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Modelling the Dynamics of Emotional Awareness

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Abstract. In this paper, based on literature from Cognitive and Affective Neuroscience, a computational agent model is introduced incorporating the role of emotional awareness states in the dynamics of action generation. More specifically, it covers both automatic, unconscious (bottom-up) and more cognitive and conscious (top-down) emotion generation processes, and their mutual interaction. The model was formalised in a dynamical system format. In different scenarios the model shows simulation results that are in line with patterns reported in literature.

1 INTRODUCTION

Generation of emotions may take place by automatic processes (unconscious, referred to as bottom-up) and/or by conscious processes (with awareness, referred to as top-down) [11, 16]. The relation between emotion and conscious awareness is a nontrivial one. Latest findings suggest that conscious influences of emotion are playing a role that should not be underestimated (cf. [14]). To address this a Levels of Emotional Awareness Scale (LEAS) to quantify emotional experience together with to elaborate emotional experience of individuals was introduced (cf. [14]). Lack of emotional awareness is considered a main factor behind many emotional disorders (e.g., alexithymia [25], schizophrenia [3]), and having insight in the neurological and behavioural basis of emotional awareness will support the understanding of the process behind this innate ability of living beings [13]. In this paper a neurologically and behaviourally inspired computational model is introduced together with neural correlates as a set of affective states that is able to describe and simulate the dynamics of emotional awareness in interaction with perception, attention, and preparing and performing actions. The precise functional contribution of the neural regions indicated in this paper may need further research and confirmation. Nevertheless, the discussed body of knowledge might be useful as a basis for a workbench for the AI community to strengthen some of the intelligent applications addressing human-like processes, and also to provide an experimental framework for neuro-cognitive-behavioral scientists.

2 NEUROLOGICAL BACKGROUND

Emotion formation is an ongoing process and not necessarily is triggered in merely an instant [10]. Emergence of emotions has different explanations, based on its automatic responses (bottom-up), or more consciously emerging (top-down). These approaches have been able to explain emotional formation in line with results from fMRI experiments [11, 16]. Examples for this bottom-up and top-down mechanisms (from [23]) are experiencing disgust as a result of smelling outdated milk and recollecting smelling outdated milk, respectively. Bottom-up emotion generation is assumed to be aroused immediately and ingrained from an external stimulus while the top-down emotion generation occurs from semantic evaluation of a situation through a cognitive influence [23]. It has been shown that different neural activations are evoked for this: thalamus, hypothalamus, ventral striatum, amygdala, anterior cingulate cortex (ACC), anterior insular cortex (AIC), orbito-frontal cortex (OFC), and/or mesial prefrontal cortex [14], with and without conscious intervention.

Evidence was found for the idea of distributed networks of regions collectively carrying out important functions of the brain (no single regions), including emotion generation [2, 31]. The amygdala is the main hub not only for monitoring the emotionally salient stimuli but also for projecting to the relevant brain areas (it has connectivity with eight of the cortical areas [17]) and transmit retrieved feedbacks to the sensory pathways, to invoke rapid and efficient generation of emotions [5, 18, 21]. The amygdala may have an important contribution when processing danger (e.g., flight or fight situation) or emotionally salient events, especially when these occur outside attention or awareness [31]. From available fMRI data it is noted that the left amygdala seems to directly contribute for both bottom-up and top-down processes and the right amygdala has shown activation only for the bottom-up responses [16]:

> '.. distinct cortical networks were involved in each type of emotion generation. On the one hand, bottom-up emotion generation activated the amygdala and occipital cortex, which have been implicated in detecting affectively arousing stimuli and modulating their encoding into memory (..), as well as right prefrontal and parietal regions implicated in attentional vigilance and individual differences in negative affective style (..). On the other hand, top-down emotion generation activated left prefrontal, cingulate, and temporal regions implicated in working memory and the retrieval of information from semantic memory (..), as well as the left amygdala and a dorsal mPFC region involved in making attributions about mental—and especially emotional—states (..). Working together, these systems may support cognitive appraisals that generate emotions from the top down.' ([16], pp. 1327-1328).

According to [18] the amygdala directly shapes the perception when perceiving an emotionally salient stimulus (bottom-up) and from [20] emotional perception contributes to identify emotionally salient information in the environment, and to generate emotional experiences and behaviour, and also from [21] emotions can be shaped by the perception through amplification mechanisms that do not overlap with other attentional processes (without leading to awareness). In this bottom-up process the brain has shown to capture the emotional perceptual features of the stimulus spontaneously but not involving conscious awareness and further subjective aspects of this emotion [15]. Therefore, perception may compel to emotion generation in the bottom-up approach.

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Feelings which concern subjective experience of emotions [7] also play their role in different ways. The insula and ACC are believed to be neural correlates of feelings [7]:

> 'While emotions are actions accompanied by ideas and certain modes of thinking, emotional feelings are mostly perceptions of what our bodies do during the emoting, along with perceptions of our state of mind during that same period of time.' ([7], pp. 110).

It may possible to have different feelings on a perceived stimulus due to pre-learned neural paths (cf. [7, 8]); only a few of them may be able to reach consciousness through attention [7, 21].

Attention is a key cognitive process that allows (by subjectively desiring) to appraise a situation with conscious awareness [26]. While perception is a key aspect in the bottom-up process, attention compels the top-down process. As information processing through perceptual pathways is to be limited, attention contributes to select the most useful information and let it reach conscious awareness [21] (these types of emotions have shown a higher scores in LEAS [14]). Furthermore, there are mainly two types of attention mechanisms: exogenous (for bottom-up) and endogenous (for top-down); with partly distinct brain circuits [21, 32]. For attention also a networked brain region has been suggested involving frontoparietal regions (see [17, 6, 32]).

It has been noted that people with a high level of emotional awareness have shown to accurately detect and discriminate emotional signals [14], and [7] has shown the advantage of conscious awareness of emotion when integrating in cognitive processes; [12] has presented four evidences for emotional awareness and its conscious experience:

> '1) AIC and ACC are commonly coactivated as revealed by a meta-analysis, 2) AIC is functionally dissociable from ACC, 3) AIC integrates stimulus-driven and top-down information, and 4) AIC is necessary for emotional awareness.' ([12], p. 3371).

Also it has been identified that the right-AIC, ventromedial Pre-Frontal Cortex (vmPFC), and ACC play a role as shared neural substrates for the awareness of bodily and emotional states (see [28]). Furthermore, for the bottom-up responses they found activity in the right-PFC (may relate to attention shifting) whereas for the top-down processes activity in dorsal left-PFC is observed [16] (may relate to semantic processing with awareness [22]). The importance of improving the emotional awareness in clinical perspectives has been highlighted, for schizophrenia [3, 13], alexithymia [25], and other cognitive disorders.

The OFC and Cholinergic Nuclei are noted to contribute to boosting emotional perceptual processing; and amygdala, fusiform gyrus, dorsolateral-PFC and inferior parietal cortices are for emotional awareness (cf. [1, 5]). It has clearly been shown that emotional perception is modulated by attention [19]; the typical interplay between attention and consciousness and/or awareness can be found in [9, 27].

3 DESCRIPTION OF THE MODEL

With the evidence presented in Section 2, a computational agent model has been designed for emotion formation which adopts parts of the models presented in [29, 30] but extends those by introducing emotional awareness in interaction with perception, and attention. An overview of this model is shown in Figure 1. Modeling causal relations discussed in neurological literature in the manner as presented here does not take specific neurons/paths into consideration but uses more abstract cognitive or mental states.The model uses three world states as inputs: for stimulus *s*, context *c*, and effect *b*. These inputs; world states WS(*s*), WS(*c*), and WS(*b*) lead to sensor states SS(*s*), SS(*c*), and SS(*b*), and subsequently to sensory representation states SR(*s*), SR(*c)*, and SR(*b*), respectively. This initiation propagates through two casual chains as proposed by Damasio [8] (for more details see [29, 30]):

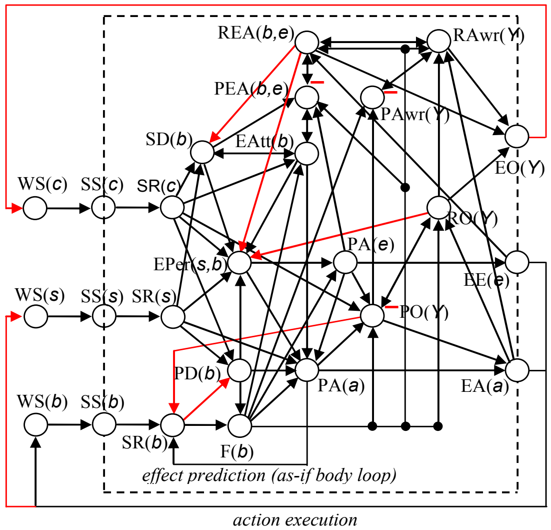

Figure 1. Overview of the computational cognitive agent model. Red colour ➔ and ▬ symbols presenting suppressions; and Y:- a,b,c,e,s.

- as-if body loop [preparation for action *a*: PA(*a*) → SR(*b*) → feeling of action *a* after: as-if loop or body loop: F(*b*)]
- body loop [PA(*a*) → execution of action *a*: EA(*a*) → WS(*b*) → SS(*b*) → SR(*b*) → F(*b*)]

The effect prediction as-if body loop contributes to action selection in a parallel mode, i.e., developing preparations PA(a_i) for a number of actions a_i where i=1,..,n. These multiple action candidates a_i are competing to get selected [7, 8]. Furthermore, this model takes the influence from performative desires for *b*: PD(*b*) on PA(*a*) and F(*b*) to introduce the influence from short term interests/goals for selecting or rejecting an action through the as-if body loop (cf. [29]). As in [29, 30] these loops have been extended with prior and retrospective effects relative to the action execution through ownership and awareness states (this model includes emotional awareness also into this). The prior or retrospective-ownership state for action *a* with *b*, *c*, *e*, and *s*: {P|R}O(Y= *a*,*b*,*c*,*e*,*s*) was to represent in how far a person attributes an action to him/herself, or to another person, whereas the prior or retrospective-awareness state for action *a* with *b*, *c*, *e*, and *s*: {P|R}Awr(Y= *a*,*b*,*c*,*e*,*s*) for the influence of conscious elements (cf. [29, 30]). Apart from the relations presented in [29, 30] this model covers two causal emotion formation processes: bottom-up and top-down. Emotional perception [5, 9, 18, 21], and attention [19, 21, 26, 27, 32] with emotional awareness [9, 12, 22, 27, 28] have been found as key factors contributing to these emotion formation processes.

3.1 Bottom-up process

In the bottom-up process, when a particular stimulus *s*, and a context *c* (which are emotionally salient) are perceived, the agent will spontaneously develop an emotional perception state for *s* with *b*: EPer*(s,b)* together with an influence from performative desires PD(*b*) [15, 21]. Subsequently preparation PA(*e*) for emotional response *e* and preparation state PA(*a*) are independently affected by the perception state EPer(*s,b*) [18, 20, 21]. Furthermore, the preparation state PA(*a*) is affected by PA(*e*) too, so that if there is a strong perception that directly strengthens the action preparation [17] leading to a spontaneous response with a higher strength (e.g., flight or fight [24]). This preparation state PA(*a*) triggers the effect prediction sub-process (as-if body loop) that internally generates a sensory representation of the bodily response and feeling for the associated emotions before actually executing the action [8].

Based on the internally simulated feeling state F(*b*) an emotional attention state EAtt(*b*) will be developed for the current selection of action *a* and its effect *b* [18, 21]. Nevertheless, the state EAtt(*b*) is not a main factor affecting EPer(*s,b*) in the bottom-up process [21]. The preparation state PA(*e*) is affected by the feeling state F(*b*) and therefore this will contribute to select the action due to satisfactory valuation together with the direction of the perception state [21]. In the bottom-up process, the strong activation level of EPer(*s,b*) is developed in an early stage of the timeline and therefore dominates the mechanism; see also, e.g., [9, 15, 21]. Due to the necessity of immediate and strong action execution in the bottom-up process the cognitive appraisal sub process on action selection (through the as-if body loop) may not significantly contribute whereas the strong activation level of EPer(*s,b*) will direct to an action preparation without getting biased from emotional attention. In this process the brain is directed to rationally engage in the big picture of the current threat [15].

A prior ownership state PO(*a,b,c,e,s*) is affected by SR(*c*) (see [30]), PA(*a*), PA(*e*), and F(*b*). The ownership state is contributing to the unconscious aspects (see [30]) and especially in the bottom-up process this explains the aspects of negative emotions (e.g., fear). For example, in a flight or fight situation though the agent knows that it is performing an action (through the ownership), he.she may not be really sure why it is doing so (due to lack of awareness). In the meantime the agent will perform emotional expression EE(*e*) of *e*, as a result of PA(*e*). Furthermore, based on the prior ownership state PO(*a,b,c,e,s*) and preparation PA(*a*) the agent will perform execution EA(*a*) of action *a* through the body loop. The sensory representation state SR(*b*) will be suppressed once the prior ownership state PO(*a,b,c,e,s*) got developed (as explained in [29, 30]); this allows to differentiate effects on SR(*b*) from the as-if body loop against effects from the body loop (see [30]). Subsequently a retrospective ownership state RO(*a,b,c,e,s*) for action *a* with *b*, *c*, *e*, and *s* will be developed; this is affected by PO(*a,b,c,e,s*), F(*b*), and EA(*a*). Both EPer(*s,b*) and PO(*a,b,c,e,s*) are suppressed by the effects of RO(*a,b,c,e,s*); therefore agent will able to dilute the strength of action (after the execution) from retrospective effects. Communication EO(*a,b,c,e,s*) of ownership for action *a* with *b*, *c*, *e*, and *s* is affected only by the RO(*a,b,c,e,s*) state in the bottom-up process and agent will able to share the information with external agents. In this bottom-up process the agent will not experience any awareness state (PAwr or RAwr) for the emotion and/or action as in [9, 15, 21, 31].

3.2 Top-Down Process

With the influence from the world through a stimulus *s*, and a context *c* the agent will be prepared by PA(*a*) for an action *a*, in relation to performative desire PD(*b*) (cf. [29]). As an effect from PA(*a*), by internal simulation the agent will develop SR(*b*) and F(*b*) through the as-if body loop as suggested by Damasio in [7, 8]. The top-down process involves a role of subjective desires SD(*b*) [14, 15, 28], an early stage of the emotional attention state EAtt(*b*) development [6, 32] relative to the emotional perception state EPer(*s,b*) and the awareness states (emotional and action). Therefore, in parallel to the above action formation process, the agent is experiencing a salient activation of subjective desires SD(*b*) as an effect from the both SR(*c*) and SR(*s*). Subsequently the agent starts to develop an emotional attention state EAtt(b_i) for b_i, giving attention to a particular b_i [6, 32]. This particular b_i may be a weak action candidate in the pool of parallel internal as-if body loop simulations. The term 'appraisal' in the literature occurs in this model through this valuation of parallel action simulations. Nevertheless, due to high attention developed for that b_i it may strengthen more and more and beat all the other candidates [14, 15, 16] (modify or suppress these evaluations [31]). The emotional attention state EAtt(*b*) has an effect from the subjective desire SD(*b*) and vice versa [26]. Because of this emotional attention state EAtt(*b*), the agent will start to develop an emotional perception state EPer(*s,b*) (the perception of emotion laden items requires attention, see [17]), and this leads to a preparation of an emotional response PA(*e*) too. Besides, PA(*e*) is affected by the feeling state F(*b*). Subsequently, the prior emotional awareness state PEA(*b,e*) of *b* and *e* develops due to the effects of SD(*b*), EAtt(*b*), PA(*e*) and F(*b*) which is another key state in the top-down process [12, 14]. As another consequence of the preparation state PA(*e*) the agent will develop an expressed emotional response EE(*e*) and experience the subsequent effects in terms of the feeling of it through the body loop [7, 8].

Together with the development of the prior emotional awareness state PEA(*b,e*), also the prior ownership state PO(*a,b,c,e,s*) will be developed as an effect from the states PA(*e*), SR(*c*), PA(*a*), and F(*b*) (this contributes to an interplay between conscious and unconscious processes in this model). Prior awareness PAwr(*a,b,c,e,s*) of *a* with *b*, *c*, *e*, and *s* is affected by the feeling state F(*b*) and the prior ownership state PO(*a,b,c,e,s*) (cf. [29, 30]). Subsequently, execution of the action *a* will be triggered as an effect of the states PO(*a,b,c,e,s*) and the PA(*a*). The retrospective emotional awareness REA(*b,e*) is affected by PEA(*b,e*), EE(*e*), F(*b*), and RAwr(*a,b,c,e,s*), and once this state REA(*b,e*) has developed it suppresses the emotional perception EPer(*s,b*) and subjective desire SD(*b*) to dilute the effects of current action formation. In parallel to that retrospective ownership RO(*a,b,c,e,s*) is affected by the states PO(*a,b,c,e,s*), F(*b*), and EA(*a*) (as in [29, 30]). Furthermore, the retrospective awareness state RAwr(*a,b,c,e,s*) is affected by the states REA(*b,e*), F(*b*), PAwr(*a,b,c,e,s*), RO(*a,b,c,e,s*), and EA(*a*). The prior awareness state PAwr(*a,b,c,e,s*) is suppressed by the retrospective awareness state RAwr(*a,b,c,e,s*). Finally, the communication (in retrospect) of ownership EO(*a,b,c,e,s*) is developed as an effect of the retrospective states RAwr(*a,b,c,e,s*), REA(*b,e*), and RO(*a,b,c,e,s*). These processes refer to the elicitation of emotions largely by cognitions through subjectively driven appraisal processes which are not primarily tied to a particular perceptual stimulus [15].

3.3 Dynamics of the model

Connections between the different state properties (the arrows in Figure 1) have weights ω_k, as indicated in Table 1. In this table the column LP refers to the (temporally) Local Properties (LP) in

Table 1. Overview of the connections and their weights. In here the red color ω_k values for negative weights.

from state	to state	weights	LP #
EA(*a*), EE(*e*)	WS(*s*)	ω_1, ω_2	1
EA(*a*), EE(*e*)	WS(*b*)	ω_3, ω_4	2
EO(*Y*)	WS(*c*)	ω_5	3
WS(*s*), WS(*c*), WS(*b*)	SS(*s* | *c* | *b*)	ω_6, ω_7, ω_8	4
SS(*s*), SS(*c*)	SR(*s* | *c*)	ω_9, ω_{10}	5
SS(*b*), PA(*a*), PO(*Y*)	SR(*b*)	ω_{11}, ω_{12}, ω_{13}	6
SR(*s*), SR(*c*), SR(*b*)	PD(*b*)	ω_{14}, ω_{15}, ω_{16}	7
SR(*s*), PD(*b*), F(*b*), PA(*e*), EAtt(*b*), EPer(*s,b*)	PA(*a*)	ω_{17}, ω_{18}, ω_{19}, ω_{20}, ω_{21}, ω_{22}	8
PD(*b*), SR(*b*)	F(*b*)	ω_{23}, ω_{24}	9
PD(*b*), SR(*c*), SR(*s*), RO(*Y*), EAtt(*b*), REA(*b,e*), SD(*b*)	EPer(*s,b*)	ω_{25}, ω_{26}, ω_{27}, ω_{28}, ω_{29}, ω_{30}, ω_{31}	10
SR(*c*), SR(*s*), EAtt(*b*), REA(*b,e*)	SD(*b*)	ω_{32}, ω_{33}, ω_{34}, ω_{35}	11
SD(*b*), SR(*c*), F(*b*), PEA(*b,e*)	EAtt(*b*)	ω_{36}, ω_{37}, ω_{38}, ω_{39}	12
EPer(*s,b*), F(*b*)	PA(*e*)	ω_{40}, ω_{41}	13
SD(*b*), EAtt(*b*), PA(*e*), F(*b*), REA(*b,e*)	PEA(*b,e*)	ω_{42}, ω_{43}, ω_{44}, ω_{45}, ω_{46}	14
PA(*e*), SR(*c*), PA(*a*), F(*b*), RO(*Y*)	PO(*Y*)	ω_{47}, ω_{48}, ω_{49}, ω_{50}, ω_{51}	15
F(*b*), PO(*Y*), RAwr(*Y*)	PAwr(*Y*)	ω_{52}, ω_{53}, ω_{54}	16
PA(*e*)	EE(*e*)	ω_{55}	17
PA(*a*), PO(*Y*)	EA(*a*)	ω_{56}, ω_{57}	18
PO(*a,b,c,e,s*), F(*b*), EA(*a*)	RO(*Y*)	ω_{58}, ω_{59}, ω_{60}	19
PEA(*b,e*), EE(*e*), F(*b*), RAwr(*Y*)	REA(*b,e*)	ω_{61}, ω_{62}, ω_{63}, ω_{64}	20
REA(*b,e*), F(*b*), PAwr(*Y*), RO(*Y*), EA(*a*)	RAwr(*Y*)	ω_{65}, ω_{66}, ω_{67}, ω_{68}, ω_{69}	21
RAwr(*Y*), REA(*b,e*), RO(*Y*)	EO(*Y*)	ω_{70}, ω_{71}, ω_{72}	22

LEADSTO format listed in the Extended Appendix[2] (see [4] for the relevance and benefits of LEADSTO in dynamic models). A weight ω_k has a value between -1 and +1 and may depend on the specific context *c*, stimulus *s*, action *a*, effect *b*, and emotion *e* involved (thus specifying the particular associations for these). By varying these connection strengths, different possibilities for the characteristics and repertoire offered by the modelled agent can be realised. Note that usually weights are assumed non-negative, except for the inhibiting connections, which are indicated in red colour in the Table 2. For the properties LP: 1, 3, 4, and 5 the function f is taken as the identity function $f(W) = W$ and for all the other states f is a combination function based on the logistic threshold function as in equations (1) (see [29, 30] for more info). In equation (1) σ is steepness and τ is threshold; which are configuration parameters that change the shape of the curve.

$$f(x) = \left(\frac{1}{1+e^{-\sigma(x-\tau)}} - \frac{1}{1+e^{\sigma\tau}} \right)\left(1+e^{\sigma\tau}\right)$$
$$when\ \mathrm{x} > 0\ \ \&\ \mathrm{f(x)} = 0\ \mathrm{when}\ \mathrm{x} < 0 \qquad (1)$$

SIMULATION RESULTS

This section discusses two simulation experiments undertaken to analyse the designed model in different scenarios. In the first scenario it simulates a fight or flight situation through the bottom-up process [24], and the second scenario simulates the emotion formation in conscious form (with top-down). Selecting suitable weight values for connections in this model was achieved through the same approach explained in [29]. Table 2 lists the connection weight values used for cognitive agent model in the indicated simulation scenarios; threshold (τ) and steepness (σ) values used for those scenarios are listed in Table 3. Furthermore; the step size (Δt) taken is 0.25. The slow value 0.5 for γ was applied for external processes modelled by LP1, LP2, and LP3, and the fast value 0.9 for γ for the internal processes modelled by the other LP's.

Table 2. Connection weight values used for cognitive agent model (Note: all blank cells hold the respective value immediately above that cell). ω: Weight; S: Simulation.

	$\omega_{1\text{-}2}$	$\omega_{3\text{-}4}$	ω_5	ω_6	$\omega_{7\text{-}8}$	ω_9	ω_{10}	ω_{11}	ω_{12}
S1	-0.5	0.8	-0.8	1	0.7	1	0.7	1	0.9
S2									1

	ω_{13}	14-15	ω_{16}	17-19	ω_{20}	ω_{21}	ω_{22}	ω_{23}	ω_{24}
S1	-0.9	0.9	-0.7	0.7	0.9	0.7	1	0.8	0.9
S2	-0.6	0.7							

	ω_{25}	26-27	ω_{28}	ω_{29}	ω_{30}	ω_{31}	32-33	ω_{34}	ω_{35}
S1	0.9	0.9	-0.9	0.8	-0.9	0.8	0.4	0.4	-0.9
S2	0.1	0.1		0.9		0.6	0.6	0.9	

	ω_{36}	ω_{37}	ω_{38}	ω_{39}	ω_{40}	ω_{41}	42-45	ω_{46}	ω_{47}
S1	0.5	0.6	0.8	0.4	0.9	0.8	0.2	-0.9	0.7
S2	0.7			0.7			0.7		0.7

	48-50	ω_{51}	52-53	ω_{54}	ω_{55}	ω_{56}	ω_{57}	ω_{58}	59-60
S1	0.7	-0.9	0.4	-0.8	1	0.9	0.9	0.9	0.8
S2			0.8		0.9	0.8	0.8		

	ω_{61}	ω_{62}	63-68	ω_{69}	70-71	ω_{72}
S1	0.4	0.4	0.4	0.5	0.4	0.9
S2	0.7	0.7	0.7	0.7	0.7	

3.4 Scenario 1: Fight-or-Flight response

Fast detection and reaction on potential threats are a fundamental adaptation for any being [31] referred as bottom-up in Section 2. The first scenario, shown in Fig. 2 describes a mostly physiological phenomenon called fight or flight response (see [24]) which looks almost automatic as there is no time available for critical cognitive evaluations. Due to the nature of fight-or-flight response (reflexive nature than highly cognitive [15, 16]), and it is an innate process mainly for survival (response time should be relatively low [6] and with a high strength of action execution [15, 16]).

In this fight or flight scenario in the presented model, the context *c* is self, and a stimulus *s* occurs (which is assumed to have

Table 3. Steepness (σ) and Threshold (τ) values used in configurations of simulations

Simulation One								
	σ	τ		σ	τ		σ	τ
PD	2	0.1	SR	4	0.025	PEA	2	3
SD	2	2	F	9	0.7	REA	1	3
EPer	2.5	0.7	EE	4	0.7	PAwr	4	2
EAtt	3.5	0.9	EA	6	0.8	RAwr	6	3
PA	3	0.1	PO	3.5	1.3	EO	3	0.1
PA	1.5	1.9	RO	2.5	1.2	WS	1	0.1
Simulation Two								
	σ	τ		σ	τ		σ	τ
PD	2	0.1	SR	2.5	0.01	PEA	3	1.3
SD	2	0.2	F	3.7	0.7	REA	3	1.1
EPer	5.5	0.8	EE	7	0.4	PAwr	8	0.7
EAtt	3	1	EA	8	1	RAwr	2.5	1.8
PA	2.5	0.5	PO	5	1.3	EO	1.2	0.9
PA	0.9	0.05	RO	6	1.2	WS	1	0.1

[2] http://www.few.vu.nl/~dte220/ECAI14Appendix.pdf

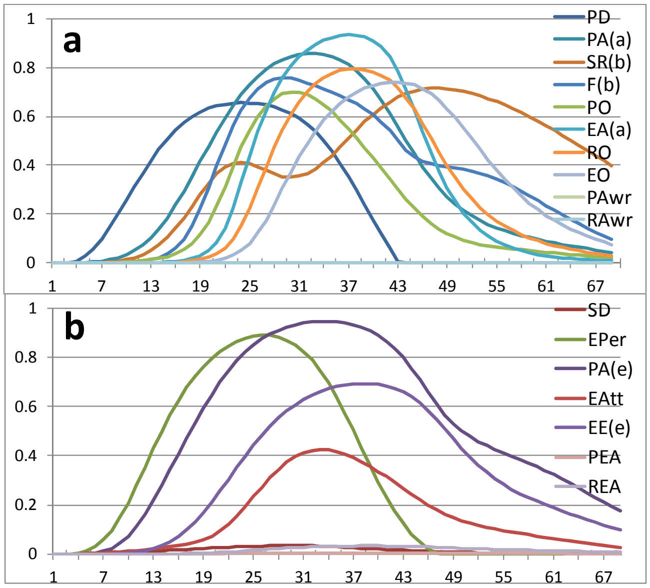

Figure 2. Scenario 1: Fight-or-Flight emotional phenomenon: (a) presents the simulation results related with action execution; whereas (b) presents those related with emotions.

strong emotional associations). As an effect of these inputs in Fig. 2 it is shown that the agent has immediately started to develop an emotional perception (mainly based on stimulus *s*, as the preparation for action *a* has not even got activated yet [15]) around time point 4, with almost non-existing subjective desires [15, 16]. In parallel with the development of the emotional perception, the agent has prepared for action *e* (emotions) rapidly (around at time point 5) before even the preparation for action *a* (which is starts around time point 8) as highlighted in [9, 21]. The agent has shown a strong emotional bias having effects from PA(*e*) on PA(*a*) [15, 16]. This strong emotional bias has led to a strong feeling (which is with the peak value of 0.75) which follows the sensory representation of *b*. The agent has executed the emotional expression of *e* in a relatively early stage of the timeline (starts around time point 12), and with low emotional attention which got activated relatively late in the timeline [6] (these observations are aligning with the literature on bottom-up process in Section 2). The agent has shown a sufficient strength in prior ownership and subsequently got executed the action *a* with a very strong peak value: 0.93; this value is the highest peak value observed for the EA(*a*) in comparison to the other simulation scenario (see Figure 3). Furthermore, these observations are in line with the explanations of the fight-or-flight response which indicate a tremendous strength in the action [15]. Moreover, it is observed that EA(*a*) exists for a considerably longer period of time in comparison to the same in the other scenario (but the overall process time is relatively less [6]). Subsequently the communication of ownership has been followed by a retrospective action ownership with acceptable strength and positions in the timeline (cf. [30]). Note that the agent has not shown any awareness, which is in line with the evidence from the literature on bottom-up processes, as discussed in Section 2.

3.5 Scenario 2: the Top-Down Process

The second scenario presents a simulation on emotion formation through the top-down approach. In this scenario the stimulus may not have a strong emotional association as in the bottom-up process [15]. Therefore mainly through appraisal with a focused intention and subjective desires [14, 15, 28], the agent will experience the emotions and perform the action. An example for this is in [15]: "*For example, fear might be elicited from the top-down when someone interprets a curt email from a prospective employer as indicative of disinterest and a low likelihood of being hired.*" [15], pp. 254. This simulation is shown in Figure 3; where the context *c* is the agent itself, and a stimulus *s* occurs. In Figure 3, part (a) it shows that the agent starts with a performative desire on the given inputs (*c, s*), and in part(b) the subjective desires are also becoming prominent (in the timeline PD(*b*) are relatively weak and with a short lifespan when comparing with the SD(*b*), and that is in line with [15, 16, 23]). Because of the performative desires, the agent triggers preparation of action *a*, which is followed by the sensory representation of the predicted effect *b* of *a* (through the internal simulation based on the as-if body loop) and subsequently by the feeling of *b* (with the aid of the activated performative desire for *b*) [7, 8]. Primarily because of the predicted feeling, the emotional attention of *b* starts to develop (with the influence from subjective desires too [26]) [19, 21, 27, 32]. From this emotional attention of *b*, the agent starts to develop an emotional perception (primarily on *b* in this time) [17], and followed by preparation of action *e*. Next, these states contribute to generate activation of a prior self-ownership state (cf. [30]). Subsequently the agent develops prior emotional awareness [9, 12, 22, 27, 28] and this leads to the execution of emotional expression (see part (b) in Figure 3). In part (a) of Figure 3, the agent develops prior awareness of action formation and this leads to the execution of action *a*. By following the emotional expression agent will develop the retrospective emotional awareness and furthermore, after the execution of the action *a*, the agent will achieve the retrospective ownership, the retrospective awareness, and finally the communication of ownership (cf. [30]). These observations are in line with Section 2.

4 DISCUSSION

The computational model introduced in this paper is based on literature from Cognitive and Affective Neuroscience. It incorporates a role for emotional awareness states with attention,

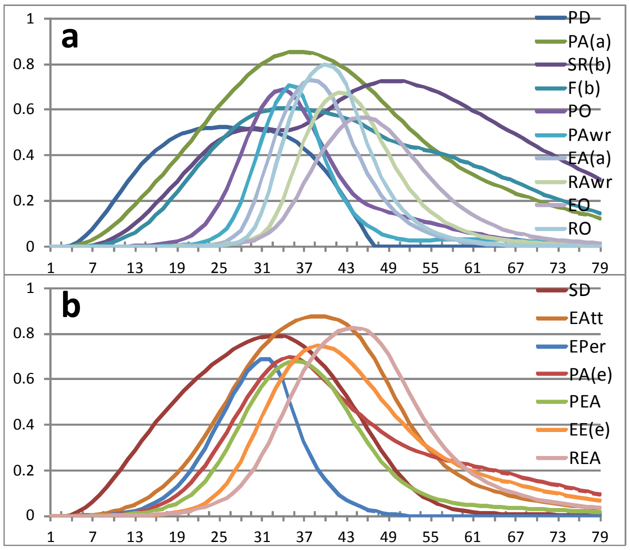

Figure 3. Scenario 2: Emotion Formation through the Top-Down Process: (a) presents the simulation results related with action execution; whereas (b) presents those related with emotions.

and perception that act reciprocally and interactively in the dynamics (top-down) of emotion generation, but also covers automatic, unconscious emotion generation processes (bottom-up), and the mutual interaction between these bottom-up and top-down processes [15, 16, 32]. The model was formalised as a dynamical system [4]. Various simulation experiments have been conducted according to different scenarios and the model shows simulation results that are in line with patterns reported in neurological literature. More importantly having two distinct value sets for Steepness (σ) and Threshold (τ) in configurations (for bottom-up and top-down) shows the comparability with the literature where two neural paths also in the human brain for emotion formation [11, 15, 16, 31]. As a summary bottom-up emotions are elicited largely by emotional perceptions with weaker subjective aspects but not necessarily being conscious (reflexive); whereas the top-down is more with conscious and appraisal driven with attention (more cognitive). It is a generic question in this domain how an emotion-laden stimuli processing relates to attention, perception and awareness [17]? The presented agent driven computational cognitive models may further contribute to evaluate, justify and further explore the boundaries with different intuitions to uplift the understanding of the above question. Incorporating a learning mechanism, and processes for emotion regulation will be some future work, together with more validations and comparisons.

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