

# COMPUTATIONAL MODELLING OF EMOTION AND REASONING

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## Abstract

CRIBB (Children's Reasoning about Intentions, Beliefs and Behaviour) is a computational model of belief-desire reasoning. This paper presents an analysis of CRIBB and the initial design for an extension that involves the implementation of a model of emotions. The impetus for this research is evidence that emotion plays a fundamental role in a variety of cognitive functions such as decision-making, learning and perception. We consider theories of emotion, perception and reasoning and also the affect that emotion has on these cognitive processes. We discuss how these theories can be modelled and integrated into the CRIBB model and present a proposed initial design for an emotional model.

**Keywords** Emotion, Computational Models, Perception, Reasoning.

## Introduction

The question of what an emotion is has been addressed by psychologists, philosophers and neuroscientists over many years. However, no consensus has yet been reached. The lack of an objective measure to conclusively establish whether a person is experiencing an emotion has led to many contrasting theories and views of emotion being formed. The traditional perspective of emotion is of something that is irrational and detracts us from reasoning. But, scientists have recently learned of many surprising roles played by human emotions especially in cognitive processes such as perception, decision-making and memory. This evidence leads us to believe that emotions are an essential part of human intelligence, including rational decision-making and learning. Therefore, emotions are believed to be a vital part of any system that attempts to imitate human intelligence computationally.

The aim of this research is to investigate theories of emotion and how they can be used to form a better computational model of reasoning. This paper describes the analysis and initial design for the integration of an emotional model into an architecture for belief-desire reasoning. Theories of emotion,

perception and reasoning will be discussed along with how emotion affects both these cognitive processes. This leads to a description of a belief-desire model and the design of how emotion can be incorporated into it.

## Psychology and Emotions

Emotions and their nature have been studied for a large number of years and throughout this time psychologists have proposed a wide-range of diverse theories of emotion. Darwin's [6] theory has an evolutionary basis in which he claims that emotions are a by-product of evolutionary history. Emotions are either simply dependent on how the nervous system is 'wired-up' or possibly are remnants of old habits. He also maintains that facial expressions of emotions are merely something that occurs in conjunction with emotion and serve no communicative function.

The James-Lange theory, based on a physiological approach, is one of the best known theories of emotion and presents an entirely different view to emotion. James proposed that bodily changes directly follow perception and these bodily changes then lead to the feeling of emotion [21]. His theory of bodily patterns affecting emotions led to research and theories which stress the importance of facial and bodily expressions in emotion. Ekman is one of the investigators researching into this area. He derived six basic emotions from research performed into universal facial expressions: fear, anger, disgust, happiness, sadness and surprise [9]. Ekman believes that there are three differentiated but interrelated systems involved in the elicitation of emotion: cognition, facial expression and ANS (autonomic nervous system) activity, with an emphasis on facial expression.

The appraisal approach has cognition as the core element in emotion. The OCC (Ortony, Clore and Collins) model [18] synthesises emotions as outcomes to situations. Emotions occur from a valenced reaction to situations consisting of events, objects and agents. The emotion type elicited is dependent upon appraisals made at each branch of the model. It also allows for an emotional state to be a situation itself, so emotions can trigger additional emotions or the same one repeatedly.

The goal-oriented approach, which also cites cognition as a central part to the elicitation of emotion, suggests that emotions arise from evaluations of events relevant to goals. Oatley and Johnson-Laird [17] argue that emotions are caused by cognitive evaluations of an event that may be conscious or unconscious. Each kind of evaluation gives rise to a distinct signal that reflects the priority of the goal, which then influences the behaviour produced accordingly. Frijda [10] cites a similar definition of emotion and states that certain stimuli elicit certain emotional phenomena because of the individual's concerns and the stimuli are relevant to the satisfaction of these concerns.

Many theorists including Ekman, Oatley and Johnson-Laird use the concept of basic emotions in their theories. Oatley and Johnson-Laird cite four basic emotions derived from evolutionary origins: happiness, sadness, fear and anger. A further five are derived from innate biological substrates: attachment, parental love, sexual attraction, disgust and interpersonal rejection. However, some other theorists question the notion of basic emotions. Duffy posed the question, at which particular degree does a characteristic become an 'emotion' or at which degree should it be a 'non-emotion' [8]. For example, a raised heartbeat is characteristic of some emotional behaviour, but in other cases non-emotional behaviour. When does the difference in the characteristic occur? Is emotion a distinguishable state or a difference in the degree certain response characteristics exhibit themselves?

According to Duffy, the phenomena that are described as emotion appear to occur in a continuum or a number of continua. The responses called 'emotional' do not appear to follow different principles of action from the other responses of the individual. She states that all responses, 'emotional' or 'non-emotional', are reactions that attempt to adapt the organism to the situation. Emotion represents a change in the energy level, or the degree of reactivity of an individual. For example, situations, which are interpreted as threatening or thwarting, are characteristically responded to with increased energy. Whereas, situations where an individual makes little or no attempt will see a decrease in the energy level. A small change in energy level may occur during 'interest' or 'boredom', whereas 'anger' would be due to an extreme change.

Duffy does support the goal-oriented view that emotions are only experienced in situations that are of significance to the individual. Also that the intensity of the 'emotion' is proportional to the level of importance that a particular goal has to an individual and degree of threat or promise the situation bears for that goal. The emotion experienced is also affected by the background and information that the individual has about the particular situation.

Scherer also examines evidence that points towards the existence of a large number of universal 'response elements' as opposed to basic emotions [20]. His concept of modal emotions attempts to address many questions including, why does the same situation not necessarily provoke the same emotional expression nor the use of the same label in two individuals? Like Duffy, Scherer sees emotion as a number of changes that occur over time in response to an event. The definition of emotion he proposes is that an emotion is "*a sequence of interrelated synchronised changes in the states of all organismic subsystems in response to the evaluation of an external or internal stimulus event that is relevant to central concerns of the organism*" [20]. The emotional state that is elicited results from the cumulative evaluation of relevant changes in internal or external stimulation. Scherer proposes that the organism makes five types of checks: novelty, intrinsic pleasantness, relevance to meeting plans, ability to cope with the perceived event and compatibility of the event with self-concept and social norms. An appraisal according to these checks is carried out which then elicited an emotional response. Scherer believes that the information from these checks is needed in order to choose how to respond. Some combinations of evaluation checks would be frequently encountered, giving rise to the same recurring patterns of state changes. The term 'modal emotions' refers to states resulting from these recurring stimulus evaluation check patterns. Although some patterns occur more frequently, the number of potential emotional states is virtually infinite [20].

Scherer and Duffy oppose the view of basic emotions and examine evidence that emotions are patterns of interrelated changes. The number of basic emotions included in various theories differs greatly. For example, the OCC model contains twenty-two different emotion types [18], whereas Oatley and Johnson-Laird only cite nine [17]. Using basic emotions in a theory can lead to what Scherer calls 'bunching' of the different emotional states around a limited number of types [20]. Conversely, the scope of emotional states in both Duffy and Scherer's theories is wider, potentially infinite. However, there are some similarities between Duffy's theory and theories that use basic emotions such as Oatley and Johnson-Laird's. Both are goal-oriented approaches that suggest emotions are only elicited in situations that are relevant to an individual's goals and that the priority of the goal affects the intensity of the emotion experienced. Goal-oriented theories also propose that cognition is an important part of emotion. However, Oatley [16] suggests that it is not just the underlying state of cognitive appraisal that occurs. Other accompanying phenomena could also occur such as body posture, facial expressions and physiological responses.

## **Emotion and Reasoning**

Research has shown that emotion affects many different aspects of human cognitive functions

including memory [3] and intelligence [12]. Among the most influential is Damasio's research which indicates a link between emotion and reasoning [5]. There has never been any doubt that emotion disrupts reasoning under certain circumstances and that misdirected or uncontrolled emotion can lead to irrational behaviour. However, evidence from Damasio and other sources also suggests the contrary. This research led to the development of the Somatic Marker Hypothesis. This states that decisions are made in circumstances, whose outcome could be potentially harmful or advantageous, and are similar to previous experience, induce a somatic response used to mark future outcomes. When the situation arises again the somatic marker will signal the danger or advantage. Thus, when a negative somatic marker is linked to a particular future outcome it serves as an alarm signal that tells us to avoid that particular course of action. If instead, a positive somatic marker is linked it becomes an incentive to make that particular choice [5]. This theory suggests that emotions play a fundamental role in brain mechanisms that are associated with basic rational and intelligent behaviour such as decision-making and reasoning.

The limbic system is seen as the seat of emotion, memory and attention in the brain [19]. Researchers have found that the amygdala, part of the limbic system, plays an important role in the coding of the emotional significance of sensory stimuli [5]. Also neurons in the amygdala are driven particularly strongly by stimuli with emotional significance. During experiments to investigate the role of emotion in brain mechanisms [5], the amygdala has been implicated as the focal point that determines the emotional significance of many kinds of emotional stimuli. Studies have also shown that mood influences the perception of ambiguous stimuli [13]. For example, if subjects were asked to quickly write words that they hear those who were happy were more likely to write 'presents' opposed to 'presence'. Cytowic's [4] research into synesthesia also points towards a link between emotion and perception. He found that there is an increase in activity in the limbic system when synesthesia occurs. Synesthesia is a condition where one sensation involuntarily conjures up another, as if the senses are 'cross-wired', this results in a heightened perceptual experience [4]. Therefore, the degree of limbic activity during synesthesia indicates that the limbic system plays a significant role in perception and also points to the involvement of emotion in the perception process.

Further research proposes that motivation and emotion serve as filters that guide perception and determine the input to the evaluation process [2]. This view is also supported by Izard [15] who argues that emotion is a guiding force for perception. He also states that most major theories of emotion agree that emotions constitute a very powerful motivational system that influences perception, cognition and coping in many important ways. This and other evidence leads us to believe that emotion plays a role in the process of perception as well as reasoning.

A simple definition of perception is the process of organising and using information that is received through the senses. But what processes are involved in perceiving? A popular approach to perception is that the relationship between distal and proximal stimuli is likely to be imperfect. We see things that are not physically present when we complete gaps in the patterns. For example, the sensation of tickle does not resemble the objects that induce it enough to mediate perception, the perceiver must add them. Therefore, the perception of the world is essentially indirect, which means something must be added to the incoming stimulus information before the final perceptual response is attained.

Gibson and his followers argued a contrasting theory of direct perception. Gibson's work was an attempt to show that distal objects and events can be specified by patterns of proximal stimulation [11]. Also the perceptual systems interact directly with the information contained in these patterns. Gibson describes how sensory data when perceived is given affordances and valences. An affordance is something that refers to both the environment and the animal in a way that no existing term does. They are properties taken with reference to the observer. Affordances of the environment are what it offers, what it provides, either for good or bad. For example, if a surface is horizontal, nearly flat and sufficiently extended and if its substance is rigid then the surface affords support [11]. Affordances can also be valenced. Positive and negative affordances are properties of things taken with reference to an observer, but not properties of the experiences of the observer. A simple example is that a fire affords both warming (positive) and burning (negative).

Davis [7] describes how Gibson's theory of perception can be used in a computational agent-based scenario. He also discusses how the interpretation of perceptual information and different personae can affect the actions of an agent in any given external situation. An agent experiencing an environmental event will perceive it according to the nature of current control states. Consider, for example, an agent, in danger, being placed in front of another agent. If the perceiving agent has adopted a selfless persona, this event may be assigned a positive valence and afforded rescue behaviours. However, if a selfish persona has been adopted by the perceiving agent, this event will be assigned a negative valence and afforded avoidance behaviours. This is one example of how a theory of perception can be incorporated into a computational model of perception, reasoning and action-selection.

### **The CRIBB Model**

CRIBB (Children's Reasoning about Intentions, Beliefs and Behaviour) is a computer model that is

based upon Bartsch and Wellman's [1] general sketch for belief-desire reasoning, although not all aspects were included in this implementation of the CRIBB model. It simulates the knowledge and inference processes of a competent child solving false-belief tasks [22]. CRIBB processes different forms of representations, depicted as rectangular boxes in figure 1, sets of inference schemata are depicted by ellipses. A simulation run in CRIBB starts by giving propositions containing facts and perceptions about the scenario in sequential steps according to the time interval in which the propositions arise. On the basis of these propositions given and the inferences drawn from them, CRIBB answers experimental test questions about the cover story. The questions can be about its own beliefs or about intentions, beliefs and behaviour of another person in the scenario.

CRIBB represents propositions about physical states of a given situation and about another person's intentions, beliefs, perceptions and behaviour. The knowledge base consists of practical syllogisms and other inference schemata, which represent the relations between these propositions. Practical syllogisms denote knowledge about the relations between intentions, behaviour and beliefs of another person. There are four types of practical syllogisms that can be used for the prediction and explanation of another person's behaviour. For example, if a person wants a proposition and believes that performing an action realises the proposition, using practical syllogisms, they will infer that they will perform the action.

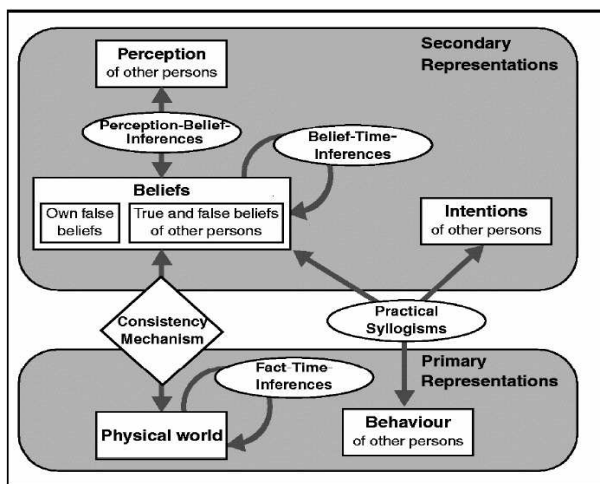


Fig. 1 Basic representational and functional parts of the CRIBB Model

There are four other classes of inference schemata: perception-belief, belief-time and fact-time, which are split into primary and secondary representations. Primary representations are the system's own beliefs about the situation and the behaviour of other people. Fact-time inferences, propositions about facts along a time scale, are classed as primary representations. Belief-time and perception-belief inference schemata are both types of secondary representation as they contain beliefs about the system's own and other

beliefs. The perception-belief schema represents the relation between perception and belief. For example, if a person perceives X at time T then a proposition about the person's belief can be inferred. The belief-time schema contains propositions beliefs along a time scale. A further element of CRIBB is a consistency mechanism that detects and resolves any contradictions in the system's beliefs. The consistency mechanism is invoked each time a new proposition is added, in order to ensure the consistency of the knowledge base. If a contradiction is found then the more certain proposition is added to the knowledge base. In the case of beliefs, the old belief is kept and marked as false. The certainty of a proposition is determined by its source. For example, if a proposition is formed from situational knowledge then this is considered more certain than a proposition based on an assumption or a derivation.

### Extending CRIBB

The importance of emotion to many cognitive abilities is apparent from numerous research findings. Therefore, emotion should be considered as an important aspect when attempting to model such brain mechanisms. Although, Bartsch and Wellman's model for belief-desire reasoning includes an emotion element, the CRIBB model does not currently implement this aspect. Therefore, the current CRIBB system does not have emotional capabilities. Consequently, CRIBB can be used as a basis on which to perform some experiments with different models of emotion.

Certain theories of emotion are more suitable for implementation in CRIBB. The main problem with many theories is that the explanation of how emotions are elicited is not detailed enough in order to produce a reasonable model. Other theories also present different problems for the transformation into a computational model. Ekman's theory presents challenges with the recognition and synthesis of facial expression and associated difficulties. This is due to the variety of facial expressions that humans' use and the recognition of the subtleties that differentiate one from another. Both the appraisal and the goal-oriented approach have some similarities and both cite cognition as the core of emotions. However, the scenarios used in CRIBB, at present, are based around a goal-oriented structure. The existence of intentions in CRIBB, from which behaviours are produced, means that there is a desired state to be achieved. This is comparable to a goal state used in theories of emotion. Therefore, implementing a goal base and using tenets of the goal-oriented approach to emotion is a more suitable foundation on which to base a model of emotions.

A model of emotion could be introduced in a number of different ways in the CRIBB model. An emotional module could be implemented as a separate element of the architecture, which is integrated with the other elements of the system. For example, the consistency mechanism in CRIBB is a separate element, but still

interacts and affects the rest of the system. However, emotion has wide ranging effects on a variety of brain functions, therefore, emotion seems not reside in just one place. So should emotion be considered as a more integrated, but ‘decentralised’ element? Duffy’s theory that emotions occur in a continuum or a number of continua, which includes both ‘emotional’ and ‘non-emotional’ behaviour, views emotion as a more integrated part of behaviour rather than a separate element. This view is also supported by Scherer who argues the pattern of all synchronised changes in the different components over time constitutes an emotion. Both of these theories also allow for a ‘decentralised’ view of emotion, which means even small differences in the subsystems can reflect real differences in the nature of the emotional episode.

Introducing emotion as a ‘decentralised’ element may create problems with communication and synchronisation with other aspects of the CRIBB system. This is due to the constant re-evaluation of plans and information processing that takes place within the system. A central monitoring system would allow the sub-systems to integrate, but also work as ‘decentralised’ and somewhat autonomous elements. Oatley and Johnson-Laird [16] propose that each goal and plan has a monitoring mechanism that evaluates events relevant to it, which broadcasts to the whole cognitive system to allow it to respond to change when it occurs. However, this needs to be extended to allow for a ‘decentralised’ model of emotion. The monitoring system would need to communicate goals and plans to the sub-systems of CRIBB. But also the sub-systems need to communicate to the monitoring system to ensure that the overall state of the system is known. For example, a small change in the perception mechanism may be inconsequential, but if it is communicated to the monitoring system, this small change could affect the overall state of the system.

## Emotions in CRIBB

Prior research has shown that emotion has effects on aspects of the reasoning process such as perception. This indicates that the individual subsystems of CRIBB such as perception, belief, intentions and behaviour can affect the nature of the emotional state individually, rather than emotion being elicited just by evaluations about the reasoning process as a whole.

Gibson’s theory of direct perception could be used to extend CRIBB’s perception mechanism to incorporate emotional capabilities. Gibson’s theory states that sensory data, when received, is given affordances and valances. Affordances are properties of the environment with reference to the observer, but they do not change as the needs of the observer changes [11]. Affordances are always there to be perceived. However, the observer may or may not perceive the affordance and whether or not they attend to it is dependent on the needs or goals of the individual. The

theory of affordances can be extended to allow emotion to exhibit an effect on perception of the environment according to the importance of needs, goals and plans to the individual.

When CRIBB is given a proposition, a belief is inferred from this. The consistency of this belief is checked with existing set of beliefs. If no contradiction is found then it is added to the belief set. If there is a contradiction then this is resolved and the most certain belief is added to the belief set. For example:

$$B := [\neg p]$$

$$P := [r, s, \neg s, q, p]$$

$$P \otimes B \rightarrow B'$$

$$B' := [r, s, q, p]$$

B is the existing belief set and P is perception set. The new set B’ contains the system’s new belief set with all possible contradictions resolved. In this scenario each perception of the world has equality. However, the ordinary world cannot be modelled either completely or accurately due to the imperfect model of the model held by the individual and limited resources available [16]. Therefore, an individual’s attention is drawn to aspects of the environment deemed important to them. Assigning an emotional affordance to each perception to reflect its emotional significance to the individual will enable a process by which perceptions can be filtered according to their importance. Hence:

$$P := [r, s, \neg s, q, p]$$

$$E := \{[importance(\text{high}, p)], [importance(\text{low}, r)]\}$$

$$B := [\neg p]$$

$$E \otimes P \rightarrow EP$$

$$EP := [p, s, \neg s, q, r]$$

$$EP \otimes B \rightarrow B'$$

$$B' := [p, s, q, r]$$

The perception set, P, contains the same perceptions as before. However, the order in which the perceptions are processed has changed according to the emotional affordance, E, attached to each one. The new belief set, B’, contains the perceptions which have been processed in the order that accords with their emotional significance to that individual. A simple example of this is if a child sees a ball and a bar of chocolate lying on the table, but they like eating chocolate more than playing with a ball. Then the chocolate will have more emotional significance to them and their attention will be drawn to the chocolate before the ball.

Emotion could be used to extend the belief and perception mechanism of CRIBB further. Consider a perception received from one source and a further perception, from a different source, that contradicts this. If, through the contradiction mechanism in CRIBB, the first perception is found to be false then this may affect the truth value of any beliefs and perceptions from that

particular source. In other words the person may now be less inclined to believe information received from this source. For example, perception,  $p$ , is received from source  $X$  and perception,  $\neg p$ , is received from source  $Y$ . If perception,  $p$ , is found to be true then a negative emotion such as anger or disappointment may be felt towards source  $Y$ . This may then have the consequence that the information received next from source  $Y$  may be seen as false regardless. Or conversely, the information from source  $X$  may now be considered more reliable than before. This situation can be represented in CRIBB by creating an emotional correspondence for each possible source. This would give an indication of the likelihood of information from this source being either true or false.

A further expansion of the belief mechanism could include a method which allows the goal base to have an effect on the belief schemata. When a belief that contradicts an existing belief is received, it may imply that an important goal is under threat. This could result in evasive action in order to maintain the goal status depending upon the goal's importance. The individual may choose to disregard the new belief, marking it as false, and maintain an inconsistent belief set and the goal's status. For example, a person has a goal is to be the best at mathematics and they believe that they are the best at mathematics. If then, information was received that someone else was better than them at algebra; they may choose to ignore this knowledge and maintain the belief that they are the best.

## Future Work

In this paper, we have presented an analysis and initial design more than an account of results. An extension to CRIBB to include emotional capabilities has been proposed using an integrated, but decentralised theory of emotion. The need for a monitoring system to control communication and synchronisation across the 'decentralised' sub-systems has also been discussed.

The perception mechanism of CRIBB has been extended and it has been shown, through design, that introducing emotion alters the order of processing and acts as a 'filter' of perceptual information to the system. This means that attention is drawn to the objects in the environment that afford high emotional significance to the individual. For example, if a child sees their mother and a stranger walk into a room, their attention will be drawn initially to their mother. This is because the mother has more emotional significance to the child than the stranger so, therefore, is perceived first. A method of emotional bias toward sources of perceptual information and beliefs had also been proposed, along with a 'goal maintenance' method. However, further scope for emotion will need to be included to expand this initial design. The consequences of introducing emotion to the other subsystems of CRIBB such as intentions and behaviour will need to be examined with

a more detailed assessment of the role of the monitoring system

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