The Logics of Emotion: A Survey of the field of Affective Computing

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Chapter 1

Introduction

As computing devices become more common, affordable and miniaturised, one can imagine a future in which such devices are capable of adapting and responding to user needs by being aware of the user's mental and emotional state. For example, if a device determines that the user is stressed, it adapts its behaviour to present information in a more terse manner whereas if it senses that the user is relaxed, the information can be presented in a more verbose way.

The aim of this project was to investigate the types of concepts that need to be represented in order to model users' mental and emotional states. In particular, the investigation focused what sorts of information can be gathered about the user and his or her situation, how this information can be represented, and how such representation might be used for the purpose of reasoning to infer information about the users' mental and emotional state.

The concepts were represented in an ontology using the Web Ontology Language (OWL). This ontology was then used to design and implement an affective conversational agent that both responds to a user's emotion and behaves as if it had emotions of its own.

Chapter 2

Sensing a User's Affective State

2.1 Biofeedback

One method of determining the affective state of a human user is to observe the user's physical responses to his or her emotions. This is usually performed using a small variety of feedback-specific devices. The most commonly used responses and devices are outlined below.

2.1.1 Meaningful biofeedback

Examples of research into emotion sensing via biofeedback are found in [27, 33, 21], etc. Generally, the following signals and measurements are found to provide meaningful information on a user's affective state:

Galvanic Skin Resistance (GSR) Two small electrodes are placed on the skin and a tiny current is passed between them; the resistance of the skin between the electrodes is then measured. GSR is a good indication of level of arousal. Usually taken on a finger or the palm of the hand, or the arch of the foot.

Blood Volume Pressure (BVP) Measured using *photoplethysmography*, which measures the BVP by measuring how much infrared light is reflected off an area of skin. BVP is often indicative of valence (high blood pressure indicates a negative emotion, low blood pressure a positive one). Usually taken on a finger or the foot.

Electroencephalogram patterns (EEG) Measures brain activity. Needs complicated instruments, quite intrusive to measure. Different brain activity patterns are characteristic of different emotions.

Electromyogram patterns (EMG) Small electrodes measure a tiny voltage from a muscle, indicating when it is contracted. An EMG Measures muscle activity. Often taken at the masseter muscle in the jaw, as a representative of facial activity. Depending on the muscle, EMG activity can be indicative of both valence and intensity; patterns can be characteristic of individual emotions.

Respiration measured using an elastic band around the chest or diaphragm; the respiration rate and amplitude can be measured.

Muscle pressure for example, on mouse, seat, floor, etc. This can be related to posture; for more info see section 2.3. Alternatively, pressure on a mouse can be an indication of frustration.

2.1.2 Devices to gather biofeedback

Several devices exist to gather biofeedback data (for example, sample the signal from EEG or EMG electrodes, or a respiration elastic). These include:

ProComp Infiniti+ multi-purpose unit with 8 general input channels for connecting sensors such as EEG, EKG, RMS EMG, skin conductance, heart rate, blood volume pulse, respiration, goniometry (angles of joints), force, and voltage input. `http://www.thoughttechnology.com/procomp.htm` This is the system that is used in almost all of the literature.

TekScan Body Pressure Measurement System measures the body's pressure against a chair. The distribution of pressure can be used to infer posture. http://www.tekscan.com/industrial/bpms_research_system.html

2.2 Facial expression recognition

It is possible to determine some affective information from the user's facial expression. (Humans do it all the time!) According to [27, pp. 174–178], the best current face recognition systems are all based on FACS, by Paul Ekman: http://face-and-emotion.com/dataface/facs/description.jsp. FACS classifies images or video clips of a face according to the emotion being expressed, using 'movement density' to determine the emotions. On the other hand, it has some limitations:

- video gives better results than still images
- can be difficult to correctly classify depictions of a mixture of emotions
- the system needs a "neutral" face between different emotions to be able to distinguish them

There is also work on linking facial expression to emotions by Emery Schubert at UNSW [36]; Schubert has produced a system for synthesising facial expression from affective cues in music.

2.3 Gesture recognition

Gestures and body movement during affective interactions can also be useful indications of affective state. Examples of work in this area are:

Posture recognition from [25]: uses a 3-layer neural network to classify postures, and then a hidden Markov model to determine the posture "states" of the user.

Head movement recognition from [20]: infrared camera (illuminated by IR LEDs) to detect eye pupil movement, related to nodding and shaking of the head. HMM-based classifier detects nods and shakes.

Gaze tracking *Related to this research, but not directly to affective computing. Seeing Machines* http://www.seeingmachines.com/ *make a product called FaceLAB which provides face, eye and blink tracking.*

2.4 Vocal prosody recognition

Variations in speech and vocal intonation are another indication of affective state. Current findings on vocal emotion, summarised in [27, pp. 178–184], are that affective cues in vocal intonation come in two varieties:

- vocal emphasis to underline the importance of parts of the spoken sentence, and
- more subtle overall cues from the style of speech. The vocal affects (overall cues) most commonly associated with emotions are shown in Table 2.1 along with their values in five basic emotions.

Further work (and a potential application) also in [28]. In this work, affective state (observed via speech prosody) is used to disambiguate the emotional content of spoken sentences. This system:

- uses Suprasegmental Hidden Markov Models SPHMM to model emotions;
- compared affect recognition using first just the words, and then both words and speech prosody, to train the SPHMM;
- found significantly better results using prosody than not using prosody.

	Fear	Anger	Sadness	Happiness	Disgust
Speech rate	much faster	slightly faster	slightly slower	faster or slower	very much slower
Pitch average	very much higher	very much higher	slightly lower	much higher	very much lower
Pitch range	much wider	much wider	slightly narrower	much wider	slightly wider
Intensity	normal	higher	lower	higher	lower
Voice quality	irregular voicing	breathy chest tone	resonant	breathy blaring	grumbled chest tone
Pitch changes	normal	abrupt on stressed syllables	downward inflections	smooth upward inflections	wide downward terminal inflections
Articulation	precise	tense	slurring	normal	normal

Table 2.1: An example of some human vocal effects associated with five basic emotions. (From I. R. Murray and J. L. Arnott. Toward the simulation of emotion in synthetic speech: A review of the literature on human vocal emotion. *Journal Acoustical Society of America*, 93(2):1097–1108, February 1993, quoted in [27, Table 6.1])

Chapter 3

Cognitive Appraisal Models of Emotion

Another approach to the detection (and then, generation) of emotions comes out of a cognitive model of the emotional process in humans. With a sufficiently accurate model of how humans cognitively produce emotions from appraisals of real-world events, it should be possible to 'second-guess' the human's emotions by performing the same appraisals on the same real-world events. Alternatively a computerised agent may simply perform appraisals for itself, and thus be able to express appropriate emotions of its own.

3.1 The approach of Ortony, Roseman, et al

"Cognitive Appraisals", from [35, 34, 22]. Each emotion is characterised by a number of yes/no appraisals of a situation giving rise to that emotion. The appraisals are listed below; the emotions (with their appropriate appraisals) are depicted in figure 3.1.

Motive Consistency (earlier, Valence) Whether the event is consistent or inconsistent with the agent's motives - this is directly linked to whether the event is perceived as positively or negatively valenced.

Agency An appraisal as to whether the event was caused by the agent itself, another agent, or the circumstances

Contact Distance Whether or not the agent's goal is one of gaining or achieving something (appetitive) or avoiding something (aversive)

Expectedness (earlier, Probability) The extent to which the event was expected

Control Potential (in earlier work, Strength) The extent to which the agent feels able to control the event

Characterological/Non-Characterological An appraisal as to whether or not the event reveals something about the underlying character of its cause

Also worth mentioning is the OCC (Ortony Clore Collins) model of emotions from [26], mentioned in [27, pp. 195–198] and used in [17] and [3]. This takes the form of a tree, where appraisals produce branches, and emotions appear at the leaves.

3.2 The approach of Smith, Ellsworth, Baillie-de Byl et al

"Appraisal Dimensions", from [37, 2, 14]. Differs from above in that appraisals are taken in a quantitative way rather than being classified in one or another category. The appraisals are slightly different but similar, and listed below. For an example of emotions characterised using this system see figure 3.2.

Pleasantness an appraisal of the valence of the event.

Anticipated Effort "fight or flight"; an appraisal of whether the event should prompt one to expend effort or do something, or whether it should prompt one to relax or withdraw quietly.

Attentional Activity The extent to which the event demands our attention, ranging from attractive attention to repulsive attention.

Certainty ranging from absolutely certain to completely at random

Self- vs Other-Responsibility/Control The extent to which an agent itself is responsible for bringing about the event that caused the emotion, as opposed to another agent.

Human vs Situational Control The extent to which an agent is responsible for bringing about the event that caused an emotion, as opposed to circumstances or the situation being responsible..

Smith and Ellsworth also hypothesised, but did not find any experimental support for, the following additional two dimensions:

Perceived Obstacle the extent to which an event is consistent or inconsistent with one's current goals, regardless of the event's inherent pleasantness.

Legitimacy The legitimacy or fairness of the outcome of an emotion-eliciting event.

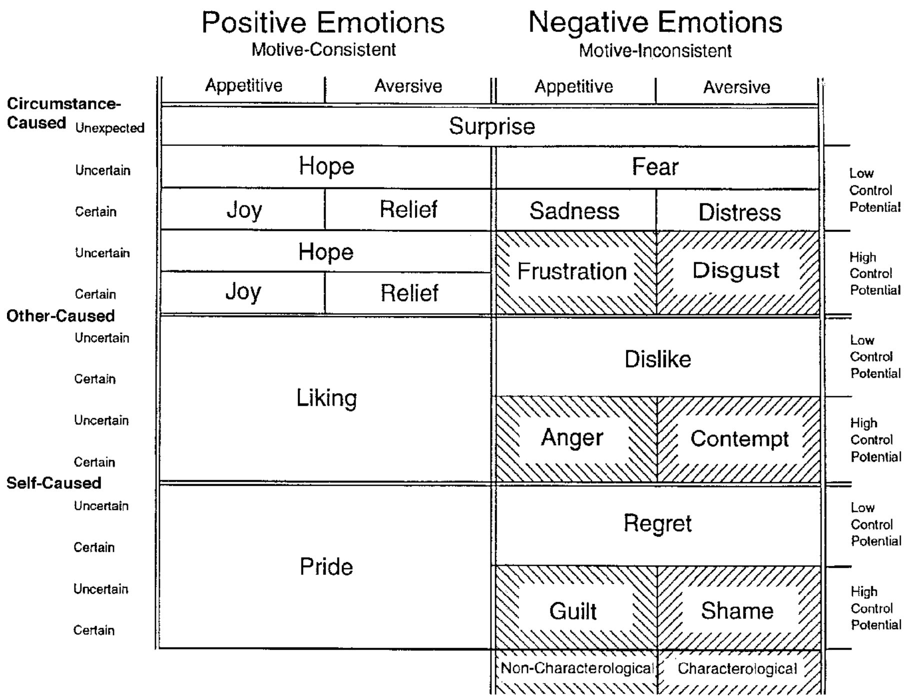


Figure 3.1: A Diagram of the Cognitive Appraisal model of emotions from [34, Figure 2]

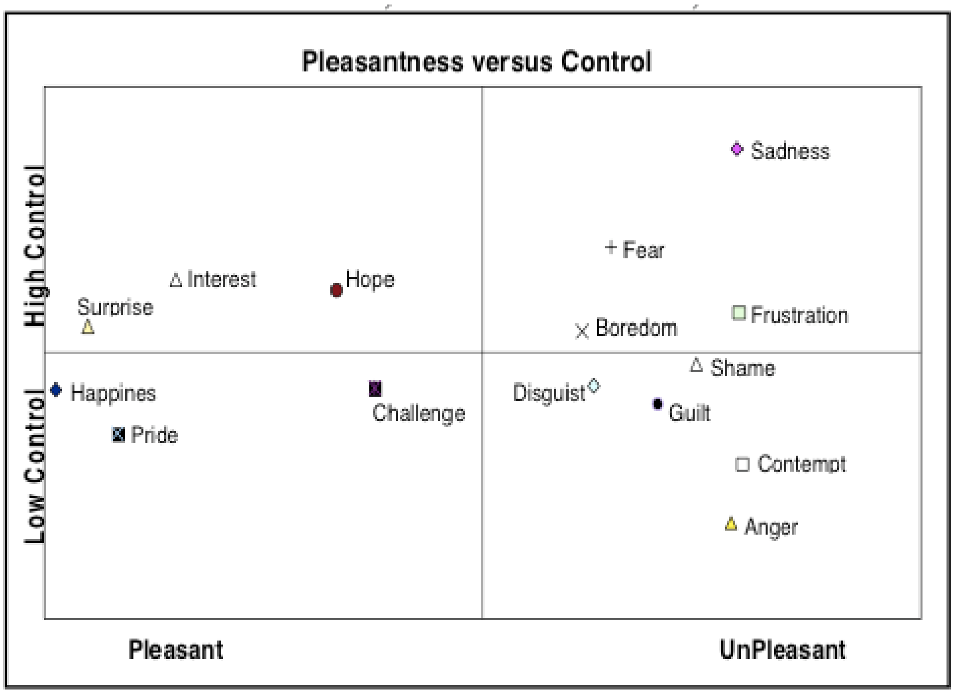


Figure 3.2: An example of emotions mapped to two of the Appraisal Dimensions from [37]: pleasantness and situational (as opposed to personal) control [14, Figure 2]

Chapter 4

The Logics of Emotion

4.1 An ontology of the relevant concepts

4.1.1 Tools

The tools used to produce this ontology are:

- OWL [4, 18]
- Protégé [18], http://protege.stanford.edu

OWL is a W3C standard and hence there is a large variety of tools available to convert ontologies from OWL into many other ontology description languages. Protégé is a platform-independent editor of taxonomies and ontologies, with excellent OWL support.

4.1.2 The Ontology

The purpose of the ontology is to enumerate the different phenomena that could be observed, the possible emotions, and the relationships between them (with possible intermediate concepts as well).

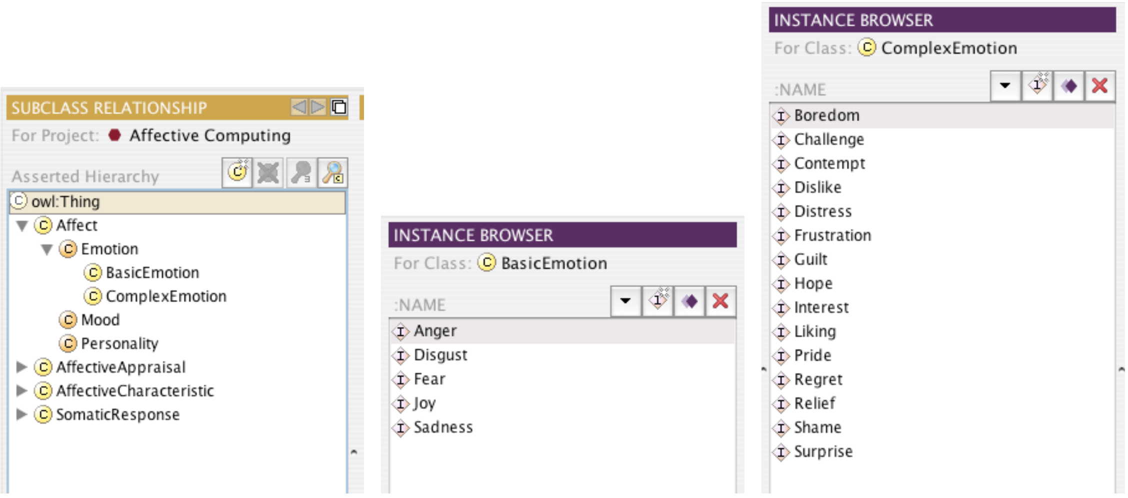
Currently the concepts, individuals and relationships described below are in the ontology. Some of the values of the relationships have been defined (values taken from the literature) but not all; there are still quite a few relationships with no defined values.

Concepts

Emotions Emotions fall into two categories, basic (`BasicEmotion`) and complex (`ComplexEmotion`). There is some doubt in the literature whether this distinction is correct or even useful, however it has sufficient support to justify including the distinction in this ontology. These two concepts are subclasses of the concept `Emotion`. Since all elements of a subclass are by definition elements of its parent class, the basic/complex distinction can be ignored if so desired. The generally accepted basic emotions are *anger*, *disgust*, *fear*, happiness (or *joy*), and *sadness* [15]. In addition to these, I have included the following complex emotions that appear in the Cognitive Appraisal literature: *boredom*, *challenge*, *contempt*, *dislike*, *distress*, *frustration*, *guilt*, *hope*, *interest*, *liking*, *pride*, *regret*, *relief*, *shame*, and *surprise*.

Affect As well as emotions, it is probably sensible to allow for longer-term concepts such as moods and personalities. These three concepts (`Emotion`, `Mood`, and `Personality`) have been generalised into a class called `Affect`; the distinction between them is made according to [23]. See figure 4.1.

Affective Appraisal A concept `AffectiveAppraisal` is created as a parent to the two cognitive appraisal concepts, `CognitiveAppraisal` and `AppraisalDimension`. (See figure 4.2.) These two concepts are further refined into their respective appraisals or dimensions; the individuals of these concepts are the possible values the appraisals or dimensions can take (in the case of the Appraisal Dimensions, the continuum has been discretised and labelled with qualitative labels such as *High*, *Low*, *VeryLow* etc; these labels form the individuals of the concepts. See figures 4.3 and 4.4.



(a) The classes of affective phenomena

(b) The instances of `BasicEmotion`

(c) The instances of `ComplexEmotion`

Figure 4.1: The Affective Phenomena part of the Ontology

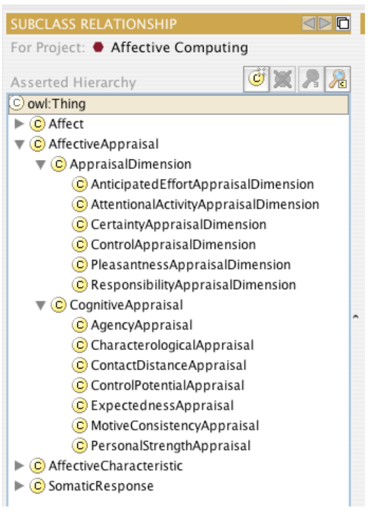
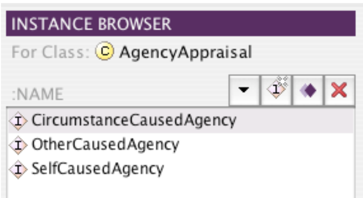
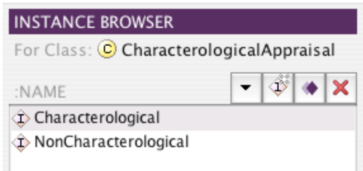


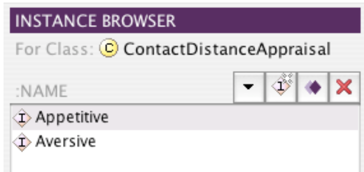
Figure 4.2: The classes of cognitive appraisals



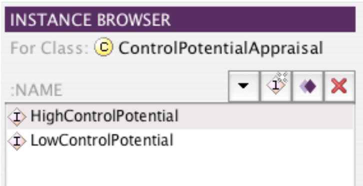
(a) The instances of `AgencyAppraisal`



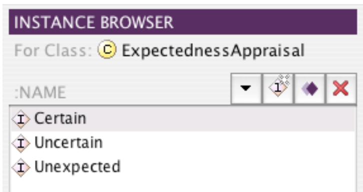
(b) The instances of `CharacterologicalAppraisal`



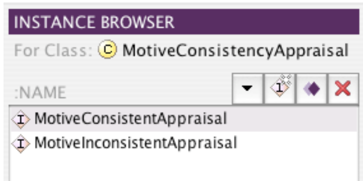
(c) The instances of `ContactDistanceAppraisal`



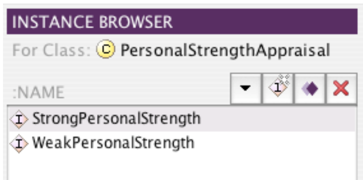
(d) The instances of `ControlPotentialAppraisal`



(e) The instances of `ExpectednessAppraisal`

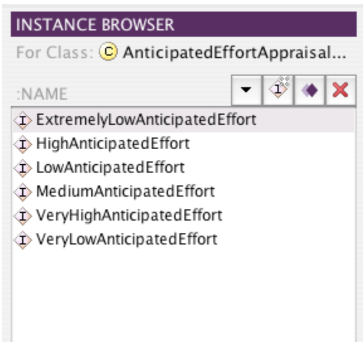


(f) The instances of `MotiveConsistencyAppraisal`

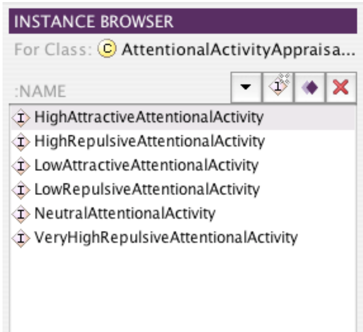


(g) The instances of `PersonalStrengthAppraisal`

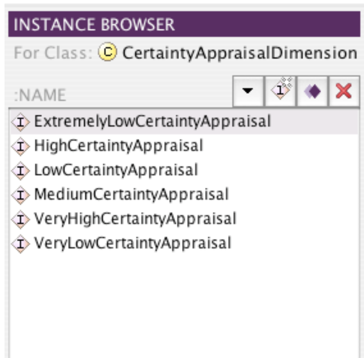
Figure 4.3: The Cognitive Appraisals part of the Ontology



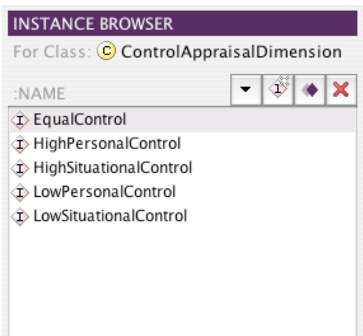
(a) The instances of `AnticipatedEffortAppraisal-Dimension`



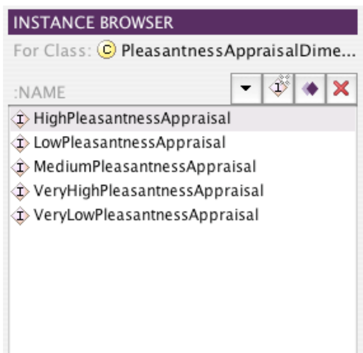
(b) The instances of `AttentionalActivity-AppraisalDimension`



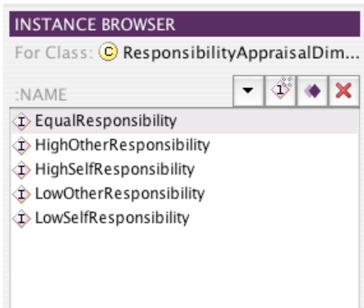
(c) The instances of `Certainty-AppraisalDimension`



(d) The instances of `Control-AppraisalDimension`



(e) The instances of `PleasantnessAppraisal-Dimension`



(f) The instances of `ResponsibilityAppraisal-Dimension`

Figure 4.4: The Appraisal Dimensions part of the Ontology

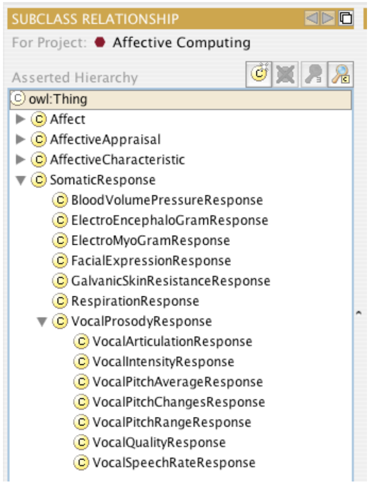


Figure 4.5: The classes of somatic response

Somatic Response A concept `SomaticResponse` is created to encompass all the possible bodily responses to emotions that can be observed by an emotion-aware agent. These responses are divided into:

- `BloodVolumePressureResponse`
- `ElectroEncephaloGramResponse`
- `ElectroMyoGramResponse`
- `FacialExpressionResponse`
- `GalvanicSkinResistanceResponse`
- `RespirationResponse`, and
- `VocalProsodyResponse`.

This last concept is further broken down into

- `VocalArticulationResponse`
- `VocalIntensityResponse`
- `VocalPitchAverageResponse`
- `VocalPitchChangesResponse`
- `VocalPitchRangeResponse`
- `VocalQualityResponse`, and
- `VocalSpeechRangeResponse`.

As for the appraisal dimensions, the individuals of these concepts are qualitative descriptions such as *High* (for the continuous concepts such as BVP), or *ResonantQuality* (for descriptive concepts such as Vocal Quality and Facial Expression). See figure 4.5.

Affective Characteristic This covers concepts that are intermediate between emotions and sensory inputs: concepts that characterise emotions and (hopefully) have a more direct relationship to sensory inputs than the emotions themselves. The concepts are

- `DurationCharacteristic`
- `FocalityCharacteristic`
- `IntensityCharacteristic`, and
- `ValenceCharacteristic`.

See figure 4.6

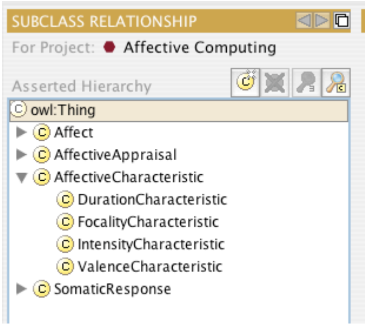


Figure 4.6: The classes of affective characteristic

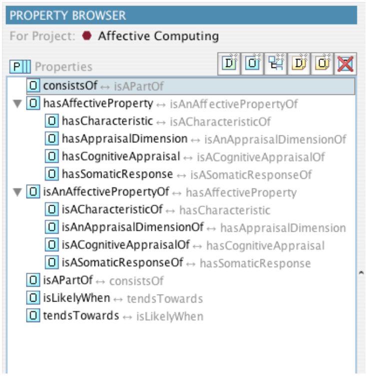


Figure 4.7: The hierarchy of relationships

Relationships

In addition to the subclass/superclass relationships, the following relationships connect different concepts in the ontology:

Properties of an affect The relationships `hasAffectiveProperty/isAnAffectivePropertyOf` relate properties of affects and the affects themselves. This property is broken down into the following four subproperties:

`hasCharacteristic/isACharacteristicOf` relate affects and affective characteristics. For instance, *DaysDuration* `isACharacteristicOf Emotion` is a condition of the concept `Emotion`.

`hasSomaticResponse/isASomaticResponseOf` relate affects and somatic responses. For instance, *HighGSRResponse* `isASomaticResponseOf` *HighIntensity*, and *Fear* `hasSomaticResponse` *PreciseArticulation*.

`hasCognitiveAppraisal/isACognitiveAppraisalof` relate affects and cognitive appraisals. For instance, *Contempt* `hasCognitiveAppraisal` *Characterological*.

`hasAppraisalDimension/isAnAppraisalDimensionOf` relate affects and appraisal dimensions.

Composition The relationships `consistsOf/isAPartOf` relate complex and basic emotions.

Tendency towards The relationships `isLikelyWhen/tendsTowards` relate shorter-term and longer-term affects (emotions, moods, personalities).

See figure 4.7.

4.2 A logical approach to reasoning about emotions

An agent using this ontology as its knowledge base should be able to reason about the emotions of other (probably human) agents it comes into contact with, as well as the situations the other agents may find themselves in and the somatic responses of the user to their emotions. It should also be able to synthesise and express emotions by finding the appropriate means of expressing an emotion from the ontology, thus producing an expression of the emotion that is believable to a human user.

Examples of agents that already behave in such a way are found in the literature, although none use an ontology as their knowledge base; rather, they tend to be closely linked to one or another emotional model. For instance, [1, 2] uses the 6-dimensional appraisal model found in [14]; [17, 22, 9, 31] use a cognitive appraisal model similar to those of Ortony, Roseman, et al; [5] uses facial and image recognition; and [7, 8, 11, 12, 24, 30, 33] use bio-feedback.

By using an ontology-based agent for emotional reasoning, it should be possible to substitute any emotional model (provided the input and output data are the same).

4.3 An agent built using this work

4.3.1 Scripting options

MPML multimodal presentation markup language [19, 6]. XML language. Designed for bi-directional communication between a presentation and the audience. Allows control of character agents, hyperlinks and voice commands, synchronisation of voice, image, gestures. Viewed in a MPML player, which uses Microsoft Agent for output.

APML affective presentation markup language [10]. Similar to MPML: XML language for dictating behaviour of an agent. Where MPML focuses on general webpage-style presentations (but enhanced via an agent and interaction), APML focuses mainly on the behaviours of a personified agent.

SCREAM scripting emotion-based minds [29]. A language in Java/Prolog that allows implementation of emotional reasoning for a "mind" backend behind a "body" frontend, scripted (for example) in MPML.

Microsoft Agent commonly used to provide the frontend to an agent. Scriptable via VBScript. Windows-only. http://www.microsoft.com/msagent/

VHML virtual human markup language. Allows specification of many different subsystems (speech, face, gesture, etc) for displaying an agent in the form of a "virtual human". http://www.vhml.org

MetaFace A system that implements VHML. http://www.metaface.computing.edu.au

4.3.2 OWL Interface

This will probably be best done with a query language; possibilities include:

OWL-QL, the OWL Query Language

This has queries such as these below, but translated into XML for querying a server:

```
Q: (isAnAffectivePropertyOf NonCharacterologicalAppraisal ?e)
   (isAnAffectivePropertyOf HighControlPotential ?e)
   (isAnAffectivePropertyOf NegativeValenceAppraisal ?e)
   (isAnAffectivePropertyOf OtherCausedAgency ?e)
   must-bind ?e
A: (isAnAffectivePropertyOf NonCharacterologicalAppraisal Anger)
   (isAnAffectivePropertyOf HighControlPotential Anger)
   (isAnAffectivePropertyOf NegativeValenceAppraisal Anger)
   (isAnAffectivePropertyOf OtherCausedAgency Anger)
```

nRQL, the New Racer Query Language

This uses the Racer reasoner. Protégé has good support for the Racer reasoner. Also has APIs for Java, C++ and CommonLisp. Queries are passed over http or tcp to a Racer server.

```
Q: (retrieve (?mother ?child) (?mother ?child has-child))
A: (((?MOTHER BETTY) (?CHILD DORIS))
    ((?MOTHER BETTY) (?CHILD EVE))
    ((?MOTHER ALICE) (?CHILD BETTY))
    ((?MOTHER ALICE) (?CHILD CHARLES)))
```

Manually

The final option is to simply use the OWL ontology as a design for implementing the same reasoning and relationships (or a subset thereof) in a logic programming language such as Prolog.

4.3.3 The Agent

Description

Due to restrictions on hardware availability and test subject availability, it was decided to forgo the biofeedback approach and restrict the agent to cognitive appraisals for its input. To demonstrate this, a simple conversational agent was produced, similar to a NPC[1] in a computer roleplaying game (for example, a shopkeeper). This has the advantage of a relitively restricted "world" for the agent to inhabit, which should make the generation of cognitive appraisals less of a challenge than it would be in the real world.

- In order to fully use the Roseman model, the agent will need certain attributes:
  - a motive, for judging valence of events
  - a sense of whether the motive is appetitive or aversive
  - a sense of agency; that is, the ability to judge who or what is responsible for an event
  - the ability to form expectations about the world and the likelihood of events
  - a sense of its own control potential
  - the ability to judge character
- In order to fully use the OCC model, the agent will need:
  - a method for determining valence (for example, the Roseman model uses consistency with a motive)
  - a sense of agency
  - the ability to estimate consequences of events
  - the ability to judge relevancy of consequences
- In order to fully use the Smith & Ellsworth model, the agent will need to be able to estimate:
  - the effort an event will require
  - the amount of attentional activity required by an event
  - the likelihood or certainty of an event
  - the extent to which an event is under the agent's control, or under the control of circumstance
  - the pleasantness of an event
  - the extent to which an event is under the agent's control, or under another agent's control

[1]NPC = non-player character

Dialogue In order to avoid problems of natural language parsing and generation, dialogue input and output takes the form of a "script tree" consisting of a set of possible player utterances, a set of possible agent responses, and a set of "successor" relations from utterance to utterance. The player is prompted to choose from a short list of possible utterances (such as in Diablo or Neverwinter Nights); the NPC selects from its possible utterances according to its underlying emotional state. The player's utterances also affect the NPC's underlying emotional state, according to the models described previously and modelled in the ontology. This means that not only should the NPC's reactions be more realistic (in that it will respond to taunts/praise/etc) but the course of the conversation will be altered depending on the affect of the NPC.

In addition, it should be possible to present a single piece of information to the NPC in multiple different ways so as to give the player a choice whether to imply a characterological judgement or high control potential etc. By giving the player choices such as "Don't beat yourself up about it; there was nothing you could have done!", the player is able to exert a deliberate influence on the player's emotions as well as the inadvertent influence of the news that he or she bears. Since the possible conversations are affected by the NPC's affect, developing a good relationship with the NPC might be the only way to get it to sell you that uber axe!

Appraisals Ideally, the NPC would have a number of different goals, both appetitive and aversive, such as to make money, to find its family, to destroy the monster that is holding the town hostage, etc. It would have a set of beliefs about the world, which it would update as contradictory information emerged; this would allow it to appraise the certainty and expectedness of news. The agent's beliefs about the world would include beliefs about the agent's control potential over parts of the world, and knowledge of certain other agents (both players and other NPCs) to allow appraisals of agency. Finally, certain pieces of information include characterological judgements of events or other agents.

However, to avoid the rather significant problem of teaching the agent to produce appraisals by comparing a knowledge base with a set of goals, etc, we simply attach appraisals to player utterances. Since the NPC operates in a limited virtual "world", this should have the same effect as adding the news to a knowledge base and then producing appraisals the long way. Since with this approach a knowledge base is not strictly required, and since keeping track of a set of beliefs in Prolog is not a terribly easy thing to do – it would be easier with modal logics, for instance – it should be possible to create the illusion that the agent keeps and revises beliefs about its world by carefully crafting the script tree. We are only demonstrating the affective reasoning and not belief revision, so this little bit of sleight-of-hand shouldn't really get customers demanding their money back. After all, we're still genuinely reasoning about things like 'the agent likes me' etc.

Biofeedback In order to use the biofeedback information given in the ontology, the agent interface will include a biofeedback simulation, where you can select value ranges for various biofeedback signals. The utterances available to the player are selected from a large set of all possible utterances based on the emotion that the interface ascribes to the user from his or her biofeedback. Choices are chosen either because they're more or less likely to be said in the player's affective state, or because events they refer to are more or less likely to have elicited the player's affective state. This utterance then changes the agent's affective state, after which the agent selects from the children of the player's utterance based on its affective state; each child is associated with one or more emotions. To avoid spending lots of time writing a script, the player's options do not depend on the agent's past responses; however in a real game setting this would be desirable.

Agent Architecture

The agent is comprised of four main modules: the dialogue input module, the biofeedback input module, the dialogue output module, and the knowledge base. The knowledge base is further broken down into four submodules: the knowledge about the Smith and Ellsworth cognitive model, the knowledge about the Roseman cognitive model, the knowledge about biofeedback, and a module to 'referee' between the submodules. This is shown diagramatically in figure 4.8.

The purpose of the various modules are as follows:

Dialogue input module Receive dialogue input from the user and affective state input from the knowledge base. Analyse the dialogue to generate a set of Roseman cognitive appraisals and Smith & Ellsworth appraisal dimension values. Send these values to the knowledge base module.

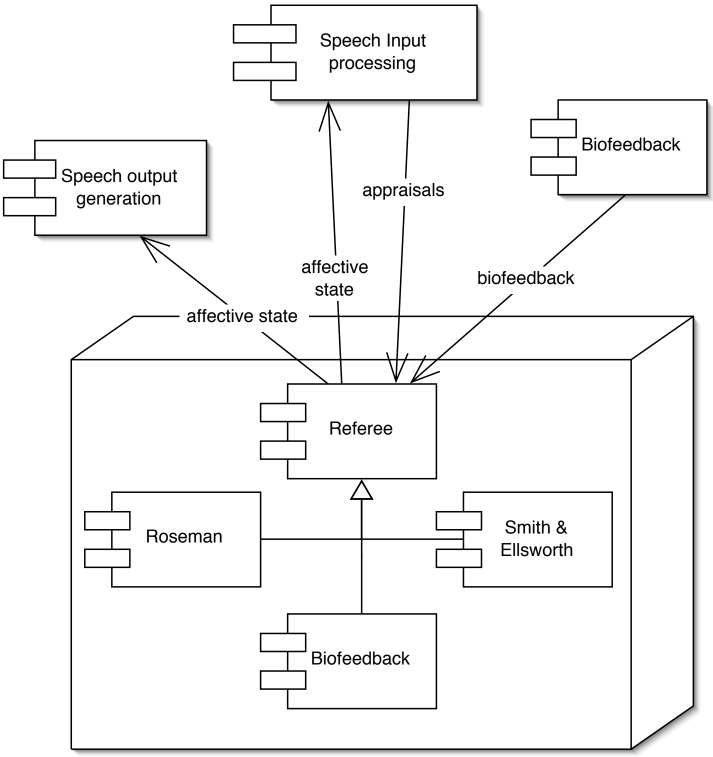


Figure 4.8: The architecture of the agent

Biofeedback input module Receive biofeedback from the user, and send that data to the knowledge base module.

Referee module Receive biofeedback and appraisal data from the biofeedback and dialogue input modules, and use the appropriate knowledge base submodules to determine an affective state (emotions and mood) from the data. Send the affective state data to the dialogue input and dialogue output modules.

Roseman knowledge module Receive Roseman cognitive appraisals from the referee and return one or more appropriate emotions to the referee.

Smith & Ellsworth knowledge module Receive Smith & Ellsworth appraisal dimension values from the referee and return one or more appropriate emotions to the referee.

Biofeedback module Receive biofeedback data from the referee and return one or more appropriate emotions to the referee.

Dialogue output module Receive affective state information fromt he knowledge base module, and use this information to produce appropriate dialogue output to the user.

Algorithms and Data Structures

Affective State The agent's affective state is stored as a 20-value vector of emotion intensities (one for each of the 20 emotions in the system). The agent's personality is stored as a 20-value vector of weights.

Eliciting an emotion via the Roseman model Using the set of appraisals attached to the player utterance, return the set of emotions consistent with those appraisals; this set may include one or more emotions, or it may be the empty set. For the purpose of the Roseman appraisals, 'consistent' means that the emotion arises either from an appraisal that is contained in the set of appraisals, or from one whose opposite is not contained in the set of appraisals.

Eliciting an emotion via the Smith & Ellsworth model Using the set of appraisals attached to the player utterance, return the set of emotions consistent with those appraisals; this set may include one or more emotions, or it may be the empty set. For the purpose of the Smith and Ellsworth appraisals, 'consistent' means that the emotion arises either from an appraisal dimension value that is contained in the set of appraisals, or from one that is not significantly different from any contained in the set of appraisals.

One problem with using the Smith & Ellsworth model like this is that it assigns every emotion a value along every appraisal dimension, even ones that may be conincidental rather than causal - for instance, Roseman hypothesises that the weak correlation between surprise and positive valence is because people are more likely to recall positively surprising experiences, rather than that they are more likely to be surprised by a positive event. The allowance of values that are not 'significantly different' should counter this problem.

Generating a mood The mood (represented as a vector as described above) is a weighted average of the prior mood, the agent's personality, and the current emotions elicited by either model. The weights are selected to make moods decay over time, and for moods that are consistent with the agent's personality to have a higher initial intensity from the same stimulus as moods that are inconsistent with the personality. The 'name' of the mood is the name of the emotion that has the highest intensity.

4.3.4 Further Work

- True conversation - NLP of typed input, and on-the-fly output generation

  In future, this system could be expanded into true conversation by prompting the user to type in a response rather than select from a list, and having the agent generate a response on-the-fly. We would then need to extract sufficient semantic information from the input to produce appraisals; and we would also need a response generation algorithm that takes the agent's emotions into account. Claude?

- Real-world knowledge
- Actual biofeedback devices for input, providing finer-grained biofeedback input
- More accurate biofeedback to affect relationships

4.4 Other applications of affective computing

4.4.1 User affect recognition in user interfaces

- Ablative reasoning to infer the cause of an emotion
- Information presented differently according to affect

4.4.2 Artificial emotions in reasoning agents

There has been some work in this area, mainly using simulated emotions to arbitrate between conflicting or competing goals. There is also a possibility that emotion-assisted search can outperform current search methods. See [1, 3, 14, 13, 16, 32]

Chapter 5

Conclusion

The end.

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