Software Requirements Specification for EMgine: A Computational Model of Emotion for Enhancing Non-Player Character Believability in Games

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Revision History

Date	Version	Notes
March 22, 2023	1.5	• Separated Emotion Generation Goal into Elicitation GS1 and Intensity Evaluation GS2 Goals • Updated Conceptual Models C7, C8 with additional information from the affective science literature • Refined descriptions of Theoretical Models T1, T2, T3, T4, T5, T6, T7 • Redefinition of Data Types TY14, TY15, TY16 • Updated descriptions of Data Types TY4, TY5, TY6, TY10, TY11 • Redefinition of Instance Models IM1, IM2, IM3, IM4, IM5, IM6, IM7, IM8, IM9, IM10, IM11, IM12, IM13, IM14, IM15, IM16, IM17, IM22, IM23, IM18, • Significant changes to Assumptions and Likely Changes due to updates of Conceptual Models, Theoretical Models, Data Types, and Instance Models • Updated Traceability matrices and graphs to reflect changes
October 22, 2022	1.0	• Completed Initial Version
July 20, 2022	0.5	• Draft document • Unconfirmed Theoretical and Instance Models • Missing non-functional requirements • Incomplete traceability information

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1 Reference Material

This section records the units, symbols, abbreviations and acronyms, and mathematical notation that appears in this document for easy reference.

1.1 Table of Units

The tasks performed by EMgine are unitless.

1.2 Table of Symbols

The table that follows summarizes the symbols used in this document along with their units, listed in alphabetical order. Symbols that only appear in the Waiting Room (Appendices B, C, and D) do not appear in this table.

Symbol	Type	Description
$\mathbb{AT}_x$	T17	The time elapsed while focusing on x
$\mathbb{B}$	–	The set of Boolean values `True` and `False`
$\mathbb{D}$	TY12	The difference between two game world states
$\mathbb{D}_\Delta$	TY13	The change that a game world event makes to a game world state
$\mathbb{E}$	TY7	Emotion states over time
$\mathbb{ES}$	TY5	An emotion state
$\mathbb{ES}_\lambda$	TY6	An emotion decay state
$\mathbb{G}$	TY14	An entity's goal
$\mathbb{I}$	TY1	Emotion intensity
$\mathbb{I}_\Delta$	TY2	A change in emotion intensity
$\mathbb{I}_\lambda$	TY3	Emotion decay constant
$\mathbb{K}$	TY4	Allowable emotion labels/types
$\mathbb{N}$	–	The natural numbers, zero inclusive
$\mathbb{P}$	TY15	An entity's plan
$P_{(P,A,D)}$	TY8	A point in PAD space
$\mathbb{R}$	–	The reals
$\mathbb{R}_{\geq 0}$	–	The set of non-negative real values
$\mathbb{R}_{>0}$	–	The set of positive real values
$\mathbb{S}$	TY10	A game world state
$\mathbb{S}_\Delta$	TY11	A game action that changes a game world state
$\mathbb{SA}$	TY16	A social attachment to entity A
$\mathbb{T}$	TY9	Abstract, linearly ordered time
$\mathbb{T}_\Delta$	TY9	The difference between two times
$\mathbb{Z}$	–	The integers

1.3 Abbreviations and Acronyms

Text	Description
A	Assumption
API	Application Programming Interface
C	Conceptual Model
CME	Computational Model of Emotion
CS	Computer Science
CTE	Oatley & Johnson-Laird's Communicative Theory of Emotions
DD	Data Definition
GD	General Definition
GS	Goal Statement
GUI	Graphical User Interface
HCI	Human-Computer Interaction
IM	Instance Model
LC	Likely Change
NF	Nonfunctional Requirement
NPC	Non-Player Character (Games)
PAD	Mehrabian's Pleasure-Dominance-Arousal Space (Affective Space Model)
PES	Plutchik's Psycho-evolutionary Synthesis (Emotion Theory)
PS	Physical System Description
PX	Player Experience
R	Functional Requirement
RE	High-Level Requirement: Ease-of-Use
RF	High-Level Requirement: Flexibility
SE	Software Engineering
SRS	Software Requirements Specification
T	Theoretical Model
TY	Type Definition
UML	Unified Modelling Language
WR	Waiting Room

1.4 Mathematical Notation

Notation	Description
$\neg x$	NOT x
$x \wedge y$	x AND y
$x \vee y$	x OR y
$\forall x$	Universal quantifier
$\exists x$	Existential quantifier
$[x, y]$	A closed interval bounded by x and y, inclusive
(x, y)	An open interval bounded by x and y, exclusive
$\lvert x\rvert$	Absolute value of x
$\sum_{i=x}^{y} s_i$	Summation of s_i from $i = x$ to y inclusive
$x \cdot y$	Multiply x and y
$P(B\lvert A)$	Conditional probability of B given A
$\{x_0, x_1, ..., x_n\}$	A set of n elements
$\{X\}$	A set of elements of type X
$X \subset Y$	X is a proper/strict subset of Y
$X \subseteq Y$	X is a subset of Y
$A \times B$	The Cartesian product of A and B
$(x_0, x_1, ..., x_n)$	A sequence of n elements
$x : X$	A variable x of type X
$x : X \rightarrow y : Y$	A function mapping $x : X$ to $y : Y$
$x \oplus y$	Shorthand for $\texttt{apply}(x, y)$, where `apply` is a function that changes x by y
$X^?$	An Option/Maybe type that returns a value of type X or Nothing/None
$\langle e_1, ..., e_n\rangle$	An enumeration with n labels
$\{l_1 = v_1, ..., l_n = v_n\}$	A record with n elements, each with a label l and value v such that no two sets of l and v must have the same type
$\{r \text{ with } x = y\}$	Update a record r that has the label x with the value y
$X \mathrel{\hat{=}} y$	Assignment of y to X; X "is defined by" y

2 Introduction

This is the Software Requirements Specification (SRS) for EMgine, a Computational Model of Emotion (CME) for Non-Player Characters (NPCs) to enhance their believability, with the goal of improving long-term player engagement. EMgine is for *emotion generation*, accepting user-defined information from a game environment to determines what emotion and intensity a NPC is "experiencing". How the emotion is expressed and what other effects it could have on game entities is left for game designers/developers to decide.

EMgine aims to provide a feasible and easy-to-use method for game designers/developers to include emotion in their NPCs, they perceive to be challenging with the current tools and restrictions (Broekens et al., 2016). EMgine should be modular and portable such that game designers/developers can use it in their regular development environment, and should not require knowledge of affective science, psychology, and/or emotion theories.

A *believable character* "...allows the audience to suspend their disbelief and...provides a convincing portrayal of the personality they expect or come to expect [from the character]" (Loyall, 1997, p. 1). Believability is not limited to "smart" or "normal" characters because it depends on the situational context and the character's personality (Lisetti and Hudlicka, 2015; Loyall, 1997; Reilly, 1996). In short: an NPC must behave reasonably within the context of the game world. Generally, NPCs are believable when they (Lankoski and Björk, 2007; Loyall, 1997; Warpefelt et al., 2013):

- Appear to be self-motivated,
- Are aware of what is happening around them, and
- React in ways appropriate for their surrounding context while adhering to their personality.

Emotion, transient responses to changes in the environment (Lazarus, 1991), is one element of believable character design (de Melo and Gratch, 2015; Emmerich et al., 2018; Gard, 2000; Lankoski and Björk, 2007; Lisetti and Hudlicka, 2015; Loyall, 1997; Paiva et al., 2005; Warpefelt et al., 2013). It is an established aspect of believability in animation (Thomas and Johnston, 1995), and game designers have acknowledged its importance in NPC design (Hudlicka and Broekens, 2009; Yannakakis and Paiva, 2015).

Characters with emotion address the core features of believability because they convey a character's goals and desires (*self-motivated*) by showing their *awareness* of, *responsiveness* to, and care (*personality*-driven) for their surroundings (Bates, 1994; Broekens, 2021; Reilly, 1996). It follows that one way to improve an NPC's believability is to have them react emotionally to their surroundings (Togelius et al., 2013; Yannakakis and Paiva, 2015).

The template presenting this SRS's information is based on Smith and Lai (2005) and Smith et al. (2007). The introductory sections describe the project stakeholders (Section 2.1), purpose of this document (Section 2.2), what background and knowledge a reader must have to understand this document (Section 2.3), the requirement scope (Section 2.4), and the organization of document sections (Section 2.5).

2.1 Stakeholders

- **Primary**
  1. **Video Game Designers/Developers**
     Game designers/developers are concerned with making enjoyable experiences for their players, so EMgine must aid them in this. Designers/developers interact with EMgine directly to give their NPCs "emotion".

A common issue raised by designers/developers is that adding emotions to their game is an involved and complicated process (Broekens et al., 2016), implying that EMgine must be simple to use in order for it to have the potential to be effective as a development tool. It must also help designers/developers see how “emotional” NPCs contribute to the player experience (PX), and to novel game design.

Video game designers/developers are not expected to have a background in Affective Science or Psychology, or an understanding of Emotion Theories.

2. **Video Game Players**
   Players do not interact with EMgine directly, instead seeing its effects through a game's NPCs. As a key stakeholder, any feature of EMgine that takes away from their entertainment must be seriously evaluated for redevelopment or removal. Video Game Designers/Developers, too, view their players as primary stakeholders of their games for similar reasons. This enforces the need to view players as primary stakeholders.

   Video game players are not expected to have a background in Affective Science or Psychology, or an understanding of Emotion Theories.

- **Secondary**

1. **Geneva M. Smith**
   The main developer of EMgine, Ms. Smith sets time constraints on its development. The initial prioritization of EMgine components to develop are set by the time and skills available to her.

   Ms. Smith's background is in Software Engineering (SE) and Human-Computer Interaction (HCI).

2. **Dr. Jacques Carette**
   An employee of McMaster University, Dr. Carette is the direct supervisor of Geneva M. Smith and part of her supervisory committee. He contributes to EMgine's design and the prioritization of development tasks.

   Dr. Carette requires EMgine to be easily explainable to non-experts of affective science and psychology, and for it to follow software engineering best practices. Dr. Carette also requires that EMgine's development be serialized to enable the communication of progress and creation of academic papers.

   Dr. Carette's background is in Mathematics and Computer Science (CS).

3. **Drs Spencer Smith, Alan Wassyng, and Denise Geiskkovitch**
   Members of Geneva M. Smith's supervisory committee and employees of McMaster University. Drs Smith, Wassyng, and Geiskkovitch evaluate her development of EMgine, and provide advice and feedback.

   Drs Smith, Wassyng, and Geiskkovitch require EMgine to be easily explainable to non-experts of affective science and psychology, and for it to follow software engineering best practices.

   Dr. Smith's background is SE and Civil Engineering, Dr. Wassyng's is SE, and Dr. Geiskkovitch's is HCI.

4. **McMaster University**
   EMgine's development is being conducted at McMaster and must adhere to its Academic Integrity and Research Ethics rules and regulations.

5. **Conference and Journal Selection Committees**
   As a research project, it is expected that any findings resulting from EMgine's development

and testing is shared with the broader academic community. This is commonly done via field-specific conference and journal papers that researchers submit for evaluation by a committee of experts in the field. Therefore, EMgine must be documented in a traceable and easily explainable manner to accelerate its translation into suitable formats for submission and consumption.

6. **The Affective Computing Research Community**
As a research project, it is expected that EMgine's development and testing is shared with the broader academic community so that members can compare other designs with, reuse, and/or build on EMgine's design, implementation, and/or testing artefacts.

2.2 Purpose of Document

This document represents the specifications of EMgine as a self-contained system that interfaces with external systems. It describes all of EMgine's necessary functionality, and the underlying assumptions and models derived from affective science, psychology, and emotion theory literature.

This document's purpose is to guide the design of EMgine's architecture and interfaces, as well as the development of its test plan. After initial development, the document's purpose is to aid in the use, maintenance, and further development of EMgine. This includes activities that change EMgine's existing components, such as those described in the likely changes (Section 6.1), or add new components.

2.3 Characteristics of Intended Reader

The intended reader of this document must have an undergraduate-level understanding of affective science and/or affective psychology. They must also know the differences between types of affect, including emotion (Broekens, 2021, p. 349; Scherer, 2000, p. 138–140), "core" affect (Barrett and Bliss-Moreau, 2009, p. 170), mood (Frijda, 2009), and personality (Revelle and Scherer, 2009). It would be beneficial if the reader is familiar with Plutchik's Psycho-evolutionary Synthesis (PES) (Plutchik, 1980), Oatley and Johnson-Laird's Communicative Theory of Emotions (CTE) (Oatley, 1992; Oatley and Johnson-Laird, 1987), and Mehrabian's Pleasure-Arousal-Dominance affective space model (PAD) (Mehrabian, 1980, 1996b).

The intended reader must also have an understanding of type, function, sequence, and set notation. They must also understand mathematical states, logical quantification, and intervals over a numerical domain.

2.4 Scope of Requirements

EMgine calculates a discrete emotion type/kind/category and associated intensity for a game entity—initially, a NPC—from user-defined information about the entity's goals, plans to achieve certain world states, attention to other entities, social attachments to other entities and game states. EMgine uses this information to update the entity's internal "emotion" state at a given time step. EMgine also provides the means to decay the intensities of an "excited" emotion state back to user-defined default values such that it can "calm down". EMgine also provides the means for a user to query an emotion state for its equivalent representation as a point in PAD space.

EMgine focuses on *emotion generation* alone. Therefore, it does not provide the functionality to calculate other types of affect such as "core" affect, mood, and personality. However, providing an emotion state's coordinates in PAD space can help EMgine interface with other user-provided components that do. The use of PAD space as a common representation for different types of affect and their interactions has proven successful in other CMEs (Broekens and DeGroot, 2004; Gebhard, 2005; Masuyama et al., 2018)).

The focus on emotion generation also means that EMgine does not define most cognitive entities and functions at all. However, there are some that are necessary for CTE's functions—goals, plans, and optional attention and social attachment components/functions. EMgine provides Application Programming Interfaces (APIs) for these components. It uses abstract types and/or defines them with elements from the provided APIs where possible. This maximizes EMgine's portability as it gives video game designers/developers as much freedom as possible to use an agent architecture of their choice. Providing inputs to the attention and social attachment APIs are optional because EMgine can still generate six of the eight "primary" emotion types defined in PES (*Anger*, *Fear*, *Sadness*, *Joy*, *Surprise*, and *Disgust*) without them. Using the API for attention allows EMgine to generate *Interest*, and the API for social attachment allows EMgine to generate *Acceptance*.

EMgine's users are responsible for providing it with definitions for a game entity's goals and plans, and for defining the default emotion state intensities and decay rates for each emotion type it contains. Users can optionally provide information for the game entity's attention and social attachments to other game entities. Users also have the option to define new emotion kinds using the provided "primary" ones and emotion intensity values.

Due to its intended use in game development, EMgine design is unconcerned with strict adherence to "realistic" emotion generation. This means that its usage scope is limited to the scope of games, which have been used for pedagogical purposes. It is left to the game designers/developers to determine if the level of realism provided by EMgine is appropriate for their application.

2.5 Organization of Document

The rest of this document is organized as follows:

- A general description of EMgine (Section 3), including the system context and constraints, as well as characteristics of the intended end users
- The problem description (Section 4.1), which defines terminology necessary for understanding subsequent models and requirements, a description of the physical system that EMgine exists in, and the goals that EMgine must achieve through its requirements
- A solution characteristics descriptions (Section 4.2), documenting EMgine's models, types, assumptions, data constraints and definitions, and properties of a correct solution
- EMgine's functional and non-functional requirements (Section 5)
- Future changes, both likely and unlikely, to EMgine's solution characteristics specification (Section 6)
- Traceability matrices and graphs (Section 7), visually describing the dependencies between document components, for reference if/when making changes to EMgine's specifications
- Suggestions for other CME designs, components, and extensions (Appendices B, C, D), including preliminary assumptions, models, and type definitions

3 General System Description

This section describes general system information and context for the specific system description and proposed solution specification (Section 4). It identifies the interfaces between the system and its environment, describes the user characteristics, and lists the system constraints.

3.1 System Context

EMgine's system context includes: the user; a development environment—which might not be specialized for game development—where users define at least one game entity associated with one or more EMgine instance and any number of game entities that are not associated with an instance of EMgine; and the game environment containing the game entities defined in the development environment. Figure 1 visually describes this, with the human user represented by a circle, game entities by "cards", and software systems by rectangles. Game entities and software systems are collected into "environments", represented by containers. Enumerated associations between elements are defined with Unified Modelling Language (UML) relationships.

Within this context, each element has responsibilities to ensure that EMgine can function correctly:

1. User (Game Designer/Developer) Responsibilities
   - Associate at least one game entity with one or more EMgine instances
   - Provide functions required to evaluate EMgine's time-dependent inputs
   - Associate EMgine emotion types with game entity animations, audio, and/or behaviours
2. Development Environment Responsibilities
   - Provide a method for interfacing with third-party systems
3. Run-time Environment Responsibilities
   - Allow game entities to store and/or update information
   - Allow game entities to exchange information
4. Game Entity Responsibilities
   - Send information about events and objects in the game environment to one or more of their associated EMgine instances
   - Execute animations, audio and/or behaviours associated with EMgine emotion types based on its outputs
5. EMgine Responsibilities
   - Detect and prevent data type mismatch, such as a string of characters instead of a floating point number
   - Allow users to modify its default parameters
   - Allow users to define new emotion types
   - Evaluate incoming information and make corresponding updates to its emotion state
   - Allow game entities to query its emotion state

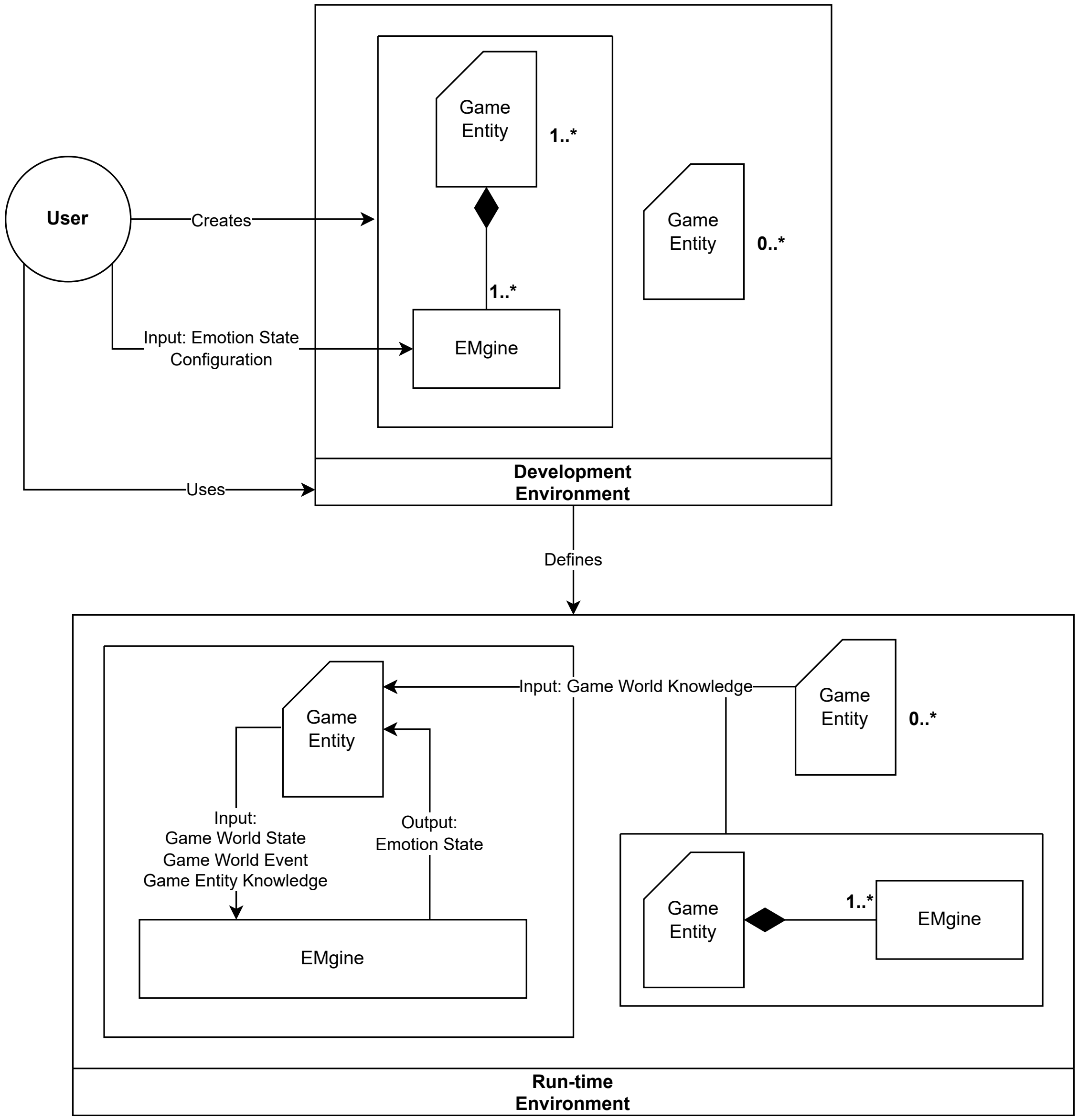

Figure 1: System Context

3.2 User Characteristics

The end user of EMgine should:

- Understand how to install third-party systems in a development environment
- Be able to read and implement APIs, understand game states, and know how to design and implement agent goals
- A general understanding of different types of emotion and how they can be expressed is an asset

3.3 System Constraints

EMgine has no known system constraints.

4 Specific System Description

This section first presents the problem description, giving a high-level view of the problem to solve (4.1), some terminology and definitions to clarify models, data, and requirements (Section 4.1.1), and goals that a solution must achieve (Section 4.1.3). It then describes characteristics of a potential solution, including Assumptions (Section 4.2.2), Theoretical Models (Section 4.2.4), General and Data Definitions (Sections 4.2.5 and 4.2.6), Data Types (Section 4.2.7), and the Instance Models derived from these (Section 4.2.8). This is followed by Constraints (Section 4.2.9) and Properties of a Correct Solution (Section 4.2.10).

One section—Conceptual Models (Section 4.2.3)—has been added to the solution characteristics that is not in the SRS template in Smith and Lai (2005) and Smith et al. (2007). It is useful for maintaining a direct connection to the affective research behind the Theoretical and Instance Models. The Theoretical Models also differ from those in the template, focusing on rewriting descriptions in the Conceptual Models with more precise natural language. This shows what interpretation of the Conceptual Models that lead to their mathematical representations in the Data Types and Instance Models.

4.1 Problem Description

The purpose of EMgine is to generate an emotion state for an entity, as well as store and update said emotion state with generated or given data. It must be done to afford users the most control over when and how EMgine generates emotion with only a layperson's understanding of emotion and emotion processes.

4.1.1 Terminology and Definitions

The Conceptual Models (Section 4.2.3) contain many definitions necessary for reducing ambiguity and making it easier to understand models and requirements. These are additional terms that do not appear in the Conceptual Models, but are still useful for the same reasons.

Affect: Any type of affective experience that has a changeable, short-term state originating from the body and impacting the mind in some way (Barrett and Bliss-Moreau, 2009; Frijda and Scherer, 2009). A general affective state is generally identified as weaker than an emotion state.

Affective Science: The interdisciplinary study of affective phenomena, related processes, and its influencing factors (Davidson et al., 2003, p. xiii).

Appraisal Theories (Perspective): These theories shift the evaluation of the environment from its objective qualities to its relation to an individual's well-being (Smith and Kirby, 2000, p. 86). They mainly focus on the link between cognitive processing and emotion elicitation (Broekens, 2021, p. 354).

Arousal: A short-term state of excitement or energy expenditure (Fowles, 2009).

Cognition: "All forms of knowing and awareness, such as perceiving, conceiving, remembering, reasoning, judging, imagining, and problem solving" (American Psychological Association, 2020a).

Core Affect: Based on affect, "...a state of pleasure or displeasure with some degree of arousal" (Barrett and Bliss-Moreau, 2009, p. 170). See also *Affect*.

Dimensional Theories (Perspective): These theories can more easily distinguish between different emotions (Scherer, 2010, p. 12; Smith and Ellsworth, 1985, p. 813) using a small number of continuous dimensions. They view emotion as an individual's interpretation of their current "core affect" (Broekens, 2021, p. 353) (i.e. elementary affective feelings). While any point in dimensional space is part of "core affect" (Lisetti and Hudlicka, 2015, p. 97), it is possible for individuals to verbally label points representing their subjective feeling of an emotion (Scherer, 2010, p. 12). This creates an effect of "plotting" emotion categories (e.g. discrete theories) as points in the space.

Discrete Theories (Perspective): These theories propose that innate, hard-wired circuits or programs elicit emotions (Ortony, 2022, p. 41; Scherer, 2021, p. 280). One of the core features of these theories is the definition of distinct emotion categories or types, like *Joy* and *Anger*, that are recognizable by a set of observable features (e.g. facial expression, typical behaviours). This "...fits with the way we talk about emotion every day...people automatically and effortlessly perceive emotion in themselves and others..." (Barrett, 2006, p. 47–48).

Emotion Expression: An affective computing task where a CME changes an entity's "observable" behaviour (e.g. facial expressions, gestures, or movements) given an emotion state (Scherer, 2010, p. 4; Fathalla, 2020, p. 2).

Emotion Generation: An affective computing task where a CME produces an emotion state given the current program and environment state (Scherer, 2010, p. 4; Fathalla, 2020, p. 2).

Emotion Kind: Names given to discrete categories/types of emotion (e.g. *Joy*, *Sadness*).

Emotion State: The set of values for each possible emotion kind.

Entity: Any discrete, identifiable, and separate object that is significant in and of themselves.

"Fast, Primary Emotions": Hard-wired and potentially inaccurate responses to innate knowledge elicited by fundamental mechanisms (e.g. instinctual fear of pain) (Picard, 1997, p. 60–70).

Feeling: Conscious mental representations and interpretations of an emotional response, and follow emotions evolutionarily and experientially (Scherer, 2009, p. 184; Scherer, 2000, p. 139). Feelings are ill-defined from a modelling perspective, and rarely, if ever, appear computationally. They are also, allegedly, unnecessary for understanding emotional behaviours (Fellous, 2004).

Game World: An imaginary universe in which game events take place (Adams, 2009). They are often two or three dimensional spaces containing characters and objects.

Global Adaptational Problem: In PES, a survival-related issue that emotion-based behaviours evolved to address and are found in some form at all evolutionary levels (Plutchik, 1980).

Gustatory: Concerned with tasting or the sense of taste. In CTE, this is associated with the mental process of withdrawing from toxins and potentially infectious agents (Oatley, 1992, p. 57). In this way, it could also be a prototype for other withdrawal-based emotions (e.g. *Hatred*, *Contempt*).

"Model of Self": In CTE, a cognitive representation of the individual's own goals, abilities, habits, and bodies, chiefly in relation with others (Oatley, 1992, p. 195).

Mood: Enduring, less intense, and more diffuse states than emotions (Frijda, 2009). Their presence is typically unclear to the experiencing individual and often have a more prolonged influence on an individual's cognition and behaviours.

Non-propositional Meaning: In relation to communication, signals with no symbolic structure or literal meaning of significance within a system (Oatley and Johnson-Laird, 1987, p. 32).

Personality: Permanent or difficult to change variables that impact affective processes (Revelle and Scherer, 2009).

Propositional Meaning: In relation to communication, signals having a symbolic structure with a literal meaning of significance to a system (Oatley and Johnson-Laird, 1987, p. 32).

Self-Preservational: In relation to self-preservation, especially regarded as a basic instinct in human beings and animals, the protection of oneself from harm or death.

"Slow, Secondary Emotions": Sometimes called "cognitively-generated emotions", these require some level of reasoning to elicit (e.g. learned fear of public speaking) (Picard, 1997, p. 60–70).

Valence: Describes the positive or negative character of emotions, their response components, and emotion-eliciting stimuli Brosch and Moors (2009). In affective science, it often appears as a dimensional variable with positive and negative poles. Assigning valence to an emotion depends on its context (e.g. behavioural tendencies vs. social interactions).

4.1.2 Physical System Description

EMgine does not interact with a physical system, and is not concerned with the physical hardware that the run-time environment and its components run on or how it generates data.

4.1.3 Goal Statements

Given an entity that is associated with at least one instance of EMgine, the entity's goals, a world state, an event that changes or could change that world state, and optional world and/or entity knowledge, EMgine's goals are:

GS1 Determining what emotion type is elicited by a change in game world state.

GS2 Determining what emotion intensity is elicited by a change in game world state.

GS3 Determining what intensity each emotion type has when decaying emotion.

GS4 Updating stored emotion values.

GS5 Allowing queries about stored emotion data.

The goal statements only describe EMgine's *tasks*. EMgine also requires goals (i.e. high-level requirements) describing its target *properties* to guide the selection of its underlying emotion theories (Section 4.2.1). This process is needed to define the Assumptions (Section 4.2.2) and Conceptual Models (Section 4.2.3). The high-level requirements directly incorporate some of the needs of video game designers/developers (Section 2.1) to improve the probability of EMgine's acceptance, which the SRS incorporates in the nonfunctional requirements (Section 5.2).

The *flexibility* goals are about making EMgine adaptable so that it can meet game designer needs (Reilly, 1996, p. 30). The aim is for EMgine to be applicable to a range of game designs while avoiding making decisions for the game developer.

RF1 Independence from an agent architecture so that designers can choose how to integrate EMgine into their game (Loyall, 1997, p. 25–26; Rodríguez and Ramos, 2015, p. 443; Broekens et al., 2016, p. 218)

RF2 Allowing the game designer to choose which of EMgine's tasks to use, as well as when and how to use them (Mascarenhas et al., 2022, p. 8:13; Guimarães et al., 2022, p. 20)

RF3 Allowing the customization or redefinition of EMgine's pre-existing configuration parameters (Reilly, 1996, p. 30; Guimarães et al., 2022, p. 20) such as the definition of time and emotion decay rates

RF4 Allowing designers to integrate new components into EMgine that influence or are influenced by emotion (Rodríguez and Ramos, 2015, p. 450; Castellanos et al., 2019, p. 353), such as mood, personality, motivations, culture, gender, and physical state

RF5 Allowing designers to choose which kinds of emotion EMgine produces (i.e. which emotions an NPC can have) (Hudlicka, 2014, p. 331), (e.g. *Anger*, *Joy*)

RF6 Allowing designers to specify how to use EMgine's outputs (Loyall, 1997, p. 86)

RF7 Allow designers to use EMgine on different levels of NPC complexity (Broekens et al., 2016, p. 220), e.g. a *Pac-man* ghost (Namco, 1980) and a *Skyrim* citizen (Bethesda Game Studios, 2011) will not have the same emotional requirements

RF8 Being efficient and scalable to minimize EMgine's impact on overall game performance (Popescu et al., 2014, p. 42)

The *ease-of-use* goals concern the usability of EMgine and showing how it supports game development. These aim to make EMgine more user-friendly and minimize maintenance to increase its chances of adoption by game developers.

RE1 Hiding the complexity of emotion generation so that game designers do not have to be knowledgeable in emotion psychology to use EMgine (Reilly, 1996, p. 28; Broekens et al., 2016, p. 220; Guimarães et al., 2022, p. 5)

RE2 Providing a clear and understandable Application Programming Interface (API) or similar that shows how to use the different aspects of EMgine (Broekens et al., 2016, p. 218)

RE3 Minimizing authorial burden as game developers add NPCs to their game (Guimarães et al., 2022, p. 5)

RE4 Allowing EMgine's outputs to be traceable and understandable (Loyall, 1997, p. 86; Guimarães et al., 2022, p. 5, 19–20)—critical for testing—by providing ways to view the range, intensity, and causes of emotion per NPC, per NPC group, and per game world area (Broekens et al., 2016, p. 219–220)

RE5 Allowing developers the option to automate the storing and decaying of EMgine's internal emotion state (Loyall, 1997, p. 86)

RE6 Showing that EMgine improves the player experience, since a sub-par design could be a detriment to the overall game and would not be of use to game development

RE7 Providing examples as to how EMgine can create novel game experiences (Broekens et al., 2016, p. 221)

The flexibility and ease-of-use goals also imply that EMgine *must not* depend on a particular entity embodiment or implementation because this limits the types of entities that it could support (related to RF1, RF7), and it *must* support the generation of *fast, primary emotions* and *slow, secondary emotions* (Picard, 1997, p. 60–70) (related to RF7).

4.2 Solution Characteristics Specification

This section expresses EMgine's solution characteristics in mathematical form via Data Types (Section 4.2.7) and Instance Models (Section 4.2.8), as well as underlying Assumptions (Section 4.2.2), Data Constraints (Section 4.2.9) and additional properties necessary for EMgine to be correct (Section 4.2.10). These components are refinements of Theoretical Models (Section 4.2.4), which are in turn refinements of Conceptual Models (Section 4.2.3). They are necessary for understanding the Data Types and Instance Models so that they can be verified.

4.2.1 Emotion Theories and Models

All potential EMgine solutions must be based on emotion theories and data to improve its *psychologically validity*, which is necessary for its behaviours to be *plausible* (Broekens et al., 2016, p. 216–217). The theories that EMgine uses must align with its overall design goals.

EMgine's theories are Oatley & Johnson-Laird's Communicative Theory of Emotion (CTE), Plutchik's Psycho-Evolutionary Synthesis (PES), and Mehrabian's Pleasure-Arousal-Dominance Space (PAD). These were chosen from a pool of potential candidates (Table 1) based on their ability to satisfy the *flexibility* and *ease-of-use* high-level requirements (Section 3.3). Note that these requirements are theory-agnostic, so any emotion theory that supports them is a reasonable choice.

The selection process follows these general steps:

1. Scoping the high-level requirements as needed
2. Scoring each candidate theory
3. Choosing theories based on their scores

Scoping The analysis separates *Providing a clear and understandable API* (RE2) into two—Input and Output—to get a better feel for each theory's usefulness. This is an acknowledgement that some theories are better for emotion expression, such as Ekman & Friesen.

The requirement for *Allowing the Integration of New Components* (RF4) is broad and should be scoped for the initial design of EMgine. New EMgine components could be non-affective (e.g. attention) and affective (e.g. personality) in nature. Integrating non-affective components should be theory-agnostic, as they are part of separate components of mind (American Psychological Association, 2020a). From a software engineering perspective, one could view the mind as a system with distinct, interacting subsystems. Modular interfaces that control interactions between EMgine—as the affective subsystem—and components from other subsystems would support this concept, while also maintaining EMgine's requirements for *Independence from an Agent Architecture* (RF1) and *Allowing Developers to Specify How to Use Outputs* (RF6). Integrating other affective components would depend on EMgine and its foundational theories. One would be limited to only those components that can be represented in terms of the emotions or other types of affect that have been connected to them.

This requirements analysis focuses on three other types of affect: core affect, mood, and personality. Of these, it prioritizes personality because it is necessary for creating the consistent and coherent agent behaviours that influence believability (Reilly, 1996, p. 26; Loyall, 1997, p. 19; Ortony, 2002, p. 203).

Finally, the *Minimizing authorial burden* requirement (RE3) is excluded from the analysis. This is due to its focus on helping game developers manage the creation of an increasing NPC population, rather than the functionality of EMgine itself.

Table 1: Theories Analysed

Perspective	Theories
Discrete	Ekman & Friesen (Ek.), Izard (Iz.), Plutchik (Plu.)
Dimensional	Valence-Arousal (V-A), PAD Space (PAD)
Appraisal	Frijda (Frj.), Lazarus (Laz.), Scherer (Sch.), Roseman (Ros.), Ortony, Clore, and Collins (OCC), Smith & Kirby (S & K), Oatley & Johnson-Laird (O & JL)

Scoring Each theory has a set of notes made during their examination, guided by individual high-level requirements. After reviewing the notes, each theory is assigned a *score* describing its relative "suitability" for that requirement (Table 2). This step is somewhat subjective because a judgement is made without true objective measures or methods. The notes are in Appendix A.

EMgine's high-level requirements are divided into two sets: *system-level*, which applies to EMgine as a whole (Tables 3 and 4), and *component-level* for requirements that only apply to specific pieces of EMgine (Tables 5 and 6). Only appraisal theories are assigned categories for component-level requirements because they concern process-related elements that discrete and dimensional theories do not address. Each theory has unique elements, which might make it better or worse suited for a particular requirement. These are noted in the analysis. However, is not unusual for theories from the same perspective to satisfy a requirement equally well. In these cases, the theories are treated as a collective unit when examining the requirement. Tables 3, 4, 5, and 6 summarize the scores for each theory and requirement.

Table 2: Summary of Scoring Categories

Score Category	Symbol	Definition
Strong	☆☆☆	The theory appears to satisfy the requirement in a clear, understandable way and is likely to aid in EMgine's usability
Good	☆☆	The theory appears to satisfy the requirement and is somewhat defined
Weak	☆	The theory describes ways that *could* satisfy the requirement, but it is not fully defined or could make EMgine harder to use
Disqualified	–	The theory does not seem likely to be able to satisfy this requirement, or it violates other requirements when it can (including psychological validity)

Choosing Theories EMgine prioritizes RF1, RF6, RF7, RF8, RE1, RE2, and RE4 because it is unlikely that developers will adopt EMgine without them. The remaining requirements offer more options to tailor it to different game designs (RF2, RF3, RE5) and/or could be satisfied as an extension later on (RF4, RF5, RE6, RE7).

Theories are *not* immediately discounted if they cannot satisfy a requirement (i.e. given score is *Disqualified*). They might be extremely strong in other areas. Instead, the coverage achieved by the *set* of chosen theories must satisfy all requirements. This allows EMgine to take advantage of the strengths of different

Table 3: Support for System-Level **Flexibility** High-Level Requirements

		Ek.	Iz.	Plu.	V-A	PAD	Frj.	Laz.	Sch.	Ros.	OCC	S & K	O & JL
RF1	*Independence from an Agent Architecture*	☆☆	☆☆	☆☆	☆☆	☆☆	☆☆☆	☆☆	–	☆☆	☆☆☆	☆☆☆	☆☆☆
RF4	*Allowing the Integration of Components*	☆	☆☽	☆☆☽	☆☆☆♃	☆☆☆♃	☆☆☆	☆	☆	☆	☆☆☆	☆	☆☆☆
RF5	*Choosing NPC Emotions*	☆	–	☆☆☆	☆	☆☆	☆	☆	☆☆	☆☆	☆☆	☆	☆☆☆
RF6	*Allowing Developers to Specify How to Use CME Outputs*	☆☆	☆☆	☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆
RF7	*Ability to Operate on Different Levels of NPC Complexity*	☆☆	☆☆	☆☆	☆	☆	☆	☆☆☆	☆☆☆	☆☆	☆☆	☆☆☆	☆☆
RF8	*Be Efficient and Scalable*	☆☆	☆☆	☆☆	☆	☆	☆☆♀	☆☆☆	☆☆	☆	☆☆	☆☆☆	☆☆☆

See Table 2 for score category descriptions.
Excludes the Coping Process because it is part of action generation.
Strictly focusing on core affect, mood, and personality.
☽ *Natively supports integration with Personality.*
♃ *Personality integration based on the Five Factor Model (OCEAN).*
♀ *Might improve if some factors are not necessary for implementation scope.*

Table 4: Support for System-Level **Ease-of-Use** High-Level Requirements

		Ek.	Iz.	Plu.	V-A	PAD	Frj.	Laz.	Sch.	Ros.	OCC	S & K	O & JL
RE2	*Having a Clear API (Output)*	☆☆☆	☆	☆☆	☆	☆	☆☆	☆☆☆	☆	☆☆☆	☆☆	☆☆☆	☆☆☆
RE6	*Showing that Emotions Improve the Player Experience*	☆☆	☆☆	☆☆	☆☆	☆☆	☆☆	☆☆	☆☆☆	☆☆	☆	☆☆	☆☆
RE7	*Providing Examples of Novel Game Experiences*	☆	☆	☆	☆☆	☆☆	☆☆	☆☆	☆☆	☆☆	☆☆	☆☆	☆☆

See Table 2 for score category descriptions.
Excludes the Coping Process because it is part of action generation.

Table 5: Support for Component-Level **Flexibility** High-Level Requirements

		Frj.	**Laz.**	**Sch.**	**Ros.**	**OCC**	**S & K**	**O & JL**
RF2	*Choosing Which Tasks to Use*	☆	☆	☆☆☆	–	☆☆	☆☆	☆☆
RF3	*Customization of Existing Task Parameters*	☆☆☆	–	☆☆	–	☆☆	☆☆	☆☆

See Table 2 for score category descriptions.
Excludes the Coping Process because it is part of action generation.

Table 6: Support for Component-Level **Ease-of-Use** High-Level Requirements

		Frj.	**Laz.**	**Sch.**	**Ros.**	**OCC**	**S & K**	**O & JL**
RE1	*Hiding the Complexity of Emotion Generation*	☆☆☆	☆☆☆	☆☆☆	☆☆	☆☆	☆☆	☆☆
RE2	*Having a Clear API (Input)*	☆☆	–	☆☆	☆☆	☆	☆☆	☆☆☆
RE4	*Traceable CME Outputs*	☆☆☆	☆☆☆	☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆
RE5	*Allowing the Automatic Storage and Decay of the Emotion State*	☆☆	☆☆	☆☆	–	☆☆	☆☆	☆☆

See Table 2 for score category descriptions.
Excludes the Coping Process because it is part of action generation.

theories while also compensating for their weaknesses. EMgine uses one theory from each of the discrete, dimensional, and appraisal perspectives to take advantage of each perspective's strengths and mitigate its weaknesses.

The discrete and dimensional theories cannot satisfy the need for *cognitively generated/slow, secondary emotions* (Section 3.3). This means that EMgine must use at least one appraisal theory. It is also known that the discrete theories can best satisfy the need for *fast, primary emotions*. There is no reason to limit the number of theories in EMgine's design, as the added complexity would be internal to EMgine (otherwise it would conflict with RE1). Therefore, EMgine must use at least one appraisal and one discrete theory.

EMgine also uses a dimensional theory because they are especially suitable for representing different types of affect and their interactions in a common space (RF4) and afford more control over what emotions could "do" in an NPC (RF6). The additional design freedom afforded to game developers, including a dimensional theory could increase EMgine's overall applicability.

- **Appraisal Theory: Oatley & Johnson-Laird**
  Three theories have *Disqualified* scores: Lazarus, Scherer, and Roseman. Roseman has an ill-defined emotion elicitation process compared to the others, so EMgine should not use it. Both Lazarus and Scherer are *Disqualified* for a priority requirement (RE2 (Input) and RF1 respectively), so EMgine should not use them either. Of the remaining theories, Oatley & Johnson-Laird seems the most promising. It has only *Good* or *Strong* scores for all requirements, and all but one priority requirement (RE1) has a *Strong* score.

- **Discrete Theory: Plutchik**
  The discrete theories vary in score for only three requirements: RF4, RF5, and RE2 (Output). EMgine should not use Izard because it is *Disqualified* for one requirement (RF5) and has no *Strong* scores. Plutchik has a better overall score distribution compared to Ekman & Friesen (7 *Good* scores to 5, and the same number of *Disqualified* and *Strong* scores) and to better support RF5. Oatley & Johnson-Laird already has a *Strong* score for RE2 (Output), so the overall design benefits more from Plutchik than Ekman & Friesen.

- **Dimensional Theory: PAD Space**
  V-A and PAD Space have identical scores, except for one—RF5—which PAD Space scores higher on. Therefore, I chose to use PAD Space for EMgine. If needed, V-A space can be constructed in PAD space due to their overlapping dimensions (Table 7).

Table 7: Comparison of Dimensions in Dimensional Theories

Dimension	**Valence-Arousal (V-A)**	**PAD (Mehrabian, 1996b)**
Pleasure/Valence	✓	✓
Arousal	✓	✓
Dominance		✓

4.2.2 Assumptions

This section helps formalize the original problem to aid the development of types, models, and definitions by filling in the ambiguous and missing information. The numbers given in the square brackets refer to where the assumption appears: Theoretical Model [T], General Definition [GD], Data Definition [DD], Data Type [TY], Instance Model [IM], or Likely Change [LC]. If there are no square brackets next to an assumption, it is generally applicable.

The Conceptual Models (Section 4.2.3) have no related assumptions because they are taken from primary sources, with no attempts at elaboration or disambiguation.

A1: All functions are *total* unless otherwise stated.

A2: Words describing concepts in conceptual models do not necessarily reflect how they are represented in a formal context.

A3: *Cognition* refers to the representation and transformation of knowledge, which might not be concious (Oatley and Johnson-Laird, 1987, p. 30).

A4: The human cognitive system is modular and asynchronous (Oatley and Johnson-Laird, 1987, p. 31).

A5: Each action and/or event that moves an entity towards its goal is a “sub-goal” [T1, LC1].

A6: A goal can elicit multiple emotions simultaneously [T1, LC2].

A7: An entity is in exactly one emotion state at any given time [T1].

A8: Emotion type and intensity do not have to be calculated together [T1, LC3].

A9: Different appraisal processes can elicit different emotions [T1].

A10: For CTE-based emotion kinds, emotion intensity is related to the degree that something impacts a goal and/or plan [T2, LC4].

A11: Emotions with the same or synonymous names in CTE and PES represent the same concept [T1].

A12: *Acceptance* is a “complex” emotion based on *Joy* [T3].

A13: *Interest* is related to the amount of time an entity spends focusing on the same thing [T4, LC5].

A14: *Surprise* is related to event probability [T5].

A15: Emotion decays more quickly the farther it is from the “equilibrium” state [T6, LC6].

A16: Each emotion kind can have its own “equilibrium” value [T6, LC7].

A17: Each emotion kind in a state can decay at its own rate [T6, LC8].

A18: Decay rates and equilibrium values can vary between entities [T6].

A19: An emotion state represents a single point in PAD Space [T7].

A20: Laypeople that judged emotion terms in one of PES and PAD would find that terms used in the other theory would have identical or nearly identical meanings [T7, LC9].

Reasoning This is derived from published, independently run empirical studies by Plutchik (PES) and Mehrabian (PAD) where they were evaluating their own affective models. For this study on emotion language, Plutchik created a list of 145 emotion terms and asked participants judged how "similar" the terms are (Plutchik, 1980, p. 159, 168–170). Terms were then assigned angular placements on a circumplex based on their relative "similarity" to each other. Mehrabian asked participants to judge the contribution of each dimension—*pleasure*, *arousal*, and *dominance*—in the experiences described by 151 terms from which it derived statistical mean and standard deviation values (Mehrabian, 1980, p. 39–45). Reports about the participants in these studies suggest that they were:

- Likely in the same age group (university undergraduates, college and graduate students), and
- Likely had an North American cultural perspective (studies done in the United States).

The publication dates (1980) further suggest that Plutchik and Mehrabian likely conducted their studies around the same time frame. Taken together, this implies that the laypeople in these studies shared common temporal and cultural experiences that would have influenced their interpretation of natural language terms.

A21: The number of ratings and standard deviation do not affect an emotion term's mean values for *pleasure*, *arousal*, and *dominance* [T7, LC10].

A22: Emotion intensities can be continuous values [TY1].

A23: Emotion intensities changes can be positive or negative [TY2].

A24: In PES, all emotion state intensities are zero (0) in the state of "deep sleep" because "deep sleep" implies that the entity lost consciousness (**?**, p. 1–2) and is not experiencing emotion at all. [TY1, TY6, LC11].

A25: In PES, the state of "deep sleep" implies that emotion type pairs are not coupled [TY4, TY5, LC12].

A26: Emotion intensities are finite [TY5].

A27: The environment can be represented by variables and events are changes in those variables [TY10, TY11].

A28: There is an external function `Cost` : $\mathbb{P} \rightarrow \mathbb{R}$ that evaluates the "cost" of the plan such that low costs are desirable [IM4, IM12].

A29: There is an external function `CausedBy` : $\mathbb{S}_{\Delta} \times A \rightarrow \mathbb{B}$ evaluates event causality, returning *True* if the entity believes that A is responsible for causing an event [IM6].

A30: There is an external function of that evaluates an event's probability, which *depends on* the previous WSV because what is "expected" and "unexpected" depends on defined preconditions (e.g. water falling on someone is unexpected on a sunny day bt not on a rainy one). This model assumes that there are exactly two outcomes for any given event—either it happens or it does not. This is for simplicity (**?**, p. 56) and an assumption that users will want more control over entity reactions in complex scenarios. [IM8].

A31: There is an external function `Dist` : $\mathbb{S} \times \mathbb{S} \rightarrow \mathbb{D}$ that evaluates the distance between two world states [IM10].

A32: There is an external user-defined value m_G representing the maximum value that goal importance can be [IM10].

4.2.3 Conceptual Models

This section focuses on descriptions from primary sources that EMgine is based on, included for transparency to ensure a direct connection to the original material. The 13 models are grouped by concern:

1. Emotion structure and types [C1, C2, C3, C4, C5]
2. Emotion generation, intensity, and decay [C6, C7, C8, C9]
3. Knowledge necessary for generating emotion via PES and CTE [C10, C11, C12, C13]

C1	Emotion

Description An emotion is a short-term affective state representing the coordinated physiological and behavioural response of the brain and body to events that an organism perceives as relevant (e.g. it impacts their goals (C10)).

Some researchers hypothesize that each emotion has a *signature* representing the coordinated response pattern it typically causes, including: behavioural and expressional characteristics; somatic and neurophysiological factors that prepare the body for action; cognitive and interpretive evaluations that give rise to the emotion; and experiential and subjective qualities unique to an individual. Elements of the signature can be innate or learned.

Emotion is also characterized by its high intensity relative to other types of affect, its tendency to come and go quickly, its association with a specific triggering event, object, or person, and clear cognitive contents.

CTE states that emotions do not always require cognition, and they do not have a internal symbolic structure that is significant to the system (i.e. non-propositional signals). The signals propagate through the system on a global level, setting and maintaining the system in a mode (emotion "mode").

Source Jeon (2017, p. 4), Scherer (2000, p. 138–140), Broekens (2021, p. 349–350), Frijda (1986, p. 249), Smith and Kirby (2001, p. 121), Hudlicka (2019, p. 133), Scherer (2001, p. 108), Carlson and Hatfield (1992, p. 6), Oatley and Johnson-Laird (1987)

Depends On C10

Ref. By C8, C9, TY5, TY7

C2	Emotion Structure (PES)

Description PES organizes its eight emotion kinds—*Fear*, *Anger*, *Sadness*, *Joy*, *Interest*, *Surprise*, *Disgust*, and *Acceptance*—into a cone (Figure 2).

The emotion types are arranged on a circular plane based on their relative similarity as determined from empirically gathered responses. In this way, emotions considered the most dissimilar appear on opposite sides of the plane. The vertical axis of the solid represents emotional intensity, with the most intense emotions at the top and a state of "deep sleep" at the bottom point. The cone shape implies that the differences between the emotions becomes less distinct at low intensities.

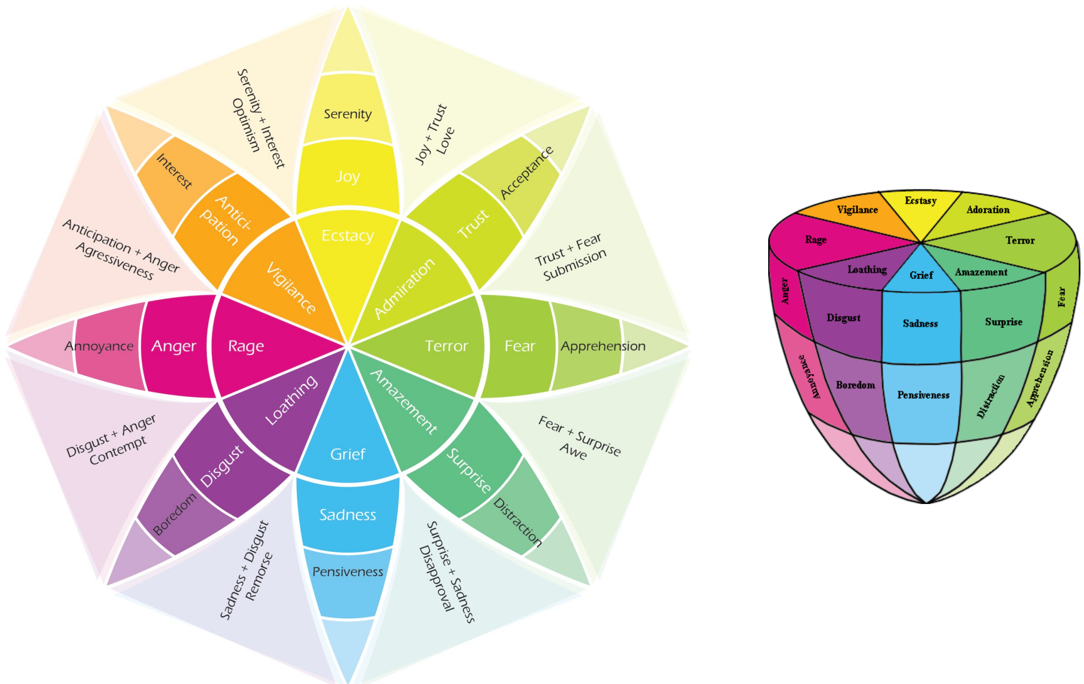

Figure 2: A flattened and 3D view of the Emotion Structure

Source Plutchik (1980); Block (1957); Conte (1976)

Depends On –

Ref. By C3, T7, TY4

C3	**Mixing Emotions (PES)**

Description PES states that complex emotions are mixtures of emotion types and intensity. It uses a colour wheel analogy to describe how to mix them, where Emotion categories are hues and intensity is saturation.

In the PES structural model (C2), the tip of the cone has no colour saturation whereas the circular plane is fully saturated with colour, respectively representing no intensity and full intensity.

Source Plutchik (1980)

Depends On C2

Ref. By R19, R20

C4	"Complex" Emotions (CTE)

Description CTE proposes that "complex" emotions are elaborations of the emotion "modes" (C6), where the system ascribes additional propositional meanings to it. For example, *Disgust* is typically called *Contempt*, *Disdain*, or *Hatred* when felt towards people instead of food, toxins, and/or contamination (Oatley, 1992, p. 60). This also means that "[e]motions are in part socially constructed, but they are constructed around a biological basis." (Oatley, 1992, p. 119)

This often requires a "model of the self" to draw meaning from, developed via individual differences and culture. This model is also tied to the individual's relationships with others (C12).

Source Oatley and Johnson-Laird (1987); Oatley (1992)

Depends On C6, C12

Ref. By T3, R21

C5	PAD Space

Description Based on studies in a variety of related fields with the goal of quantifying different types of affective phenomena (e.g. emotion, core affect, mood, personality), PAD describes describes a small set of nearly orthogonal dimensions for analysing emotional states and behaviours, while as relating them to other affect types and experiences. Points in this space can represent different affective phenomena. The dimensions are present in all affective reactions that are operative in any situation:

- *Pleasure* measures the positive-negative aspects of the emotion state (related to *valence*),
- *Arousal* is how alert and active the individual is in that state, and
- *Dominance* is how much control the individual feels they have in that state.

The range of each dimension is -1 to 1 representing mean ratings for emotion terms. Means are based on ratings from 16 to 31 subjects, transformed to the -1 to 1 scale. Statistical significance—measured from a mean of 0 with ($p > 0.01$)—and standard deviations differ between ratings.

Three dimensions are optimal for general characterizations and measurements of emotional states, as two dimensions cannot distinguish between clusters of affect and additional dimensions added little value to evaluations

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Source Mehrabian (1980, 1996b)

Depends On –

Ref. By T7, TY8

C6	Emotion Modes (CTE)

Description CTE hypothesizes that a system can change its emotion "mode" (i.e. type) at plan junctures, identifiable by changes in the likely success of a plan (C11). These junctures are assumed to be distinctive and recurring. The system enters a "mode" based on the current plan state and if/how goals (C10) are impacted, and form the basis for other emotion "types" (see C4).

Emotion	Juncture of Current Plan	Next State
Happiness	Sub-goals being achieved	Continue, modifying if needed
Sadness	Failure of a major plan or loss of an active goal	Do nothing/Search for a new plan
Anxiety	Self-preservation goal threatened	Stop, Attend to Environment/Escape
Anger	Active plan frustrated	Try harder/Aggress
Disgust	Gustatory goal violated	Reject substance/Withdraw

CTE proposes that the emotion "modes" inhibit each other, and there might also be conflicts that prevent the system from settling into a "mode". Being in an emotion "mode" is a necessary—but not sufficient—condition to experience emotion. A true emotion also requires the assignment of meaning to the "mode" and the scheduling of voluntary actions.

Source Oatley and Johnson-Laird (1987); Oatley (1992)

Depends On C10, C11

Ref. By C4, C7, C8, T1

C7	"Other Emotions"

Description Researchers continue to debate if *Surprise* and *Interest* are "emotions". CTE is unsure of their status, but proposes that:

- *Surprise* "...is elicited by a sudden unexpected event..." (Oatley and Johnson-Laird, 1987, p. 33). This seems to align with the "stopping" behaviour tendencies that PES associates with *Surprise*. Sudden, unexpected events cause *Surprise*, and could represent an interruption and abrupt transition to another emotion "mode" (C6)
- *Interest* "...implies sustained attention to certain external events" (Oatley and Johnson-Laird, 1987, p. 33) (C13). This seems to align with the "starting" behaviour tendencies that PES associates with *Interest*

Both descriptions imply that *Surprise* and *Interest* can coexist with, or are part of, other emotion "modes".

Source Oatley and Johnson-Laird (1987); Oatley (1992), Plutchik (1984)

Depends On C6, C13

Ref. By T4, T5

C8	Emotion Intensity (CTE)

Description Overall, emotion intensity is a relatively understudied topic. CTE proposes that the intensity of an emotion (C1) corresponds to how entrained the system is in a "mode" (C6) and to what degree it is "locked into" it. There appear to be four determinant categories of emotion intensity evaluation:

- How much the entity "values" affected internal conditions (e.g. goals),
- The "seriousness" or "value" of the event that affected those internal conditions,
- Contextual considerations of elements such as coping, support, and unexpectedness, and
- The entity's personality attributes that affect factors such as emotion response thresholds and dispositions towards different emotions.

Source Frijda et al. (1992); Oatley and Johnson-Laird (1987); Oatley (1992)

Depends On C1, C6

Ref. By T2

C9	Emotion Decay

Description Emotions (C1) do not last indefinitely—they dissipate after a time, implying the presence of an emotion decay mechanism. This requires a specification of baseline values for each emotion and as well as one or more decay functions.

Source Broekens (2021)

Depends On C1

Ref. By T6

C10	Goals

Description Goals compel systems to act in ways that achieve a desired objective. They are essential for emotion processing, identifying what elements of the current world state are relevant to an individual rather than relying on properties of the environment alone. Entities use goals to know when events impact them and by how much. Goals are also connected to emotions, partially motivating emotion-driven behaviours.

PES describes goals as being in service to global adaptational problems, whereas CTE view them as symbolic representations of possible environmental states that a system wants to achieve.

Source Smith and Kirby (2009a), Broekens et al. (2016, p. 223), Plutchik (1980); Oatley and Johnson-Laird (1987), Ortony (2002, p. 208)

Depends On –

Ref. By C1, C6, C11, T1, TY14

C11	Plans (CTE)

Description CTE describes plans as sequences of transformations between symbolic representations of possible environmental states, linking the current state to a goal (C10). To "make" a plan is to create a sequence of transformations, and to "execute" the plan is to enact the sequence in the world.

A system forms plans with imperfect and incomplete knowledge of the environment, and often only looks one or two steps ahead.

Source Oatley and Johnson-Laird (1987)

Depends On C10

Ref. By C6, T1, TY15

C12	Social Relationship

Description CTE states that many emotions are social, occurring in the course of one's relationships with others. This allows them to construct mutual plans to coordinate the actions of multiple actors, which also requires each actor to have a "model of the self".

The emotion of *Acceptance* (i.e. *Trust*)—an elementary component of social life—in PES also implies the existence of relationships with others. "Affective trust" builds on past experiences with, feelings of security, confidence, and satisfaction towards, and the perceived level of selfless concern demonstrated by a partner regardless of what the future holds. The biological basis of affective trust might lie in social attachment and affiliation due to the role of oxytocin.

A social relationship is a representation of the history shared between the individual and another person, entity, or thing. They can be established implicitly based on precedents and customs (i.e. culture).

Source Oatley and Johnson-Laird (1987); Fehr and Zehnder (2009); Rempel et al. (1985)

Depends On –

Ref. By C4, T3, TY16

C13	Attention

Description Attention is a set of mechanisms that allow a limited-capacity system to select salient or goal-relevant information. These mechanisms might work in parallel. Behavioural effects of attention vary between systems, partially due to personality.

Source Vuilleumier (2009)

Depends On –

Ref. By C7, TY17

4.2.4 Theoretical Models

These models refine the Conceptual Models (Section 4.2.3) using natural language to improve their precision. This is a necessary step for reducing ambiguity by explicitly stating how the primary sources are understood and showing how they relate to the mathematically-defined Data Types (Section 4.2.7) and Instance Models (Section 4.2.8) using Assumptions (Section 4.2.2).

T1	Evaluate Emotion Kind from Goals and Plans

Description The emotion kinds ("modes") that CTE defines (C6) that overlap with PES (A11)—*Happiness*, *Sadness*, *Fear*, *Anger*, *Disgust*—in terms of goals (C10) and plans (C11) can be re-conceptualized as:

- *Joy* (*Happiness*) occurs when an event transitions the previous world state to the current world state such that there is a change in the distance to a goal state where there is less distance between it and the current world state compared to the distance between it and the previous world state (i.e. a "sub-goal" of the goal, A5)

- *Sadness* occurs when an event transitions the previous world state to the current world state such that there is an unreachable plan state, implying that the plan is no longer viable, or when the distance from the current world state to a goal state is insurmountably large, implying that it is not possible to reach that goal state (i.e. "lost")

- *Fear* (*Anxiety*) occurs when a potential event transitions the current world state to a future world state where the distance between the future world state and a goal state is larger than the distance from the current world state and a goal state for a goal of type "Self-Preservation" OR it is impossible to satisfy the desired states of two different goals

- *Anger* occurs when an event transitions the previous world state into the current world state that is not part of the entity's plan, but there is a series of events that transitions the current world state to another state that makes progress in the entity's plan

- *Disgust* occurs when an event transitions the previous world state, where the entity's gustatory goal was satisfied, to the current world state that dissatisfies the goal such that the distance between the goal state and the current world state is larger than the distance to the previous world state

If an event elicits multiple emotions (A6), they all contribute to a single emotion state (A7).

Emotion intensity is evaluated separately (A8, see T2). The emotions *Surprise*, *Interest*, and *Acceptance* are evaluated differently because they are not part of CTE's primary emotions (A9, see T5, T4, and T3 respectively).

Sources –

Depends On A5, A6, A7, A8, A9, A11, C6, C10, C11

Ref. By TY14, IM1, IM2, IM3, IM4, IM5, IM9, IM10, IM11, IM12, IM13

T2	Evaluate Emotion Intensity (CTE)

Description Of the four identified factors of emotion intensity (C8), only the value of the internal condition and the event are within EMgine's scope. Users can extend EMgine's intensity evaluations by integrating contextual considerations and/or personality attributes to the evaluation after getting the initial evaluation.

Emotion intensity is proportional to the force causing an emotion state ("entrained") and how fixed or non-adjustable that force is ("locked in"). From this, EMgine assumes that emotion intensity directly relates to the degree that something impacts a goal or plan such that an entity would want to maintain the momentum caused by an emotion "mode" as long as that goal and/or plan is affected (A10). This aligns with the idea of an affected "internal condition".

Sources –

Depends On A10, C8

Ref. By TY1, IM9, IM10, IM11, IM12, IM13

T3	Evaluate *Acceptance* Elicitation and Intensity

Description CTE define "emotions of attachment" as an example of infant-level social emotions, linking them to the "basic" emotion *Happiness*. Therefore, EMgine takes the proposal that Trust is *Happiness* elaborated with information about social attachment (A12).

Taking *Acceptance* as a "complex" emotion (C4), it can be defined as *Joy* (*Happiness*) elaborated with information about social relationships (C12) such that an entity experiences *Acceptance* when *an event transitions the previous world state to the current world state such that there is a change in the distance to a goal state where there is less distance between it and the current world state compared to the distance between it and the previous world state AND a socially-relevant entity caused the event*. An entity might also establish a relationship with another entity that is attributed with causing the state, which would also elicit *Acceptance*.

For intensity, this implies that it is proportional to the intensity of *Joy* and the strength of the relationship with the entity that the state is attributed to.

Sources Oatley (1992, p. 178–179, 192)

Depends On A12, C4, C12

Ref. By TY1, IM6, IM14

T4	**Evaluate *Interest* Elicitation and Intensity**

Description “Sustained attention to certain external events” (C7) implies that it occurs when an entity is focused on the same thing (e.g. task, another entity) for an extended period of time (A13). From this, and ignoring the implied limitation to events, EMgine conceives *Interest* as an evaluation where: *a significant amount of attention is paid to something*. This suggests that there is a “baseline” amount of attention/time paid to something before it triggers *Interest*, which can differ between foci.

For intensity, this implies that it is proportional to the amount of time spent focused on the same thing and relative to the “baseline” time spent.

Sources –

Depends On A13, C7

Ref. By TY1, IM7, IM15

T5	**Evaluate *Surprise* Elicitation and Intensity**

Description The description of *Surprise* (C7) needs clarification about what is meant by a “sudden unexpected” event. Researchers have proposed that events appraised to be a contradiction of explicitly or implicitly held expectations and beliefs elicit *Surprise*, which lab-based experiments found convincing supporting evidence. Quantitative models of *Surprise* intensity rely on event probabilities such that an “unexpected” event is an improbable one, and assume that intensity increases monotonically with the degree of unexpectedness. This has no obvious conflicts with CTE’s concept of emotions as system-wide nonpropositional communication signals, EMgine conceives Surprise as an evaluation where *a significantly-improbable event happens* (A14).

Sources ?

Depends On A14, C7

Ref. By TY1, IM8, IM16

T6	Decaying Emotion State

Description Emotion decay (C9) is a function of time such that the emotion state returns to its "equilibrium" intensities as time progresses. It is assumed that:

- The speed that intensities return to "equilibrium" are assumed to be functions of distance such that larger differences between an intensity and its "equilibrium" cause larger changes in intensity (A15)
- Each emotion kind has its own "equilibrium" value (A16) and can decay at different rates (A17), allowing entities to vary the length of time it takes for them to return to "normal" variations between emotion kinds (e.g. if they experience *Joy* they might extend that state by prolonging the decay to "equilibrium")
- Decay rates and equilibrium values can differ between entities (A18)

Sources –

Depends On A15, A16, A17, A18, C9

Ref. By TY3, TY6, IM17

T7	Getting an Emotion State as a PAD Point

Description Assuming that an entity can only occupy one point in PAD Space at any given time (A19), the intensities for each discrete emotion in an emotion state must be combined into a single value for each dimension in the space. However, there is no direct mapping between these spaces. EMgine must define reference points in PAD Space for each emotion kind in the PES structure (C2), effectively "mapping" them to PAD points. EMgine's approach for this heavily relies on the comparison of emotion terms in each model for equal or comparable semantic meaning, which is both subjective and error-prone. Unfortunately, there does not appear to be a more reliable alternative.

From Plutchik's list of emotion terms and angular placements (Plutchik, 1980, p. 170), assumed to have identical or nearly identical meanings to PAD terms (A20), EMgine defines eight "boundaries" around circumplex areas for each of its emotion kinds. "Boundary" terms are those where the perceived qualitative meaning changes between it and the next listed term (Table 8, Figure 3). For example, the change from "Attentive" to "Joyful" distinguishes a "boundary" between the *Interest* and *Joy* areas because they do not "feel" like they have the same qualitative meaning (i.e. "Joyful" implies a higher degree of pleasantness than "Attentive", which does not imply either pleasantness or unpleasantness). This mimics the idea of discrete emotion "families" such that EMgine can use one affective term to specify a PAD Space reference point to serve as the emotion "family"'s dimensional representation (Figure 4). Gaps between "boundary" terms are inevitable due to the discrete nature of angular placements. However, they are relatively small (between 0.3° and 7.3°), so EMgine ignored them instead of trying to compensate for them to avoid introducing additional "translation errors".

EMgine compiled eight lists—one for each derived circumplex "area"—of exact or nearly exact matches of emotion terms in Plutchik and PAD Space (Table 9). EMgine takes a single term from each list as its

PAD Space reference point for that Plutchik emotion, giving preference to PAD terms that have statistically significant means ($p < 0.01$) for each dimension, then to semantically equivalent terms. If there was no term equivalence, EMgine took the term closest to the midpoint of the Plutchik circumplex "area". EMgine ignores number of ratings and standard deviation of PAD terms for simplicity (A21). All terms achieved significance for *pleasure* and *arousal*. *Interested* and *Disgust* are not statistically significant for *dominance*.

An emotion term's *pleasure*, *arousal*, and *dominance* mean values (C5) form a reference point. Number of ratings and standard deviation do not affect reference points.

$k \in \mathbb{K}$	**PES** Range on Circumplex (°)	Term	Circumplex Location (°)	PAD Ref. #
Fear	[65.0, 86.0]	Terrified	75.5	102
Anger	[200.6, 249.0]	Angry	212.0	82
Sadness	[88.3, 138.0]	Sad	108.5	151
Joy	[323.4, 338.3]	Joyful	323.4	20
Interest	[249.7, 322.4]	Interested	315.7	8
Surprise	[138.3, 156.7]	Astonished	148.0	74
Disgust	[160.3, 193.7]	Disgusted	161.3	75
Acceptance	[340.7, 57.7]	Affectionate	52.3	34

Sources Mehrabian (1980, p. 40, 42–45), Plutchik (1980, p. 159, 170)

Depends On A19, A20, A21, C2, C5

Ref. By IM24

Table 8: Summary of EMgine-defined Areas on the PES Circumplex Structure based on Plutchik's Empirical Data

Label	**Range** (°)	**Midpoint** (°)
Acceptance	[340.7, 57.7]	19.20
Fear	[65.0, 86.0]	75.50
Sadness	[88.3, 138.0]	113.15
Surprise	[138.3, 156.7]	147.50
Disgust	[160.3, 193.7]	177.00
Anger	[200.6, 262.0]	231.30
Interest	[249.7, 322.4]	286.05
Joy	[323.4, 338.3]	330.85

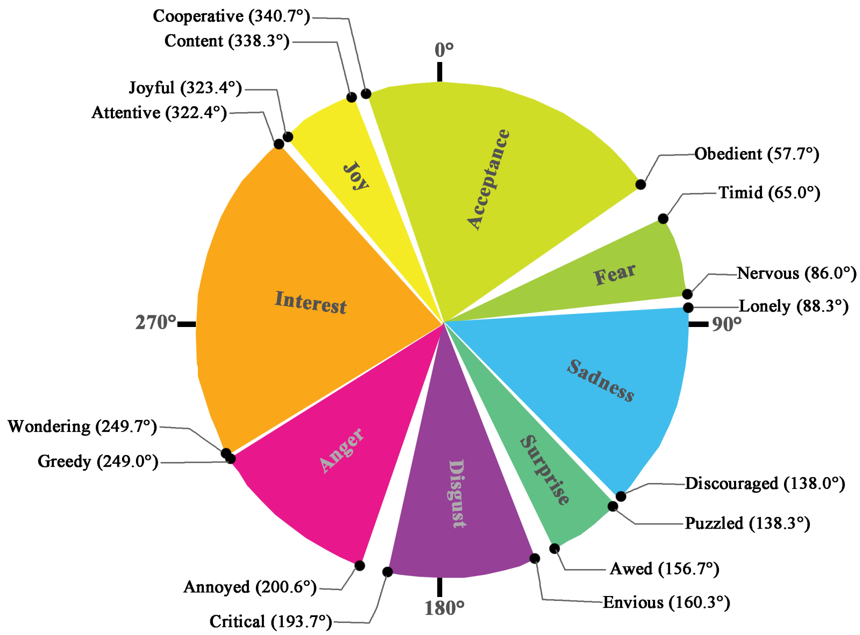

Figure 3: EMgine-Specific Emotion Kind Boundaries on the PES Circumplex Structure based on Plutchik's Empirical Data

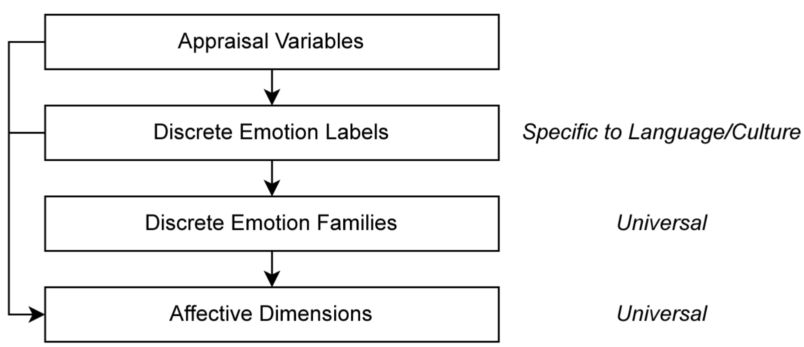

Figure 4: Mapping Data Between Perspectives, Adapted from Scherer (2010, p. 15)

Table 9: Emotion Terms in Both PES and PAD Space with their Associated Empirical Data from Each

Plutchik			PAD Space								
						P		A		D	
Area	**Term**	**Angle**	**Term**	**#**	**N**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Acceptance	Affectionate	52.3°	Affectionate	34	29	0.64*	0.26	0.35*	0.34	0.24*	0.40
	Cooperative	340.7°	Cooperative	43	31	0.39*	0.32	0.13*	0.27	0.03	0.34
Fear	Anxious	78.3°	Anxious	50	28	0.01	0.45	0.59*	0.31	-0.15	0.32
	Humiliated	84.0°	Humiliated	99	27	-0.63*	0.18	0.43*	0.34	-0.38*	0.30
	Terrified	75.7°	Terrified	102	29	-0.62*	0.20	0.82*	0.25	-0.43*	0.34
	Helpless	80.0°	Helpless	104	29	-0.71*	0.18	0.42*	0.45	-0.51*	0.32
	Embarrassed	75.3°	Embarrassed	110	29	-0.46*	0.30	0.54*	0.26	-0.24*	0.40
	Shy	72.0°	Shy	117	29	-0.15	0.33	0.06	0.30	-0.34*	0.28
	Timid	65.0°	Timid	131	28	-0.15	0.41	-0.12	0.37	-0.47*	0.31
Sadness	Gloomy	132.7°	Solemn	72	29	0.03	0.39	-0.32*	0.26	-0.11	0.33
	Grief-Stricken	127.3°	Anguished	107	29	-0.50*	0.30	0.08	0.46	-0.20*	0.34
	Guilty	102.3°	Guilty	118	29	-0.57*	0.19	0.28*	0.38	-0.34*	0.28
	Remorseful	123.3°	Regretful	123	30	-0.52*	0.24	0.02	0.32	-0.21*	0.28
	Depressed	125.3°	Depressed	126	27	-0.72*	0.21	-0.29*	0.44	-0.41*	0.28
	Despairing	133.0°	Despairing	127	27	-0.72*	0.21	-0.16	0.34	-0.38*	0.25
	Lonely	88.3°	Lonely	128	29	-0.66*	0.35	-0.43*	0.36	-0.32*	0.30
	Meek	91.0°	Meek	129	29	-0.19	0.58	-0.25*	0.32	-0.41*	0.42
	Bored	136.0°	Bored	132	28	-0.65*	0.19	-0.62*	0.24	-0.33*	0.21
	Rejected	136.0°	Rejected	137	29	-0.62*	0.24	-0.01	0.38	-0.33*	0.27
	Discouraged	138.0°	Discouraged	150	30	-0.61*	0.25	-0.15	0.32	-0.29*	0.32
	Sad	108.5°	Sad	151	30	-0.63*	0.23	-0.27*	0.34	-0.33*	0.22
Surprise	Surprised	146.7°	Surprised	52	29	0.40*	0.30	0.67*	0.27	-0.13	0.38
	Awed	156.7°	Awed	56	30	0.18*	0.34	0.40*	0.30	-0.38*	0.21
	Astonished	148.0°	Astonished	74	30	0.16*	0.26	0.88*	0.19	-0.15*	0.26
	Confused	141.3°	Confused	121	30	-0.53*	0.20	0.27*	0.29	-0.32*	0.28
Disgust	Disgusted	161.3°	Disgusted	75	29	-0.60*	0.20	0.35*	0.41	0.11	0.34
	Contemptuous	192.0°	Contempt	85	29	-0.23*	0.39	0.31*	0.33	0.18*	0.29
	Suspicious	182.7°	Suspicious	90	29	-0.25*	0.23	0.42*	0.21	0.11	0.32
	Distrustful	185.0°	Skeptical	91	29	-0.22*	0.28	0.21*	0.25	0.03	0.33
	Displeased	181.5°	Displeased	109	29	-0.55*	0.21	0.16	0.34	-0.05	0.41
	Indignant	175.0°	Quietly Indignant	114	26	-0.28*	0.35	0.04	0.36	-0.16	0.40
	Dissatisfied	183.0°	Dissatisfied	122	30	-0.50*	0.22	0.05	0.28	0.13	0.32

Table 9: *(Continued)* Emotion Terms in Both PES and PAD Space with their Associated Empirical Data from Each

Plutchik			**PAD Space**								
						P		**A**		**D**	
Area	**Term**	**Angle**	**Term**	**#**	**N**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Anger	Aggressive	232.0°	Aggressive	13	28	0.41*	0.30	0.63*	0.25	0.62*	0.24
	Irritated	202.3°	Irritated	78	29	-0.58*	0.16	0.40*	0.37	0.01	0.40
	Defiant	230.7°	Defiant	79	28	-0.16*	0.30	0.54*	0.37	0.32*	0.42
	Hostile	222.0°	Hostile	81	29	-0.42*	0.31	0.53*	0.36	0.30*	0.32
	✍Angry	212.0°	Angry	82	29	-0.51*	0.20	0.59*	0.33	0.25*	0.39
	Annoyed	200.6°	Mildly Annoyed	83	29	-0.28*	0.16	0.17*	0.28	0.04	0.31
	Furious	221.3°	Enraged	84	29	-0.44*	0.25	0.72*	0.29	0.32*	0.44
	Scornful	227.0°	Scornful	89	28	-0.35*	0.21	0.35*	0.27	0.29*	0.32
Interest	Adventurous	270.7°	Bold	1	27	0.44*	0.32	0.61*	0.24	0.66*	0.30
	Proud	262.0°	Proud	7	29	0.77*	0.21	0.38*	0.34	0.65*	0.33
	✍Interested	315.7°	Interested	8	29	0.64*	0.20	0.51*	0.21	0.17	0.40
	Elated	311.0°	Elated	17	28	0.50*	0.47	0.42*	0.14	0.23*	0.36
	Hopeful	298.0°	Hopeful	18	29	0.51*	0.30	0.23*	0.33	0.14	0.41
	Wondering	249.7°	Wonder	54	30	0.27*	0.37	0.24*	0.35	-0.17*	0.26
	Curious	261.0°	Curious	58	28	0.22*	0.30	0.62*	0.20	-0.01	0.34
Joy	✍Joyful	323.4°	Joyful	20	29	0.76*	0.22	0.48*	0.26	0.35*	0.31
	Happy	323.7°	Happy	31	29	0.81*	0.21	0.51*	0.26	0.46*	0.38

N *Number of Ratings*
SD *Standard Deviation*
* *Statistically Significant* ($p > 0.01$)
✍ *Chosen term*

4.2.5 General Definitions

No additional information is required to build the data definitions.

4.2.6 Data Definitions

No data definitions are needed.

4.2.7 Data Types

This section defines types for realizing EMgine's Instance Models (Section 4.2.8). Data types also allow for type checking to verify and enforce constraints (Section 4.2.9), and defining model interfaces.

Data types TY9, TY10, TY11, TY12, TY13, TY14, TY15, TY16, and TY17 are APIs for users to implement for their specific needs.

- TY9, TY10, TY11, TY12, TY13, and TY14 are mandatory
- TY15 is optional, but necessary for modelling *Anger* and using the complete *Sadness* model
- TY16 is optional, but necessary for modelling *Acceptance*
- TY17 is optional, but necessary for modelling *Interest*

TY1	**Type of Emotion Intensity**
Symbol	$\mathbb{I}$
Type	$\mathbb{R}_{\geq 0}$

Description Emotion intensity (T2, T3, T4, T5) is a non-negative real value (A22, A24).

Sources –

Depends On A22, A24, T2, T3, T4, T5

Ref. By TY2, TY5, TY6, IM17, IM18, R2, R19, R20

TY2	**Type of Emotion Intensity Change**
Symbol	$\mathbb{I}_\Delta$
Type	$\mathbb{R}$

Description A change in emotion intensity represents the magnitude of a difference to be applied to an emotion intensity (TY1). It is a real value because:

- Emotion intensity is assumed to both increase and decrease (A23), and
- The magnitude of a change should not be explicitly coupled to fit the type of $\mathbb{I}$

Sources –

Depends On A23, TY1

Ref. By IM9, IM10, IM11, IM12, IM13, IM14, IM15, IM16, IM18, IM19, R3

TY3	**Type of Emotion Intensity Decay Rate**
Symbol	$\mathbb{I}_\lambda$
Type	$\mathbb{R}_{>0}$

Description Emotion decay rate (T6) is a real-valued, strictly positive constant. It is equivalent to the spring constant k_s in a damped harmonic oscillator, which is always strictly positive.

Note that this tightly couples the emotion decay model (IM22) with the data type such that changing the underlying model of one likely means changing the other as well.

Sources `https://en.wikipedia.org/wiki/Harmonic_oscillator#Damped_harmonic_oscillator`

Depends On T6, IM17

Ref. By TY6, IM17, R4

TY4	**Type of Emotion Kinds**
Symbol	$\mathbb{K}$
Type	⟨`Fear`, `Anger`, `Sadness`, `Joy`, `Interest`, `Surprise`, `Disgust`, `Acceptance`⟩
Invariants	• $\mathbb{K}$ is finite and ordered • Each element of $\mathbb{K}$ is uniquely paired with exactly one other element that is not itself

Description Emotion kinds is an enumeration representing the PES emotion kinds (C2). "Opposing" emotions as defined in PES are enforced via the invariant regarding unique pairings. They are not functionally paired such that the experience of one reduces the experience of the other because it would make a state of "deep sleep" impossible (A25).

Defining Emotion Kinds independently of Emotion Intensity (TY1) allows them to be theory-agnostic (i.e. not strictly tied to PES). This means that EMgine can still be functional if there is *some* definition for Emotion Kinds, which could have differing types and number labels than PES.

Sources –

Depends On A25, C2

Ref. By TY5, TY6, IM19, R5, R19, R20, R21

TY5	**Type of Emotion State**
Symbol	$\mathbb{ES}$
Type	$\{\texttt{intensities} : \mathbb{K} \rightarrow \mathbb{I}, \texttt{max} : \mathbb{K} \rightarrow \mathbb{I}\}$
Invariant	$\forall k : \mathbb{K} \Rightarrow 0 \leq \texttt{intensities}(k) \leq \texttt{max}(k)$

Description An emotion state is a record with:

- A function `intensities` mapping Emotion Kinds (TY4) to Emotion Intensities (TY1), representing the current intensity of each emotion kind in the state. This is similar to a vector of intensity values, which Computational Models of Emotion commonly use to represent affective states.
- A function `max` mapping Emotion Kinds (TY4) to a maximum intensity value (TY1). This encodes a maximum intensity for each emotion kind individually, allowing users to vary this value between emotion kinds in a state. Storing maximum intensities in the Emotion State Data Type localizes these constraints to a specific state, allowing the maximum intensities of other states to vary. This also makes it easy to ensure that its constraints are satisfied when updating `intensities`.

The invariant ensures that emotion intensity is finite (A26). Each element in $\mathbb{ES}$ is independent (A25, C1).

Sources Broekens (2021, p. 358)

Depends On A25, A26, C1, TY1, TY4

Ref. By TY7, IM19, IM20, IM21, IM22, IM24, R6

TY6	**Type of Emotion Decay State**
Symbol	$\mathbb{ES}_\lambda$
Type	$\{\texttt{equilibrium} : \mathbb{K} \rightarrow \mathbb{I}, \texttt{decayRates} : \mathbb{K} \rightarrow \mathbb{I}_\lambda\}$
Invariants	$\left(\sum_{k \in \mathbb{K}} \texttt{equilibrium}(k)\right) > 0$

Description Emotion state decay (T6) is a record tied to Emotion State via $\mathbb{K}$ (TY4) that has:

- The function `equilibrium` maps Emotion Kinds to Emotion Intensities ($\mathbb{K} \rightarrow \mathbb{I}$, TY1), encoding the "equilibrium" intensity for each $k : \mathbb{K}$. It must satisfies the invariant to prevent situations where every value in `equilibrium` is zero (i.e. constantly zero, A24), assumed to be a state of "deep sleep". Therefore, at least one emotion type in the equilibrium state must be non-zero for the entity to be "awake".

- The function `decayRates` maps Emotion Kinds to Emotion Intensity Decay Rates ($\mathbb{K} \rightarrow \mathbb{I}_{\lambda}$, TY3), encoding the decay rate for each emotion kind. This allows users to vary decay rates between kinds (T6).

Collecting this information into Emotion Decay State makes it easier to maintain and access for automating a decay process (RE5).

Sources –

Depends On A24, T6, TY1, TY3, TY4

Ref. By IM22, IM23, R7

TY7	Type of Emotion
Symbol	$\mathbb{E}$
Type	$\mathbb{T} \rightarrow \mathbb{ES}$

Description Emotion $\mathbb{E}$ (C1) is the assignment of an emotion state $\mathbb{ES}$ (TY5) to an instant in time $t : \mathbb{T}$ (TY9).

Sources –

Depends On C1, TY5, TY9

Ref. By IM20, IM21, IM23, R8

TY8	Type of PAD Point
Symbol	$P_{(P,A,D)}$
Type	$(\texttt{pleasure} : [-1, 1] \subset \mathbb{R}, \texttt{arousal} : [-1, 1] \subset \mathbb{R}, \texttt{dominance} : [-1, 1] \subset \mathbb{R})$

Description A PAD point (C5) is a 3-tuple representing a point in the space defined by the *pleasure* (P), *arousal* (A), and *dominance* (D) dimensions (T7).

Sources Mehrabian (1980)

Depends On C5

Ref. By IM24, R9

TY9	**Type of Time and Delta Time**
Symbol	$\mathbb{T}, \mathbb{T}_{\Delta}$
Type	–

Description Time is an abstract type that is linearly ordered. A Delta Time is the difference between two Time values.

Sources –

Depends On –

Ref. By TY7, TY17, IM17, IM20, IM21, IM22, IM23, R10

TY10	**Type of Game World State View (WSV)**
Symbol	$\mathbb{S}$
Type	–

Description A world state "view" is a subset of the game world state $\mathbb{W}$, an abstract type describing a configuration of game world characters, objects, and variables (A27). A subset is sufficient because entities only need to know aspects that are relevant to them, which is frequently only a portion of $\mathbb{W}$.

Sources –

Depends On A27

Ref. By TY12, TY13, TY14, TY15, IM1, IM2, IM3, IM4, IM5, IM6, IM8, IM10, R11

TY11	**Type of Game World Event**
Symbol	$\mathbb{S}_{\Delta}$
Type	–

Description A game world event is an abstract type describing a game action that changes a game world's configuration of characters, objects, and/or variables. An event is a subset of elements in a WSV (TY10) because evaluations only need to know about "changing" aspects relevant to the entity.

EMgine evaluates the next WSV caused by an event by applying the event to the current WSV $\mathbb{S} \times \mathbb{S}_\Delta$. EMgine evaluate this as $s \oplus s_\Delta$, shorthand for `apply`(x, y), which is a function that changes x by y (A27).

Sources –

Depends On A27

Ref. By TY13, TY14, TY15, IM1, IM2, IM3, IM4, IM5, IM6, IM8, R12

TY12	**Type of Distance Between Two Game World States**
Symbol	$\mathbb{D}$
Type	–

Description The distance between two WSVs $s_x : \mathbb{S}$ and $s_y : \mathbb{S}$ (TY10) is an abstract type describing the difference between each configuration element in s_x and s_y.

Sources –

Depends On TY10

Ref. By TY14, IM1, IM2, IM3, IM13, R13

TY13	**Type of Change in Distance of a Game World State**
Symbol	$\mathbb{D}_\Delta$
Type	–

Description A change in distance of a WSV $s : \mathbb{S}$ (TY10) caused by a game world event $s_\Delta : \mathbb{S}_\Delta$ (TY11) is an abstract type describing the magnitude of change that s_Δ causes in s.

Sources –

Depends On TY10, TY11

Ref. By TY14, IM1, IM2, IM3, IM5, IM6, IM9, IM11, IM14, R14

TY14	**Type of a Goal**
Symbol	$\mathbb{G}$
Type	$\{\texttt{goalState} : \mathbb{S} \rightarrow \mathbb{B}, \texttt{goal} : \mathbb{S} \rightarrow \mathbb{D}, \texttt{goal}' : \mathbb{S} \times \mathbb{S}_\Delta \rightarrow \mathbb{D}_\Delta, \texttt{importance} : \mathbb{R}_{\geq 0}, \texttt{type} \subseteq \{\texttt{SelfPreservation}, \texttt{Gustatory}\}\}$

Description A goal (C10) is represented by:

- The `goalState` predicate represents the entity's desired WSV $\mathbb{S}$ (TY10). If they are not already in `goalState` and striving to maintain it, they are in another state and want to move towards or away from `goalState`.
- The function `goal` maps a WSV $\mathbb{S}$ to a distance $\mathbb{D}$ (TY12) between it and `goalState` to measure the difference between the current WSV and desired one.
- The function `goal′` is the derivative of `goal`, measuring a change in the distance $\mathbb{D}_\Delta$ (TY13) to `goalState` when a WSV $s : \mathbb{S}$ is changed by a game event $s_\Delta : \mathbb{S}_\Delta$ (TY11).
- The goal's perceived relative `importance` to the entity such that higher values reflect a higher importance, mimicking an individual's tendency to be motivated to achieve higher importance goals over lower importance ones. If this is set to zero, EMgine assumes that the goal has no importance to the entity and does not trigger emotion processes when affected by world events.
- CTE's descriptions of emotion-elicitation conditions imply that goals can be assigned the types of *Self-Preservation* and/or *Gustatory* (T1). Goal `type` stores this information, allowing a goal to have none, one, or both of these types.

Sources Broekens (2021, p. 361), Izard (1977, p. 204)

Depends On C10, T1, TY10, TY11, TY12, TY13

Ref. By IM1, IM2, IM3, IM5, IM6, IM9, IM10, IM11, IM13, R15

TY15	**Type of Plan**
Symbol	$\mathbb{P}$
Type	$\{\texttt{actions} : (\mathbb{S}_{\Delta 1}, ..., \mathbb{S}_{\Delta n}), \texttt{toProgress} : ((\mathbb{S} \rightarrow \mathbb{B})_0, ..., (\mathbb{S} \rightarrow \mathbb{B})_n), \texttt{nextStep} : \mathbb{S} \times \mathbb{N} \rightarrow \mathbb{S}, \texttt{isFeasible} : \mathbb{S} \rightarrow \mathbb{B}\}$ where $n : \mathbb{N}_{>0}$, $\texttt{nextStep}(s : \mathbb{S}, i : \mathbb{N}) = \begin{cases} s, & i = 0 \\ \texttt{nextStep}(s, i) \oplus \texttt{planActions}(i), & \textit{Otherwise} \end{cases}$, and $\texttt{isFeasible}(s : \mathbb{S}) = \bigwedge_{i=0}^{n} \texttt{toProgress}(i, \texttt{nextStep}(s, i))$

Description A plan (C11) is represented by:

- A sequence of `actions` as world events (TY11) such that applying them to an initial WSV (TY10) generates a series of "good" WSVs that satisfy a sequence of predicates on them representing plan progression (`toProgress`), where each element in `actions` is something the entity can do (i.e. there are no elements in `actions` that the entity believes are impossible)
- At some step $i : \mathbb{N}$, the function `nextStep` evaluates the next WSV in the plan by applying the *ith* plan action to the *ith* `nextStep` where `nextStep`$(s, 0)$ is the initial state $s : \mathbb{S}$
- A constant `isFeasible` generated by checking that, for each step $i : \mathbb{N}$ starting from $i = 0$ and a WSV $s : \mathbb{S}$, each evaluation of `nextStep`(s, i) satisfies the *ith* condition in `toProgress`

The Plan Data Type is not explicitly connected to the Goal type so that users can apply it to entity plans that are not oriented towards an EMgine-specific goal $\mathbb{G}$ (TY14).

Sources –

Depends On C11, TY10, TY11

Ref. By IM2, IM4, IM10, IM12, R16

TY16	**Type of Social Attachment**
Symbol	$\mathbb{SA}$
Type	$\mathbb{Z}$

Description A social attachment is an extensible type containing a "degree" or "level" of attachment to some other entity A. A social attachment is linearly ordered such that higher "degrees" or "levels" represents a closer attachment to A which can reflect a "history" with A (C12).

Since Social Attachment is just an association between two entities, what users take as the "other" entity need not be limited to other characters—it could refer to objects, actions, or other game elements.

Sources Broekens (2021, p. 359–360)

Depends On C12

Ref. By IM6, IM14, R17

TY17	**Type of Attention**
Symbol	$\mathbb{AT}_x$
Type	$\mathbb{T}_\Delta$

Description Attention (C13) is an extensible type containing the number of consecutive time steps $t : \mathbb{T}_\Delta$ (TY9) that have elapsed while focusing on some x.

Sources –

Depends On C13, TY9

Ref. By IM7, IM15, R18

4.2.8 Instance Models

Instance Models refine the Theoretical Models (Section 4.2.4) into mathematical representations using Assumptions (Section 4.2.2) and Data Types (Section 4.2.7). These models address EMgine's Goals (Section 4.1.3):

- GS1 is addressed by IM1, IM2, IM3, IM4, IM5, IM6, IM7, and IM8
- GS2 is addressed by IM9, IM10, IM11, IM12, IM13, IM14, IM15, and IM16
- GS3 is addressed by IM17, IM22, and IM23
- GS4 is addressed by IM18, IM19, and IM20
- GS5 is addressed by IM21 and IM24

IM1	**Evaluate *Joy* Elicitation**
Input	$g : \mathbb{G}, s_{prev} : \mathbb{S}, s_{\Delta} : \mathbb{S}_{\Delta}, \epsilon_J : \mathbb{D}_{\Delta}$
Output	$(dist_{prev} : \mathbb{D}, dist_{now} : \mathbb{D}, dist_{\Delta} : \mathbb{D}_{\Delta})^? \stackrel{\circ}{=} J$

$$\text{where } J = \begin{cases} (g.\texttt{goal}(s_{prev}), \\ g.\texttt{goal}(s_{prev} \oplus s_{\Delta}), & g.\texttt{goal}(s_{prev}) > g.\texttt{goal}(s_{prev} \oplus s_{\Delta}) \\ g.\texttt{goal}'(s_{prev}, s_{\Delta})), & \wedge \,|\, g.\texttt{goal}'(s_{prev}, s_{\Delta}) \,|\, > \epsilon_J \\ \text{None}, & \textit{Otherwise} \end{cases}$$

Description Given an entity goal (TY14), the *previous WSV* (TY10), an event that transformed the *previous WSV* into the current one (TY11), and a "tolerance" threshold for distance changes between WSVs (TY13), evaluate the elicitation of *Joy* (T1) by determining if the event progresses the entity *towards* goal achievement by evaluating if the distance to the goal state (TY12) is larger in the *previous WSV* unchanged by the event compared to the WSV changed by the event ($g.\texttt{goal}(s_{prev}) > g.\texttt{goal}(s_{prev} \oplus s_{\Delta})$) such that it causes a noticeable change in distance to a goal from a WSV by evaluating if its magnitude exceeds a minimum "threshold" ($|\, g.\texttt{goal}'(s_{prev}, s_{\Delta}) \,| > \epsilon_J$).

If the condition fails, the function returns None because the event did not elicit *Joy* for this goal.

The threshold ϵ_J controls the entity's "sensitivity" to changes such it experiences *Joy* more easily with lower threshold values compared to high ones.

Sources –

Depends On T1, TY10, TY11, TY12, TY13, TY14

Ref. By IM6, R22

IM2	**Evaluate *Sadness* Elicitation**
Input	$g : \mathbb{G}^?, p : \mathbb{P}^?, s_{prev} : \mathbb{S}, s_\Delta : \mathbb{S}_\Delta$
Output	$(g_{sadness} : \mathbb{G}^?, p_{sadness} : \mathbb{P}^?, s_{now} : \mathbb{S}, dist_{now} : \mathbb{D}^?)^? \doteq S$

$$S = \begin{cases} (\text{None}, p, s_{prev} \oplus s_\Delta, \text{None}), & p \neq \text{None} \wedge p.\texttt{isFeasible}(s_{prev}) \\ & \wedge \neg p.\texttt{isFeasible}(s_{prev} \oplus s_\Delta) \\ (g, \text{None}, s_{prev} \oplus s_\Delta, \\ g.\texttt{goal}(s_{prev} \oplus s_\Delta)), & g \neq \text{None} \wedge |g.\texttt{goal}(s_{prev} \oplus s_\Delta)| = +\infty \\ \text{None}, & \mathit{Otherwise} \end{cases}$$

Description Given either an entity goal (TY14) or plan (TY15), the *previous WSV* (TY10), and an event that transformed the *previous WSV* into the current one (TY11), evaluate the elicitation of *Sadness* (T1) by:

- If given a plan ($p \neq$ None), determine if the plan was feasible in the *previous WSV* and is not feasible in the current WSV created by applying the event to the previous WSV ($p.\texttt{isFeasible}(s_{prev}) \wedge \neg p.\texttt{isFeasible}(s_{prev} \oplus s_\Delta)$).
- If given a goal ($g \neq$ None), determine if the event created a WSV from the *previous WSV* where the distance to the goal state (TY12) is infinitely large in WSV changed by the event (i.e. is unachievable, $|g.\texttt{goal}(s_{prev} \oplus s_\Delta)| = +\infty$).

If both conditions fail, the function returns None because the event did not elicit *Sadness* for this goal.

Sources –

Depends On T1, TY10, TY11, TY12, TY14, TY15

Ref. By R22

IM3	**Evaluate *Fear* Elicitation**

Input $g : \mathbb{G}, g' : \mathbb{G}^?, s_{now} : \mathbb{S}, s_\Delta : \mathbb{S}_\Delta, \epsilon_F : \mathbb{D}_\Delta$

Output $(g_{fear} : \mathbb{G}, dist_{now} : \mathbb{D}, dist_{next} : \mathbb{D}, dist_\Delta : \mathbb{D}_\Delta, g_{lost} : \mathbb{G}^?)^? \doteq F$

$$\text{where } F = \begin{cases} (g, g.\texttt{goal}(s_{now}), & \texttt{SelfPreservation} \in g.\texttt{type} \\ g.\texttt{goal}(s_{now} \oplus s_\Delta), & \wedge \neg(g.\texttt{goal}(s_{now}) > g.\texttt{goal}(s_{now} \oplus s_\Delta)) \\ g.\texttt{goal}'(s_{now}, s_\Delta), & \wedge \, | \, g.\texttt{goal}'(s_{now}, s_\Delta) \, | > \epsilon_F \\ \text{None}), & \\ (g, g.\texttt{goal}(s_{now}), & g' \neq \text{None} \\ g.\texttt{goal}(s_{now} \oplus s_\Delta), g'), & \wedge \, \texttt{WillConflict}(g, g', s_{now}, s_\Delta) \\ (g', g'.\texttt{goal}(s_{now}), & g' \neq \text{None} \\ g'.\texttt{goal}(s_{now} \oplus s_\Delta), g), & \wedge \, \texttt{WillConflict}(g', g, s_{now}, s_\Delta) \\ \text{None}, & \textit{Otherwise} \end{cases}$$

where $\texttt{WillConflict}(g_1, g_2, s_{now}, s_\Delta)$
$= (g_1.\texttt{goal}(s_{now}) > g_1.\texttt{goal}(s_{now} \oplus s_\Delta)) \wedge | \, g_2.\texttt{goal}(s_{now} \oplus s_\Delta) \, | = +\infty$

Description Given at least one of two entity goals (TY14), the *current WSV* (TY10), an event that will transform the *current WSV* into a future one (TY11), and a "tolerance" threshold for distance changes between WSVs (TY13), evaluate the elicitation of *Fear* (T1) by:

- Determining if the entity perceives a threat to its goal g by evaluating if it concerns self-preservation ($\texttt{SelfPreservation} \in g.\texttt{type}$) and there is a potential event that progresses an entity *away* from goal achievement by increasing the distance to the goal state compared to the *current WSV* ($\neg(g.\texttt{goal}(s_{now}) > g.\texttt{goal}(s_{now} \oplus s_\Delta))$) such that it causes a noticeable change from an evaluation of its minimum "threshold" ($| \, g.\texttt{goal}'(s_{now}, s_\Delta) \, | > \epsilon_F$).
- If given two goals ($g' \neq$ None), determining if they conflict by evaluating if the potential event progresses one while simultaneously making the distance to the other (TY12) infinitely large ($\texttt{WillConflict}\ (g_1, g_2, s_{now}, s_\Delta)$).

If all conditions fail, the function returns None because the event did not elicit *Fear* for these goals.

The threshold ϵ_F controls the entity's "sensitivity" to changes such it experiences *Fear* more easily with lower threshold values compared to high ones.

Sources –

Depends On T1, TY10, TY11, TY12, TY13, TY14

Ref. By R22

IM4	Evaluate *Anger* Elicitation

Input $s_{prev} : \mathbb{S}, s_\Delta : \mathbb{S}_\Delta, ps : \{\mathbb{P}\}$

Output $(s_{now} : \mathbb{S}, p_{fail} : \mathbb{P}, ps_{alt} : \{\mathbb{P}\})^? \doteq A$

$$\text{where } A = \begin{cases} (s_{prev} \oplus s_\Delta, p_\alpha, \forall p \in \{\mathbb{P}\} \\ \to p.\mathtt{isFeasible}(s_{prev} \oplus s_\Delta), & \begin{array}{l} \exists p_\alpha \in ps \to (\forall p \in ps \\ \quad \to p \neq p_\alpha \wedge \mathtt{Cost}(p_\alpha) \leq \mathtt{Cost}(p)) \\ \wedge \neg p_\alpha.\mathtt{isFeasible}(s_{prev} \oplus s_\Delta) \\ \wedge \exists p \in ps \to p.\mathtt{isFeasible}(s_{prev} \oplus s_\Delta) \end{array} \\ \text{None}, & \mathit{Otherwise} \end{cases}$$

Description Given the previous WSV (TY10), and event that transformed the *previous WSV* into the current one (TY11), and a set of entity plans (TY15), evaluate the elicitation of *Anger* (T1) by determining if the transition from the *previous WSV* into the current one makes the entity's lowest effort plan ($\exists p_\alpha \in ps \to (\forall p \in ps \to p \neq p_\alpha \wedge \mathtt{Cost}(p_\alpha) \leq \mathtt{Cost}(p)$, A28) impossible to progress ($\neg p_\alpha.\mathtt{isFeasible}(s_{prev} \oplus s_\Delta)$), but there is at least one other plan for achieving the same end-state ($\exists p \in ps \to p.\mathtt{isFeasible}(s_{prev} \oplus s_\Delta)$). Therefore, the entity can continue working towards a desired end-state but must use a plan that requires more effort ("frustrated") and the entity experiences *Anger*.

If the condition fails, the function returns None because the event did not elicit *Anger* for this goal.

Note that the set of plans that the model returns is a strict subset of the provided set of plans $ps_f \subset ps$ because it has at least one plan fewer due to the infeasibility of p_α.

Sources –

Depends On A28, T1, TY10, TY11, TY15

Ref. By R22

IM5	Evaluate *Disgust* Elicitation

Input $g : \mathbb{G}, s_{prev} : \mathbb{S}, s_\Delta : \mathbb{S}_\Delta, \epsilon_{DS} : \mathbb{D}_\Delta, \epsilon_{DN} : \mathbb{D}_\Delta$

Output $(dist_{prev} : \mathbb{D}, dist_{now} : \mathbb{D}, dist_\Delta : \mathbb{D}_\Delta)^? \doteq D$

$$\text{where } D = \begin{cases} (g.\mathtt{goal}(s_{prev}), \\ g.\mathtt{goal}(s_{prev} \oplus s_\Delta), \\ g.\mathtt{goal'}(s_{prev}, s_\Delta)), & \begin{array}{l} \mathtt{Gustatory} \in g.\mathtt{type} \\ \wedge\, g.\mathtt{goal}(s_{prev}) \leq \epsilon_{DS} \\ \wedge\, g.\mathtt{goal}(s_{prev} \oplus s_\Delta) > \epsilon_{DS} \\ \wedge\, |g.\mathtt{goal'}(s_{prev}, s_\Delta)| > \epsilon_{DN}) \end{array} \\ \text{None}, & \mathit{Otherwise} \end{cases}$$

Description Given an entity goal (TY14), the *previous WSV* (TY10), an event that will transform the *previous WSV* into the current one (TY11), and two "tolerance" thresholds for distance changes between WSVs (TY13), evaluate the elicitation of *Disgust* (T1) by determining if the goal is gustatory-related ($\mathtt{Gustatory} \in$

$g.\mathtt{type}$), *the previous WSV* satisfied that goal within some "satisfaction threshold" ($g.\mathtt{goal}\ (s_{prev}) \leq \epsilon_{DS}$), and the event transitioned into the current WSV where the goal is unsatisfied ($g.\mathtt{goal}(s_{prev} \oplus s_{\Delta}) > \epsilon_{DS}$) such that the difference is noticeable ($|\, g.\mathtt{goal'}(s_{prev}, s_{\Delta})\,| > \epsilon_{DN}$).

The threshold ϵ_{DS} defines an entity's "tolerance" for goal dissatisfaction such that higher values means that the entity allows larger distances between the current WSV and its goal state before experiencing *Disgust*. The threshold ϵ_{DN} controls the entity's "sensitivity" to WSV changes such it experiences *Disgust* more easily with lower threshold values compared to high ones.

Sources –

Depends On T1, TY10, TY11, TY13, TY14

Ref. By R22

IM6	**Evaluate *Acceptance* Elicitation**
Input	$r_A : \mathbb{SA}^?, g : \mathbb{G}, s_{prev} : \mathbb{S}, s_{\Delta} : \mathbb{S}_{\Delta}, \epsilon_{A1} : \mathbb{S}_{\Delta}, \epsilon_{A2} : \mathbb{S}_{\Delta}$
Output	$(r_A : \mathbb{SA}, distAttribToA_{\Delta} : \mathbb{D}_{\Delta})^? \doteq Acc$
	$\text{where } Acc = \begin{cases} (r_A, dist_{\Delta} - \epsilon_{A2}), & r_A \neq \text{None} \wedge \mid J(g, s_{prev}, s_{\Delta}, \epsilon_{A1}).dist_{\Delta} \mid > \epsilon_{A2} \\ & \wedge\ \mathtt{CausedBy}(s_{\Delta}, A) \\ \text{None}, & \mathit{Otherwise} \end{cases}$

Description Given an Option type that might contain the entity's social attachment to another (TY16), one of the entity's goals (TY14), the *previous WSV* (TY10), an event that will transform the *previous WSV* into the current one (TY11), and two "tolerance" thresholds for distance changes between WSVs (TY13), evaluate the elicitation of *Acceptance* (T3) towards some entity A by determining if: the entity has a social attachment to A ($r_A \neq \text{None}$); the goal, WSV, event, and a tolerance "threshold" elicit *Joy* ($J(g, s_{prev}, s_{\Delta}, \epsilon_{A1})$ from IM1) and the change in distance returned from that evaluation exceeds a minimum threshold ($|\, dist_{\Delta}\,| > \epsilon_{A2}$); and the entity attributes the occurrence of the event to A ($\mathtt{CausedBy}(s_{\Delta}, A)$, A29).

If these conditions fail, the function returns None because the event did not elicit *Acceptance* for this goal and entity A.

The threshold ϵ_{A2} controls the entity's "sensitivity" to changes such it experiences *Acceptance* more easily with lower threshold values compared to high ones. This threshold also moderates the elicitation "magnitude" by returning the change in distance between WSVs that exceeds it ($dist_{\Delta} - \epsilon_{A2}$) so that the "magnitude" is relative to how easily "impressed" the entity is.

If an entity has no social attachment yet, users could use this as a mechanism for establishing one:

1. Create a new social attachment $r'_A : \mathbb{SA}$
2. Use it to evaluate the presence of *Acceptance*:
   (a) If *Acceptance* is present, store r'_A
   (b) Otherwise discard it

Sources –

Depends On A29, T3, TY10, TY11, TY13, TY14, TY16, IM1

Ref. By R22

IM7	**Evaluate *Interest* Elicitation**
Input	$at_x : \mathbb{AT}_x, \epsilon_{Inr} : \mathbb{AT}_x$
Output	$\mathbb{AT}_x^? \doteq Inr$ where $Inr = \begin{cases} at_x - \epsilon_{Inr}, & at > \epsilon_{Inr} \\ \text{None}, & Otherwise \end{cases}$

Description Given the attention paid to an entity x (TY17) and a "tolerance" threshold, evaluate the elicitation of *Interest* (T4) by determining if the amount of attention paid to x exceeds the threshold ($at > \epsilon_{Inr}$).

If this condition fails, the function returns None because the entity is not experiencing *Interest* towards x.

The threshold also moderates the elicitation "magnitude" by returning the amount of attention that exceeds it ($at_x - \epsilon_{Inr}$) so that the "magnitude" is relative to how much x "fascinates" the entity.

Sources –

Depends On T4, TY17

Ref. By R22

IM8	**Evaluate *Surprise* Elicitation**
Input	$s_{prev} : \mathbb{S}, s_\Delta : \mathbb{S}_\Delta, \epsilon_P : [0, 1]$
Output	$[0, 1]^? \doteq Sur$ where $Sur = \begin{cases} \epsilon_P - P(s_\Delta \vert s_{prev}), & P(s_\Delta \vert s_{prev}) < \epsilon_P \\ \text{None}, & Otherwise \end{cases}$

Description Given the *previous WSV* (TY10), an event that transformed the *previous WSV* into the current one (TY11), and a "tolerance" threshold, evaluate the elicitation of *Surprise* (T5) by determining if the improbability of the event in *the previous WSV* is below the threshold ($P(s_\Delta|s_{prev}) < \epsilon_P$, A30).

If this condition fails, the function returns None because the event did not elicit *Surprise* in the entity.

The threshold also moderates the elicitation "magnitude" by returning how much the event's improbability falls below it ($\epsilon_P - P(s_\Delta|s_{prev})$) so that the "magnitude" is relative to how "impossible" the entity believes the event is.

Sources –

Depends On A30, T5, TY10, TY11

Ref. By R22

IM9	Evaluate *Joy* Intensity
Input	$g : \mathbb{G}, d_\Delta : \mathbb{D}_\Delta$
Output	$i_\Delta : \mathbb{I}_\Delta \mathrel{\hat{=}} \lvert d_\Delta \rvert \cdot g.\texttt{importance}$

Description Given an entity goal (TY14) and a change in distance between two WSVs (TY13), evaluate the intensity change of *Joy* (T2, TY2) by treating the entity goal as the affected "internal condition" whose "value" is its `importance` and the magnitude of change in distance caused by the event is its "seriousness" or "value" because it measures how much the event moved the entity towards the desired goal state (T1).

Using goal `importance` as a scaling factor moderates intensity changes such that its magnitude varies for entities observing the same d_Δ whose goals only differ in their `importance`. Note that the *Joy* elicitation model outputs a tuple with element $dist_\Delta$ (IM1), which users can provide as the input d_Δ.

Sources –

Depends On T1, T2, TY2, TY13, TY14

Ref. By R23

IM10	Evaluate *Sadness* Intensity
Input	$g : \mathbb{G}^?, p : \mathbb{P}^?, s_{prev} : \mathbb{S}, i_{max\Delta} : \mathbb{I}_\Delta$
Output	$i_\Delta : \mathbb{I}_\Delta \mathrel{\hat{=}} \begin{cases} \dfrac{1}{\lvert dist_p \rvert}, & p \neq \text{None} \\ \dfrac{g.\texttt{importance}}{m_G} \cdot i_{max\Delta}, & g \neq \text{None} \end{cases}$ where where $dist_p : \mathbb{D} = \texttt{Dist}(s_{prev}, p.\texttt{nextStep}(s_{prev}, \lvert p.\texttt{actions} \rvert))$

Description Given either an entity goal (TY14) or plan (TY15), the *previous WSV* (TY10), and a maximum intensity change (TY2), evaluate the intensity change of *Sadness* (T2) from two possible "internal conditions" affected by the event that determines the eliciting event's "value" or "seriousness" (T1):

- An entity plan with a "value" equal to the distance to the desired end-state before it became infeasible, such that the event's "value" or "seriousness" is inversely proportional to the distance between the plan's end-state and the previous WSV where the plan was feasible. This means that plans the entity was close to completing elicit more intense *Sadness* compared to ones that were farther from completion.

For evaluating the "seriousness" of a plan becoming infeasible, the function generates the plan's end-state from the previous WSV by applying every plan action to it ($p.\texttt{nextSteps}(s_{prev}, |p.\texttt{actions}|)$), then calculates the distance between the generated plan end-state and the previous WSV s_{prev} (A31). This emulates an evaluation of "how close" the entity was to plan completion.

- An entity goal with a "value" equal to its `importance`, but the event's "value" or "seriousness" is not necessarily tied to the event—an entity can experience intense *Sadness* if they were significantly far from the goal state (e.g. if there is a goal to see a loved one before they pass, losing them feels equally painful if one just began saving money for a plane ticket or if they have already spent a week with them). This means that goals with higher `importance` elicit more intense *Sadness* compared to less important ones relative to some maximum *Sadness* an entity can experience.

  For evaluating the "seriousness" of a goal being "lost", the goal's `importance` relative to m_G (A32) is a scaling factor that moderates a maximum intensity change $i_{max\Delta}$ such that its magnitude varies for entities with different `importance` valuations in otherwise identical goals. This effectively normalizing it to $[0, 1]$. The function can access m_G itself so that the user does not have to provide it. Users do provide the value of $i_{max\Delta}$ so that they have more control over how much an entity experiences emotion changes (i.e. the model does not have to be relative to the maximum possible *Sadness* intensity).

Note that the *Sadness* elicitation model outputs a tuple with elements $g_{sadness} : \mathbb{G}^?$ and $p_{sadness} : \mathbb{P}^?$ (IM2), which users can supply as the inputs g and p.

Sources –

Depends On A31, A32, T1, T2, TY2, TY10, TY14, TY15

Ref. By R23

IM11	**Evaluate *Fear* Intensity**
Input	$g : \mathbb{G}, g_{lost} : \mathbb{G}^?, d_\Delta : \mathbb{D}_\Delta$
Output	$i_\Delta : \mathbb{I}_\Delta \triangleq \begin{cases} d_\Delta \cdot g.\texttt{importance}, & g_{lost} = \text{None} \\ d_\Delta \cdot \dfrac{g_{lost}.\texttt{importance}}{g.\texttt{importance}}, & g_{lost} \neq \text{None} \end{cases}$

Description Given at least one entity goal (TY14) and a change in distance between two WSVs (TY13), evaluate the intensity change of *Fear* (T2, TY2) by treating the entity goal as the affected "internal condition" whose "value" is its `importance` and the magnitude of change in distance caused by the event is its "seriousness" or "value" because it measures how much the event will move the entity away the desired goal state or, when there are two goals, move the entity towards one while making the other unachievable (T1).

Using goal `importance` as a scaling factor moderates intensity changes such that its magnitude varies for entities with different `importance` valuations in otherwise identical goals that observe the same d_Δ. In the case where conflicting goals elicited *Fear*, the scaling factor is a ratio between their `importance` values such that the "value" of the progressed goal tempers that of the "lost" goal—the intensity of *Fear* is higher when the `importance` of the "lost" goal is larger than the `importance` of the other goal.

Note that the *Fear* elicitation model (IM3) outputs a tuple with elements $g_{fear} : \mathbb{G}$, $g_{lost} : \mathbb{G}^?$, and $dist_\Delta$, which users can use as the inputs g, g_{lost}, and d_Δ.

Sources –

Depends On T1, T2, TY2, TY13, TY14

Ref. By R23

IM12	**Evaluate *Anger* Intensity**
Input	$p : \mathbb{P}, ps : \{\mathbb{P}\}$
Output	$i_\Delta : \mathbb{I}_\Delta \doteq \exists p_\beta \in ps \rightarrow$ $(\forall p \in ps \rightarrow p \neq p_\beta \wedge \texttt{Cost}(p_\beta) \leq \texttt{Cost}(p)) \rightarrow \texttt{Cost}(p_\beta) - \texttt{Cost}(p)$

Description Given an infeasible entity plan (TY15) and a set of feasible plans that achieve the same end-state, evaluate the intensity change of *Anger* (T2, TY2) by treating the change in entity plan availability as the affected "internal condition" and their "value" is the amount of effort the entity needs to execute them (i.e. plan "cost", A28). The difference in "cost" between the infeasible plan and the next lowest "cost" plan is its "seriousness" or "value" because it measures how much additional effort the entity needs to achieve the same result. Both of these values are subjective because the entity assigns them. Therefore, evaluating *Anger* intensity is the difference between the subjective "cost" of the "frustrated" plan and the next lowest "cost" plan (T1).

Taking the difference between plan "costs" ensures that *Anger* is more intense if the "cost" of the next most desirable plan increases compared to the original one. If these plans are for achieving a goal, users can choose to scale the resulting *Anger* intensity with the goal's importance manually.

Note that the *Anger* elicitation model (IM4) outputs a tuple with elements $p_{fail} : \mathbb{P}$ and $ps_{alt} : \{\mathbb{P}\}$, which users can use as the inputs p and ps.

Sources –

Depends On A28, T1, T2, TY2, TY15

Ref. By R23

IM13	**Evaluate *Disgust* Intensity**
Input	$g : \mathbb{G}, d : \mathbb{D}$
Output	$i_\Delta : \mathbb{I}_\Delta \mathrel{\hat{=}} d \cdot g.\texttt{importance}$

Description Given an entity goal (TY14) and the distance between the *current WSV* and the goal state (TY12), evaluate the intensity change of *Disgust* (T2, TY2) by treating the the entity goal as the affected "internal condition" and its "value" is its `importance`. The distance between the current state and the desired goal state is the event's "seriousness" or "value" because it measures how much the event moved the entity out of it (T1).

Using goal `importance` as a scaling factor moderates intensity changes such that its magnitude varies for entities observing the same d_Δ whose goals only differ in their `importance`.

Note that the *Disgust* elicitation model (IM5) outputs a tuple with element $dist_{now}$, which users can supply as the input d.

Sources –

Depends On T1, T2, TY2, TY12, TY14

Ref. By R23

IM14	**Evaluate *Acceptance* Intensity**
Input	$r_A : \mathbb{SA}, r_{min} : \mathbb{SA}, d_\Delta : \mathbb{D}_\Delta$
Output	$i_\Delta : \mathbb{I}_\Delta \mathrel{\hat{=}} \begin{cases} \lvert d_\Delta \rvert \cdot \dfrac{r_A}{r_{min}}, & r_A < r_{min} \\ \lvert d_\Delta \rvert, & \textit{Otherwise} \end{cases}$

Description Given the entity's social attachment to another entity A (TY16), the minimum social attachment that an entity must have with A to "fully" experience *Acceptance* towards it, and a change in distance between two WSVs (TY13) evaluate the intensity change of *Acceptance* (T3, TY2) by treating the entity's social attachment to A as the affected "internal condition" and the magnitude of change in distance caused by the event *attributed* to A is its "seriousness" or "value" because it measures how much A helped moved the entity towards the desired goal state.

Using r_{min} to "normalize" r_A creates a scaling factor that moderates intensity changes such its magnitude varies with social attachment level. Tuning the minimum "level" changes the entity's resistance to the experience of *Acceptance* so that they appear more trustful or distrustful of other entities. Consequently, the entity's Emotion Intensity Change value depends on the entity's relationship to the other relative to their minimum "trust level".

Note that the *Acceptance* elicitation model (IM6) outputs a tuple with element $distAttribToA_\Delta$, which users can use as the input d_Δ.

Sources –

Depends On T3, TY2, TY13, TY16

Ref. By R23

IM15	**Evaluate *Interest* Intensity**
Input	$at : \mathbb{AT}_x, at_{min} : \mathbb{AT}_x, i_{\delta_x} : \mathbb{I}_\Delta$
Output	$i_\Delta : \mathbb{I}_\Delta \stackrel{\circ}{=} \begin{cases} i_{\delta_x} \cdot \dfrac{at}{at_{min}} & at < at_{min} \\ i_{\delta_x}, & Otherwise \end{cases}$

Description Given the entity's elapsed attention invested in x (TY17), the minimum attention that an entity must spend on x to "fully" experience *Interest* towards it, and a subjective attention "value" i_{δ_x} (TY2) representing the entity's "fascination" with x such higher values elicit more intense *Interest* with smaller changes in attention, evaluate the intensity change of *Interest* (T4) by treating the entity's entity's attention as the affected "internal condition" and the entity-specific minimum attention as the event's "seriousness" or "value" because the "event" driving *Interest* elicitation is not necessarily the same as "world events".

Users can specify different attention "valuations" for i_{δ_x} so that entities are more "intrigued" by some x than others.

Using the minimum attention to "normalize" at creates a scaling factor that moderates intensity changes such its magnitude varies with uninterrupted, invested attention. Tuning the minimum "level" changes the entity's resistance to the experience of *Interest* so that they appear to be more or less "captivated" by x.

Note that the *Interest* elicitation model (IM7) outputs a value with type $\mathbb{AT}_x$, which users can supply as the input at.

Sources –

Depends On T4, TY2, TY17

Ref. By R23

IM16	**Evaluate *Surprise* Intensity**
Input	$discr_{s_\Delta} : [0,1], i_{max\Delta} : \mathbb{I}_\Delta$
Output	$i_\Delta : \mathbb{I}_\Delta \stackrel{\circ}{=} i_{max} \cdot discr_{s_\Delta}$

Description Given the "discrepancy" between the event and its improbability and a subjective "unexpectedness value" $i_{max\Delta}$ that measures how easily an entity is "startled" such higher values elicit more intense *Surprise* with smaller event probability discrepancies, evaluate the intensity change of *Surprise* (T5, TY2) by treating the entity's prediction about an event's probability as the affected "internal condition". Although the "event" driving *Surprise* is a "world event", its elicitation is driven by an entity's internal prediction about it rather than some event "valuation" or "seriousness". Therefore, an entity-specific "unexpectedness value" is the event's "seriousness" or "value" because the "event" driving *Interest* elicitation is not necessarily the same as "world events". This value scales with the based on a common-sense hypotheses about the monotonically increasing relation between *Surprise* intensity and event unexpectedness.

Users can specify different values for $i_{max\Delta}$ so that entities are more "startled" by some events than others.

Note that the *Surprise* elicitation model (IM8) outputs a value with type $[0, 1]^?$, which users can supply as the input $discr_{s_\Delta}$ if it is not None.

Sources **?**, p. 54, 56

Depends On T5, TY2

Ref. By R23

IM17	Decaying an Emotion Intensity
Input	$i_0 : \mathbb{I}, i_{Eq} : \mathbb{I}, i_\lambda : \mathbb{I}_\lambda, \Delta t : \mathbb{T}_\Delta, \zeta : \mathbb{R}_{>0}$

Output

$$i : \mathbb{I} \mathrel{\hat{=}} I_\lambda + i_{Eq}$$

$$\text{where } I_\lambda = \begin{cases} e^{-\sqrt{i_\lambda}\cdot\zeta\cdot\Delta t}\cdot(i_0 - i_{Eq})\cdot\Bigg(\cos(\omega\cdot\Delta t) \\ \quad + \left(\dfrac{\sqrt{i_\lambda}\cdot\zeta}{\omega}\right)\cdot\sin(\omega\cdot\Delta t)\Bigg) & , \quad 0 < \zeta < 1 \\ \quad \text{where } \omega = \sqrt{i_\lambda}\cdot\sqrt{1-\zeta^2} & \\ e^{-\sqrt{i_\lambda}\cdot\Delta t}\cdot(i_0 - i_{Eq})\cdot\left(1 + \sqrt{i_\lambda}\cdot\Delta t\right), & \zeta = 1 \\ \dfrac{i_0 - i_{Eq}}{2}\cdot\Bigg(\left(1 + \dfrac{\zeta}{Q}\right)\cdot e^{-\sqrt{i_\lambda}\cdot(\zeta - Q)\cdot\Delta t} \\ \quad + \left(1 - \dfrac{\zeta}{Q}\right)\cdot e^{-\sqrt{i_\lambda}\cdot(\zeta + Q)\cdot\Delta t}\Bigg) & , \quad \zeta > 1 \\ \quad \text{where } Q = \sqrt{\zeta^2 - 1} & \end{cases}$$

Description Given an initial emotion intensity $i_0 : \mathbb{I}$ (TY1) and equilibrium intensity $i_{Eq} : \mathbb{I}$, an emotion decay rate $i_\lambda : \mathbb{I}_\lambda$ (TY3), the elapsed time since emotion decay began $\Delta t : \mathbb{T}_\Delta$ (TY9), and a strictly positive and real-valued damping ratio ζ, evaluate the "decayed" intensity $i : \mathbb{I}$ based on the case of ζ.

Adding i_{Eq} to I_λ shifts the position from 0 to the equilibrium point. The damping ratio $\zeta : \mathbb{R}_{>0}$ determines how much emotion intensity oscillates as an returns to equilibrium.

Model Derivation Emotion decay (T6) is modelled by a damped harmonic oscillator mass-spring system of the form:

$$x''(t) + c \cdot x'(t) + k_s \cdot x(t) = 0$$

where $x''(t)$, $x'(t)$, and $x(t)$ are the acceleration, speed, and position of a mass m at time t, c is a strictly positive and real-valued damping coefficient, and k_s is a spring constant. Emotion intensity is then equivalent to the "position" of the mass in the system and the system's oscillation behaviour is a way for users to define an entity's "emotional stability".

The damping ratio ζ and natural angular frequency of the system ω_n govern its behaviour:

$$\zeta = \frac{c}{2 \cdot \sqrt{m \cdot k_s}}, \ \omega_n = \sqrt{\frac{k_s}{m}}$$

Closed-forms of each case for ζ are necessary because the general solution allows for imaginary numbers, which are not computationally tractable:

- If $0 < \zeta < 1$, the system is *underdamped* such that it oscillates as it returns to equilibrium. As ζ approaches 1, the oscillations decrease more quickly. This could represent an entity that is "emotionally unstable", alternating between high and low emotion intensities before returning to their "normal" state. Position x at time t is given by:

$$x(t) = e^{-r \cdot t} \cdot (A \cdot \cos(\omega \cdot t) + B \cdot \sin(\omega \cdot t))$$
$$\text{where } A = x_0, \ B = \frac{v_0 + x_0 \cdot \omega_n \cdot \zeta}{\omega}, \ r = \omega_n \cdot \zeta$$
$$\text{and } \omega = \omega_n \cdot \sqrt{1 - \zeta^2}$$

- If $\zeta = 1$, the system is *critically damped* such that it returns to equilibrium as quickly as possible without overshooting it. This could represent an entity that is the most "emotionally stable", recovering more quickly and directly than entities with other ζ values. Position x at time t is given by:

$$x(t) = e^{-\omega_n \cdot t} \cdot (x_0 + (v_0 + x_0 \cdot \omega_n) \cdot t)$$

- If $\zeta > 1$, the system is *overdamped* such that it does not oscillate as it returns to equilibrium. As ζ increases, the system reaches equilibrium more slowly. This could represent an entity that is "emotionally unstable", experiencing their emotions longer than others. Position x at time t is given by:

$$x(t) = C \cdot e^{-r_1 \cdot t} + D \cdot e^{-r_2 \cdot t}$$
$$\text{where } C = \frac{1}{2} \cdot \left(x_0 + \frac{v_0 + x_0 \cdot \omega_n \cdot \zeta}{\omega}\right), \ D = \frac{1}{2} \cdot \left(x_0 - \frac{v_0 + x_0 \cdot \omega_n \cdot \zeta}{\omega}\right),$$
$$r_1 = \omega_n(\zeta - \sqrt{\zeta^2 - 1}), \ r_2 = \omega_n(\zeta + \sqrt{\zeta^2 - 1})$$
$$\text{and } \omega = \omega_n \cdot \sqrt{\zeta^2 - 1}$$

Substitutes $k_s = i_\lambda$, $m = 1$ such that $\omega_n = \sqrt{i_\lambda}$, $x_0 = x(t_0) = i_0 - i_{eq}$, $v_0 = 0$, and $t_0 = 0$ such that $t = 0 + \Delta t = \Delta t$ into each model of position, where $i_0 : \mathbb{I}$ is the "initial" intensity, $i_{eq} : \mathbb{I}$ is the "equilibrium" intensity, $\Delta t : \mathbb{T}_\Delta$ is the elapsed time since $t : \mathbb{T} = 0$, and $i_\lambda : \mathbb{I}_\lambda$ is the intensity's decay rate and simplifying produces the described output model.

Sources https://en.wikipedia.org/wiki/Harmonic_oscillator#Damped_harmonic_oscillator, https://www.lehman.edu/faculty/anchordoqui/chapter23.pdf, **?**

Depends On T6, TY1, TY3, TY9

Ref. By TY3, IM22, R24

IM18	**Updating an Emotion Intensity with an Emotion Intensity Change**
Input	$i : \mathbb{I}, i_\Delta : \mathbb{I}_\Delta$
Output	$i' : \mathbb{I} \doteq \begin{cases} 0.1 \cdot \log_2\left(2^{10 \cdot i} + 2^{10 \cdot i_\Delta}\right), & i_\Delta > 0 \\ 0.1 \cdot \log_2\left(2^{10 \cdot i} - 2^{10 \cdot \lvert i_\Delta \rvert}\right), & i_\Delta < 0 \\ i, & \mathit{Otherwise} \end{cases}$

Description Given an emotion intensity $i : \mathbb{I}$ (TY1) and emotion intensity change $i_\Delta : \mathbb{I}_\Delta$ (TY2), output a new emotion intensity $i' : \mathbb{I}$ using the logarithmic function so that it not strictly additive and both values contribute to the output such that its magnitude is at least as much as the highest input.

Sources **?**, Broekens (2021, p. 370)

Depends On TY1, TY2

Ref. By IM19, R27

IM19	**Create a new Emotion State by Updating Emotion Intensities in an Existing Emotion State**
Input	$es : \mathbb{ES}, i_\Delta : \mathbb{K} \to \mathbb{I}_\Delta$
Output	$es' : \mathbb{ES} \doteq es'$ with $(\forall k : \mathbb{K}$ $\to es'.\mathtt{intensities}(k) = \mathtt{clamp}(I_k, 0, es.\mathtt{max}(k)), es'.\mathtt{max}(k) = es.\mathtt{max}(k))$ where $I_k = \mathtt{UpdateIntensity}(es.\mathtt{intensities}(k), i_\Delta(k))$ from IM18

Description Given an emotion state $es : \mathbb{ES}$ (TY5) and a function from emotion kinds to intensity changes $i_\Delta : \mathbb{K} \to \mathbb{I}$ (TY4, TY2), output a new emotion state es' by replacing updating the intensities in es.`intensities` with i_Δ using IM18.

A logarithm is an unbounded function and emotion intensities are assumed to be finite (i.e. have a maximum value), so it is necessary to clamp the updated intensity.

Sources –

Depends On TY2, TY4, TY5, IM18

Ref. By R28

IM20	**Updating Emotion**
Input	$e : \mathbb{E}$, $t : \mathbb{T}$, $es : \mathbb{ES}$
Output	$e' : \mathbb{E} \doteq \{ e \text{ with } e(t) = es \}$

Description Given an emotion $e : \mathbb{E}$ (TY7), emotion state $es : \mathbb{ES}$ (TY5), and a time $t : \mathbb{T}$ (TY9), output a new emotion e' by adding es to e at time t.

Sources –

Depends On TY5, TY7, TY9

Ref. By IM23, R29

IM21	**Getting an Emotion State**
Input	$e : \mathbb{E}$, $t : \mathbb{T}$
Output	$es : \mathbb{ES} \doteq e(t)$

Description Given an emotion $e : \mathbb{E}$ (TY7) and a time $t : \mathbb{T}$ (TY9), output the emotion state $es : \mathbb{ES}$ (TY5) at $e(t)$.

Sources –

Depends On TY5, TY7, TY9

Ref. By IM23, R30

IM22	Decay an Emotion State
Input	$es_0 : \mathbb{ES}, es_\lambda : \mathbb{ES}_\lambda, \Delta t : \mathbb{T}_\Delta, \zeta : \mathbb{R}_{>0}$
Output	$es : \mathbb{ES} \doteq \{ \forall k \rightarrow es \text{ with } es.\mathtt{intensities}(k) = D \}$ where $D = \mathtt{Decay}(es_0.\mathtt{intensities}(k), \Delta t, \zeta, es_\lambda.\mathtt{decayRates}(k), es_\lambda.\mathtt{equilibrium}(k))$ from IM17

Description Given an initial emotion state $es_0 : \mathbb{ES}$ (TY5), an emotion decay state $es_\lambda : \mathbb{ES}_\lambda$ (TY6), the difference between two times $\Delta t : \mathbb{T}_\Delta$ (TY9), and a damping ratio $\zeta : \mathbb{R}_{>0}$, generate a new emotion state $es : \mathbb{ES}$ by decaying intensity for every emotion intensity in es_0 using IM17.

Sources –

Depends On TY5, TY6, TY9, IM17

Ref. By IM23, R25

IM23	Generating the Next State in Emotion By Decay
Input	$e : \mathbb{E}, es_\lambda : \mathbb{ES}_\lambda, \{t : \mathbb{T}, t' : \mathbb{T} \rightarrow t < t'\}, \zeta : \mathbb{R}_{>0}$
Output	$e \doteq \{ e \text{ with } e(t') = \mathtt{DecayState}(e(t), t' - t, \zeta, es_\lambda) \}$ from IM20, IM21, and IM22

Description Given an emotion $e : \mathbb{E}$ (TY7), an emotion decay state $es_\lambda : \mathbb{ES}_\lambda$ (TY6), two times $t, t' : \mathbb{T}$ (TY9) such that t comes before t', and a damping ratio $\zeta : \mathbb{R}_{>0}$, update emotion e by extracting the emotion state at time t using IM21 and generating a new emotion state from it using IM22 and adding it to e at time t' using IM20.

Sources –

Depends On TY6, TY7, TY9, IM20, IM21, IM22

Ref. By R26

IM24	**Getting an Emotion State as a PAD Point**
Input	$es : \mathbb{ES}$
Output	$$p : P_{(P,A,D)} \mathrel{\hat{=}} \texttt{clamp}\left(0.1 \cdot \log_2\left(\sum_{k\in\mathbb{K}} 2^{10\cdot v(k)\cdot I_k}\right), -1, 1\right)$$ $$\text{where } I_k = \frac{es.\texttt{intensities}(k)}{es.\texttt{max}(k)}$$ $$\text{and } v\,(k : \mathbb{K}) : P_{(P,A,D)} = \begin{cases} (-0.62, +0.82, -0.43)\,, & k = \texttt{Fear} \\ (-0.51, +0.59, +0.25)\,, & k = \texttt{Anger} \\ (-0.63, -0.27, -0.33)\,, & k = \texttt{Sadness} \\ (+0.76, +0.48, +0.35)\,, & k = \texttt{Joy} \\ (+0.64, +0.51, +0.17)\,, & k = \texttt{Interest} \\ (+0.16, +0.88, -0.15)\,, & k = \texttt{Surprise} \\ (-0.60, +0.35, +0.11)\,, & k = \texttt{Disgust} \\ (+0.64, +0.35, +0.24)\,, & k = \texttt{Acceptance} \end{cases}$$

Description Given an emotion state $es : \mathbb{ES}$ (TY5), output a point in PAD space $p : P_{(P,A,D)}$ (TY8) by converting each intensity in es to a PAD point by scaling it to the associated maximum intensity such that multiplying it with the chosen reference points returns its relative PAD position to that point (T7). This ensures that higher intensity emotions weigh more than lower intensity emotions, contributing more to the overall PAD value. The model evaluates these points such that an emotion kind with zero intensity has the coordinates $(0, 0, 0)$—the neutral PAD value—and one at maximum intensity has the same value as the corresponding reference point. It then sums the individual points into an overall PAD point, clamping it to $[-1, 1]$ to adhere to the constraints on TY8.

The function inside `clamp` is based on the one from Em/Oz (**?**) and GAMYGDALA (Popescu et al., 2014, p. 38). It relies on a logarithm so that it not strictly additive and all values contribute to the output such that its magnitude is at least as much as the highest input. Although not experimentally verified, it emulates these desired behaviours and reportedly works well.

This model does lose information about the converted emotion state because it is combining information from eight discrete categories into one point in a three-dimensional space (**?**, **?**, p. 172; Broekens, 2021, p. 353). After conversion, it is nearly impossible to determine which emotion kind-intensity combinations contributed to the point's generation. Should a user need this information, they must associate the state with the point manually.

Sources Mehrabian (1980, p. 40, 42–45)

Depends On T7, TY5, TY8

Ref. By R31

4.2.9 Data Constraints

The Data Types (Section 4.2.7) impose constraints on EMgine's inputs and outputs. No additional constraints are needed.

4.2.10 Properties of a Correct Solution

- The emotion kinds and intensities generated by EMgine must be reasonable with respect to a believable animated character for the eliciting context as defined in the related document "Validation Test Plan for EMgine: A Computational Model of Emotion for Enhancing Non-Player Character Believability in Games (Version 1.0)"
- All of EMgine's outputs must adhere to its associated data type definition(s) as defined in Section 4.2.7, which can be verified by type checking all references to them for type safety

5 Requirements

This section provides the functional requirements (R), the business tasks that the software is expected to complete; and the nonfunctional requirements (NF), the qualities that the software is expected to exhibit.

5.1 Functional Requirements

EMgine must:

R1: Enforce data type definitions (Section 4.2.7).

R2: Provide a data type for $\mathbb{I}$ (TY1).

R3: Provide a data type for $\mathbb{I}_\Delta$ (TY2).

R4: Provide a data type for $\mathbb{I}_\lambda$ (TY3).

R5: Provide a data type for $\mathbb{K}$ (TY4).

R6: Provide a data type for $\mathbb{ES}$ (TY5).

R7: Provide a data type for $\mathbb{ES}_\lambda$ (TY6).

R8: Provide a data type for $\mathbb{E}$ (TY7).

R9: Provide a data type for $P_{(P,A,D)}$ (TY8).

R10: Provide a formal specification of $\mathbb{T}$ and $\mathbb{T}_\Delta$ for users to implement (TY9).

R11: Provide a formal specification of $\mathbb{S}$ for users to implement (TY10).

R12: Provide a formal specification of $\mathbb{S}_\Delta$ for users to implement (TY11).

R13: Provide a formal specification of $\mathbb{D}$ for users to implement (TY12).

R14: Provide a formal specification of $\mathbb{D}_\Delta$ for users to implement (TY13).

R15: Provide a data type for $\mathbb{G}$ that a user can extend with additional information (TY14).

R16: Provide a data type for $\mathbb{P}$ that a user can extend with additional information (TY15).

R17: Provide a data type for $\mathbb{SA}$ that a user can extend with additional information (TY16).

R18: Provide a data type for $\mathbb{AT}_x$ that a user can extend with additional information (TY17).

R19: Provide a method to define new emotion kinds/types/categories (C3) as functions of $\mathbb{K}$ and $\mathbb{I}$ (TY4, TY1).

R20: Provide a method to define new emotion types (C3) as partitions of $\mathbb{I}$ for a $k : \mathbb{K}$ (TY1, TY4).

R21: Provide a method to define new emotion types (C4) as functions of $\mathbb{K}$ (TY4) and functions of $\mathbb{B}$.

R22: Provide a method for determining emotion kind/type/category elicitation using IM1, IM2, IM3, IM4, IM5, IM6, IM7, and IM8.

R23: Provide a method for computing emotion intensity using IM9, IM10, IM11, IM12, IM13, IM14, IM15, and IM16.

R24: Provide a method for computing a decayed emotion intensity using IM17.

R25: Provide a method for computing the decayed intensities of an emotion state using IM22.

R26: Provide a method for computing the next emotion state for an emotion type by decaying one of its existing emotion states using IM23.

R27: Provide a method for updating intensity with an intensity change using IM18.

R28: Provide a method for updating all intensities in an emotion state using IM19.

R29: Provide a method for adding an emotion state to an emotion structure using IM20.

R30: Provide a method for getting an emotion state from an emotion structure using IM21.

R31: Provide a method for "translating" an emotion state into a PAD point using IM24.

5.2 Nonfunctional Requirements

The nonfunctional requirement (NF) categories reflect desirable software qualities (Ghezzi et al., 2003) and Volere nonfunctional requirements categories (Robertson and Robertson, 2010). EMgine does not have any known Security or Political nonfunctional requirements, so the SRS omits these categories. There are no known requirements for specifying Correctness or Reliability requirements that do not directly correlate with Verifiability and are independent of the target application, so the SRS omits these categories.

The SRS adapts relevant nonfunctional requirements from GLaDOS (Smith, 2017, p. 144–164), EMgine's precursor.

Robustness

NF1: EMgine's operations shall return a valid result and inform game developers if it is unable to produce one from the given inputs and its constraints are known.

Rationale: There could be situations where the given inputs do not produce a recognized output, but producing one does not change the program's functionality (e.g. a default return value) or is recoverable (e.g. number out of its known range). EMgine must be able to communicate this to game developers so that they can create recovery strategies.

Fit Criterion: EMgine always returns a result doing so is possible and the game developer is made aware of the issue.

NF2: EMgine shall make no changes and inform the game developer if it is not possible to produce an output from the given inputs and a valid result is not available.

Rationale: There could be situations where the given inputs do not produce a recognized output, and producing one is not possible (e.g. changing a maximum bound). EMgine must be able to communicate this to game developers so that they can create recovery strategies, and without completing the operation.

Fit Criterion: EMgine does make any changes any components if it is not possible to return a valid result and the game developer is made aware of the issue.

Performance

NF3: EMgine shall evaluate and create/update an emotion state in a time frame consistent with human cognitive processing during a reaction time task.

Rationale: EMgine imitates emotional responses in digital entities. This promotes an expectation that such responses are the same speed as human responses, which is independent of its computational efficiency (see NF5).

Fit Criterion: The time taken between accepting system inputs and producing a response must be within 70ms and 300ms (MacKenzie, 2013, p. 47).

NF4: EMgine shall allow game developers to configure parameters to change its complexity for different types of entities at design time (RF7).

Rationale: In addition to game entities themselves having variable levels of complexity (e.g. *Pac-man* ghost (Namco, 1980) vs. *Skyrim* citizen (Bethesda Game Studios, 2011)), a game developer might want to change an entity's complexity to reflect its relative importance in the environment (e.g. distance to player), when there is a high concentration of game entities in an area, or other performance-enhancing techniques.

Fit Criterion: A game developer is able to configure EMgine for a game entity that has the same complexity as a *Pac-man* ghost to their satisfaction.

NF5: EMgine shall be resource efficient (RF8).

Rationale: Video games are known for taxing hardware and software resources to the limit. EMgine must not impede on other game components' needs to be viable (related to NF4).

Fit Criterion: The efficiency of EMgine components is no worse than comparable components in a library for one-dimensional physics.

Verifiability

NF6: EMgine shall allow each of its "atomic" functions to be verified individually.

Rationale: Game developers are able to pick-and-choose which of EMgine's components to use. They must be confident that components that do not depend on others are verifiable on their own. This also supports component maintainability (see NF9) and reusability (see NF12).

Fit Criterion: Any EMgine component that is identified as a stand-alone entity can be verified independently of other components.

NF7: EMgine shall allow game developers to trace components' outputs to their inputs (RE4).

Rationale: Game developers will encounter unwanted during development. They must be able to see which of EMgine's components is causing the behaviour, verify that the module itself is working as expected, and update their use of it accordingly.

Fit Criterion: When given an expected output and actual output of a program that uses EMgine, a game developer is able to identify where the output mismatch starts and correct it.

Maintainability

NF8: EMgine shall be self-supporting.

Rationale: There will be no dedicated team to help EMgine's game developers.

Fit Criterion: Game developers are able to answer questions with only EMgine's documentation and examples (related to NF18, NF19).

NF9: EMgine shall isolate theory-specific elements to their own modules.

Rationale: Research evolves, and so does one's understanding of established theories. If there is a new development that affects EMgine's underlying emotion theories, it should be easy to find and update those parts. EMgine can do this by isolating theory-specific elements in their own units. This is strongly related to, but different from, NF12.

Fit Criterion: Changes to theory-specific components do not affect theory-agnostic components.

NF10: EMgine components shall be easy to modify and combine with user-defined ones for game developers with an Object-Oriented design/development background (RF2, RF4).

Rationale: EMgine adheres to standard Object-Oriented design practices (see NF25).

Fit Criterion: After their fifth modification to EMgine, game developers should be able to make modifications within one working day.

NF11: EMgine shall be translatable to non-English languages.

Rationale: EMgine must not assume that all game developers are proficient in English.

Fit Criterion: Natural language components of EMgine and its documentation must be localized to three or fewer files.

Reusability

NF12: EMgine must allow a game developer to change the underlying emotion theories and/or models.

Rationale: Some CME elements do not necessarily have to be theory-specific (e.g. definition of emotion intensity versus how it is evaluated). Someone should be able to reuse these parts in completely new CME designs that might use different underlying emotion theories and/or models. This is strongly related to, but different from, NF9.

Fit Criterion: EMgine components that are not specified from a particular emotion theory and/or model can be isolated and retooled for a CME that uses different theories.

Portability

NF13: EMgine shall be usable with different development environments and tools that it shares an implementation language with directly or could share via an intermediary language.

Rationale: Game developers will have preferences about development environments, practices, and tools. EMgine needs to limit its dependence on specific environments and language proprietary elements in EMgine's implementation language for longevity and long-term impact.

Fit Criterion: Game developers are able to use EMgine in conjunction with their preferred development environment and tools that uses the same implementation language as EMgine by modifying 5 interfaces at most. It follows that if it is possible to interface EMgine with an environment or tool that has the same implementation language as itself, and it is possible to translate another language into the shared implementation language, then it is possible for game developers to use EMgine with environments and/or tools in that other language as well.

Operational & Interoperability

NF14: EMgine shall be usable with different agent architectures and/or frameworks (RF1) that can be realized in the same implementation language as EMgine or in a compatible intermediary language.

Rationale: Game developers will have preferences about agent architectures and frameworks. EMgine must use generic references to agent components that are also not specific to its implementation language to avoid association with a specific one, which could discourage game developers from using it.

Fit Criterion: Game developers are able to use EMgine in conjunction with their preferred agent architecture or framework that can be realized in the same implementation language as EMgine. It follows that if it is possible to interface EMgine with an architectures or framework that has the same implementation language as itself, and it is possible to translate another language into the shared implementation language, then it is possible for game developers to use EMgine with architectures and/or frameworks in that other language as well.

NF15: EMgine's functionality shall not rely on an entity's embodiment or implementation.

Rationale: Since EMgine should be agent architecture and framework independent (see NF14), it cannot assume that an entity will have embodiment-specific features that it can use.

Fit Criterion: EMgine is usable with game entities with no functional embodiment.

Understandability

NF16: EMgine's APIs shall follow the coding conventions of EMgine's implementation language.

Rationale: Following the code and naming conventions of EMgine's implementation language will make it easier to understand EMgine's content and functionality.

Fit Criterion: A game developer familiar with the EMgine's implementation language understands its structure without referring to EMgine's documentation.

Usability

NF17: EMgine shall not require game developers to have knowledge of affective science and/or emotion research, nor should it use jargon in any of its descriptions (RE1).

Rationale: Assuming that most video game designers/developers (Section 2.1) have little/no academic knowledge of affective science and/or emotion research, it is unrealistic to expect them to know the psychological theories behind EMgine.

Fit Criterion: Game developers can implement EMgine components as-is in game entities without any knowledge of PES, CTE, or PAD Space and without being confused by EMgine's terminology and descriptions.

NF18: EMgine shall document essential usage information in the user-facing software components (RE2) such that game developers can learn it quickly and confidently.

Rationale: Game development is a rapid and stressful process, so game developers will not adopt any tool or system that cannot be picked up easily. New-to-EMgine game developers are likely to try using it as-is to see what it can do and become acquainted with it. Essential information, such as a high-level description of a component's purpose, should be embedded in the user-facing files as a "quick start" guide.

Fit Criterion:

- A game developer who has not used EMgine before should not need external product documentation to use its components as-is
- An empirical game developer study of game developers (Section 2.1) with Object-Oriented design experience and whom are given EMgine's user manual shall have statistically significant results regarding their confidence in the use of EMgine after one week of practice

NF19: EMgine shall document usage examples for each component, and some ways to combine them.

Rationale: Game developers that are advanced EMgine users likely want to customize EMgine and combine its components in different ways. Additional information about each component, and examples for addressing design problems such as handling multiple simultaneously generated emotion types, must be available to support this.

Fit Criterion: A game developer should be able to understand and apply concepts from EMgine documentation.

NF20: EMgine shall allow game developers to customize and/or redefine its configuration parameters (RF3).

Rationale: It is highly unlikely that vanilla EMgine will meet a game developer's needs perfectly. game developers must be able to tailor EMgine for their purposes to increase its longevity and long-term impact. *Fit Criterion*: A game developer should be able to modify and/or add a EMgine component without affecting other parts of the system.

NF21: EMgine shall allow game developers to specify how to use its outputs and/or states (RF6).

Rationale: EMgine is not supposed to tell game developers *what* to do with its components and outputs, only *how* it can help them accomplish their design goals. Therefore, its documentation should include examples demonstrating what it can do so they can use it as they require.

Fit Criterion: A game developer can use EMgine values with game entities that are not NPCs.

NF22: EMgine shall not require a game developer to add "emotional" functionality on a per-entity basis (RE3).

Rationale: Using EMgine will increase the development and testing time, but this must be minimized so that its perceived benefits outweigh its costs.

Fit Criterion: As the number of game entities using EMgine increases, game developer effort towards implementing EMgine functionality in entities increases at a rate that is better than linear.

NF23: EMgine shall allow game developers to automate the storing and decaying of an emotion state if they wish (RE5).

Rationale: These are general maintenance tasks that most game developers will want to happen in the absence of emotion generation. Allowing game developers to automate these tasks as they see fit will also reduce authorial burden (see NF22)

Fit Criterion: Game developers can set EMgine to automatically update an emotion state when it generates emotions, and set conditions for initiating emotion decay.

Look & Feel

NF24: EMgine shall appear to be professional and approachable.

Rationale: For EMgine to have an impact outside of the academic sphere, it must appear to be a professionally developed product so that industry people do not hesitate to try it.

Fit Criterion: EMgine has a user guide, documented design, and well-organized source code.

NF25: EMgine shall adhere to standard Object-Oriented design practices.

Rationale: Game developers typically use Object-Oriented languages such as C/C++, C#, and Java/ JavaScript (Sweeney, 2006) and many game engines are based on the Object-Oriented paradigm[1].

Fit Criterion: A game developer should be able to use EMgine's components as data and/or objects both within game engines and not.

[1] https://en.wikipedia.org/wiki/List_of_game_engines, Accessed July 27, 2022

Cultural (World)

NF26: EMgine shall allow game developers to choose which kinds of emotion it produces (RF5).

Rationale: While the biological basis of emotion categories might be universal, the language people describe them with are not (Oatley, 1992, p. 115–122). EMgine should not enforce the Euro-American affective lexicon because it might be difficult to understand and/or meaningless to a different culture. This would hinder EMgine's overall usability.

Fit Criterion: Game developers can create their own emotion labels for built-in categories and/or create their own categories (related to R19, R20, R21).

Cultural (Game Development Work)

NF27: EMgine shall demonstrate that it improves PX (RE6).

Rationale: A common goal of game design is to create an interesting PX (McAllister and White, 2015, p. 11). EMgine must show that it contributes to this, which will encourage industry people to try it (related to NF24).

Fit Criterion: An empirical user study of a game with EMgine functionality and participants that are video game players (Section 2.1) shall have statistically significant results implying that the game has a better PX than a game without EMgine functionality.

NF28: EMgine shall demonstrate ways that it can create novel game experiences (RE7).

Rationale: Even if EMgine improves PX (see NF27), game developers might hesitate to try it if there does not appear to be a sufficient benefit from learning a new tool and integrating it into a game design.

Fit Criterion: Game demos that use EMgine will be freely available.

NF29: EMgine's game demos shall adhere to common expectations about the connection between goals, events, and emotions.

Rationale: Even though they are intended as examples, the database elements that are included with the basic architecture should still adhere to commonly held beliefs about how people react to different events.

Fit Criterion: After playing a demo, 75% of players should be able to articulate why a game entity "experienced" its emotions in relation to its goals and game events.

Legal

NF30: EMgine shall be released as Open-Source Software.

Rationale: Allowing people to use, study, and change EMgine's source code can increase its longevity and long-term impact, as it does not rely on a single developer to update and maintain it. It also encourages trust in EMgine because game developers can examine its source code (related to NF20).

Fit Criterion: EMgine is published with an open-source license.

NF31: EMgine shall adhere to all terms and conditions of McMaster's Academic Integrity Policy.

Rationale: Intellectual honestly and ethical practices are prerequisites for EMgine's acceptance, as failure to do so will make stakeholders reject it on principle. As EMgine design and development is happening at McMaster University, this is the policy to follow.

Fit Criterion: EMgine does not violate McMaster's Academic Integrity Policy.

6 Future Changes

Change is inevitable. This section describes what likely and unlikely changes someone might make to EMgine and their impact on the different solution components to ease the process.

6.1 Likely Changes

LC1: Definition of “sub-goal” [A5].

LC2: A goal can elicit only one emotion at a time [A6].

LC3: Coupling the evaluation of emotion kind and intensity [A8].

LC4: CTE-based emotion intensity might not be related to the degree that a goal and/or plan is impacted [A10].

LC5: Different eliciting conditions for *Interest* [A13].

LC6: Emotion’s decay speed is not affected by its distance from “equilibrium” [A15].

LC7: Emotion kinds have a common “equilibrium” value [A16].

LC8: Emotion kinds have a common decay rate [A17].

LC9: Emotion terms in PES and PAD are not directly comparable [A20].

LC10: PAD values are influenced by number of ratings and standard deviations [A21].

LC11: The minimum value of emotion intensity is not zero (0) [A24].

LC12: Coupling “opposing” PES emotions [A25].

6.2 Unlikely Changes

The Conceptual Models (Section 4.2.3) will not change as they are drawn directly from primary sources. Changes to these models implies changes to PES, CTE, and/or PAD, or changing one of these to a different theory/model.

7 Traceability Matrices and Graphs

The purpose of the traceability matrices is to provide easy references on what has to be additionally modified if a certain component is changed. Every time a component is changed, the items in the column of that component that are marked with an "X" may have to be modified as well.

- Table 10 shows the dependencies of Theoretical Models, Instance Models, and Likely Changes on the Assumptions (A1, A2, A3, and A4 are excluded from the matrix because they are generally applicable)
- Table 11 shows the dependencies between Conceptual Models
- Table 12 shows the dependencies between Conceptual Models, Theoretical Models, and Data Types
- Table 13 shows the dependencies between Data Types
- Table 14 shows the dependencies of Instance Models on Theoretical Models
- Table 15 shows the dependencies between Instance Models
- Table 16 shows the dependencies of Instance Models on Data Types
- Table 17 shows the dependencies of Functional Requirements on Conceptual Models and Type Definitions
- Table 18 shows the dependencies of Functional Requirements on Data Constraints and Instance Models

	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	A21	A22	A23	A24	A25	A26	A27	A28	A29	A30	A31	A32
T1	X	X	X	X	X		X																					
T2						X																						
T3								X																				
T4									X																			
T5										X																		
T6											X	X	X	X														
T7															X	X	X											
TY1																		X		X								
TY2																			X									
TY4																					X							
TY5																					X	X						
TY6																				X								
TY10																							X					
TY11																							X					
IM4																								X				
IM6																									X			
IM8																										X		
IM10																											X	X
IM12																								X				
LC1	X																											
LC2		X																										
LC3				X																								
LC4						X																						
LC5									X																			
LC6											X																	
LC7												X																
LC8													X															
LC9																X												
LC10																	X											
LC11																				X								
LC12																					X							

Table 10: Traceability between Assumptions and Other Items

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
C1	X									X			
C2		X											
C3		X	X										
C4				X		X						X	
C5					X								
C6						X				X	X		
C7						X	X						X
C8	X					X		X					
C9	X								X				
C10										X			
C11										X	X		
C12												X	
C13													X

Table 11: Traceability between Conceptual Models

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	T1	T2	T3	T4	T5	T6	T7
T1						X				X	X			X						
T2								X							X					
T3				X								X				X				
T4							X										X			
T5							X											X		
T6									X										X	
T7		X			X															X
TY1															X	X	X	X		
TY3																			X	
TY4		X																		
TY5	X																			
TY6																			X	
TY7	X																			
TY8					X															
TY14										X				X						
TY15											X									
TY16												X								
TY17													X							

Table 12: Traceability between Conceptual Models, Theoretical Models, and Data Types

	TY1	TY2	TY3	TY4	TY5	TY6	TY7	TY8	TY9	TY10	TY11	TY12	TY13	TY14	TY15	TY16	TY17
TY1	X																
TY2	X	X															
TY3			X														
TY4				X													
TY5	X			X	X												
TY6	X		X	X		X											
TY7					X		X		X								
TY8								X									
TY9									X								
TY10										X							
TY11											X						
TY12										X		X					
TY13										X	X		X				
TY14										X	X	X	X	X			
TY15										X	X				X		
TY16																X	
TY17									X								X

Table 13: Traceability between Data Types

	T1	T2	T3	T4	T5	T6	T7
IM1	X						
IM2	X						
IM3	X						
IM4	X						
IM5	X						
IM6			X				
IM7				X			
IM8					X		
IM9	X	X					
IM10	X	X					
IM11	X	X					
IM12	X	X					
IM13	X	X					
IM14			X				
IM15				X			
IM16					X		
IM17						X	
IM24							X

Table 14: Traceability between Instance and Theoretical Models

	IM1	IM17	IM18	IM20	IM21	IM22
TY3		X				
IM6	X					
IM19			X			
IM22		X				
IM23				X	X	X

Table 15: Traceability between Instance Models and a Data Type

	TY1	TY2	TY3	TY4	TY5	TY6	TY7	TY8	TY9	TY10	TY11	TY12	TY13	TY14	TY15	TY16	TY17
IM1										X	X	X	X	X			
IM2										X	X	X		X	X		
IM3										X	X	X	X	X			
IM4										X	X				X		
IM5										X	X		X	X			
IM6										X	X		X	X		X	
IM7																	X
IM8										X	X						
IM9		X											X	X			
IM10		X								X				X	X		
IM11		X											X	X			
IM12		X													X		
IM13		X										X		X			
IM14		X											X			X	
IM15		X															X
IM16		X															
IM17	X		X						X								
IM18	X	X															
IM19		X		X	X												
IM20					X		X		X								
IM21					X		X		X								
IM22					X	X			X								
IM23						X	X		X								
IM24					X			X									

Table 16: Traceability between Instance Models and Data Types

	4.2.9	C3	C4	TY1	TY2	TY3	TY4	TY5	TY6	TY7	TY8	TY9	TY10	TY11	TY12	TY13	TY14	TY15	TY16	TY17
R1	X																			
R2				X																
R3					X															
R4						X														
R5							X													
R6								X												
R7									X											
R8										X										
R9											X									
R10												X								
R11													X							
R12														X						
R13															X					
R14																X				
R15																	X			
R16																		X		
R17																			X	
R18																				X
R19		X		X			X													
R20		X		X			X													
R21			X				X													

Table 17: Traceability between Data Constraints, Conceptual Models, Type Definitions, and Requirements

	IM1	IM2	IM3	IM4	IM5	IM6	IM7	IM8	IM9	IM10	IM11	IM12	IM13	IM14	IM15	IM16	IM17	IM18	IM19	IM20	IM21	IM22	IM23	IM24
R22	X	X	X	X	X	X	X	X																
R23									X	X	X	X	X	X	X	X								
R24																	X							
R25																						X		
R26																							X	
R27																		X						
R28																			X					
R29																				X				
R30																					X			
R31																								X

Table 18: Traceability between Instance Models and Requirements

The purpose of the traceability graphs is to provide a difference view of traceability between components. Arrows represent dependencies such that the component at the arrow's head depends on the component at its tail. Therefore, if a component is changed, the components that it points to might also need to be changed.

- Figure 5 shows Conceptual Model dependencies on each other
- Figure 6 shows the dependencies between Conceptual Models and Affective Theories/Models
- Figure 7 shows the dependencies on the Assumptions
- Figure 8 shows Data Type dependencies on Conceptual Models, Theoretical Models and other Data Types, and Theoretical Model dependencies on Conceptual Models
- Figure 9 shows Instance Model dependencies on Theoretical Models
- Figure 10 shows Instance Model dependencies on Data Types
- Figure 11 shows Instance Model dependencies on each other and TY3
- Figure 12 shows the dependencies of Functional Requirements on Conceptual Models, Data Types, and Instance Models

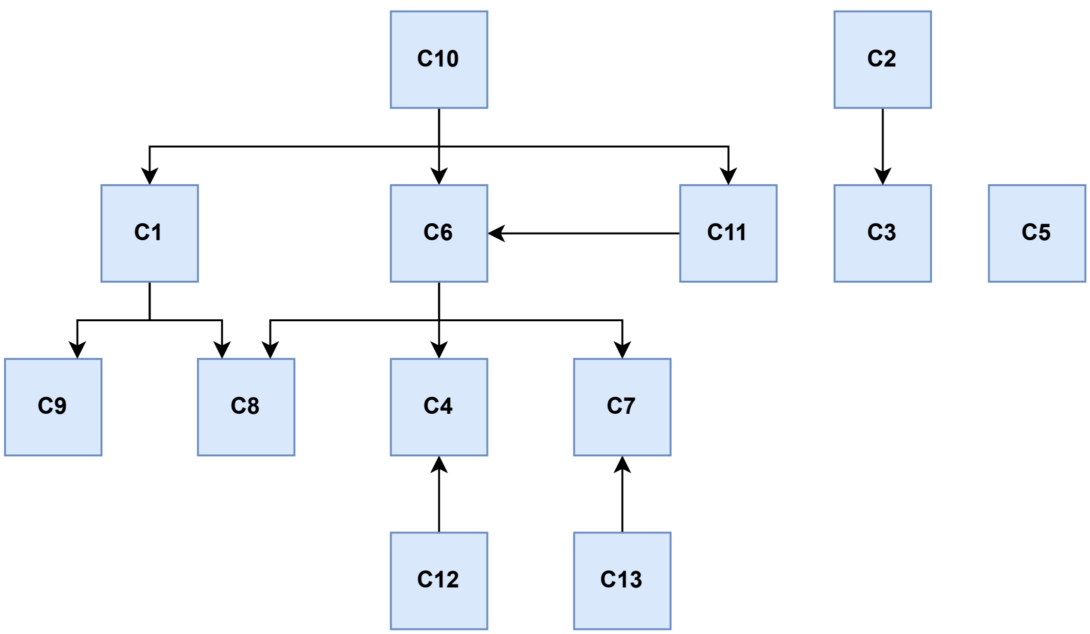

Figure 5: Dependencies between Conceptual Models (Section 4.2.3)

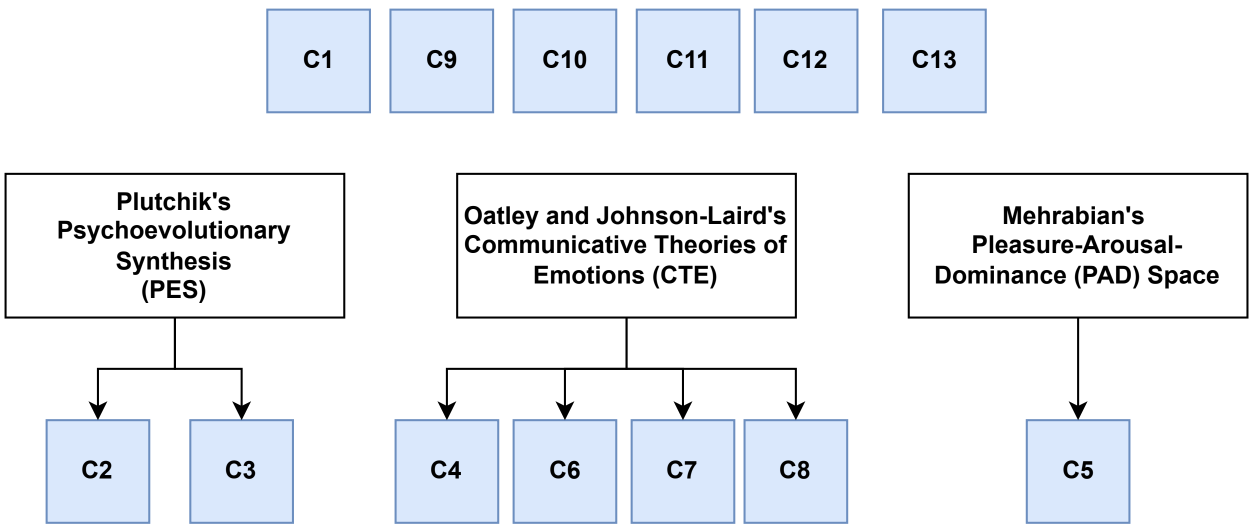

Figure 6: Conceptual Model Dependencies on Affective Theories/Models (Section 4.2.3)

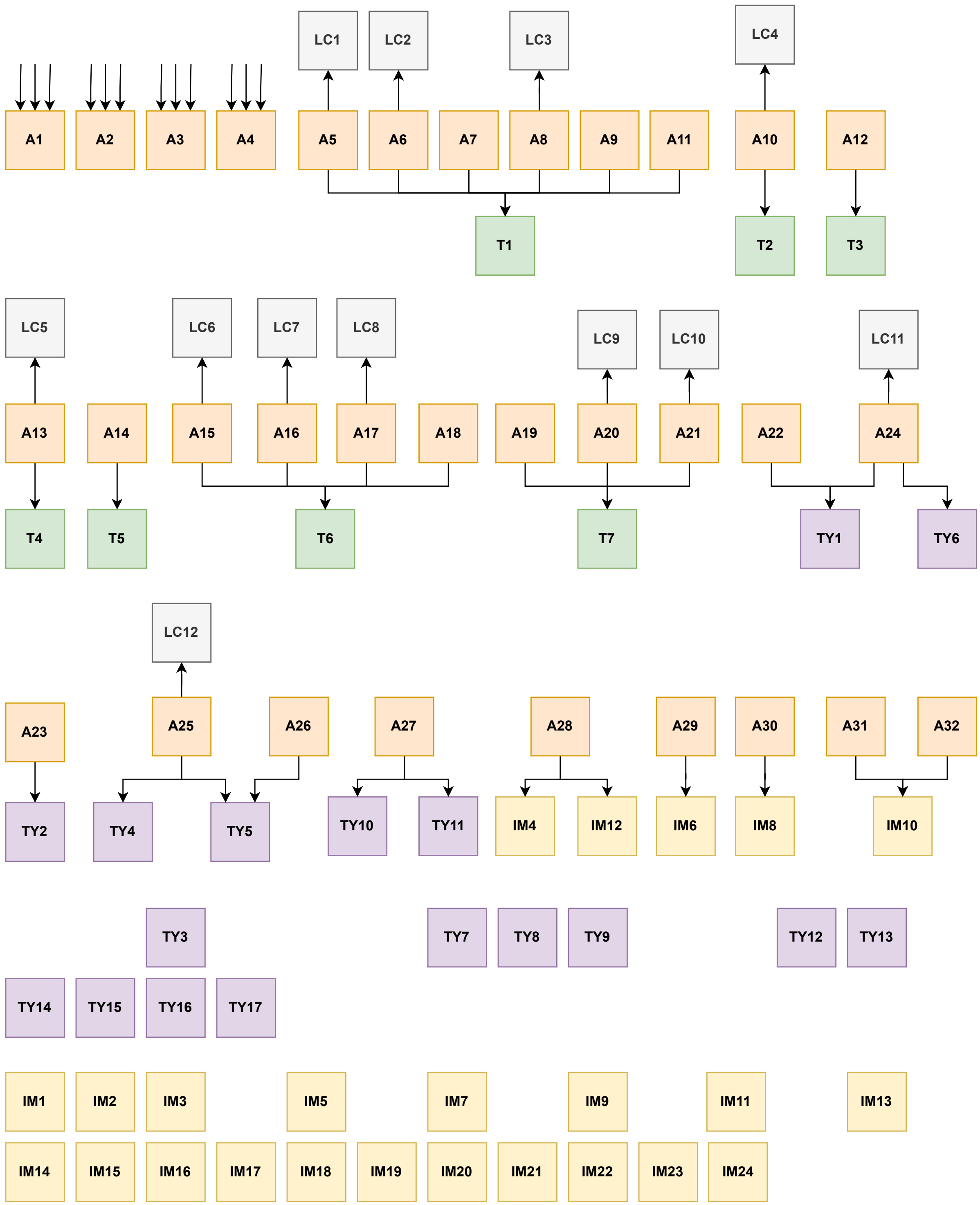

Figure 7: Dependencies on Assumptions (Orange) (Section 4.2.2)

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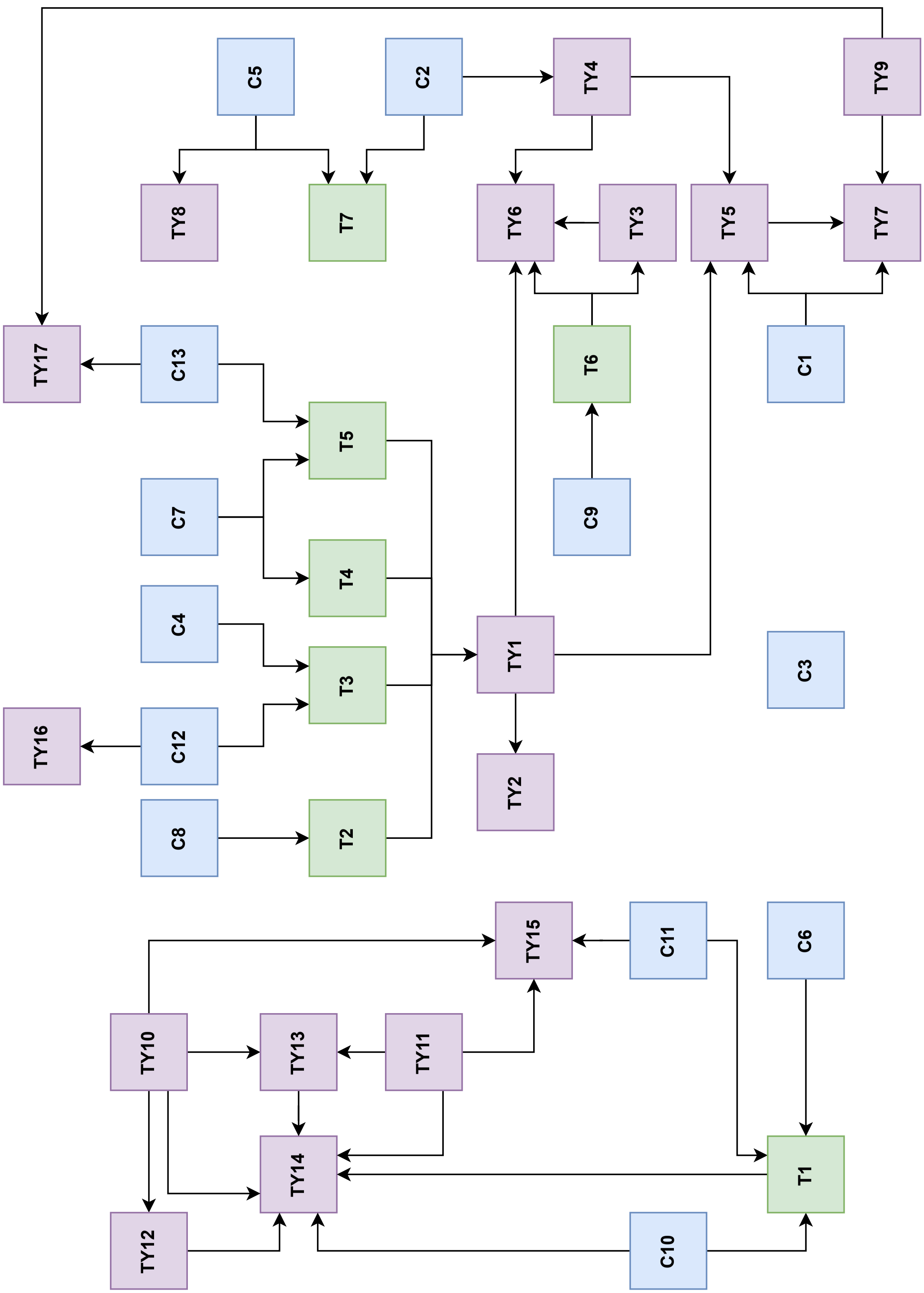

Figure 8: Traceability between Theoretical Models (Green) and Data Types (Purple), and their dependencies on Conceptual Models (Blue) (Sections 4.2.4, 4.2.7, and 4.2.3)

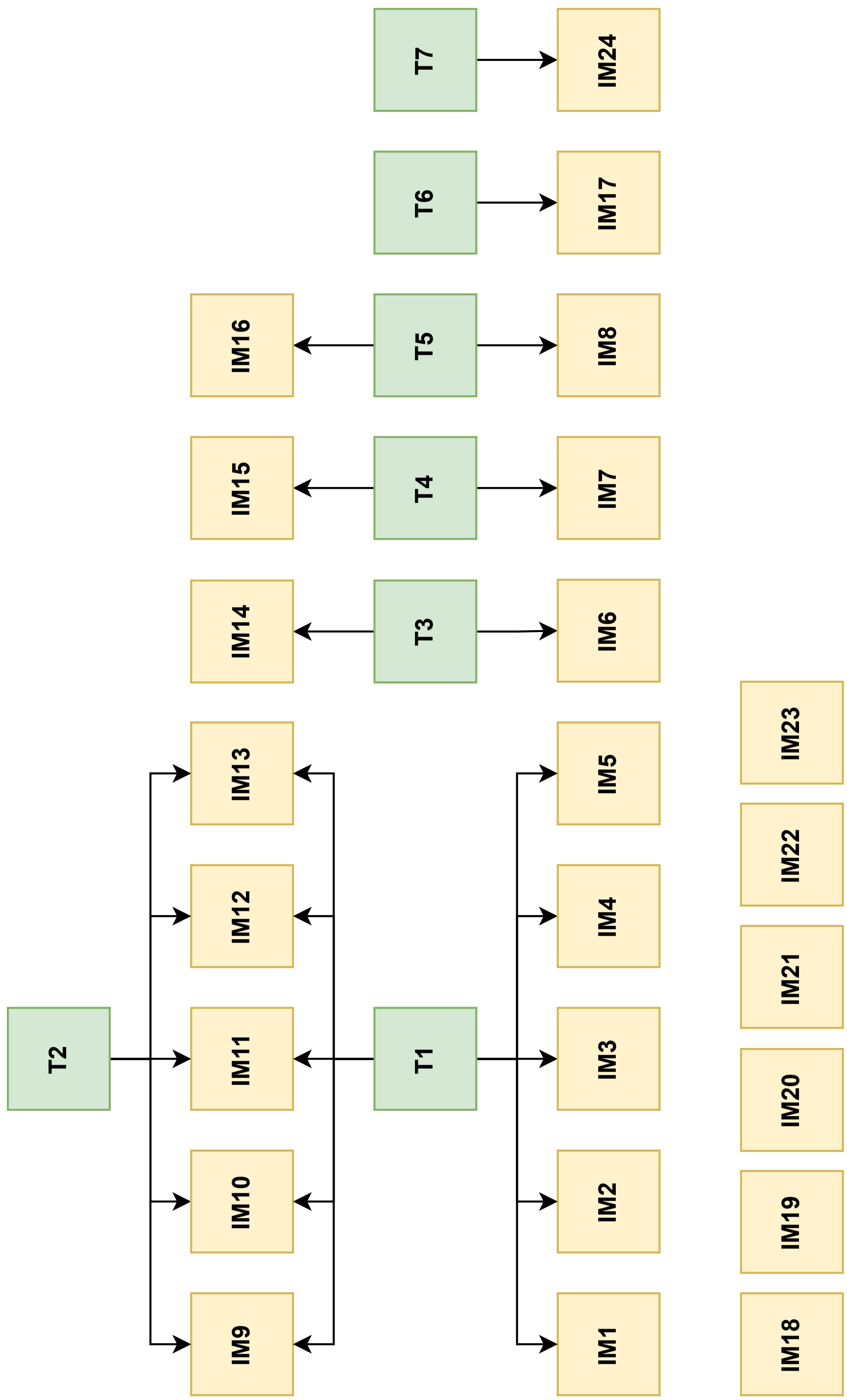

Figure 9: Instance Models (Yellow) and their Dependencies on Theoretical Models (Green) (Sections 4.2.4 and 4.2.8)

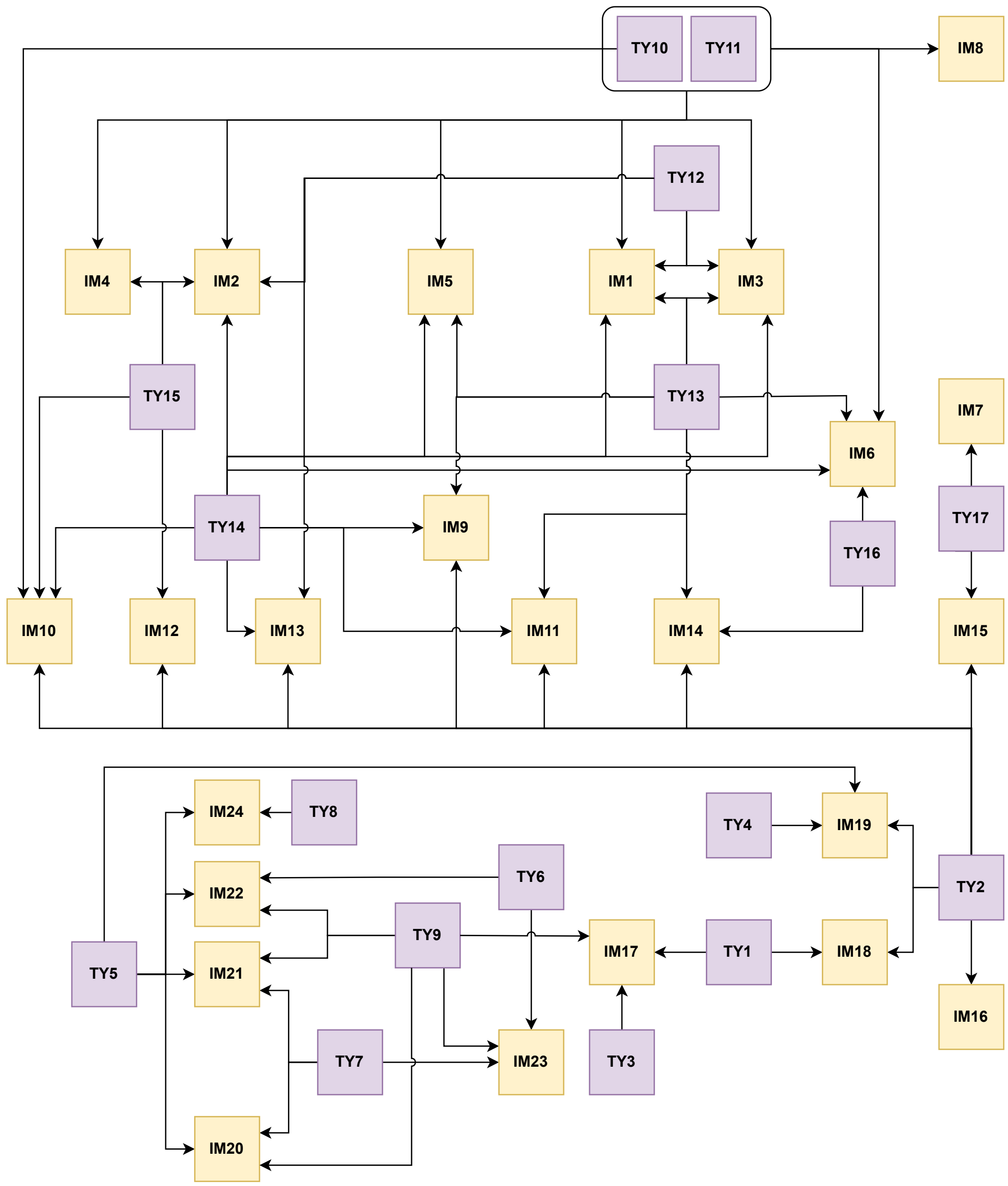

Figure 10: Instance Models (Yellow) and their Dependencies on Data Types (Purple) (Sections 4.2.7 and 4.2.8)

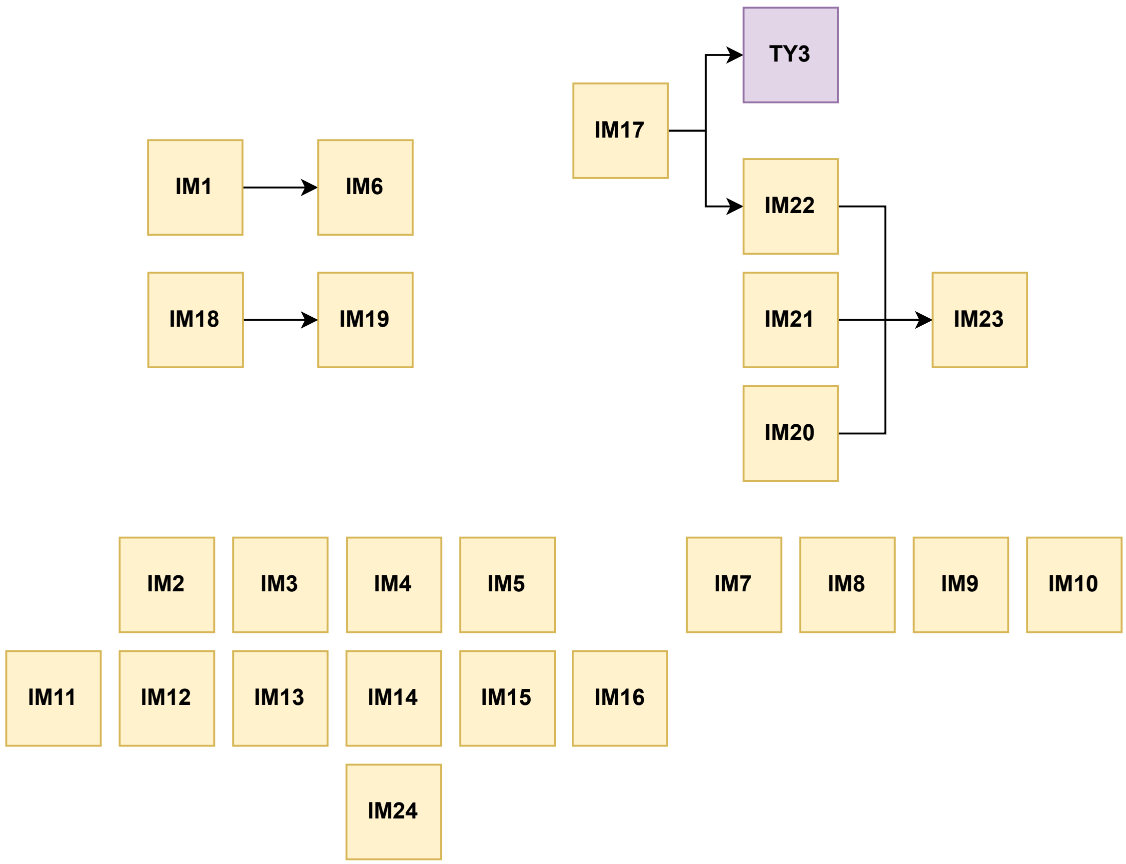

Figure 11: Dependencies between Instance Models (Section 4.2.8) and TY3 (Section 4.2.7)

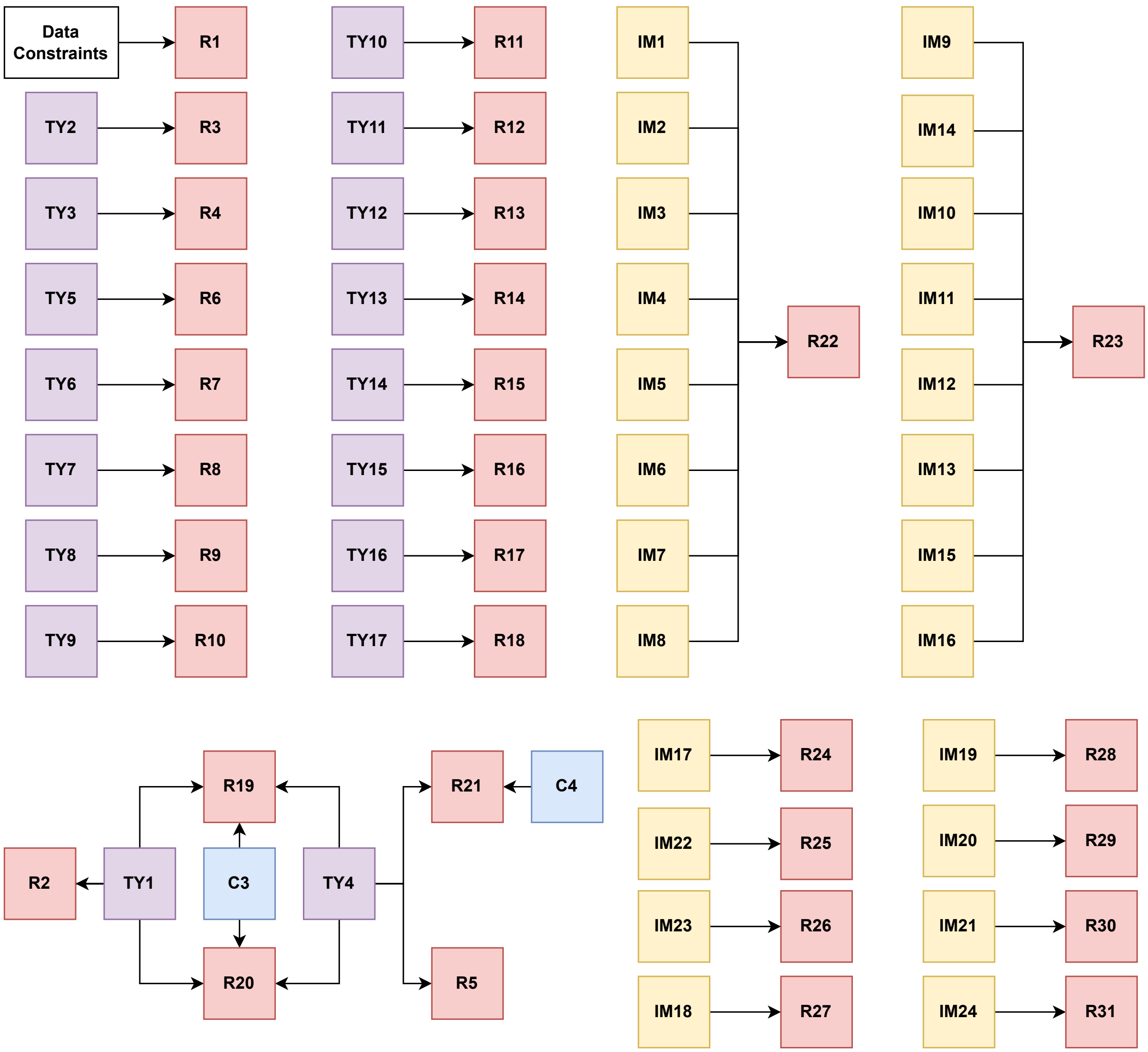

Figure 12: Functional Requirements (Red) and their Dependencies on Conceptual Models (Blue), Data Types (Purple), Instance Models (Yellow), and Data Constraints (Sections 4.2.3, 4.2.7, 4.2.8, 4.2.9, and 5.1)

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A Notes On Emotion Theories With Respect to High-Level Requirements and Emotion Theories

These are the notes created about emotion theories with respect to high-level requirements during analysis (Section 4.2.1). Tables 3, 4, 5, and 6 summarize the resulting scores.

A reminder that the scores are somewhat subjective, and depend on one's understanding of the requirements and current state of emotion literature.

A.1 Discrete Theories

The discrete theories are the most likely candidates for satisfying high-level requirements that depend on understanding what emotion an NPC has, as this is their core focus. This includes the flexibility requirements for *Allowing the Integration of New Components* (RF4) and *Choosing Which NPC Emotions to Use* (RF5), and the ease-of-use requirements for *Having a Clear API (Output)* (RE2) and *Showing That Emotions Improve the Player Experience* (RE6).

A.1.1 Flexibility: Allowing the Integration of New Components (RF4)

All three discrete theories provide variable levels of native support for personality, but only Plutchik does not touch on mood. None of them touch on core affect.

- **Ekman & Friesen** (☆)
  - Moods and personality are inferred from emotion signals (e.g. many *Joy*-related signals could suggest a cheerful mood) (Ekman, 1999, p. 48, 55–56)
  - Little information beyond these definitions → developers would need to create patterns of emotions for each mood and trait, could become too time consuming and error-prone
  - No coverage of Core Affect, Personality and Mood are error-prone and time consuming
- **Izard** (☆)
  - Natively accounts for personality (Izard and Ackerman, 2000, p. 253–254; Izard, 1977, p. 44)
    - Emergent phenomena that begins at birth and develops as the individual interacts with their environment
    - Treated as a product of emotions associated with patterns in perception, cognition, and behaviour
    - → Requires developers to create patterns for each personality trait, which is likely to be too time consuming and error-prone
  - Seems to acknowledge two definitions of mood
    - Defined as a "continuing total life condition" similar to what he calls an emotion trait, or tendencies towards certain emotion experiences (Izard, 1991, p. 17, 171) → in the view of stable traits and fluid states, conceptualization appears to be closer to personality than mood
    - As a state, defined as an enduring emotion state that is too mild to enter conciousness but can influence mental health and bodily systems, such as the immune system (Izard, 1991, p. 21) → closer to working definition of mood in EMgine's context

→ could be realized as a timed function that monitors an NPC's emotion state and acts on those that have not surpassed a given threshold (minimal effort to implement)

- No coverage of Core Affect, Mood requires minimal effort, Personality is error-prone and time consuming

- **Plutchik** (☆☆)
  - Natively accounts for personality
    - Connects its emotion circumplex directly to a circumplex of personality traits[2] (Plutchik, 1997, p. 27–28) → could mechanize with a simple weighting mechanism such that emotions are easier or harder to elicit
    - Built around a layperson's understanding of personality → upholds the *Hiding the Complexity of Emotion Generation* (RE1) requirement
  - circumplex is a way to incorporate a model of mood
    - Agreement that it can be represented by an elliptical circumplex with arousal as the shorter dimension (Feldman, 1995, p. 806, 812, 814)
    - Could add an additional element such that the length of the arousal dimension changes with context → afford more creative freedom than a fixed model
    - Can uphold the *Hiding the Complexity of Emotion Generation* requirement (RE1) with a well-designed interface, with details available for advanced users
  - Dimensional nature of theory could aid in a non-native representing core affect → could map the intensity dimension to arousal and the relative positions of an emotion to some anchor points as *valence*
    - Mapping might not be understandable due to debate about the *valence* of *Surprise* and its relation to *Anticipation* (Susanto et al., 2020, p. 98) → concessions could be made, such as listing some categories as zero *valence*, since EMgine is unconcerned with realism
    - Can uphold the *Hiding the Complexity of Emotion Generation* requirement (RE1) with a well-designed interface, with details available for advanced users
  - Ability to build *some* type of Core Affect and Mood representation on top of existing theory, Personality native to theory and built on a layperson's perspective

A.1.2 Flexibility: Choosing What Emotions the NPC can Have (RF5)

Within each discrete theory's set of emotions, it would be easy to exclude any of them if they are not needed. However, *adding* more emotions to a set is less clear cut. There does not seem to be any convincing empirically validated or verifiable rules for creating "non-basic" emotions in discrete theories (Ortony, 2022, p. 6). This does not impact EMgine because it does not need to replicate true affective phenomena—it need only produce convincing results.

- **Ekman & Friesen** (☆)
  - Do not believe that there are "non-basic" emotions (Ekman, 1999, p. 55, 57)

[2] The assumption that the circumplexes can be connected this way might be naive. They might be unique to the modelled domain rather than showing similarities across them (Feldman, 1995, p. 815).

    * Each emotion represents a family of related states that share a theme, and variations between members are the result of learning
    → Requires developers to either associate different situations for the desired variations manually or create a learning mechanism to create them as the NPC interacts with the game environment
    * Unideal → Could be difficult to adapt this kind of system to simple games, violating the *Ability to Operate on Different Levels of NPC Complexity* requirement (RF7); requires some knowledge of psychology and neuroscience, violating the *Hiding the Complexity of Emotion Generation* (RE1) requirement
  - Facial expressions can be blends of prototypical primary ones (Ekman, 2007, p. 69)
    * Step removed from the emotion generation process, and would likely happen in an emotion expression component
    * Would need to translate the blended expression into an emotion to use it for emotion generation → feasible, but error-prone, method as facial expression interpretations can be subjective
  - No “non-basic” emotions, translating from facial expressions is error-prone

- **Izard** (–)
  - “New emotions” are the product of affective-cognitive structures (Izard, 1992, p. 564–565)
    * Association of primary emotion patterns or clusters with images, thoughts, and memories
    → Requires developers to either create these structures manually or create a learning mechanism to create them as the NPC interacts with the game environment
    * Unideal → Same reasons as Ekman & Friesen, violating both the *Ability to Operate on Different Levels of NPC Complexity* and *Hiding the Complexity of Emotion Generation* requirements (RF7, RE1)
  - Difficult to adapt to different NPC complexities, requires knowledge for connecting emotions to cognitive patterns

- **Plutchik** (☆☆☆)
  - One of the better developed theories of emotion mixes (LeDoux, 1998, p. 113; Ortony, 2022, p. 3, 5)
  - Might be the only discrete theory to focus on this aspect of the “primary” emotions (Ekman, 1999, p. 47)
  - Colour wheel analogy uses concepts and terms that are generally understood by laypeople → does not require any knowledge of the theory to use
    * Lacks clarity about technical rules for combining emotions (Johnson-Laird and Oatley, 1992, p. 208–209; Ortony, 2022, p. 5) **BUT** laypeople tend to attribute the same underlying primary emotions to named emotions outside the primary set (Plutchik, 1984, p. 204–205)
    → Implies that a game developer can apply their own experiences when deciding how to represent a new emotion with the Plutchik circumplex
  - Ability to build additional emotions from existing set, based on a layperson’s understanding of emotions and their combinations

A.1.3 Ease-of-Use: Having a Clear API (Output) (RE2)

The discrete theories are generally easy for laypeople to understand. All three theories connect their emotions to distinctive behaviours that can be applied to situations of variable complexity. This makes for a clean output API, providing an emotion category that developers can attach to "buckets" of related behaviours and expressions that are "familiar".

- **Ekman & Friesen** (☆☆☆)
  - Have publications that are meant for the general public (e.g. Ekman (2007)) → accessible to laypeople
  - Use of facial expressions is a helpful tool for conveying meaning about their primary emotions
- **Izard** (☆)
  - Gains understandability by connecting its emotions to facial expressions, although some emotions are not connected to one
  - → Weakens its usability, as some developers might actively avoid the emotions that cannot be readily represented on the face
- **Plutchik** (☆☆)
  - Construction based on similarities and differences between affective terms as they are understood in (English) language → can help developers understand each emotion based on their understanding of the word's meaning and its relative position to other emotion words on the circumplex
  - Each primary emotion is also connected to an intended behaviour pattern, like rejection and exploration (Plutchik, 1984, p. 202)
    - ∗ Addresses problems of "missing" facial expressions with characteristic or typical behaviours (Julle-Danière et al., 2020, p. 20–21; Schindler et al., 2013, p. 101)
    - → Could help developers conceptualize what each emotion could look and act like, can include facial expressions
  - Does not directly benefit from assigned facial expressions, but some connections could be made with Ekman & Friesen and Izard (Table 19) → understanding of emotion terms and associated behaviours is not as "clear cut"

A.1.4 Ease-of-Use: Showing that Emotions Improve the Player Experience (RE6)

Like the *Having a Clear API (Output)* requirement (RE2), discrete theories are generally understandable by laypeople. This helps identify ways to design studies to evaluate and ways to build the player experience.

- **Ekman & Friesen** (☆☆)
  - Emotions could be directly connected to an expression module built on the Facial Action Coding System (FACS), which is part of the theory itself (Ekman et al., 2002)
  - Players could report on their experiences based on NPC expressions → relatively easy to test how emotions impact a player, but limited to facial expressions alone

Table 19: Primary Emotions in Discrete Theories

Emotion	**Ekman & Friesen (Ekman, 2007)**	**Izard et al. (1993)**	**Plutchik (1997)**
Happiness/Enjoyment/Joy[♃♀]	✓	✓	✓
Sadness[♃♀]	✓	✓	✓
Fear[♃♀]	✓	✓	✓
Anger[♃♀]	✓	✓	✓
Surprise[♃♀]	✓	✓	✓
Disgust[♃♀]	✓	✓	✓
Contempt[☽♀]	✓	✓	𓅞
Interest[♀]		✓	✓
Guilt[𓀾]		✓	𓅞
Shame[♀]		✓	𓅞
Shyness[♀]		✓	
Acceptance[𓀾𓇋]			✓

♃ *Associated with a facial expression by Ekman and Friesen (2003).*
♀ *Associated with a facial expression by Izard (1971, p. 236–237), Izard (1977, p. 85–91).*
☽ *Associated with a facial expression by Ekman (2007, p. 184–186).*
𓅞 *As a mixture of the primary emotions.*
𓀾 *Might not have a characteristic expression (Keltner and Buswell, 1996, p. 155; Schindler et al., 2013, p. 106), but artistic renditions of facial expressions exist (e.g. Le Brun (1760)).*
𓇋 *Plutchik is noted as the only researcher to consider Adoration—the highest intensity of Acceptance—a primary emotion (Schindler et al., 2013, p. 87–88).*

- **Izard** (☆☆)
  - Considerable overlap between Ekman & Friesen and Izard regarding facial expressions (Ekman, 2007, p. 3) → could be connected to an emotion expression component built on FACS, probably with minimal effort
  - Players could report on their experiences based on NPC expressions → relatively easy to test how emotions impact a player, but limited to facial expressions alone
- **Plutchik** (☆☆)
  - Could be connected to facial expressions, but there is no obvious match for *Acceptance* emotion type
  - Associates each emotion with a behaviour that could be applied to a number of actions and expressions that an NPC could need → design studies around these behaviour classes
  - Players could report on their experiences based on NPC expressions → relatively easy to test how emotions impact a player, but likely an element of subjectivity in matching behaviours to meaning

A.1.5 Examining the Remaining Requirements

The absence of a defined emotion elicitation tasks in the discrete theories is a double-edged sword—some requirements are trivial to satisfy, while others are impossible. The lack of elicitation processes makes it impossible for discrete theories to satisfy most task-related requirements—they simply do not exist. This means that they *cannot* be categorized for the component-level requirements (Tables 5 and 6). For the remaining system-level requirements (Tables 3 and 4), the theories satisfy the requirements in similar ways, so they are examined as a single unit.

- *Flexibility: Independence from an Agent Architecture (RF1)* (☆☆)
  - No specific tasks → effectively architecture-agnostic
  - Only require processes that satisfy input and output requirements
- *Flexibility: Allowing Developers to Specify How to Use Outputs (RF6)* (☆☆)
  - No specific tasks → affords flexibility for specifying how to use EMgine's outputs
  - Theoretically could hook up any process to EMgine using the emotions as "buckets" for collecting related behaviours
- *Flexibility: Ability to Operate on Different Levels of NPC Complexity (RF7)* (☆☆)
  - Could add processes and parameters as needed → does not affect core EMgine processes
- *Flexibility: Be Efficient and Scalable (RF8)* (☆☆)
  - Could add processes and parameters as needed → does not affect core EMgine processes
- *Ease-of-Use: Providing Examples of Novel Game Experiences (RE7)* (☆)
  - No immediately obvious features for novel game mechanics, challenges, or other elements

A.2 Dimensional Theories

The dimensional theories are the most likely candidates for satisfying requirements related to CME expansion, as they aim to discover the structure of emotion and how they relate to other mental states (Reisenzein et al., 2013, p. 250; Broekens, 2021, p. 353). This mainly concerns the flexibility requirements for *Allowing the Integration of New Components* (RF4) and *Choosing What Emotions the NPC can Have* (RF5).

For this analysis, the V-A model is treated as a circumplex as it is a reasonable representation of affective states (Remington et al., 2000, p. 296), and is more consistent with affective structure (Barrett and Russell, 1999, p. 12). The circumplex also tends to form regardless of the data collected, research domain, and analysis (Russell, 1997, p. 211). This representation is not perfect. There are still issues, such as inclusion/exclusion of terms, self-report weaknesses, and the effect of context on state positions (Remington et al., 2000, p. 298). However, it also provides more structure to an otherwise two-dimensional and nebulous space.

A.2.1 Flexibility: Choosing What Emotions the NPC can Have (RF5)

Neither V-A or PAD strictly enforce the inclusion of specific emotion types. Instead, the use of dimensions allows for an infinite number of affective states. While this trivially supports the ability to *Choose What Emotions the NPC can Have* (RF5), it might not be practical for EMgine on its own. Instead, adding specific emotions is guided by point locations representing named emotions. This removes the burden of deciding where an emotion is located in dimensional space from game designers.

- **V-A** (☆)
  - Space represented by *valence* and *arousal* only represents part of an emotion episode (Yik et al., 2002, p. 90; Roseman, 2011, p. 441; Lisetti and Hudlicka, 2015, p. 97)
  - Unideal → some emotions, like *Anger* and *Fear*, are difficult to differentiate without additional information
    - Might be some of the most common emotions that a game designer will use → could be the *only* two emotions required in some games (e.g. NPCs in oppositional First Person Shooters (FPSs) due to the game's pace and the limited time and ways that players interact with them)
  - Adding new emotions cannot be adequately contained in V-A
- **PAD** (☆☆)
  - Accompanied by a list of 151 emotion labels (Mehrabian, 1980, p. 42–45) identified from empirical data → notes their average location in PAD space and the standard deviation in the data
  - List is still finite and cannot account for cultural differences, might not cover all of the affective states that a game designer needs → list is long enough that there is a reasonable chance that a game designer can find all the affective state labels that they require
  - Prone to interpretation errors, as the designer's definition and the definition used to locate points in PAD space might not be the same → designers can make their own judgements of the suitability of a term based on its coordinates, potentially violating *Hiding the Complexity of Emotion Generation* (RE1)

A.2.2 Flexibility: Allowing the Integration of New Components (RF4)

Both V-A and PAD can trivially represent core affect, as they both natively include the dimensions of *valence* and arousal. Like Plutchik, both dimensional theories could also model mood as an elliptical circumplex with relative ease. Unlike Plutchik, this mapping is native due to the presence of both a *valence*/*pleasantness* and arousal dimension. This only leaves an evaluation of the ability to represent personality in V-A and PAD.

The dimensional theories seem to have variable levels of built-in support for representing personality. This analysis focuses on support for the Five-Factor Model OCEAN[3] personality traits (Costa and McCrae, 1992). With research ongoing in personality psychology, there is still a good consensus on the usefulness of OCEAN as a descriptive model (Yik et al., 2002, p. 100–101; De Raad and Perugini, 2002, p. 3). OCEAN has, arguably, also become known among the general populace as a personality profile tool due to its accessible language (De Raad and Perugini, 2002, p. 1) and use in career counselling (Costa Jr. et al., 1995, p. 135;

[3] Defined as "psychological entities with causal force" (American Psychological Association, 2020b). Although they have the same dimensions, this differs from the Big Five Model, which "views the five personality dimensions as descriptions of behaviour and treats the five-dimensional structure as a taxonomy of individual differences".

Howard and Howard, 1995; Hurtado Rúa et al., 2019, p. 528). This familiarity makes it ideal for EMgine, which cannot assume that a user will have an academic understanding of psychology. For game design, the OCEAN model will also likely prove convenient for defining NPC personalities, as Costa and McCrae (1992) provide a questionnaire consisting of five-point Likert scales representing statement agreement to measure how each factor contributes to personality. It has also been translated to several languages (Yik et al., 2002, p. 84). This implies that a simple tool presenting game designers with the questionnaire is sufficient for defining a new NPC personality in EMgine with OCEAN traits.

- **V-A** (☆☆☆)
  - Relating OCEAN personality traits with circumplex structures is more consistent than simple structures → two structures have close-fitting probability plots supporting an ideal circumplex structure and the third has convincing and serviceable, but less satisfactory, probability plot (Gurtman, 1997, p. 84–87, 90)
    - Some evidence that the interpersonal traits of Extroversion and Agreeableness are best described with a circumplex → Extroversion can be related to the *valence* dimension (McCrae and Costa, 1989, p. 590, 593)
    - Extroversion/Neuroticism → represents the affective plane (Gurtman, 1997, p. 84–87, 90)
    - Unnamed or "mixed" Agreeableness/Neuroticism plane (Gurtman, 1997, p. 84–87, 90)
    - All three planes can be layered over each other in the polar coordinate system (Gurtman, 1997, p. 84–87, 90)
    - Does not appear to be support for Openness or Conscientiousness (Gurtman, 1997, p. 84–87, 90)
  - Alternate hypothesis puts OCEAN traits as points on the circumplex → a high value in a trait implies a higher tendency to experience the type of affect represented in the same space (Yik et al., 2002, p. 94–96)
    - Locates the angles for each trait in five languages—English, Spanish, Korean, Chinese, and Japanese
    - Configuration option → pre-build some cultural differences into EMgine
- **PAD** (☆☆☆)
  - Personality[4] can be inferred by averaging an individual's emotional states across a representative sample of day-to-day situations (Mehrabian, 1996b, p. 262)
  - As traits, the PAD dimensions were found to be a good base description of personality (Mehrabian, 1980, p. 64)
  - Other personality scales are represented as linear combinations of the three dimensions (Mehrabian, 1996b, p. 267), forming a line through the space
    - Provides lines estimates for the OCEAN personality traits[5] in terms of *pleasure*, arousal, and *dominance* (Mehrabian, 1996a, p. 91 Eq. 11C–13C), and from the dimensions to PAD space (Mehrabian, 1996a, p. 90 Eq. 1D–5D)
    - Gender agnostic (Mehrabian, 1996a, p. 89) → removes a layer of complexity that one might consider when adding the OCEAN model of personality to EMgine

[4]Mehrabian refers to *emotional traits* or *temperament*. Since he defines them as "...stable over periods of years or even a lifetime" (Mehrabian, 1996b, p. 262) and temperament is a biologically-based bias in personality development (Kagan, 2009), they are assumed to be equivalent to personality traits in EMgine.

[5]*Trait Sophistication* is assumed to be equivalent to *Trait Openness* (McCrae and Costa Jr., 1997, p. 826–827).

A.2.3 Examining the Remaining Requirements

Dimensional theories are similar to the discrete theories in that they have no defined emotion elicitation tasks, so they are also unable to satisfy the component-level requirements (Tables 5 and 6). However, for the remaining system-level requirements (Tables 3 and 4), the dimensional theories do not necessarily satisfy the same requirements as discrete theories. Again, the dimensional theories satisfy the requirements in similar ways, so they are examined as a single unit.

- *Flexibility: Independence from an Agent Architecture (RF1)* (☆☆)
  - Coordinate space that does not depend on its surrounding environment → effectively architecture-agnostic
  - Only require processes that satisfy input and output requirements
- *Flexibility: Allowing Developers to Specify How to Use CME Outputs (RF6)* (☆☆☆)
  - Numerical representation → easy to pipe them to other computational processes, such as facial expression generation and decision-making
  - Potential to violate *Having a Clear API (Output)* (RE2) → resolve by providing alternate definitions of the dimensions that are easier to understand for non-experts
- *Flexibility: Ability to Operate on Different Levels of NPC Complexity* (RF7) (☆) AND *Flexibility: Be Efficient and Scalable* (RF8) (☆)
  - Numerical representation could satisfy these requirements → requires one of:
    - Developers to have some understanding of what the dimensions mean and how different factors impact them → violates *Hiding the Complexity of Emotion Generation* (RE1)
    - Providing alternate definitions of the dimensions that are easy to understand as with *Allowing Developers to Specify How to Use CME Outputs* (RE2) → potential to violate *Hiding the Complexity of Emotion Generation* (RE1)
- *Ease-of-Use: Having a Clear API (Output) (RE2)* (☆)
  - Output API has three numerical components → requires developers to know how each dimension affects NPC behaviours
  - Inference on quantities like *pleasantness* (*valence*) and *excitement* (arousal) likely not as automatic as identifying *Joy* and *Fear*
    - Could minimize problem with a circumplex structure
    - Disagreements between different models as to where certain data points should be (Remington et al., 2000, p. 287) → could reduce the psychological validity of EMgine
- *Ease-of-Use: Showing that Emotions Improve the Player Experience (RE6)* (☆☆)
  - Numerical representation with limited variables → easy to manipulate in experimental settings
  - Might be difficult for future user study participants to answer questions about combinations of values → could use a proxy mapping values to affective labels
- *Ease-of-Use: Providing Examples of Novel Game Experiences (RE7)* (☆☆)

  - Numerical representation → leverage as a game mechanic where players manipulate affective variables as they would other resources like character and item statistics (Adams, 2009, p. 292, 466, 559–560, 578)
  - Can be implemented alongside similar mechanics (e.g. status attributes in Computer Role-Playing Games (CRPGs), character-related puzzles in adventure and social simulation games)

A.3 Appraisal Theories

Due to their nature, the appraisal theories are the only ones that can satisfy the *component-level* requirements in addition to *system-level* ones.

A.3.1 Flexibility: Independence From an Agent Architecture (RF1)

Appraisal theories are built on the assumption that cognition is essential in emotion processes (Gratch and Marsella, 2015, p. 55; Broekens, 2021, p. 354), and that emotions *about* something that has been intentionally evaluated (Ortony, 2022, p. 11). This prevents complete separation from agent architectures in general because of the information required for the appraisal process. Therefore, the goal is *not* to identify theories that can exist independently of an external system—it is to identify which theories are agnostic about what that architecture is.

- **Frijda** (☆☆☆)
  - Core process is an information processing system (Frijda, 1986, p. 453–456) that begins with an encoding stage that tries to match incoming events with known types and their implications for causes and consequences
    - Also need to encode actions to evaluate coping potential
    - Matching process requires users to define event and action types, then tag relevant game elements with them
      - Event types are tailored to the external architecture → affords maximal architecture independence
  - Concerns are dispositions towards the achievement or non-achievement of situations that remain dormant as long as its satisfaction conditions are met (Frijda, 1986, p. 335–336, 466–467)
    - Do not have to generate emotion from “active” pursuits alone (e.g. goals and motivations), can also be driven by events that just *happen* that change a satisfaction condition
    - → Can account for a much wider range of events, supports independence from specific architectures and information structures
  - Action tendencies only specify *what* type of action should happen, not *how* (Frijda, 1986, p. 70)
    - Freedom to connect the actions represented in the architecture to any type of action readiness → separate process can decide which action to execute
    - → Can account for a much wider range of behaviours, supports independence from specific architectures and information structures
- **Lazarus** (☆☆)
  - Relational themes described in context of goal achievement, requires pre-existing knowledge to drive appraisal (Lazarus, 1991, p. 81, 145) → goal-based architecture or system

  - Multiple references to goals, beliefs, and knowledge requirements (Lazarus, 1991, p. 39, 151, 177, 210) → implies a Belief-Desire-Intention (BDI) architecture, coping coded as intentions
    - Has been used to model players (Yannakakis and Togelius, 2018, p. 208–209), unsure of use for creating NPCs

- **Scherer** (–)
  - Conceptualizes theory as an information processing system (Scherer, 2001, p. 103–104)
    - Structure based on Cowan (1988)
      - Requires components for: attention, memory, goal/need/motivation, reasoning, and a self-model to evaluate appraisal dimensions (Scherer, 2001, p. 100)
      - Goals/needs/motivations do not have to be concious (Scherer, 2001, p. 96, 119)
      - Potential to violate *Ability to Operate on Different Levels of NPC Complexity* (RF7) if some parts cannot be excluded
    - Assumes multiple processing levels of varying complexity (Scherer, 2001, p. 103)
      - Faster, less sophisticated levels call "higher" levels when they cannot resolve an evaluation
      - Add more processing layers as needed → potential to support *Ability to Operate on Different Levels of NPC Complexity* (RF7)
    - Parts of the system are represented with a neural network (Scherer, 2001, p. 105)
      - An implementation of Scherer this way was found to be at least partially black-box (Meuleman, 2015, p. 143–144) → violation of *Traceable CME Outputs* (RE4)
  - → Emotion generation is *not* independent of the surrounding processes

- **Roseman** (☆☆)
  - Focus on the relationship between appraisal values and emotions, how those emotions impact different systems in response, and the structure of emotions (Roseman, 2001, p. 68, 81) → does not touch on the emotion process itself, effectively architecture-agnostic
  - Some appraisal dimensions have cognitive contents (Roseman et al., 1996, p. 265) → requires some type of architecture to provide appraisal inputs

- **OCC** (☆☆☆)
  - Requires modelling, planning, reasoning, and predictive processes (Ortony et al., 2005, p. 185–186) → not unique to emotion (Clore and Ortony, 2002, p. 36), do not require a separate architecture to support EMgine
    - Precursors to expectations about outcomes and world states, and self-reflection (Ortony et al., 2005, p. 195)
    - Inputs include memory and knowledge (Smith and Kirby, 2000, p. 101)
    - Assumes that significance detection is cognitive (Clore and Ortony, 2002, p. 42)
  - Requires representations of goals/wants, standards/beliefs, and tastes/attitudes (Ortony et al., 1988, p. 39–45)
    - Evaluate different input types (Ortony et al., 1988, p. 48)
    - Can interact to help/hinder each other (Ortony et al., 1988, p. 47)

    * Must be coherent and relatively stable internal structure, like a goal hierarchy, to evaluate the environment by to produce consistent results in both kind and intensity (Ortony, 2002, p. 194–195) → coherence depends on how the user defines these structures, not directly dependent on EMgine
  - Acknowledges that there are different potential action outcomes (Clore and Ortony, 2002, p.41) → potential to create architecture-agnostic outputs
  - Later ties emotion to changes in the body similar to neurobiological theories (Ortony et al., 2005, p. 174, 177, 188, 195; Clore and Ortony, 2002, p. 24–25, 28–29) → at least partially architecture dependent because of dependence on embodiment

- **Smith & Kirby** (☆☆☆)
  - Conceptualized as a process model, built from previously gathered findings on the effects of emotion and mood on cognition (Smith and Kirby, 2000, p. 85)
    * Builds from the framework described by Smith and Lazarus (1990) (Smith and Kirby, 2001, p. 122)
      · Does not appear to have the same kinds of dependencies on goals, beliefs, and intentions → more likely to be architecture-agnostic
    * Views emotion as a well-being monitor or guidance system for attentional and motivational functions (Smith and Kirby, 2000, p. 90–91) → idea of a "guidance system" does not belong to any single architecture, potential to apply to many
    * Not empirically tested → EMgine not concerned with "correct" results, just interesting ones
  - Accounts for more than one appraisal process, processes work in parallel (Smith and Kirby, 2000, p. 91–92; Smith and Kirby, 2001, p. 129)
    * Specifies two appraisal types for automatic reactions (i.e. priming and activation of memories) and deliberative analysis (i.e. reasoning) → notes that concept appears in previous proposals (e.g. Leventhal and Scherer (1987), Sloman et al. (2005))
    * Proposes that memory is a network (Smith and Kirby, 2000, p. 94, 102)
      · Allows priming and spreading activation → appraisal is continuous, activated quickly and automatically, and does not require much attention
      · Knowledge in memory does not have to be organized in schemas
    * Proposes that reasoning uses highly developed and abstract thinking processes (Smith and Kirby, 2001, p. 130; Smith and Kirby, 2000, p. 95–96)
      · Requires that memory items be associated with semantic meaning → resulting appraisals can be integrated back into memory for associative processing (i.e. learning)
    * Users are not required to have these processes → core idea of appraisal unaffected because it does not rely on these two specific appraisal types or definitions

- **Oatley & Johnson-Laird** (☆☆☆)
  - Assumes that the cognitive system is modular and asynchronous, similar to Minsky (1986) (Oatley and Johnson-Laird, 1987, p. 31–32), model-driven rather than rule-driven (Johnson-Laird and Oatley, 1992, p. 205–206) → aligns with the idea of architecture independence
    * Top-level module organizes whole system, can reorganize system goals and plans (Oatley, 1992, p. 50–51) → top-level control module in software architecture

- Implicitly assumes that individuals have beliefs, desires, and needs that they make goals about and plans to achieve (Johnson-Laird and Oatley, 1992, p. 213)
  - Defines "cognitive" as psychological explanations in terms of knowledge representations and transformations that might not be conscious (Oatley and Johnson-Laird, 1987, p. 30) → acts on transformations on data, could be defined for a generalized data representation
  - Core elements are goals and plans (Oatley and Johnson-Laird, 1987, p. 30)
    - Goals → symbolic representations of possible environments states to achieve
    - Plans → sequences from the current environment state to a goal, can include instinctive and highly practised ones (i.e. automatic)
  - Emotions as a mechanism for managing cognitive resources and goal priorities (Johnson-Laird and Oatley, 1992, p. 207–208), and responding to models—including social ones for cooperation and competitive planning—that are proven invalid in the moment (Johnson-Laird and Oatley, 1992, p. 205–206)
    - Triggered when smoothly flowing action is interrupted, detects significant change in goal or plan outcomes, typically at plan junctures (Oatley, 1992, p. 46, 48; Oatley and Johnson-Laird, 1987, p. 35–36)
    - Cause the system to enter an "emotion mode" that inhibits other "emotion modes" or oscillates between multiple "modes" (Oatley and Johnson-Laird, 1987, p. 34) → comparable to other system state changes
    - "Modes" associated with different goal priorities, possible actions, and skills (Oatley and Johnson-Laird, 1987, p. 37)
  - → Does not necessarily imply a Belief-Desire-Intention (BDI) architecture
- Assumes a two-pathway system (Oatley and Johnson-Laird, 1987, p. 32–34)
  - Reactive → propagates a global "signal" to setup an emotion "mode"
  - Deliberative → invoke individual functions, reason about system state for planning
  - → Does not depend on specific architecture features, assume that "planning" does not have to be formal
  - Can naturally cause temporal shifts in emotion quality as different processes add meaning (influenced by individual and cultural factors) to a goal/plan change (Oatley and Johnson-Laird, 1987, p. 47)

A.3.2 Flexibility: Choosing Which CME Tasks to Use (RF2)

Appraisal theories are assumed to need some minimum number of processes for emotion generation. Therefore, they are evaluated on the ability to call them individually as needed. It is assumed that a game designer can choose when the emotion generation as a complete process is called.

- **Frijda** (☆)
  - Core emotion process is interdependent (Frijda, 1986, p. 454) → unrealistic to allow its components to be called out of turn
  - Possible to skip and/or interrupt processes (Frijda, 1986, p. 461–463)
    - Direct implementation would require theory knowledge → violates *Hiding the Complexity of Emotion Generation* requirement (RE1)

        - Could build interrupts over the emotion process, temporarily bypassing it (i.e. automatic responses) → emotion process continues at its current pace and updates emotion state when it finishes
    - Task choice difficult to realize within the process, can implement interrupts that bypass the system and act like automatic responses

- **Lazarus** (☆)
    - Emotion process is interdependent (Lazarus, 1991, p. 39, 208–211) → unrealistic to allow its components to be called out of turn
    - No obvious mention of ways to skip or interrupt tasks
    - Define separate processing levels for societal, psychological, and physiological tasks (Lazarus, 1991, p. 211) → could turn whole levels on/off as needed
    - Create switches/input points for designers to allow internal processes (i.e. emotion-based coping) to influence the appraisal process and outcomes (Lazarus, 1991, p. 210)
        - Potential to violate *Hiding the Complexity of Emotion Generation* (RE1) → make available to advanced users

- **Scherer** (☆☆☆)
    - Monitoring system triggers appraisal cycles based on relevance (Scherer, 2001, p. 99) → choose when to start and stop reappraisals and/or update appraisal registers
    - Check individual appraisal units (SEC) to update systems and when to see what the current action tendency is (Scherer, 2001, p. 104, 106) → requires caution, as it could cause cascading changes in interdependent modules, which also changes the current appraisal
    - Define separate processing levels for different types of information (i.e. sensory-motor, schematic, conceptual) (Scherer, 2001, p. 102–103) → could turn whole levels on/off as needed

- **Roseman** (–)
    - Focus on the relationship between appraisal values and emotions, how those emotions impact different systems in response, and the structure of emotions (Roseman, 2001, p. 68, 81) → does not touch on the emotion process itself

- **OCC** (☆☆)
    - Emotion structure built with three distinct branches → could choose a subset of branches
        - Some emotions (e.g. *Anger*) only possible if event and attribution-based emotion branches active (Ortony et al., 1988, p. 19; Ortony, 2002, p. 195; Steunebrink et al., 2009, p. 7)
        - Each branch requires at least one evaluated variable to proceed, additional variables can retain neutral values (Ortony et al., 1988, p. 59, 81, 84) → could choose which tasks to run based on what values are needed
        - Insufficient information could mean that the process will not produce a result

- **Smith & Kirby** (☆☆)

- Builds on Smith and Lazarus (1990) (Smith and Kirby, 2001, p. 122) ∴ assume that its core emotion process is also interdependent and it is unrealistic to allow its components to be called out of turn
- Control over sources of appraisal inputs ((Smith and Kirby, 2000, p. 93–94, 100); Smith and Kirby, 2001, p. 129–130)
    * Sources interact and their separate information integrated before appraisal
    * Can control when sources provide information, when to integrate, and how to integrate them → control emotion generation at the triggering stage
    → Potential to choose tasks that provide and integrate inputs, controlling emotion generation process
    * No obvious information about how to integrate information sources

- **Oatley & Johnson-Laird** (☆☆)
    - Base elements are goals and plans → can decide which plan junctures to call emotion generation at
    - Emotion "modes" have a basic meaning that deliberative processes can build on (Oatley and Johnson-Laird, 1987, p. 35, 43), definition of two pathways that can propagate to the whole system (i.e. reactive) or invoke individual functions (i.e. deliberative) (Oatley and Johnson-Laird, 1987, p. 32–34)
        * Freedom to choose which tasks to call when additional information is needed to add nuance to emotion states
        * Game developer would need to provide all additional tasks → does *not* violate *Hiding the Complexity of Emotion Generation* (RE1) because of its partial basis on an intuitive, "folk" understanding of emotion embedded in language (Oatley, 1992, p. 74–75, 86–87)

A.3.3 Flexibility: Customizing Existing Task Parameters (RF3)

Differing from when emotion generation tasks are called is the ability to control their functionality, such as variable sensitivity and activation thresholds. Ideally, EMgine should allow game designers to manipulate as many system parameters as possible to maximize customizability, effectively creating "individual differences" with each change.

- **Frijda** (☆☆☆)
    - Notes many potential elements that can be parametrized, one hypothesised source of individual differences (Frijda, 1986, p. 456–458)
        * Each phase in the core emotion process can be influenced individually both internal and external inputs
        * Different and variable sensitivity levels/thresholds/concern priorities for matching inputs with satisfaction conditions
        * Variable acceptance conditions for connecting a generated meaning structure with action readiness modes/emotions
        * Open ended parameters → allow designers to customize additional parameters to influence emotion generation

- Potential to implement some parameters implicitly from system state

- **Lazarus** (–)
  - Discussion of appraisal styles implies that emotion process dispositions are part of an encoding process, not the appraisal itself (Lazarus, 1991, p. 138)
    * Some individual difference contained in the structure and organization of goals (Lazarus, 1991, p. 99) → outside EMgine's scope
    * Personality defined as goal commitments, beliefs, and knowledge are inputs to emotion generation (Lazarus, 1991, p. 209) → outside EMgine's scope

    → No explicit mention of "tuning" the emotion generation process directly

- **Scherer** (☆☆)
  - Parameters associated with appraisal registers (Scherer, 2001, p. 105–106)
    * Individual variables combined with weighted functions that change with the "confidence" in the data → mechanize as a user-defined task parameter
    * Action tendency activation "strength" tied to appraisal profile and degree of "definiteness" of individual checks → potential for parametrised activation thresholds based on strength and confidence in appraisal check accuracy

- **Roseman** (–)
  - Focus on the relationship between appraisal values and emotions, how those emotions impact different systems in response, and the structure of emotions (Roseman, 2001, p. 68, 81), empirical validation of appraisal dimension influence on resulting emotion (Roseman et al., 1996, p. 242, 244) → does not touch on the emotion process itself

- **OCC** (☆☆)
  - Parametrization of emotion intensity and activation thresholds → change how easily and intensely emotions are produced (Ortony et al., 1988, p. 81–83, 184, 189)
    * Variable weights on emotion intensity function
    * Modulation of emotion thresholds → change how strong the emotion is before it manifests
  - Elicitation rule conflict resolution not addressed (Ortony et al., 1988, p. 190) → allow customization of rule priority
  - Handling "mixed emotions", coexisting positive and negative emotions from the same appraisal (Ortony et al., 1988, p. 51–52) → implement customizable mechanism to determine which to express at any given moment
  - Suggest varying parameters on emotion generation mechanisms (Ortony, 2002, p. 203) → process not well defined, limits ability to implement it
  - If multiple processing levels are implemented, can parametrize the thresholds for control and interrupt thresholds from each one (Ortony et al., 2005, p. 185)
  - Not many guidelines are given about how these work → risk of reducing psychological validity

- **Smith & Kirby** (☆☆)

  - Builds on Smith and Lazarus (1990) (Smith and Kirby, 2001, p. 122) ∴ assume that its core emotion process does not allow direct "tuning" either
  - Control over sources of appraisal inputs (Smith and Kirby, 2000, p. 93–94, 100)
    * Sources interact and their separate information integrated before appraisal → control degrees of interaction and weights during information integration
    * Can control when sources provide information → "sensitivity" or activation thresholds
    * No obvious information about how to integrate information sources

- **Oatley & Johnson-Laird** (☆☆)
  - Emotions elicited by relative changes in success probabilities at plan junctions (Oatley, 1992, p. 98) → candidate for implementing sensitivity thresholds
  - Mentions temporal differences in emotion intensity, variable emotion decay rates of emotion, replacement with other emotions elicited by the same scenario (Oatley, 1992, p. 22–23) → candidates for customizing how emotion quality and intensity varies over time and context
  - Few guidelines about how to define parameters → low risk of violating psychological validity due to its partial basis on an intuitive, "folk" understanding of emotion embedded in language (Oatley, 1992, p. 74–75, 86–87)

A.3.4 Flexibility: Allowing the Integration of New Components (RF4)

When included, the appraisal theories tend to define other affective types relative to emotion. This implies that integrating them requires no additional structures in favour of building on top of existing features. This makes them ideally suited for *Allowing the Integration of New Components* (RF4) in this aspect.

Although integrating non-affective components should be theory-agnostic, how easily this can be done varies between appraisal theories. Therefore, the analysis examines their ability to integrate both affective and non-affective components.

- **Frijda** (☆☆☆)
  - Proposes that adding, removing, and/or modifying the components of emotion creates different types of affect (Frijda, 1986, p. 253) → does not require changes to emotion generation, definitions built on top of existing emotion definitions and functions
    * Later refinement for an implemented version of the theory related mood, personality, and sentiments to emotion by their focus and duration (Figure 13)
    * Could derive core affect from emotion process via the *valence* and *demand character* appraisal dimensions and arousal value (Frijda, 1986, p. 207, 454)
  - Inclusion of a "Regulation Processes" block that can affect nearly all parts of the emotion process (Frijda, 1986, p. 545)
    * Multiple points to introduce new components and processes → easy to add non-affective components
    * Potential to violate *Hiding the Complexity of Emotion Generation* (RE1) if users can access points directly → create an interface to hide entry points, make it easier to use and understand

- **Lazarus** (☆)

- Personality not seen as a set of innate traits that manifest in appraisal and coping (Lazarus, 1991, p. 316), defined as a collection of goals, needs, commitments, knowledge, attitudes, and beliefs that influence how an event is perceived and how the individual acts on the resulting action tendency (Smith and Lazarus, 1990, p. 623–624, 628) → implicitly defined
  * Affords flexibility (i.e. not limited to a set of values) → supports creative freedom, definitions of individual characters based on their goals and knowledge rather than numerical values
  * More difficult to define personality quickly (e.g. have to decide what beliefs a character with a desired personality would have)
- Mood is "an existential state or condition of life" that is appraisal-dependent, related to subjective well-being (Lazarus, 1991, p. 266–267)
  * Could define as a state that aggregates appraisal results into a "satisfaction/dissatisfaction" value
- Equates affect to subjective experience (Lazarus, 1991, p. 57)
  * Could define core affect using *goal congruence* as *valence*
  * arousal is part of an action tendency, tied to the emotion's core relational theme (Lazarus, 1991, p. 58–59, 150) → not explicitly defined
- Potential interface points for external processes part of input generation/output manipulation (Lazarus, 1991, p. 210) → does not have to integrate with emotion generation process, trivial to add non-affective components

• **Scherer** (☆)

- Proposes definitions for mood and personality (Scherer, 2000, p. 140–141), but are not accounted for in the working theory (Scherer, 2001, p. 93, 119)
  * Personality could be defined as sensitivities in appraisal dimension and register functions, mood as temporary sensitivities caused by previous appraisals → potential to violate psychological validity
- No clear connection to core affect
- Potential to integrate non-affective components at the information processing, appraisal objective steps (Scherer, 2001, p. 104) → might require knowledge of how those components work, violating *Hiding the Complexity of Emotion Generation* (RE1)

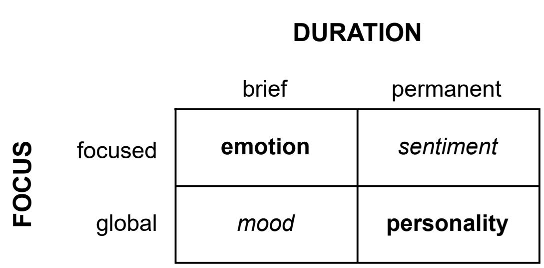

Figure 13: Proposed Relation Between Emotion and Other Affective Types (Adapted from Moffat (1997, p. 136))

- **Roseman** (☆)
  - Suggests that mood and personality are tied to emotion generation (Roseman, 2001, p. 81–83), ways to describe appraisal styles for individual or families of emotion (Roseman, 2001, p. 88–89) → implicitly defined
    - Affords flexibility (i.e. not limited to a set of values) → supports creative freedom, definitions of individual characters based on their goals and knowledge rather than numerical values
    - More difficult to define quickly (e.g. have to decide what appraisal dispositions a character with a desired personality would have)
    - Could be extended to represent cultural influences on emotion generation
  - No clear connection to core affect
    - Could define core affect using *situational state* and *motivational state* as *valence*
    - No obvious component for arousal
  - Focus on the relationship between appraisal values and emotions (Roseman, 2001, p. 81) → does not focus on other parts of the generation process, no obvious place to integrate non-affective processes
- **OCC** (☆☆☆)
  - Proposes that personality is a unique parameter profile defining how emotion generation behaves within and between process levels (Ortony et al., 2005, p. 189–190)
    - Tuning emotion generation for each NPC → personality implicitly supported by *Customizing Existing CME Task Parameters* (RF3)
    - Could implement personality inventories as parameter profiles (Ortony et al., 2005, p. 191–192) → no explicit definitions given, potential to violate psychological validity if done incorrectly, might not matter if the profiles do what the developer expects
  - Moods described as free-floating, object-less affective states that can influence emotion but can also arise from sources independently of emotion (Clore and Ortony, 2002, p. 27) → could be linked to personality "parameter profiles" by treating it as an initial condition
    - Defined as temporally-driven parameter changes (Ortony et al., 1988, p. 184, 189–190) → implicitly supported by *Customizing Existing CME Task Parameters* (RF3)
  - Potential to represent core affect
    - Physiological arousal is a global intensity variable, roughly proportional to base emotion intensity—approximately represented by the sum of the absolute unsigned values of some variables[6]—or perhaps even only parts of this (i.e. subjective importance of the situation) (Ortony et al., 1988, p. 51, 65–66) → other factors can influence it, and has a slow rate of decay, supports *Customizing Existing CME Task Parameters* (RF3)
    - It follows that *valence* might be approximated as sum of the absolute signed values of the same variables (i.e. is the overall feeling positive or negative?)
  - Two potential ways to integrate non-affective components

[6] *desireability*, *undesireability*, *praiseworthiness*, *blameworthiness*, *appealingness*, and *unappealingness*

        * As part of the input generation process → designer-driven, supports *Ability to Operate on Different Levels of NPC Complexity* (RF7)
        * As a method for controlling task parameters → implicitly supported by *Customizing Existing CME Task Parameters* (RF3)

- **Smith & Kirby** (☆)
    - No clear definitions for personality, mood, or core affect
        * Potential correlation between *emotion-focused coping potential* and some personality traits (Smith and Kirby, 2009b, p. 1366–1368, 1369) → suggests that personality are parameters on the emotion generation process
        * Core affect could be constructed from *motivational congruence* (as *valence*) and *motivational relevance* (as arousal) → not necessarily empirically supported, potential to violate psychological validity
    - Appraisal registers synthesize information from multiple sources, levels of processing (Smith and Kirby, 2001, p. 130)
        * Multiple points to introduce new components and processes → easy to add non-affective components
        * Integrating non-affective components would require manipulating the detector mechanisms, potential to violate *Hiding the Complexity of Emotion Generation* (RE1) if users can access points directly → create an interface to hide entry points, make it easier to use and understand

- **Oatley & Johnson-Laird** (☆☆☆)
    - Emotions often have moods and sentiments associated with them (Oatley, 2000, p. 87) → implies that adding these affective types would be an extension of existing emotion structures
    - Temperaments (i.e. personality traits) hypothesized to be enduring predispositions towards emotion “modes” (Oatley and Johnson-Laird, 1987, p. 34; Oatley, 1992, p. 61)
        * Also defines sentiments—enduring emotional dispositions about something, typically other individuals (Oatley, 2000, p. 81) → potential to define two sets of personality traits (general and target-specific), affords more creative freedom
    - Moods defined directly in the theory as control signals that persist after the cause of an emotion passes/no longer associated with semantic content and keeps the system in a particular state (Oatley and Johnson-Laird, 1987, p. 32; Oatley, 1992, p. 64)
        * Could be realized as a temporary predispositions towards emotion “modes” or a longer lasing, low intensity emotion state (Oatley and Johnson-Laird, 1987, p. 34–35) → potential to allow both, give user the choice of which to use, affording more creative freedom
    - Potential to define core affect based on how a goal is affected (positive or negative) for *valence*, emotion intensity as arousal → no explicit definitions given, potential to violate psychological validity if done incorrectly, might not matter if the profiles do what the developer expects
    - Assume that the cognitive system is modular and asynchronous (Oatley and Johnson-Laird, 1987, p. 31) → implies that adding non-affective processes is feasible, should not require knowledge of the inner workings of emotion generation

A.3.5 Flexibility: Choosing NPC Emotions (RF5)

Like the discrete theories, the appraisal theories tend to define emotions as categories to group different aspects of a response together. In this sense, excluding predefined emotions is trivial. Once again, *adding* new ones is unclear and there are no obvious "rules" to follow. EMgine can still take advantage of them though, because new emotions need only make sense to the developer so that they can use them. Therefore, the appraisal theories are evaluated for what a developer would need to do and how easy it is to realize.

- **Frijda** (☆)
  - Emotions as descriptions of action readiness in response to different combinations of events, or by the nature of the emotional object (Frijda, 1986, p. 72–74) → defining new emotions requires defining new action tendencies
    - Require modifications to the emotion generation process (i.e. defining appraisal patterns) → violates *Hiding the Complexity of Emotion Generation* (RE1)
    - Some "non-basic" emotions are blends, can define a limited set of additional emotions → limited flexibility
    - Define emotions by pairing existing ones with an event or object type and assigning it a new name → similar to scripting, event-coding
- **Lazarus** (☆)
  - Emotions associated with themes that can coexist (Lazarus, 1991, p. 229)
    - Potential to allow developers to create named combinations representing "new" emotions → necessarily create more complicated emotions
    - Defining emotions that are not combinations would require new appraisal pattern definitions (i.e. modify emotion generation process) → violates *Hiding the Complexity of Emotion Generation* (RE1)
- **Scherer** (☆☆)
  - "Emotions" defined as the net effect of continuous, fluctuating subsystem changes (Scherer, 2001, p. 106, 108)
    - Adding new emotions requires identification and naming of a set of subsystem changes (i.e. requires an understanding of how emotions are generated) → violates *Hiding the Complexity of Emotion Generation* (RE1)
  - "Innate" emotions[7] (e.g. *Joy*) attributed to common adaptational issues that produce consistent system effects (Scherer, 2001, p. 108, 113) → range of known emotions are products of mixtures and/or blends of "innate" ones
    - Some emotion profiles have "open" entries that can accept any value for that dimension → potential to define emotion family "members" by providing specific values for "open" entries, potential to violate *Hiding the Complexity of Emotion Generation* (RE1)
    - Intensity differences can also differentiate otherwise identical emotions → define new emotions by intensity class, external to the emotion generation process so no violation of *Hiding the Complexity of Emotion Generation* (RE1)

[7] Scherer calls them *modal* emotions.

- **Roseman** (☆☆)
  - Proposes that more than one emotion can be experienced simultaneously due to different evaluations (Roseman, 2001, p. 81)
    - Definition of new emotions as mixtures → external to the generation process, so no violation of *Hiding the Complexity of Emotion Generation* (RE1)
    - Emotions are logically grouped by response strategy (e.g. *attack*, *exclude*) → potential for a design tool to guide the process of defining new emotions?
- **OCC** (☆☆)
  - Emotions necessarily tied to cognitive abilities that build on four basic affective states (Ortony et al., 2005, p. 183–184) implies that adding "new" emotions is about adding meaning → dependent on what is available for inputs, designer-driven, supports *Ability to Operate on Different Levels of NPC Complexity* (RF7)
  - Propose smaller emotion structure for believable agents, collapsing 22 emotions into five positive and five negative ones (Ortony, 2002, p. 193–194)
    - Potential to add "new" emotions as more cognitive processes are added → dependent on what is available for inputs, designer-driven, supports *Ability to Operate on Different Levels of NPC Complexity* (RF7)
  - *Surprise* as a special case, can be added in connection with the *unexpectedness* appraisal variable (Ortony, 2022, p. 13–14, 16–17)
  - "New" emotions can be defined as differences in intensity/elicitation thresholds (e.g. *Pleased* for low intensity and *Ecstatic* for high) (Ortony et al., 1988, p. 185)
    - External to the emotion generation process → no violation of *Hiding the Complexity of Emotion Generation* (RE1)
- **Smith & Kirby** (☆)
  - Unclear how additional emotions could be defined
  - Hypothesizes that emotion categories are likely dense clusters in dimensional space (Smith and Scott, 1997, p. 245–246)
    - Potential to combine with V-A or PAD Space, define new emotion categories from existing data clusters → would require some understanding of source material, potential violation of *Hiding the Complexity of Emotion Generation* (RE1)
    - Developers could collect their own data to find affective "clusters" in a dimensional space → time consuming, error-prone, potential violation of *Hiding the Complexity of Emotion Generation* (RE1)
- **Oatley & Johnson-Laird** (☆☆☆)
  - How people describe emotions in everyday language indicates underlying cognitive meanings (Johnson-Laird and Oatley, 1992, p. 210) → can build on layperson's understanding of emotions, supports *Hiding the Complexity of Emotion Generation* (RE1)
  - Emotion "modes" are not absolute definitions, only have heuristic properties that capture general classes of events (Oatley, 2000, p. 87) → potential to create more refined emotions by constraining the classes

    * "New"/"adult" emotions are based on emotion "modes", deliberative processes attach more meaning to them (Oatley and Johnson-Laird, 1987, p. 35, 43; Oatley, 1992, p. 76–78)
    * Can also be defined at junctions of mutual plans with one or more other agents, requires a self-model (Oatley and Johnson-Laird, 1987, p. 44, 46, 48) → way to integrate cultural differences due to the impact on models and reasoning processes (Oatley and Johnson-Laird, 1987, p. 47)
  - Emotions that have different semantic contents can exist simultaneously (Oatley, 1992, p. 104) → potential to define emotion "mixtures"
    * External to the emotion generation process → no violation of *Hiding the Complexity of Emotion Generation* (RE1)

A.3.6 Flexibility: Allowing Developers to Specify How to Use CME Outputs (RF6)

There is clearly a difference between reflexes and emotions: one is very difficult to control how one reacts and the other has a range of them to pick from (Fellous, 2004, p. 45). The idea of emotion *components* also suggests that there is flexibility in which system aspects are affected and how (Hudlicka, 2019, p. 133; Scherer, 2001, p. 108; Roseman, 2011, p. 436). This implies that *any* appraisal theory should be able to strongly support this requirement. The question is now how well each theory defines what this means.

- **Frijda** (☆☆☆)
  - Set the output boundary of EMgine at the action proposer (i.e. action tendency), relevance and control precedence signals, and physiological change generators (i.e. arousal) points (Frijda, 1986, p. 455)
    * Would also allow for another layer to group these into emotion categories (Frijda, 1986, p. 72)
    * Can feed the outputs back into EMgine → provide an interface so that this is a matter of "flipping a switch", supported by *Customizing Existing CME Task Parameters* (RF3)
    → Allows maximum flexibility for defining what to do with outputs that is agnostic to how "action" is defined
- **Lazarus** (☆☆☆)
  - Set the output boundary of EMgine at the appraisal outcome (i.e. action tendency, subjective experience, physiological response), would also allow for labelling the output with emotion categories (Lazarus, 1991, p. 209–210)
    * Excludes coping process integral to the theory → could be added as an external component, supported by *Allowing the Integration of New CME Components* (RF4)
    * Resulting NPC actions would impact their interpretation of the environment → implicitly supports reappraisal process (Lazarus, 1991, p. 134)
    * Can feed the outputs back into EMgine → provide an interface so that this is a matter of "flipping a switch", supported by *Customizing Existing CME Task Parameters* (RF3)
    → Allows maximum flexibility for defining what to do with outputs that is agnostic to how "action" is defined
- **Scherer** (☆☆☆)

- Set the output boundary of EMgine at the action tendency level, would also allow for labelling the output with emotion categories (Scherer, 2001, p. 107, 113) → allows maximum flexibility for defining what to do with outputs that is agnostic to how "action" is defined
- Allow users to access individual appraisal registers (Scherer, 2001, p. 104) → affords more flexibility
  * Each part of the appraisal process makes changes to different subsystems, creates a continuously changing outputs (Scherer, 2001, p. 107) → appraisal "history" encoded in unique pattern caused by subsystem changes, values update frequently
  * Potential to violate *Hiding the Complexity of Emotion Generation* (RE1) → make available for advanced users
  * Potential to violate psychological validity → how a user uses the values should be external to EMgine, so its internal psychological validity would remain intact

- **Roseman** (☆☆☆)
  - Set the output boundary of EMgine at the "response strategy", the typical physiological, phenomenological, expressive, behavioural, and motivational emotion contents (Roseman, 2013, p. 141; Roseman, 2001, p. 75; Roseman, 2018, p. 146–148, 151–152)
    * Potential to connect components directly to existing game modules if available (e.g. "expressive" as an input to NPC animation, "motivation" to planning) → user chooses which ones to use, supported by *Choosing Which CME Tasks to Use* (RF2)
    * Differentiates between "action tendency" and what action is actually taken, informed by emotion intensity (Roseman, 2011, p. 436) → input to the behaviour/expression selection process, explicitly built-in support for *Allowing Developers to Specify How to Use CME Outputs* (RF6)
    * Also notes that there is consistency in what types of responses that each emotion elicits (Roseman, 2011) → creates consistent behaviour necessary for believability (Ortony, 2002, p. 200)
    → Allows maximum flexibility for defining what to do with outputs that is agnostic to the system at large

- **OCC** (☆☆☆)
  - Set the output boundary of EMgine at the evaluation of emotion category and intensity (Ortony et al., 1988, p. 19, 69)
    * Propose that action tendencies are not necessary or sufficient to define emotion because some emotions might not have a "characteristic" action tendency as defined as voluntary actions following emotion (Ortony et al., 1988, p. 11) → allows the generation of emotions that do not have one, removes constraint from user
    * Claims "action tendency" is a set of components that emotions constrain themselves to, but might not use all components (Ortony, 2002, p. 198, 201) → creates consistent behaviour necessary for believability (Ortony, 2002, p. 200)
    → Allows maximum flexibility for defining what to do with outputs that is agnostic to the system at large

- **Smith & Kirby** (☆☆☆)

- Set the output boundary of EMgine at "emotional response", contains appraisal outcome (e.g. emotion category and dimensions, intensity), physiological activity (e.g. arousal, facial expressions), and action tendencies (Smith and Kirby, 2001, p. 123, 130)
    - Users can separate components and send them to different system process
    - Can also send components back into appraisal processes via appraisal sources → potential for different interpretations due to processing in appraisal source (Smith and Kirby, 2000, p. 99)
    - → Allows maximum flexibility for defining what to do with outputs that is agnostic to the system at large

- **Oatley & Johnson-Laird** (☆☆☆)
    - Set the output boundary of EMgine at control signals, labelled with an emotion category (Oatley, 1992, p. 50, 54)
    - Control signals are global entities or "alarms" that change the system "mode" when a goal is impacted by an active plan, bringing it into focus (Oatley, 1992, p. 62–63)
        - Users can choose which system components are receptive to the signal and to what degree → supported by *Choosing Which CME Tasks to Use* (RF2) and *Customizing Existing CME Task Parameters* (RF3)
        - → Allows maximum flexibility for defining what to do with outputs that is agnostic to the system at large

A.3.7 Flexibility: Ability to Operate on Different Levels of NPC Complexity (RF7)

Due to the assumed role of cognition in emotion processes (Gratch and Marsella, 2015, p. 55; Broekens, 2021, p. 354), there is also an assumed level of NPC complexity needed for an appraisal-based CME to properly function. Therefore, the appraisal theories are evaluated based on how much cognitive processing is required to produce results.

- **Frijda** (☆)
    - Requires encoded categories for events and rules for inputs, action structures for evaluating coping, process to evaluate event/action implications, definition of concern structures (Frijda, 1986, p. 457) → effort to create likely to linearly increase with respect to game complexity
        - Some can be implicitly evaluated in EMgine → relieves some of the authorial burden from game designers
    - Regulation processes can be added as needed, not mandated in the core emotion process (Frijda, 1986, p. 454, 456) → can potentially adapt to increases in NPC/game complexity
        - Path in process to add planning if needed, but not critical to function (Frijda, 1986, p. 462)
    - Requires a monitoring process (i.e. blackboard structure) to continuously update situational meaning (Frijda, 1986, p. 459) → space requirements increases with information sources

- **Lazarus** (☆☆☆)
    - Purpose of appraisal is to "integrate the two [personal interests with environmental realities] as effectively as possible" (Lazarus, 1991, p. 135) → complexity controlled by EMgine, can be made relatively simple

- Complexity in individual factors and environmental conditions evaluations that get passed to appraisal (Lazarus, 1991, p. 209–210) → designer controlled, can define to match game complexity
  - Minimally requires definitions for goals, "ego type", event causes, predictions about the impact of actions and future events (Lazarus, 1991, p. 149–150)
  - → Could connect to hard-coded data/processes for low-complexity games (e.g. *Pac-Man* (Namco, 1980)), increase complexity with game
- Implication of a central data structure to store appraisal values as they become available (Lazarus, 1991, p. 134, 151, 189, 210–211)
  - Stores outputs of appraisal evaluations, not the inputs
  - → Complexity likely to be constant or linearly increase with respect to the number and complexity of inputs

- **Scherer** (☆☆☆)
  - Built-in support for variable NPC complexity
    - Appraisal dimension groupings (SECs) can be as complex as the information processing system allows, often a continuous or graded scalar or multidimensional evaluation (Scherer, 2001, p. 94) → numerical values easier to manipulate
    - Assumes three levels of processing (sensory-motor, schematic, conceptual) that interact (Scherer, 2001, p. 102–103) → potential to derive some information in EMgine implicitly from inputs
      - Provide option to turn these tasks off or configure them → support for *Choosing Which CME Tasks to Use* (RF2) and *Customizing Existing Task Parameters* (RF3)
  - Reappraisals run until a monitoring system signals termination or adjustment, appraisal components updated by reappraisals (Scherer, 2001, p. 99) → game designer can decide when to terminate appraisal cycles based on game needs, support of *Customizing Existing Task Parameters* (RF3) and *Be Efficient and Scalable* (RF8)
  - Appraisal registers updated as new information becomes available, central structure, can control relative importance of each value using a weighted function to represent "goodness" of data (Scherer, 2001, p. 105);
    - Implies a temporal and confidence value for each register (Scherer, 2001, p. 106) → game designer can decide when to evaluate emotion state based on these values, support of *Customizing Existing Task Parameters* (RF3)

- **Roseman** (☆☆)
  - Suggestion that there are different versions of appraisal mechanisms of variable complexity triggered as time allows (Roseman, 2001, p. 77), and influenced by emotion intensity (Roseman, 2011, p. 440)
    - Can specify different appraisal mechanisms → game designers can build on top of input API, choose how information is synthesised into EMgine inputs
  - Still requires empirical data to determine the minimum cognitive requirements for appraisals (Roseman, 2001, p. 87–88)

        * Lowest level involves fixed action patterns (Clore and Ortony, 2002, p. 32) → correspondence with core EMgine tasks, direct match between generated emotion and assigned behaviours for it as assigned by game designer
        * With no defined process, do not know how to integrate cognitive processes into EMgine

- **OCC** (☆☆)
    - Has three levels of processing (reactive, routine, reflective) (Ortony et al., 2005, p. 175–177, 179)
        * OCC proper part of the highest processing level, "reflective", does not interact with external environment → requires cognitive/high-level processes, inputs from other two levels
        * Number of potential emotions restricted in reactive (no emotions) and routine (four emotions) levels → violates *Choosing NPC Emotions* (RF5)
        * Assumptions make it unlikely to be applicable to architectures that are simpler than adult humans (Sloman et al., 2005, p. 220)
    - Produce a simpler, less rigorous architecture with one processing level
        * Complexity might lie in how variables are evaluated and how goals/standards/attitudes are represented, coding of rules appears relatively simple (Ortony et al., 1988, p. 182–188)
        * Could allow for user-defined evaluations and representations → support as a Domain-Specific Language (DSL) to avoid violating *Hiding the Complexity of Emotion Generation* (RE1)

- **Smith & Kirby** (☆☆☆)
    - Potential to design multiple appraisal mechanisms that rely on different functions (e.g. planning, expectation evaluation) → clear distinction between available functions and EMgine's abilities
        * Number of appraisal variables determines types of emotion available (Yih et al., 2016a,b), (Yih et al., 2020, p. 488–492)
        → Number of potential emotion categories tied to NPC complexity
        * Potential to violate *Choosing NPC Emotions* (RF5) → assuming that NPC complexity and what emotions the game designer wants them to have are directly proportional, this is unlikely to be a concern

- **Oatley & Johnson-Laird** (☆☆)
    - Distinguishing emotion types changes based on cognitive abilities (Oatley and Johnson-Laird, 1987, p. 40–41), possible goal and plan representations (Oatley, 1992, p. 57–58)
        * Emotion "modes" as "base classes" of emotion
        → Number of potential emotion categories tied to NPC complexity
        * Potential to violate *Choosing NPC Emotions* (RF5) → assuming that NPC complexity and what emotions the game designer wants them to have are directly proportional, this is unlikely to be a concern

A.3.8 Flexibility: Be Efficient and Scalable (RF8)

The main concern for the efficiency and scalability of the appraisal theories is how they evaluate inputs. However, this complexity seems to lie in creating the inputs. Since this precedes their transformation into emotions, action tendencies, and other components, a lot of this burden is passed to the game developer. Ideally, EMgine would handle more of these tasks. However, this also allows developers to choose how they want to generate inputs. Ultimately this gives them more freedom, and allows EMgine to merge more easily into different games and underlying architectures. What EMgine focuses on, then, is helping game developers manage different evaluation processes.

- **Frijda** (☆☆)
  - Uses 17–24 appraisal dimensions to create unique profiles for emotions, not all dimensions needed for each emotion (Frijda, 1986, p. 205–219; Frijda, 1987, p. 121–124)
    - Efficiency might be hindered if more dimensions are evaluated than are needed
    - Give developers choice of appraisal dimensions → compromises *Hiding the Complexity of Emotion Generation* (RE1)
  - Scalability mostly driven by complexity of inputs and externally-defined regulation processes → depends on complexity of evaluations to generate inputs, designer-driven
- **Lazarus** (☆☆☆)
  - Dependent on knowledge (Lazarus, 1991, p. 145), knowledge evaluation mechanisms → depends on designer chosen architecture
  - Appraisal process appears to be of a fixed complexity once inputs are given (Lazarus, 1991, p. 210), implies that scalability depends on complexity of knowledge processes and inputs → depends on complexity of evaluations to generate inputs, designer-driven
- **Scherer** (☆☆)
  - Uses 16 appraisal dimensions divided into four groups (Scherer, 2001, p. 114–115) → minimum set of appraisal dimensions necessary to differentiate emotion families (Scherer, 2001, p. 94)
  - Groups are evaluated in order to avoid using unneeded expensive processes (Scherer, 2001, p. 99–100, 102–103)
    - Does not exclude potential to begin getting partial results by running the four components in parallel
    - Groups can have more than one associated process → lower level processes for each group first, higher level processes only used if they do not return results
    - Can add a central controller to allow integration of additional processes similar to Smith & Kirby appraisal detector (Scherer, 2001, p. 103–105)
    - → Efficiency tied to the complexity of inputs, partially designer-driven
    - → Mechanisms for scalability built-in, but requires more overhead costs to manage them, might conflict with *Ability to Operate on Different Levels of NPC Complexity* (RF7)
- **Roseman** (☆)
  - Suggests that there are different versions of appraisal mechanisms of variable complexity triggered as time allows (Roseman, 2001, p. 77) → potential for scalability, efficiency

  - Focuses on the structure of emotions and appraisal dimensions (Roseman, 2001, p. 68, 81) → no further information given

- **OCC** (☆☆)
  - Uses 3–19 variables to differentiate emotion families, not all variables needed for each emotion (Ortony et al., 1988, p. 19, 60, 69) → can prevent evaluation of some variables based on which branch of the tree is active
  - Efficiency tied to complexity of inputs (Ortony et al., 1988, p. 182–188) → tied to evaluation mechanisms, designer-driven
  - Can introduce mechanisms such that lower-complexity processes run first and call higher-complexity processes if they cannot produce a result (Ortony et al., 2005, p. 179) → more control of efficiency and scalability
  - Can have two parallel emotion-elicitation mechanisms → can produce conflicting results (Clore and Ortony, 2002, p. 37–39, 54)
    - Memory-based heuristics, which is faster and more error-prone → improved efficiency, could run into memory-related scalability issues
    - Deliberative processing, which is slower and less error-prone → reduced efficiency, more scale-friendly

    → Could create a more believable result, but might conflict with *Ability to Operate on Different Levels of NPC Complexity* (RF7)

- **Smith & Kirby** (☆☆☆)
  - Uses 7–16 variables to create unique profiles for emotions, not all dimensions needed for each emotion (Yih et al., 2020, p. 489; Yih et al., 2016a)
    - Efficiency might be hindered if more dimensions are evaluated than are needed
    - Give developers choice of appraisal dimensions → compromises *Hiding the Complexity of Emotion Generation* (RE1)
  - A few variables could be evaluated by EMgine (e.g. *motivational relevance*) → efficiency and scalability controlled by EMgine
  - Some evaluation processes produce inputs *for* EMgine → designer-driven, architecture dependent
    - Appraisal detector continuously monitors for changes in variables, combines information and called appraisal process (Smith and Kirby, 2001, p. 129–130) → implicitly enforces scalability as developers add and remove processes
      - Detector must only require minimal resources to function well (Smith and Kirby, 2000, p. 90–91) → acknowledges that efficiency is essential
    - Support for multiple, parallel user-defined processes that could have variable complexity levels (Smith and Kirby, 2000, p. 91–92) → create mechanism for developers to define when complex processes activate

- **Oatley & Johnson-Laird** (☆☆☆)

- Assumes a system that coordinates multiple plans and goals under time and resource constraints (e.g. plans only work 1–2 steps ahead) (Oatley and Johnson-Laird, 1987, p. 31, 36) → property of the architecture, designer-driven
- Goals and plans associated with emotion has their own monitoring mechanisms (Oatley, 1992, p. 50) → can decide which ones to associate with EMgine, built in scalability
  * Mechanism would work on goal and plan information → can be made efficient
- Emotions can be given more complex meanings by evaluating more information via selective function calls (Oatley and Johnson-Laird, 1987, p. 32–34) → designer-dependent and ties scalability, efficiency to the needs of the game, supports *Ability to Operate on Different Levels of NPC Complexity* (RF7)

A.3.9 Ease-of-Use: Hiding the Complexity of Emotion Generation (RE1)

The appraisal theories generally have strong support for this requirement. Designers do not need to known what is done with the inputs they provide, so the processing of those inputs can be hidden from them.

- **Frijda** (☆☆☆)
  - System arranged so that information can be supplied at any point to black box processes, tracked by an internal monitor/situational meaning blackboard structure (Frijda, 1986, p. 455–456, 459) → do not need to know how the process uses information
- **Lazarus** (☆☆☆)
  - Appraisal assigns personal meaning to knowledge (Lazarus, 1991, p. 145) → do not need to know how the process uses information
  - Six appraisal dimensions, reappraisal accounts for changes to input values (Lazarus, 1991, p. 134, 149–150) → can incorporate changing information as a queue of input values
- **Scherer** (☆☆☆)
  - Inputs combined into registers (Scherer, 2001, p. 105), patterns of register values matched to emotions (Scherer, 2001, p. 114–115) → do not need to know how this is done
    * Some dimensions are pure information (e.g. *intrinsic pleasantness*) (Lazarus, 1991, p. 146) → inherently hides process complexity
    * Appraisal dimension groupings (SECs) can be divided into hard-wired and deliberative units (Scherer, 2001, p. 102) → do not need to know which ones are deliberative or not
  - Changes in SECs can cause continuously changing outputs (Scherer, 2001, p. 107) → need only query if there has been a change, do not need to know if the generation process triggered
- **Roseman** (☆☆)
  - Inputs pattern-matched to emotion families (Roseman, 2001, p. 70–71, 81) → do not need to know what the patterns are
  - Focus on the relationship between appraisal values and emotions (Roseman, 2001, p. 81) → does not focus on other parts of the generation process
- **OCC** (☆☆)

- Inputs pattern-matched to emotions, combined into intensity values, and compared to threshold rules (Ortony et al., 1988, p. 69, 189) → do not need to know how this is done
- Need to know patterns of variables to support *Choosing NPC Emotions* (RF5) → potential to expose variable patterns, but not how the variables are combined or compared to threshold rules

- **Smith & Kirby** (☆☆)
  - Inputs combined into single unit by appraisal register, triggers generation process (Smith and Kirby, 2001, p. 130) → do not need to know how this is done
  - Need to know patterns of variables to support *Choosing NPC Emotions* (RF5) (Yih et al., 2020, p. 489; Yih et al., 2016a) → potential to expose variable patterns, but not how they are used

- **Oatley & Johnson-Laird** (☆☆)
  - Emotions as products of interpretations of goals and plans (Oatley and Johnson-Laird, 1987, p. 30) → do not need to know how they are interpreted
  - Need to provide additional information to support *Choosing NPC Emotions* (RF5)
    * Add contextual information to generated emotion (Oatley, 1992, p. 76–78) → does not require knowledge of how the emotion was produced
    * Tied to "folk" understanding of emotions, their consequences, and antecedents (Johnson-Laird and Oatley, 1992, p. 214–215) → minimizes potential to violate this requirement

A.3.10 Ease-of-Use: Having a Clear API (Input) (RE2)

It is not enough for an appraisal theory to be clear in what it requires for appraisal. It must also be clear in what it does with those inputs to produce an unambiguous output. Therefore, the theories are analysed for both their necessary inputs, how those could be realized as an input interface, and how those inputs map to appraisal outputs.

- **Frijda** (☆☆)
  - Minimally requires definition of concerns (which include goal definitions), environment states/events, action (tendency) structures (Frijda, 1986, p. 454, 457) → generally do not know how to define inputs (Roseman, 2001, p. 86–87)
  - At least 20 variables listed (Frijda, 1986, p. 205–216), smaller list of 14 variables have preliminary empirical validation (Frijda, 1987, p. 128–131) → potential to overwhelm users with the full list
    * Some variables describe knowledge (e.g. *valence* (Frijda, 1986, p. 207)) → cannot be removed from input variable list
    * Some variables could be derived from knowledge (e.g. *change* derived from previous and current state, implicit in definition of "event" (Frijda, 1986, p. 209–210)) → exchange variables for knowledge in input list
      · Might be able to reduce the required input list if there are overlaps in required knowledge for many variables
      · Replace variable names with knowledge that is generally understood (e.g. states, goals) → supports *Hiding the Complexity of Emotion Generation* (RE1)

- * Some variables might be encoded implicitly in others (e.g. *presence/absence*, *urgency* (Frijda, 1986, p. 208–209, 455)) → do not have to be exposed to user, reduce required input list in API
  * Unique profiles for some emotions (Frijda, 1986, p. 217–219), empirical validation of some patterns (Frijda, 1987, p. 122–123) showing that each emotion uses a subset of variables → might be able to define subsets of variables if some emotions are not needed

  → Options error-prone, require careful design of EMgine
  * Do not know how to define some of these inputs (Roseman, 2001, p. 86–87)

- **Lazarus** (–)
  - Minimally requires local and global "ego-identity" goals, causal agents and their control over an event, coping potential, predictions about future prospects (Lazarus, 1991, p. 102, 149–150) → generally do not know how to define inputs (Roseman, 2001, p. 86–87)
    * Correlate with five appraisal dimensions
    * Written in natural/familiar language, conceptualized as entities and values → supports *Hiding the Complexity of Emotion Generation* (RE1)
  - Appraisal patterns are not clearly unique (e.g. *Anxiety* and *Disgust* only differ in ego-involvement, but what is the difference between "protection against existential threats" and "being at risk of a poisonous idea"? (Lazarus, 1991, p. 237, 261)) → prone to assumption biases, threatening psychological validity

- **Scherer** (☆☆)
  - Minimally requires goals, events and their properties (e.g. *predictability*, *intrinsic pleasantness*), causality, predictions about events, time constraints on goals, predictions about the controllability over potential outcomes, ability to influence and/or adapt to potential outcomes, and information about the agent's conception of self-ideal and social norms
  - 15 appraisal variables divided into four groups internally for organization and flow (Scherer, 2001, p. 94) → potential to overwhelm users with the full list
    * Some variables describe knowledge (e.g. *intrinsic pleasantness* (Scherer, 2001, p. 95)) → cannot be removed from input variable list
    * Some variables could be derived from knowledge (e.g. *discrepancy from expectation* derived from current state prediction about current state from previous ones (Scherer, 2001, p. 96)) → exchange variables for knowledge in input list
      · Might be able to reduce the required input list if there are overlaps in required knowledge for many variables
      · Replace variable names with knowledge that is generally understood (e.g. probabilities, goals) → supports *Hiding the Complexity of Emotion Generation* (RE1)
    * Unique profiles for some emotions that have some empirical support (Scherer, 2001, p. 114–117) showing that each emotion uses a subset of variables → might be able to define subsets of variables if some emotions are not needed

    → Options error-prone, require careful design of EMgine
    * Do not know how to define some of these inputs (Roseman, 2001, p. 86–87)

- **Roseman** (☆☆)

- Minimally requires goals, current environment states, causal agents, predictions and confidence values about future events, coping potential, if a problem is intrinsic or instrumental
- Seven appraisal variables create 17 emotion categories, accounts for all variable combinations (Roseman, 2001, p. 68–69) → empirically validated and compared with dimensions from other appraisal theories (Roseman et al., 1996, p. 256, 260,267), revised as new data is collected (Roseman, 2001, p. 72, 75)
- Generally do not know how to define these inputs (Roseman, 2001, p. 86–87) → hypothesize that appraisal variables influence each other, some might be inputs to the evaluations of others (Roseman et al., 1996, p. 271)

- **OCC** (☆)
  - Clear distinctions between events, agents, and objects (Ortony et al., 1988, p. 58) → minimally requires goals, changes to goals, agents, standards, and preferences
  - At least four global variables and 15 local variables to distinguish between emotions (Ortony et al., 1988, p. 69) → potential to overwhelm users with the full list
    - Reduce the list by using some variables to calculate others (e.g. *physiological arousal* is evaluated from other variables (Ortony et al., 1988, p. 65)) → applies to few variables, might violate *Ability to Operate on Different Levels of NPC Complexity* (RF7)
    - Reduce the list by ignoring some variables → unclear how to choose which or how many variables to keep
    - Limit the variables to the six variables that distinguish events, agent, and object-related emotions → unable to differentiate emotions in the same branch
    - Generally do not know how to define these inputs (Roseman, 2001, p. 86–87)

- **Smith & Kirby** (☆☆)
  - Minimally requires goals, environment states/events, agent actions and their confidence in their efficacy, agent dispositional traits, event causality, agent responsibility, and predictions about the desirability of future environment states
    - Inputs required for three of seven appraisal dimensions empirically tested (Smith and Kirby, 2009b, p. 1357, 1361–1362, 1367)
    - A fourth variable might be dependent on one of the three tested variables (Smith and Kirby, 2001, p. 138) → observed tendency, not examined directly
    - Other dimensions have yet to be tested (Smith and Kirby, 2009b, p. 1369)
  - Sixteen appraisal variables (seven "core" variables (Smith and Kirby, 2001, p. 123), approximately nine additional ones derived from empirical data (Yih et al., 2020, p. 489; Yih et al., 2016a)) make unique patterns for 20 emotions → not all patterns accounted for, potential to overwhelm users with the full list
    - Some variables appear to describe knowledge (e.g. *likeability* (Yih et al., 2016a)) → cannot be removed from input variable list
    - Some variables derived from knowledge (e.g. *motivational relevance* derived from goals and environment states (Smith and Kirby, 2009b, p. 1361)) → exchange variables for knowledge in input list

- Might be able to reduce the required input list if there are overlaps in required knowledge for many variables
- Replace variable names with knowledge that is generally understood (e.g. probabilities, goals) → supports *Hiding the Complexity of Emotion Generation* (RE1)

* Emotion appraisal profiles show that each emotion uses a subset of variables (Yih et al., 2020, p. 489; Yih et al., 2016a) → might be able to define subsets of variables if some emotions are not needed

→ Options error-prone, require careful design of EMgine

- **Oatley & Johnson-Laird** (☆☆☆)
  - Emotions elicited at plan junctions where probabilities of goal success changes (Oatley, 1992, p. 98) → minimally requires information about current state of plans and goals
  - Goals as symbolic representations of environments states, plans as transformations between the current environment state and a goal (Oatley and Johnson-Laird, 1987, p. 30)
    * Goals → active/dormant, achievement status, type (e.g. self-preservation, gustatory), known conflicts with other goals
    * Plans → active/dormant, priority

    → Little to no additional information required

A.3.11 Ease-of-Use: Having a Clear API (Output) (RE2)

Many appraisal theories output emotion as a series of components rather than explicit categories. This has the potential to clutter the output API, and potentially violating requirements like *Hiding the Complexity of Emotion Generation* (RE1) and *Traceable CME Outputs* (RE4). However, the componential outputs lend themselves well to supporting *Allowing Developers to Specify How to Use CME Outputs* (RF6) as this would allow users to only use the parts relevant to their design. Fortunately, most of the examined theories relate output component groups with a named emotion. This allows EMgine to create output "packages" that are labelled with an emotion category and intensity that can be unpacked by advanced users. This creates a small output API while supporting *Hiding the Complexity of Emotion Generation* (RE1), *Traceable CME Outputs* (RE4), and *Allowing Developers to Specify How to Use CME Outputs* (RF6).

- **Frijda** (☆☆)
  - Outputs three data "packages": an arousal value, relevance and control precedence signals, and action tendencies (Frijda, 1986, p. 454–455) → provides "how strong", "what priority", and an abstracted "how to behave"

  → Supports *Hiding the Complexity of Emotion Generation* (RE1)
  - arousal and action tendency "packages" might not be immediately understandable
    * Can associate action tendencies with emotion words (Frijda, 1986, p. 72) to improve understandability
    * arousal given a more recognizable name and/or made into an optional or hidden output
- **Lazarus** (☆☆☆)
  - Outputs one data "package" tagged with an emotion label and core theme, containing two "sub-packages": physiological response and action tendencies (Lazarus, 1991, p. 209–210)

    * Also includes subjective experience components, which requires reasoning about the emotion process → skip in design
    * Do not have to manage "sub-packages" directly → supports *Allowing Developers to Specify How to Use CME Outputs* (RF6) and *Hiding the Complexity of Emotion Generation* (RE1)

- **Scherer** (☆)
  - No direct output → emotions emergent, related to a series of subsystem changes (Scherer, 2001, p. 113)
    * Might not be immediately clear what the information means or what can be done with it → violates *Traceable CME Outputs* (RE4), potential violation of *Hiding the Complexity of Emotion Generation* (RE1)
  - Could output an emotion term and associated action tendency when the changes match a known pattern (Scherer, 2001, p. 117)
    * Support *Hiding the Complexity of Emotion Generation* (RE1) and *Traceable CME Outputs* (RE4)
    * Advanced users could examine the changes directly → supports *Allowing Developers to Specify How to Use CME Outputs* (RF6)
    * Potential to have subsystem changes that do not match any known patterns → EMgine might appear to be non-functional
- **Roseman** (☆☆☆)
  - Outputs a "package" labelled with an emotion category containing "sub-packages" for typical physiological, phenomenological, expressive, behavioural, and motivational contents (Roseman, 2001, p. 75)
    * "Package" contents represents coordinating systems for a coping strategy (Roseman, 2013, p. 141)
    * Designed to impose categorical distinctions on continuous appraisal dimensions (Roseman, 2001, p. 75, 80), might explain why laypeople see emotions as discrete entities (Roseman, 2013, p. 147) → achieves understandability of discrete theories, supports *Hiding the Complexity of Emotion Generation* (RE1)
    * Differentiates reward seeking and punishment avoidance (Roseman et al., 1990, p. 910) → easier to distinguish between emotion states
    * Do not have to manage "sub-packages" directly → supports *Hiding the Complexity of Emotion Generation* (RE1) and *Allowing Developers to Specify How to Use CME Outputs* (RF6)
- **OCC** (☆☆)
  - Outputs two fields: emotion category and intensity (Ortony et al., 1988, p. 183–184) → simple presentation of "what" and "how strong", achieves understandability of discrete theories
  - Supports *Hiding the Complexity of Emotion Generation* (RE1)
- **Smith & Kirby** (☆☆☆)
  - Outputs a "package" labelled with an emotion category, core relational theme, and intensity, wrapped around appraisal dimension values (Smith and Kirby, 2001, p. 123, 125)

    * Do not have to manage appraisal dimensions directly → supports *Hiding the Complexity of Emotion Generation* (RE1) and *Allowing Developers to Specify How to Use CME Outputs* (RF6)
    * Include a "sub-packages" of facial muscle movements using FACS and physiological changes (Smith and Kirby, 2001, p. 133–135), motivational goals and coping strategies (Yih et al., 2016a; Yih et al., 2016b, Yih et al., 2020, p. 488–492) derived from appraisal values → additional suggestions for advanced use cases

- **Oatley & Johnson-Laird** (☆☆☆)
  - Basic emotion "modes" are psychologically and physiologically distinct (Oatley and Johnson-Laird, 1987, p. 48), assigned labels are not strict definitions (Johnson-Laird and Oatley, 1992, p. 217) and rely on intuitions about emotions from experience and language (Oatley, 1992, p. 69–71, 74–75, 82, 86–87) → generally understandable
  - Outputs an emotion "signal" rather than a concrete state (Johnson-Laird and Oatley, 1992, p. 214) → affords flexibility for both state-based and stateless emotion definitions
    * Potential to connect both definitions to expressive and action-based mechanisms (Oatley and Johnson-Laird, 1987, p. 31)
    * As signals, only have a small number (five) (Oatley and Johnson-Laird, 1987, p. 33) → requires a small signal recognition process to pick up emitted signals
  - Supports *Hiding the Complexity of Emotion Generation* (RE1) and *Allowing Developers to Specify How to Use CME Outputs* (RF6)

A.3.12 Ease-of-Use: Traceable CME Outputs (RE4)

Generally, the process view afforded by appraisal theories also allows for traceability between inputs and outputs, supporting testing and debugging. The appraisal theories also produce, or connect their outputs to, emotion categories which supports *Hiding the Complexity of Emotion Generation* (RE1) and *Having a Clear API (Output)* (RE2).

- **Frijda** (☆☆☆)
  - "Blackboard" structure as central information hub, retains history of evaluation (Frijda, 1986, p. 459) → built-in traceability tool
    * Potential to violate *Hiding the Complexity of Emotion Generation* (RE1) → could be designed to avoid psychology jargon, use everyday language
- **Lazarus** (☆☆☆)
  - Appraisal patterns shown as a decision tree (Lazarus, 1991, p. 222) → visualization of appraisal showing where inputs are used
    * Six appraisal dimensions → tree is a manageable size
    * Potential to violate *Hiding the Complexity of Emotion Generation* (RE1) → could be designed to avoid psychology jargon, use everyday language
  - Appraisals are not sequential (Lazarus, 1991, p. 151), has multiple mechanisms (Lazarus, 1991, p. 189), is transactional and temporal in nature (Lazarus, 1991, p. 210–211), reappraisal as a key process (Lazarus, 1991, p. 134) → implies a central data structure, like a blackboard, to store information as it becomes available

    * Potential to violate *Hiding the Complexity of Emotion Generation* (RE1) → could be designed to avoid psychology jargon, use everyday language

- **Scherer** (☆)
  - Suggested system representation is a neural network (Scherer, 2001, p. 105) → might not produce traceable/explainable results
  - Each appraisal unit (SEC) changes different subsystems → creates a continuously changing outputs, "history" of the appraisal (Scherer, 2001, p. 107) that is helpful for debugging
    * Many possible combinations → difficult to have consistent outputs for testing
- **Roseman** (☆☆☆)
  - Appraisal as a selection mechanism in a system (Roseman, 2001, p. 76, 81–83) → requires decision rules, potential to provide trace as a decision tree
    * Seven appraisal dimensions → tree is a manageable size
    * Potential to violate *Hiding the Complexity of Emotion Generation* (RE1) → could be designed to avoid psychology jargon, use everyday language
- **OCC** (☆☆☆)
  - Eliciting conditions written to reflect how they are talked about in everyday language, how people tend to experience them (Clore and Ortony, 2002, p. 25–26) → connection between inputs and outputs (emotion category/intensity pair) generally understandable
    * Could include a trace function showing effects of input variables and values, changes in expression thresholds → make as an advanced system function to maintain *Hiding the Complexity of Emotion Generation* (RE1)
- **Smith & Kirby** (☆☆☆)
  - Two potential points for tracing (Smith and Kirby, 2001, p. 130)
    * Appraisal detector output where information is merged into one unit before appraisal → show trace of how information is combined
      · Converting disparate inputs that developers know of into aggregated values → unlikely to violate *Hiding the Complexity of Emotion Generation* (RE1)
      · Would require a customizable detector to support EMgine's flexibility → supported bby *Customizing Existing CME Task Parameters* (RF3)
    * After converting appraisal unit into an emotion → can show trace of appraisal pattern as a decision tree
      · Sixteen appraisal dimensions (Yih et al., 2020, p. 489; Yih et al., 2016a) → unmanageable tree size
      · Could reduce tree size by removing dimensions that are not relevant to the elicited emotion → provides information about which variables were not used
      · Potential to violate *Hiding the Complexity of Emotion Generation* (RE1) → could be designed to avoid psychology jargon, use everyday language
- **Oatley & Johnson-Laird** (☆☆☆)

- Connection of emotion "mode" triggers with plans and goals (Oatley and Johnson-Laird, 1987, p. 36)
    * Create a trace function that presents goal and plan information used to produce outputs
    * Leverage computational knowledge
- Adding cognitive meanings to an emotion "mode" could explain language and cultural differences (Johnson-Laird and Oatley, 1992, p. 218) → can trace the impact of cognitive processes on the elicitation of new emotions

A.3.13 Ease-of-Use: Providing Examples of Novel Game Experiences (RE7)

Each theory presents different ways to create novel game mechanics and interactions due to their differing focuses. The role of the self and culture is commonly discussed, suggesting new ways that NPCs can develop and interact with players. However, in all cases, realizing these requires additional components or relies on a particular type of NPC functionality. For this reason, all of the theories are only good (☆☆) candidates for satisfying this requirement.

- **Frijda** (☆☆)
    - Incorporate additional components as needed to make finer distinctions between emotion states (Frijda, 1986, p. 216)

    → Potential for social and cultural based mechanics
- **Lazarus** (☆☆)
    - Coping as part of variable NPC responses (Lazarus, 1991, p. 112–115) → part of action generation, outside the scope of EMgine
    - Role of biological and social variables in the development of the emotion process (Lazarus, 1991, p. 39) → varying EMgine parameters based on NPC "age" to alter processing
    - Core relation themes and the stages of the emotion process (Lazarus, 1991, p. 106, 121) → potential to relate to narrative drama
- **Scherer** (☆☆)
    - Normative significance evaluation accounts for the role of self-esteem/self-concept, social, and cultural influences in emotion generation (Scherer, 2001, p. 98)

    → Potential for social and cultural based mechanics
- **Roseman** (☆☆)
    - Ties response strategies to appraisal dimensions (Roseman, 2013, p. 144) → emotions differentiated by strategy (Roseman, 2013, p. 148; Roseman, 2001, p. 76)
        * Subjective interpretation of emotion state → closer to emotion recognition in real life
        * Requires knowledge about dimensions → violates *Hiding the Complexity of Emotion Generation* requirement (RE1)

        → Unideal, available for advanced users only
    - Proposed connected between different bases of racism (Roseman, 2001, p. 84–85) → potential for a social intervention mechanics

- **OCC** (☆☆)
  - Implement NPC curiosity when no other emotion processes are active (i.e. resting state) (Ortony et al., 2005, p. 194) → enhance believability
    - Make the state slightly positive instead of zero → engages in exploratory behaviour
    - Requires expectations to know when things are different and might warrant action
  - Define mood as repeated emotion elicitations (Ortony et al., 1988, p. 189) → dynamic and potentially player-unique game sessions
- **Smith & Kirby** (☆☆)
  - Proposed connection between appraisal dimensions and individual facial movements, physiological activities (Smith and Scott, 1997, p. 237–240, 242–243)
    - → Connection to non-human (e.g. alien, animal) and non-humanoid (e.g. computer, city) representations for emotion expression
- **Oatley & Johnson-Laird** (☆☆)
  - English names for basic emotions imply behaviours of social creatures (Johnson-Laird and Oatley, 1992, p. 209) → social role of emotions
  - Group dynamics using communication between agents at plan junctions via emotion, modelling "contagious" emotions, mutual plans between NPCs (Oatley and Johnson-Laird, 1987, p. 31, 40–44) → requires a model of the self (i.e. NPC models itself)
    - Potential to model computationally as a system → recursively defined, informed by language and culture
    - → Maintenance and propagation of cultural values and norms via learning and guidance
    - → Learning new ways to handle plan junctions can lead to evolving abilities to represent individual and cultural differences
  - Sentiments → model influence of social emotions on NPC relationships (Oatley, 2000, p. 78, 80–86)
    - Connection to social goals: affiliation, protection, dominance → potential to overlay onto PAD Space?
  - Narrative planning (Oatley, 1992, p. 6–7, 107–108, 225)
    - Mental simulation of personal plans to understand potential reactions in advance, simulation of others' plans to understand their emotions → directly tied to narratives and can account to responses to stories and films
    - → Integration into narrative planning to elicit specific emotions from different NPCs
  - Reliance on plans → partial violation of *Independence From an Agent Architecture* requirement (RF1)

A.3.14 Examining the Remaining Requirements

The appraisal theories are sufficiently different and satisfy most of the requirements in different ways. However, they are also relatively sparse for certain aspects of the emotion process (e.g. emotion decay, intensity) and have comparable information for two ease-of-use high-level requirements.

- *Ease-Of-Use: Allowing the Automatic Storage and Decay of the Emotion State (RE5)*
  - Frijda, Lazarus, Scherer, OCC, Smith & Kirby, Oatley & Johnson-Laird (☆☆)
    - ∗ No explicit description about how to store or decay an emotion state
    - ∗ Time-dependent process approach (Frijda, 1986, p. 453; Lazarus, 1991, p. 39, 209; Ortony et al., 1988, p. 189; Oatley, 1992, p. 22–23; Smith and Kirby, 2000, p. 85) → could support its design
    - ∗ Could be integrated via existing processes like reappraisal (Scherer, 2001, p. 99) and monitoring (Smith and Kirby, 2001, p. 129–130)
    - ∗ Supports *Customizing Existing CME Task Parameters* (RF3) → include parameters to turn automation off, change entire decay functions or only some of their variables, allow for multiple context-dependent decay functions
  - Roseman (–)
    - ∗ Focus on the relationship between appraisal values and emotions, how those emotions impact different systems in response, and the structure of emotions (Roseman, 2001, p. 68, 81), empirical validation of appraisal dimension influence on resulting emotion (Roseman et al., 1996, p. 242, 244) → does not touch on the emotion process itself
- *Ease-Of-Use: Showing that Emotions Improve the Player Experience (RE6)*
  - Scherer (☆☆☆)
    - ∗ Associates each emotion with action tendencies (Scherer, 2001, p. 108) → could be applied to a number of actions and expressions that an NPC could need
    - → design studies around behaviour classes that players evaluate with respect to their experience
    - → Some cross-cultural validation, connected to FACS-coded facial expressions (Scherer, 2001, p. 116–118)
  - Frijda, Lazarus, Roseman, and Smith & Kirby (☆☆)
    - ∗ Associates each emotion with action tendencies (Frijda, 1986, p. 88; Lazarus, 1991, p. 87, 122; Roseman, 2013, p. 143; Yih et al., 2016a; Yih et al., 2016b; Yih et al., 2020, p. 488–492) → could be applied to a number of actions and expressions that an NPC could need
    - → design studies around behaviour classes that players evaluate with respect to their experience
  - Oatley & Johnson-Laird (☆☆)
    - ∗ Associates each emotion with action tendencies (Oatley, 1992, p. 55, 108, 192, 212) → could be applied to a number of actions and expressions that an NPC could need
    - → design studies around behaviour classes that players evaluate with respect to their experience
    - ∗ Focus on the connection between emotion and plans and goals in narrative and language (Oatley, 1992, p. 70–71) → suggest that it is especially amenable to studies of NPC intentionality and believability
  - OCC (☆)
    - ∗ Provides an emotion and intensity as output → gives only a few guidelines about action tendency associations (Ortony, 2002, p. 197).

B Suggestions for Extending Modelled Components

B.1 Modelling Energy

The type of energy (WR1) currently represents a generic store that an NPC can have. This can be expanded into different types of energy. *Emotional Energy* is one possible kind to include, which could affect the updating (IM18) and decaying (IM22) of the NPC's internal emotion state. For example, an NPC with high emotional energy has an easier time maintaining their current emotion than one with low emotional energy.

B.1.1 Type Definitions

WR1	**Type of Energy**
Symbol	$\mathbb{J}$
Type	–

Description Energy is an abstract type that is linearly ordered.

Sources –

Depends On –

Ref. By WR33, WR36

WR2	**Type of Energy Change**
Symbol	$\mathbb{J}_\Delta$
Type	–

Description Energy change is an abstract type representing a magnitude.

Sources –

Depends On –

Ref. By WR4, WR33 (via WR4)

B.2 Modelling Actors and Actions

B.2.1 Type Definitions

WR3	**Type of Actor**
Symbol	$\mathbb{A}$
Type	–

Description Actor is an abstract type representing actors in the game environment. Actors are game entities that are able to act on the game environment, and include the player, NPCs, and non-sentient environment elements (e.g. a storm).

Sources –

Depends On –

Ref. By WR32, WR37

WR4	**Type of Action**
Symbol	$\mathbb{AC}$
Type	$\{\texttt{makesChange} : \mathbb{S} \rightarrow \mathbb{S}_{\Delta}, \texttt{successLikelihood} : [0, 1], \texttt{energyCost} : \mathbb{J}_{\Delta}\}$

Description An action ($\mathbb{AC}$) is a record containing its effect on the world state ($\texttt{makesChange} : \mathbb{S} \rightarrow \mathbb{S}_{\Delta}$), its likelihood of being successful ($\texttt{successLikelihood} : [0, 1]$), and the amount of energy that is needed to execute it ($\texttt{energyCost} : \mathbb{J}_{\Delta}$).

Sources –

Depends On TY10, TY11, WR2

Ref. By WR32, WR33, WR34, WR36, WR37, WR38

B.3 Coping Potential

The model for *Coping Potential* (WR33) is intended to evaluate individual actions that an NPC can take, but a game designer might want to create a plan with these actions. A plan carries more weight, but the weight might not be equal to the sum of weights for each action. Two models have been created for this based on a separate conceptual model, representing empirically collected data (Folkman and Lazarus, 1985), which can be realized as types (TY) or data definitions (DD).

B.3.1 Conceptual Models

WR5	**Coping Strategies**

Description Coping strategies are ill-defined classes of related behaviours developed to address a general collection of related stimuli and scenarios. Using a strategy changes the individual-environment relationship, which can change the individual's emotional state by altering the original appraisal (WR19). There are two types of coping:

- Problem-focused: Acting directly on the environment to manage demands and change the individual-environment relationship, creating new information for Appraisal. These strategies can be risky and expensive, and are closely related to the individual's power and control over the environment.
- Emotion-focused: Changing the individual's internal representations of the individual-environment relationship—changing how the available information is perceived—in order to reduce or eliminate perceived harms and threats. These strategies include changing or omitting information or redirecting attention (WR15). In extreme cases, the individual alters or changes their goals (C10).

Source Lazarus (1991)

Depends On –

Ref. By WR6, WR7, WR21, WR22, WR23

B.3.2 Type Definitions

WR6	**Representation of Coping Types**

Symbol $\mathbb{CP}$

Type $(name : \text{String}, value : \mathbb{R})$

Equation $\mathbb{CP} = \mathtt{CopingType}$, where

$$\mathtt{CopingType} \in \left\{ \begin{array}{l} (\mathtt{Confrontive}, 0.70), (\mathtt{Distance}, 0.61), (\mathtt{Self-Control}, 0.70), \\ (\mathtt{SeekSocialSupport}, 0.76), (\mathtt{AcceptResponsibility}, 0.66), \\ (\mathtt{EscapeAvoid}, 0.72), (\mathtt{PlanfulProblemSolving}, 0.68), \\ (\mathtt{PositiveReappraisal}, 0.79) \end{array} \right\}$$

Description Coping types are a set of coping action classes (WR5) and their value based on the "Ways of Coping" factor analysis. Each class has a general theme of coping that can be acted on in different ways.

Sources Folkman and Lazarus (1985)

Depends On WR5

Geneva M. Smith and Dr. Jacques Carette
Dept. of Computing and Software—McMaster University

Ref. By WR7

WR7	**Representation of Coping Subtypes**
Symbol	$\mathbb{CP}_{<:}$
Type	$(\mathit{name} : \text{String}, \mathit{value} : \mathbb{R})$
Equation	$\mathbb{CP}_{<:} = \mathsf{CS}_{>:}$, where

$$\mathsf{CS}_{\texttt{Confrontive}} \in \left\{ \begin{array}{l} (\texttt{StandGround}, 0.70), (\texttt{ChangeAccountablesMind}, 0.62), \\ (\texttt{ExpressAnger}, 0.61), (\texttt{LetFeelingsOut}, 0.58), \\ (\texttt{TakeChanceOrRisk}, 0.32), (\texttt{UnlikelyOutcome}, 0.30) \end{array} \right\}$$

$$\mathsf{CS}_{\texttt{Distance}} \in \left\{ \begin{array}{l} (\texttt{RefuseSeriousness}, 0.55), (\texttt{IgnoreSituation}, 0.54), \\ (\texttt{RefuseToDwell}, 0.50), (\texttt{AttemptForget}, 0.50), \\ (\texttt{SeekBrightSide}, 0.34), (\texttt{AcceptFate}, 0.25) \end{array} \right\}$$

$$\mathsf{CS}_{\texttt{Self-Control}} \in \left\{ \begin{array}{l} (\texttt{BottleFeelings}, 0.55), (\texttt{HideFeelings}, 0.46), \\ (\texttt{SaveRelationship}, 0.40), (\texttt{ReconsiderPlan}, 0.40), \\ (\texttt{StopInterference}, 0.37), (\texttt{ImagineRoleModel}, 0.37), \\ (\texttt{SeeOtherView}, 0.28) \end{array} \right\}$$

$$\mathsf{CS}_{\texttt{SeekSocialSupport}} \in \left\{ \begin{array}{l} (\texttt{GetInformation}, 0.73), (\texttt{GetConcreteHelp}, 0.68), \\ (\texttt{GetAdvice}, 0.58), (\texttt{DiscussFeelings}, 0.57), \\ (\texttt{AcceptSYmpathy}, 0.56), (\texttt{ProfessionalHelp}, 0.45) \end{array} \right\}$$

$$\mathsf{CS}_{\texttt{AcceptResponsibility}} \in \left\{ \begin{array}{l} (\texttt{CritisizeSelf}, 0.71), (\texttt{RealizeOwnRole}, 0.68), \\ (\texttt{PromiseToChange}, 0.49), (\texttt{Apologize}, 0.39), \end{array} \right\}$$

$$\mathsf{CS}_{\texttt{EscapeAvoid}} \in \left\{ \begin{array}{l} (\texttt{WishAway}, 0.66), (\texttt{HopeForMiracle}, 0.55), \\ (\texttt{Fantasize}, 0.54), (\texttt{Overindulge}, 0.49), \\ (\texttt{AvoidOthers}, 0.46), (\texttt{Denial}, 0.42), \\ (\texttt{TargetOthers}, 0.40), (\texttt{Oversleep}, 0.36) \end{array} \right\}$$

$$\mathsf{CS}_{\texttt{PlanfulProblemSolving}} \in \left\{ \begin{array}{l} (\texttt{DoubleEffort}, 0.71), (\texttt{MakePlan}, 0.61), \\ (\texttt{NextStep}, 0.45), (\texttt{ImproveSituation}, 0.44), \\ (\texttt{Experience}, 0.40), (\texttt{MultipleSolutions}, 0.38) \end{array} \right\}$$

$$\mathsf{CS}_{\texttt{PositiveReappraisal}} \in \left\{ \begin{array}{l} (\texttt{GoodPersonalChange}, 0.79), (\texttt{GainedExperience}, 0.67), \\ (\texttt{NewFaith}, 0.64), (\texttt{RediscoverImportance}, 0.64), \\ (\texttt{Pray}, 0.56), (\texttt{ChangeSelf}, 0.55), \\ (\texttt{InspiredCreativity}, 0.43) \end{array} \right\}$$

Description Coping subtypes are more concrete instances of coping types (WR6) with their own values that reflect their relative importance to other subtypes of the same super type. Values are based on the "Ways of Coping" factor analysis.

Sources Folkman and Lazarus (1985)

Depends On WR5

Ref. By –

C Suggestions for Other Cognitive Architecture Module Specifications

These are preliminary specifications for types and models that are not within the scope of EMgine, but are necessary for it to function. They are to be seen only as suggestions when specifying these supporting modules.

C.1 Defining Lists of Goals

This is a simple specification of an indexed list of items with the type of Goal (TY14).

C.1.1 Type Definitions

WR8	**Type of Goal Labels**
Symbol	$\mathbb{L}$
Type	–

Description An ordered set of labels. These will typically be the set $[1, 2, ..., n-1, n]$.

Sources –

Depends On –

Ref. By WR9

WR9	**Type of Indexed Goal Set**
Symbol	$\mathbb{IS}$
Type	$\mathbb{L} \rightarrow \mathbb{G}$

Description An indexed goal set is an assignment of $\mathbb{G}$ to the labels $\mathbb{L}$. Each element in $\mathbb{L}$ is uniquely assigned a $\mathbb{G}$.

Sources –

Depends On TY14, WR8

Ref. By –

C.2 Evaluating the Static Importance of a Goal

The preliminary specification for evaluating the importance of a Goal (TY14) is inspired by Lazarus (1991), which relates the importance of goals to an individual's ego-identity.

C.2.1 Assumptions

A33: Ego types have an order of importance [WR12].

C.2.2 Conceptual Models

WR10	Ego Identity

Description Ego-identity is a representation of the individual in the world, encompassing roles, relationships, and societal functions. It is used to categorize, organize, and prioritize personal goals (C10).

There are seven types of ego-identity: self esteem, social esteem, moral values, ego-ideals, meanings and ideas, other persons and their well-being, and life goals.

Source Lazarus (1991, p. 101–102)

Depends On –

Ref. By WR11, WR12, WR13, WR14

C.2.3 Type Definitions

WR11	Type of Ego
Symbol	$\mathbb{O}$
Type	{`SelfEsteem`, `SocialEsteem`, `Morals`, `Ideals`, `Meaning`, `WellBeingOfOthers`, `LifeGoals`}
Invariants	$\mathbb{O}$ is finite and ordered

Description Ego is a set of labels representing the ways an individual can view their relationship with the world itself and the entities in it.

Sources –

Depends On WR10

Ref. By WR12, WR13, WR14

WR12	**Type of Ego Identity**
Symbol	$\mathbb{ID}$
Type	$\{\texttt{importance} : \mathbb{O} \to \mathbb{R}^+\}$

Description Each element in $\mathbb{O}$ has a importance function ($\texttt{importance}$) that returns a non-negative real value denoting its relative weight compared to other elements in $\mathbb{O}$ (A33).

Sources –

Depends On A33, WR10, WR11

Ref. By WR14

WR13	**Type of the Goal-Ego Importance**
Symbol	$\mathbb{GE}$
Type	$\mathbb{G} \times \mathbb{O} \to [0, 1]$

Description The goal-ego importance describes the value each $\mathbb{G}$ has with respect to an ego type $o : \mathbb{O}$, described as a weight in $[0, 1]$ (WR10).

Sources –

Depends On TY14, WR10, WR11

Ref. By WR14

C.2.4 Theoretical Models

WR14	**Evaluating Static Goal Importance**
Input	$g : \mathbb{G}, ge : \mathbb{GE}, id : \mathbb{ID}$
Output	$importance \doteq \sum_{e \in \mathbb{O}} ge(g, e) \cdot id.\texttt{importance}(e)$

Description The static importance of g given by the sum of weights for each type of ego proportional to how much the goal impacts an ego type and the importance of the ego type to the NPC ($\sum_{e \in \mathbb{O}} ge(g, e) \cdot id.\texttt{importance}(e)$).

This can be combined with the size of impact that an event has on g to get an in-the-moment importance of g.

Sources Lazarus (1991, p. 94–98)

Depends On TY14, WR10, WR11, WR12 WR13

Ref. By –

C.3 Modelling Attention

Attention is an independent component of cognition that an influence and be influenced by emotion.

C.3.1 Conceptual Model

WR15	**Attention**

Description The amount of information gathered by the senses is usually enormous and the individual is unable to process it all in an efficient manner. The attention mechanism evolved to filter, classify, and amplify incoming information to manage this volume and ensure that the most important information is handled first. Information relevant to an individual's goals (C10) must be reliably identified in order to produce behaviours that increase the likelihood of achieving them. Novel and unexpected stimuli prompt a quicker response to maximize the amount of available information for cognitive processes. Attention can also be influenced by perceived personal relevance, familiarity, and the current emotion state (C1).

Source Plutchik (1980); Lazarus (1991); Slavin (2012)

Depends On –

Ref. By WR16, WR26, WR27

C.3.2 Type Definitions

WR16	**Type of Attention**
Symbol	$\mathbb{AT}_x$
Type	$\left\{\texttt{focus} : \{[0,1]_0 : \mathbb{R}, [0,1]_1 : \mathbb{R}, ..., [0,1]_n : \mathbb{R}\}, \texttt{novelty} : \{\mathbb{R}, ..., \mathbb{R}\}, \texttt{familiarity} : \frac{1}{\texttt{novelty}}\right\}$
Invariant	The sum of the elements in `focus` is less than 1 There is a matching element in `novelty` for every element in `focus`

Description Attention ($\mathbb{AT}_x$) is a record of three, equal length vectors representing elements in the game environment:

- The `focus` vector represents how much something in the game environment is taking of the NPC's attention as a percentage. The sum of values in `focus` cannot exceed 1, or more attention is being used than is available.
- The `novelty` vector, which corresponds to the elements in `focus` represents how unfamiliar the NPC is with that element in the game environment.
- The `familiarity` vector, derived from the `novelty` vector, representing how familiar an NPC is with the element in the game environment

Sources –

Depends On WR15

Ref. By –

C.4 Modelling Social Relationships

Social relationships are prominent elements in CTE. The components needed to model and maintain them could stand as an independent unit.

C.4.1 Conceptual Models

WR17	**Social Relationship**

Description A relationship can be defined by three factors—*volatility*, *dependability*, and *faith*—which are treated as subjective probability judgements. The factors are weighted based on the security and confidence that the individual has in the relationship. A relationship's security and confidence is built over time via mutually satisfying interactions where the partner demonstrates their benevolence and honesty to the individual. These are tied directly to its component factors of volatility, dependability, and faith.

- In the beginning, the *volatility* factor is key as the partner builds confidence by acting in predictable ways that demonstrate care for the individual. At this stage, relationship confidence is negatively impacted by volatile actions as it is difficult for the individual to make accurate predictions about the partner's actions and intentions.
- In an established relationship, the partner's *dependability* is developed with each accurate prediction about events containing increasing levels of personal risk where they influenced the outcome. Shared goals, similar beliefs, and attributing part of a personal gain to the partner's involvement all increase dependability. While self-sacrificing actions quickly increase the strength of a relationship, mutual exchanges can also increase a relationship's confidence if the individual's self-esteem is reinforced by their partner.
- As an evaluation of the relationship itself, *faith* directly increases the confidence and security of the relationship proportional to the size of the risk taken after an accurate predictions is made. An inaccurate prediction surely decreases confidence in the relationship, but the size and nature of this effect is unclear.

After an event where another player impacted the outcome, the associated relationship is updated: positively if a benefit was obtained and negative if a loss was incurred. The size of the impact is determined by the size of gain or loss, regardless of the accuracy of the prediction.

Source Rempel et al. (1985)

Depends On –

Ref. By WR18, WR29

C.4.2 Type Definitions

WR18	**Type of a Social Relationship**
Symbol	R^S
Equation	$\{\texttt{volatility} : \mathbb{R}, \texttt{dependability} : \mathbb{R}, \texttt{faith} : \mathbb{R}^+,$
	$\texttt{security} : \texttt{volatility} \times \texttt{dependability} \times \texttt{faith} \to \mathbb{R}^+,$
	$\texttt{confidence} : \texttt{volatility} \times \texttt{dependability} \times \texttt{faith} \to \mathbb{R}^+\}$

Description The social relationship type (R^S) represents the relationship between two NPCs (WR17) defined by:

- Values representing the perceived `volatility` and `dependability` of the other NPC's behaviours with respect to this NPC's well-being as a real value,
- A non-zero, real value for `faith` which represents the perceived "goodness" of the relationship,

- A `security` value, a non-negative real value that is a function of `volatility`, `dependability`, and `faith`, where the value of `security` is inversely proportional to the belief that the other NPC wishes harm on the NPC holding this relationship, and
- A `confidence` value, a non-negative real value that is a function of `volatility`, `dependability`, and `faith`, where a higher value represents a greater confidence in the perceived plausibility of this relationship's representation,

The `security` and `confidence` functions can have different definitions between NPCs. There outputs must always depend on the `volatility`, `dependability`, and `faith` variables.

Sources –

Depends On WR17

Ref. By WR37

D Suggestions for Modelling Lazarus's Cognitive Appraisal

D.1 Assumptions

A34: Changing the completion status of a goal is worth more than a change that does not [WR31].

A35: Only one NPC action can be executed at a time [WR33].

A36: Appraisals operate on the scale of time steps [WR33].

A37: Each emotion category can be uniquely identified by a combination of appraisal values [WR35].

A38: If ego involvement is listed as ego-identity, any of the ego types can be used as well as references to relationships and knowledge [WR35].

A39: The ego type used in an appraisal is tied to the affected goal [WR35].

A40: Confirming the importance of an ego type, goal, relationship, or other type of knowledge is a praiseworthy act

D.2 Conceptual Models

WR19 Appraisal

Description In CA, an appraisal assigns personal significance to the individual-environment relationship. It integrates objective, but not always truthful, knowledge with the individual's goals equally via cognitive processes. Both knowledge and Goals (C10) are necessary in appraisal and make the process faster and more selective.

Appraisal is divided into two units, primary (WR20) and secondary (WR21), whose responses represent knowledge that have been assigned personal significance. These are mapped to a core relational theme and the associated emotional response pattern.

	Primary (WR20)			**Secondary** (WR21)		
	Rel.	**Congr.**	**Ego**	**Acc.**	**CP**	**FE**
Fear (WR22)	Y*	-*	Identity, Meaning*	N/A	Uncertain	Uncertain
Anger (WR23)	Y*	-*	Esteem (Self, Social)*	Blame*	Favours *Attack*!	Improve with *Attack*!
Sadness (WR24)	Y*	-*	Any*	None*	Unfavourable*	Potential to improve
Joy (WR25)	Y*	+*	Any	N/A	N/A	Favours continuation*
Disgust (WR28)	Y*	-*	Any*	N/A	N/A	N/A
Trust (WR29)	Y*	+*	Identity*	N/A	N/A	Favours continuation

* Sufficient and necessary to the appraisal.
! Facilitates emotion.
Expected congruence.
Associates it with hope. If unfavourable, it is associated with hopelessness and depression. CA sees *Sadness* and depression as different states.
If unfavourable or uncertain, the emotion is muted or undermined.
Affirmed by another individual ("...a desire for mutual affection, which is affirming to our ego-identity..." (Lazarus, 1991, p. 278).).

Appraisals are not necessarily sequential in nature, but are ordered by their relative importance—if the results of primary appraisal determine the event to be irrelevant, then secondary appraisal has limited, if any, value. Appraisal questions can be answered in any order and are used to filter through potential emotions in structure reminiscent of a decision tree, from least to most specific emotion, starting with its valence.

While not disagreeing with the purpose of *Interest* or *Surprise* in PES, CA does not consider them full emotions. They are instead considered to be states of arousal that watches and waits for additional information for the appraisal process and does not have an appraisal pattern itself.

Source Lazarus (1991)

Depends On C10, WR20, WR21

Ref. By –

WR20	**Primary Appraisal**

Description In CA, primary appraisal – which can be influenced by needs, desires, values, and beliefs about personal relevance – is required for all emotions and can usually determine if the experience is positive or negative by determining:

- **Goal Relevance (Rel.)**: Establishes if there are personal goal (C10) or stakes affected by the current individual-environment relationship. "If there is no goal relevance, there cannot be an emotion; if there is, one or another emotion will occur, depending on the outcome of the transaction."
- **Goal Congruence (Congr.)**: "Goal congruence or incongruence refers to the extent to which a transaction is consistent or inconsistent with what a person wants – that is, either it thwarts or facilitates personal goals" (C10).
- **Type of Ego-involvement (Ego)** (WR10): "...refers to the diverse aspects of ego-identity or personal commitments." It establishes what aspect of the self is affected. Ego-involvement is "...probably involved in all or most emotions, but in different ways depending on the type of ego-involvement that is engaged by a transaction", distinguishing between similar emotions, such as *Joy* (no involvement) and *Affection* (identity).

Source Lazarus (1991, p. 149–150)

Depends On C10

Ref. By WR22, WR23, WR24, WR25, WR26, WR27, WR28, WR29, WR19, WR30, WR31

WR21	**Secondary Appraisal**

Description In CA, secondary appraisal asks what resources and actions are available to the individual for coping with the individual-environment relationship, which specifies which emotion is felt. It can be influenced by expectations and beliefs about potential actions and the individual's ability to act on them. It establishes:

- **Accountability (Acc.)**: Assigns *Blame* and *Credit* for the individual-environment relationship. It "derives from knowing who or what is accountable or responsible...if this knowledge is accompanied by the knowledge that the...act was under the accountable person's control, credit or blame is assigned."
- **Coping Potential (CP)**: "Coping potential refers to whether and how the person can manage the demands of the encounter or actualized personal commitments..." (WR5). At this point, nothing is acted on as it "is not actually coping but only an evaluation by a person of the prospects for doing or thinking something that will, in turn, change or protect the person-environment relationship". How much energy the individual believes they have is likely a factor, as the pursuit of goals must require it.
- **Future Expectations (FE)**: "Future expectancy has to do with whether for any reason things are likely to change psychologically for the better or worse (i.e., becoming more or less goal congruent)."

Source Lazarus (1991, p. 150)

Depends On C10, WR5

Ref. By WR19, WR22, WR23, WR24, WR25, WR26, WR27, WR28, WR29, WR32, WR33, WR34

WR22	Fear

Description *Fear* is characterized by:

- Self-preservation or the avoidance of pain—physical, mental, or spiritual
- Changes in the person-environment relationship that create:
  - A threat or increased risk of imminent physical harm, or
  - Uncertain threats to the individual's mental or spiritual well-being
- Both *Coping Potential* and the potential *Future Impact (Expectancy)* are uncertain (WR21)

Stimuli are evaluated on their perceived probability of risk increase. The most common triggers are directly associated with self-preservation and pain avoidance, such as falling and snakes, or with the absence of a stimuli or event associated with safety, such as a protective individual or object.

The intensity of *Fear* is likely impacted by the severity of the potential harm (WR20), if the harm is immediate or pending, and if there are coping strategies (WR5) that can be used to mitigate the threat.

Source Plutchik (1980); Lazarus (1991); Ekman (2007)

Depends On C1, WR5, WR20, WR21

Ref. By WR36

WR23	Anger

Description A harmful action that halts the progression of goal achievement impacting the perception of the self is key to *Anger*, where something:

- Is identified as being accountable for the harmful action
- They are perceived to have had control or agency over the harmful action

Stimuli or events that are unwanted and predicted to lead to harmful consequences, such as threats and rejection, often result in *Anger*. A frustrated goal (C10) can result in *Anger* as it might be perceived as a threat the the individual's identity if they tie its achievement to their self-worth. *Anger* can also be caused by another's perceived *Anger* if the cause is known.

The importance of the affected goal, degree of blockage (WR20), and the degree of blame (WR21) assigned impact the intensity of *Anger*. If blame cannot be assigned, a scapegoat might be used as a coping strategy (WR5) or compound the intensity of the current scenario with the next one that induces *Anger*.

Source Plutchik (1980); Lazarus (1991); Ekman (2007)

Depends On C1, WR5 WR20, WR21

Ref. By WR37

WR24	Sadness

Description The definition of loss is essential to identifying triggers of *Sadness*. In this context, a loss is something that the individual:

- Wants but no longer possesses,
- Are helpless to regain, and
- Have not yet been able to compensate or adjust for.

Separation, real or imagined failures, and helplessness are instances of this type of loss. *Sadness* can also be triggered by another's *Sadness* as it is an empathetic emotion and easily mirrored.

The intensity of *Sadness* is directly impacted by the degree (WR20) and permanence (WR21) of the loss. The intensity of previous experiences of *Joy* (WR25) have also been cited, implying that a priority value is assigned to the retainment of what was lost and has a role in determining the intensity of the experienced *Sadness*.

Source Plutchik (1980); Lazarus (1991); Ekman (2007); Izard (1977)

Depends On C1, WR20, WR21, WR25

Ref. By –

WR25	**Joy**

Description *Joy* is defined by goal progression (WR20) when the individual perceives their life to be generally good. Depending on the type of goals (C10) affected, this can mean:

- Maintaining the person-environment relationship as it is when the goal is to maintain the current situation, or
- Observing changes in the person-environment relationship that makes the achievement of a goal more likely to occur.

Joy is triggered by stimuli and events that cause the individual to feel safe and secure in their surroundings where little personal effort is required to maintain it. This can include being with loved ones, relief from physical pain and discomfort, and praise.

Factors impacting the intensity of *Joy* include a positive evaluation of future progress (WR21) and the elapsed time since progression was made on the affected goal such that a large time gap increases intensity. Intensity might also be inversely proportional to the likelihood of goal achievement, where the more unlikely goal achievements elicit stronger reactions than highly likely goal achievements.

Source Plutchik (1980); Lazarus (1991); Ekman and Friesen (2003); Ekman (2007)

Depends On C1, WR20, WR21

Ref. By WR24

WR26	**Interest**

Description *Interest* is a response to something that:

- Will likely impact a goal in the future
- Can be inspected to reduce the uncertainty of its future impact

Interest arises when something catches the individual's attention (WR15) and provides some level of stimulation—a conscious change in perception, by observing something novel, or by considering possibilities in relation to goal achievement (WR20)—principally guided by novelty and complexity. In general, people tend to find the most interest in one of three types: objects, ideas, or people.

It is likely that the desirability of the potential benefit of the event, person, or object, coupled with the likelihood of a beneficial pay-off (WR21), are factors in the evaluation of *Interest*. As indicators of when *Interest* might be invoked, novelty and complexity might also play a role in the emotion's intensity.

Source Plutchik (1980); Lazarus (1991); Izard (1977); Tomkins (1962); Ortony et al. (1988)

Depends On C1, WR15, WR20, WR21

Ref. By –

WR27	**Surprise**

Description *Surprise* is a response to events that an individual is ill-prepared for which are:

- Sudden
- Unexpected or incorrectly predicted

As it is impossible to elicit *Surprise* from a correctly predicted outcome, the trigger is the size of the difference between what is observed (WR15) and what was expected regardless of the person, event, or object itself.

Surprise is influenced by the level of uncertainty, which reflects how much information the individual needs to collect in order to appraise the situation effectively (WR20, WR21) and the confidence level of a prediction about the individual-environment relationship. This is complemented by familiarity, which can help reduce the amount of information necessary to gather information.

Source Plutchik (1980); Lazarus (1991); Ekman (2007); Ortony et al. (1988); Izard (1977)

Depends On C1, WR15, WR20, WR21

Ref. By –

WR28	**Disgust**

Description Distaste is the underlying theme of *Disgust*, which is identified by:

- Self-preservation (C10)
- The anticipation of harm if contacted (WR20)
- Coping potential and future expectancy are known (WR21)

Compared to other emotions, *Disgust* is restricted in content and rigid in the type of factors that can elicit it. The most common universal trigger of *Disgust* is bodily fluid that has left the body – blood, mucus, faeces, vomit, and urine. Other themes – including strange things, diseases, misfortune, and moral taint – are learned and heavily influenced by personality and culture.

The level of unappealingness of the stimuli has a significant impact on the intensity of *Disgust*, both from sensory evaluations and in anticipation of contamination from "indigestion". A counter factor, the degree of familiarity with it and its origins, can temper the reaction.

Source Plutchik (1980); Lazarus (1991); Rozin et al. (1999); Ortony et al. (1988)

Depends On C1, C10, WR20, WR21

Ref. By –

WR29	**Trust**

Description Affective *Trust*, or *Affection* in CA, is an emotion arising from a long-term relationship with an honest and benevolent partner. This suggests that *Trust* is identified by:

- A desire to care for the partner and a willingness to put oneself at risk for them – physically, emotionally, or socially
- An future expectation that the partner will demonstrate their care for the individual, often via an affirmation of the individual's value and increased security, confidence, and intimacy in the relationship

As it is tied to relationships (WR17) and expectations of future benefits, *Trust* is likely triggered when an individual makes a risk assessment involving the partner where a favourable outcome is expected (WR20, WR21). After the event has passed, the individual will likely experience another emotion fitting to the outcome.

The intensity of *Trust* is influenced by the individual's relationship with the partner. The component factors of a relationship – volatility, dependability, and faith – influence the intensity of *Trust*. Their relative weights are determined by the confidence and security of the relationship, and also by the individual's gender – men treat these factors independently whereas women tend to associate them.

- When no personal relationship exists intensity is influenced solely on the partner's reputation and past and current actions – their volatility.
- Once a relationship is established, the individual's perception of their partner's dependability has more influence than their past experiences on predictions of future outcomes – their dependability.
- When the relationship has developed to the highest level of confidence and security, the individual puts weight in faith – the strength of the relationship and their personal security and self-esteem than their partner's history, actions, or dependability when determining how much risk they are willing to put themselves in.

Source Plutchik (1980); Lazarus (1991); Rempel et al. (1985)

Depends On C1, WR17, WR20, WR21

Ref. By –

D.3 Theoretical Models

WR30	Evaluating Goal Relevance
Input	$g : \mathbb{G}$, $s : \mathbb{S}$, $s_\Delta : \mathbb{S}_\Delta$
Output	$r \doteq \lvert g.\texttt{goal}'(s, s_\Delta)\rvert$

Description A change in the game state (s_Δ) from the current state (s) is relevant to a goal (g) if its function $\texttt{goal}'(s, s_\Delta)$ returns a value whose magnitude is non-zero. This indicates that there is a change in s by s_Δ which moves it closer to the state represented by $\texttt{goal}$.

Sources –

Depends On TY10, TY11, TY14, WR20

Ref. By –

WR31	Evaluating Goal Congruence
Input	$g : \mathbb{G}$, $s : \mathbb{S}$ $s_\Delta : \mathbb{S}_\Delta$, $B \in \mathbb{R}^+$
Output	$c \doteq cg + b$ where

$$cg = g.\texttt{goal}'(s, s_\Delta), \text{ and}$$

$$b = \begin{cases} B \cdot cg, & G > 0 \land G' = 0 \\ -B \cdot cg, & G = 0 \land G' > 0 \\ 0, & \text{Otherwise} \end{cases}$$

$$\text{where } G = g.\texttt{goal}(s)$$

$$\text{and } G' = g.\texttt{goal}'(s, s_\Delta)$$

Description Goal congruence (c) is a measure of how a change in the world state (s_Δ) affects the completion status of a goal $g.\texttt{goal}'(s, s_\Delta)$.

A value b proportional to cg is added to c to "boost" the value (A34) when a previously unsatisfied goal is now satisfied ($g.\texttt{goal}(s) > 0 \land g.\texttt{goal}'(s, s_\Delta) = 0$) or a previously completed goal is no longer satisfied ($g.\texttt{goal}(s) = 0 \land g.\texttt{goal}'(s, s_\Delta) > 0$).

Sources –

Depends On TY10, TY11, TY14, A34, WR20

Ref. By WR32, WR33, WR34, WR35, WR37, WR38

WR32	**Evaluating Accountability**
Input	$(actor : \mathbb{A}, a : \mathbb{AC}, deliberate : \mathbb{B}), g : \mathbb{G}, s : \mathbb{S}, B \in \mathbb{R}^{+}$
Output	$acc \mathrel{\hat{=}} \begin{cases} \text{Credit}, & deliberate \wedge C > 0 \\ \text{Blame}, & deliberate \wedge C < 0 \\ \text{None}, & \text{Otherwise} \end{cases}$ where $C = c(g, s, a.\mathtt{makesChange}(s), B)$

Description Accountability (acc) is a categorical assignment of fault for an action (a) that is caused by an actor ($actor$). It is derived from an assigned value of the actor's intention ($deliberate$) and an evaluation of benefit or harm given by goal congruence ($c(g, s, a.\mathtt{makesChange}(s), B)$):

- Credit is given if the event is deliberately caused and is beneficial ($deliberate \wedge c(g, s, a.\mathtt{makesChange}(s), B) > 0$),
- Blame is given if the event is deliberate and causes harm ($deliberate \wedge c(g, s, a.\mathtt{makesChange}(s), B) < 0$), and
- Neither Credit or Blame is given if the event is not deliberately caused ($\neg deliberate$) or has no effect on the evaluated goal ($c(g, s, a.\mathtt{makesChange}(s), B) = 0$).

Sources –

Depends On TY10, TY14, WR3, WR4, WR21, WR31

Ref. By WR35, WR37

WR33	**Evaluating Coping Potential**
Input	$a : \overrightarrow{\mathbb{AC}}, g : \mathbb{G}, s : \mathbb{S}, B \in \mathbb{R}^{+}, E : \mathbb{J}, d : [0, 1] \in \mathbb{R}^{+}$
Output	$cp \mathrel{\hat{=}} \sum_{i=0}^{n} d^{i} \cdot q(i)$ where $q = p$ sorted in descending order and $p(i) = \begin{cases} C(i) \cdot L(i) \cdot J(i), & J(i) < 1 \wedge C(i) > 0 \\ 0, & \text{Otherwise} \end{cases}$ where $C(i) = c(g, s, a(i).\mathtt{makesChange}(s), B)$, $L(i) = a(i).\mathtt{successLikelihood}$, and $J(i) = 1 - \frac{a(i).\mathtt{energyCost}}{E}$

Description Coping potential (cp) is a sum of the effectiveness of a vector of actions ($a : \overrightarrow{\mathbb{AC}}$). Actions are assumed to be independent because only one action can be executed at a time (A35) and appraisals are evaluated on a moment-to-moment basis (A36).

The vector of action effectiveness values is sorted in descending order (q), and each value is decayed by a factor of d^i. This maintains the full value of the most effective action's value the total coping potential, but the value of additional actions has increasingly diminished returns. This ensures that the additional value associated with having multiple effective actions is preserved, but recognizes that one might not see a difference when adding another effective action to an already large set.

The effectiveness of an action ($p(i)$) is measured by how useful it is, its likelihood of success, and how easy it is to act on. This is given by the product of its expected goal congruence ($c(g, s, a(i).\texttt{makesChange}, B)$), likelihood of success ($a(i).\texttt{successLikelihood}$), and anticipated energy usage ($a(i).\texttt{energyCost}$) as it relates to the available energy (E).

An action is excluded from the vector of potential actions if it does not affect or negatively affects the given goal ($C \not> 0$), or it requires more than the available energy ($J \not< 1$).

Sources –

Depends On TY10, TY14, A35, A36, WR1, WR2 (via WR4), WR4, WR21, WR31

Ref. By WR35, WR36, WR38

WR34	**Evaluating Future Expectancy**
Input	$g : \mathbb{G}, s : \mathbb{S}, a : \overrightarrow{\mathbb{AC}}, otherChange : \mathbb{S}_\Delta, B : \mathbb{R}^+$
Output	$fe \mathrel{\hat{=}} c(g, s, \Delta S, B) - c(g, s, s_\Delta, B)$
	where $\Delta S = a(i).\texttt{makesChange}(s) + otherChange$
	and $i = \texttt{argmax}_a\ a.\texttt{successLikelihood}(s)$

Description Future expectancy (fe) is an evaluation of the difference in goal congruence between this world state ($c(g, s, s_\Delta, B)$) and the next predicted world state ($c(g, s, \Delta S, B)$). If the difference is:

- Positive ($fe > 0$), then the next world state is predicted to be more goal congruent – an improvement over the current world state
- Negative ($fe < 0$), then the next world state is predicted to be less goal congruent – worse than the current than the current world state
- Zero ($fe = 0$), then the next world state is predicted to have the same goal congruence – there is no improvement or loss over the current world state

The next predicted world state is the sum of two world state changes. One is the action that is most likely to succeed from a vector of actions ($a(i) \in \overrightarrow{\mathbb{AC}}$), representing the part of the future that the NPC can control. The other is a world state change that is not caused by the NPC's actions – the parts of the future that the NPC cannot control – such as the actions of others and naturally occurring events (*otherChange*).

Sources –

Depends On TY10, TY11, TY14, WR4, WR21, WR31

Ref. By WR35, WR39

WR35	**Evaluating Emotion Type from an Appraisal (*Fear*, *Anger*, *Sadness*, *Joy*, *Disgust*, and *Trust*)**
Input	$g : \mathbb{G}$, $ge(g) : \mathbb{GE}$, $s : \mathbb{S}$, $s_\Delta : \mathbb{S}_\Delta$, $B : \mathbb{R}^+$, $(actor : \mathbb{A}, a : \mathbb{AC}, deliberate : \mathbb{B})$, $a : \overrightarrow{\mathbb{AC}}$, $E : \mathbb{J}$, $d : [0,1] \in \mathbb{R}^+$, $T_{cp} : \mathbb{R}^+$, $T_{fe} : \mathbb{R}^+$
Output	$e \triangleq$ match (C, GE, A, CP, FE) to $\mid (C < 0, O, \text{None}, CP < T_{cp}, \_) \to$ Sadness $\mid (C < 0, ge(g, \texttt{SelfEsteem}) > 0 \vee ge(g, \texttt{SocialEsteem}) > 0, \text{Blame}, \_, \_) \to$ Anger $\mid (C > 0, \_, \_, \_, FE > T_{fe}) \to$ Joy $\mid (C < 0, O, \_, \_, \_) \to$ Fear $\mid (C < 0, O, \_, \_, \_) \to$ Disgust $\mid (C > 0, O, \_, \_, \_) \to$ Trust fi where $R = r(g, s, s_\Delta, \varepsilon)$, $C = c(g, s, s_\Delta, B)$, $A = acc((actor, a, deliberate), g, s, B)$, $CP = cp(\{a\}, g, s, B, E, d)$, $FE = fe()$, and $O = \{\exists o \in ge(g) \mid ge(g).o > 0\}$

Description An appraisal (WR19) is the output of pattern matching where each emotion kind has a unique pattern (A37). Since some patterns are more detailed than others, the patterns are read sequentially to avoid unintentional matches.

A pattern is comprised of values for goal congruence (C), the ego type associated with g (GE, A38, A39), accountability (A), coping potential (CP), and future expectancy (FE).

Sources –

Depends On TY10, TY11, TY14, A37, A38, A39, WR1, WR3, WR4, WR13, WR19, WR31, WR32, WR33, WR34

Ref. By –

WR36	**Determining the Intensity of *Fear***
Input	$g : \mathbb{G}, s : \mathbb{S}, B : \mathbb{R}^+, a : \overrightarrow{\mathbb{AC}}, E : \mathbb{J}, d : [0,1] \in \mathbb{R}^+, t_\Delta : \mathbb{T}$
Output	$I_{\texttt{Fear}} : \mathbb{I}_\Delta \doteq \begin{cases} \dfrac{g.\texttt{importance}}{t_\Delta \cdot cp(a,g,s,B,E,d)}, & cp > 0 \wedge t_\Delta > 0 \\ g.\texttt{importance}, & \text{Otherwise} \end{cases}$

Description A change in the intensity of *Fear* ($I_{\texttt{Fear}} : \mathbb{I}_\Delta$) is:

- Proportional to the importance of the affected goal ($g.\texttt{importance}$)—a higher importance increases intensity
- Inversely proportional to the time that the event is expected (t_Δ), such that a shorter expected time increases intensity
- Inversely proportional to the NPC's ability to mitigate risk as measured by their coping potential ($cp(a, g, s, B, E, d)$), such that a higher coping potential decreases intensity

If at least one of cp or t_Δ are 0, then the intensity of *Fear* is equivalent to the importance of the goal. This represents situations where the NPC has no available actions that can affect the current world state ($cp = 0$), or when there is no time to prepare for the harmful event ($t_\Delta = 0$).

Sources –

Depends On TY9, TY2, TY10, TY14, WR1, WR4, WR22, WR33

Ref. By WR40, WR41, WR42

WR37	**Determining the Intensity of *Anger***
Input	$g : \mathbb{G}, s : \mathbb{S}, B : \mathbb{R}^+, (actor : \mathbb{A}, a : \mathbb{AC}, deliberate : \mathbb{B}), rl : R^S$
Output	$I_{\texttt{Anger}} : \mathbb{I}_\Delta \doteq \begin{cases} A, & acc((actor, a, deliberate), g, s, B) = \text{Blame} \\ 0, & \text{Otherwise} \end{cases}$ where $A = g.\texttt{importance} \cdot Control + I_{Store}$, $Control = \dfrac{rl.\texttt{confidence}}{rl.\texttt{security}} + c(g, s, a.\texttt{makesChange}(s), B)$, and $I_{Store} = \begin{cases} A, & acc((actor, a, deliberate), g, s, B) \neq \text{Blame} \\ 0, & \text{Otherwise} \end{cases}$

Description A change in the intensity of *Anger* ($I_{\texttt{Anger}} : \mathbb{I}_\Delta$) is:

- Proportional to the importance of the affected goal ($g.\texttt{importance}$)—a higher importance increases intensity
- Proportional to the degree of *Blame* that the offending *actor* is perceived to have, represented as a perceived amount of control over their actions (*Control*), such that a higher degree of control increases intensity
- Linearly increased by the total intensity of all previous encounters of *Anger* since the last *Blame* assignment where it could not be assigned (I_{Store}), representing a suppression of *Anger* since no suitable target is available

If Blame has been successfully assigned to *actor* in the evaluation of accountability ($acc((actor, a, deliberate), g, s, B) = \text{Blame}$), the intensity is equivalent to A and I_{Store} is reset to 0; otherwise, the emotion is suppressed and the intensity is 0 and the stored intensity of *Anger* is I_{Store}.

The degree of *Control* that *actor* has is a linear combination of two parts. The first is an evaluation of the relationship between this NPC and *actor*. The relationship is evaluated by: the confidence in the NPC's knowledge of the relationship ($rl.\texttt{confidence}$), such that a higher confidence increases perceived control; and an evaluation of how much harm the NPC believes *actor* intends ($rl.\texttt{security}$), such that a higher value decreases perceived control. The second part is an evaluation of how much harm the action of *actor* has caused, given as a congruence evaluation on their action ($c(g, s, a.\texttt{makesChange}(s))$).

Sources –

Depends On TY2, TY10, TY14, WR3, WR4, WR18, WR23, WR31, WR32

Ref. By WR43, WR44, WR45

D.4 Instance Models

WR38	**(Instance Model) Evaluating Coping Potential with No Energy Cost**
Input	$a : \overrightarrow{\mathbb{AC}}, g : \mathbb{G}, s : \mathbb{S}, B \in \mathbb{R}^+, d : [0,1] \in \mathbb{R}^+$
Output	$cp \mathrel{\hat{=}} \sum_{i=0}^{n} d^i \cdot q(i)$ where $q = p$ sorted in descending order and $p(i) = \begin{cases} C(i) \cdot L(i), & C(i) > 0 \\ 0, & \text{Otherwise} \end{cases}$ where $C(i) = c(g, s, a(i).\texttt{makesChange}(s), B)$, and $L(i) = a(i).\texttt{successLikelihood}$

Description If energy is assumed to be infinite, then the effectiveness of an action is only measured by its goal congruence ($c(g, s, a(i).\mathtt{makesChange}, B)$) and likelihood of success ($a(i).\mathtt{successLikelihood}$). Actions with no or negative effects on the goal (g) are excluded from the vector of potential actions.

Coping potential (cp) remains the sum of the effectiveness ($p(i)$) of the vector of these actions ($a : \overrightarrow{\mathbb{AC}}$). The vector is sorted in descending order (q) and each action is decayed by a factor of d^i. This ensures that the full value of the most effective action is maintained in the sum, but each subsequent effectiveness is reduced such that there are diminishing returns on large sets of actions.

Sources –

Depends On TY10, TY14, WR4, WR31, WR33

Ref. By –

WR39	**Evaluating Future Expectancy with NPC Actions Only**
Input	$g : \mathbb{G}, s : \mathbb{S}, a : \overrightarrow{\mathbb{AC}}, B : \mathbb{R}^+$
Output	$fe \mathrel{\hat{=}} c(g, s, \Delta S, B) - c(g, s, s_\Delta, B)$
	where $\Delta S = a(i).\mathtt{makesChange}(s)$
	and $i = \mathtt{argmax}_a\ a.\mathtt{successLikelihood}(s)$

Description Future expectancy (fe) is an evaluation of the difference in goal congruence between this world state ($c(g, s, s_\Delta, B)$) and the next predicted world state ($c(g, s, \Delta S, B)$). If the difference is:

- Positive ($fe > 0$), then the next world state is predicted to be more goal congruent – an improvement over the current world state
- Negative ($fe < 0$), then the next world state is predicted to be less goal congruent – worse than the current than the current world state
- Zero ($fe = 0$), then the next world state is predicted to have the same goal congruence – there is no improvement or loss over the current world state

The next predicted world state is determined by an action that is most likely to succeed from a vector of available actions ($a(i) \in a : \overrightarrow{\mathbb{AC}}$).

Sources –

Depends On TY10, TY11, TY14, WR4, WR31, WR34

Ref. By –

WR40	**Calculating the Intensity of *Fear* with Energy and without Time**
Input	$g : \mathbb{G}$, $s : \mathbb{S}$, $B : \mathbb{R}^{+}$, $\{a : \mathbb{AC}\}$, $E : \mathbb{J}$, $d : [0,1] \in \mathbb{R}^{+}$
Output	$I_{\texttt{Fear}} : \mathbb{I}_{\Delta} \triangleq \dfrac{g.\texttt{importance}}{cp(\{a : \mathbb{AC}\}, g, s, B, E, d)}$

Description A change in the intensity of *Fear* ($I_{\texttt{Fear}} : \mathbb{I}_{\Delta}$) without time considerations is:

- Proportional to the importance of the affected goal ($g.\texttt{importance}$)—a higher importance increases intensity
- Inversely proportional to the NPC's ability to mitigate risk as measured by their coping potential ($cp(\{a : \mathbb{AC}\}, g, s, B, E, d)$), such that a higher coping potential decreases intensity

Sources –

Depends On TY2, TY10, TY14, WR1, WR4, WR33, WR36

Ref. By –

WR41	**Calculating the Intensity of *Fear* without Energy and with Time**
Input	$g : \mathbb{G}$, $s : \mathbb{S}$, $B : \mathbb{R}^{+}$, $\{a : \mathbb{AC}\}$, $d : [0,1] \in \mathbb{R}^{+}$, $t_{\Delta} : \mathbb{T}$
Output	$I_{\texttt{Fear}} : \mathbb{I}_{\Delta} \triangleq \dfrac{g.\texttt{importance}}{t_{\Delta} \cdot cp(\{a : \mathbb{AC}\}, g, s, B, d)}$

Description A change in the intensity of *Fear* ($I_{\texttt{Fear}} : \mathbb{I}_{\Delta}$) without energy considerations is:

- Proportional to the importance of the affected goal ($g.\texttt{importance}$)—a higher importance increases intensity
- Inversely proportional to the time that the event is expected (t_{Δ}), such that a shorter expected time increases intensity
- Inversely proportional to the NPC's ability to mitigate risk as measured by their coping potential ($cp(\{a : \mathbb{AC}\}, g, s, B, d)$), such that a higher coping potential decreases intensity

Sources –

Depends On TY9, TY2, TY10, TY14, WR4, WR36, WR38

Ref. By –

WR42	**Calculating the Intensity of *Fear* without Energy or Time**
Input	$g : \mathbb{G}, s : \mathbb{S}, B : \mathbb{R}^+, \{a : \mathbb{AC}\}, d : [0, 1] \in \mathbb{R}^+$
Output	$I_{\texttt{Fear}} : \mathbb{I}_\Delta \mathrel{\hat{=}} \dfrac{g.\texttt{importance}}{cp(\{a : \mathbb{AC}\}, g, s, B, d)}$

Description A change in the intensity of *Fear* ($I_{\texttt{Fear}} : \mathbb{I}_\Delta$) without energy or time considerations is:

- Proportional to the importance of the affected goal ($g.\texttt{importance}$)—a higher importance increases intensity
- Inversely proportional to the NPC's ability to mitigate risk as measured by their coping potential ($cp(\{a : \mathbb{AC}\}, g, s, B, d)$), such that a higher coping potential decreases intensity

Sources –

Depends On TY2, TY10, TY14, WR4, WR36, WR38

Ref. By –

WR43	**Calculating the Intensity of *Anger* with Stored Intensity and without a Social Relationship**
Input	$g : \mathbb{G}, s : \mathbb{S}, B : \mathbb{R}^+, (actor : \mathbb{A}, a : \mathbb{AC}, deliberate : \mathbb{B})$
Output	$I_{\texttt{Anger}} : \mathbb{I}_\Delta \mathrel{\hat{=}} \begin{cases} A, & acc((actor, a, deliberate), g, s, B) = \text{Blame} \\ 0, & \text{Otherwise} \end{cases}$ where $A = g.\texttt{importance} \cdot c(g, s, a.\texttt{makesChange}(s), B) + I_{Store}$, and $I_{Store} = \begin{cases} A, & acc((actor, a, deliberate), g, s, B) \neq \text{Blame} \\ 0, & \text{Otherwise} \end{cases}$

Description A change in the intensity of *Anger* ($I_{\texttt{Anger}} : \mathbb{I}_\Delta$) is:

- Proportional to the importance of the affected goal ($g.\texttt{importance}$)—a higher importance increases intensity
- Proportional to the degree of *Blame* that the offending *actor* is perceived to have, such that a higher degree of control increases intensity

- Linearly increased by the total intensity of all previous encounters of *Anger* since the last *Blame* assignment where it could not be assigned (I_{Store}), representing a suppression of *Anger* since no suitable target is available

If Blame has been successfully assigned to *actor* in the evaluation of accountability ($acc((actor, a, deliberate), g, s, B) = \text{Blame}$), the intensity is equivalent to A and I_{Store} is reset to 0; otherwise, the emotion is suppressed and the intensity is 0 and the stored intensity of *Anger* is I_{Store}.

The degree of control that *actor* has is an evaluation of how much harm the action of *actor* has caused, given as a congruence evaluation on their action ($c(g, s, a.\texttt{makesChange}(s))$).

Sources –

Depends On TY2, TY10, TY14, WR3, WR4, WR31, WR32, WR37

Ref. By –

WR44	**Calculating the Intensity of *Anger* without Stored Intensity and with a Social Relationship**
Input	$g : \mathbb{G}$, $s : \mathbb{S}$, $B : \mathbb{R}^+$, $(actor : \mathbb{A}, a : \mathbb{AC}, deliberate : \mathbb{B})$, $rl : \mathbb{SA}$
Output	$I_{\texttt{Anger}} : \mathbb{I}_\Delta \hat{=} \begin{cases} A, & acc((actor, a, deliberate), g, s, B) = \text{Blame} \\ 0, & \text{Otherwise} \end{cases}$ where $A = g.\texttt{importance} \cdot Control$ and $Control = \dfrac{rl.\texttt{confidence}}{rl.\texttt{security}} + c(g, s, a.\texttt{makesChange}(s), B)$

Description A change in the intensity of *Anger* ($I_{\texttt{Anger}} : \mathbb{I}_\Delta$) is:

- Proportional to the importance of the affected goal ($g.\texttt{importance}$)—a higher importance increases intensity

- Proportional to the degree of *Blame* that the offending *actor* is perceived to have, represented as a perceived amount of control over their actions (*Control*), such that a higher degree of control increases intensity

If Blame has been successfully assigned to *actor* in the evaluation of accountability ($acc((actor, a, deliberate), g, s, B) = \text{Blame}$), the intensity is equivalent to the calculated intensity (A); otherwise, the emotion is suppressed and the intensity is 0.

The degree of *Control* that *actor* has is a linear combination of two parts. The first is an evaluation of the relationship between this NPC and *actor*. The relationship is evaluated by: the confidence in the NPC's knowledge of the relationship ($rl.\texttt{confidence}$), such that a higher confidence increases perceived control; and an evaluation of how much harm the NPC believes *actor* intends ($rl.\texttt{security}$), such that a higher value decreases perceived control. The second part is an evaluation of how much harm the action of *actor* has caused, given as a congruence evaluation on their action ($c(g, s, a.\texttt{makesChange}(s))$).

Sources –

Depends On TY2, TY10, TY14, WR3, WR4, WR18, WR23, WR31, WR32, WR37

Ref. By –

WR45	**Calculating the Intensity of *Anger* without Stored Intensity and without a Social Relationship**
Input	$g : \mathbb{G}, s : \mathbb{S}\ \ B : \mathbb{R}^{+}, (actor : \mathbb{A}, a : \mathbb{AC}, deliberate : \mathbb{B})$
Output	$I_{\texttt{Anger}} : \mathbb{I}_{\Delta} \triangleq \begin{cases} A, & acc((actor, a, deliberate), g, s, B) = \text{Blame} \\ 0, & \text{Otherwise} \end{cases}$ where $A = g.\texttt{importance} \cdot c(g, s, a.\texttt{makesChange}(s), B)$,

Description A change in the intensity of *Anger* ($I_{\texttt{Anger}} : \mathbb{I}_{\Delta}$) is:

- Proportional to the importance of the affected goal ($g.\texttt{importance}$)—a higher importance increases intensity
- Proportional to the degree of *Blame* that the offending *actor* is perceived to have, represented as a perceived amount of control over their actions, such that a higher degree of control increases intensity

If Blame has been successfully assigned to *actor* in the evaluation of accountability ($acc((actor, a, deliberate), g, s, B) = \text{Blame}$), the intensity is equivalent to the calculated intensity (A); otherwise, the emotion is suppressed and the intensity is 0.

The degree of control that *actor* has is an evaluation of how much harm the action of *actor* has caused, given as a congruence evaluation on their action ($c(g, s, a.\texttt{makesChange}(s))$).

Sources –

Depends On TY2, TY10, TY14, WR3, WR4, WR23, WR31, WR32, WR37

Ref. By –
