# Annotating affective neuroscience data with the Emotion Ontology

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**ABSTRACT**

The Emotion Ontology is an ontology covering all aspects of emotional and affective mental functioning. It is being developed following the principles of the OBO Foundry and Ontological Realism. This means that in compiling the ontology, we emphasize the importance of the nature of the entities in reality that the ontology is describing. One of the ways in which realism-based ontologies are being successfully used within biomedical science is in the annotation of scientific research results in publicly available databases. Such annotation enables several objectives, including searching, browsing and cross-database data integration. A key benefit conferred by realism-based ontology is that suitably annotated research results are able to be aggregated and compared in a fashion that is based on the underlying reality that the science is studying. This has the potential of increasing the power of statistical analysis and meta-analysis in data-driven science. This aspect has been fruitfully exploited in the investigation of the functions of genes in molecular biology.

Cognitive neuroscience uses functional neuroimaging to investigate the brain correlates of areas of mental functioning such as memory, planning and emotion. The use of functional neuroimaging to study affective phenomena such as the emotions is called 'affective neuroscience'. BrainMap is the largest curated database of coordinates and metadata for studies in cognitive neuroscience, including affective neuroscience (Laird *et al.*, 2005). BrainMap data is already classified and indexed using a terminology for classification, called the 'Cognitive Paradigm Ontology' (CogPO), that has been developed to facilitate searching and browsing. However, CogPO has been developed specifically for the BrainMap database, and the data are thus far not annotated to a realism-based ontology which would allow the discovery of interrelationships between research results across different databases on the basis of what the research is about. In this contribution, we describe ongoing work that aims to annotate affective neuroscience data, starting with the BrainMap database, using the Emotion Ontology. We describe our objectives and technical approach to the annotation, and mention some of the challenges.

## 1 INTRODUCTION

Research in affective science faces the need to integrate results obtained on the basis of subjective reports with those obtained through different sorts of scientific experimentation, and to compare results across disciplines. Even within each discipline and methodological paradigm, data are distributed across multiple databases and the primary literature. Efforts to harmonize the schemas and vocabularies used to describe such data have thus far not been very successful (Derrfuss and Mar, 2009).

Currently, therefore, it is impossible to automatically retrieve and reconcile data relevant to a given research question across multiple data sources. Such integration depends on the existence of (1) a shared, disambiguated and clear reference terminology for the domain (Frijda and Scherer, 2009; Scherer, 2005), and (2) a realism-based reference ontology that provides a formal description for how terms in the terminology relate to entities in reality (Smith and Ceusters, 2010). To address this requirement, we are developing the Emotion Ontology, a specialization of the Mental Functioning Ontology (MF, Hastings *et al.* (2012). MF is an overarching modular domain ontology that aims to represent all aspects of mental functioning, including mental processes such as thinking and mental qualities such as intelligence. It is based on the Basic Formal Ontology (BFO) (Grenon and Smith, 2004) and is being developed in the context of the OBO Foundry (Smith *et al.*, 2007), following the principles of Ontological Realism (Smith and Ceusters, 2010).

Ontologies are widely used for database annotation to enable searching, browsing and cross-database integration (Stevens and Lord, 2009; Smith *et al.*, 2007). A key benefit conferred by realism-based ontology is that suitably annotated research results are able to be aggregated and compared in a fashion that is based on the underlying reality that the science is studying. This has the potential of increasing the power of statistical analysis and meta-analysis in data-driven science, an aspect that has been particularly fruitful in the investigation of the functions of genes in molecular biology (Azuaje *et al.*, 2006; Hill *et al.*, 2008). We believe that the annotation of research results in affective neuroscience with the Emotion Ontology will similarly yield the potential for novel ontology-based analysis methods to be developed. This contribution describes our ongoing efforts towards realizing this objective.

The remainder of this introduction gives an overview of the Emotion Ontology and the BrainMap database for which annotations are initially being proposed. Thereafter, in our Methods section, we describe the structure of the proposed ontology annotations, present a synopsis of the experimental methods used in affective neuroscience investigations, and describe how these will be used to determine the ontology type to which results are annotated. Finally, we highlight some open issues.

### 1.1 The Emotion Ontology

The Emotion Ontology (MFO-EM) is a module that extends the Mental Functioning Ontology (MF) with representations of those types that belong to the domain of emotions and, more broadly, affective phenomena. Figure 1 illustrates the upper levels of the ontology beneath relevant MF and BFO entities. Definitions of core

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terms are reproduced in the figure, but for reasons of space the interested reader is referred to (Hastings *et al.*, 2011) for a fuller description of the ontology structure and core terms.

Each aspect of the ontology from this upper level is then developed further with specific subtypes annotated and defined beneath them. Table 1 shows representative lower levels for some of the entities in the ontology. For example, specific subtypes of 'emotion occurrent' include 'anger' and 'grief'; specific subtypes of 'subjective emotional feeling' include 'feeling in control' and 'feeling energetic'; specific subtypes of 'appraisal' include 'appraisal of dangerousness' and 'appraisal of pleasantness'.

| Emotion Occurrent | Subjective Emotional Feeling | Appraisal |
|---|---|---|
| anger | feeling alert | appraisal of causal agency |
| anxiety | feeling at ease | appraisal of causal intent |
| compassion | feeling bad | appraisal of dangerousness |
| contempt | feeling calm | appraisal of expectedness |
| despair | feeling energetic | appraisal of familiarity |
| disappointment | feeling good | appraisal of goal importance |
| disgust | feeling in control | appraisal of justice |
| embarrassment | feeling nervous | appraisal of loss |
| fear | feeling out of control | appraisal of pleasantness |
| grief | feeling restless | appraisal of predictability |
| guilt | feeling strong | appraisal of social attention |
| happiness | feeling tired | appraisal of suddenness |
| hate | feeling weak | appraisal of urgency |
| ... | ... | ... |

**Table 1.** Example expanded subtypes of upper level entities 'emotion occurrent', 'subjective emotional feeling' and 'appraisal'

Emotion types such as fear show enormous variance across instances, just as do anatomical types such as ear or jaw. Realism-based ontologies represent what is always the case. Thus, much of what is known about the different emotion types cannot be straightforwardly expressed in these ontologies, since they do not always occur in every emotion instance of that type. Not all persons experiencing fear have fearful facial expressions, not all instances of fear cause raised heart rate, and so on. To address this issue, following the strategy of the Foundational Model of Anatomy (Rosse and Mejino, 2003), we introduce 'canonical' emotion types, which represent the standard, normal or prototypical instance of a particular emotion type. As discussed in (Smith *et al.*, 2011) for the case of pain, canonical mental processes are congruent with their function, i.e. the purpose for which humans evolved to have processes of that type. Canonical fear thus involves an appraisal of dangerousness, while non-canonical fear, such as that caused by flowers in persons suffering from *anthophobia*, may obtain even in cases where the person is absolutely aware that the eliciting object is not dangerous, or that the potential danger of the eliciting object does not warrant the level of fear. 'Canonical fear' is thus a subtype of 'fear' in the ontology. The canonical emotion type can then be augmented with what is known about that emotion in terms of its components: canonical fear is associated with appraisals of dangerousness that are appropriate to the actual level of dangerousness of the situation or object elicitor, with action tendencies involving 'fight or flight' responses, with physiological responses such as feeling cold or sweating, and with characteristically fearful facial expressions. Each of these aspects of the canonical emotion confer an evolutionary advantage on the bearer, thus resulting in the development of the emotion in the way that it has developed. Note that appraisals in our ontology need not be strictly higher-order cognitive acts, that is, we allow for canonical fear also in animals such as primates and dogs (as described in Hastings *et al.* (2011), see also Robinson (2005)).

## 1.2 BrainMap

BrainMap is a curated database of functional neuroimaging research results, including functional and structural neuroimaging experiments with coordinate-based results (Laird *et al.*, 2005). Other such databases include SumsDB (Van Essen *et al.*, 2005) and the Brede database (Nielsen, 2003). These databases can be contrasted with automated approaches such as used by the NeuroSynth project (Yarkoni *et al.*, 2011), which harvests activation coordinates from the literature and associates them with the most frequent words appearing in the publication. This can lead to odd results, such as the word 'indeed' being significantly associated with a brain region. We have chosen to begin our annotation project with BrainMap as it is at present the largest and most comprehensively annotated of these functional imaging databases (Derrfuss and Mar, 2009).

The BrainMap database is curated from the primary literature. The curation involves capturing the activation coordinate results of neuroimaging experiments into the database together with the literature reference. BrainMap also provides supporting software and tools for sharing and analysing neuroimaging results. The primary objective of the database is to enable meta-analysis studies, and BrainMap is one of the projects that is at the forefront of the effort to share and redistribute neuroscientific research results as open data. The goal is to promote greater reuse and reproducability of the results of publicly funded neuroscience research.

BrainMap is supported by a classification of experimental paradigms, the Cognitive Paradigm Ontology (CogPO) (Turner and Laird, 2012). Research paradigms in cognitive neuroscience are repeatedly applied across multiple experiments, in order to render the experimental results comparable, just as assay designs are repeatedly applied in chemical biology across multiple laboratories (Lane and Nadel, 2002). CogPO includes representations of such paradigms, including the stimuli presented (e.g. sounds, images), the instructions given (e.g. count to 10, try to discern the gender of a face in a photograph), and the responses requested (e.g. press a specific button). It also includes some terminology referring to some emotion types, e.g. 'anger' and 'fear', beneath 'behavioural domain'.

Since the domain of CogPO is experiments, its authors have attempted to align its upper levels to the Ontology of Biomedical Investigations (OBI) (Brinkman *et al.*, 2010). Despite this, CogPO is currently not being developed following the principles of ontological realism used by BFO and MF. One shortcoming, from this perspective, of the CogPO classification in its current form, is that it incorporates definitions for classes that are not true for all instances. For example, 'response' is defined as 'The overt or covert behavior which is elicited from the subject in an experimental condition'. At the same time, various behaviors such as blinking and swallowing are classified as 'overt response', thus as instantiating a type of response, yet many instances of such behaviors (indeed, the majority of instances) do not take place as responses in any kind of experiment. Another shortcoming is evident in that 'behavioral experimental paradigm' is classified as a planned process (i.e. an occurrent), yet the definition given for this term classifies paradigms as descriptions: paradigms are said to "describe ...

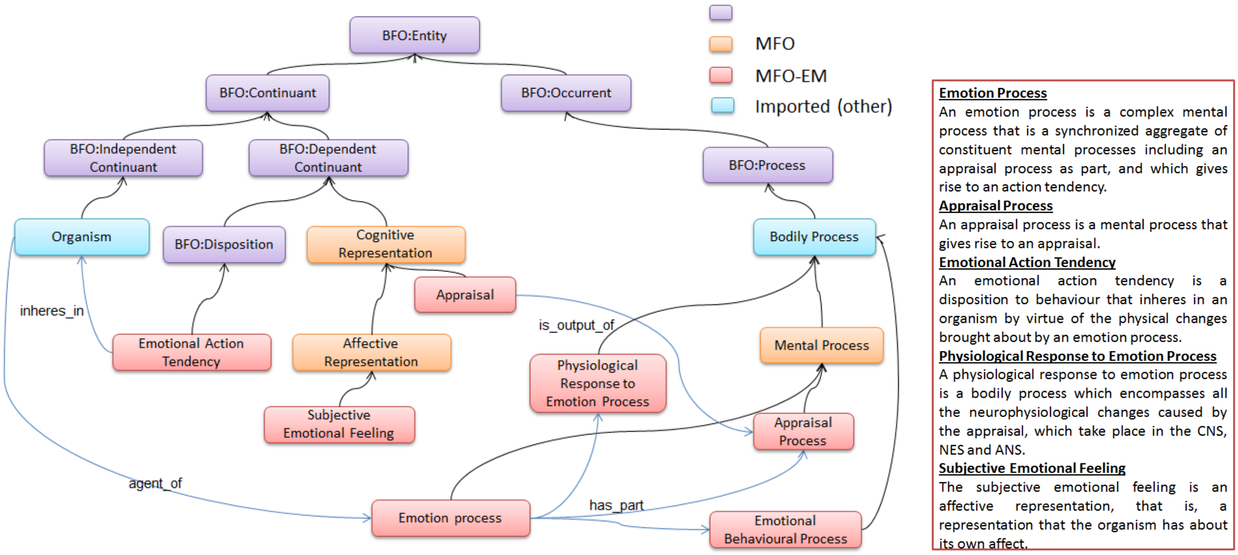


**Fig. 1.** An overview of the Emotion Ontology. Unlabelled arrows represent subsumption relations. For further detail, refer to (Hastings *et al.*, 2011).

behavioral aspects of the experiment". This indicates a confusion between information and what it is about. The focus of CogPO on experiments rather than on mental functioning, together with the mentioned shortcomings, render our effort in annotation of affective neuroscience information with the Emotion Ontology non-redundant. Furthermore, the implicit assumption behind the design of CogPO is that mental processes are not first-rate citizens in the ontology since they are unobservable. Our ontological realism admits mental processes as entities in their own right on the basis of the fact that they are first-person experienceable. The annotation of BrainMap with CogPO and with EM can, we believe, complement each other for the purposes of useful search and indexing of functional neuroimaging data.

## 2 METHODS

### 2.1 Structure of ontology annotations

Annotations of gene products (such as proteins) to the Gene Ontology types encode statements about the functions, processes and locations of those gene products, based on various types of evidence including experimental assays, scientific literature, textbook knowledge and algorithmic prediction (Hill *et al.*, 2008). The Gene Ontology annotations are curated by multiple research groups internationally, but are amassed in the central Gene Ontology Annotation (GOA) database (Camon *et al.*, 2004).

An ontology annotation consists of three components: a `<database-record-id>`, an annotation of `<evidence>` and lastly the `<ontology-entity>` that the annotation is about. Annotations are not themselves part of the ontology, but can be used in conjunction with the ontology in analysis tasks. For the current project, the `<database-record-id>` will be an identifier for an entry in the BrainMap database, which links to the coordinate data showing areas of statistically significant brain activation that have been reported in the study corresponding to that identifier. The `<evidence>` for the assertion will be the citation to the scientific literature that has been curated into that record in the database. And the `<ontology-entity>` will refer to an appropriate entity within the emotion ontology, as described further below.

### 2.2 Methods in affective neuroscience

As a preliminary survey to assess the feasibility of our approach, we sampled 14 studies from the BrainMap database that investigated affective topics such as anger and fear, spanning a date range from 1998 to 2009. In particular, we analysed the methods employed in the experimental part of the research in order to evaluate which representational unit (Smith *et al.*, 2006) in the Emotion Ontology would best correspond to what the subjects in the investigation were undergoing at the time that their brains were being imaged. For example, in one study (Morris *et al.*, 1998) the subjects were asked to determine the gender of the persons whose face was depicted, while being shown faces with various degrees of angryness and happiness and fearfulness depicted. The researchers were not interested in the gender recognition - they tricked the subjects - but rather in whether the angry/non-angry faces activate distinct brain parts. The recognition of gender in pictures of facial expressions is chosen as a task in order that the same task can be performed in the display of emotional faces as in the display of control (neutral) faces, and the resulting brain activity compared, with statistically significant differences in activity then ascribed to the difference in conditions, i.e. the emotional content of the picture rather than any other aspects. The facial expressions were generated at different intensities by computerised 'blending' of different facial expressions representing neutral, happy and fearful faces. The images used were sourced from a standard library of emotional facial expressions. One of the findings of the paper was that the amygdala was statistically significantly implicated in the processing of fearful facial expressions. Another study (Onur *et al.*, 2009) involved subjects viewing video clips with emotional content (happy, neutral, fearful) while being exposed to either a placebo or to reboxetine, a norepinephrine reuptake inhibitor. It was found that the active substance reboxetine was able to induce an amygdala response bias towards fear signals that did not appear in the subjects given the placebo.

Dominant paradigms for investigating neural correlates of emotion processing included the display of visual stimuli such as emotional faces or video clips with emotional content, the presentation of auditory stimuli with emotional content (such as screams or sounds of disgust, as used in (Phillips *et al.*, 1998)), and the use of personal scripts to evoke memories of emotional experiences in subjects. A particularly innovative paradigm used professional actors as the subjects of the investigation, hypothesising that actors would be better at evoking occurrent emotional responses within the experimental context than ordinary subjects (Pelletier *et al.*, 2003).

### 2.3 Strategy for creating annotations

Guided by the extensive annotation in BrainMap, for each combination of study design characteristics in which a different mental phenomenon is induced in the study participants, we will create an *annotation template* that specifies the association between that study design and the best Emotion Ontology term with which to perform the annotation. This will be the term that represents the mental process type that is instantiated in the patient during the experiment. In the case of one of the oldest and most widely used affective neuroscience research paradigms, subjects are shown a display of pictures containing emotional facial expressions. In this case, the mental process that the subject is undergoing is *visual perception of a static image*, and the object that is represented in the image being perceived is a human face bearing an emotional facial expression. During experimental designs in which the patient is being shown a video with emotional content, the subject is undergoing *visual perception of a video*, with the video as the relevant object. In both of these cases, the relevant ontology type is MF:*visual perception*, and these types may be specialized into subtypes for the case where the object of the perception is static (a picture) or moving (a video).

There is an important further dimension of relevance for affective neuroscience researchers which pertains to the representational content of the image or video itself. This may be angry facial expressions in some cases and fearful facial expressions in others; it may show actors expressing disgust in some videos and loving interactions in others. These differences are very important for annotation of research results in affective neuroscience, since it is known that brain activity varies with differences in the representational content of the object of perception – that is, the brain reacts differently to pictures of angry faces compared to how it reacts to pictures of fearful faces. However, the distinction is not significant in terms of the underlying mental process to the extent that the ontology would be augmented with terms such as *perception of a picture of an angry facial expression*, since that would lead to a combinatorial explosion in the number of ontology entities and ultimately an unmanageable hierarchy, a well-known problem with old-style classification systems and controlled vocabularies (Rector *et al.*, 1994).

Our strategy to accommodate annotation to these complex composite redundant entities will be to introduce a separate module extending the ontology with *defined classes* which are about 'portions of reality' in a way similar to how the representational units in a realism-based ontology denote universals (Smith and Ceusters, 2010). These defined classes will be described with full logical definitions specifying the mental process as well as the object, which in the case of these perceptual processes are information artifacts of different sorts (Ruttenburg *et al.*, 2012). It can be convenient in some application contexts to assign identifiers or names to such defined classes for engineering purposes, such as for ease of storing ontology annotations in this case, but they are not *bona fide* ontology entities in their own right. We will use the Web Ontology Language (OWL) for this effort, version 2 (Grau *et al.*, 2008), which is supported by logic-based automated reasoners that are able to compute the classification of such defined classes within the ontology proper.

The defined class labelled with *perception of a picture of an angry facial expression* would be fully logically defined, according to the conventions described in (Ceusters and Smith, 2010), as:

MF:*visual perception* `and`
has-participant `some` (
IAO:*picture* `and` is-about `some`
MFOEM:*characteristic angry facial expression* )

(Manchester syntax, Horridge and Patel-Schneider (2009).)

This composite term would be assigned as the annotation target in the annotation template for the experimental design using pictures of angry faces. Each annotation template can then be programmatically applied multiple times to records in BrainMap. The results of this process will form the EM annotations to BrainMap.

## 3 OPEN ISSUES

The design of suitable paradigms for the investigation of brain correlates of mental processes is well known to be a challenging aspect of cognitive and affective neuroscience, since the need to perform experiments within the confines of brain imaging equipment means that the full range of human experiences is not available to the experimenter. The so-called 'cognitive paradigms', or characteristic experimental designs, represent a proxy for the real research subject. Paradigms may be rather sophisticated: the use of professional actors who are trained in self-induction of emotional states in order to effect emotional performances is a case in point. Much work goes into the development and validation – across multiple experiments – of novel paradigms (Turner and Laird, 2012). But it is nevertheless not straightforward to assert in an ontology annotation that a particular study result using a paradigm for studying fear that involves perception of pictures of fearful faces represents brain activation for *canonical fear*. Indeed, the reaction to viewing a picture of an angry face may well be, appropriately, *fear* rather than anger. Our approach to annotation using templates based on the mental phenomena induced in the study participant during the experiment therefore is not sufficient to motivate an annotation for that study to the emotion type that is, in some sense, the "subject" of the investigation. The subjects may be perceiving angry faces but not experiencing anger, even though anger is the subject of the investigation as intended by the experimenter. Additional evidence may augment scientific knowledge about the mental phenomena experienced by the subjects to the extent that additional annotations are possible. For example, there is some evidence that empathetic emotional reactions may harness the same brain circuitry as the canonical emotions (Iacoboni, 2009). This, together with further evidence that, e.g., perception of pictures of angry facial expressions elicits empathetic anger as a response, would motivate creating an annotation to the ontology entity *empathetic anger*, a subtype of anger, for those experiments that involved perception of angry facial expressions. This matter is currently an open question that will be the subject of future research.

## 4 CONCLUSION

The increasing trend towards interdisciplinary research into all aspects of human functioning necessitates a new and broader focus on what the research is about, transcending the historical boundaries between disciplines. Realism-based ontology is designed specifically to facilitate this objective through categorising and describing not only scientific investigations themselves but also the entities in reality that are the subject of such investigations across different disciplines, in a way that allows research results to be unified through data annotation and automated integration. This is particularly pertinent in the case of research into complex human functioning such as the emotions, where the ordinary scientific method of objectivity and reproducibility is difficult to secure. We have described ongoing work to harness the Emotion Ontology in the annotation of research results in affective neuroscience contained in the BrainMap database. The work we have described is in a preliminary stage and much remains for future work, including creating the implementation for the annotation strategy described herein and making the results available in a database.

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