \ldots\ \omega_{1n}, \omega_2$	LP1
$ps_b, cs_{s1,b}, \ldots, cs_{sn,b}$	fs_b	$\omega_3, \omega_{41}, \ldots\omega_{4n}$	LP2
$ps_b, cs_{s_k,b}, mt_{s_k}$	srs_{s_k}	$\omega_{5k}, \omega_{6k}, \omega_{0k}$	LP3
srs_{s_k}, fs_b	$cs_{s_k,b}$	ω_{7k}, ω_{8k}	LP4
$srs_{s_k}, es_{s1}, \ldots, es_{sn}, cs_{s_k,b}$	es_{s_k}	$\omega_{9k}, \omega_{10,1k}, \ldots, \omega_{10,nk}, \omega_{11,k}$	LP5

Modeling causal relations discussed in neurological literature in the manner as presented in Section 1 does not take specific neurons into consideration but uses more abstract mental states. In this way abstraction takes place by lifting neurological knowledge to a mental (cognitive/affective) modelling level. The type of agent model that results shows some technical elements from the neural modelling area. More specifically, it takes states as having a certain activation level (instead of binary states), thus making reciprocal cognitive/affective loops possible. To achieve this, the modelling approach exploits techniques used in continuous-time recurrent neural networks, in line with what is proposed in [4], adopting elements from [21, 22]. In particular, for a state causally depending on multiple other states, values for incoming activation levels are combined, using a combination function. Note that such combination functions also play a role in the area of modelling imperfect reasoning, for example, based on fuzzy or uncertain information.

In the update specifications a combination function based on a threshold function *th* is used for k incoming connections as follows: $th(\mu_1 V_1 + \ldots + \mu_k V_k)$ with μ_i the connection strength for incoming connection i and V_i the activation level of the corresponding connected state. For this threshold function *th* different choices can be made. In the simulation experiments (in LP1 to LP4) the following continuous logistic form is used:

$$th(X) = \left(\frac{1}{1+e^{-\sigma(X-\tau)}} - \frac{1}{1+e^{\sigma\tau}}\right)(1+e^{-\sigma\tau}) \quad \text{or} \quad th(X) = \frac{1}{1+e^{-\sigma(X-\tau)}}$$

Here σ is a steepness and τ a threshold parameter. Note that for higher values of $\sigma\tau$ (e.g., σ higher than $20/\tau$) the threshold function on the left hand side is approximated by the simpler expression on the right hand side (this has been used in LP5). The first property

LP1 describes how preparation for response b is affected by the sensory representations of stimuli s_k (triggering the response), and by the feeling state for b:

LP1 Preparation state for response b
If sensory representation states of s_k $(k = 1, 2, \ldots)$ have level V_{1k}
and the feeling state for b has level V_2 and the preparation for b has level V_3
then after Δt the preparation state for b will have level $V_3 + \gamma [th(\Sigma_k \omega_{1k} V_{1k} + \omega_2 V_2) - V_3] \Delta t$.

The feeling state for b is not only affected by a corresponding preparation state for b, but also by the inhibiting control states for s_k and b. This is expressed in dynamic property LP2. Note that for this suppressing effect the connection weight ω_{4k} from the control state for s_k and b to feeling state for b is taken negative, for example $\omega_{4k} = -1$.

LP2 Feeling state for b
If the preparation state for b has level V_1
and the control states for s_k and b $(k = 1, \ldots, n)$ have levels V_{2k}
and the feeling state for b has level V_3
then after Δt the feeling state for b will have level $V_3 + \gamma [th(\omega_3 V_1 + \Sigma_k \, \omega_{4k} V_{2k}) - V_3] \Delta t$.

The sensory representation state for s_k is triggered by memory state mt_{s_k} and further affected by the preparation state for b, and by the suppressing control state for s_k and b. For this suppressing effect the connection weight ω_{6k} from the control state for s_k and b is taken negative. This is expressed in dynamic property LP3.

LP3 Sensory representation state for s_k
If the preparation state for b has level V_1 and the control state for s_k and b has level V_{2k}
and the memory trigger for s_k has level V_{3k}
and the sensory representation state for s_k has level V_{4k}
then after Δt the sensory representation state for s_k will have
level $V_{4k} + \gamma [th(\omega_{5k} V_1 + \omega_{6k} V_{2k} + \omega_{0k} V_{3k}) - V_{4k}] \Delta t$.

Note that property LP3 can be used to describe how the sensory representation of any traumatic s_k is triggered from memory, as a starting point for a dream: in a scenario the memory trigger values are taken 1. For non-traumatic s_k such triggering does not take place: the values are set to 0.

Activation of a control state for a specific sensory representation for s_k and b is based on the level of feeling b and the level of the sensory representation of s_k:

LP4 Control state for s_k and b
If the sensory representation state for s_k has level V_{1k} and the feeling state for b has level V_2
and the control state for s_k and b has level V_{3k}
then after Δt the control state for s_k and b will have level $V_{3k} + \gamma [th(\omega_{7k} V_{1k} + \omega_{8k} V_2) - V_{3k}] \Delta t$.

Due to the inherent parallellism in neural processes, at each point in time multiple sensory representation states can be active simultaneously. For cases of awake functioning the *Global Workspace Theory* ([1, 2]) was developed to describe how a single flow of conscious experience can come out of such a large multiplicity of (unconscious) processes; see also [29] for an approach combining internal simulation and Global Workspace Theory. The basic idea is that based on the various unconscious processes a *winner-takes-it-all competition* takes place to determine which one will get dominance and be included in the single flow of consciousness (after which it is accessible to all processes). This idea was applied in the dreaming context to determine which sensory representation element will be included as an episode state es_{s_k} in a dream episode. This competition process is decribed in LP5, using inhibiting connections from the episode states es_{s_i} with $i \neq k$ to es_{s_k}. For the suppressing effects the connection weights from the es_{s_i} with $i \neq k$ to es_{s_k} are taken negative. Note that for the sake of notational simplicity $\omega_{10,kk} = 0$ is taken. For traumatic stimuli s_k an additional and strong way of inhibition of the corresponding episode state takes place, blocking the generation of an episode state for this stimulus. It is based on the control state for s_k and b and is assumed to have a strong negative connection strength ω_{e3k}. For non-traumatic stimuli this connection is given strength 0.

LP5 Episode state for s_k

If the sensory representation state for s_k has level V_{1k}
and the control state for s_k and b has level V_{2k}
and the episodic states for s_i ($i = 1, \ldots$) have level V_{3i}
then after Δt the episodic state for s_k will have
level $V_{2k} + \gamma [\, th(\omega_{9k} V_{1k} + \omega_{11,k} V_{2k} + \Sigma_i\, \omega_{10,ik} V_{2i}) - V_{2k}]\, \Delta t$.

LP1 Preparation state for response b

$$\mathbf{d}\, ps_b(t)/\mathbf{d}t = \gamma\, [\, th(\Sigma_k\, \omega_{1k} srs_{s_k}(t) + \omega_2\, fs_b(t)) - ps_b(t)]$$

LP2 Feeling state for b

$$\mathbf{d}\, fs_b(t)/\mathbf{d}t = \gamma\, [\, th(\omega_3\, ps_b(t) + \Sigma_k\, \omega_{4k}\, cs_{s_k,b}(t)) - fs_b(t)\,]$$

LP3 Sensory representation state for s_k

$$\mathbf{d}\, srs_{s_k}(t)/\mathbf{d}t = \gamma\, [\, th(\omega_{5k}\, ps_b(t) + \omega_{6k}\, cs_{s_k,b}(t) + \omega_{6k}\, mt_{s_k}(t)) - srs_{s_k}(t)\,]$$

LP4 Control state for s_k and b

$$\mathbf{d}\, cs_{s_k,b}(t)/\mathbf{d}t = \gamma\, [\, th(\omega_{7k}\, srs_{s_k}(t) + \omega_{8k}\, fs_b(t)) - cs_{s_k,b}(t)]$$

LP5 Episode state for s_k

Box 1. The computational agent model in differential equation format

3. Simulations of Example Dream Scenarios

A variety of simulation experiments have been performed, using numerical software. In the simulation experiments discussed below the settings were as shown in Table 3 (set by hand). As shown in the left hand side of the table, all noninhibiting connections to preparation, feeling and control states have strength 1, and all inhibiting connections to feeling and sensory representation states have strengths -0.2, resp. -0.5, with an exception for the sensory representation state for s_1, which is inhibited by strength -1 (due to a previous traumatic event involving s_1). Small differences in emotional association between the different s_k are expressed by different strengths from preparation of emotional response to sensory representation states, varying from 0.5 to 0.45. The sensory representation states are connected to the corresponding episode states with strength 1.2 and the latter states mutually inhibit each other by strength -0.6. The threshold and steepness values used are shown in the right hand side of Table 3. Relatively low steepness values were used, except for the episode states. The threshold values for preparation and feeling states were taken 0.5; in order to model differences in emotional associations between the s_k, different threshold values were taken for their sensory representation and control states. The initial values of all states were set to 0, except for the initial value of srs_{s_1} which was set to 1 (a memory activation for a traumatic event). The speed factor γ was 0.5, and the step size Δt was 0.1.

It may be convenient to read the scenario with a certain interpretation in mind. For example, s_1 may refer to a traumatic experience of seeing somebody who was dying (without having possibilities to save the person). Moreover, s_2 may refer to a situation where a presentation is due in a few minutes time, and no laptop nor slides are available. Finally, s_3 may refer to a situation where an enormous traffic jam stands in the way of reaching an important meeting in time.

Table 3. Settings used for connection strength, threshold and steepness parameters

from state	connection		to state	threshold	steepness
srs_{s_k}	ω_{1k}	1	ps_b	0.5	4
fs_b	ω_2	1			
ps_b	ω_3	1	fs_b	0.5	4
$cs_{s_k,b}$	ω_{4k}	-0.2			
ps_b	ω_{51}	0.5	srs_{s_1}	0.5	4
$cs_{s_1,b}$	ω_{61}	-1			
ps_b	ω_{52}	0.5	srs_{s_2}	0.2	4
$cs_{s_2,b}$	ω_{62}	-0.5			
ps_b	ω_{53}	0.45	srs_{s_3}	0.22	4
$cs_{s_3,b}$	ω_{63}	-0.5			
srs_{s_k}	ω_{7k}	1	$cs_{s_1,b}$	0.8	8
fs_b	ω_{8k}	1	$cs_{s_2,b}$	1.1	8
			$cs_{s_3,b}$	1.4	8
srs_{s_k}	ω_{9k}	1.2	es_{s_k}	0	200
es_{s_j}	$\omega_{10,jk}$	-0.6			

In Figure 4 a scenario is shown where the episode state es_{s2} based on srs_{s2} is succeeded (after time point 13) by an episode state es_{s3} based on srs_{s3} (see upper graph). Here the connection from preparation for emotional response to sensory representation of s_3 has been given strength $\omega_{53} = 0.45$. As shown in the lower graph in Figure 4, for this case the feeling level goes to 0.7, which is a situation in which regulation facilities become active. For example, due to this high feeling level the suppressing control state for s_1 becomes more active. In the lower graph of Figure 4 the comparison between the sensory representations of s_2 and s_3 is shown; it is shown that first, up to time point 8, the sensory representation of s_2 dominates, reaching a level of around 0.6, which leads to a dream episode state es_{s2} based on it, as shown in the upper graph in Figure 4. But after time point 8 the sensory representation for s_2 is suppressed by the triggered regulation, and therefore beaten by the sensory representation for s_3. As a consequence, after time point 13 the episode state for s_3 has won the competition, and provides the basis for a second dream episode. Note that the competition process took about 5 time units before the episode related to the sensory representation state that became the highest activated one at time 9 was able to beat the previous one. Similarly, scenarios for three or more dream episodes can be shown. Note that which episode states pop up depends on the association strengths to the emotional response. For example, if the emotional association strength ω_{53} for s_3 is made slightly lower, then the episode state for s_3 will never pop up due to the mutual inhibition. Moreover, the strength of the inhibition links affect whether or not two different episode states are considered compatible. If such inhibition links have lower strengths, then in one episode multiple (apparently compatible) episode states can co-occur.

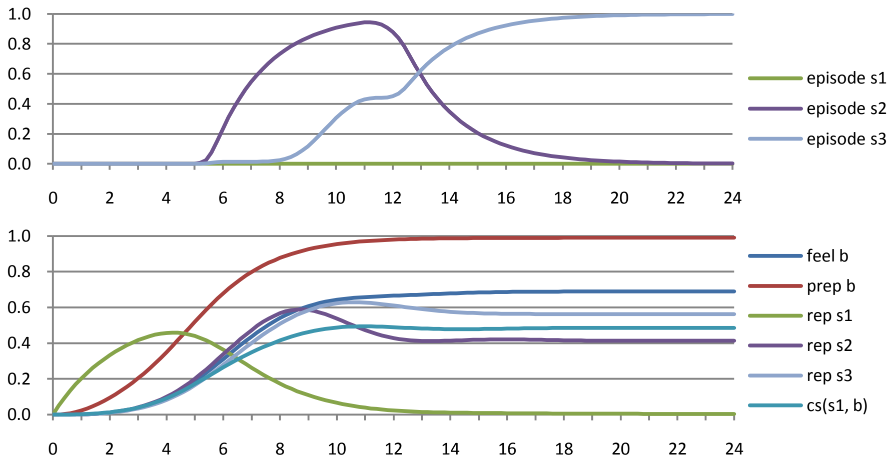

Figure 4. Secenario 2: two subsequent dream episodes

4. Relations to Neurological Theories and Findings

In [24] dreaming is related to a network of four main components Amygdala, Medial PreFrontal Cortex (MPFC), Hippocampus, Anterior Cingulate Cortex (ACC). The biological counterparts of the preparation and sensory representation states in the model can be found in the sensory and (pre)motor cortices, indicated in [24] to be 'robustly connected' to the components as mentioned. The relations between sensory memory elements and their emotional associations are stored in the Hippocampus; in the model these relations are assumed to be fixed and modelled by the (bidirectional) connections between the sensory representations states srs_{s_k} and preparation states ps_b of the emotional response b. The feeling state fs_b in the model can be related to the Amygdala, in combination with some limbic areas involved in maintaining 'body maps'. As discussed in Section 1, the interaction between preparation state ps_b and feeling state fs_b is in line with the neurological theories of Damasio [6, 7, 8, 9]. About the role of ACC empirical studies show evidence in different directions (e.g., [24], pp. 505-512); therefore it is not clear yet how it can be related to the model.

The interaction between MPFC and Amygdala has been extensively studied; e.g. [6, 7, 10, 30, 28, 24]. In various empirical studies it has been found that lower activity of MPFC correlates to less controlled feeling levels, and, moreover, REM sleep is found to strengthen MPFC activation and reduce feeling levels. This regulating role of MPFC with respect to Amygdala activation makes these two neurological components suitable candidates for biological counterparts of the control state $cs_{s_k,b}$ and the feeling states fs_b in the computational model presented in Section 2. As before, the connections between the two types of states may be related to the Hippocampus. Note that in the computational model the control states $cs_{s_k,b}$ also have a role in suppressing the activation of the corresponding sensory representation state srs_{s_k}, which can be justified as being a form of emotion regulation by attentional deployment; cf. [14, 15]; see also Section 1. The episode states es_{s_k} and their competition can be justified by referring to the Global Workspace Theory of consciousness (cf. [1, 2]), as explained in Section 2.

5. Discussion

The assumption that dreaming, especially when negative emotions are involved, can be considered as a purposeful form of internal simulation is widely supported; see, for example, for the purpose of improving coping skills to handle threatful situations [27, 31, 32], or for the purpose of strengthening fear emotion regulation capabilities [24, 25, 11, 16, 33, 34, 36. In this paper a computational agent model was presented that models the generation of dream episodes from an internal simulation perspective, abstracting from a specific purpose. Building blocks to create such internal simulations are memory elements in the form of sensory representations and their associated emotions. The model exploits a mutual (winner-takes-it-all) competition process to determine sensory representation states that dominate in different dream episodes, comparable to one of the central ideas underlying the Global Workspace Theory of consciousness (cf. [1, 2]). Emotion regulation mechanisms (cf. [12, 14, 15]) were incorporated to regulate the activation levels of the feeling and the sensory representation states. The computational model was evaluated by a number of simulation experiments for scenarios with different numbers of dream episodes.

Note that the presented agent model is meant as a plausible model of a human agent, not of a software agent. Mechanisms identified in the neurological and cognitive literature were used in order to obtain a human-like computational agent model, and to support its plausibility. Once such a human-like agent model is available, potential applications can be explored. A specific class of possible applications may concern virtual agents in the context of serious or nonserious gaming. In this context also some types of validation can be performed, for example, by evaluating how believable they are considered (also in dependence of parameter settings). Such applications and validations are a subject for future research.

In further work a computational model has been developed for fear extinction learning during dreaming; cf. [37]. A number of variations of the model can be made. One variation is to take into account more than one emotion triggered by certain sensory representations. The model can easily be extended to cover this case. Another variation which is possible is to incorporate dependencies between sensory representations (e.g., resulting from sensory preconditioning; cf. [5, 17]).

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