The Embodied Dynamics of Emotion, Appraisal and Attention

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Abstract. Emotions can be considered inextricably linked to embodied appraisals - perceptions of bodily states that inform agents of how they are faring in the world relative to their own well-being. Emotion-appraisals are thus relational phenomena the relevance of which can be learned or evolutionarily selected for given a reliable coupling between agent-internal and environmental states. An emotion-appraisal attentional disposition permits agents to produce behaviour that exploits such couplings allowing for adaptive agent performance across agent-environment interactions. This chapter discusses emotions in terms of dynamical processes whereby attentional dispositions are considered central to an understanding of behaviour. The need to reconcile a dynamical systems perspective with an approach that views emotions as attentional dispositions representative of embodied relational phenomena (embodied appraisals) is argued for. Attention and emotion are considered to be features of adaptive agent behaviour that are interdependent in their temporal, structural and organizational relations.

Key words: embodied appraisals, dynamical systems, relational phenomena, attentional emotion-appraisal amalgams

1 Introduction

The study of emotional and attentional states has historically been viewed as separable though increasingly in recent years, studying emotional and attentional phenomena in isolation has been viewed as problematic. Emotional response mechanisms, for example, have been argued to bias attention to the processing of particular survival-relevant stimuli allowing for behavioural persistence ([1], [2], [3], [4]), whereas emotion-oriented global behavioural dispositions have been argued to be fundamentally attentional at an organismic or macroscopic level of abstraction ([5]). This chapter addresses the interdependence of emotion and attention by seeking to explain the function of emotions from an agent-environment relational perspective whilst attempting to understand how such functionality might be realized given the requirement of a temporally persistent global-scale agent attentional disposition allowing for situational context appraisal. Essentially, an attempt is made to reconcile the dynamical systems approach, taken

by Lewis ([6], [7]), allowing for stable macroscopic attentional dispositions, with the embodied appraisal theory of emotions, posited by Prinz ([8]), allowing for more or less complex temporal survival-relevant agent-environment relations to be apprehended.

To briefly summarize, the argument developed in this chapter attempts to reconcile the function-oriented embodied agent-environment relational perspective with the mechanism-oriented dynamical systems approach to conceptualizing emotions. In so doing, it is suggested that this can yield:

- the conception of emotions in terms of function realized through a plausible mechanism,
- the production of a more complete theory of emotions in terms of attentional emotion-appraisal phenomena.

The overall perspective taken in this chapter is, therefore, one of emotions as being inseparable from appraisals and that in being embodied and attentionally disposed through temporal stability they allow for the apprehension of complex agent-environment relations. This affords adaptive and functional relevance to the possessors of emotions through an attention-realizing mechanism. The layout of this chapter is as follows: Section 2 provides a brief overview of the approach to emotion theory that views emotions as elicited by cognitive appraisals. Such appraisals relate fundamental agent needs to environmental contingencies and are therefore rendered worthy of attentional disposition. Section 3 describes theories that similarly view emotions as states related to appraisals but focuses on what is considered to be the neglected temporal component of emotional response. This approach thus offers a dynamical perspective to emotion-oriented attentional dispositions. Emphasis is placed on the dynamical systems perspective of Lewis ([7]), which rejects the hypothesis that appraisal and emotions can be causally differentiated. This section thus provides a more or less plausible mechanism for emotion-appraisal states although limitations of this approach are discussed.

Succeeding sections offer a view on embodiment and appraisal imbuing a perspective on emotions with functional relevance. This covers the ground for a reconciliation between Lewis's theory and that of an embodied appraisal approach pertaining to relational properties of agent-environment interactions as referred to by Prinz ([8]); following this a more complete theory of emotions incorporating attentional emotion-appraisals is offered. Section 4 describes the importance of embodied 'somatic' states to agent emotions while Section 5 poses the question of how much does such embodiment matter? The subsequent section provides a brief description of approaches relevant to the theoretical issues outlined that can be usefully studied in robots and artificial systems and that might hopefully yield insights into the limitations of our current understanding of emotional phenomena. In the final section some concluding remarks are made.

2 Appraisal Theories of Emotion

One of the most researched areas into emotion function (particularly in the areas of psychology and philosophy) is that which falls under the general banner of appraisal theory. While theories have differed regarding the appraised dimensions that allow for the elicitation of emotions ([9]), in general, it can be said that appraisal theorists of emotion focus on two central facets underlying emotion activation:

- *appraisal*: the perception of matters of subjective concern-relevance in situated interaction,
- *response*: elicitation of behavioural, physiological and cognitive state changes providing some functional role in respect to the concerns involved.

Classically these have tended to be considered independent processes, with many theorists ([10], [11],[12]) arguing in favour of temporal causal models distinguishing the two processes. Modern theories, however, on the perception-action interdependent nature of cognition argue against clear separability of appraisal and response (e.g., [6], [7], [13], [14]). The fundamental point of this more contemporary perspective is that embodied agent-environment coupling assumes a spatio-temporal interplay between perceptual modalities and sensory-motor coordination. Lazarus ([15]), for example, argues that in the case of emotion, appraisal and response are not independent processes but interdependent emergent properties of one and the same process: the adaptational encounter.

From the perspective elaborated it follows that processes that attentionally orient an agent may precede or be a prerequisite for coupled appraisal-emotion processes. The attentional influence on appraisal-emotional dispositions can be viewed according to two fundamental modulatory functions:

- as an 'interrupt' ([15], [16]) whereby according to Lazarus ([15], p.17) "emotional reaction itself ... turns the attention away from ongoing activity",
- serving in the persistence of states that promote the coherence of goal-directed agent-environment interactions ([1], [2], [3], [4]).

Such emotion-oriented attentional dispositions can, therefore, be considered at the global (macroscopic) level ([7], [13]). This agent-level state change is conceived as the result of a number of interacting recurrent processes dynamically elaborating a macroscopic psychological and neurobiologically describable agent state. An emotion-appraisal that relates the condition-specific needs of the agent to present environment contingencies can be considered a functional manifestation of relational activity "... that establishes, weakens, and negates the physical and cognitive relations of the subject with the environment, by means of locomotion and modifications of bodily and sensory exposure" (Frijda [5], p.55). That is, emotional behavior is fundamentally attentional in nature. In essence, emotions, appraisals and attention are indissolubly functionally and mechanistically linked.

3 A Dynamical Perspective

The approach to the study of emotions based on the understanding of the inseparability of appraisal and emotion response has motivated the development of theories of emotions as processes in dynamical systems inherent in organism organization. Scherer ([13]), for example, has proposed a process model of emotion whereby emphasis is placed on continuous evaluative monitoring of the organism's environment. Scherer criticizes the trend of emotions researchers classifying emotions according to subjectively reported stable states when the reality, Scherer ([13]) claims, is that emotional reactions are "incredibly complex, multicomponential processes that cannot be captured and described by verbal labels". One aspect of such emotion descriptions that is missing, according to Scherer, is an account of the dynamic, continuously fluctuating nature of emotion processes. Scherer has attempted to address this lack via his 'component process model of emotions'. Lewis ([6], [7]), who like Scherer espouses a nonlinear, dynamic view of emotional activations, nevertheless criticizes Scherer's process model of emotions on the grounds that it, like many other classical appraisal theoretic accounts of emotion, views appraisal as antecedent to emotion - a criticism he also levies at other theories of appraisal, e.g., [17]. Lewis holds the view that emotions are in fact both cause and effect of appraisals. Lewis offers a model of 'appraisal-emotion amalgams' in which emotions are generated by 'triggering perturbations' and serve to affect appraisals of events insofar as they relate to 'perception', 'arousal', 'attention', 'action tendency', 'evaluation', 'feeling tone', and 'reflection'. These 'microscopic processes' are involved in bidirectional causal relationships such that their recurrent interactions allow for the macroscopic state that is the appraisal-emotion amalgam. Lewis ([7]) has highlighted the relevance of his approach to appraisal-emotions as wholes (rather than appraisals and emotions being causally and temporally independent modules) to the dynamical systems theory (DST) approach to the study of cognition ([18], [19], [20]) whereby "[i]n real time, coherent, macroscopic unities ... arise through the spontaneous coordination of microscopic constituents" ([7], p.173).

Lewis, unlike Scherer, places emphasis on the emergence of stable states induced by the effects of negative feedback on the amplifying effect on states receiving positive feedback: "Stability anchored in negative feedback circuits can spread out across the whole system through entrainment (or synchronization) with other circuits." (p.174). This increasingly popular position as to a possible 'mechanism' for the engendering of emotions (or emotion-appraisals) is similarly described by the neuroscientist Jaak Panksepp ([21], [22]): "The basic emotional systems may act as 'strange attractors' within widespread neural networks that exert a certain type of 'neurogravitational' force on many ongoing activities of the brain, from physiological to cognitive." ([21], p.3).

The following perhaps encapsulates the position held by Lewis (and also Panksepp): "... appraisal-emotion amalgams ... are construed as globally coherent states arising and stabilizing through nonlinear causal transactions among appraisal and emotion consitutuents." ([7], p.174). So, once triggered, recurrent interactions between the microscopic process constituents of the emotion-

appraisal amalgams induce a rapid self-amplifying effect on the activity of the interaction of the appraisal-emotion constituents of the system. The self-amplifying effect thus engendered results in a positive feedback loop between perceptual, emotional and attentional processes that initially perpetuate the positive feedback effect but are then inhibited or constrained by negative feedback effects as the amplification grows. This chain of events, culminating in a stabilization phase (phase transition), is referred to by Lewis as *Emotion Interpretations* or *EIs*. It is suggested in this chapter, that when appraisal-emotion amalgams arrive at the stable, or 'globally coherent' phase of the *EI* they can be considered fundamentally attentional at the level of the whole agent; that is, they can be considered as *attentional emotion-appraisal amalgams*.

Lewis's dynamical systems approach to emotion-appraisals was conceived as a means of providing a bridge between psychological and neurobiological mechanisms for emotion-appraisal processing. Lewis provides evidence for regulation and recurrence in neural networks in the brain and nervous system with particular reference to the neuroanatomical structures that are often cited as being important to emotion elicitation and regulation, i.e. the orbitofrontal cortex (OFC), the amygdala, and the brain stem/basal forebrain (see also [2], [21], [23]). Lewis provides three neuroanatomically situated modulatory loops termed: motivated object loop, motivated monitoring loop, motivated action loop. These loops are involved in emotion elicitation and regulation, attention orientation, and preparedness for action, respectively. Of these loops the 'motivated object loop' involves tight recurrent connections between OFC, amygdala, sensory cortices, brain stem/basal forebrain. The existence of such a similar network of regulation based on recurrent neural network activity has received an abundance of empirical support from neuroscientists ([3], [23], [24], [25], [26], [27]). This system can be said to be responsible for emotion elicitation and regulation with respect to exogenously or endogenously triggered perturbations including perceived external stimuli. Lewis does not place emphasis on how emotional responses are triggered in this particular network. However, the nature of how and when emotion-oriented states are triggered is of fundamental importance to the understanding of emotion function.

A number of criticisms of Lewis's approach have been made in the 'Open Peer Commentary' section in his 2005 *Behavioral and Brain Sciences* article of which most pertinent to the discussion in this chapter are those of Frijda ([28]). While generally complimentary of the approach Frijda nevertheless makes, among others, the following queries:

1. *whether appraisals stabilize into macroscopic states, and if so why.* There seems to be a scarcity of evidence in this regard at present. Lewis's argument for the emergence of macroscopic stable states revolves around the regulatory effects of bidirectional, recurrent interaction of microscopic processes identifiable in neurobiological mechanisms and structures in the brain. How such 'stability' may be identified is, however, contentious.
2. *Lewis's notion that emotion-appraisal amalgams are not so much functional (i.e. pre-wired or learned responses) but rather a function of self-organization.*

Are self-organization constraints functional from the perspective of being amenable to evolutionary selection pressures? Or perhaps might they be considered merely a side-effect of processes inherent to the organization of living systems?

3. "What are the phenomena that make analysis in terms of self-organization notions desirable?" ([28], p. 206). It might be said that if different emotional stages (in terms of internal agent states) can be correlated to behavioural dispositions or actions, or if local and global attractor states in terms of neural and physiological activity can be arrived at and in turn correlated to more cohesive behavioural dispositions or actions, then this would be desirable.

Regarding Frijda's third point, gauging how agent-environment relational phenomena are shaped and made coherent over time given evolutionary and ontogenetic persistence and selection pressures might be testable. This could inform emotions theorists of what emotions are in terms of: neurobiological, behavioural and relational states, not just between internal (emotion-cognition) and external (behavioural) activity but also between agent-environment relations.

Of Lewis's other opponents, Carver ([29]), in his critique of the 2005 article, suggests that the issue of behavioural functionality is neglected and thereby detracts from the usefulness of the perspective being detailed. Lewis, in the same article, retorts: "He (Carver) believes that action tendencies ... are the same as coherent actions. But raw action tendencies are useless for effective behavior." Lewis then goes on to state: "the evolutionary advantage of emotion for a sophisticated brain is to constrain and guide cognition until it coheres around a plan." ([7], p. 226). It is not clear, however, how action tendencies (which may take the form of preparatory but nevertheless functionally communicative emotional expressions) and coherent actions can be so easily demarcated. Clearly the development of a theoretical approach that allows for testable predictions is desirable. Assuming a functional perspective grounded in evolutionary selection pressures might provide a starting point in this sense. Such a theoretical position could then be tested via the use of artificial evolution using simulation models or experiments in the real-world (with robots). This adaptive component seems to be missing from the Lewis model.

Interestingly a hint at an approach that might reconcile Lewis's DST approach to the study of emotion-appraisal-attention processes and an approach that includes more explicit reference to evolutionarily determined function is provided by Lewis himself. He refers to Lazarus's 'core relational themes' in order to explain how self-organization may apply to adaptive systems via the components being coordinated in the service of subsistence: "Superordinate appraisal themes, such as Lazarus's core relational themes (e.g., irrevocable loss), might hold subordinate, interacting appraisal processes in place, while those processes simultaneously fuel the superordinate." - the macroscopic unity constrains the degrees of freedom of the microscopic constituents. The idea is also said to be "consistent with Frijda's ([30]) modeling of appraisal as a cumulative gestalt, and it is explicitly captured by Scherer's ([13]) view of appraisal

as a higher-order parameter 'enslaving' its constituents." So, a DST approach to the study of emotions is being proffered, with an explanation of the microscopic and macroscopic mutually reinforcing phenomena inherent, via recourse to agent-environment relational phenomena. The angle of emotion-appraisals as being functionally relevant according to their identifying core relational themes is explored further in the next section.

4 The Embodiment of Attentional Emotion-Appraisals

In order to produce behaviour that can be considered adaptive, autonomous and intelligent agents are required to interact with their environments via attention-orienting bodily states. In simple terms, disembodied agents cannot be adapted to any particular environment and therefore it is contentious to suggest that they exhibit intelligent behaviour at all ([31]). The term embodiment, however, provides different meanings to different researchers - we ([32]) have previously provided an overview of the different nuanced meanings that embodiment has entailed in reference to cognition, for example.

The use of the term 'embodiment' referred to in this chapter, however, and relevant to attentional emotion-appraisals, comes in the form of non-neurological bodily states, i.e. somatic states that include skeletomuscular, visceral, hormonal dynamics. That attentional dispositions to such endogenous states might be of adaptive value to agents regarding agent-environment interactions has been explored by proponents of somatic theories of emotion as pioneered by William James in the late 19th century, and has since been reinvigorated by the likes of Antonio Damasio ([23], [26]) and Jesse Prinz ([8]).

Endogenous attentional emotion-appraisals may be modulated - interrupted, reinforced - through a process of the context-based evaluation of the relevance of a perceived stimulus to the continued viability of the embodied organism. Such agent assessments of viability are a function of deviations from homeostatic viability zones, e.g., [26], [33], [34]. Damasio ([23], [26]) suggests that emotions can emerge via two routes. The first route consists in activity of somatic states induced through perception of a stimulus evaluated as being emotionally relevant (i.e. via the ventromedial prefrontal cortex and amygdala system). Such somatic state change is relayed back to the cortical and subcortical structures, in particular in the somatosensory and insular cortices, via neuromodulatory effects elicited in brain stem nuclei. Such a neuronal pattern of bodily activity represents the emotional feeling of the organism ([26]). The second route allows for a short cut in the process whereby the neuroanatomical structures in the brain implicated in representing the emotional feeling state are activated in the absence of the bodily state changes; this can only happen, however, given that the organism has previously learned such patterns of neuronal activity. This off-line representation provides the organism with the potential to enact a swifter response to the emotion-eliciting stimulus. Damasio put forward his *somatic marker hypothesis* of emotional feeling as an explanation as to why such attention to endogenous states might be adaptive to organisms. He has suggested

that the somatic marker "forces attention on the ... outcome to which a given action may lead, and functions as an automatic alerting signal". In this sense, like Frijda, Damasio would say that emotions are fundamentally attentional in nature but attentional, in this case, to matters of the body rather than to matters outside of the body. Emotions are thus said by Damasio to be "about the life of the organism, its body to be precise" ([26]) and are in this sense relational though with respect to the internal workings of the embodied organism as opposed to the relational dispositions of embodied organisms situated in their environments or as in the case described by Lewis, as referred to in this chapter, the emotion-cognition relation relating appraisal-emotion microscopic parts to macroscopic wholes.

Damasio's notion of the importance of endogenously directed attentional emotion-appraisals has been extended by Prinz ([8]) to include its relational relevance with respect to agent-environment interactions. Prinz views emotions as embodied appraisals identifying relational phenomena which relate perceived external events to the continued integrity of the perceiving embodied organism. As Prinz puts it: "Our perceptions of the body tell us about our organs and limbs, but they also carry information about how we are faring." ([8]). In this view emotions are *perceptions* of somatic states that represent core relational themes (adapted from Lazarus, [15]). Prinz gives the example of the perception of the external stimulus of a snake eliciting bodily changes that are appraised as stereotyped patterns of activation and the neural registering of this stereotyped pattern ('fear') represents the core relational theme 'danger'. This view differs from that of Lazarus insofar as the representations of core relational themes are not arrived at through explicit mental judgements but rather through appraisals of somatic state changes that need not be consciously deliberated. This view of emotion can also be considered an extension of Damasio's and James's somatic theories in that emotions here are defined as being 'about something' - they are directed towards something. This relational aspect is lacking in other somatic theories of emotion at least in terms of emphasis. Being 'about something' regarding agent-environment relations also implies that emotions have triggering objects of relevance to agent well-being - an aspect of Lewis's DST approach that is lacking detailed explanation, as mentioned in section 3. Carver ([29]) similarly suggests that emotions are triggered by relational events. He makes the point that emotion elicitation is triggered by the subcortical registering of perceived emotional events via physiological changes preparing the body for action owing to an event appraised as being important to the self.

In the previous section Lewis's DST approach was criticized on account of its not being overly concerned with the issue of the functional relevance of emotion-appraisals. In contrast it might be said that Prinz's embodied appraisal theory of emotion does not provide an adequate mechanism for the realization of emotions as 'embodied appraisals'. In accordance with Lewis he views emotions and appraisals as interdependent and inseparable, but additionally proposes that embodied appraisals are both the emotions which register 'patterned physiological responses' and representations of core relational themes. However, it can be said

that this definition does not sufficiently account for the relevance of temporal factors in emotion response in allowing for the emergence of, and in thereafter moulding complex emotions.

The key difference between the two theorists, the 'protagonists' of this chapter, is apparent in the use of the term Prinz borrows from Dretske (in [8]): 'reliable causation'. On this account core relational themes (or stimuli that can be represented as such) trigger emotional states because the eliciting stimuli have, over evolutionary time, reliably caused particular outcomes to organisms the effects of which have been influenced by preparatory physiological states providing dispositions to action that are constitutive of the particular emotion. To this end the tracking of core relational themes is functional whereby function implies a property that has been evolutionarily selected for (also see [35]). Such core relational themes are tracked by particular stimuli, e.g., a snake, and are represented via the bodily state changes elicited. This allows for a stereotyped physiological profile to be instantiated and perceived, e.g., as 'fear'. The registering and endogenous perception of the bodily state changes is the emotion and simultaneously the embodied appraisal that also represents the core relational theme, e.g., 'danger'. Naturally, the extent to which such stereotyped physiological profiles can be considered to exist in biological organisms such that they might be of informational relevance and could thus reliably be perceived as representations of core relational themes is controversial. The theory of emotions existing as natural kinds differentiable only via physiological profiles has been challenged by the likes of [36] and [37] while of even the most recognized champions of the concept of emotions as being reliably constituted in physiological profiles (e.g., Ekman, Levenson, Friesen) [38] has suggested that such profiles for emotions may exist only for the basic emotions (or 'affect programs' see [37]) consisting in fear, anger, happiness, disgust, surprise, sadness, and that even then the existence of such profiles is controversial[1]. More generally stereotyped bodily state changes existing as emotion profiles have been described with respect to purportedly culturally universal facial expression ([39]) though again such universality appears to hold up best against close scrutiny where basic emotions are concerned. On this basis the plausiblity of Prinz's function of emotion as natural kinds being realized by the mechanism of embodied appraisals can be questioned. To what extent are bodily state changes representative of reliable and stereotyped 'emotion' profiles? Prinz uses the term 'calibration profiles' (plastic, situation-dependent stimuli perceptions antecedent to embodied appraisals) as a means of explaining how both basic emotions and 'higher cognitive emotions' can make use of embodied appraisals and thus be considered as conceptually clustered. Nevertheless, it is not clear that even the 'basic' emotions are not tracked and perceived according to embodied appraisals driven by plastic and complex spatio-temporal dynamics as opposed to fixed patterns of

[1] This is a point that Prinz himself acknowledges: "At present, there has been no decisive evidence for the physiological distinctness of all emotions", but tentatively concludes: "Nevertheless, existing evidence is suggestive".

somatic activity being elicited by plastic and more or less complex calibration profiles.

Certainly in accordance with Dretske's approach reliable causation is key to Prinz's representational notion of emotions but this applies not just to there existing a relatively stable environment that allows for the perception of a particular state relevant to the continued well-being of the agent but also to internal states that enable the agent to perceive such external conditions. In this sense it might be extrapolated that Prinz would view Lewis's theory of emotion-appraisal processes as being compatible with his theory to the extent that emotion-appraisal amalgams tend towards stable macroscopic states that can be viewed as being fundamentally attentional in character allowing for coherent and temporally persistent responses. From this perspective it follows that interactions of emotion-appraisal microscopic processes that do not engender a stable macroscopic level or that are precursorial to it can only be considered to consist in proto-emotional states, i.e. non-full-fledged emotional states (alternatively these states might be more generally considered proto-affective - see [16]). In contrast, it does not follow that all of Lewis's emotion-appraisal macroscopic stable states consist in emotions; where the triggering conditions for such states are not object-oriented - either external to the embodied agent, e.g., perceived stimulus in the environment, or internal to the embodied agent, e.g., perceived stimulus brought forth in memory - the stable state is not representative of a core relational theme. Such states might include moods, non-emotional feelings, etc. On this account Lewis's dynamical systems approach that yields emotion-appraisal amalgams is incorporated within the Prinz perspective though it can also be said that Lewis's perspective adds to the theory of Prinz: The notion of core relational themes being represented in emotions perhaps does not sufficiently acknowledge the role of temporality in emotion formation. Whereas Lewis's macroscopic stable state emotion-appraisal amalgams might refer to Prinz's emotional states as embodied appraisals and the Lewis emotion-appraisal amalgams that do not yield stable states should be considered akin to some form of proto-emotion or non-full-fledged emotion in the Prinz conception, the account of dynamics in agent-environment and emotion-appraisal interplay may be of crucial importance to the formation of emotions as bodily state perceptions, particularly of the 'higher-cognitive' kind (e.g., pride, envy, shame, guilt).

4.1 The Neurobiological Anatomy of Stimulus Processing

In order to appreciate more fully the need to reconcile the more functional 'embodied appraisal as emotions' approach of Prinz with its emphasis on the tracking of agent-environment relations to the more mechanistic dynamical systems approach of Lewis with its emphasis on the neurobiologically realized psychology of emotion-appraisals it is necessary once more to appeal to neurobiological data. This can elucidate how emotional stimuli are evaluated and processed and how the dimension of time allowing for increasingly elaborate emotion-appraisal processing might be enacted. One recurrent emotion-appraisal network identified

by Lewis was that of the 'motivation object loop' pertinent to emotion elicitation and regulation. The *dual-route* hypotheses of Edmund Rolls and Joseph LeDoux seek to describe the role of regulatory features of interactions of certain of the neuroanatomical structures identified by Lewis in this loop. The LeDoux ([2], [3]) dual route hypothesis, in particular, makes explicit the distinction between the cortical and subcortical processing of emotion-relevant stimuli. The subcortical route essentially involves the processing of a stimulus from the sensory thalamus to the amygdala without cortical mediation; this route is known as the 'low road' or the 'quick'n'dirty' route. Via this route particularly strong emotion-eliciting stimuli, e.g., the perception of a 'fast, moving object headed in the subject's direction', can lead to rapid, motor responses almost entirely in the absence of mediation from higher level processing, and this is true for human beings as much as it is for other animals according to LeDoux. The cortical route is, by comparison, time-delayed, but allows for more fine-grained stimulus processing. The neuroanatomical structures involved include the sensory cortex, association cortex, hippocampal formation and prefrontal cortex. The latter two structures are implicated in providing context-relevance for the perceived stimulus as retrieved from memory. The reciprocal connections between prefrontal cortex and amygdala ensure that the two structures have a mutually regulating effect and the orbitofrontal cortex section of the prefrontal cortex, in particular, serves to mediate amygdala neuronal firing according to whether stimulus-response object reward evaluation expectations are met. The point is that the relatively high latency for cortical processing means that the processing of stimuli that are part of complex context-specific events requires time in order for appropriate emotional responses to be engendered. Indeed humans with brain damage in areas of the orbitofrontal cortex tend to produce particularly impulsive behaviour and act in socially inappropriate ways (e.g., [33]). So, in relation to the perspective on emotion of Prinz the extent to which plastic 'calibration files' (essentially emotion eliciting dimension sets) can allow for 'recalibrated' embodied appraisals reliably and adaptively registering core relational themes for such complex emotions must be questioned and *attentional emotion-appraisal amalgams* (temporally stable states) might be required for an engendering of emotions via the intricate and cohesive agent-environment dynamic interplay. The importance of such dynamics incorporating context-based environmental cues is not acknowledged in Prinz's account. In summary, we might suggest that *attentional emotion-appraisal amalgams* in agents can be fostered by the processing of exogenous and also endogenous stimuli but the inseparability of agent-environment interactions requires that agent responses, in order for them to be profitable to agent well-being and thus adaptive, account for reliable relationships between agent and environment. Such relationships require bodies and persistent states both internal and external to the organism in order for agent-environment relations meaningful from the perspective of agent well-being to be apprehended and represented. Furthermore, complex context-dependent agent-environment relations are most easily apprehended when the temporal dimension is exploited and it is suggested that where *attentional emotion-appraisal amalgams* (the macro-

scopic level stable emotion-appraisal amalgams in Lewis's terms) exist, a means for such exploitation exists owing to the promotion of coherent and persistent behaviours that such global states afford.

5 Does the Body Always Matter?

In the previous section it was briefly mentioned that, according to Damasio (also Prinz [8]), emotions can be elicited by two routes: 1) the *body loop*, whereby neuromodulatory changes in the brain provoke bodily state changes which are then perceived in the brain in structures such as the somatosensory cortex and insular cortex; 2) the *as-if body loop*, whereby changes in the body can be circumvented allowing for a swifter response by the organism with the obvious survival advantage that that permits. It was also mentioned that in order for such an *as-if body loop* to be viable in a living organism, it would have to be embodied in an agent that had previously processed emotion-eliciting stimuli according to the original body loop; that is, in living organisms the previous use of a *body loop* is a prerequisite for the viable functioning of an *as-if body loop*. The question as to whether or not an *as-if-body loop* can engender arbitrary emotional states independently of the body is perhaps more open, though it might be hard to imagine an organism lacking the perception of bodily changes, imagined or otherwise, as having emotions. As William James ([40], p.190) put it with regard to bodily changes: "our feeling of the changes as they occur is the emotion." And further with respect to the emotion of 'fear': "What kind of an emotion of fear would be left if the feeling neither of quickened heart-beats nor of shallow breathing, neither of trembling lips nor of weakened limbs, neither of gooseflesh nor of visceral stirrings, were present ...". Although James did not explicitly postulate a theory of an *as-if body loop* his point regarding the feeling of the bodily changes still holds. Indeed, it is one thing to be without these bodily changes but it is another to be without the perception of such changes when describing an emotion.

This particular problem of 'higher' level and perhaps macroscopic dynamic processes being separable from the lower level consitituents is also pertinent to the developmental dependence of the orbitofrontal cortex (OFC) on the amygdala for evaluating the emotional significance of a particular perceived stimulus ([24]). Once fully developed the OFC does not require the less plastic sub-cortical structure of the amygdala. Indeed the issue of separability between higher level dynamics produced in the nervous system and the microscopic processes that give rise to it can be more generally applied to the nature of living organisms with nervous systems. A particular position of relevance to the argument adopted in this chapter is that of Barandiaran and Moreno ([41]) whose emphasis on the role of the macroscopic states produced by the nervous system to *attentional emotion-appraisal amalgams* as being potentially separable from the underlying interactions of microscopic processes that give rise to such global states warrants explanation here. According to these researchers the self-organized system that is the living organism can be hierarchically decoupled into two aspects: cellular

metabolism, and nervous system. These are hierarchically decoupled in the sense that although the architecture of the nervous system is produced and maintained through cellular metabolism the dynamic state of the nervous system can not easily, or obviously, be determined from cell metabolic state or the metabolic state of the viscera.

As a fundamental feature of their dynamical systems approach to the study of emotions, Barandiaran and Moreno refer to the interplay between what has been termed ([42]) 'the nervous system of the interior' (INS) and the sensory-motor nervous system (SMNS) which they suggest relates to similar notions of emotions theorists such as Damasio and Lewis. The INS revolves around a particular substrate - neuroendocrine system, autonomic nervous system, limbic system and other neural structures. The interplay between these structures is said to allow for the maintenance of the network of recursively and interactively maintained structures that is constitutive of the agent's complex embodied organization in the face of perturbatory pressures. The authors suggest that the modulatory effect of the INS can anticipate potential destabilizing effects of perturbations to the dynamic structures before the body (organismic structure) is damaged and the organization disintegrated. Such anticipations of the effects of perceived perturbations may be registered by bodily state changes that violate homeostatically maintained viability boundaries which is the essence of Damasio's somatic marker hypothesis. Furthermore, the amygdala-OFC self-regulatory system may provide an evaluation of stimulus-response reward-punishment expectations from which adaptive anticipatory responses can be initiated. The regulatory and recursive effects of the various survival-relevant systems consist in the onset, stabilization and disruption of stable attractor states providing the organizational primitives (dynamic structures) that allow for the macroscopic organizational coherence constitutive of complex living organisms. These effects then provide attentional dispositions that in turn feed back into the recurrent dynamics of the system.

Barandiaran and Moreno go on to suggest that there is a gradual ontogenetic supersession of SMNS dynamic structures being triggered by bodily state changes with SMNS dynamic structures instead being recursively related. Such a transition might be related to Damasio's *as-if body loops* whereby having learned the relevance of particular stimuli or events to somatic states which are then perceptible to the somatosensory cortex, the embodied organism is able to short cut the process through direct perception of imagined (as-if) body state change via patterns in the nervous system allowing for speedier response and hence a greater capacity to maintain the embodied self-organized system that is the organism. This could allow for anticipatory responses that serve to protect the organism against external threats and may also protect the organism from physical damage caused by excessive physiological homeostatic deviation, e.g., damage caused by excess stress. The authors further suggest that a major role of emotional and appraisal dynamics is to modulate SMNS dynamics for global state coherence via 'attention' where attention is taken to mean "amplification of sensory perturbations in order to satisfy a certain stability condition goal".

Regarding the potential to model *attentional emotion-appraisal amalgams* in non-biological systems, if the details of cellular metabolic substrate can be abstracted away, and the dimensions of the nervous system reduced to computational processes, it may be possible to implement aspects of the INS-SMNS interplay to allow for *attentional emotion-appraisal amalgams* or properties of such processes to be incorporated within artificial systems, e.g., robots, in a manner that would allow for greater potential to extract insights into the real world phenomena of interest. The complexity of bodily states might prove a constraint on the complexity of emotion-oriented states but need not be absolutely prohibitive to adaptive states.

6 Modelling Approaches in Artificial Systems

From an embodied dynamical systems perspective recurrent artificial neural networks can be analysed in terms of their trajectories through state space and the effects of attractors on those trajectories. However, as highlighted in the previous section, the generation of an *as-if body loop* requires at least the initial presence of the *body loop* and therefore adaptation and/or learning are seen as crucial elements of any emotion-oriented attentional system. This could be modelled via the artificial evolution of networks incorporating plasticity rules, as in Di Paolo's homeostatic adaptation [43], or alternatively by modelling learning in the internal and external sensorimotor loop (cf., e.g., [44]) though neither approach can be said to fully account for bodily states.

Of particular theoretical interest in light of the discussion presented in previous sections of this chapter is the relational modelling approach that strives to appreciate the link between not just agent and environment but the interaction between agent body, nervous system and environment. Beer ([45], [46]) has made the dynamics of this interaction the focus of his approach to modelling adaptive behaviour in robots and artificial systems. In this view agent and environment are conceived as two coupled dynamical systems and Beer advocates a methodology concerned with the evolving of artificial neural networks to produce autonomous behaviour. Beer suggests that the biological substrate that gives rise to the self-organization inherent in nervous systems allowing for autonomous and adaptive behaviour need not be critical. He comments that many different combinations of biochemical mechanisms can permit similar dynamics and that in fact a cellular nervous system isn't necessary for behaviour at all. On this advocation the approach adopting embodied forms of artificial neural networks that allow for attractor states to emerge as a consequence of autonomous dynamics may provide a promising research avenue.

Parisi ([47]) outlined a methodological approach he refers to as *Internal Robotics* as a response to the classical approach in robotics of focusing on interactions between robot body (morphology) and environment. Similar to Beer, Parisi distinguishes between nervous system, rest of body, and environment. A number of principles underlying the *internal robotics* approach are made with respect to the interactions between the nervous system and the rest of the body, and

between the nervous system and the external environment. One point is made that the nervous system interacts with the environment via the body and as such the nervous system-external environment circuit is less explicitly influenced by evolutionary selection pressures.[2] Of relevance to the argument outlined in this chapter is that whereas states in the nervous system are always in contact with the rest of the body (e.g., bodily physiology, skeletomuscular responses), so that we might envisage that certain regularly activated physiological profiles might be correlated with patterns of neuronal activity, the external environment is not *always* present to the nervous system and so patterns of neuronal activity may not so accurately reflect environmental contingencies. Perhaps Prinz's theory of emotions as embodied appraisals represents something of a reconciliation in that *particular* environmental contingencies (core relational themes) can have, ontogenetically, been correlated with the interplay between nervous system and environmentally elicited bodily state changes (elicited via more or less elaborate current calibration files). Indeed this point is elaborated by Parisi who suggests that "emotional or affective components [of behaviour] emerge from the interactions of the nervous system with the rest of the body" which is contrasted with cognitive components of behaviour which are said to arise from interactions between nervous system and external environment. It is suggested in this chapter, and in accordance with Lewis, that these 'agent-nervous system'-'agent-rest of body' interactions via which such a correlation may be rendered adaptive depend particularly on the temporal dynamics between these two internal states.

Parisi applies his methodological approach to an experiment involving *robots that sleep*. This consists of an interconnected artificial neural network with a recurrently connected 'physiological' node representing a 'biological clock' that regulates inputs from the environment and then in turn inputs to the neural network ('nervous system'). In this sense the robot nervous system is connected indirectly to the environment through its body. This particular connectivity (where nervous system and environment are not directly connected) proved most effective from the perspective of robot viability in environments where a light source was varied.

In general, much recent research in biologically inspired robotics has focused on the interactions between nervous system, bodily states and external environment which are in this sense seen as inseparable, can be viewed as interconnected dynamical systems, and in some way relate events endogenous or exogenous to the artificial organism to the well-being of the organism. However, research demonstrating the emotional significance of such events in terms of emergent interconnected dynamical microscopic processes allowing for globally coherent and stable macroscopic states is lacking. It is posited that a promising approach to the study of adaptive and autonomous behaviour using robots is one guided by a methodology incorporating the ideas of Beer and Parisi. This approach can be

[2] This is consistent with the notion of a fundamental property of an autopoietic (living) system, i.e. organization is affected by structure rather than by the external environment for which Di Paolo [34] has suggested homeostatic regulation is critical for explaining his notion of 'adaptivity'.

furthered where emphasis is placed on the significance of the existence of reliable, recurrent and persistent relational states in agent-environment interactions that can be exploited by adapting agents (over ontogenetic and evolutionary time) as dynamically organized systems that have at least simple internal bodily states. It is suggested that such a methodological approach will allow for the conditions whereby *attentional emotion-appraisal amalgams* can emerge as adaptive states allowing for flexible and autonomous agent behaviour. It is also suggested that the emergence or not of such stable states attentionally disposed to tracking relational phenomena relevant to agent well-being, as correlated (linearly or non-linearly) with one or more of other bodily, behavioural and environmental dynamic patterns, might allow for the sort of testable hypotheses that could render such a model of emotion-appraisal-attention relevant to the current DST approach of Lewis falsifiable and amenable to an in-depth parameter sensitivity analysis.

7 Concluding Comments

To briefly recapitulate the arguments postulated in this chapter, it has been sought to reconcile two perspectives on emotion-appraisals: that of Prinz ([8]) with that of Lewis ([7]). The focus of these perspectives can be said to be in the former case 'functional', focusing on evolutionarily persistent agent-environment relational states, and in the latter case 'mechanistic', focusing on psychological and neurobiological levels of explanation. It was suggested that the two approaches were complementary insofar as the one facilitated explanation of the other allowing for a more complete theory of emotion-appraisal states in terms of *attentional emotion-appraisal amalgams*.

The dynamical systems approach to the study of emotion, appraisal and attention is a promising new methodological angle affordable to computational modelling and for enhancing behavioural adaptivity in robots. It has been argued that research via computational modelling into the functional relevance of dynamical systems to emotion-oriented attentional phenomena requires recourse to evolutionary or at least life-history survival-relevant pressures. In this sense an organism's ability to exploit existing internal self-organizational dynamics to provide structurally-coupled coherence in agent-environment interactions can facilitate a sort of intrinsic teleology. This occurs via stable macroscopic states in emotion-appraisal amalgams that are fundamentally attentional in nature and allow for coherence in action dispositions and behavioural persistence allowing for the exploitation of similarly stable environmental phenomena.

The interest in studying the dynamics of coupled systems is not restricted to the domain of emotion-appraisal-attentional phenomena and therefore the theoretical approach proposed here may have wider implications. Colombetti and Thompson ([14]), for example, point to appraisal-emotion inseparability as being similar to perception-action loops as described by the enactive approach to perception and cognition ([48], [49]). Consistent with this view, emotions can be seen as patterns of dynamic activity providing salience to bias the enaction of senso-

rimotor loops (similar to [50]). This might be argued to provide for some form of behavioural and agent-environment organizational cohesion. Thompson ([51]) suggests that the enactive approach ([48]) purports that "a cognitive being's world is not a pre-specified, external realm, represented internally by its brain, but a relational domain enacted or brought forth by that being's autonomous agency and mode of coupling with the environment." Essentially, the world is not an external phenomenon internally represented but rather a relational domain existing as agent-environment coupling. This view does not preclude the possibility, however, that such a relational domain cannot itself be internally monitored in at least some situations - this is the essential premise of Prinz and one for which in this chapter it has been argued can apply for emotions given the elicitation and dynamically modulated emotion-appraisal integration of stereotyped physiological profiles.

As a final comment on modelling real-world phenomena, Panksepp ([52]) has suggested that testing Lewis's position with respect to emotion-appraisal is not easily achieved via the use of brain imaging techniques in humans and that such abilities are difficult to detect in animals given the lack of a propensity to communicate psychological states. The ability to control the effects of mitigating variables and to analyse performance over time in a manner that is non-intrusive to the objects/subjects of interest allows computational approaches to the study of such organizations the potential to glean particular insights not at the disposal of neuroscientists. The inability of such an approach to replicate as opposed to simulate real world phenomena need not be considered disadvantageous either; rather, abstracting away details which are hypothesized to be superfluous to the specific phenomena of interest can be seen as an advantage of such an approach - experiments can demonstrate how the phenomena of interest are explicable according to the processes hypothesized or, alternatively, according to how such phenomena are actually rather more complex than had been envisioned. Either finding must be evaluated as yielding important insights to researchers from all relevant disciplines.

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