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Using Gross' Emotion Regulation Theory to Advance Affective Computing

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Abstract

Affective computing is the study and development of systems that are able to interpret, recognize, process, and simulate human affects. Several researchers have pointed out that affective computing, and computational modeling of emotions in particular, is highly fragmented and that models that are built are rarely incremental or contrasted with one another. Moreover, even though emotion regulation is seen as an important aspect of emotion, almost no models of emotion regulation exist. This thesis tries to advance the field of computational modeling of emotion using the theory of emotion regulation by Gross. First, the theory by Gross is fit into the landscape of emotion theory. In particular, Gross' theory is compared with the theory by Lazarus, Frijda and the OCC and the difference between coping and emotion regulation is investigated. Then, some models of emotion are compared with one another based upon the results found. Finally it is shown how the ideas of Gross can be used to modify and extend already two existing models: EMA and the formalization of Broekens et al. This thesis does not only focus on the results obtained, but also on developing constructive methods to compare and extend theories and models, which is believed to also contributed to advancing affective computing.

Acknowledgements

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Contents

Introduction

She faced them and spoke sarcastically, "Surely you know the fundamental First Law of Robotics."

The other two nodded together. "Certainly," said Bogert, Irritably, "a robot may not injure a human being or, through inaction, allow him to come to harm"

"How nicely put," sneered Calvin. "But what kind of harm?"

"Why – any kind."

"Exactly! Any kind! But what about hurt feelings? What about deflation of one's ego? What about the blasting of one's hopes? Is that injury?"

Lanning frowned, "What would a robot know about-" And then he caught himself with a gasp.

"You've caught on, have you? This robot reads minds. Do you suppose it doesn't know everything about mental injury? Do you suppose that if asked a question, it wouldn't give exactly that answer that one wants to hear? Wouldn't any other answer hurt us, and wouldn't Herbie know that?"

"Good Heavens!" muttered Bogert.

- Isaac Asimov, *Liar!*

While the idea that robots can anticipate on our emotional state was definitely science fiction when Asimov wrote *Liar!* in 1941, this scenario comes very close to our life nowadays. Robots play an increasingly prominent role in our society. Besides industrial robots, used for example in the car industry, the use of robots with a social character is growing (Fong, Nourbakhsh, & Dautenhahn, 2003). In particular, robots that can be used to support humans on an emotional level seem very promising in a society with an aging population. There are already several companion-robots on the market for elderly people (Broadbent, Stafford, & MacDonald, 2009). Another place where these robots can be used is in hospitals, where they can support sick children in places where there parents cannot join them, during radiation therapy for example (Stiehl et al., 2009). In order for these type of robots to fully support people in various settings, robots need some internal model of how the human emotion system works.

Affective Computing

Affective computing is the research field that is concerned with the study and development of systems that are able to interpret, recognize, process, and simulate human affects. Researchers in this field explore how interaction between humans and technology is influenced by affective factors, how affect sensing and affect generation techniques can inform our understanding of human affect, and how we can design, implement and evaluate systems that involve affective processes (Calvo, D'Mello, Gratch, & Kappas, 2015).

Part of the research in affective computing is concerned with computational modeling of emotions. Here, researchers try to develop and validate models of human emotion mechanisms. The goal of this field is twofold. The first goal is theoretical: researchers try to achieve better understanding of human emotions by creating models of these theories. The second is applied: researchers try to extend models of artificial intelligence with emotions in order to increase their capability to deal with unknown environments (Reisenzein et al., 2013).

Affective computing, and computational modeling of emotion in particular, is a relatively young field. While emotions have been a matter of interest since the ancient Greeks (Solomon, 2000), the field of affective computing started blooming after the famous paper *Affective Computing* of Picard (Picard, 1995).

Being such a young field comes with several problems. The two main problems are that the theoretical field of emotion theory is highly fragmented and lacks of precision (See e.g. (Reisenzein et al., 2013; Hudlicka, 2011) and that the models that are built are rarely incremental or contrasted with one another (S. Marsella, Gratch, & Petta, 2010). In other words, it seems like researchers tend to 'start over' every time they try to build a model and base their model upon a theory that does not contain the necessary details.

Moreover, even though emotion regulation is often seen as an important aspect of emotion, there are almost no models of emotion regulation (Soleimani & Kobti, 2012). Gross developed an influential theoretical framework of emotion regulation, that he defines as both the conscious and unconscious regulation of your own emotions or someone else's (Gross, 2011). This theory will play a dominant role in this thesis. Since robots that support humans in emotional situations do not only have to recognize emotions but also support humans in handling them, we believe that models of emotion regulation will be very important for affective computing.

Aim of this Thesis

In this thesis, we will investigate how Gross' ideas about emotion regulation can be used to advance affective computing, in particular computational modeling of emotions. Since we want to actively help to mature the field, we don't want to 'start over' and present a new model or a new formalism. Instead, we will propose some adaptations and improvements of existing models. Besides providing adaptations of existing models, another main aim of this thesis will be to provide more clarity in the theoretical landscape of emotion theory and emotion modeling, and to provide an example of how incremental research in this field can be executed.

The main research question of this thesis is:

How can the theory of emotion regulation as defined by Gross help to advance the field computational emotion modeling?

By answering this question, we want to address the two main problems of the field so far: (1) the fragmented field of emotion theory and (2) the lack of incremental research. Therefore, we have formulated the following two sub-questions:

- *How does Gross' theory fit into the theoretical landscape of emotion theory?*
- *How can we adapt or extend an existing model of emotion with the notion of emotion regulation as formulated by Gross?*

In Chapter 1, we will answer the first question and we will see that emotion regulation mainly fits *Appraisal theory*. Therefore, we will compare three influential appraisal theories of emotion with one another and with the notions by Gross. The second sub-research question will be addressed in Chapters 2 and 3. In Chapter 2 we will introduce and compare several computational models of emotion and emotion regulation and in Chapter 3 we will propose an extension based on Gross' notion to two of these models.

Chapter 1

The Theoretical Landscape of Emotion

The main aim of this thesis to investigate how the theory of Gross can advance the field of computational emotion modeling. In particular, we want to expand models of emotion with a notion of emotion regulation described informally by Gross (Gross, 2011). Before we take a look at the differences between the computational models, we think it is important to look at the psychological theories that form the theoretical basis of these models. First, when working with models of theories from a certain field of research, we think it is important to know the origin of the theory and to understand why certain assumptions are made. Second, it is important to see whether Gross' theory is compatible with the theories that form the basis of computational models of emotion, because if this is not the case, extending the formal models that are based on these theories will be very challenging, if not impossible. Finally, as several researchers (e.g. (Reisenzein et al., 2013; Hudlicka, 2011)) plead, there is a need to organize the theoretical landscape of emotion. By comparing theoretical properties, we hope the differences and similarities between different theories will become clearer and that this can help future researchers to select a theory that suits their specific needs.

This chapter aims to find out how the theory of emotion regulation fits into the theoretical landscape of appraisal theory and emotion theory in general. In particular, a comparison will be made between three influential theories within affective computing. First a short overview of the aim of emotion theory in general will be given followed by some general trends within emotion. Next, the focus will be put on appraisal theory, the branch of emotion theories that that is most influential in affective computing, and this branch will be compared to the assumptions Gross and Thomson make about emotions. Then, the four different views on appraisal theory will be compared; Lazarus theory (Lazarus, 1991), the OCC model (Ortony, Clore, & Collins, 1988), the theory of Frijda (Frijda, 1986) and the theory of Scherer (Scherer, 1984). This chapter will be concluded with a comparative analysis of the theory of Gross and Thompson in relation to the analysis of these four different appraisal theories.

1.1 Theories of Emotion

Reasoning about emotion can be found throughout history, dating back to the ancient Greek philosophers around 400 BC. Although philosophy developed as the pursuit of reason, emotions were never completely neglected by philosophers and remain of interest in this field today (Solomon, 2000). In the last third of the nineteenth century, psychology was founded as an independent field. Psychology concerned 'the science of consciousness', and emotion became one of the interests of this discipline. Many of the current theories of emotion have their roots in this period (Arnold, 1960). During the behaviorist phase of psychology, in which the main focus was on the functional connection between stimulus and response, internal physiological events and hypothetical concepts were mainly ignored and emotion research declined. It was not until the cognitive revolution of the early 1960s, in which the human brain was approached as a complex information processing system, that emotion returned as a general field of interest (Reisenzein, 2014). Nowadays, emotion research is a broad and interdisciplinary field, which includes neuroscience, sociology, computer science, linguistics, literary studies, and cultural anthropology (Lewis & Haviland-Jones, 2000).

Since the aim of this thesis is to advance the field of affective computing an models of agents that could be used within an agent, we will restrict ourselves to the psychological theories of emotion. First, the aim of psychological theories of emotion will be discussed and several distinctions that can be made will be described. Then several trends within emotion theory will be discussed.

1.1.1 A Psychological Theory of Emotion

The main goal of a psychological theory of emotion is to describe the phenomena which are considered to be emotions and to explain these phenomena in terms of the structure and fundamental processes of an individual (Frijda, 2000). This is also referred to as the *reverse-engineering of the emotion system* (Reisenzein, 2014; Reisenzein et al., 2013). In particular, psychological theories of emotion focus on the processes connected to emotion within an individual, even though these processes might have been caused outside the individual in a social or cultural context (Frijda, 2000).

While there has been a considerable amount of research in the area of emotions, there is unfortunately no widely accepted theory of emotion or an *ultimate correct theory of emotion* (Reisenzein et al., 2013). Strongman wrote an overview which concludes over 150 different theories of emotions (Strongman, 2003). Although most of these theories are only interesting historiographically, many others are still influential today (Reisenzein et al., 2013). An ultimate theory of emotion will explain every aspect of emotion. However, since this theory has not yet been found, most theories try to explain only a part of the emotion system.

The reverse-engineering of the emotion system can be broken down in two ways. Reisenstein refers to these two ways as the horizontal and the vertical division of the emotion system (Reisenzein et al., 2013). The horizontal division separates between different aspects of the emotion process where a theory can try to explain only a single aspect of the emotion system, for example how emotions are generated. The vertical division separates between different levels of abstraction of the description. Both distinctions are discussed in further detail below.

Horizontal division: Five fundamental questions of emotion theory

According to Reisenzein, the emotional process can be broken down into five different aspects. He has formulated these aspects in the following five fundamental questions[1] about emotions (Reisenzein, 2014, p.2) :

1. How are emotions generated?
2. What effects (in particular adaptive or functional effects) do emotions have on subsequent cognitive processes and behavior?
3. What are emotions?
4. Which parts of the emotion system are inherited and which are acquired through learning?
5. How are emotions biologically realized or implemented?

According to Reisenzein, a complete theory of emotion gives an explanation to at least the first three questions. The fourth and fifth are seen as helpful -or maybe even necessary- to answer the first three. As said before, most theories only focus on a part of the emotion process. Therefore, most emotion theories focus on only one or two of these questions and omit the others.

Vertical division: Three levels of explanation

Dennett described three different levels - or stances - in which a system can be explained (Dennett, 1971). Marr described similar distinctions some years later (Marr, 1982)[2]. The aim of Dennett was to distinguish different kinds of theories to predict the behavior of a system. When predicting the behavior of a system, the input of the system and assumptions about the inner working of the system are combined to predict what the system is going to do. The type of assumptions made about the system is what determines on which level the theory is formulated. Dennett used the example of playing against a chess computer and using a model to predict its next move. Marr used his levels of explanation to describe the human visual processing system.

Physical stance The lowest level of explanation described by Dennett is the physical stance. On this level the predictions or explanations of the behavior of the system are based on how the system is physically realized and solved with the use of laws of nature. According to Dennett, this level of explanation is often used in daily life - "If you turn on the switch, you'll get a nasty shock" (Dennett, 1971, p. 88) - but rarely for a computer. If you want to describe a theory about a computer on this level it would contain an explanation of how the electrical current runs through every component in the computer and how this would result in some change on the screen or letters getting out of the printer. When we look at the human brain as the system we want to describe, theories that include assumptions about, for example, synaptic mechanisms and action potentials would fit into this level.

[1] These questions roughly corresponds to the aspects of emotion theories mentioned bij Frijda in (Frijda, 2000)

[2] We choose to follow the distinction made by Dennett, since similar work also used this distinction (Frijda, 2000; Reisenzein et al., 2013). We do believe that the differences between the two theories are minimal, but investigating this claim lies outside the scope of this thesis.

Design stance The next level is the design stance. On this level the relation between the input and output is described in terms of algorithms that transform the input into the output. In contrast with the previous level, the details of how the algorithm is physically realized are omitted. Dennett explains this level as the program of the computer. When one wants to predict the behavior using this kind of theory, the input of the systems can be fed to the algorithms and the output will be the prediction. On this level there is more focus on the representations than in the previous stance. Often it is assumed that the system is able to be divided into different functionalities, that each have their own algorithm or function. The division and functions are the things that are studied.

Intentional stance The highest or most abstract level described by Dennett is the intentional stance. On this level the behavior of the system is described in terms of the beliefs and goals of the system. It is important to note that this does not mean that you also assume that the system actually possesses these beliefs and goals, you only treat the system *as if* it has beliefs and goals. With this stance, the prediction of the behavior is based on what the most reasonable (optimal according to weighted goals) next move would be. On this level the focus lies more on what the problem and solutions are, than on how the problems are being solved within the system. This level roughly corresponds to the famous computational level[3] of Marr.

Theories of emotions can be described on different levels. As emphasized by Marr, certain levels are more suited to describe certain observations (Marr, 1982). For example, the explanation of blushing when feeling ashamed could easily be expressed on the design level, referring to the change in the hormone levels in the blood. On the other hand, trying to explain the behavior of someone who is angry at her sister, because she thinks she secretly borrowed her dress and ruined it, probably would be more easily expressed on the intentional level in terms of beliefs and goals. This is also something that one should be aware of when examining and comparing different theories. Although theories formulated within different levels could seem very dissimilar at first sight, they do not necessarily have to contradict each other. Actually, Marr argues that theories from different levels form a hierarchy, with the most abstract level at the top. This view can also be applied to the stances of Dennett, see Figure 1.1. When going back to Dennett's example of the computer playing chess, an intentional stance would describe a computer that tries to win a game of chess. But there can be several computer programs that will behave the way predicted by the intentional stance. Analogously, these programs can run on different physical machines but still execute the programs in the same way.

In the next subsection, several trends in emotion theories within psychology are described. As will become clear, most theories that are used for emotion modeling are written in the intentional stance. This is not surprising, since emotion modeling and emotion theory have not reached a general theory yet. The first priority of psychologists concerned with emotion is still to understand what emotion is and how it works. When the goal is to understand an algorithm, it is more easily understood by looking at the nature of the problem than by examining the mechanism in which the algorithm is embodied (Marr, 1982).

[3] Not to be confused with the notion of a computational model. More about this in Section 2.1.

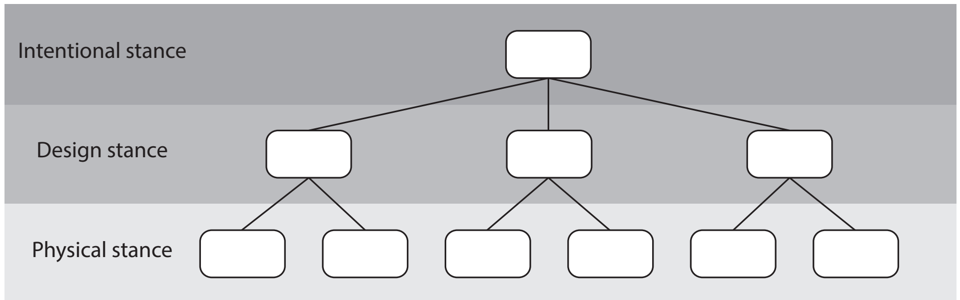

Figure 1.1: Visualization of how different theories of different levels of Dennet can form a hierarchy. One theory on the intentional stance can correspond to multiple theories on the design stance and a theory on the design stance can correspond with multiple theories on the physical stance.

1.1.2 Trends in Emotion Psychology

One of the problems when modeling emotions is the theoretical fragmentation of the research field (Reisenzein et al., 2013). When trying to model a phenomenon, one usually takes a look at different trends within the research field to look how the different views correlate. The problem with emotion theory is that there are many different theories and most of the time it is not clear whether and how they relate to one another. This is evident when looking at researchers that try to address different theories of emotions. The way in which theories are grouped together differs from scholar to scholar. Even when only looking at papers that focus on modeling of emotions, there are big differences: some make the distinction between cognitive and non-cognitive theories (Reisenzein et al., 2013; Reisenzein & Döring, 2009), others distinguish between bodily, mental or cognitive (Reisenzein, 2014), some just mention different specific theories that are often used when modeling emotion (S. Marsella et al., 2010; Scherer, 2010), and some order emotions along a continuum (Gross & Barrett, 2011).

Below we distinguish between four trends within emotion psychology. This distinction is mainly drawn from those made by Hudlicka (Hudlicka, 2011) and Reisenzein (Reisenzein & Döring, 2009). We wanted to use a distinction that included most of the theories used to model emotions, but also some of the famous and influential theories that help to shape the field. By no means do we want to argue that these trends are complete, so that every emotion theory will fit in one of these trends. Nor do we want to argue that they are discriminating, in the sense that every theory will only fit within one category, or that the distinction is perfect, meaning all researchers would agree with the theories they are grouped together with. We only argue that for our purposes the differences between these views will make easier to see relations, similarities and differences between the assumptions that are made within different theories of emotion.

As a final remark, and also emphasized by Hudlicka (Hudlicka, 2011, p11), these trends should not be viewed as competing for one 'true explanation' of emotion, but rather as different perspectives with a different focus on emotion and with a different underlying research tradition.

Somatic theories

Somatic theories are theories that mainly focus on the bodily aspect of emotion. The resemblance between these theories is the intuition that it feels a special way to have them (Reisenzein & Döring, 2009). Somatic theories focus on the phenomenal aspect of emotions, thus emotions are seen as sensation-like experiences. William James[4] used the famous metaphor of stating that emotions have 'warmth', they are 'hot' experiences compared to the 'cold' non-emotional states. (Reisenzein & Döring, 2009). The disagreement among somatic theorists is the causal link between the bodily reactions and the awareness of emotions. On the one hand there are the bodily theorists such as James (James, 1884) and Lange (Lange, 1885) who argue that emotions are caused by the changes in the body. On the other hand there are the mental-feeling theorists such as Cannon (Cannon, 1927) and Bard (Bard, 1934), who believe that the emotions and bodily reactions are generated at the same time. The James-Lange theory has been the leading theory for about 40 years, but is mainly discarded by modern researchers[5].

Discrete theories

Discrete theories are theories that discriminate between a small set of basic emotions, usually including joy, sadness, fear, anger and disgust[6]. The main assumption is that every emotion has its own unique mechanism that is frequently assumed to be innate and hardwired into the brain. Every basic emotion has its own characteristic pattern of triggers, behavior and subjective experiences (Hudlicka, 2011; Gross & Barrett, 2011). Theories that fit into this trend are for example the work of Panksepp (Panksepp, 1998) and LeDoux (LeDoux J., 2000).

Cognitive or componential theories

Cognitive or componential theories share two assumptions about emotions. The first assumption is that there are several distinct components involved in the generation of emotions (e.g. a physiological, a behavioral, a subjective, and a cognitive component). The second assumption is that emotions require certain "higher-order" mental representations; in other words, cognition is essential for emotion. This second assumption is in contradiction with the somatic theories ((Hudlicka, 2011), (Reisenzein & Döring, 2009)). One of the leading theories in emotion modeling, appraisal theory, is part of this trend. We will investigate appraisal theory in depth later in this thesis.

[4] According to Reisenstein he developed one of the first theories of emotions that tried to answer all three questions stated in Section 1.1.1. (Reisenzein, 2014)

[5] Nevertheless, there are some researchers who proposed several modified theories of the James-Lange theories, e.g. (Damasio, 2008; Scherer, 1991)

[6] For some this might be a recognizable set of emotions. In the movie Inside Out (Docter & del Carmen, 2015) you take a look inside the head of a young girl and see how these five emotions influence her behavior. Interesting to note here is that Paul Ekman was one of the psychologists who advised Pixar on the psychological aspect of this movie. His work (e.g. (Ekman, 1992)) is often characterized within the discrete emotions (Gross & Barrett, 2011)

Dimensional theories

Dimensional theories identify emotions with a position within a two- or three-dimensional space. A frequent used dimensional theory is the two-dimensional theory of Russell (e.g. (Russell, 2003)). In this theory emotions are characterized by their level of valence and arousal. Another famous example is the PAD space (Mehrabian, 1995) that is used in Kismet (see Figure 1.2), a robot that is designed to express emotion (Breazeal, 2003). PAD is very similar to Russell's theory but has an extra third dimension; dominance. This third dimension is added to differentiate between emotions that have the same arousal and valence, such as anger and fear (Hudlicka, 2011).

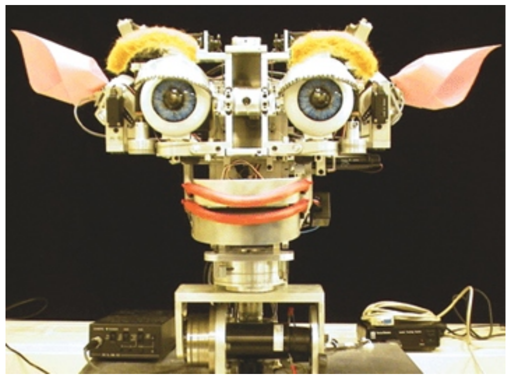

Figure 1.2: The emotional robot Kismet. From (Breazeal, 2003).

1.2 Appraisal Theory

As pointed out by Marsella et al., computational models of emotion are usually based upon appraisal theory (S. Marsella et al., 2010). Roughly speaking, appraisal theory claims that emotions arise from the interaction between things that we find important and things or events that happen in the environment (Scherer, 1991). For example, imagine that a friend drops one of your plates which then shatters into pieces. Now the level and type of emotions you feel can differ depending on how you relate to this plate. It could for example be a plate that you inherited from your grandmother that passed away two months ago, or a plate that you got as a gift from your mother-in-law which you hated but could not throw away. In the first case you could get angry or sad, in the second case you could feel relieved. Now imagine that the plate only fell, but did not break. Now, your emotional response would probably be totally different; relieved when it belonged to your grandmother and disappointed when it was an ugly gift from your mother-in-law. So it is not only the environment or things that we find important, but the interaction between these two things that give rise to and determine our emotional responses. This process of interpreting some event in terms of our beliefs, desires and goals is called *appraisal* and according to appraisal theorists it is this process that gives rise to emotions.

1.2.1 The General Assumptions of Appraisal Theory

Although most appraisal theorists try to focus on the differences between their theories, there are many similarities between different appraisal theories. Moors et al. wrote an article in which they described six features of appraisal theories (Moors, Ellsworth, Scherer, & Frijda, 2013).

1. *Definition of Appraisal.* According to Moors et al. appraisal is "the process that detects and assesses the significance of the environment for well-being" (Moors et al., 2013, p. 120). By *significance for well-being* is meant whether some event is conducive or obstructive for things that are important for an individual, such as the needs, attachments, values, current goals and beliefs.

2. *Emotion as a process.* The main assumption made by appraisal theories is that emotion is seen as a process rather than a mental state. Appraisal researchers normally use the term *emotion* to mean *emotional episode*, which demonstrates that they view emotion as a systematic series of events; a process.

3. *Components.* Appraisal theorists believe that the emotional process is composed out of changes in several components. These components, also called subsystems, include the following:

    (a) An appraisal component that evaluates the environment and the interaction between the person and the environment.

    (b) A motivational component that controls action readiness and action tendencies.

    (c) A somatic component that regulates physiological responses.

    (d) A motor component that is in charge of the actual behavior of an individual.

    (e) A feeling component that regulates the subjective experience or feelings of the individual.

4. *Recursive.* According to appraisal theory, the emotion process is recursive. This means that the outcome of the emotion process can influence the emotion process. This can happen both in a direct or indirect way: direct in the sense that the change in one of the response components can directly influence the appraisal component, indirect in the sense that a change in one of the response components can influence the situation that caused the emotion which can influence the emotion process itself.

5. *Role of appraisal in emotion.* According to appraisal theorists, appraisal is the key to emotion, it is the thing that triggers the emotion. Appraisal is what determines the intensity, behavior and feelings.

6. *Implications for individual, cultural and developmental differences.* Since different people have different values and values are influenced by culture and upbringing, appraisal theories can account for differences in people's emotional responses to the same situation.

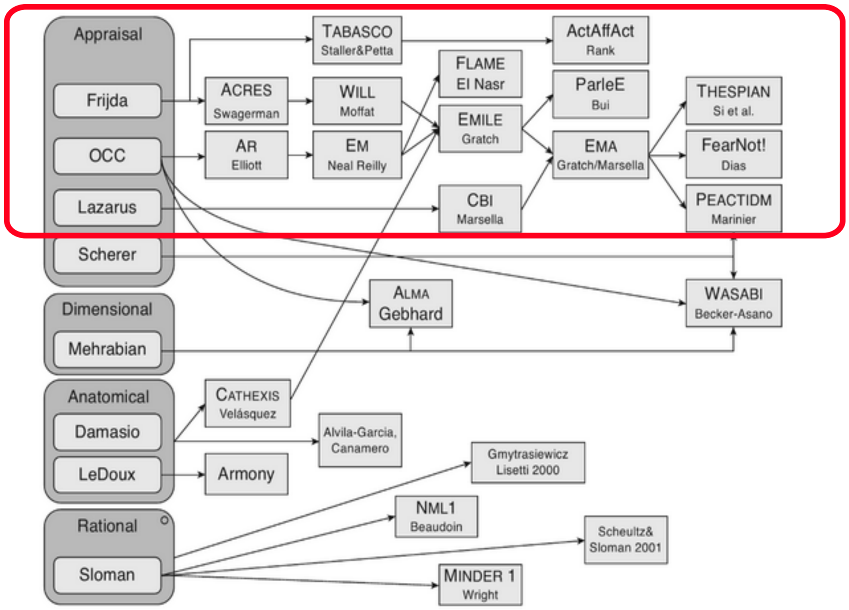

Figure 1.3: Overview of computational models of emotions together with the theory of emotion they are based on. The red square shows the models that are influenced by the theories considered in this chapter. Adapted from (Gratch & Marsella, 2014, p.6)

1.2.2 Frijda, the OCC, and Lazarus

There exist a lot of different specific theories within appraisal theory. While there are several efforts to make the similarities and differences between these theories clearer (see e.g. (Moors et al., 2013; Scherer, 1991; Hudlicka, 2011)), the exact relations between theories are still vague (Reisenzein et al., 2013). Below, we have tried to advance the field of emotion theory by comparing three appraisal theories of emotion; Frijda's theory (Frijda, 1986), Lazarus' theory (Lazarus, 1991), and the theory developed by Ortony, Clore and Collins, often referred to as OCC, (Ortony et al., 1988). This is only a small subset of all influential theories within appraisal theory. For example the work of Scherer (Scherer, 1982), Roseman (Roseman, 1984) and Smith and Ellsworth (Smith & Ellsworth, 1985a) also have had a lot of influence. Because of time constraints, we choose to focus on just three theories. As can be seen in Figure 1.3, there are a lot of computational models that are based on these three theories (S. Marsella et al., 2010) and since this thesis aims to extend computational models, we have chosen these three theories.

The reason for comparing these three theories is twofold, firstly to clarify some part of the theoretical landscape and secondly to introduce theories before comparing them with Gross' theory of emotion regulation. As also pointed out by Reisenzein et al. (Reisenzein et al., 2013), fully reconstructing and comparing every aspect of each emotion theory is cumbersome and not always necessary. Instead, we have tried to compare the three theories on aspects that are relevant when building a computational model based upon a theory.

But what part of a theory is the most relevant for computational models? Hudlicka described a set of questions a theory of emotion ideally provides an answer to when modeling emotion (Hudlicka, 2011). According to Hudlicka, a model needs "sufficient details to operationalize the computational task necessary" (Hudlicka, 2011, p. 33). In other words, the central question that a theory needs to answer is: *How does some stimulus generate some emotional response?* The answer to this question includes information about the stages of the emotion process and the relations between these stages, but also information about which cognitive structures are necessary for the system to work. In addition to this proposal by Hudlicka, we also have the tools from section 1.1 and the components of models of appraisal proposed by Marsella et al. (S. Marsella et al., 2010). In their chapter they have proposed a compositional view of model building to promote incremental research on computational models of emotion.

Below, we will compare the Frijda's theories, Lazarus' theory, and the OCC theory on different aspects. After a short introduction per theory, we will place them in the horizontal and vertical division described in section 1.1.1. Next we will compare the definitions of emotions and go through all components mentioned by Marsella et al. Finally, we will compare the schematic overview of the theories.

A short introduction

Frijda's Theory In 1986, Frijda wrote his very influential book *The Emotions* (Frijda, 1986). In this book, Frijda aims to develop a psychological theory of emotion. He starts with stating the still existing problem of emotion: it has no widely accepted definition. He states that for this reason a definition of emotion cannot exist without a theory of emotion it is based on. The aim of his book is not only to find a definition of emotion, but also to try to fully understand the phenomenon including its nature, function, interrelations, and necessary conditions. Frijda starts his investigation with examining the cases in which humans use emotion-related concepts in their language. He states that there are three distinguishable moments when this happens. First, when describing behavior that seems to have no external purpose. For example when someone is smashing dinner plates during an argument, the broken plates could hardly be the goal of the action. Second, to describe physiological changes that seem to have no physical cause, such as crying without pain or trembling without cold. And finally, to describe a subjective experience, for instance to say things like "I feel happy". Frijda used these three observations as the basis of his research about emotions.

Lazarus' Theory Lazarus started working on affective processes during the Second World War, researching the influence that stress has on people, a very relevant psychological problem during this time (Lazarus, 1993). Later in his career, Lazarus shifted his work from stress towards emotions. As we will also see later, the notion of coping, usually associated with stress, remained one of the key aspects in his scientific work. With the book *Emotion and Adaptation* (Lazarus, 1991), Lazarus tried to give a complete conceptualization of emotions that would clarify the underlying theoretical decisions of a psychological theory of emotion. Interesting to note here is that both Lazarus and Frijda developed their theory during the same period of time and potentially influenced each other.

The OCC The emotion theory developed by Ortony, Clore and Collins (Ortony et al., 1988) is one of the most frequently used theories for a basis of computational models (Hudlicka, 2011)[7]. The main aim of the OCC is to explain the cognitive structure of emotions. Ortony, Clore and Collins have tried to be very specific about which emotions there could be, what the relations are between emotions and to lay the foundation of a computationally tractable model of emotion that could be used within AI.

Horizontal division

As described in section 1.1.1, the horizontal division separates between different aspects of the emotion processes. Not all theories cover the same part of the emotion generative process. We introduced the five questions formulated by Reisenzein to see what the focus of a certain theory is. In Figure 1.4, an overview is given of which theory focuses on which question.

	Frijda	Lazarus	OCC
1) How are emotions generated?	Yes	Yes	Yes
2) What effects do emotions have on subsequent cognitive processes and behavior?	Yes	Very brief	No
3) What are emotions?	Yes	Yes	Yes
4) Are emotions inherited and which are acquired through learning?	No	Brief	No
5) How are emotions biologically realized or implemented?	Brief	Very brief	No

Figure 1.4: Overview of which theory covers which questions.

It is striking that the OCC is more limited than Frijda's and Lazarus' theories. The OCC only fully covers questions one and three. This is not that surprising, since Ortony et al. focus mainly on the cognitive structure of emotions. On the other hand, the theories by Frijda and Lazarus cover more questions. This is because the aim of their theories differs from the OCC model. Frijda's aim is to find a definition of emotion and to try to fully understand emotions Lazarus wants to define a rich and complete conceptualization of emotion.

The main difference between Lazarus and Frijda is the part of the emotion process on which they focus. Frijda devotes a whole part of the book on the behavioral, physiological, and experience part of emotion. As said above, Frijda used these phenomena to start an investigation of a satisfying definition of emotion in general. Lazarus, however, focuses on how emotions are generated and

[7] Some theorists will not consider OCC to be an appraisal theory of emotion. However, as already pointed out by Hudlicka, when comparing the OCC with appraisal theories from an intentional point of view there are some structural similarities between the two (Hudlicka, 2011, p.24). Since the OCC is very influential in affective computing and the theory is similar to the field of appraisal theory, we decided to take it into account while examining the theoretical field of appraisal theory.

how we can define specific emotions, such as anger and joy. He also covers the social influences of emotions, where he briefly touches upon question 4 about what is innate and what is learned. Both Frijda and Lazarus briefly discuss the biological aspect of emotions, although Frijda considers more details than Lazarus. As also explained in the next section, this is not because they do not think it is not important, but because their theories are on a more abstract level.

Vertical division

As explained in section 1.1.1, Dennett described three levels in which a system can be explained; the physical stance, the design stance and the intentional stance. Theories of emotion can be explained within these different levels. For Frijda, Lazarus, and the OCC, most of the theory is explained in the intentional stance, because the system that is examined, in this case the human emotion system, is assumed to have beliefs and goals. Therefore the theories are all describing the problem on an abstract level. Nevertheless, Frijda includes some facts about the biological basis of emotion, which could be captured in the physical stance, but this stays rather general.

It is not surprising that these theories are mostly formulated in the intentional stance, since emotion modeling and emotion theory did not reach a general theory yet. The first priority of psychologists concerned with emotion is still to understand what emotion is and how it works. As pointed out by Marr (Marr, 1982), when the goal is to understand the algorithm, it is more easily understood by looking at the nature of the problem than by examining the mechanism in which the algorithm is embodied.

Definition of emotion

As stated before, there is no general agreement on the definition of emotion. For this reason, every definition of emotion presupposes a theory. As mentioned above, all three theories have a slightly different aim and focus on the emotional process, so they also define emotion in a different way.

The OCC has the most clearly stated definition of what an emotion is:

> "Our working characterization views emotions as valenced reactions to events, agents, or objects, wit their particular nature being determined by the way in which the eliciting situation is construed." (Ortony et al., 1988, p.13)

Frijda emphasizes multiple times that the definition of an emotion can only be a product of a theory. He gives several definitions that he slightly modifies throughout his book. In the end, he states that:

> "Emotions are defined as changes in action readiness. That is: emotions are changes in readiness for action as such (we called these changes in activation), or changes in cognitive readiness (they have come under investigation as attentional arousal), or changes in readiness for modifying or establishing relationships with the environment (we called these action tendencies), or changes in readiness for specific concern-satisfying activities (we called these desires and enjoyments)." (Frijda, 1986, p.466)

Lazarus states that it is almost impossible to give a definition of emotion, since the only good definition is his complete theory. Despite these objections, he introduces the following definition:

> "Emotions are, in effect, organized cognitive-motivational-relational configurations whose status changes with changes in the person—environment relationship as this is perceived and evaluated (appraised)." (Lazarus, 1991, p.38)

As can be seen, the definitions are a reflection of the focus of the theories. In general, all theories agree that emotions are seen as a reaction to something that happens in those parts of the environments that a subject cares about, which is a general assumption of appraisal theory. However, the OCC has a focus on what is causing the reaction, Frijda focuses more on the effects emotions have on other systems and Lazarus adds multiple perspectives on emotion, which emphasizes the social aspect of emotion.

Inputs of the emotion process

As said before, all appraisal theories of emotion assume that emotions are elicited by some interaction between the environment and the person. This is also the case in these three theories. Here we focus on what is exactly eliciting these emotions. As can be seen below, there are differences in the way these components are called and structured. But overall, all three theories separate their input variables between the individual and the environment.

Frijda describes three inputs to the emotion process: *stimulus events*, *concerns*, and *side conditions*. Stimulus events are the trigger of the emotion, they describe the full situation in which the emotion is elicited[8]. Concerns are the things that are important to the individual[9]. With side conditions, Frijda refers to other dispositional parameters or capabilities that characterize and bias the emotion system, but are no part of it. Roughly speaking, these are all the things that the system needs in order to function according to Frijda.

Lazarus defines the input of the emotion systems by the *antecedent variables*. They consist of environmental conditions of an *adaptational encounter*, the event that triggers the emotion, and the personality variables of an individual. The environmental variables include demands, resources and constraints of what is being faced. The personality variables include goal commitments, beliefs and knowledge.

The OCC also distinguishes between variables in the environment and the individual. The environment is split up into three major aspects: *events*, *agents* and *objects*. Events are the construal of what is happening, objects are things in the environment, and agents are everything that can causally effect a particular context, including humans, nonhuman animate beings, inanimate objects and abstractions such as institutions. For example, when someone gets a flat tire, he or she can get angry at the bike. In this case, the bike is not seen as an object but as an agent. The variables of an individual include *goals*, *standards* and *attitudes*. The OCC provides a detailed definition of goals, including a specific structure and different types depending on their properties. Standards are

[8]Frijda emphasizes that the term stimulus is used as a convention, since emotion are rarely caused by a single stimulus, but usually by a situation as a whole. For example, the emotion felt when running into your neighbour in front of your house is different from the emotion felt when accidentally running into your neighbour during a holiday at the other side of the world.

[9]Frijda notes that he prefers the term concerns over terms comparable to motive or goal, since these tend to emphasize some degree of control or behavior of the individual, while concerns capture a broader spectrum of concept that do not necessarily need some form of action.

beliefs about what is morally right or wrong, often determined by culture. Finally, attitudes can be defined as a dispositional liking or disliking towards certain objects.

The first difference we would like to point out here, is the definition of the environment. Where Frijda defines that stimulus events can also be created internally, Lazarus only defines an adaptational encounter. He does not exclude this encounter to happen hypothetically, but in contrast to Frijda, he does not mention this explicitly. The same holds for the OCC, where the events are defined as 'things that are happening'. Again, this does not exclude things that happen in the mind, but this is never explicitly mentioned

Another difference is to which extent details are provided. Frijda describes the concerns quite generally as a disposition to an occurrence of some event. Lazarus already distinguishes goals, beliefs and knowledge and the OCC even distinguishes between different type of goals and proposes a structure in which the goals relate to each other.

Appraisal variables

As described in section 1.2.1, all appraisal theories describe emotion as some process that assesses the significance of the environment for well-being. Which aspects of the environment, goals, and beliefs are essential are described by the appraisal variables. Appraisal variables are the product of the assessment of significance: *the appraisal process*. Even though all appraisal theories have appraisal variables, they have different names and structures within each theory. A full overview of all appraisal variables of all three theories can be found in Appendix A.

Frijda refers to the appraisal variables with the *situational meaning structure*. This can be seen as the situation as it appears to the subject. Frijda differentiates between three groups of components, or variables, within the situational meaning structure: *core components*, *context components*, and *object components*. In general, core components determine whether a situation is emotional or not, context components determine the nature of the emotion and object components describe the properties of the object towards which the emotion is directed.

Lazarus uses the term *appraisal components* to refer to the appraisal variables. He divides these components in two groups: *primary* and *secondary* appraisal. Primary appraisal components determine how relevant a situation is to the person's well-being and secondary appraisal components determine resources and options for coping with the situation. Roughly speaking, the core components of Frijda correspond to primary appraisal components and context components of Frijda refer to secondary appraisal components.

In the OCC appraisal variables are not explicitly mentioned, but they can be seen as the combination of the local and global variables, see also (Hudlicka, 2011). The global variables are factors that can influence all emotions, local variables are variables that are influential for some emotions, but not for others.

As described in various literature, see e.g. (Hudlicka, 2011; Reisenzein et al., 2013; Broekens, DeGroot, & Kosters, 2008), most psychological theories of emotion do not contain the necessary level of clarity a computational model needs. This is evident when looking at the specific variables of the appraisal structure of these theories. Some variables are very clear and specific, while others resemble some vague intuition about an aspect that influences emotion rather than a well-defined variable. This is mostly the case when we look at Frijda's theory. For most of his components it is not very clear which values they can adopt. Sometimes it is not even clear if they are binary, discrete, or continuous. Other components are even ill-defined, as for example the "further object components", which include everything that is not captured in the rest of the object components. When we look at the OCC, things are more clear. While it is not explicitly stated which values the variables can adopt, it is easy to imagine that most of them work on some sort of scale. Desirability for example, which measures how desirable some event is assessed to be, can be easily thought of as a value between 0 and 1. The same holds for the theory by Lazarus where goal relevance, for example, can easily have a value between 0 and 1.

This difference can also be seen when examining the structure of the appraisal variables. In the OCC model, the variables have a well-defined structure, associating certain variables with certain groups of emotions. Frijda, on the other hand, does not make very strong assumptions on which appraisal variables are associated with which emotions. Lazarus is in between Frijda and the OCC on this aspect. While his variables are not as structured as the OCC model, he does make some strong assumptions about some of the variables. For example, coping potential is only associated with negative emotions. While the structure of the OCC provides more support when building a model, the strong assumptions may not always be necessary. This could limit a model based on the OCC theory. A model based on the less structured appraisal variables does not have these problems.

What also is striking is the difference in the number of appraisal variables used in each theory. Lazarus only defined 6 variables, while the OCC and Frijda defined 15 and 25 respectively. As pointed out by Moors et al., the number of variables is closely related with the number of emotions a theory wants to express. This can be seen when we discuss specific emotions.

All theories agree on certain appraisal variables. Although names differ, all have a notion of whether something is relevant and congruent to some goal and what or who caused the situation. However, there are also so differences. We can see that Frijda and Lazarus take a notion of coping potential (how well the subject thinks he or she can deal with the situation) into account, which the OCC lacks. On the other hand, the OCC has a notion of unexpectedness, which is lacking in Frijda's and Lazarus' theory. Also, both Frijda and the OCC add a notion about what the emotion is about. In the OCC this is very clear, since it is the basis of their structure. Frijda also differentiates whether the emotion concerns an object or a person, since this influences the type of emotion.

From appraisal patterns to specific emotions

In appraisal theory, emotions correspond to specific configuration of the appraisal variables. We have just seen that the theories have different appraisal variables, this implicitly means that the same emotions have different mappings. As said before, different number of appraisal variables lead to a different number of emotions. Lazarus distinguishes 14 emotions, Frijda 31 and the OCC has 22 different ones. A full overview of which emotions are covered by which theory can be seen in Appendix B.

To illustrate the difference between how the appraisal variables are mapped to specific emotions within the theories, we compared the way 'Anger' is specified. In Figure 1.5 the different approaches are compared. As can be seen, all three theories have a notion of negativity and some other person that is the blamed. Frijda and Lazarus also have some notion of control, or the intuitive idea that actions can have some influence of the situation.

	Positive character	Negative character	Desire	Interest	Positive valence	Negative valence	Presence	Absence	Certainty	Uncertainty	Change	Open	Closed	Intentionality of other	Intentionality of self	Controllability	Noncontrollability	Modifiability	Finality	Object	Event	Focality	Globality	Strangeness	Familiarity	Value
Anger	x	x			x	x	x	x						x		x					x	x				

Frijda

Appraisals for Anger*

Primary Appraisal Components

1. If there is goal relebance, the any emotion is possible, including anger. If not, no emotion.
2. If there is goal incongruence, then only negative emotions are possible, including anger.
3. If the type of ego-involvement is engaged is to preserve or enhance the self- or social-esteem aspect of one's ego-identity, then the emotion possibilities include, anger, anxiety, and pride.

Secondairy Appraisal Components

4. If there is blame, which derives from the knowledge that someone is accountable for the harmful actions, and they could have been controlled, then anger occurs. Of the blame is to another, the anger is directed extrernally; if to oneself, the anger is directed internally.

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5. If coping potential favors attack as viable, then anger is facilitated.
6. If future expectancy is positive about the environmental response to attack, then anger is facilitated.

* Appraisal components sufficient and necessary for anger are 1 through 4.

Lazarus

ANGER EMOTIONS

TYPE SPECIFICATION: (disapproving of) someone else's blameworthy action and (being displaced about) the related undesirable event

TOKENS: anger, annoyance, exasperation, fury, incensed, indignation, irritation, livid, offended, outrage, rage, etc.

VARIABLES AFFECTING INTENSITY

(1) the degree of judged blameworthiness

(2) deviations of the agent's action from person/role-based expectations

(3) the degree to which the event is undesirable

EXAMPLE: The woman was angry with her husband for forgetting to buy the groceries

OCC

Figure 1.5: The mapping from a specific configuration of the appraisal variables to the anger emotion. Adapted from (Frijda, 1986, p.218), (Lazarus, 1991, p.226) and (Ortony et al., 1988, p.148) respectively.

The effects of emotion

The major effect of emotion according to Frijda is an *action tendency*: the tendency to act in a certain way. Action tendency is one of the most essential concepts of Frijda's theory. The intuition behind action tendencies is that even though you do not always act upon your emotions, you do experience an urge to do so. Action tendencies precede actual actions but are independent of them. Emotions can not only create action tendencies, but also enhance or denigrate them. Imagine for example that you are trying to work with a new computer program that does not do what you want it to do. The frustration will make you want to throw your computer out of the window, but this is (hopefully) not something you really do. Nevertheless, the tendency still exists. Next to action tendencies, Frijda also mentions that emotions lead to overt actions and physiological arousal.

Interestingly, the OCC seems to disagree with Frijda on the importance of action tendencies with emotion. They state that they think action tendencies are neither necessary nor sufficient for emotions, but they could simply be concomitants of emotions. What is slightly problematic is that they do not differentiate between action tendencies and actions, while this distinction is explicitly made by Frijda. Therefore this disagreement might be smaller than it seems. But since the OCC is lacking a definition of an action tendency, it is difficult to completely assess this disagreement.

Lazarus distinguishes between short-term and long-term effects of emotions. The short-term effects are similar to the effects mentioned by Frijda, including action tendencies, actions and some physiological response. Lazarus also specifically mentions some subjective experience as the output, while Frijda claims that this arises from the consciousness of the emotion process taking place. In contrast with Frijda, Lazarus mentions the long-term effects that emotions can have, including the influence of emotional patterns on social functioning and subjective well-being.

Regulatory processes

Both Frijda and Lazarus claim the processes that regulate emotions are part of the emotion system. Lazarus refers to this processes as *coping* and Frijda as *emotion regulation*. Since this is related to Gross' theory of emotion regulation, we will discuss this in depth later in this chapter, after we have seen Gross' theory.

Schematic overview

Since we have seen the basic concepts and the inputs and outputs of the system, it is time to describe and compare the full systems. The first thing to notice is that even though the OCC assumes that emotion is caused by a process, they do not give a explicit description of the process. Their focus lays on how specific emotions are generated and what distinguishes one emotion from another. We will come back to this issue later in this chapter. Frijda and Lazarus, however, do give a description of the emotion generative process. Therefore, we will only compare Frijda's and Lazarus' theory in this final part of this section.

What is important to note here, is that both Frijda and Lazarus see emotion as a flow of psychological events and not as discrete events. Therefore, even though the environmental variables are depicted as antecedents of emotion, they can also be seen as a mediator or consequent of the process, depending on which point you enter. Besides this, different processes can run simultaneously and the information processing flow doesn't necessarily run from top to bottom. Therefore it is important to remember that the schematic overviews are discrete and linear simplifications of emotion. Nevertheless, these simplifications can be very helpful when designing a computational model of emotion. Therefore, we do include them in this comparison.

In Figure 1.6, a schematic overview of the emotion generative process according to Frijda is given. In general, an individual encounters some events (1), appraises these events regarding the relevance to his or her concerns (2) and the difficulty of dealing with them (3,4). Then an action tendency emerges (5) which influences both bodily responses (6) as overt behavior (7).

In Figure 1.7, a schematic overview of the emotion generative process according to Lazarus is given. Here, the process starts with the interaction between personality factors and situational conditions, leading to a situational construal. Next the appraisal process takes places, leading into some appraisal outcome. This process leads to different effects, including physiological response and a coping process.

As emphasized above, these are schematic simplifications of the emotion system. This means that even though at first glance it seems both systems have a slightly different order, this does not imply that they actually have a different view on how the emotion system works. The main difference is the importance and influence of regulatory processes. While in Lazarus' theory the coping processes are only indirectly affected by the parts that they influence, Frijda states that there is constant feedback between the emotion generative processes and regulatory processes. We will discuss this in depth in the next section, were we compare the theories of appraisal theory with the theory of Gross.

Conclusion

Besides all the specific differences mentioned above, what became clear is that overall the theory of Frijda covers the most material concerning emotion theory, but is also the most vague. On the other hand, the OCC covers the smallest part of emotion theory, but also the most specific and clearly defined theory. Lazarus' theory is somewhere in the middle. Moreover, Lazarus theory discriminates only 13 emotions, the OCC 22 and Frijda distinguishes the most, namely 31. Finally, the OCC seem to disagree with Frijda and Lazarus on the importance of action tendencies, but this claim is difficult to verify.

A strategy that is often used by researchers that try to build a model of emotion, is to combine several aspects of several theories. From the comparison above it becomes clear that finding a complete and specific theory is very difficult. The more detailed and specific a theory becomes, the smaller part of the emotion process it covers. A way to deal with this, is to use a mix of several theories. Here we want to emphasize that although we think this is a very constructive strategy, one should be very explicit on which parts are takes from which theory.

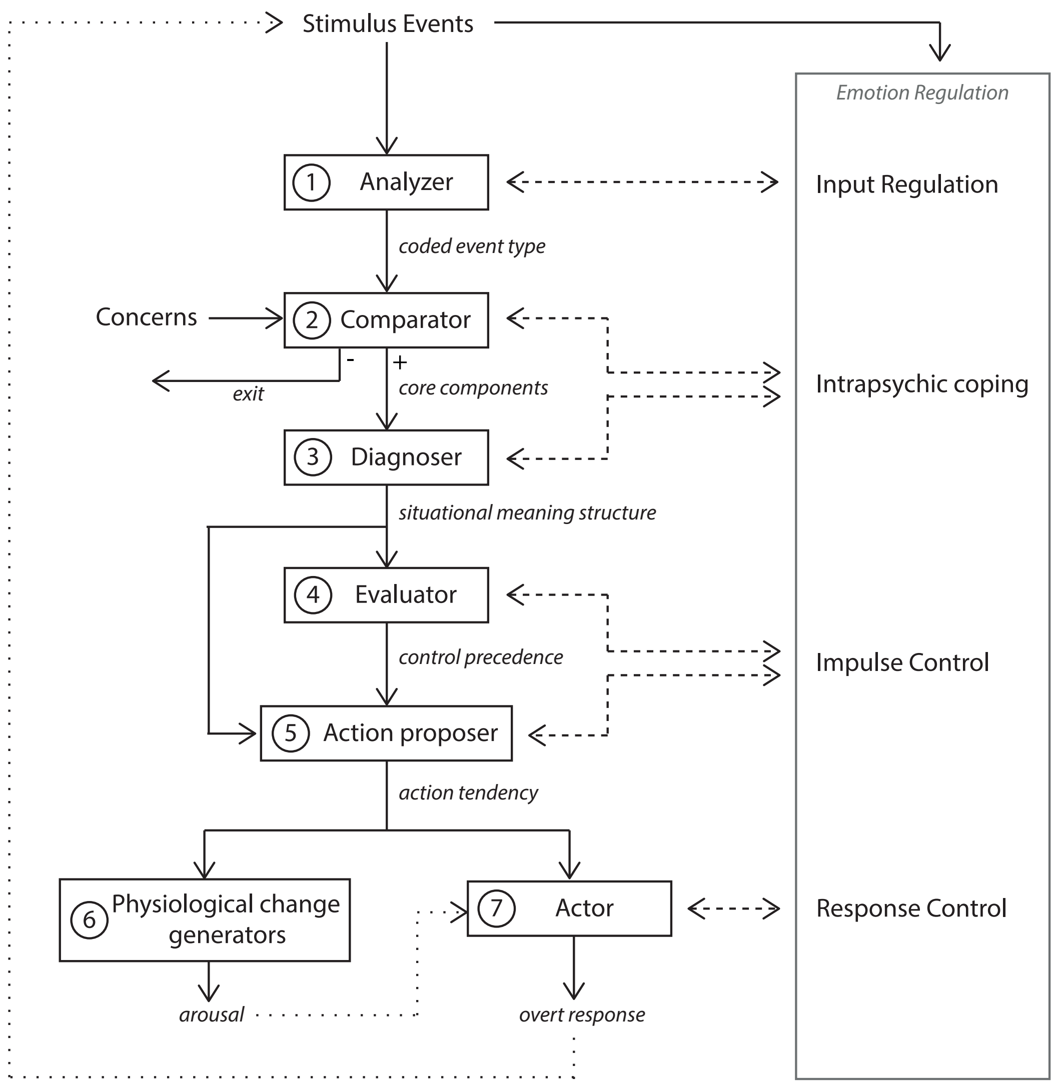

Figure 1.6: The emotion process according to Frijda. The black lines are part of the core emotion process, the dashed line to the regulatory processes and the dotted line represents feedback processes. Adapted from (Frijda, 1986, p.456).

1.3 Gross' Theory of Emotion Regulation

In the previous section we shed some light on the theoretical landscape of appraisal theory. The main aim of this chapter is to see how the theory by Gross fits into this landscape. Before we can investigate this, we first need to understand Gross' theory. In this section we will give an overview of Gross' view on emotion regulation. Since emotion regulation presupposes a notion of emotion, Gross also makes some general claims about emotion itself. Therefore, we start this section with

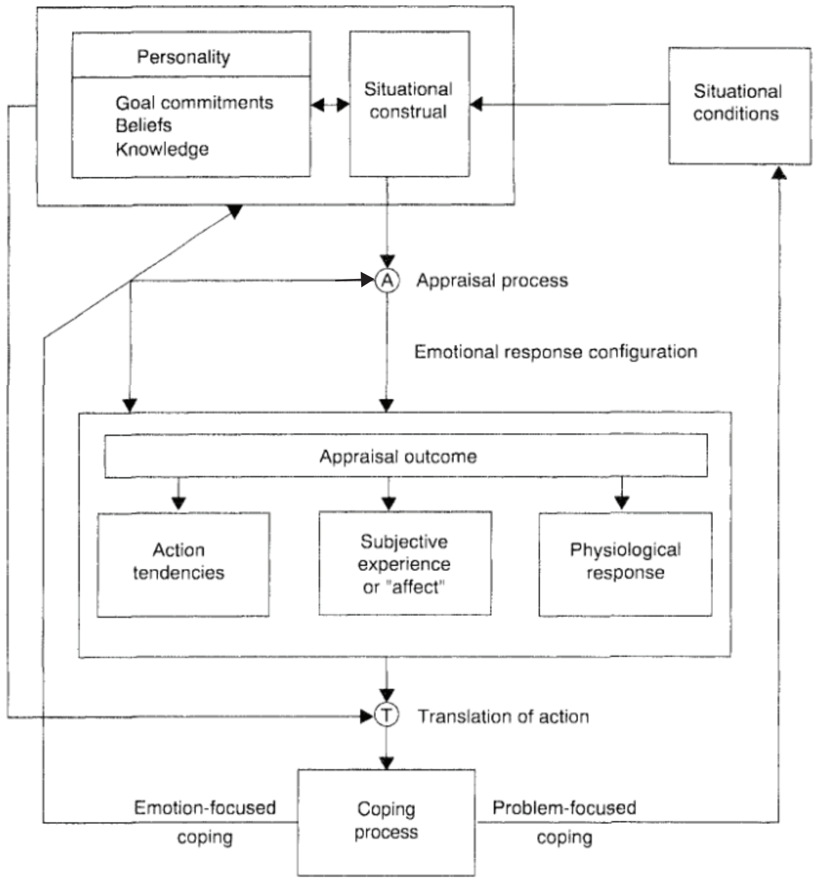

Figure 1.7: The emotion process according to Lazarus. From (Lazarus, 1991, p.210).

Gross' view on emotions and then move on to explain his view on emotion regulation. We will end this chapter with a section in which we will see how Gross' ideas fit into the field of appraisal theory.

1.3.1 Gross' View on Emotions

Gross states that the classical way of defining a concept is ill-suited for emotion. With 'the classical way of defining' Gross refers to researchers that search for both the necessary conditions (what something must have to be an emotion) and sufficient conditions (which aspects will make assure that something is an emotion) with which they try to construct a precise and well-defined definition of a concept. Gross states that the reason this type of definition will not work is because "emotion" is a term that originates from everyday language. It refers to a very broad range of phenomena which is very ill-defined. To give an example from Gross, both the surprise at a friend's new tattoo and the grief at the death of a loved one are considered to be emotions. These two emotions are so different in intensity and duration, that it will be very complicated, maybe even impossible, to define a precise definition that includes both concepts but still excludes non-emotional phenomena.

Gross takes a different approach. He argues that it will be more successful to formulate a *prototype conception* of emotion. Prototype conceptions emphasize typical features that may or may not be present in a specific instance of the concept. One of the typical features of a chair is for example that is has four legs, but this does not mean that an object with three legs cannot be a chair or that every object with four legs -such as a table- must be a chair.

The three core features of emotion

Gross describes three core features of emotions:

1. *The importance of relevance.* Emotions emerge when an individual experiences a situation which they think is relevant for their personal goals. Gross refers here to the concept 'goal' in the broadest sense of the word. Goals can be enduring or transient, conscious or unconscious, and simple or complex. What is important about this feature is that it is not the goal or the situation, but solely the meaning of the situation for the goals of an individual that induces emotion. When this meaning changes, so does the emotion.

2. *Whole-body phenomena.* Emotions are whole-body phenomena that have an impact on the change in subjective experience, behavior, and physiology. Emotions make people feel something, but they also create impulses to act in a certain way and not in certain other ways.

3. *Changes are optional.* The changes linked with emotion are rarely obligatory. Gross does emphasize that emotions have a certain imperative character, they can interrupt our current activity and force themselves into our awareness. However, Gross states that there are more social responses that emotions must compete with. Gross agrees with the view of James (James, 1884), who approaches emotions as response tendencies, which may be regulated in several ways. Gross stresses that this third feature of emotion is the most crucial feature when considering emotion regulation, because this is the feature that makes emotion regulation possible.

A Modal Model of Emotion

Gross developed a modal model of emotion based on these three core features of emotion. In Figure 1.8 a schematic view of this model is given. It represents a sequence that consists of four elements. First there is a *situation* that gives rise to an emotion. This situation can be both internal or external. Next, the *attention* of the person is focused on the situation. Then, the situation is *appraised* in comparison to the goals of the individual. This appraisal generates an *emotional response* that involves changes in the experimental, behavioral, and neurobiological systems.

1.3.2 Gross' View on Emotion Regulation

As pointed out by Gross, the term emotion regulation is ambiguous. It can refer to situations where emotions influence behavior or thought (regulation by emotions) or it can refer to situations where

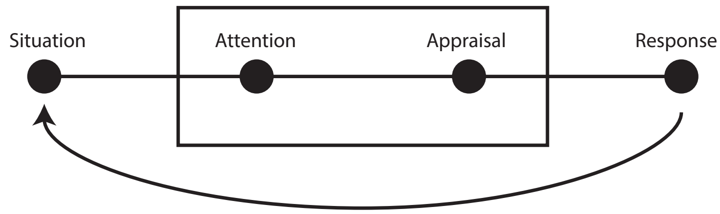

Figure 1.8: The modal model of emotions from Gross. Adapted from (Gross, 2011, p.5)

processes try to regulate emotion (the regulation of emotions) (Gross, 2011). Since in this thesis we want to compare different theories, we need to be very explicit about the definitions of concepts to avoid this type of ambiguities. In this section we will introduce Gross' notion of emotion regulation which will play a vital role in this thesis.

Gross defines emotion regulation as "the heterogeneous set of processes by which emotions are themselves regulated" (Gross, 2011). In other words, he refers to the regulation of emotions. Gross takes these set of processes to be very broad. He includes automatic, controlled, conscious, and unconscious processes. Gross also points out that both intrinsic processes (emotion regulation within yourself) and extrinsic processes (emotion regulation within others) are part of emotion regulation (Gross, 2011).

Throughout his work, Gross has emphasized that people can decrease and increase both positive and negative emotions. Often emotion regulation is associated with decreasing the intensity of negative emotions or increasing the intensity of positive emotions. According to Gross this view is overly simplified. It also often occurs that people try to increase their negative emotions or decrease their positive emotions (Gross, 2011, 1998, 2002). This happens for example in situations in which this is socially desirable or in order to achieve a goal. Imagine for example a boxer that intensifies her own anger to perform better during a fight or someone suppressing joy when a family dinner that they did not wanted to go to is canceled at the last minute.

According to Gross, there are multiple strategies to find and classify emotion regulatory processes. One approach can be to exactly describe what people do when they are trying to regulate their emotions. But according to Gross there are possibly an infinite number of ways in which people can regulate their emotions. Therefore, he believes that this type of analysis has a too low level of abstraction. A second approach can be to categorize emotion regulation strategies by which component is regulated, such as the physiology, expression or experience. Gross argues that following this approach has the disadvantage of grouping processes together that have important underlying differences. For example, when you want to inhibit the expressive behavior associated with emotion you can both change the way you think about the situation or relax your facial muscles. The approach used by Gross is a process-oriented approach in which strategies are classified by which part of the emotion generative process they try to influence (Gross, 1998)

On a higher level, Gross distinguishes between antecedent-focused and response-focused regulation strategies. The first focuses on a family of strategies that try to influence the emotion generation process before some appraisal patterns has given rise to full-blown emotional response. On the other hand, response-focused strategies are strategies that try to influence the responses on the emotion generative process (Gross, 2011). Note that by this distinction Gross mainly focuses his categorization on *when* the emotion regulation strategy can be applied.

On a lower level, Gross distinguishes five different types of emotion regulatory strategies: (1) situation selection, (2) situation modification, (3) Attentional deployment, (4) Cognitive change, and (5) Response modulation (Gross, 2011, 1998). These strategies are discussed in more detail below. Every type of strategy influences a different part of the modal model of emotion described before (See Figure 1.9). The first four strategies are antecedent-focused, while the last one response-focused. To frame the discussion of these different strategies, imagine a student that has an approaching essay deadline. The student has multiple ways of trying to reduce their stress about the deadline.

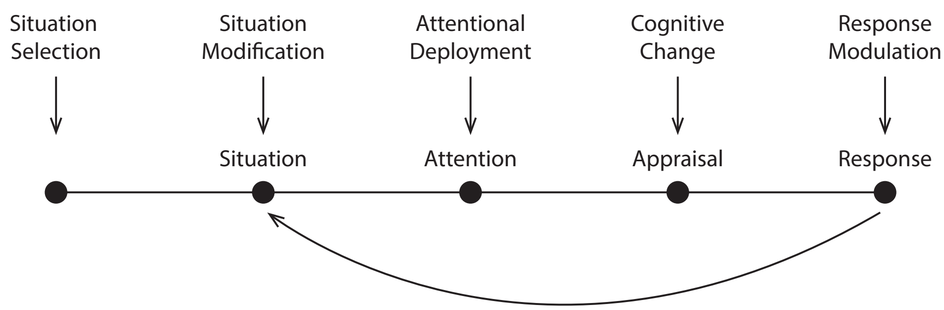

Figure 1.9: Different emotion regulation strategies according to Gross. Adapted from (Gross, 2011, p.6).

Situation selection Situation selection refers to actions taken to increase or decease the likelihood of ending up in a situation that elicits and emotional response. This requires to predict which features of future events are likely to elicit an emotional response. In our example of the student, they can make a planning to try finish the essay a couple of days before the deadline.

Situation modification Situation modification refers to efforts that directly modify the current situation to alter its emotional impact. In the case of our student, they can sent an email to the professor to ask for an extension so there is enough time left to finish the essay. As described before, Gross uses the term situation to capture a rather vague collection of events. This means that it is sometimes difficult to draw a distinction between situation selection and situation modification, since adapting a situation can create a new one.

Attentional deployment Attentional deployment refers to efforts to change the attention of an individual to change the emotional impact of a situation. Contrary to the last two strategies, this strategy does not try to change the situation but tries to change the emotional impact without changing the situation. In our student example, the student could search for plane tickets for a summer holiday instead of working on the essay.

Cognitive change Cognitive change includes strategies that modify the way an individual thinks about the situation. This includes the famous concept of reappraisal introduced by Lazarus, that will be discussed later. In our student example, the student might start to think it is not bad to fail since he or she has have a high average or because you can always take the resit.

Response Modulation Response modulation includes all strategies that influence physiological, experimental or behavioral responses. While all the previous strategies are antecedent-focused, these strategies are response-focused since they are executed after the full emotional response. In the case of the student, this happens when the stress of the deadline is fully thriving. Now, the student might take a warm shower to calm his- or herself down or do some yoga exercises to slow down his or her heart-rate.

1.4 Comparing Gross and Appraisal Theory

One of the aims of this thesis is to extend models with a notion of emotion regulation, therefore it is important that the theory of Gross is compatible with the theory that forms the basis of the models. With compatible we mean that there are no contradicting statements within the assumptions of Gross and appraisal theorists. In this section we will see how Gross' theory fits into the field of appraisal theory. It is important to note that we are comparing these theories from a computer science point of view. Our aim is not to find the ultimate truth about emotions, but to determine which theories could be combined when building models without the risk of ending up with an inconsistent model. As we have seen, Gross does not refer to one specific theory of emotion but to appraisal theory as a whole. Therefore, we will first compare Gross' theory with the general ideas of appraisal theory and after this with the specific theories introduced above.

1.4.1 Gross and General Appraisal Theory

In the last sections, we have seen both Gross' theory and the general assumptions made by appraisal theorists. When you compare these two ideas, they seem similar. Below, we have pointed at some aspects of both theories to show that this is the case:

- Gross agrees with appraisal theories on the definition and the importance of the appraisal process. Moors et al. argue that appraisal is the key of every appraisal theory and Gross claims that without appraisal, there is no emotion.
- Gross emphasizes that emotions are whole body phenomena. According to Moors et al. appraisal theories include several components, which are spread out over the body. Implicitly this means that they agree that emotion is a whole body phenomena. Even though Gross does not mention this explicitly, he agrees that there are multiple components of the body that play a role in the emotion process.
- Gross also emphasizes that emotion is a recursive process, similar to appraisal theory

- While Gross emphasizes that emotion can be regulated, regulatory processes are not necessarily a part of appraisal theories. Nevertheless, Moors et al. argued that appraisal can be influenced by culture and upbringing which already implies that emotions can be influenced. Also, as we have seen above, both Lazarus and Frijda have added regulatory processes to their theory of emotion.

In short, the theory of Gross and general appraisal theory are compatible. This makes the claim of Gross, that his theory is based on general assumptions of appraisal theory, valid. The next thing that we like to investigate is whether this the theory of Gross is also consistent with the theory of Frijda, Lazarus and the OCC. Since Gross' theory revolves around emotion regulation, he only spends a couple of pages on his ideas about emotions. Frijda, Lazarus and the OCC, on the other hand, dedicated hundreds of pages on how emotions work. Therefore it is not very surprising that Gross' ideas are less thought out, less specific, and contain much less detail than the three theories. For this reason, we have put some more focus on comparing the regulatory processes since here Gross does provide a lot of details.

1.4.2 Gross and Frijda

As can be seen in Figure 1.10 it is quite straightforward to compare the Gross' process with Frijda's process, since each part of the process by Gross corresponds to parts of the process by Frijda. Clearly, Frijda provides more details than Gross. Nevertheless, both theories are compatible.

Emotion Regulation

Frijda also adds a notion of emotion regulation to his model. According to Frijda emotions that are observed and felt are caused by the balance between the elicitation of action tendencies on the one hand, and the inhibition of the same action tendencies on the other. Or as Frijda puts it, "people don't only have emotions, they also handle them" (Frijda, 1986, p. 401). Instead of handling, which falsely implies that some form of voluntary action must be involved, Frijda uses the term *regulation*. Regulation is defined as "all the processes that have the function of modifying other processes-actions, experiences- instigated by a given stimulus situation" (Frijda, 1986, p. 408). In other words, emotion regulation consists out of all the processes that modify any part of the emotion process. These processes do not have to be voluntarily or conscious, in fact most of the time they are not. This is very similar to Gross' view on emotion regulation.

Frijda distinguishes roughly between two types of regulatory processes: *inhibitory mechanisms* and *outcome-controlled processes*. Inhibitory mechanisms are automatic, pre-wired mechanisms that are triggered by a stimulus. Inhibitory mechanisms are considered to be purely stimulus-controlled; they happen no matter what the outcome of the regulatory process will be. Examples of inhibitory mechanisms are startle and freeze reactions. Outcome-controlled processes are, as the name already implies, purely outcome-controlled. Outcome-controlled processes are initiated because there is an indication, either from previous experience or from feedback obtained from the environment, that the processes will lead to a more desirable result. Within outcome-controlled processes Frijda further distinguishes between voluntary and non-voluntary actions.

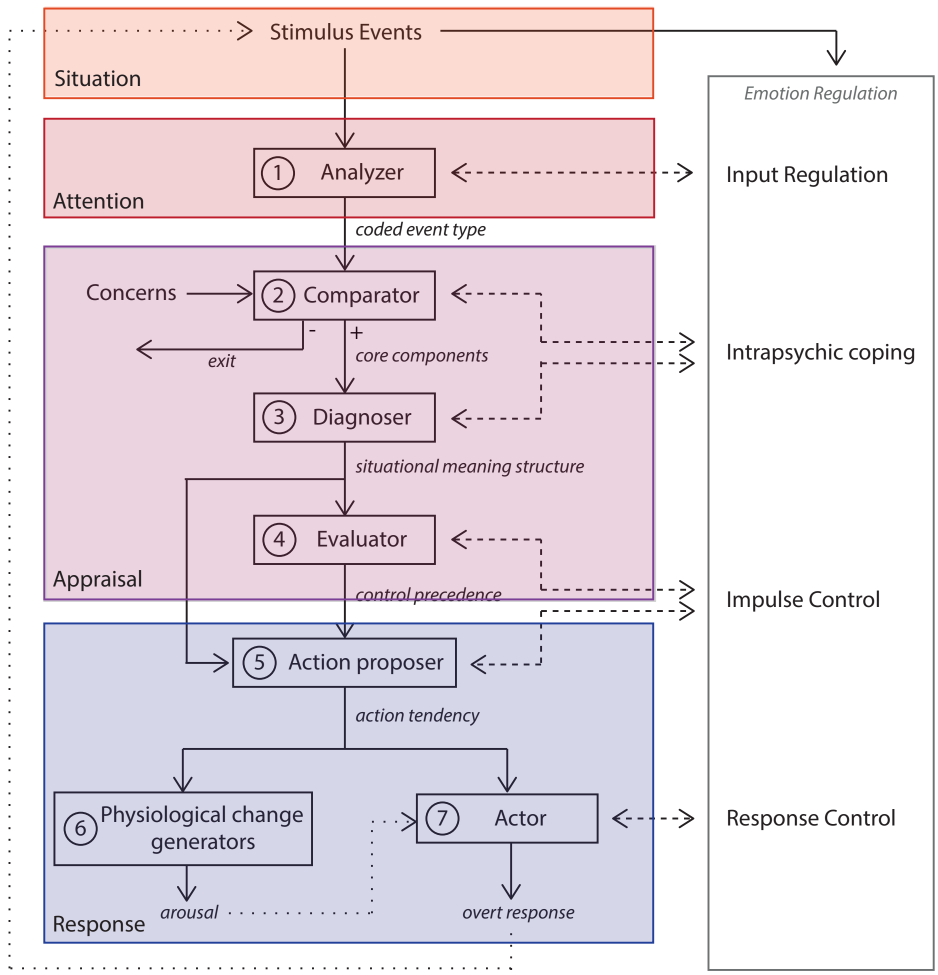

Figure 1.10: The schematic view of Frijda compared to the modal model of Gross. Adapted from (Frijda, 1986, p.456).

Here Frijda and Gross slightly disagree on definitions. When Gross talks about emotion regulation, he only refers to processes that Frijda refers to with the outcome-controlled processes. The inhibitory mechanisms is something that Gross would refer to as coping. Note that, as we will see below, this is not the what Lazarus refers to when he talks about coping.

Regulatory processes of each of the above described types can affect every phase of the emotion process (see Figure 1.6). Frijda distinguishes between four different moments where regulation takes place; *input regulation*, *intrapsychic coping*, *impulse control* and *response control*.

- *Input regulation:* Input regulation is the set of processes that influence the control of stimuli. Roughly, this comes down to approaching and avoiding stimuli. Many emotions can be avoided by simply avoiding the stimuli that elicits the emotion. For example, someone who is afraid of heights avoids fear by staying on the ground. Likewise, selective exposure to information is part of input regulation. Smokers who read less about lung cancer than non-smokers to reduce their discomfort are an example of selective exposure. Instead of avoiding stimuli, new stimuli can be actively searched for distraction, for example when joking during stress-full situations.

- *Intrapsychic coping:* Frijda defines intrapsychic coping as "constructing situational meaning structure in such a fashion that the situation is appraised more favorable, less harmfully, or more tolerably than the actual state of affairs warrants or imposes in the first place" (Frijda, 1986, p. 420-421). This is a term that is originally defined by Lazarus and used by Frijda. Intrapsychic coping can be achieved by distorting the environment, also called *denial*, or by weakening the affective relationship with reality.

- *Impulse control:* Impulse control are the processes that help to let the emotion die down or kept within bounds once the emotion has arisen. This can be realized by denigrating the event, make it seem more attractive, or reappraise one's coping potential. Another way to control the impulses is by response suppression, for example by counting till ten before saying or doing anything when you are angry.

- *Response control:* Response control are the processes that interfere with the actual overt response of the emotional system. This can be achieved either by direct response suppression, or by starting responses which are incompatible with the response that needs to be controlled. An example of response control is kicking the door instead of the person you are angry at.

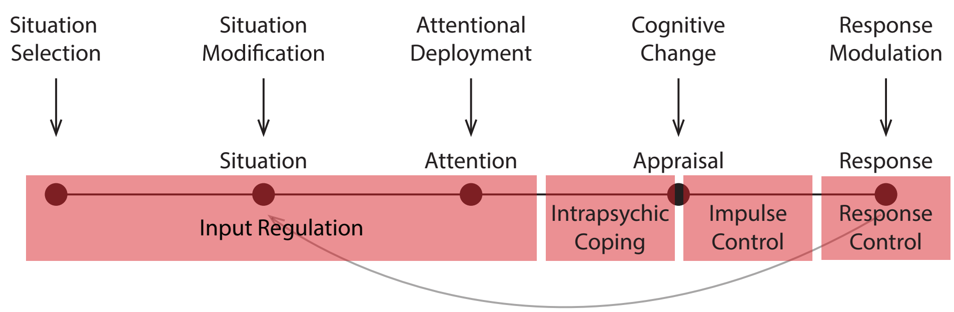

Figure 1.11: The emotion regulation strategies of Gross and Frijda compared. Adapted from (Gross, 2011, p.6).

As can be seen, this distinction is similar to the distinctions made by Gross. In Figure 1.11 the two are compared. Noteworthy is that Gross makes a finer distinction in the beginning in the process, while Frijda makes more distinctions within the appraisal process.

The last thing that is important to note here, is that Gross and Frijda both emphasize that there is not always a clear distinction between different strategies. In particular, the distinction becomes blurred when the event or situation that elicits the emotion is a thought of memory.

1.4.3 Gross and Lazarus

As said before, Gross' definition of emotions is way less specific than the one of Lazarus. One of the ways this is prominent, is in the level of detail of the emotion process. In Figure 1.12, we visually compared the schema of Gross with the schema of Lazarus. As can be seen, Lazarus includes a more detailed view.

Noteworthy is the role of attention. While Gross sees this as a separate step of the emotion process (see Figure 1.8), Lazarus defines an adaptational encounter as something that a subject focuses on. He sees the shifting of attention more as a response of emotion, instead of an antecedent of emotion:

> "In short, emotions focus attention on some concerns and, by the same token, distract attention away from other concerns that are not so pressing, depending on whether one is speaking of the interrupted original activity or the new adaptational demand." (Lazarus, 1991, p.17)

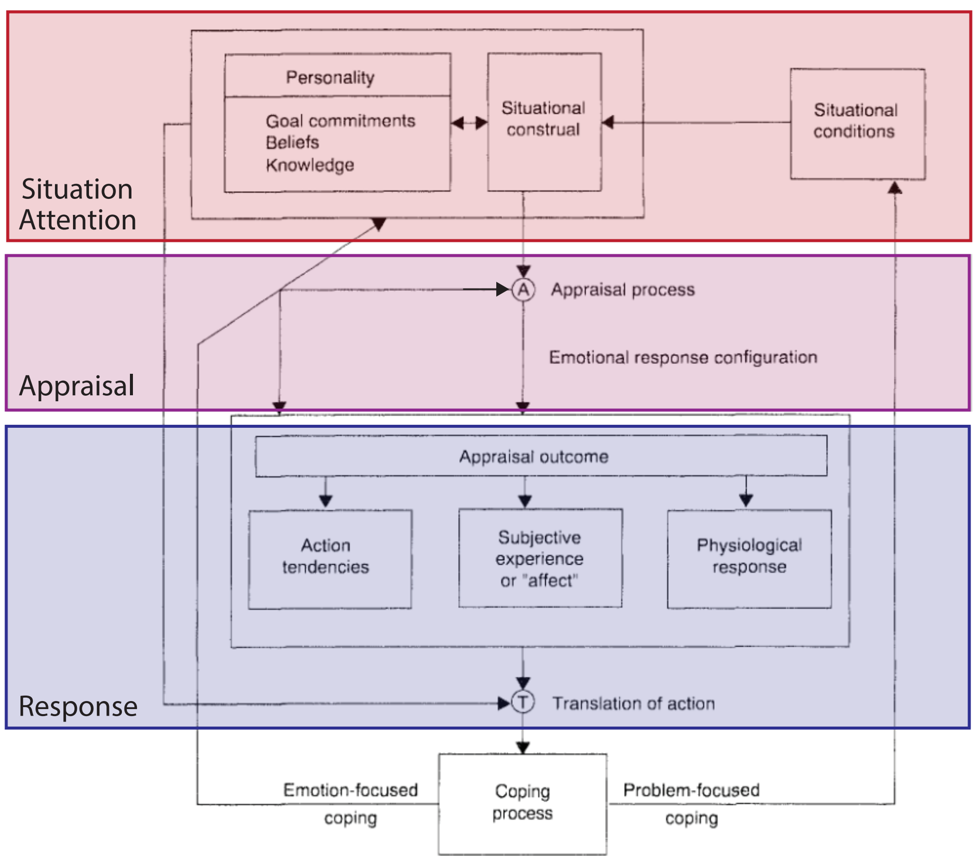

Figure 1.12: The process view of Lazarus compared to the model model of Gross. Adapted from (Lazarus, 1991, p.210).

Coping and emotion regulation

As stated above, Lazarus started working on stress and coping mechanism and moved towards emotion research later on. While coping is usually associated with stress, it plays a major role in Lazarus' theory. Lazarus argues that because of this association, the importance of coping in emotion is largely underestimated. In his work, Lazarus uses the term coping in a broader sense. He argues that coping is a more general process that directly and indirectly affects emotion itself. Processes that try to regulate emotions is exactly what Gross refers to when he talks about emotion regulation. Since we want to compare Gross' notion with the ones of Lazarus, we will compare the notions of coping of Lazarus with emotion regulation of Gross into more depth here.

Problem-focused and emotion-focused coping Lazarus differentiates between two types of coping: *problem-focused coping* and *emotion focused-coping* or *cognitive-coping*. While problem-focused coping alters the actual relationship or environment by performing an action, emotion-focused coping alters how the situation is attended to. When, for example, your neighbours make a lot of noise which results in you being irritated or angry, you can step by to ask if they can be a little quieter (problem-focused coping), or you can think about the fact that they are usually very quiet and try to not get angry about it. (emotion-focused coping).

While both Lazarus and Gross distinguish between different type of strategies instead of naming all specific strategies that people could have, there is a difference in how they group them together. Lazarus distinguishes on *what* is regulated, either the environment or the emotion itself. Gross, on the other hand, separates between *when* (or at which point) in the emotion process the regulatory process is intervening. This can be clearly seen in Figure 1.12. The emotion-focused coping goes into every aspect of Gross modal model, so emotion-focused coping strategies can be any of the emotion regulation strategies given by Gross. Gross on the other hand does not make a distinction between what is being regulated, so situation modification strategies can both be emotion-focused or problem-focused coping.

Type of process Lazarus argues that coping processes are "planfull, deliberate and rational" (Lazarus, 1991, 227). In other words, he argues that coping is per definition conscious. This is in contrast with Gross, who argues that emotion regulation processes can also be unconscious, effortless, and automatic.

The focus on negative emotions A more subtle difference between coping and emotion regulation is that that coping is more focused on decreasing the effect of negative emotions . This is also pointed out by Gross where he argues that coping has an "predominant focus on decreasing negative affect" (Gross, 2011, p.9). While Lazarus acknowledges that researchers often associate coping with stress, and thus with dealing with negative circumstances, he tries to use coping in a more broad and general way.

Nevertheless, when examining his theory it becomes evident that coping is often associated with negative emotions rather than positive. For example, while most negative emotions have an associated coping mechanism, with most positive emotions Lazarus claims that this is not relevant.

This predominant focus can also be found in the definition that Lazarus gives on coping, where he describes that it contains all "cognitive and behavioral aspects to manage specific external or internal demands (and conflicts between them) that are taxing or exceeding the resources of that person" (Lazarus, 1991, p.112). While Gross takes a more general stance that includes all processes that regulate emotions.

Some researchers use the differences sketched above to contrast coping with emotion regulation. Gross, for example, tries to draw a clear distinction between the two based upon the above described focus on negative affect and the emphasis on much larger periods of time "e.g. coping with bereavement" (Gross, 2011, p.9). Although we agree with the first statement, we think the second argument Gross refers to the narrow view of the psychological coping that Lazarus has expanded in *Emotion in Adaptation*. Lazarus, for example, argues that pouting and gloating can be seen as coping processes (Lazarus, 1991, p.228), which last for a very short amount of time. Thus coping according to Lazarus is not restricted to long lasting periods of time. In (Bosse, Pontier, & Treur, 2010), Bosse et al. argue that "Gross' definition of emotion is very much related to the well-known notion of coping [..], but with some subtle differences" (Gross, 2011, p.211) where they refer to Gross' argument about the predominant focus on negative affect.

In this thesis we are trying to unify the field of emotion theory rather than drawing even more distinctions, therefore we believe it is more constructive to treat coping as a subset of emotion regulation processes. This is also very close to the stance taken by Frijda, who refers to some of the processes that Lazarus gives as being emotion regulation processes. In other words, during this thesis we will take the stance that emotion regulation includes *all* processes that adapt or interfere with the emotion and coping processes are *specific* emotion regulatory process that are conscious, deliberate, and mainly focused on the negative emotions. The main difference between the two is the way they are grouped together. But as we will show later, this is a difference that can be used in our advantage.

1.4.4 Gross and the OCC

As already stated above, the OCC does not include any regulatory processes since this lays outside of the scope of their research. In the final chapter of the book however, Orthony et al. mention some ideas about coping. This notion is a more restricted and simple notion than the notion of Lazarus, since they merely refer to the literal linguistic meaning of coping: dealing with the situation. The statements they make about coping are very general, therefore they do not cause any contradiction with the ideas of Gross.

To be able to combine the OCC with Gross' theory we need an emotion process, something that is lacking in the OCC. Without such a process, it is very difficult to interpret the whole framework of Gross since it is based upon the distinction of on which point in the process the strategy is interpreted. The distinction between coping processes by Lazarus would, for example, be easier to interpret. This is not nescessarily a problem, since there are several ways to deal with this.

One approach is to extract some sort of process or order from the OCC. This is an approach followed by for example (Steunebrink, 2010), see Figure 1.13. As could be seen in a previous section, the OCC covers almost all components sketched by Marsella et al. A logical way of putting them together is to follow the order that Marsella and al. give to their components. This comes down to following the general idea of appraisal theory. Since their theory can be easily placed within this field, this process follows quite naturally from their theory.

Another solution is one that is already proposed earlier in this thesis: combine the OCC with other appraisal theories, for example the theory of Lazarus or Frijda. As we have seen, the OCC is more specific on certain areas, which is something that is very useful when building a computational model. Since both Frijda and Lazarus do provide some description of the emotion process,

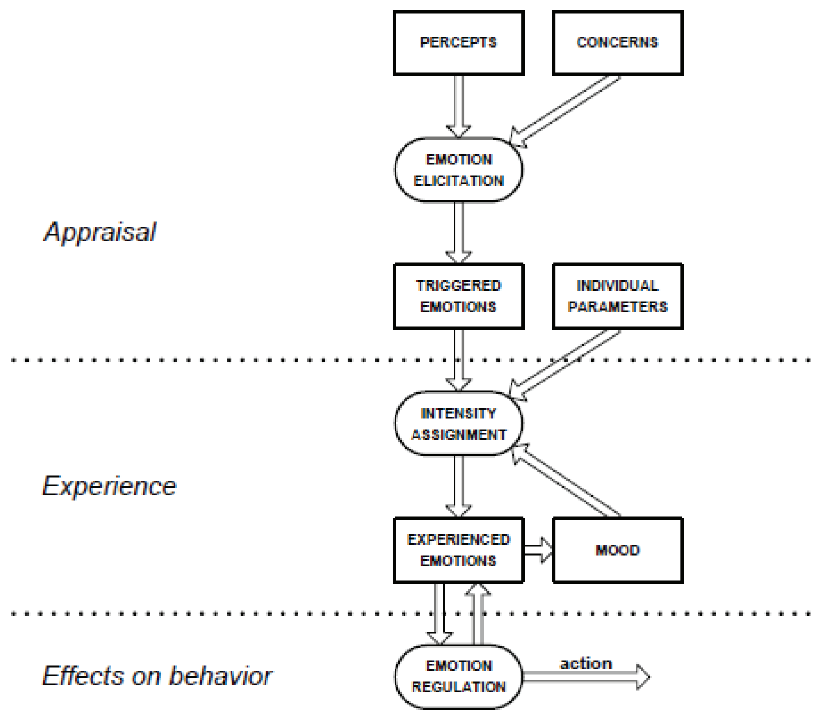

Figure 1.13: A process emotion of emotion based upon the OCC. From (Steunebrink, 2010, p.38).

1.4.5 Conclusion

As could be seen, Gross' theory is compatible with appraisal theory. We have also shown that Gross theory is compatible with Frijda, although his definition of emotion regulation slightly differs from Gross'. Moreover, Lazarus' definition of coping can be seen as a subset of emotion regulation, namely the strategies interfere with the emotion and coping processes are *specific* emotion regulatory processes that are conscious, deliberate, and mainly focused on the negative emotions. The main difference is the way in which the processes are grouped together. Lazarus groups on *what* the processes are regulating, while Gross focuses on *when* the processes are regulating. Finally, we have seen that althought the OCC does not explicitly provides us with an emotion process, there are several ways to combine the OCC and Gross' theory.

1.5 Conclusion

In this chapter we have shown how Gross' theory fits into the landscape of emotion theory. We started this investigation with stating what it is that a psychological theory is trying to explain, and provided theoretical frameworks to help discriminate and group several aspects of emotion theory. After providing a short overview of different trends within emotion, we have zoomed into appraisal theory and compared three different theories in more details: Frijda (Frijda, 1986), Lazarus (Lazarus, 1991) and the OCC (Ortony et al., 1988). Finally we have seen Gross' theory and shown to which extent this theory is compatible with appraisal theory in general and these specific appraisal theories in particular.

In short, Gross and general appraisal theory are compatible. This implies that, at least in principle, we can use models that are based upon general appraisal theory to be extended with Gross' ideas about emotion regulation. As we have also seen, Gross' theory is compatible with all three models that we have compared. All three models have their own advantages and challenges. While Frijda's theory is very compatible with Gross', the theory itself is rather vague and underspecified. Lazarus included a notion of coping that slightly differs from the notion of emotion regulation. As said before, we do not believe coping is different from emotion regulation, but think that coping can be seen as a subset of emotion regulation. In contrast with the theory of Frijda, the OCC model provides a very detailed and specific theory of emotions. However, to extend a model based on the OCC with a notion of emotion regulation, some additions, in specific adding a certain process view of emotion, must be done.

Besides the findings of how Gross' theory and these three appraisal theories relate to one another, we believe that also the way we found these results contribute to the field of computational emotion modeling. There is not a straightforward method to do comparative research this. In this Chapter, we have combined several ideas about what a theory of emotion is and used these to find some more abstract and structural differences and similarities between them.

In the next chapter, we will introduce and compare several computational models of emotion.

Chapter 2

Computational Models of Emotion

As emphasized multiple times in this thesis, it is difficult to get a coherent overview of the field of affective computing. Researchers that build computational models of emotions often start from scratch, using the paradigm and tools they favor, which has lead to a field that is difficult to oversee (S. Marsella et al., 2010). Following some recent researchers (see e.g. (Hudlicka, 2011; Reisenzein et al., 2013; S. Marsella et al., 2010)), we want to help mature this field and do incremental research instead of starting from scratch. In other words, we want to extend or modify existing computational models of emotion to include a notion of emotion regulation developed by Gross.

The aim of this chapter is to introduce and compare existing models that can be extended with Gross' notion. First, we will explain what exactly we mean when we talk about computational models. Next, we will argue why computational models are important. Then we will introduce some general aspects of computational models of emotions followed by a discussion of a formalization of Gross' theory. Finally, we will give some overview and short comparison of influential models within the field.

2.1 What is a Computational Model?

While the term *computational model* is widely used within the emotion modeling literature, most researchers do not give a clear definition of this term[1]. Since one of our goals is to untangle the field of affective computing, we think it is important to clarify what we mean when we talk about a computational model.

In this thesis, we follow the definition given by Sun (Sun, 2008). He mainly writes from a cognitive science perspective, but we believe that his distinctions also apply to computational models of emotion when we consider them from an AI perspective.

Definition of a computational model

Sun argues that cognitive computational models are *process-based*, *detailed* models that provide understanding of various cognitive functions (Sun, 2008, p.3). Computational models describe

[1] We can see this in for example (Reisenzein et al., 2013) or in (Hudlicka, 2011).

cognition in terms of computer algorithms and programs and are often seen as the bridge between cognitive science and computer science (Sun, 2008).

According to Sun, computational models can be contrasted with two other types of models that are used within cognitive science: *mathematical models* and *verbal-concept models*. Mathematical models capture relationships between variables by using equations and lack the process-based focus that is essential in computational models. Verbal-concept models are written in natural language and often lack a formal description that can be given by a computational model. The theories of Frijda, Lazarus and the OCC are examples of verbal-concept models.

Different levels of abstraction

Besides the type of a model, we can also distinguish between *different levels of abstraction*. In Section 1.1.1, we have introduced the terminology of Dennett, who distinguishes between the *intentional stance*, *design stance*, and the *physical stance*. These levels of abstraction also apply to computational models, since a cognitive process can be modeled from different perspectives. For example, the basic concepts of a model can range from beliefs and desires, to artificial neurons that are supposed to represent parts of the brain.

Unfortunately, as we will see below, this is an area in which different researchers use different terminology for the same concepts and the same terminology for different concepts. Besides Marr and Dennett, there are several researchers that try to capture different levels of abstraction using different terms (see e.g. (Sun, Coward, & Zenzen, 2005; Newell & Simon, 1976)). This makes comparing research purely on the terms that are used almost impossible. To avoid confusion, we will shortly discuss some terminology that we will encounter later on in this thesis.

One of the terminologies that is particularly of interest to us, is the distinction made by Broekens et al., who distinguish between *structural*, *process* and *computational* models (Broekens et al., 2008; Broekens & DeGroot, 2006). Structural models, also called black-box models, describe the structural relations between different aspects of the input and output. Process models describe how these structural relations arise and interact in terms of cognitive operations, mechanisms and dynamics. A computational model describes in an unambiguous manner how the 'device' behaves. In other words, a structural model provides tools to describe the structural relations in a certain (static) situation, a process model provides tools to describe the underlying processes that give rise to these structural relations, and a computational model provides some concrete algorithm in which these models are implemented (See Figure 2.1A).

What is interesting to note here, is that all these different terminologies try to capture the same aspect of modeling: you can describe the same phenomenon from different perspectives, and these perspectives are related to each other. If we move from a more abstract perspective to more concrete perspective, there are multiple details that need to be filled in, and this can be done in multiple ways. This is not only the case in the theory of Dennett and Broekens et al (see Figure 2.1), but also in the models of Marr (Marr, 1982), Sun et al (Sun et al., 2005), Newel and Simon (Newell & Simon, 1976), and many more.

It is important to stress here that the three terms concerning the word computational -a *computational model* as defined by Sun, a *computational model* as defined by Broekens et al. and a *computational level theory* as defined by Marr- do not refer to the same concept. A computational

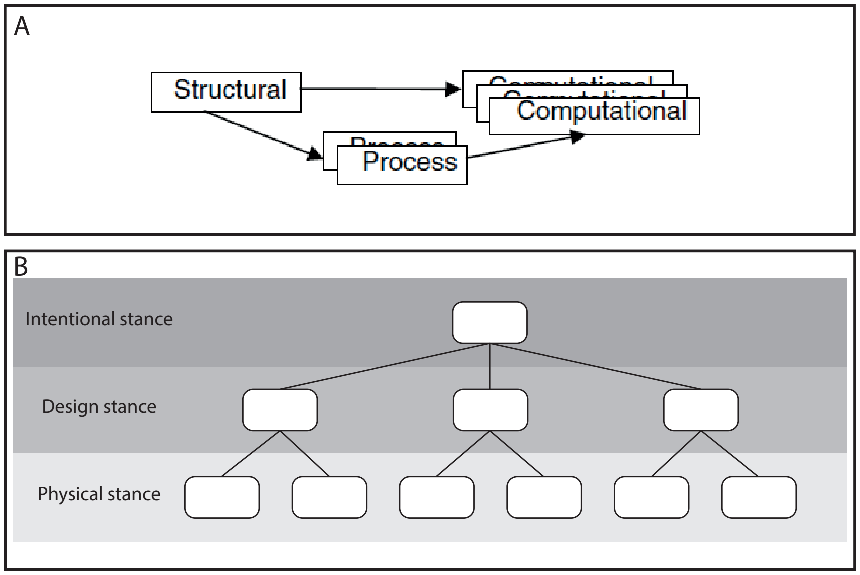

Figure 2.1: **A:** Possible mappings between structural, process and computational models according to Broekens et al. From (Broekens et al., 2008, p.176). **B:** A visualization of how the different theories formulated in different stances form a hierarchy, see also Section 1.1.1.

model as defined by Sun is a *type* of model, where the computational level of Broekens et al and the computational level theory, refer to the *level of abstraction* a model is formulated in. We could have a computational model (as defined by Sun) that is also a computational level theory or a computational level as defined by Broekens et al., but this is not necessarily the case. To make it even more complicated: a computational level theory only specifies the input and output of the system, but does not specify how this input is transformed into an output. A computational model as defined by Broekens et al., on the other hand, does specify unambiguously how the input is transformed into the output, and thus provides an algorithm for some more abstract model. Hence, a computational model as defined by Broekens is not a computational level theory, and the other way around. To avoid any confusion, every time we mention a computational model in this thesis, we mean a computational model as defined by Sun.

Four different paradigms

Sun distinguishes four paradigms in which computational models can be expressed: *logic*, *connectionism*, *Bayesian inference*, and *cognitive architectures*. We will give an overview of these four paradigms below. Noteworthy is that the development of hybrid models, in which different paradigms are combined, is becoming more prominent within cognitive science (Isaac, Szymanik, & Verbrugge, 2014).

Logic Logical models, sometimes referred to as *symbolic models*, frame cognitive functions by using logical systems and see reasoning as computing within these systems. The goal is to find certain intrinsic, context-independent structures that can predict and explain human thinking. Logic is one of the oldest paradigms used for modeling the mind (Isaac et al., 2014). During the last decades, the use of logic within cognitive science became controversial since experimental evidence was found that supports the claim that humans do not reason according to logic. Some recent research, however, disagrees with this statement[2] (Isaac et al., 2014). Logical methods are often used within AI, since the logical structure is easily translated into computer applications (Bringsjord, 2008).

Connectionism Connectionist models are inspired by how computation works in the human brain. For this reason, connectionist models are also often referred to as *artificial neural networks*. Processing in these models is characterized by patterns of activation that run across several simple processing units. These simple units are all connected and form complex networks together. Contrary to the logical methods, representations are distributed among the units and knowledge is indirectly stored in the strength of the connections. Connectionist models are often used to model the learning process and developmental phenomena (Thomas & McClelland, 2008).

Bayesian inference Bayesian models link human cognition and inductive interference. The main question Bayesian models try to answer is: *how can you make good generalizations and predictions about what is happening or going to happen, when you only have limited and noisy data?* The main idea of this method is to use *Bayes' theorem* to find the most probable hypothesis of what is happening given certain prior knowledge. Bayesian inference has many connections with statistics and machine learning, and can help to bridge the gap between theories that focus on the importance of innate and domain specific knowledge and on domain-general learning mechanisms. Nowadays, Bayesian inference is one of the main paradigms used in computational linguistics (Griffiths, Kemp, & Tenenbaum, 2008).

Cognitive architectures While the models above mainly focus on one aspect of cognition, cognitive architectures try to model various cognitive functions within *one* model. Cognitive architectures can be symbolic or connectionist, but often are hybrids of both paradigms. Cognitive architectures can be used as a basis for AI applications, or to test psychological hypotheses (Taatgen & Anderson, 2008). Examples of cognitive architectures are ACT-R (Anderson, 1996) and SOAR (Newell, 1990).

2.2 The Advantages of Computational Models

In the previous section, we have seen what a computational model is. The question that naturally follows from this is: what can one gain from these models? We have already discussed this to some extent in the introduction of this thesis, but before we move on, we think it is important to give some solid argumentation of why computational modeling is useful.

[2]This very interesting topic lies, unfortunately, outside the scope of this thesis. More information on this topic can be found in, for example, (Isaac et al., 2014).

The field of cognitive computational modeling is an interdisciplinary field including psychology, AI, robotics, and human computer interaction (HCI). As we will show below, computational modeling can be used as a tool to advance all these fields, since it allows for previously unaddressed questions to be explored, along with finding new interesting research questions (S. Marsella et al., 2010). In particular, we will show below how computational modeling be used both to understand human cognition better, and to improve models that mimic cognitive functions. Since we have seen in the introduction that these are the two main goals of affective computing, we believe that computational modeling is very relevant for this field.

Psychology

The classical approach in psychology is to understand human cognition through observations of human behavior. Computational modeling is one of the alternatives to this approach. With computational modeling, certain assumptions about the basis of the human cognitive system can be made explicit and tested more easily (Sun, 2008). Additionally, computational models are often a formalization of a certain verbal-conceptual theory. The process of formalizing a theory that is written in natural language will expose hidden assumptions and make it easier to derive predictions (S. Marsella et al., 2010).

Moreover, if a cognitive process has a formal description, this gives rise to a range of formal tools that are used in computer science, mathematics, and logic to investigate the properties of functions. In particular, tools from complexity analysis can provide a precise measure of how 'difficult' the description of a cognitive function is. This measure can tell us something about how cognitively plausible a certain theory is[3].

AI, robotics, and HCI

Research has shown that emotions play a functional, often adaptive, role in human behavior. This has motivated researchers within AI and robotics to explore whether the integration of emotions, similar to the one of humans, can lead to more intelligent, flexible, and capable systems. Social emotions, for example, could be used as a mechanism to improve group cooperation. Computational models could be used as a starting point of such applications. Moreover, research has shown how powerful emotions are in shaping social interaction. This implies that emotions could also be used to improve human computer interaction applications (S. Marsella et al., 2010). Emotion regulation in particular could be used to improve the human-like behavior of robots or visual agents in various AI applications. It can also be used in the field of Ambient Intelligence, where it can be useful, for instance, when some system maintains the emotional state and the emotional regulation processes of the user (Bosse, Pontier, & Treur, 2007). Imagine, for example, a system that adapts the light in an apartment to the emotional state of the user.

[3]Research in this direction is often based on the *tractable cognition thesis*, that states that a cognitive function must be *tractable*. Here, tractable can have several formal definitions, such as being polynomial computable, or Fixed-parameter tractable. See e.g. (Van Rooij, 2008)

2.3 Different Types of Computational Models of Emotion

Hudlicka divides computational models of emotion into two different categories: *models of emotion generation* and *models of emotion effects*. Models of emotion generation are mainly trying to capture the evolving dynamic processes associated with the occurrence of emotions. These models are often based on appraisal theory. Models of emotion effects focus on the effect of emotions both on visible features, such as facial expressions, and the effects of emotions on behavior, attention, and perception (Hudlicka, 2008).

The aim of this thesis is to extend some existing model of emotion with the notion of emotion regulation as developed by Gross. As we have seen in the previous chapter, the majority of Gross' emotion regulation strategies interfere in the emotion generation process (see Figure 1.9). For this reason, the most straightforward approach is to start with a model of emotion generation. In the previous chapter we have seen that Gross' theory is compatible with appraisal theory. Since most emotion generation models are also based upon appraisal theory, we will mainly focus on computational models of emotion generation that are based upon appraisal theory in the rest of this thesis.

We acknowledge that this bias is partly justified by the fact that a lot of researchers are following this line of research and might be, as Hudlicka phrased it nicely, "looking for the key under the lamp because the light is there" (Hudlicka, 2008, p.2). Nevertheless, since emotion modeling is a relatively new field and the aim of this thesis is to extend and unify existing research instead of creating even more competing models, we choose to follow the approach of the majority of researchers in this thesis.

Different paradigms in emotion generation modeling

In the section above, we have described four computational modeling paradigms: *logic*, *connectionism*, *Bayesian inference* and *cognitive architectures*. What stands out is that most models of emotion generation are either based on logic or written in some cognitive architecture. Reisenzein et al., for example, only discusses logical models and cognitive architectures, when giving an overview of models within emotion modeling (Reisenzein et al., 2013). While it is not the case that there are no connectionist or Bayesian models in emotion theory, most models of appraisal theory mentioned fall within these two paradigms.

We think that the main reason[4] for this is that both the logical and cognitive architecture paradigms are more suited for modeling appraisal theories. In both paradigms it is easier to represent high-level and abstract representations and, as can be seen in the previous chapter, appraisal theory precisely refers to relatively abstract and high-level representations such as goal relevance. It is more straightforward to translate these concepts into logical concepts than into patterns of activation or probability distributions.

We can also see this when we consider emotion models within the other paradigms. Thagard et al., for example, developed HOTCO (Thagard, 2002), a connectionist model of emotion. We can

[4]We also believe that this has something to do with the traditional rivalry between connectionism and symbolism within AI, but this lies outside the scope of this thesis. See (Isaac et al., 2014) for some interesting thoughts on this issue.

see that this model is very limited in which part of the emotion process is modeled. Thagard et al. also claim that "it is far from providing a complete account of the range of emotions discussed by appraisal theory" (Thagard & Nerb, 2002, p279). Most Bayesian models used in affective computing on the other hand, deduce emotional states from data. Conati, for example, uses a Bayesian network deduce a student's emotional state based on their actions (Conati, 2002).

2.4 Computational Models of Emotion Regulation

Although the field of emotion regulation is widely investigated in the psychological literature (e.g. (Gross, 2011; Gross & Barrett, 2011; Ochsner & Gross, 2005)), there are almost no computational models of emotion regulation (Bosse, Pontier, & Treur, 2010). Models that do exist generally focus on specific aspects of emotion regulation, often at a more neurological level (see e.g. (Thayer & Lane, 2000)).

One noteworthy exception to this is the work of Bosse et al. (Bosse, Pontier, & Treur, 2010, 2007), who formalized Gross' notion of emotion regulation. They have provided a clear, concise, and tested formalization of Gross' theory, which we believe is useful when extending or adapting a model of emotion to include emotion regulation. Moreover, using an already existing formalization of Gross' theory fits well with our aim of doing incremental research within affective computing. Therefore, we will discuss their formalization in more detail below.

Modeling approach

Bosse et al. have formalized emotion regulation in the modeling language LEADSTO (Bosse, Jonker, Van Der Meij, & Treur, 2007), which integrates qualitative logical aspects with quantitative numerical aspects. They argued that this is suitable because both qualitative aspects, such as decisions to regulate one's emotions, and quantitative aspects, such as emotional levels, play an important role in Gross' theory of emotion regulation. Noteworthy is that Bosse et al. claim they mainly use LEADSTO as a 'vehicle' and there are possibly other ways to implement their model (Bosse, Pontier, & Treur, 2010, p.216).

Regulation strategies

Bosse et al. have formalized the *antecedents focused strategies* proposed by Gross, which are *situation selection*, *situation modification*, *attentional deployment* and *cognitive change* (see Section 1.3.2)[5]. As seen in the previous chapter, every strategy interferes with some aspect of the emotion process. Bosse et al. have modeled this by introducing a set K of elements k: *Situation*, *Sub_situation*, *Aspect*, and *Meaning* which all correspond to some aspect of the emotion generation process (see in Figure 2.2) (Bosse, Pontier, & Treur, 2010).

[5] Bosse et al. argue that since their model is generic in the sense that it would be straightforward to add *response modulation*, the last regulation strategy (Bosse, Pontier, & Treur, 2010, p.214).

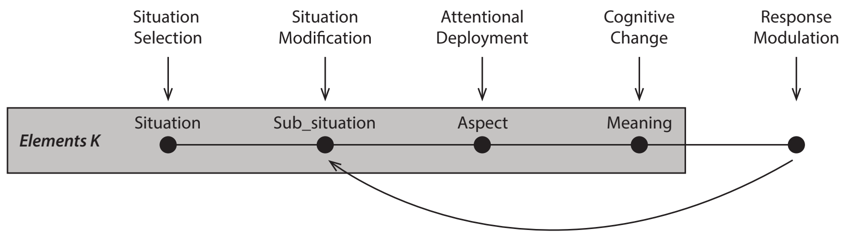

Figure 2.2: The elements *K* (*Situation, Sub_situation, Aspect,* and *Meaning*) of Bosse et al. mapped upon the modal model of emotion by Gross.

The emotional response level

Every element k is associated with a certain emotional value v_k. Via an element-specific weight factor w_k, this emotional value v_k contributes to the general emotional response level (*ERL*), which can be interpreted as the intensity of the emotion. While calculating the *ERL*, the *persistency* of an agent (formalized by β) is also taken into account. For example, someone who is only angry for a short amount of time after a fight will have a low β (Bosse, Pontier, & Treur, 2010, p.214). The ERL is calculated using the following update rule:

$$ERL_{new} = (1-\beta) \cdot \sum_k (w_k \cdot v_k) + \beta \cdot ERL$$

Noteworthy is that Bosse et al. choose to model only *one* emotion. The ERL can, for example, be interpreted as the intensity of anger or the intensity of sadness (Bosse, Pontier, & Treur, 2010, p.214). The advantage of this approach is that Bosse et al. do not commit to one specific theory of emotion. As we have seen in the previous chapter, this is in line with Gross' approach, who also only commits to general appraisal theory, but not to any specific theory of emotion. We can imagine this formalization could be used both as an extension of a model in which an agent only experiences *one* specific emotion regarding a certain situation, and of a model in which agents can experience *multiple* emotions regarding a certain situation. In the former there will only be one *ERL* per situation, in the latter there will be an *ERL* per emotion that can be experienced in a situation.

The emotion regulation process

Another variable that plays an important role in the formalization of Gross' theory is ERL_{norm}: the emotion response level that is aimed for. The influence of this variable is similar to the concept of *homeostasis*: the idea that the human body aims to keep physiological variables continuously within a certain range. The difference between *ERL* and ERL_{norm}, captured by the variable d, is the start of the regulation process. In other words, an emotion is regulated when the difference between the intensity and the intensity that is aimed for is too large. The difference d forms the basis of the way in which emotion is regulated.

Bosse et al. have modeled the emotion regulation process by 'choosing'[6] a new value for v_k based on this difference d. For example, changing the value of v_{aspect}, corresponds to applying an attentional deployment regulation strategy.

Besides the difference d, the new value of v_k also depends on the modification factor α_k. This factor α_k depends on both the personal tendency to adjust the emotional value of k (γ_k) and the cost c_k of adapting this aspect of the situation. The factor γ_k, in turn, depends on the basic personal tendency to adapt situation k ($\gamma_{basic\,k}$), certain events that influence personal tendencies like traumas or therapy (*Event*), and the personal speed with which events influence personal tendencies (ζ_k). An overview of all variables can be found in Table 2.1 and an overview of the dependencies between variables can be seen in Figure 2.3. For simplicity we will omit the exact mathematical dependencies between the variables here, but they can be found in (Bosse, Pontier, & Treur, 2007) and (Bosse, Pontier, & Treur, 2010).

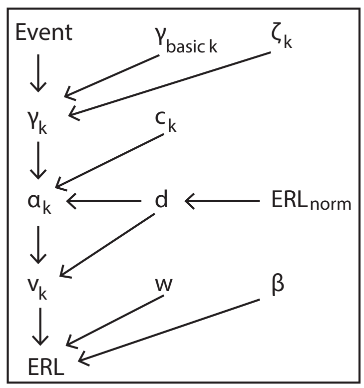

Figure 2.3: Dependencies between the variables of Bosse et al. Adapted from (Bosse, Pontier, & Treur, 2010, p.215).

ERL$_{norm}$ revisited

Noteworthy is that the notion of ERL_{norm} is not part of Gross' theory, but based upon biological concepts found in e.g. (Velásquez, 1997). Gross does not give any explicit guidelines of when humans exactly start to regulate their emotions. One of the reasons for this could be that Gross' theory is a *descriptive* theory of emotion regulation. It describes how we regulate our emotions, simply assuming that we do so. In the case of computational modeling, you need a *prescriptive* theory that answers the question of *when* exactly emotion regulation happens, which is something that Gross' theory lacks. Bosse et al. used the elegant solution of ERL_{norm}, which in our opinion fits very well with the rest of Gross' theory. This is an example of how certain assumptions that might not be so obvious in the verbal-concept theory, can become very explicit when formalizing a theory.

An aspect that is very prominent in the theory of Gross is that positive emotions can be down-regulated and negative emotions can be up-regulated. For example, when attending a funeral you

[6] Although Bosse et al. use terms like 'choosing', they do not claim that the emotion regulation process is always conscious. As can be seen in the previous chapter, this is in line with the viewpoint of Gross.

Variable	Meaning
ERL	Emotion Response Level
ERL_{norm}	Emotion Response Level that is aimed at
d	Difference between ERL and ERL_{norm}
β	Slowness of adjustment ERL
K	Set of elements indicated strategies incorporated
w_k	Weight of element k in adjusting the ERL
v_k	Emotional value for element k
α_k	Modification factor that represents the flexibility to change the emotional value of element k
γ_k	Personal tendency to adjust the emotional value of element k much or little
$\gamma_{\text{basic } k}$	Basic personal tendency to adjust the emotional value of element k much or little
c_k	Cost of adjusting emotional value v_k
$Event$	Value of an event that reflects the impact it has on personal tendency γ
ζ_k	Variable that determines the speed with which events influence personal tendencies

Table 2.1: Variables addressed in the model of Bosse et al. Adapted from (Bosse, Pontier, & Treur, 2010, p.215) and (Bosse, Pontier, & Treur, 2007, p.3).

want to feel extra sad, or during a meeting you want to be extra angry to get what you want. This aspect is not very prominent in the formalization by Bosse et al. It would be possible to use ERL_{norm} to formalize this aspect, since in principle ERL_{norm} can be used to both up- and down-regulate emotions. The problem is that ERL_{norm} does not depend on the situation K or the goals of an agent in this formalization, while this is something that you would need when modeling the funeral or meeting example.

One solution is to let ERL_{norm} depend on K and a BDI structure of the agent, but we believe that it is conceptually more elegant to introduce a second emotional response level that is aimed for, for example ERL_{sit}. This emotional response level will be dependent on the situation K and the BDI-structure of the agent. In contrast with ERL_{norm}, this ERL_{sit} is more dynamic and dependent on a specific context. Now the base of emotion regulation, captured with the difference d, does not only depend on ERL and ERL_{norm}, but also on ERL_{sit}. In this way we can also model conflicting regulatory processes, for example when you are a generally happy and outgoing person that would like to feel happy but you want to feel sad because you are attending a funeral. Here ERL_{norm} could capture the personality traits of the person and ERL_{sit} the emotional expectations of a specific context. We will come back to this idea in the next chapter.

Incorporating unsuccessful strategies

As said before, we think this formalization of Gross' theory is clear, concise, and very useful when extending a model of emotion with Gross' emotion regulation theory. We do believe that some parts are slightly over-simplified. The main aspect we believe to be too simple is that applying a regulation strategy is equivalent to adapting the emotional value v_k of element k of the situation. This leaves no space for strategies that are unsuccessful. Especially when applying a situation modification strategy, there is always some uncertainty about the effect of a certain action. To be able to model this more realistically, the formalization should either be extended massively or combine it with a computational model that already has some rich representation of the world. Clearly, we believe the latter strategy is the most suitable.

2.5 Computational Models of Emotion

In the previous section, we have introduced a formalization of Gross' theory by Bosse et al (Bosse, Pontier, & Treur, 2010). As could be seen, we believe that this model is very suitable to use as an extension of an existing computational model of emotion. In this section, we will argue which model we have chosen as a basis. We will start with a short overview of some influential models of emotion, compare these models, and provide argumentation on which model we have chosen as the basis.

Introducing several computational models of emotion

In the beginning of this chapter, we provided a framework in which we can place and compare specific models of emotion. Since there are so many models of emotion used in affective computing, it is almost impossible to compare all models of emotion and emotion regulation. For this reason, we have limited our comparison to models that have been influential in the field. This resulted in a selection of eight models. Before we compare these models, we will first give a short introduction per model.

FLAME Flame (Fuzzy Logic Adaptive Model of Emotions) is a logical representation that maps events and observations to emotional states. The model also includes several inductive learning algorithms for learning patterns of events, associations among objects, and expectations. Flame is used to drive the behavior of characters in interactive narrative environments (El-Nasr, Yen, & Ioerger, 2000).

EMA EMA (EMotion and Adaptation) 0is a fully implemented computational model of emotion that has been applied to a number of systems that must simulate realistic human emotional responses, such as virtual humans (S. C. Marsella & Gratch, 2009).The name of the model is based upon *Emotion and Adaptation*, the very influential book by Lazarus (Lazarus, 1991).

I-PEFiC$^{\text{ADM}}$ I-PEFiC$^{\text{ADM}}$ is an adaptation of the Interactive model of I-PEFiC (Perceiving and Experiencing Fictional Characters). A module of affective decision making was added to simulate irrational robot behavior (Hoorn, Pontier, & Siddiqui, 2008).

Steunebrink et al. Steunebrink et al. provide a formalization of the OCC model using KARO (e.g. (van der Hoek, van Linder, & Meyer, 1999)), a mixture of dynamic, epistemic, and doxastic logic together with BDI operators that deal with the motivational aspect of artificial agents (Steunebrink, Dastani, & Meyer, 2007, 2009).

WASABI WASABI ((W) Affect Simulation for Agents with Believable Interactivity) is an architecture that simulates affect. To be able to simulate emotions, a simulated embodiment is added to a virtual cognitive agent (Becker-Asano & Wachsmuth, 2009).

FAtiMA FAtiMA (Fearnot AffectTIve Mind Architecture) is an agent architecture that is especially designed to use personality and emotions to influence the behavior of an agent. This cognitive architecture is developed to build affective agents and is used in several scenarios. Recently, a modular version of FAtiMA was developed to make it easier to use lighter and simpler versions that only contain some of its components (Dias, Mascarenhas, & Paiva, 2014).

ALMA ALMA (A Layered Model of Affect) is a general programming tool that incorporates emotions, moods, and personality. This tool aims to make it easier for application developers to construct computational models of emotions for various applications (Gebhard, 2005).

Broekens et al. Broekens et al. provide a general formalization of appraisal theory using set theory. In their formalization they leave certain theory-specific aspects open (such as appraisal-dimensions and emotions), so this can be adapted by the user to their theory of choice. They also provide an implementation of the framework, but here we will limit ourselves to their formalization (Broekens et al., 2008).

Comparison

Recently, there has been quite some literature in which different computational models are compared with one another (see e.g. (Reisenzein et al., 2013; S. Marsella et al., 2010; Bosse, Gratch, & Hoorn, 2010)). Several methods are proposed, but often models are compared on which part of the emotion process is covered and how they are implemented. Unfortunately, most of these comparisons only take a number of the models into consideration. This is not surprising, since such an in-depth

Model	Theory	Paradigm	Uses	Stance
Flame	(Mainly) OCC (Ortony et al., 1988)	(Mainly) Logic	Fuzzy Logic	Design
EMA	Lazarus (Lazarus, 1991)	Cognitive Architecture	SOAR (Newell, 1990)	Design
I-PEFiC^{ADM}	Smith and Ellsworth (Smith & Ellsworth, 1985b)	Cognitive Architecture	LEADSTO (Bosse, Jonker, et al., 2007)	Design
Steunenbrink et al.	OCC (Ortony et al., 1988) and Frijda (for emotion regulation) (Frijda, 1986)	Logic	KARO (van der Hoek et al., 1999)	Intentional
WASABI	OCC (Ortony et al., 1988) and dimensional theories (Mehrabian & Russell, 1974)	Cognitive Architecture	MAX (Becker, Kopp, & Wachsmuth, 2004)	Design
FAtiMA	Appraisal theory in general	Cognitive Architecture	-	Design
ALMA	OCC (Ortony et al., 1988) and Mehabrian (Mehrabian, 1995)	Cognitive architecture	-	Design
Broekens et al.	Appraisal theory in general	Logic	Set Theory	Intentional

Table 2.2: A comparison of several computational models of emotion on the aspects introduced in this chapter. Note that not all these models fit neatly within one paradigm.

comparison is very involved and takes a lot of time, and often it is easier to just work with the tools that are provided by the research institute that one works at.

Ideally, we would like to compare each of the models above in the same level of depth as provided in some of the research. Nevertheless, due to time and space constraints, we have chosen to focus on untangling the theory, as we have done in the previous chapter, and proposing extensions of an already existing models, in the next chapter. Hence, we have kept the comparison quite simple, focusing on the overall properties of the models. For extensive comparisons of several of these models, see e.g. (Reisenzein et al., 2013; S. Marsella et al., 2010; Bosse, Gratch, & Hoorn, 2010).

An overview of several properties of all the models is given in Table 2.2. First, note that most models have different goals. Some models are mainly developed to provide some formal basis of the theory, like Steunebrink et al. Others try to develop some programming tool, like ALMA, and others want to develop a working application like EMA. Second, we can see that the OCC theory is very popular among computational models. Finally, we can observe that most models are formulated in either the intentional or the design stance. We believe this is related to the comments made in Section 2.3, were we stated that appraisal theory refers to relatively abstract and high-level representations. For this reason it is not surprising that most models are relatively abstract.

2.6 Conclusion

In this chapter we have have introduced and compared several models within affective computing. We started by expanding on the notion of *a computational model* and discussed several types, level of abstractions, and paradigms, and looked at some possible applications of these kinds of models. Next, we looked at the computational model of emotion regulation by Bosse et al., in some more detail and proposed some improvements to this model. Finally, we compared several models within the field of affective computing.

Similar to Chapter 1, we believe that besides concrete information about these models, also the method of comparing these models and clarifying different notions in the field, are helping to advance the field of computational modeling of emotion.

In the following chapter, we will extend EMA and the formalization of Broekens et al. with a notion of emotion regulation. Here, the knowledge obtained in this chapter will be used in several ways, for example for motivating the choice of these two models and using the idea's of Bosse et al.

Chapter 3

Extending Models with Emotion Regulation

The aim of this thesis is to show how Gross' notion of emotion regulation can advance the field of affective computing. In the previous Chapters, we have shown how this theory fits into the theoretical landscape and provided details about research methods and models within affective computing. In this Chapter we will show how the ideas described before can be used to advance some concrete models in affective computing. In an ideal situation, we would have liked to extend multiple models, set-up some extensive testing to see the effect of these improvements on the performance of the models and then report these results back so they can be incorporated in emotion theories. Unfortunately, this is not possible within this project, given the amount of space and time available. Therefore, we will conclude this thesis with some proposals to improve or extend existing models. Even though this is not an ideal solution, we believe this chapter shows how fruitful such an extension could be and provides some useful insight in how the field of affective computing can be advanced using Gross' theoretical framework. We will consider implementation, testing and reporting back to the psychologists working on emotion theory as future work.

To show how Gross' ideas can be used, we have chosen to propose an extension to several models. Since we want to demonstrate how these ideas advance affective computing as a whole, we chose to extend two very different models: the formalization by Broekens et al. and EMA.

Even though we believe that the formalization by Broekens et al. is slightly over-simplified (we will come back to this below), we do believe it is an elegant frame-work that could benefit from an extension with Gross' notion of emotion regulation. Moreover, precisely because this model is relatively simple, it allows for a precise and detailed extension within a reasonable amount of time and makes it possible to show how Gross' notion can be used in a detailed way.

In contrast to the formalization by Broekens et al., EMA is very advanced and detailed. Moreover, this model also incorporates some notion of coping, which makes it very interesting to extend it with a notion of emotion regulation, regarding the discussion in Section 1.4.3 about coping and emotion regulation. As said before, we think this is a very big disagreement within affective computing. By incorporating both notions in one model, we hope some of this disagreement can be solved. Besides this, we believe EMA is one of the most advanced models within affective computing, which makes it a very interesting model to examine.

This chapter is structured as follows. We will first discuss the formalization by Broekens et al., followed by EMA. For each model we will give an overview of the model, followed by some comments and remarks about this model, and finally we will provide some suggestions of how this formalization could be extended using emotion regulation.

3.1 The Formalization by Broekens et al.

The framework of Broekens et al. is based on set theory, which is known for its expressiveness, since nearly all mathematical concepts can be expressed in this formal language (Reisenzein et al., 2013, p.9). As explained in the previous Chapter (see Section 2.1), this framework is a structural model, meaning that the goal is to give a declarative semantics of appraisal. In other words, the framework tries to give a formal definition what appraisal *is*, not *how* appraisal theory works. This means that the model provides formal tools to describe a (static) situation in a precise way.

3.1.1 The Formalization

Broekens et al. used set theory as a basis of the formalization, which means that every aspect of the emotion process is expressed by a set. Nevertheless, Broekens et al. discriminate between three main constructs: *data*, *processes* and *dependencies*. Below, we will explain these three constructs in more detail. A visual representation of the model of Broekens et al. can be found in Figure 3.1.

Data

Roughly speaking, Broekens et al. discriminate between four type of data: *events* (w), *mental objects* (o), *appraisals* (v), and *emotion components* (i). To be able to distinguish between potential data and the data that is actually used in some situation, two sets are needed per type of data. For example, PW is the set of potential events in the world and $W(\subseteq PW)$ is the set with events that are actually in the world of the agent during a situation. Similarly we have PO and O[1] containing mental objects, PV and V containing appraisals and PI and I containing emotion components. In other words, the sets PW, PO, PV, and PI denote what is possible and the sets W, O, V and I denote the actual situation (see Figure 3.1).

Besides these sets, there are the sets D and E that contain the appraisal dimensions and emotional responses respectively. The set D contains elements such as *pleasantness* or *suddenness* and the set E elements such as physiological or facial responses. Emotions are modeled as a subset of E. We will come back to this in the discussion of the model in Section 3.1.2.

As mentioned before, the formalization of Broekens et al. is generic. Therefore, the sets D and E do not have any predefined elements, since appraisal dimensions, actual emotions and emotional responses differ between appraisal theories. When using this formalization to model some specific emotion theory, D and E must be defined by the user.

The formal definitions of the data can be found in Table 3.1. We can observe that not all data has the same type. While the events (e) and mental objects (o) are relatively simple concepts, both the appraisals (v) and emotion components (i) are tuples, a data structure consisting of multiple

[1]The set O is often referred to as the working memory, even though Broekens et al. do not claim to model working memory perse (Broekens et al., 2008, p.177).

other objects. In the case of the appraisals, Broekens et al. adopt the assumption that appraisals are always object-directed. This means that you always appraise some mental object with respect to several appraisal dimensions (the elements in the set D). To be able to model this, both elements, the mental object and appraisal dimension, need to be part of the appraisal. For example if we appraise a mental representation of a bear o_b to be unpleasant, we get that $(o_b, d_p, -1) \in V$. Thus, as can also be seen in Table 3.1, we have that $\forall v \in PV$ it holds that $v = (o, d, r)$ with $o \in O$, $d \in D$ and $r \in [-1, 1]$.

On the other hand, emotional responses are not directed towards one object. But, there are several aspects of the emotional response that are captured in the set E. For example the responses of smiling can be defined as $(e_s, 0.7) \in I$. So we have that for all $i \in PI$ it holds that $i = (e, r)$ with $e \in E$ and $r \in [-1, 1]$.

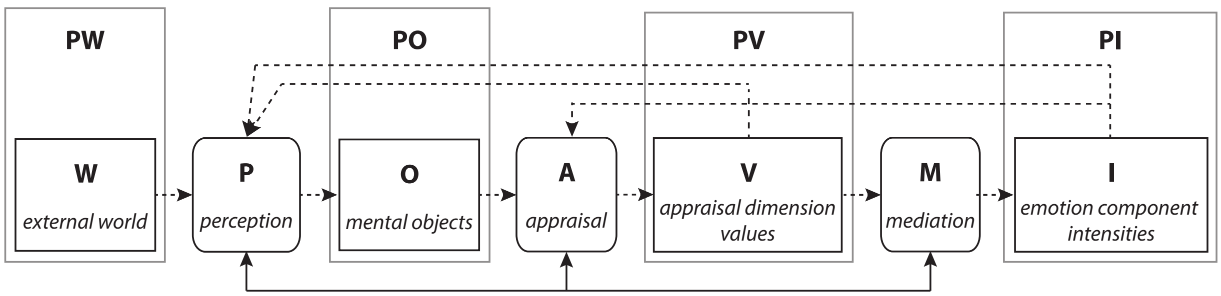

Figure 3.1: A visual representation of the formalization of Broekens et al. Adapted from (Broekens et al., 2008, p.177).

Processes

Following appraisal theory, Broekens et al. distinguish three types of processes: *perception* (P), *appraisal processes* (A) and *mediating processes* (M).These processes are modeled as a set of functions from (sets of) data to (sets of) data. Perception, for example, is modeled as a set of functions from a combination of what happens in the world, the current appraisals, and the current emotion to (a set of) mental representations. To ensure that the elements in the actual situation (thus the sets W, O, V, I) match with the image of the processes, there are several constraints per process. Below, we will give a formal description of every process.

Perception Perception is modeled by the set $P = \{p_1, p_2, ..., p_n\}^2$, where we have that for each $p \in P$ it holds that

$$p : \mathbb{P}(PW \cup PV \cup PI) \rightarrow \mathbb{P}(PO)$$

Where $\mathbb{P}(x)$ denotes the power set of a set x. In words, a perception process $p \in P$ generally maps a portion of the agent's environment, several of the agent's current appraisal-dimension values and

[2]Here, the same comment about n holds as before, it denotes that a set has a finite but arbitrary size

Set	Definition
$PW = \{w_1, w_2, ..., w_n\}$	The set containing all potential observable objects and events in the environment.
$W \subseteq PW$	The set containing all objects and events that are *currently* available to the agent for perception.
$PO = \{o_1, o_2, ..., o_n\}$	The set containing all potential mental objects.
$O \subseteq PO$	The set containing all mental objects that are *currently* in the working memory of the agent.
$D = \{d_1, d_2, ..., d_n\}$	The set of appraisal dimensions. Every d_i is an appraisal element. This set depends on a specific theory that is formalized. In the case of Lazarus, we would have `future_expectancy` and `goal_congruence` in D for example.
$PV = \{v_1, v_2, ..., v_n\}$	The set of potential appraisal-dimension values. We have that for each $v \in PV$ that $v = (o, d, r)$ with $o \in O$, $d \in D$ and $r \in [-1, 1]$. Since PV contains all possible elements, it holds that $PV = O \times D \times [-1, 1]$.
$V \subseteq PV$	The set of *current* appraisal dimension values. This includes the following constraint: if $v = (o, d, r) \in V$ and $v' = (o', d', r') \in V$ with $v \neq v'$ then $o \neq o'$ or $d \neq d'$. In words, every object is only appraised once with respect to one appraisal dimension.
$E = \{e_1, e_2, ..., e_n\}$	The set of possible components of the emotional response, including for example, subjective feelings, facial expressions and physiological reactions.
$PI = \{i_1, i_2, ..., i_n\}$	The set of emotional response component intensities. We have that for each $i \in PI$, $i = (e, r)$ with $e \in E$ and $r \in [-1, 1]$. Since PI contains all possible elements, it holds that $PI = E \times [-1, 1]$.
$I \subseteq PI$	The set of *current* emotion-component intensities. Here we have the constraint that if $i = (e, r) \in I$ and $i' = (e', r') \in I$ with $i \neq i'$ then $e \neq e'$. In words, every response-component can only have *one* intensity.

Table 3.1: The table containing all formal definitions of the data. More details can be found in the text. Note that even though most sets has e_n elements, this does not imply they have the same size. The subscript n is used to denote that the set has some arbitrary but finite size.

some of its emotional-response-component intensities to zero or more mental objects that are then part of the working memory. Besides this definition, there are also the following two constraints:

$$(\forall o \in O)\,(\exists p \in P)\,(\exists x \in \mathbb{P}(W \cup V \cup I)) \text{ such that } (o \in p(x)) \tag{3.1}$$

$$\text{If } (\exists o \in PO)\,(\exists p \in P)\,(\exists x \in \mathbb{P}(W \cup V \cup I)) \text{ such that } (o \in p(x)), \text{ then } (o \in O) \tag{3.2}$$

This ensures that every object in O is the result of some perception process in P on (some part of) the input, and that every element in the image of p is an element of O. Or in other words, O is the union of all $p(x)$ where p ranges over all elements in P and x over $\mathbb{P}(W \cup V \cup I)$.

To make the intuition more clear, we will use a running example of a very simple baby [3]. Imagine that there are only two objects in the baby's world: a dog (d) and a mom (m). This means that $PW = \{d, m\}$. The baby also only has two potential mental objects: o_d and o_m, thus $PO = \{o_m, o_d\}$. Now imagine that we are in a situation in which the dog is present, hence $W = \{d\}$. Now we say that $P = \{p_s\}$, where p_s is the perception function of seeing. The function p_s is defined such that $m \in x$ if and only if $o_m \in p_s(x)$ and $d \in x$ if and only if $o_d \in p_s(x)$. Thus, p_s always maps m to o_m and d to o_d. Now, by the definition of p_s and constraints 4.1 and 4.2, we have that $O = \{o_d\}$ must hold. This means that after seeing the dog, the baby has some mental representation of the dog.

Appraisal Appraisal is modeled by the set $A = \{a_1, a_2, ..., a_n\}$, where we have that for each $a \in A$ it holds that:

$$a : \mathbb{P}(PO \cup PI) \rightarrow \mathbb{P}(PV)$$

Which means that each appraisal process $a \in A$ interprets mental objects in the context of emotional-response-component intensities and attributes appraisal dimension values to a set of (potentially other) mental objects. Where it also holds that

$$(\forall v \in V)\,(\exists a \in A)\,(\exists x \in \mathbb{P}(O \cup I)) \text{ such that } (v \in a(x)) \tag{3.3}$$

$$\text{If } (\exists v \in PV)\,(\exists a \in A)\,(\exists x \in \mathbb{P}(O \cup I)) \text{ such that } v \in a(x), \text{ then } (v \in V) \tag{3.4}$$

Similar to perception, these constraints make sure that if an appraisal exists, there must also be a responsible process with corresponding input, and vice versa.

If we now continue with the baby example, and assume that we have two appraisal dimensions, *pleasantness* and *suddenness* (thus $D = \{d_p, d_s\}$) and we have two corresponding appraisal processes ($A = \{a_p, a_s\}$). Now, the set PV is filled with all possible combinations of (o, d, r), with $o \in O$, $d \in D$ and $r \in [-1, 1]$ (since $PV = O \times D \times [-1, 1]$). We assume that the baby appraises seeing the baby as unpleasant and sudden. Thus we have that $a_p(\{o_d\}) = \{(o_d, d_p, -1)\}$ and $a_s(\{o_d\}) = \{(o_d, d_s, 1)\}$ and assume that for all other inputs x we have that $a_s(x) = \emptyset$ and $a_p(x) = \emptyset$. Now, since we had $O = \{o_d\}$, we have that $V = \{(o_d, d_p, -1), (o_d, d_s, 1)\}$. In other words, the baby has two appraisals that concern the dog: it is unpleasant and sudden.

Mediating process Mediating is modeled by the set $M = \{m_1, m_2, ..., m_n\}$, where we have that for each $m \in M$ it holds that:

$$m : \mathbb{P}(PV) \rightarrow \mathbb{P}(PI)$$

[3] This example is based on the example used by Broekens et al.

Where it holds that:

$$(\forall i \in I)\,(\exists m \in M)\,(\exists x \in \mathbb{P}(V)) \text{ such that } (i \in m(x)) \tag{3.5}$$

$$\text{If } (\exists i \in PI)\,(\exists m \in M)\,(\exists x \in \mathbb{P}(V)) \text{ such that } i \in m(x), \text{ then } (i \in I) \tag{3.6}$$

This means that each appraisal process $m \in M$ maps appraisal-dimension values to emotional-response-component identities, and if some response exists then there must also a responsible process with corresponding input and vice versa.

Suppose that our baby has two emotional responses: crying and laughing. Thus $E = \{e_c, e_l\}$. Now, similar to PV, PI consists of all (e, r) tuples, thus $PI = E \times [-1, 1]$. Assume that $M = \{m_e\}$ where it holds that $m_e(\{(o_d, d_p, -1), (o_d, d_s, 1)\}) = \{(e_c, 1)\}$, $m_e(\{(o_d, d_p, 1), (o_d, d_s, 1)\}) = \{(e_l, 1)\}$ and $m_e(x) = \emptyset$ for all other input x. This means that the if the dog is appraised as unpleasant and sudden, the baby will cry and if the dog is appraised as pleasant and sudden, the baby will laugh. Now, since we had $V = \{(o_d, d_p, -1), (o_d, d_s, 1)\}$, we have that $I = \{(e_c, 1), (e_l, 0)\}$. In other words, the baby starts to cry when he or she sees the dog.

Dependencies

Dependencies are used to describe the *structural relationships* between different elements. One of the ways these dependencies can be used, is for example to force the fact that if there is a perception process $p \in P$ that maps some event $w \in W$ to some mental object $o \in O$, there is also an appraisal process $a \in A$ that maps this o to some appraisal dimension value $v \in V$. Since we do not go into depth into this part of the model any further here, we omitted this part of the model in this thesis. For more details see (Broekens et al., 2008, p.181).

3.1.2 Remarks on the Formalization of Broekens et al.

Before moving on to extending the model with emotion regulation, we will first discuss some remarks we have on this model. The first thing that is evident is that the formalism is timeless. This means that there is no evolution of the internal state and appraisals cannot develop over time. Broekens et al. mention that this is considered to be future work (Broekens et al., 2008, p.178). We think that this is an unusual choice, since one of the general aspects of the emotion process is that it is recursive (see Section 1.2.1). To be able to capture the time aspect completely, we believe you need to be able to describe relationships within the emotion process over time. Moreover, within appraisal theory, the emotion process is seen as a schematic series of events (see also Section 1.2.1). This of course is not necessarily a process over time, but we believe that this would be the most natural formalization.

When we consider a timeless formalism from the emotion regulation from Gross' emotion regulation perspective, we believe this is even more problematic. The notion *before* and *after* are vital in Gross' theory, since differences between strategies are based on *when* some regulation strategy occurs. Even though it would in principle be possible to formalize these notions without time by describing them in structural relations, we believe this does not fully capture the phenomena. This shows how formalizing can reveal aspects of a verbal theory that do not seem to be that important when just considering the verbal theory. As can be seen later, we decided to extend the model with a (very simple) notion of time.

The second aspect that we want to point out is the relation between emotional response and emotions. As explained before, emotions are formalized as a subset of E. Joy for example, can be modeled as the set $\texttt{JOY} \subseteq E$ where JOY contains elements as $(\texttt{happyfeeling}, r), (\texttt{smile}, r)$ where $r > 0.5$. This means that Broekens et al. model emotions separate from the mental object that caused them. Even though this might be the way some appraisal theories formalized emotions, in the three cases we have seen in Chapter 1; Frijda's theory, the OCC, and Lazarus' theory, this was not the case. This is the most evident in the OCC model, where emotions are defined by what type of object elicited them. But also in the case of Frijda and Lazarus, the emotions are defined as a mapping over the appraisal variables. Since the appraisal variables are clearly related to some object, the emotions are too.

We think the notion of emotions given by Broekens et al. is closer to the notion of *mood*, which is often seen as a higher-level affective process. This also roughly corresponds with the view of Gross. In (Gross, 2011) he states:

> Emotions may also be distinguished from moods [...]. Moods often last longer than emotions, and compared to moods, emotions are typically elicited by specific objects and give rise to behavioral response tendencies relevant to this objects. (Gross, 2011, p.6)

Since emotions are still modeled as response tendencies by Broekens et al., it does not mean that their formalization is not in line with Gross' notion. Nevertheless, we believe it is more intuitive to define emotions as a subset of the appraisal patterns. There is a lot more to say about this topic, and we believe that the difference between mood and emotions deserves some research of its own. Since the difference is not crucial here, we will limit ourselves to commenting on this topic.

Besides these remarks, we also think that the model is too simple to fully capture appraisal theory. First of all, the notion lacks some connection with the rest of the agent. In particular we can not model the effect of emotions on behavior since there is no specific model of actions that can be taken by the agent. Besides this, Broekens et al. modeled almost all cognitive entities as mental objects. This means that mental objects do not only include mental representations of the objects that are perceived, but also beliefs, goals and desires of the agent. Moreover, most cognitive processes are formalized as perception processes, such as $\texttt{inductive\_reasoning} \subseteq P$. Even though this does allow for a very flexible use of the formalization, we believe that this also largely ignores a lot of structural relations between emotions and other parts of cognition that are vital in understanding the emotion system. An example of a formalization in which these relations are defined into more detail is (Steunebrink, 2010). Nevertheless, the fact that this model is fairly simple, makes it very suitable for the aim of this chapter, since it allows for a relatively simple but detailed illustration of how a formalization can be extended with a notion of emotion regulation.

3.1.3 Adding Emotion Regulation

We would like emotion regulation to have an influence on the actual situation (W, V, O, and I). Since Broekens et al. build a whole structure around processes and how these influence these sets, we believe it is more suitable to let most emotion regulation strategies influence the situation indirectly, by influencing the processes. In a way, this means we see emotion regulation as a sort of *meta process*, since it is a process that influences processes that influence the situation.

Before we go to the formal definitions of the regulation strategies, we first make some extensions to the model. We will first extend it with potential processes, then extend with a notion of time and finally extend the model with notion of emotion regulation.

Adding potential processes

We first extend the model with potential processes. The reason for this is twofold: firstly, we want let emotion regulation strategies influence the processes by adding or removing certain processes from the current set. In the case of our baby, for example, the baby could perform some attentional deployment strategy by closing its eyes. This results that $p_s \notin P$, but we do want to have the definition of p_s somewhere to make this possible. Secondly, we want to extend the model with a notion of time, and since the processes can change over time we need sets that contain all possible processes.

Below, the formal definitions of these sets are given.

Definition 1. *The set* $PP = \{p_1, p_2, ...p_n\}$[4] *is the set that contains all potential perception processes available to the agent, where we have that* $P \subseteq PP$.

Definition 2. *The set* $PA = \{a_1, a_2, ...a_n\}$ *is the set that contains all potential appraisal processes available to the agent, where we have that* $A \subseteq PA$.

Definition 3. *The set* $PM = \{m_1, m_2, ...m_n\}$ *is the set that contains all potential mediation processes available to the agent, where we have that* $M \subseteq PM$.

Adding Time

As said before, we think it is important that the model is extended with a notion of time. Formalizing time is a research area on its own (see e.g. (van Lambalgen & Hamm, 2008) for some overview and interesting perspective on the matter). Here, we choose to use a very flexible but simple and popular way of doing this. We modeled the time as a set together with a linear order on this set. This intuitively implies we think of a time line, which means that we can always talk about how different moments in time relate to each other. The formal definition is given below:

Definition 4. *The set* $T = \{t_1, t_2, ...\}$ *is a set of time points and the relation* $\leq$ *is a linear order (total, reflexive, anti-symmetric, and transitive) over* T. *For example, we could use* $T = \mathbb{N}$ *and let* $\leq$ *be the standard definition of* $\leq$ *defined over* $\mathbb{N}$.

The idea behind the extension is as follows: at every time point $t \in T$, we have an instance of the static situation such as defined in the original model of Broekens et al (See Figure 3.2). In this

[4] In the formalization of Broekens et al. the name *PP* is already used. But since we do not use that part of the formalization here, we decided to use it anyway so that the names of the sets are consistent

way, we will be able to not only define functions and relationships within *one* static situation, but also *over time* between different static situations. To formalize this idea, we introduce the following functions:

Definition 5. *We define the functions Ω^W, Ω^P, Ω^O, Ω^A, Ω^V, Ω^M and Ω^I as follows:*

$$\Omega^W : T \to \mathbb{P}(PW)$$
$$\Omega^P : T \to \mathbb{P}(PP)$$
$$\Omega^O : T \to \mathbb{P}(PO)$$
$$\Omega^A : T \to \mathbb{P}(PA)$$
$$\Omega^V : T \to \mathbb{P}(PV)$$
$$\Omega^M : T \to \mathbb{P}(PM)$$

Given some time-point $t \in T$, $\Omega^X(t)$ will represent the set X at time-point t, where $X \in \{W,P,O,A,V\}$. For simplicity, we will use X_t to denote $\Omega^X(t)$. Thus, V_t is the set V at time t.

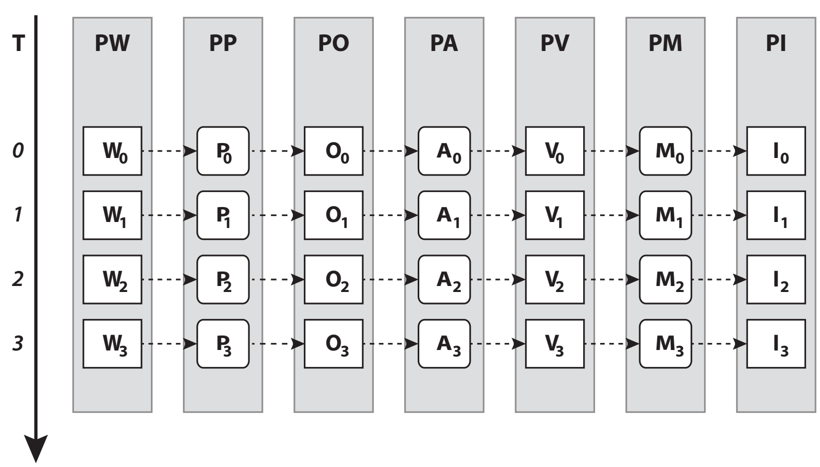

Figure 3.2: A graphical representation of our extension with time. Instead of just one situation, we defined $|T|$ many representations ordered at which time t they occur. This makes it possible to also define constraints between certain situations *over* time.

Now we do not have *one* set W, but $|T|$ many sets. This means that we need to adapt all definitions introduced so far. This can be done in a very straightforward manner, since the constraints given remain to hold within one situation at some point $t \in T$. Concretely, this means that we can replace all occurrences of W, P, O, A, V and M with W_t, P_t, O_t, A_t, V_t and M_t respectively. Constraints 4.3 and 4.4, for example, will be adapted as follows:

$$(\forall t \in T)(\forall v \in V_t)(\exists a \in A_t)(\exists x \in \mathbb{P}(O_t \cup I_t)) \text{ such that } (v \in a(x))$$
$$\text{If } (\exists t \in T)(\exists v \in PV)(\exists a \in A_t)(\exists x \in \mathbb{P}(O_t \cup I_t)) \text{ such that } v \in a(x), \text{ then } (v \in V_t)$$

At this moment, we have decided to not add any other constraints between sets over time. We could do this by, for example, adding constraints between V_t and V_{t-1}, to describe how appraisals change over time. We consider this to be very interesting future work.

The domain of the regulation strategies

As said before, we will model emotion regulation strategies as processes. To follow the approach of Broekens et al. this means that we model the strategies as functions. Therefore, we need to define the domain and codomain of these functions.

When we consider Gross' theory, we believe it is the most straightforward to state that emotion regulation strategies arise from beliefs and desires (PO), emotions (PV) and emotional responses (PI). For this reason, we will define every emotion regulation strategy as a function from $\mathbb{P}(PO \cup PV \cup PI)$ to some other set.

Here, the beliefs and desires could come from the set O_t at the same time as when the regulation strategy is defined. But, the emotional responses, appraisal dimensions and some (other) mental objects should come from some situation at time $t' < t$. For simplicity, we defined that all these objects come from the same situation t'. Extending this to make sure these objects can come from multiple situations before t is relatively straightforward, it would just make the definitions rather cumbersome here.

Note that, as we also saw in the formalization of Bosse et al. (Bosse, Pontier, & Treur, 2007), this aspect of emotion regulation, which we believe can be summarized as the answer to the question: 'what is causing people to regulate their emotions?', has not been discussed in much detail in Gross' theory. To keep multiple interpretations of this question open, we have decided for this rather general and unrestricted formalization.

The codomain of the regulation strategies

In contrast to the regular processes (P, A, M), we would like the regulation strategies to not completely define the other processes or data in some situation. Recall that O, for example, is defined as the union of all perception processes in P on some subset of the current situation. This implies that if there is no perception process, there are no objects in O. This is not a feature we want for the regulation strategies: even though there are no attentional deployment strategies active at time t, this doesn't mean that there are no perception processes active. We think this is in line with Gross' theory, since he states that we have the ability to regulate our emotions, but this doesn't mean we always do so. To model this, we cannot use the same kind of constraints that are used at the other processes, since the processes and their domain completely define the next set.

What we want to model here, is that regulatory processes not only force certain processes to be active (which means to be in P, A or M) but also to force some of them to be not active. Remember that p_s modeled the perception process of seeing in the baby example. Now, imagine the case in which baby could close its eyes as a form of attentional deployment, we want a attentional deployment process to force that $p_h \notin P$.

We modeled this in the following way. The output of every regulation process is a product of two sets. This means that if we have a regulation process r on some input x, then we have that $r(x)$

is a tuple that contains two sets. Thus $r(x) = (i, o)$, where it holds that if $p \in i$ then we want this process p to be active (so $p \in P \cup A \cup M$) and if $p \in o$ we do *not* want this process to be active (so $p \notin P \cup A \cup M$).

Formally this means that all regulation strategies are defined as a function from $\mathbb{P}(X) \rightarrow \mathbb{P}(Y) \times \mathbb{P}(Y)$, with X the union of all sets that influence this strategy and Y being the sets that this strategy influences.

Situation selection and modification

As can be seen in Figure 3.3, we formalized both situation selection and situation modification as functions that change W_t based upon some situation before. In contrast to the other regulation strategies, situation selection and modification directly influence a data set. The reason for this is that there is no elaborate formalizations of actions that can influence the environment. Moreover, since the model of Broekens et al. does not have a very elaborate model of the world, we made no formal distinction between situation selection and situation modification here.

We first formally define a set that contains all possible situation selection and modification strategies:

Definition 6. *$PSI = \{si_1, si_2, ..., si_n\}$ is the set of all possible situation selection and situation modification strategies that are available to the agent. It holds that for all $si \in PSI$ we have that*

$$si : \mathbb{P}(PO \cup PV \cup PI) \rightarrow \mathbb{P}(PW) \times \mathbb{P}(PW)$$

Secondly, we define a function Ω^{SI}, similar to other Ω functions we have defined before, that given some $t \in T$, describes which situation selection and modification strategies are active at that moment.

Definition 7. *$\Omega^{SI} : T \rightarrow \mathbb{P}(PSI)$ is a function that given some time point $t \in T$ describes the situation selection and situation modification strategies for the agent at time t. We will use SI_t to denote $\Omega^{SI}(t)$. For all $t, t' \in T$ with $t' < t$ we have that:*

If $(\exists w \in PW)\,(\exists si \in SI_t)\,(\exists x \in \mathbb{P}(O_{t'} \cup V_{t'} \cup I_{t'} \cup O_t))\,(\exists i, o \in \mathbb{P}(PW))$ *such that* $(si(x) = (i, o))$
then, if $(w \in i))$*, then* $(w \in W_t)$
and, if $(w \in o)$*, then* $(w \notin W_t)$

As explained before, this constraint makes sure that some elements are added to the world and some are deleted. It does allow for the fact that if there are no situation selection or modification processes (thus $SI = \emptyset$) there could still be some elements in the world ($W \neq \emptyset$ could hold). Moreover, these strategies are influenced by the beliefs the agent a t time t (hence time O_t) and some situation that happens before $t' < t$.

Attentional deployment

We modeled attentional deployment as influencing the perception process. As can be seen in Section 1.3.2, attentional deployment does not change the situation but tries to change the emotional impact instead. For example, imagine our baby that closes its eyes. So at time t, attentional deployment influences the perception processes, based upon the situation before $(t' < t)$.

Similar to situation selection and modifications, we first formally define all possible attentional deployment strategies.

Definition 8. *$PAD = \{ad_1, ad_2, ..., ad_n\}$ is the set of all attentional deployment strategies available to the agent. It holds that for all $ad \in PAD$ we have that*

$$ad : \mathbb{P}(PO \cup PV \cup PI) \rightarrow \mathbb{P}(PP) \times \mathbb{P}(PP)$$

Then, we formally define Ω^{AD} as a function that, given some time t, defines the attentional deployment strategies at time t.

Definition 9. *$\Omega^{AD} : T \rightarrow \mathbb{P}(PAD)$ is a function that given some time point $t \in T$ describes the attentional deployment strategies for the agent at time t. We will use AD_t to denote $\Omega^{AD}(t)$. For all $t, t' \in T$ with $t' < t$ we have that:*

If $(\exists p \in PP)\,(\exists ad \in AD_t)\,(\exists x \in \mathbb{P}(O_{t'} \cup V_{t'} \cup I_{t'} \cup O_t))\,(\exists i, o \in \mathbb{P}(PP))$ *such that* $(ad(x) = (i, o))$
then, if $(p \in i))$*, then* $(p \in P_t)$
and, if $(p \in o)$*, then* $(p \notin P_t)$

Here, we again have the constraint that makes sure that some perception processes are part of P_t and some are *not* part of P_t.

Cognitive change

As can be seen in Section 1.3.2, cognitive change strategies modify the way an individual thinks about a situation. This includes both reappraisal and, for example, changing its beliefs or goals about a situation. Therefore, at a point t, cognitive change can influence both A_t (reappraisal) or O_t (which includes the beliefs and desires of the agent) based on some situation before $(t' < t)$.

Below, we give a formal definition of cognitive change. This definition is very similar to the one of attentional deployment, only including two constraints, since the output could both be an appraisal process or a mental object.

Definition 10. *$PCC = \{cc_1, cc_2, ..., cc_n\}$ is the set of all cognitive change strategies available to the agent. It holds that for all $cc \in PCC$ we have that*

$$cc : \mathbb{P}(PO \cup PV \cup PI) \rightarrow \mathbb{P}(PA \cup PO) \times \mathbb{P}(PA \cup PO)$$

Definition 11. *$\Omega^{CC} : T \rightarrow \mathbb{P}(PCC)$ is a function that given some time point $t \in T$ describes the attentional deployment strategies for the agent at time t. We will use CC_t to denote $\Omega^{CC}(t)$. For all*

$t,t' \in T$ with $t' < t$ we have that:

If $(\exists a \in PA)\,(\exists cc \in CC_t)\,(\exists x \in \mathbb{P}(O_{t'} \cup V_{t'} \cup I_{t'} \cup O_t))\,(\exists i,o \in \mathbb{P}(PA \cup PO))$ *such that* $(cc(x) = (i,o))$
then, if $(a \in i))$*, then* $(a \in A_t)$
and, if $(a \in o)$*, then* $(a \notin A_t)$
If $(\exists mo \in PO)\,(\exists cc \in CC_t)\,(\exists x \in \mathbb{P}(O_{t'} \cup V_{t'} \cup I_{t'} \cup O_t))\,(\exists i,o \in \mathbb{P}(PA \cup PO))$ *such that* $(cc(x) = (i,o))$
then, if $(mo \in i))$*, then* $(mo \in O_t)$
and, if $(mo \in o)$*, then* $(mo \notin O_t)$

Response modulation

As can be seen in Section 1.3.2, response modulation includes all strategies that influence responses to the emotion. We modeled this by letting response modulation influence the mediation process, which is responsible for the emotional response of the agent.

Below, we give a formal definition of response modulation. This formalization is very similar to the ones given above.

Definition 12. *$PRM = \{rm_1, rm_2, ..., rm_n\}$ is the set of all cognitive change strategies available to the agent. It holds that for all $rm \in PRM$ we have that*

$$rm : \mathbb{P}(PO \cup PV \cup PI) \rightarrow \mathbb{P}(PM) \times \mathbb{P}(PM)$$

Definition 13. *$\Omega^{RM} : T \rightarrow \mathbb{P}(PRM)$ is a function that given some time point $t \in T$ describes the attentional deployment strategies for the agent at time t. We will use RM_t to denote $\Omega^{RM}(t)$. For all $t,t' \in T$ with $t' < t$ we have that:*

If $(\exists m \in PM)\,(\exists rm \in RM_t)\,(\exists x \in \mathbb{P}(O_{t'} \cup V_{t'} \cup I_{t'} \cup O_t))\,(\exists i,o \in \mathbb{P}(PM))$ *such that* $(rm(x) = (i,o))$
then, if $(m \in i)$*, then* $(m \in M_t)$
and, if $(m \in o)$*, then* $(m \notin M_t)$

Example

After introducing all this technical machinery, it is time to illustrate what we can do with this extension by giving a simple example. Remember the baby example sketched in Section 3.1: We had a baby that had one object in the world, namely a dog (d), one perception process seeing (p_s), that maps the dog d to a mental object o_d. The constraints of the model enforce that this is the only object in the working memory. Then, we had two appraisal processes, that corresponded to the dimensions *pleasantness* and *suddeness* (a_p and a_s) such that the object o_d will be appraised as unpleasant $(o_d, d_p, -1)$ and sudden $(o_d, d_s, 1)$. These are also the only appraisal values of the baby. Finally, we have one mediating process (m_e), that maps these appraisals to one response, crying $(e_c, 1)$. Hence, the baby started crying as a response to seeing the dog.

Now, we make this the situation at time $t = 0$ (see Figure 3.4). This means that $\Omega^W(0) = W_0 = \{d\}$, $\Omega^P(0) = P_0 = \{p_s\}$, etc. Now, to illustrate the added machinery, we describe two possible

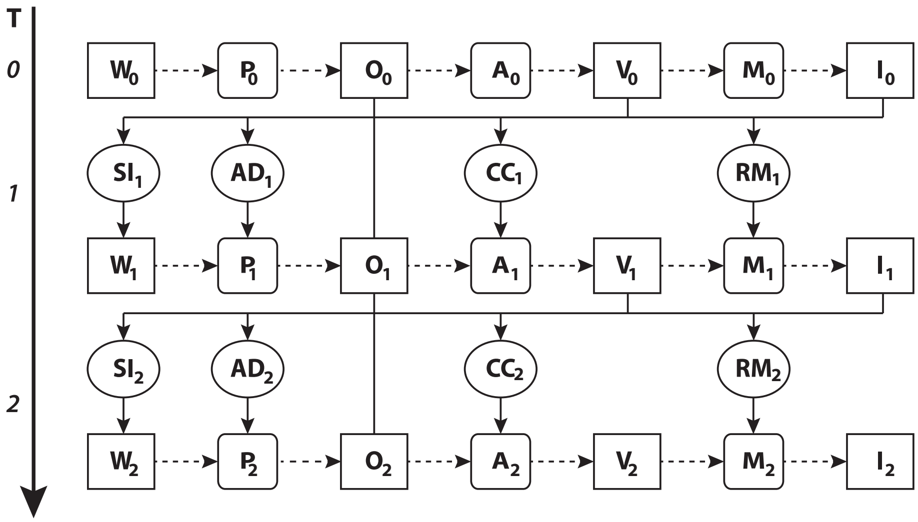

Figure 3.3: A graphical representation of the extension of the model of Broekens et al. with emotional regulation. More details can be found in the text. Note that the representation is slightly simplified, since it supposes SI_2 must be influenced by O_1, V_1 and I_1. But this could also be O_0, V_0 and I_0 for example.

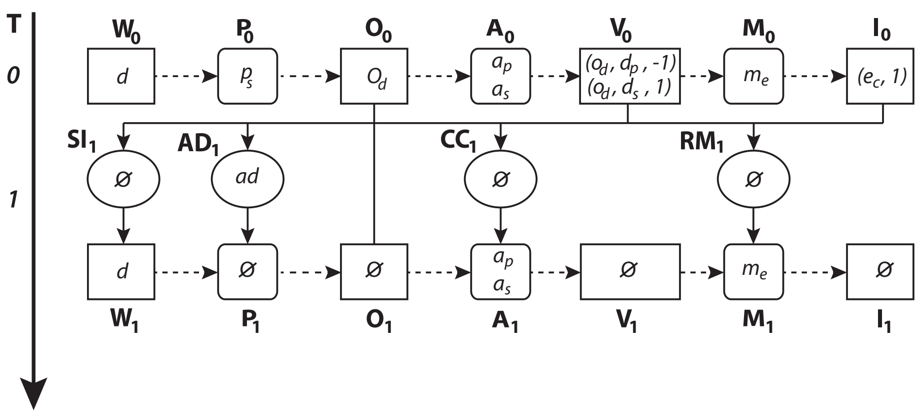

Figure 3.4: A visualization of the first example.

scenarios, the baby adopting an attentional deployment strategy and the baby adopting a cognitive change strategy.

We will first model the action of the baby that closes his or her eyes (see Figure 3.4). Let ad be attentional deployment strategy available to the baby, so $ad \in PAD$. Moreover, we have that $ad(O_0 \cup P_0 \cup I_0) = (\emptyset, \{p_s\})$ and for all other x, $ad(x) = \emptyset$. Now, we have that $AD_1 = \{ad\}$. This means that no perception process is added, but the process representing seeing (p_s) is deleted from the situation. So $P_1 = \emptyset$, even if we assume that the dog is still there (so $W_1 = \{d\}$). But by the way the model is built and the processes are defined, this means that all the other data sets at $t = 1$ are also empty. In other words, the baby stops crying and does not respond to the dog anymore.

In the second example, we start with the same situation, only in this case we have that the baby reappraises the situation (see Figure 3.5). Let cc be an cognitive change strategy that is available to the the baby. This means that we have that $cc \in PCC$. Furthermore, we have that $cc(O_0 \cup P_0 \cup I_0) = (\{a'_p\}, \{a_p\})$ and for all other x, $cc(x) = \emptyset$. This means that the appraisal process that mapped the dog as being unpleasant (a_p) is replaced by a new appraisal process (a'_p) that appraised the dog as being pleasant. In particular we have that, $a'_p(\{o_d, (e_c, 1)\}) = (\{(o_d, d_p, 1)\})$. This means that we get that $A_1 = a'_p, a_s$ which means that $V_1 = \{(o_d, d_p, 1), (o_d, d_s, 1)\}$. From the way we defined m_e before, we get that $I_1 = \{(e_l, 1)\}$. In other words, the baby starts laughing when seeing the dog.

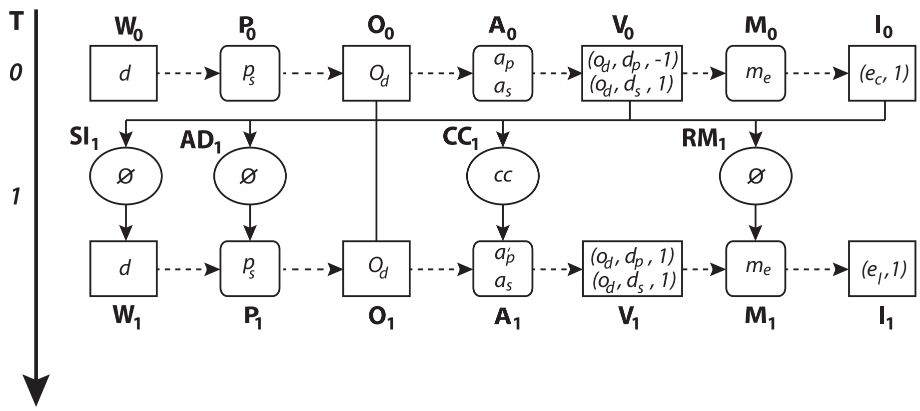

Figure 3.5: A visualization of the second example.

Conclusion

In this section, we have introduced and expanded the model of Broekens et al. This model is a descriptive or computational level model[5], which means that it can be used to describe rather than explain the emotion process. To extend the model with a notion of emotion regulation, we have first expanded the model with a notion of time. This shows that time is a very important aspect of Gross' notion of emotion regulation. One of the insights this formalization gave us is that this is a possible distinguishable feature of Gross' theory. Moreover, we have modeled emotion regulation as some sort of meta process. As said before, we believe that this corresponds to the way Gross defines emotion regulation, since these strategies work on emotions. This insight teaches us more about how we can interpret Gross' notions in a more mathematical or formal way.

Besides the insights given above, we believe more can be learned from this. First of all, the way we have extended the model of Broekens et al, can be used as a starting point to extend more complex formalizations of the emotions process, such as for example (Steunebrink, 2010). Moreover, since we now have a more mathematical notion of emotion regulation, we can do a

[5]Not to be confused with a computational model, see Section 2.1

complexity analysis (see Section 2.2), to analyse how cognitive plausible this model is or use it as a base for building a computational model.

In the next section we will introduce and expand a more complex model: EMA.

3.2 EMA

In contrast with the model of Broekens et al., EMA is a computational model in the form of a working computer application. EMA is developed by Jonathan Gratch and Stacy Marsella at the computational Emotion Group at the University of Southern California. As also mentioned in the previous Chapter, the name EMA is based upon the title of the book by Lazarus: EMotion and Adaptation, which indicates that their model is mainly based upon the theory of Lazarus. The aim of EMA is twofold: trying to understand human cognition better and building virtual humans. This makes this model an excellent example of work within affective computing, since it embodies the two main goals of affective computing.

EMA is a rich and detailed model. We will not go into every detail of the model here, but we will focus on the parts that are important when expanding the model with a notion of emotion regulation.

What is important to note here is that although EMA is a detailed model, the amount of literature on the details is very limited. Therefore, it is difficult to give concrete suggestions to adapt, improve, or extend the model. For this reason, the suggestions in this section will remain rather general and abstract. Nevertheless, we believe this still shows how Gross' theory can be used to advance models within affective computing. Moreover, we think EMA is one of the most detailed and advanced models of emotion within affective computing and for that reason we believe it is important to include this model in this thesis.

3.2.1 Details of EMA

In Figure 3.6, you can see the general process of EMA. The EMA algorithm can be seen in Table 3.2. It is prominent that EMA is based upon the theory of Lazarus, since we can observe many similarities between the two. Besides the appraisal and emotion mappings, compare for example Figure 3.6 with Figure 1.7.

Causal interpretation

One of the most important parts of EMA is the *causal interpretation*. This is the agent's interpretation of the agent-environment relationship (as defined by Lazarus as the *situational construal*, see Section 1.2.2) and is the current mental state concerning past, present, and future desires or actions (see Figure 3.7). This concept is based on a mixture of symbolic and numerical representations that are common within AI, including STRIPS (Fikes & Nilsson, 1971) and ideas from BDI (Bratman, 1987). The causal interpretation is divided within *past events*, the *current world description (CWD)* and the *possible future outcomes*.

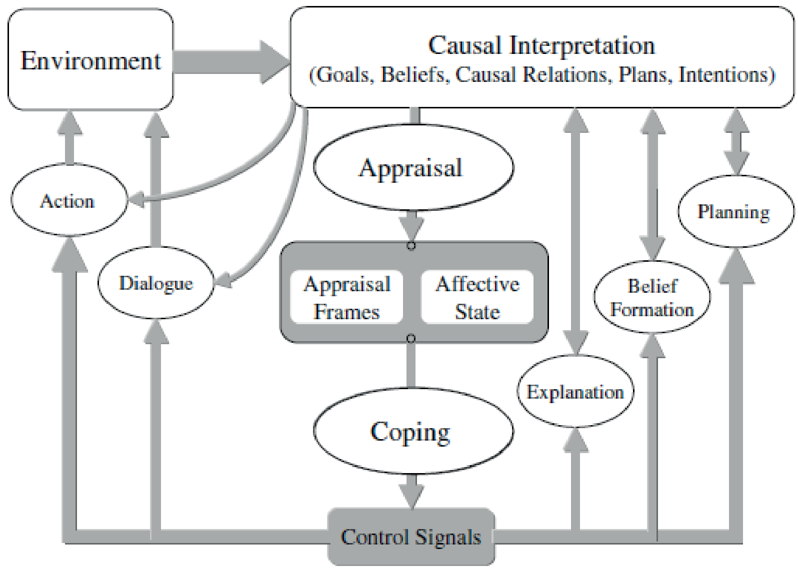

Figure 3.6: The computational instantiation of EMA, from (Gratch & Marsella, 2004a, p.278).

The EMA algorithm	
1.	Construct and maintain a causal interpretation of ongoing world events in terms of beliefs, desires, plans, and intentions.
2.	Generate multiple appraisal frames that characterize features of the causal interpretation in terms of appraisal variables.
3.	Map individual appraisal frames into individual instances of emotions.
4.	Aggregate emotion instances into a current emotional state and overall mood.
5.	Adopt a coping strategy in response to the current emotional state.

Table 3.2: The EMA algorithm, adapted from (Gratch & Marsella, 2004a, p.280).

The CWD is a conjunction of propositions that hold in the current situation. For example, the CWD of the situation of Figure 3.7 could be:

`¬injured ∧ U-Have ∧ U-raised ∧ bird-approach ∧ striking-distance`

All (possible) actions of the agent are represented with preconditions and effects (based upon the STRIPS formalism (Fikes & Nilsson, 1971)). This means that executing an action will require some propositions to be in the CWD, and will then add and delete certain propositions with a certain probability (indicating actions can fail). Moreover, relations between actions and states are represented with causal links. States and actions have some decision-theoretic annotations, including *utilities* to represent the agent's preference and *probabilities* to denote the agent's certainty in the truth-value.

Note that since in the actions only the things that are changed are defined, in the CWD everything that is not true also needs to be defined. This means that even if there is no sound, $\neg$ `sound` must be part of the CWD. But since there are an infinite number of things that are *not* the case in a certain situation, the CWD should contain an infinite number of propositions that should be defined in advance. This is problematic and, as also pointed out by Marsella and Gratch, an aspect of the *Frame Problem* (McCarthy & Hayes, 1969). More generally, the frame problem in AI[6] can be summarized as how to describe everything that is not affected by actions when we have a dynamic domain. Marsella and Gratch say the following about this:

> ”This is an aspect of the frame problem [...] and there are a number of standard approaches for addressing it and which could be incorporated into EMA. (S. C. Marsella & Gratch, 2009, footnote 9)

Even though we agree that there are several solutions to this version of the frame problem, such as Default Logic or minimizing Abnormalities (see (Lifschitz, 2015)), we do think this is an issue of EMA that should be addressed into more detail. Especially since most solutions require a different way of drawing inferences, which will lead to other types of behavior (see (Stenning & van Lambalgen, 2011), for an introduction to the relation between different kinds of logic and cognition). So we believe that incorporating one of these standard approaches into EMA, should have a high priority.

Cognitive operators

As said before, EMA is built upon the cognitive operator SOAR (Newell, 1990). In EMA, mental processes are organized using a set of primitive cognitive operators that use and update the current causal interpretation. This happens by keeping track of changes in perception, creating new inferences, initiate or terminate actions and retract or adopt commitments. For more detailed information about this, see (Gratch & Marsella, 2004a; S. C. Marsella & Gratch, 2009).

Appraisal frames

After the causal interpretation is constructed, appraisal frames are associated with each proposition (see Figure 3.7). The aim of the appraisal frame is to continuously associate a set of appraisal variables with each proposition. See Table 3.3 for an overview of the appraisal variables. As can be seen in Appendix C, these are very similar to the variables that are described by Lazarus.

Every appraisal frame is also mapped to some emotion. This mapping is inspired by Lazarus' theory. For example, if `expectedness` is `low` and `perspective` is `self`, the appraisal frame gets the emotion *surprise*. Or, when the `desirability of another` is smaller than 0 and the `causal attribution` is `self`, the emotion *guilt* is mapped to this appraisal frame. An overview of this can be found in (Gratch & Marsella, 2004b).

[6]Not to be confused with the broader philosophical problem concerning the epistemological issues concerning human cognition, as for example defined by Dennett (Dennett, 1996)

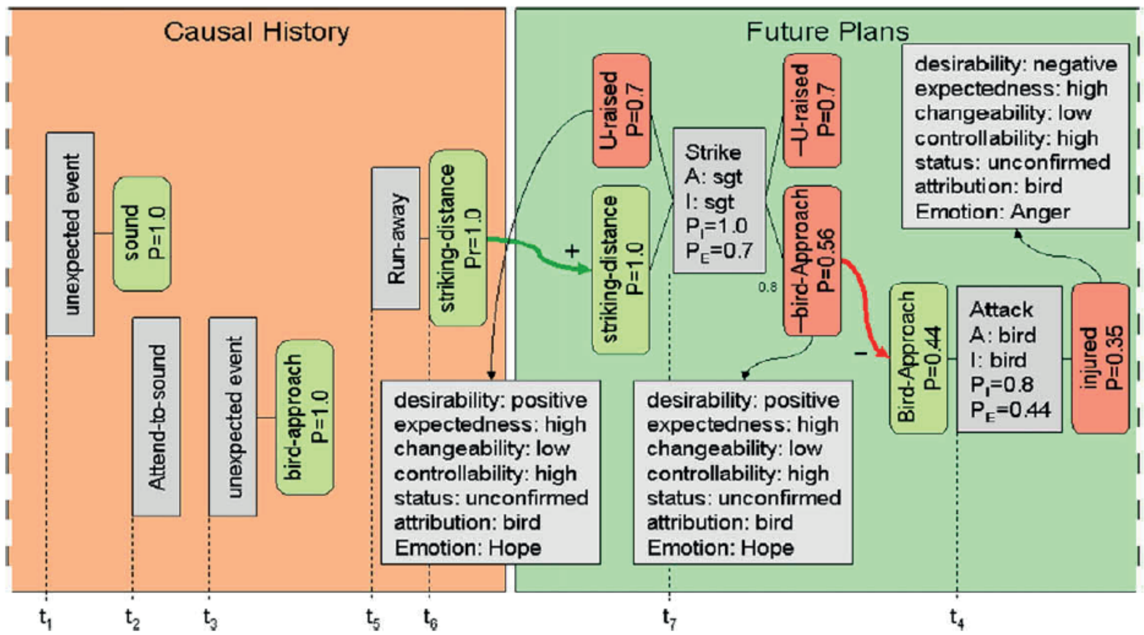

Figure 3.7: The causal interpretation at the moment an agent starts to plan. In this example, an agent (`sgt`) that is holding an umbrella was confronted with a bird that flew through the window. As response to this, she just ran away. Right now, she is planning to strike the bird, but this would possible lead to the bird attacking the agent. As can be seen, appraisal frames and their mapped emotion are connected to propositions in the future plans. From (S. C. Marsella & Gratch, 2009, p.88).

Appraisal variables within EMA	
`Relevance`	The significance of an event, either true or false.
`Perspective`	From whom some event is judged.
`Desirability`	Whether the proposition is desirable or undesirable.
`Likelihood`	The certainty of whether some event is going to happen.
`Expectedness`	To which extend it could have been expected.
`Causal attribution`	Who deserves credit or blame.
`Controllability`	To which extend the outcome can be controlled by the agent.
`Changeability`	To which extend the proposition can be altered by some agent.

Table 3.3: The appraisal variables defined in EMA. For more details, see (S. C. Marsella & Gratch, 2009, p.80).

When building a concrete model of appraisal and emotion, one needs to know what type of process appraisal is. Is it relatively slow, sequential and deliberate or fast and automatic, or some combination of both? Here we can find another example that shows that theories of emotions are often not detailed enough to completely build computational models based on them. While Lazarus did specify the appraisal variables, he did not specify what type of process appraisal is. This means that when building a model, you need to make some strong assumptions about this. Gratch and Marsella adopted the assumption that appraisal is fast, parallel, and automatic (S. C. Marsella & Gratch, 2009, p.80).

Mood

Besides appraisal frames and corresponding emotions, a second level of emotional state is used within EMA. The appraisal frames are combined into a higher-level *mood*. This mood represents a summary of various appraised events, but is disassociated from the original eliciting event. Since this formalization of mood is a combination of emotions, it tends to change slowly over time. The mood is represented as a set of emotion labels paired with an intensity. In EMA both appraisal frames and mood are influencing emotional effects and coping behavior.

Coping

Another fundamental aspect of EMA and the main reason we examine it here, is that it integrates a notion of coping. Although Gratch and Marsella claim that their notion of coping is based on Lazarus theory, they also make the comment that they "move away from the broad distinction between problem-focused and emotion-focused strategies more commonly used in coping literature" (S. C. Marsella & Gratch, 2009, p.83). The main argument they give for this is that they believe this distinction is too ambiguous when making concrete coping strategies (S. C. Marsella & Gratch, 2009, p.83).

Gratch and Marsella have organized strategies in terms of their impact on the agent's *attentions*, *beliefs*, *desires*, or *intentions*. Wishful thinking is for example a strategy that falls under belief-related coping, and action selection or avoiding under intention-related coping. All coping strategies can be found in Appendix C. Note that, even though Marsella and Gratch moved away from the original distinction defined by Lazarus, they still distinguish between *what* is influenced by the strategy, in contrast to Gross' theory in which strategies are grouped by *when* they influence the process (see Section 1.4.3).

Coping determines, from moment to moment, how the agents responds to the appraised significance of the events. As can be seen in the following quote, Marsella and Gratch follow the same definition of coping as given by Lazarus:

> "Within EMA, coping strategies are proposed to maintain desirable or overturn undesirable in-focus events." (S. C. Marsella & Gratch, 2009, p.82)

This means that coping is mainly used to decrease negative affect and increase positive affect (see discussion in Section 1.4.3). As explained before, Gross' notion is more general than that and also includes strategies that try to increase negative emotions and decrease positive emotions. For this reason, we think EMA could benefit from incorporating Gross' notion.

3.2.2 Improvements

Similar to the model of Broekens et al., we will give some suggestions of how we can extend or enrich EMA based on the ideas of Gross. As explained above, these suggestion will remain rather general, but there will be a stronger focus on what we could do with these extensions.

When versus what

Marsella and Gratch point out that coping strategies define a space of atomic actions that could (immediately) be applied by the cognitive operators of EMA. Once chosen, these atomic actions will be added to the causal interpretation as plans or intentions. One of the processes that can be influenced by emotion regulation, is the selection of actions that are actually being executed. Unfortunately, Marsella and Gratch do not provide enough details to give any concrete suggestions how this process could be adapted. To still give some suggestions, we will make the following two general assumptions:

1) Every coping / regulation strategy is annotated with the type of strategy it belongs to. For example, when the strategy 'silver lining' is added as a potential atomic action, we know this is a desire-related coping strategy.

2) We assume that appraisal frames and moods 'activate' potential coping / regulation strategies. This concretely means that they are added as a potential plan to the causal interpretation. Which action is eventually executed depends on the causal interpretation as a whole.

As said above, in EMA the regulation strategies are ordered by *what* they try to influence, while Gross distinguishes *when* or *at which point* the process interferes the emotion regulation process. We propose to group the strategies in a matrix, and combine these two views together. Now every strategy does not only have a marker of *what* it influences (such as a belief or attention) but also *which part* of the process it influences. For example, while avoiding and faking a smile are both intention-related, avoiding falls under situation selection and faking a smile under response modulation.

We believe that there are many useful applications of this extension. First of all, this more fine grained distinction could help to make the response to certain events more human-like, resulting in a more realistic virtual human. Moreover, it becomes easier to add a form of personality to the model. To achieve this, personality variables can be added to the causal interpretation which make certain types of strategies to be more likely to actually be executed than others. This corresponds to the fact that different people have different ways of dealing with their emotion (Gross, 2002).

In particular, there is a lot of literature on which strategies are more successful than others. In (Gross, 2001) it is found, for example, that antecedent-focused regulation strategies are more successful than response-focused regulation strategies. This type of findings could be investigated in more detail using EMA. It could, for example, be investigated whether these tendencies emerge naturally or whether it is something that is learned from the environment. This type of research is difficult to conduct among humans, so finding more about this with EMA would really have scientific value.

Another very interesting thing that could be investigated is how changing personal preferences influence the intensity of emotions. This could give more insight into the human emotion system, but could also help to set up therapy to help people handle emotions in a better way. In (Gross, 2002), it is pointed out that even though it is well known that emotion dysregulation is a prominent feature of many forms of personality disorders, the link between affective science and clinical science is not often made (Gross, 2002, p.288). EMA could help to develop knowledge about how emotion regulation could provoke certain symptoms and what are possibly effective methods to treat them.

Finally, since now the model incorporates both the ideas of Gross and Lazarus about coping and emotion regulation, the differences between these two theories could be investigated. In particular, the claims we made in section 1.4.3, could be investigated in more detail. We think especially this last option is a very interesting way to extend this research.

Regulation

Another idea by Gross that could be used in EMA is to not only increase positive and decrease negative emotions, but also to decrease positive and increase negative emotions. We believe the ideas of Bosse et al. of the previous Chapter are very suitable for this. In (Bosse, Gratch, & Hoorn, 2010), this idea is also proposed. We think it would be even more interesting is if we also add the notion of ERL_{sit} (see Section 2.4).

The notions ERL_{norm} and ERL_{sit} could be added as variables to the causal interpretation. Now, ERL_{norm} would be influenced by personality factors and ERL_{sit} by the situation. As also explained in section 2.4, this balance could play an important role in determining which strategy is actually executed.

Besides all the advantages similar to the ones proposed in the subsection above, adding this to EMA could help to investigate whether the assumptions made by Bosse et al. result in actual human-like behavior. This is especially interesting, since they make an attempt to fill some holes in the theory that are underspecified. In other words, the results of this research could be reported back to psychologists who work on theories of emotions. This kind of feedback loops are exactly the methods proposed in (Reisenzein et al., 2013), that can help to improve the inter- and intradisciplinary exchange that can help to advance the field of affective computing.

3.2.3 Conclusion

In this section, we have introduced EMA, a computational model in the form of a working computer application developed by Gratch and Marsella. EMA is one of the most rich and detailed models within affective computing, but also lacks some documentation concerning the details of the implementation. As pointed out above, we believe that one important aspect that should be discussed into more detail, is the way the frame problem will be fixed within the model.

We proposed two extensions to EMA, first to divide the strategies by both *what* is affected and *when* the process is regulating the situation. Second to add the expanded formalism of Bosse et al. from the previous Chapter to also decrease positive emotions and increase negative emotions.

We gave several reasons why these extensions could be interesting. For example to improve the human-like behavior of EMA but also to test new experimental therapies regarding emotional regulation disorders. Finally, we believe that extending EMA in this way could solve several debates and gaps that occur in de psychological theories of emotion.

3.3 Conclusion

In this final Chapter we have introduced two models of emotion, EMA and the formalization of Broekens et al. The first was a computational model in the form of a computer application, the second a formalization in set theory of appraisal theory. By extending these two very different models, we have showed how the ideas introduced in the other chapters of this thesis could be applied to several types of models. Moreover, we did not only extend two very different models, we also used a very different approach to extend both models. We believe we showed how these ideas introduced in this thesis can be applied in very different ways. In particular, we have proposed to extend EMA in such a way that the emotion regulation vs coping debate could be investigated into more detail. Finally, we have showed how these extensions could improve these models and affective computing as a whole and proposed several ways this research could be continued.

Conclusion

In this thesis we have tried to advance the field of computational modeling of emotions by using Gross' theory of emotion regulation. In the introduction we have stated the research question of this thesis:

How can the theory of emotion regulation as defined by Gross help to advance the field computational emotion modeling?

We believe that the main way the field of computational modeling can be advanced is by addressing the two main problems that are in the field today: (1) the fragmented field of emotion theory and (2) the lack of incremental research. To make these two approaches precise, we have formulated the following two sub-questions:

- *How does Gross' theory fit into the theoretical landscape of emotion theory?*
- *How can we adapt or extend an existing model of emotion with the notion of emotion regulation as formulated by Gross?*

In Chapter 1 we have focused on the first sub-question. Here, we have seen that the theory by Gross fits best into the field of appraisal theory. We have found that Gross' theory and appraisal theory are compatible. This means that models based on appraisal theory can be extended with the notion of emotion regulation by Gross without the risk that there are theoretical contradictions on this aspect of the model. Moreover, this implies that the theoretical research in emotion regulation and appraisal theory could cooperate and inspire each other.

We have also compared three specific appraisal theories -the theories by Frijda, Lazarus, and the OCC- with one another and Gross' theory. Here, we have found that all theories can be combined with Gross' notion. They all have their own strengths and weaknesses and the choice of a (specific) theoretical basis for a model depends on the intended purpose. Generally speaking, the more concepts a theory covers, the less specific and detailed it is.

To compare these theories, we have combined several ideas of what a theory of emotion is and used this as a tool to find structural similarities and differences between the models that are useful when building a computational model. Here, we believe that not only the answer to this sub-research question, but also the method that was used to find this answer helps to advance the field of computational emotion modeling. We hope that these ideas on how to compare theories can be used to do similar comparative research in the future.

Finally, we have considered the difference that is often presumed to exist between coping and emotion regulation. We believe that for the purpose of computational modeling of emotions, we can treat coping as a subset of emotion regulation. Coping processes are often conscious, deliberate and focused on negative emotions. Emotion regulation processes on the other hand, can also be unconscious or concerned with positive emotions. The main difference is the way the processes are grouped together. In the case of emotion regulation they are ordered by means of *when* they interfere in the emotion process, while with coping the processes are organized by *what* they interfere with.

Before we can extend or adopt an existing model of emotion with the notion of emotion regulation, we first needed to know what models there are and how they relate to one another. In Chapter 2, we have introduced and compared several models of emotions. We started the chapter with clarifications of certain concepts that are used often but that we believe are not very clear, such as the term computational model. Next, we introduced some principles on which models can be compared. Some of these principles are similar to the ones introduced in Chapter 1 and some are more model-specific. Finally, we gave an overview of a subset of models on these criteria.

We have also introduced the computational model of emotion regulation by Bosse et al. They provided an elegant framework, its main disadvantages being that it does not model any notion of emotion or does not have a very elaborate representation of the world. As shown in the Chapter, this does make the ideas and formalization of this model useful in extending a model of emotion. Besides introducing this model, we also proposed an adaptation of the model, based on ideas found and explained in Chapter 1.

Similarly to Chapter 1, we believe that not only the comparison, but also the clarification of principles and the way the comparison was performed contribute to advancing the field of computational modeling of emotions.

In chapter 3, we have proposed extensions to two models: EMA and the formalization of Broekens et al. The main aim of this Chapter was to illustrate how the ideas proposed before can be used to extend some existing model with a notion of emotion regulation. To show how these ideas can by applied to very different type of models, we choose these two very different models. The model of Broekens et al. is a computational level formalization of general appraisal theory, while EMA is a detailed implementation based on the theory of Lazarus. We also chose two different approaches. In the case of Broekens et al., we provided a detailed formalization of Gross' ideas within this framework. Although the model of Broekens et al. is slightly oversimplified, we hope that these ideas can be the starting point of expanding more detailed formalizations. In the case of EMA, we have proposed rather high-level changes that can incorporate the ideas by Gross into EMA. Finally, we have shown how these improvements can advance affective computing in the future.

Future Work

As mentioned in several places in this thesis, there are many ways in which this research can be expanded upon. First of all, we can elaborate on the proposals in Chapter 3 into more detail and test whether they actually lead to better models. The results of these tests can then be a basis for more psychological research about the relationship between emotion and emotion regulation. We believe in particular it would be very interesting to look into the coping verus emotion regulation debate. One can also expand on the steps that we have taken in this thesis. In Chapter 1 and 2 only a subset of theories and models could be considered, and more theories and models can be added to this comparison. Finally, the methods used in this thesis could be worked out in more detail. There could for example, be more important criteria on which models or theories can be compared.

Finally, although we haven't completely build an Asimovian robot that can anticipate on our emotions, we believe we have brought the field of affective computing one step closer to actually doing so.

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Appendix A

The Situational Meaning Structure (Frijda)	
Core Components	
Objectivity	An emotional event is something that feels like it “overcomes” a person. The subject feels effected and passive in this sense.
Relevance	An emotional situation claims attention.
Reality level	A measure of how ‘real’ a situation feels. For example, when someone is murdered in front of your face or in a movie, will result in a different emotional response.
Difficulty	Emotional situations are difficult, in the sense that the subject does not have a direct obvious solution.
Urgency	The degree in which the situation needs an immediate response.
Seriousness	How serious the implications are considered to be.
Valence	Whether the potential outcome of the situation is positive or negative to the subject.
Demand Character	Whether the actual outcome of a situation is desirable, interesting, postive, or negative.
Clarity	To which extend it is clear what it is that is happening.
Multiplicity	Corresponds to which extend an situation gives rise to a mixture of emotions.
Context Components	
Presence and absence	An positive emotion can be elicited by the presence of something positive or the absence of something negative, the same holds for a negative emotion.
Certainty and noncertainty	This component measures how certain the effects of the situation are.
Change	A definite reference to some other situation with whom the comparison gives rise to some emotion.
Openness - closedness	Modulation of presence and absence.
Intentionality	Who is considered to be responsible for creating the event, self or another agent.
Controllability	To which extend the event can be modified by the agents own actions.

Modifiability	To which extend the event can be changed. Not necessarily by the actions of the agent.
Object evaluation v.s. event evaluation	Whether the situation concerns an person, object, or the outcome of an event
Focality - Globality	Whether the event is tied to some specific event or more the environment as a whole.
Strangeness - familiarity	How familiar a subject is to the situation.
	Object components
Ego as constituent	When the person itself is a factor of the situation.
Ego as object	Whether the subject is an explicit part of the situation.
Object fate v.s. subject fate	Who's well-being is at sake.
Value relevance v.s. contingency	Whether things are good or bad with respect to suprapersonal values.
Further object components	All other components that could play a role. Specifically to distuingish between culturally dependent emotions.

Based on (Frijda, 1986, p.205-216).

Appraisal Components (Lazarus)	
	Primary Appraisal
Goal relevance	The extent on which an encounter touches on personal goals.
Goal congruence or incongruence	The extent to which an encounter is consistent or inconsistent with the desires of the subject.
Type of ego-involvement	Different aspects of the ego-identity or personal commitments that play a role in the encounter.
	Secondary Appraisal
Blame or Credit	Who is responsible for the situation.
Coping potential	Whether and how the person can manage the demands of the encounter.
Future expectancy	Whether the encounter is likely to change for the better or the worse.

Based on (Lazarus, 1991, p.149-150).

Variables of the OCC	
Global Variables	
Sense of reality	The object needs to be construed as being sufficiently ‘real’.
Proximity	How close a situation is, both temporal and psychological.
Unexpectedness	How expected the situation is to the agent.
Arousal	Physiological arousal, combing all non-cognitive aspects of emotion.
Local Variables	
Likelihood	Estimation of how likely the situation is.
Effort	Both physical and mental effort.
Desirability-for-other	The degree of which the event is desirable for some other person.
Liking	The degree of how much you like some other person involved in the situation.
Deservingness	How much you think some other person deserved the situation.
Strength of cognitive unit	How affiliated someone feels to a certain ’cognitive unit’, such as an institution, football team, etc.
Expectation-deviation	How much the situation differs from what is usually the case.
Familiarity	How many times the person is exposed to this situation before.

Based on (Ortony et al., 1988, p.60-81).

Appendix B

Emotions covered by Frijda

- Joy
- Distress
- Desire
- Interest
- Grief
- Sorrow
- Fear
- Hope
- Anger
- Challenge
- Boredom
- Satisfaction
- Contentment
- Security
- Relief
- Anxiety
- Despair
- Disappointment
- Hate
- Frustration
- Guilt
- Contempt
- Resignation
- Love
- Admiration
- Pride
- Disgust
- Self-hatred
- Depression
- Bliss
- Indignation

Emotions covered by Lazarus

- Anger
- Fright
- Anxiety
- Guilt
- Shame
- Shame
- Sadness
- Envy
- Jealousy
- Disgust
- Happiness/Joy
- Pride
- Love/Affection
- Relief

Emotions covered by OCC

- Joy
- Distress
- Happy-for
- Sorry-for
- Resentment
- Gloating
- Hope
- Fear
- Satisfaction
- Fears-confirmed
- Relief
- Disappointment
- Pride
- Self-reproach
- Appreciation
- Reproach
- Gratitude
- Anger
- Gratification
- Remorse
- Liking
- Disliking

Appendix C

Coping Strategies of EMA	
Attention-related coping	
Seek information	Try to resolve potential uncertainty concerning the truth-value of certain state propositions.
Suppress information	Actively trying not to resolve potential uncertainty concerning truth-value of a certain state.
Belief-related coping	
Shift responsibility	Move the credibility or blame from self towards an other agent, or the other way around.
Wishful thinking	Increase the probability of a desirable outcome of some pending state or lower the probability of an undesirable outcome of some pending state.
Desire-related coping	
Distance / Mental disengagement	Lower the utility of a state that is desired or threatened.
Positive reinterpretation / Silver lining	Increase the utility of a positive side effect of an action that had some negative outcome.
Intention-related coping	
Planning / Action selection	Form a new intention to perform some external action that improves an an outcome that is appraised negatively.
Seek instrumental support	Form a new intention to convince someone else to perform an external action that improves your situation.
Make amends	Form a new intention to rectify things that went wrong.
Procrastination	Delay an intention to some later time.
Resignation	Drop an intention.
Avoidance	Take some action that attempts to remove the agent from some potentially harmful situation.

Based on (S. C. Marsella & Gratch, 2009, p.82-83).