Understanding the Burden of Illness: Steps Towards an Ontology of Patient Experience

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Abstract. Burden is a key concept in healthcare research, reflecting the challenges that illness and its management impose on patients, caregivers, and healthcare systems. While burden has been the focus of considerable scientific and clinical attention, the burden concept has attracted little in the way of theoretical attention. This has led to the absence of definitional consensus, which has, in turn, complicated the effort to provide ontological support for burden-related research. The present paper seeks to address these gaps by introducing the Biomedical Burden Ontology (BBO), a formal framework designed to represent and integrate burden-related data within biomedical informatics. The BBO is grounded in the Atlassian view of burden, which conceptualises burden as an individual's obligatory participation in non-preferred processes. The ontology is implemented in the Web Ontology Language (OWL) and leverages Basic Formal Ontology (BFO), alongside existing ontologies such as the Mental Functioning Ontology (MFO) and the Emotion Ontology (MFOEM). Additionally, the BBO incorporates insights from predictive processing theories of brain function, framing burden as a disruption of an individual's capacity to fulfil 'optimistic' predictions. By providing a structured approach to representing burden, the BBO facilitates research into patient experience, supports the development of minimally disruptive medicine, and enables more effective measurement of burden in clinical and policy contexts.

Keywords: Patient Phenomenology, Symptom Burden, Treatment Burden, Illness Burden, Biomedical Ontology, Predictive Processing, Basic Formal Ontology

1. Introduction

The study of burden is a long-standing feature of the medical literature, reflecting the diverse challenges that illness and its management imposes on patients, caregivers, and healthcare systems. While the scope of early research was directed to the challenges encountered by patients and caregivers as they attempted to live with life-limiting conditions (e.g., Downes, 1942), the focus of more recent research has been directed towards the challenges associated with evolving treatment regimens, aging populations, and structural changes in the provision of healthcare (May et al., 2014). The increasing prevalence of multimorbidity presents additional complexities, as patients must navigate multiple, often conflicting, treatment regimens (Holland et al., 2024).

Unfortunately, while burden has been the focus of scientific and medical attention for the better part of a century, burden concepts have received little in the way of analytic scrutiny. This has led to a lack of theoretical understanding regarding the nature of burden. It has also complicated efforts to achieve definitional consensus in respect of burden-related terms. At present, there is no overarching theoretical account of burden—one that would accommodate multiple types of burden within a single theoretical

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framework. Nor is there any consensus on how different types of burden should be defined for the purpose of scientific research. Within a medical context, researchers have undertaken research into multiple types of burden, including symptom burden (Gapstur, 2007; Cleeland, 2007), treatment burden (Eton et al., 2022; Hounkpatin et al., 2022; May et al., 2014; Rosbach and Andersen, 2017; Sav et al., 2013; Tran et al., 2015), and side-effect burden (Gapstur, 2007). It has, however, proved surprisingly difficult to state what these burdens are and how they are related to one another.

All this has prompted calls for greater theoretical attention to burden concepts (Demain et al., 2015; Eton et al., 2022; Sav et al., 2013). In respect of treatment burden, for example, Sav et al. (2013), suggest that:

> The lack of a clear conceptual model of treatment burden has contributed to our inability to measure its impact or identify people most at risk, thereby obscuring the health professional's role in assisting people to alleviate this burden. It has generated confusion and misinterpretation that detracts from appropriate and timely management or prevention. A crucial first step in assessing treatment burden and articulating the role of health professionals is defining the concept itself and developing a framework for understanding its occurrence and impact. (Sav et al., 2013, p. 313)

Paralleling the lack of theoretical attention is the absence of any discernible ontological support for burden. As far as we can tell there are no ontologies that provide specific support for burden, and a search for the terms "treatment burden" (or "symptom burden") on the European Bioinformatics Institute (EBI) Ontology Lookup Service (OLS)[1] yields little in the way of useful results. The absence of ontological support is somewhat surprising given the scientific interest in burden, although the lack of theoretical attention and definitional consensus is undoubtedly a barrier to ontology development: If there is little agreement as to what burdens are, then it is difficult to see how the ontological effort should proceed.

We thus confront a twofold challenge: firstly, we need a better theoretical understanding of burden; secondly, we need better ontological support for burden, specifically, the types of burden that occur in a medical context (for the sake of convenience, we will refer to these as "biomedical burdens"). Our aim in the present paper is to meet this twofold challenge. Firstly, we answer the call for greater theoretical attention by proposing a novel theoretical account of burden, dubbed the Atlassian view. Secondly, we use this theoretical account as the basis for developing an ontology of biomedical burdens. This ontology—dubbed the Biomedical Burden Ontology (BBO)—formalises our conceptual understanding of burden, while also providing support for the representation of burden-related data. The BBO relies on Basic Formal Ontology (BFO) as an upper-level or foundational ontology (Arp et al., 2015; Otte et al., 2022).[2] It also leverages a number of existing ontologies, the most important of which are the Mental Functioning Ontology (MFO) and the Emotion Ontology (MFOEM) (Hastings et al., 2011b, 2012). These ontologies target the realm of mental and affective phenomena, which is important given the phenomenological orientation of the BBO. In particular, the BBO approaches burden from a subjective (or experiential) standpoint, casting burden as one aspect of the lived experience of patients. In this respect, the BBO forms part of a wider effort to develop ontologies that provide support for research into what is called patient phenomenology (Larsen et al., 2022; Larsen and Hastings, 2020).

The structure of the paper is as follows: In Section 2, we provide an overview of the proposed Atlassian view of burden. Section 3 describes the core elements of the BBO, focusing on those entities suggested by

[1] See https://www.ebi.ac.uk/ols4.

[2] The choice of BFO is motivated by its widespread adoption across a number of scientific areas. BFO is one of the most popular foundational ontologies, used by over 300 ontologies (Otte et al., 2022). It also serves as the basis for many ontologies within the Open Biological and Biomedical Ontology (OBO) Foundry, which is a large collection of open and interoperable ontologies that cover various aspects of the medical and life sciences (Smith et al., 2007).

the Atlassian view. Section 4 then expands the discussion (on both the theoretical and ontological front), connecting the BBO to recent work in cognitive neuroscience and the philosophy of mind. In Section 5 we describe how the BBO can be used to represent burden-related data, specifically the data obtained from psychometric instruments. Section 6 outlines efforts to connect the BBO to a wider suite of medical entities drawing on recent work into burden indicators. Finally, Section 7 outlines areas for future work, including potential applications of the BBO in clinical and scientific contexts.

The BBO is implemented in the Web Ontology Language (OWL). Throughout the paper, we employ specific typographical conventions to refer to ontology elements. OWL classes are rendered in bold uppercase font, **`LIKE THIS`**; OWL properties are rendered ***`likeThis`***; and OWL individuals are rendered `:LIKE THIS`. Instances of OWL properties are rendered in italic font, *`likeThis`*.

2. Understanding Burden

To develop an ontology of biomedical burdens, it helps to have a basic understanding of what we mean by the term "burden." But what are burdens, exactly? Are burdens members of a common ontological kind, such as the class of continuants, or are they members of different kinds, such as continuants and occurrents?

As a means of answering this question, it will help to consider some of the situations in which we might refer to someone as being burdened. First, consider someone who struggles to carry a heavy backpack. Such a person is, we might say, someone who is burdened by the backpack. In this case, the burden appears to be a physical object or (in BFO terms) a **`MATERIAL ENTITY`**. This suggests that at least some burdens belong to the metaphysical category of independent continuants. But not all burdens seem to be like this. Consider another case, where an individual acquires a commitment to water their neighbour's plants while they are on vacation. In this case, the burden seems more abstract than in the backpack case. It is perhaps best understood as something akin to an obligation or duty. One is, we might say, burdened by an obligation (or duty) to do something they would prefer not to do.[3] In such cases, the burden appears more like a dependent continuant than it does an independent continuant. Consider, for example, that obligations have been understood as relational qualities (Arp et al., 2015) and relational qualities belong to the metaphysical category of specifically-dependent continuants. Finally, consider a situation in which a person is burdened by a sense of guilt or regret regarding some past transgression. In this case, the burden is arguably something like an occurrent entity. This is at least how affectively-charged phenomena (like guilt) have been represented in existing ontologies, such as the MFOEM (see Hastings et al., 2011b).

All this suggests that burdens are unlikely to be subsumed under a common ontological heading. Rather than burdens being of a single ontological kind (e.g., continuants), it seems more likely that burdens exist as different kinds: Some burdens are continuant entities; others are occurrent entities.

On the other hand, there is a point of commonality in the aforementioned cases, although it is one that tends to be obscured by our linguistic practices. This relates to the way in which an individual is 'obliged' to participate in some sort of process. This is perhaps most easily understood in relation to the plant watering case. Here, the relevant individual has an obligation to engage (or participate) in a certain *process* (i.e., the watering of the plants), and the relevant burden cannot be understood in the absence

[3]The connection between burden and obligation is further evidenced by phrases such as the "burden of proof." In Latin, the word for burden is "onus," and the use of this term, at least in an Anglophone context, is suggestive of a duty or obligation. To say that the onus is on the prosecution to prove the guilt of the defendant is more or less equivalent to saying that the prosecution is obliged to prove the guilt of the defendant.

of this process. Suppose, for example, that the neighbour were to delegate the task of plant watering to someone else—someone who could be entrusted with the horticultural task. In this case, it is hard to see why the neighbour would be subject to burden, and this is so even though the original commitment (the commitment to ensure the plants are watered) remains intact. In this case, then, it is watering of the plants that is the real source of the burden, not merely the obligation to ensure that the plants are watered.

Next consider the backpack carrying case. Here, the burden appears to be the backpack. Indeed, it is not immediately clear that the burden could be anything other than the backpack. This is, at least, the entity that is picked out by our linguistic practices. Note, however, that the backpack cannot, by itself, exist as a burden. Its status as a burden derives from the fact that someone is obliged to *carry* it. In other words, the true nature of the burden is not so much the backpack; it is more the fact that someone is 'obliged' to participate in a process that also involves the backpack. From an ontological standpoint, the backpack is a material entity, as is the person. But both these entities are participants in another sort of entity, namely, a process, or, more generally, an occurrent entity.

Finally, consider the person burdened by guilt. As noted above, in existing ontologies guilt has been represented as a particular sort of process. The person burdened by guilt is then a participant in this process.[4] Once again, we arrive at the idea that someone is burdened only to the extent that they are required to participate in some sort of process. Processual participation thus appears to be a common feature of situations in which we encounter a terminological appeal to burden.

There is, however, another aspect to this processual participation that is arguably crucial to our understanding of burden. Consider that in each of the foregoing cases there is a sense in which the relevant individual is 'obliged' to participate in a process. The participation is, we might say, obligatory, in the sense that the individual has little choice as to whether or not the process occurs. Indeed, in some cases, the choice may be entirely absent. In the guilt case, for example, there may be things an individual can do to prevent themselves from feeling guilty, but in order to be burdened by guilt there must be a sense in which the guilt occurs regardless of the wishes of the individual. This is even clearer when we turn our attention to symptoms, such as pain, nausea, and fatigue. In respect of pain, for example, the proponents of BFO understand pain to be a particular sort of process,[5] so our experience of pain must entail a form of processual participation—one in which we participate in a pain process. This participation, it should be clear, is not at all like those situations where we decide to go for a walk or sit on the couch. In such cases, we have a degree of choice as to whether or not the process will be brought into existence courtesy of our own actions. Pain (and a great many other symptoms) are not like this. Pain is something that just happens to us. We might wish we were not in pain, but we cannot simply disengage from the pain. We cannot suspend our participation in the pain process by, if you like, 'walking' away from it. Indeed, if this option was available to us—if we could just suspend our participation in the pain process at any point—then it is far from clear that we would regard pain as particularly burdensome. Part of what makes the pain burdensome is the fact that we have no choice regarding our participation in the relevant process. Rather than being optional, our participation is obligatory. We are obliged to experience the pain (and thus endure the pain) despite our wishes to the contrary.

[4]This is consistent with the way guilt is modelled in the MFOEM. According to the MFOEM, guilt is represented as a type of emotion occurrent. An emotion occurrent is then defined as "a processual emotion in which a person participates over a specific time period" (Hastings et al., 2011a, p. 72).

[5]Smith et al. (2011), for example, represent pain as a bodily process. In addition, recent revisions to the Ontology for General Medical Science (OGMS) depart from the earlier characterization of symptoms as bodily features (see Scheuermann et al., 2009) by proposing a new definition of symptom. According to this revised definition, a symptom is a "process experienced by the patient, which can only be experienced by the patient, that is hypothesized to be clinically relevant."

What about the backpack and plant-watering cases? These cases, it should be clear, are not the same as those in which we are obliged to experience pain or guilt. Indeed, it is difficult to see how the appeal to obligatory participation could be made to work in situations featuring intentional actions—situations where an individual has some genuine choice or control as to what happens next. In the backpack case, for example, the burden derives from the fact that an individual is carrying a backpack. In principle, however, there is no reason why the individual (the carrier) could not suspend their participation in the carrying process (e.g., by depositing the backpack on the ground). In this sense, then, the relevant form of participation cannot be an obligate form of participation. The carrying process is, at least, not obligatory in the sense that the backpack carrier has no choice as to whether or not the carrying process will continue. When we say that a person is 'obliged' to carry the backpack, what we mean is that there is no realistic alternative as to whether or not the carrying process should continue. Perhaps, for example, the backpack contains supplies that are vital to the continued survival of the carrier. Absent the backpack and the carrier may be at risk of starvation or exposure. In this sense, then, the backpack cannot be simply abandoned by the wayside. The backpack must be borne, for the fate of the bearer is tied to the continuation of the carrying process. Strictly speaking, the carrying process is not of the obligate variety, but it is obligate in a more practical (all things considered) sense. It is what we might call *effectively obligate*.

The notion of participation being effectively obligate is one that can be applied to any situation where an individual has a genuine choice regarding action alternatives. In the plant watering case, for example, the individual does have a choice as to whether or not they water their neighbour's plants, but the costs of failing to water the plants (e.g., a deterioration of neighbourly relations) may be no less than the costs of doing what one is expected to do. A similar sort of dilemma may confront patients undergoing a course of medical treatment. In principle, there is nothing that would prevent the patient from ceasing their participation in a treatment process, but such decisions are seldom straightforward. Again, the participation in treatment processes is effectively obligate in the sense that the abandonment of a course of treatment may culminate in outcomes that are no less irksome than those associated with treatment continuation. Often the best one can do in such situations is to simply persist with the current course of action despite one's wishes to the contrary.

These insights serve as the basis of a theoretical account of burden dubbed the Atlassian view (Smart et al., 2024).[6] According to the Atlassian view, burdens are tied to situations in which an agent (or subject) (*S*) is 'obliged' to participate in a process (*P*). This reflects the point of commonality between the various cases discussed above. In the backpack case, for example, *P* is a carrying process and *S* is the individual who is obliged to participate in this process.

One virtue of the Atlassian view is that it is readily applicable to many of the types of burden discussed in the medical literature. In respect of treatment burden, for example, the burden arises as the result of an individual's participation in processes that are intended to treat an ongoing illness or disease (i.e., treatment processes). The same applies to other types of biomedical burden, such as symptom burden, side-effect burden, and disease burden (see Table 1). What is common to these types of biomedical burden, we suggest, is that a given individual (e.g., a patient) is obliged to participate in a particular sort of process (*P*). It is then the nature of *P* (i.e., *P*'s status as a symptom process) that determines the distinction between burden types. Symptom burden is thus a type of burden that occurs as a result of one's (obligatory) participation in *symptom* processes. Treatment burden is a type of burden that occurs as a result of one's (obligatory) participation in *treatment* processes. And so on.

[6]The Atlassian view is named after the Titan, Atlas, who was condemned (obliged) to hold up the heavens or sky for eternity after the Titanomachy. In Greek, the word "Atlas" means enduring. The Roman poet, Virgil, referred to Atlas as "duros" (meaning hard). Today, we know this word as "endure" (McGushin, 1964).

Table 1

Biomedical burdens according to the Atlassian view. Different types of burden are distinguished according to the nature of the process in which a human individual is obliged to participate.

Burden Type	**Process Type**	**Comments**
Disease Burden	Disease Course	The totality of all processes through which a given disease instance is realised.
Symptom Burden	Symptom Process	A process that typically occurs as part of a disease course (e.g., pain, fatigue, nausea, or anxiety).
Treatment Burden	Treatment Process	A process that is performed as part of a treatment regimen or treatment plan (e.g., the process of injecting insulin).
Side Effect Burden	Side Effect	A process that occurs as the consequence of (i.e., as the *effect* of) a treatment process.
Epistemic Burden	Epistemic Process	An epistemic (e.g., learning) process that needs to be performed to improve an individual's understanding of a disease or treatment process.
Financial Burden	Financial Process	A process that involves the transfer of monetary resources from one entity to another (e.g., paying for medication).
Travel Burden	Travel Process	A process that involves an individual travelling to a specific location (e.g., attending healthcare appointments).

Unfortunately, while the notion of obligatory participation is important, there are reasons to think it cannot, on its own, capture the full nature of burden. Consider that in the plant watering case, a person acquires a commitment to water their neighbour's plants, and they are thus obliged to engage in a particular sort of process. There is, however, no reason to assume that the mere presence of this commitment is the basis for a burdensome experience. If the plant watering process is perceived as enjoyable—as something the plant waterer *wants* to do—then it is hard to see why we should insist on the presence of burden. More generally, it seems implausible to think that one could be burdened by something that one wants to do, and this is so, even if the relevant form of participation is of the obligate variety. All living organisms are obliged to participate in certain processes, such as eating, drinking, and sleeping, but it is hard to see why these processes ought to be glossed as particularly burdensome. The spectre of burden only arises in situations where we are obliged to do things that we would prefer *not* to do. More generally, burdens are tied to situations in which we are obliged to participate in processes that we would (in some sense) prefer not to be a participant in. For the sake of convenience, let us refer to these processes as *non-preferred processes*. By combining non-preferred processes with the notion of obligate participation, we arrive at the following characterization of the Atlassian view:

> **Atlassian View of Burden:** The term burden refers to a situation in which a subject (*S*) is obliged to participate in a process (*P*) and *P* is a non-preferred process, meaning that *S* prefers that they are not a participant in *P*.[7]

This account of burden seems intuitively plausible given the kinds of burden referred to in the medical literature (see Table 1). According to the Atlassian view, a treatment burden is a type of burden in which a patient is obliged to participate in a treatment process, even though they would prefer not to be a participant in such a process. Similarly, symptom burden is a type of burden in which a patient is obliged to participate in a symptom process despite their wishes to the contrary.

[7]This formulation should not be taken to imply that obligation alone is sufficient for burden. In line with the first-person orientation of the paper, we acknowledge that there could be differences in the way that individuals appraise situations as being either burdensome or non-burdensome. What may count as burdensome for one individual may not count as burdensome for another.

The main problem with the Atlassian view is that much of the focus has now shifted to the notion of a non-preferred process. Understanding what makes a process a non-preferred process is arguably crucial to understanding why our participation in the process is appraised as burdensome. And yet the Atlassian view is silent on this issue. Consider, for example, that the vast majority of symptom processes probably qualify as non-preferred processes, and they are also processes in which our participation is of the obligate variety. Despite this, it would be a bit of a stretch to say that all symptoms qualify as burdensome. At the very least, the burdensomeness comes in degrees. A mild cough that persists for a couple of days is, to be sure, an inconvenience, but it is little more than that. A cough that persists for many months (as in the case of whooping cough) is an entirely different matter.

As things stand, then, there is more work to be done to complete our theoretical picture of burden. This is not to say we regard the Atlassian view as incorrect; it is simply to note that more needs to be said about the nature of non-preferred processes. In particular, we need an account that explicates the distinction between preferred and non-preferred processes. We will not attempt to resolve this issue here, for the issue forms the basis of the discussion in Section 4. As we will see, the discussion in Section 4 does not undermine the Atlassian view of burden, and thus there is no reason why the Atlassian view cannot be used as the starting point for ontology development. In the next section, we describe how the various elements of the Atlassian view can be represented in a BFO-conformant ontology.

3. Modelling Burden

In this section, we provide an overview of the BBO.[8] The BBO is implemented as an extension of existing ontologies, many of which are included in the OBO Foundry. Aside from BFO, the BBO incorporates entities from OGMS (Scheuermann et al., 2009), the MFO (Hastings et al., 2012), the MFOEM (Hastings et al., 2011b), and the Cognitive Process Ontology (CPO) (Limbaugh et al., 2019, 2020). The BBO also relies on entities from the Information Artifact Ontology (IAO) (Smith and Ceusters, 2015), as well as the more recent information modelling extensions provided by the Common Core Ontologies (CCO) (CUBRC, 2020; Jensen et al., 2024).

At the heart of the BBO is the **BURDEN PROCESS** class. This is represented as a subtype of **AFFECTIVE PROCESS**, which is one of the classes curated in the MFOEM. Different types of biomedical burden (e.g., **TREATMENT BURDEN** and **SYMPTOM BURDEN**) are represented as subtypes of the **BURDEN PROCESS** class (see Figure 1). The **BURDEN PROCESS** class is defined as follows:

> **BURDEN PROCESS** $=_{def.}$ An affective process that is a synchronised aggregate of constituent mental processes including an appraisal process, which produces an appraisal of burden.

As suggested by this definition, appraisal processes are one of the processes that occur as part of burden processes. Appraisal processes are important, for they are the means by which certain situations are appraised as burdensome.[9]

In the MFOEM, appraisal processes are represented by the **AFFECTIVE APPRAISAL PROCESS** class, which is a type of **MENTAL PROCESS**. Unfortunately, the semantic description of this class

[8]The latest version of the BBO is available at: https://git.soton.ac.uk/meldb/ontologies/ and https://bioportal.bioontology.org/ontologies/BBO. The logical consistency of the BBO was assessed using the HermiT reasoner. Quality checks were further conducted using ROBOT (Jackson et al., 2019) and OOPS! (Poveda-Villalón et al., 2014). Similar checks were performed for the extension ontology discussed in Section 6.

[9]The emphasis on appraisal processes also establishes a point of contact with Lazarus and Folkman's (1984) transactional theory of stress and coping. This is a feature of some strands of burden-related research (e.g., Cheng et al., 2019).

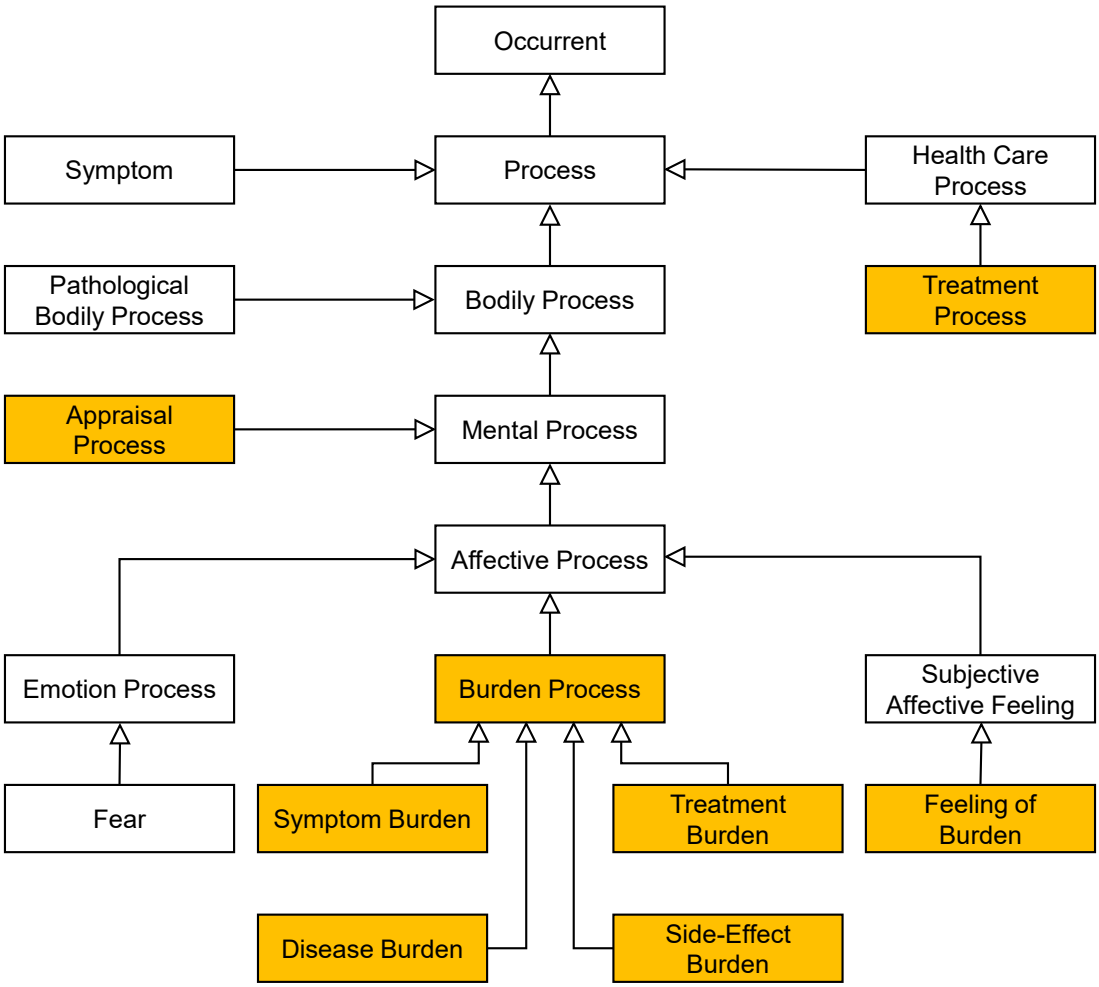


Fig. 1. Different types of biomedical burden (e.g., treatment burden) are represented as subtypes of the **BURDEN PROCESS** class. Coloured boxes indicate classes that are specific to the BBO, while non-coloured boxes indicate classes sourced from other ontologies, such as BFO, OGMS, MFO, and MFOEM.

includes a semantic axiom that ties affective appraisal processes to emotion occurrents. Specifically, **AFFECTIVE APPRAISAL PROCESS** is asserted as a subclass of both **MENTAL PROCESS** and the class of entities that occur as part of at least one **EMOTION PROCESS**. This makes the **AFFECTIVE APPRAISAL PROCESS** unsuitable for modelling burden, since our intuition is that burden is a distinct type of affective entity, one that is separate from both emotion and mood entities.[10] Given this, the BBO includes an **APPRAISAL PROCESS** class that is asserted as a direct subclass of **MENTAL PROCESS**. In the BBO, the output of an **APPRAISAL PROCESS** is an **APPRAISAL OF BURDEN**, which is asserted as a type of **APPRAISAL**, which is, in turn, a type of **COGNITIVE REPRESENTATION** (see

[10]It should, however, be noted that the current version of the BBO does not assert that **BURDEN PROCESS** is disjoint from **EMOTION PROCESS**. This allows for the possibility of reclassification as theories of affect evolve.

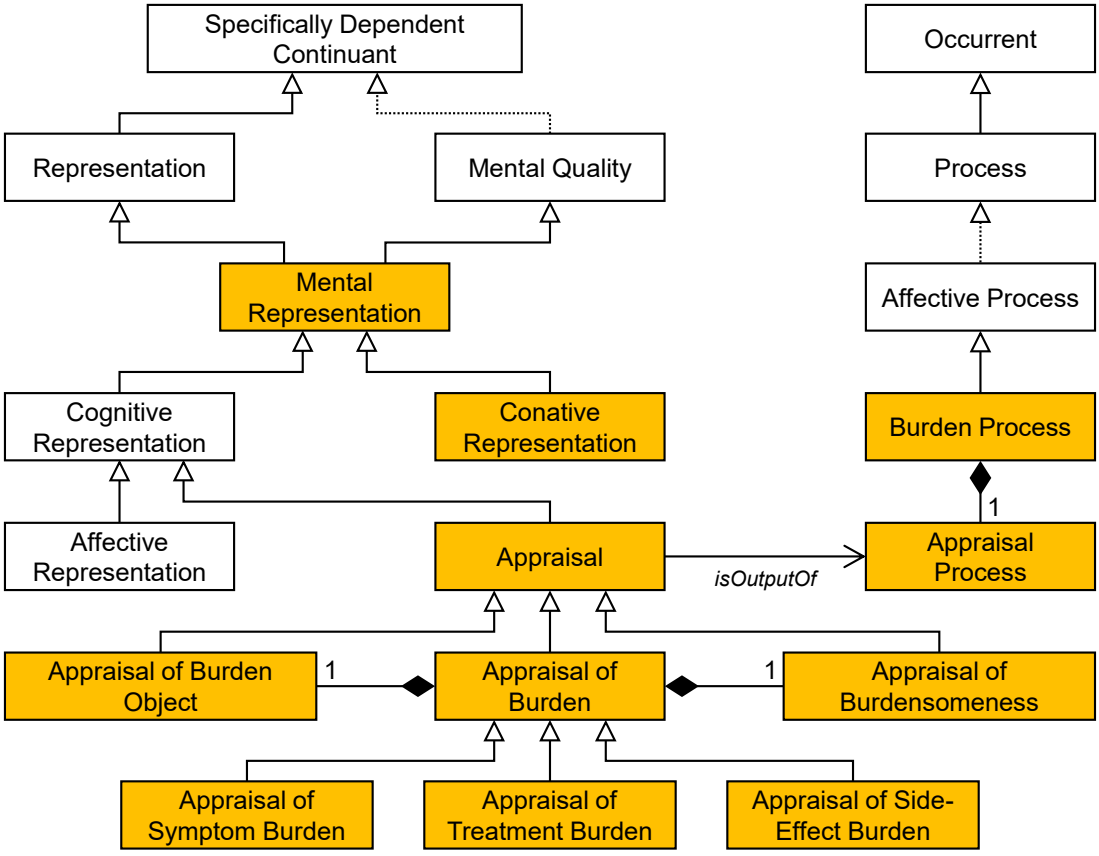


Fig. 2. Burden appraisals are represented as subtypes of the **APPRAISAL** class. Each **APPRAISAL OF BURDEN** consists of an **APPRAISAL OF BURDEN OBJECT** and an **APPRAISAL OF BURDENSOMENESS**. [Dashed lines represent indirect taxonomic relationships.]

Figure 2). An **APPRAISAL OF BURDEN** is a composite representation comprising at least two further representational entities. These are the **APPRAISAL OF BURDEN OBJECT** and the **APPRAISAL OF BURDENSOMENESS** (see Figure 2). The former entity (i.e., **APPRAISAL OF BURDEN OBJECT**) refers to what we call the 'object' of burden, which is the situation that an individual deems to be burdensome (e.g., a situation in which an individual is obliged to participate in a given treatment process). The latter entity (i.e., **APPRAISAL OF BURDENSOMENESS**) represents the reason why the object of burden is deemed to be burdensome. In the BBO, this is understood in terms of the impact or effect of one's (obligatory) participation in a process. Specifically, situations are appraised as burdensome when they disrupt an agent's capacity to bring about states-of-affairs denoted by instances of the **CONATIVE REPRESENTATION** class. Section 4 explores this idea in greater detail.

As with other types of appraisal (e.g., the appraisal of pleasantness), the **APPRAISAL OF BURDEN** is intended to represent the appraisal-related cognitions that individuals have about certain situations. This notion of 'aboutness' is what is sometimes called the *content* of a representation. In the BBO, the content of burden appraisals is given by a particular type of **INFORMATION CONTENT ENTITY** (**ICE**),

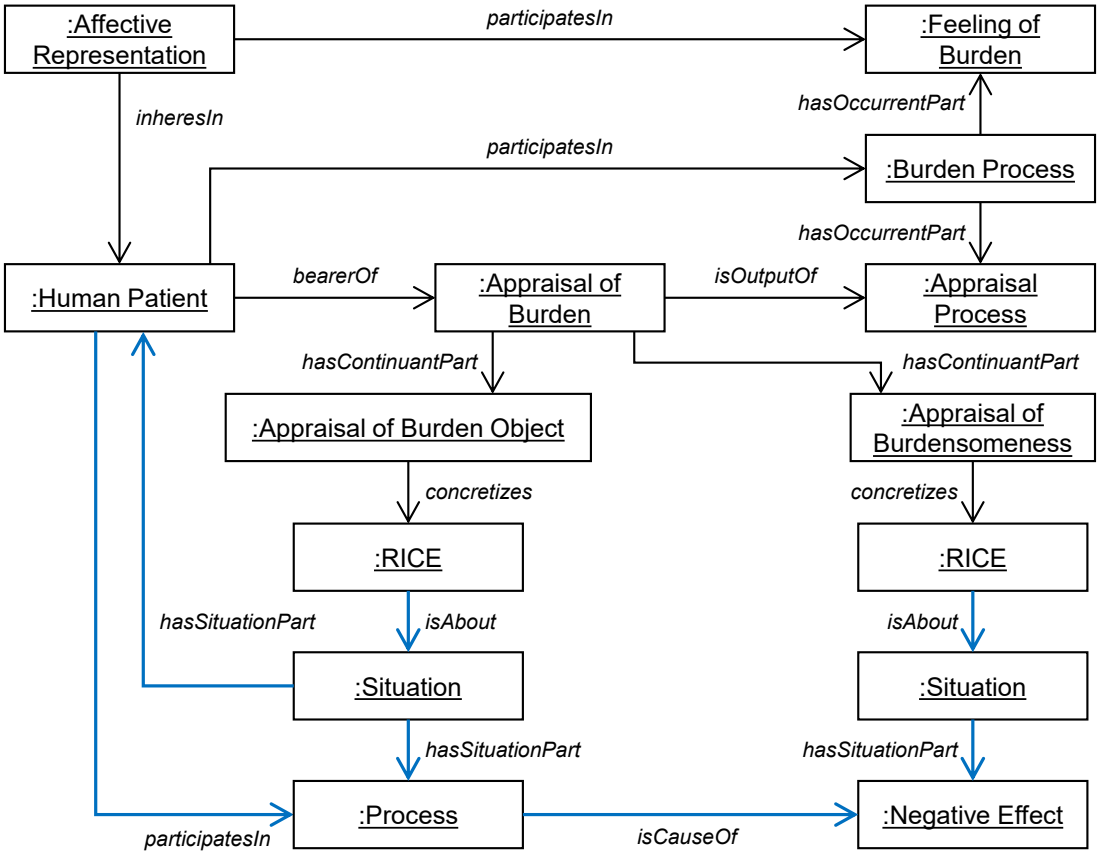
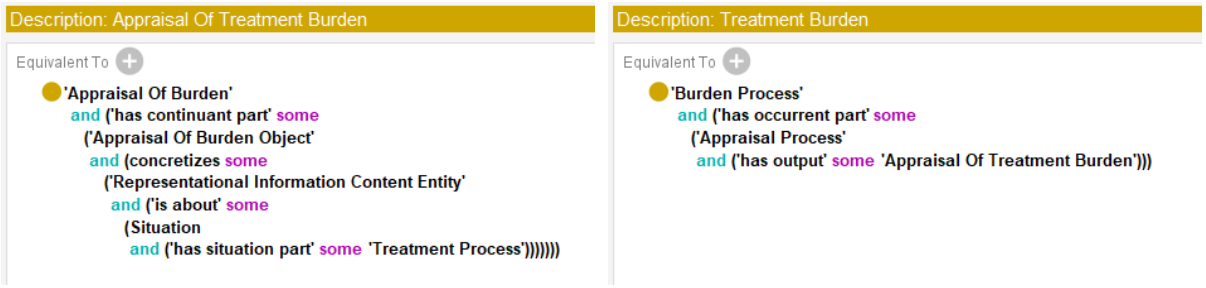


Fig. 3. Using the BBO to represent a case of treatment burden. Blue arrows indicate relations from the Modal Relation Ontology (see main text for details).

called **REPRESENTATIONAL INFORMATION CONTENT ENTITY** (**RICE**). This class is taken from the CCO suite, specifically, the Information Entity Ontology (see CUBRC, 2020). Instances of the **RICE** class are then used to connect burden appraisals to **SITUATIONS**.[11] Specifically, a **BURDEN APPRAISAL** is connected to a **RICE** via the ***concretizes*** relation, and a **RICE** is connected to a **SITUATION** via the ***isAbout*** relation.

An example of this representational scheme is depicted in Figure 3. In particular, Figure 3 shows how the BBO can be used to model a case of treatment burden. [Note that the nodal elements (or boxes) in Figure 3 correspond to OWL individuals, not OWL classes.] The subject of burden in this figure is represented by `:HUMAN PATIENT`. `:HUMAN PATIENT` is the *bearerOf* a `:PATIENT ROLE`, which establishes the status of `:HUMAN PATIENT` as a patient (not depicted in Figure 3). In addition to `:PATIENT ROLE`, `:HUMAN PATIENT` is also the *bearerOf* an `:APPRAISAL OF BURDEN`, which is pro-

[11] The **SITUATION** class functions as a container class for occurrent and continuant entities that comprise a particular "portion of reality" (see Smith and Ceusters, 2015). In short, instances of the **SITUATION** class function as container entities that aggregate occurrent and continuant entities into a single entity. The elements (or constituents) of a **SITUATION** are then specified via a custom BBO relation, namely, ***hasSituationPart***.



(a) Appraisal of Treatment Burden (b) Treatment Burden

Fig. 4. The characterization of **APPRAISAL OF TREATMENT BURDEN** and **TREATMENT BURDEN** in the Protégé ontology editor.

duced by :APPRAISAL PROCESS.[12] The :APPRAISAL OF BURDEN OBJECT *concretizes* a :RICE, which *isAbout* a :SITUATION. And within this :SITUATION, we find a :TREATMENT PROCESS that involves :HUMAN PATIENT as a participant. Figure 3 thus depicts a state-of-affairs in which a patient appraises a situation as being burdensome, and this situation is one that features the patient as a participant in a treatment process. This establishes :HUMAN PATIENT as the subject of (treatment) burden, while the object of burden is the :SITUATION that is being appraised as burdensome.[13]

Note that some of the relations in Figure 3 are depicted in blue font (e.g., *isAbout*, *hasSituationPart*, *participatesIn*, and so on). These relations are so-called modal relations, which form part of the CCO, specifically, the Modal Relation Ontology (see CUBRC, 2020). The use of these modal relations enables the BBO to refer to future states-of-affairs, as when an individual who is obliged to water their neighbour's plants appraises themselves as being burdened, even though they have not (as yet) begun to water the plants. At present, it remains unclear whether all burden appraisals are about future states-of-affairs; nevertheless, we suspect that modal relations will be a common feature of burden modelling efforts. This is not to say that present situations are irrelevant to our understanding of burden; it is merely to note that burden appraisals are often tied to things that will happen in the future (i.e., beyond the present moment).[14] The importance of this future-oriented perspective will become clearer in Section 4.

While one can explicitly denote burden processes as being of a particular type (as is the case in Figure 3), it is also possible to rely on the semantic description of classes within the BBO to support the automatic classification of burden instances via subsumption reasoning. Figure 4 shows the logical expressions that support subsumption reasoning in respect of treatment burden. In this case, an **APPRAISAL OF BURDEN** is classified as an **APPRAISAL OF TREATMENT BURDEN** based on the type of **PROCESS** that features as part of the **SITUATION** that is being appraised as burdensome (see Figure 4a). This classification then serves as the basis for classifying a (generic) **BURDEN PROCESS** as a particular instance of **TREATMENT BURDEN** (see Figure 4b).

[12] For reasons of simplicity, we have represented burden appraisals as inhering in a human individual. Readers should, however, note that the more correct characterization is one of burden appraisals (*qua* mental qualities) inhering in some part of the cognitive system of a human individual. See Limbaugh et al. (2020), for more on this.

[13] Figure 3 also shows how the subjective experience of burden (or the feeling of burden) is represented within the BBO. Here, the BBO follows the strategy adopted by the MFOEM. Specifically, the feeling of burden is represented by the **FEELING OF BURDEN** class, which specialises the MFOEM **SUBJECTIVE AFFECTIVE FEELING** class (see Figure 1).

[14] See Cassell (1982), for a similar (future-oriented) approach to suffering. Cassell (1982, p. 133) notes that: "In order for a situation to be a source of suffering it must influence the person's perception of future events."

4. Expectations and Non-Preferred Processes

According to the Atlassian view, burdens are tied to obligatory forms of participation in non-preferred processes. As we noted in Section 2, however, the Atlassian view doesn't tell us anything about the distinction between preferred and non-preferred processes, and this distinction looks to be rather crucial, for it is hard to see why one would feel particularly burdened by one's participation in a *preferred* process (i.e., a process that one was perfectly happy to be a participant in—a hobby let's say). The question, then, is what marks the distinction between a preferred and non-preferred process?

The BBO approach to this issue is rooted in a class of theories that depict the biological brain as a hierarchically organised prediction machine. Specifically, the BBO draws on recent work into predictive processing (Clark, 2013, 2016; Hohwy, 2013) and active inference (Friston et al., 2015; Parr et al., 2022) accounts of brain function. According to these accounts, the brain is organised as a hierarchy of neural layers (or neural regions). Each layer in the hierarchy strives to predict the activity of subordinate layers by issuing predictions emanating from a so-called generative model. Prediction errors are then propagated back up the hierarchy where they trigger short-term shifts in patterns of neural activity, as well as longer-term changes in synaptic connectivity. The overarching imperative of the brain is then cast as the attempt to minimize prediction error across all layers of the neural hierarchy.

A key virtue of predictive processing is its ability to provide a unified account of both perception and action. In regard to perception, the aim is to tailor predictions to match the statistical structure of incoming sensory inputs. Given that the primary source of perturbations to neural activity stems from sensory input, the minimization of prediction error requires the brain to acquire (either through evolution or learning) a generative model that embodies the causal structure of the sensorium; i.e., a model of the causal forces and factors that give rise to sensory data (Friston, 2010; Parr et al., 2022).[15] This makes sense, for the best way to predict the incoming sensory stream is to learn about the causal forces and factors that govern the statistical structure of the sensory input. Perception can then be understood as the brain's attempt to infer the deeply nested (and thus hierarchically structured) suite of causal forces and factors that best 'explain' the present sensory situation. In short, we perceive the world when higher-level predictions succeed in predicting the activity of lower-level neural regions (Clark, 2015). They do this by, in effect, recreating the sensory signal from the top-down, similar to how a generative Artificial Intelligence (AI) system generates text, images, and other digital artifacts. Prediction errors are then used to adjust the higher-level predictions so as to yield better predictions, thereby minimizing prediction error.

In the case of perception, then, initial (higher-level) predictions regarding the sensory scene are progressively adjusted in the wake of (upward-flowing) prediction errors. Suppose, however, that the flow of information were to be inverted. Thus, instead of predictions being adjusted by prediction error, suppose that the predictions were held constant and the activity of lower-level neural regions was adjusted to conform to the prediction. In this case, the activity of the lower-level regions would settle into those patterns of activity that were consistent with the prediction, which is to say they would correspond to those sensory states-of-affairs that would obtain if the prediction were to be an accurate reflection of the current sensory reality. Applying this to the realm of proprioceptive information yields a predictive processing account of action (e.g., Friston et al., 2010). To see how this works, imagine that you want to reach for a mug of coffee on your desk. According to predictive processing, this motor intention is encoded as a high-level prediction that refers to the sensory state that would obtain if you were in fact reaching for the coffee. Obviously, before you initiate the reaching movement, this prediction is false, and

[15] As characterised by Clark (2016, p. 21): "A generative model [...] aims to capture the statistical structure of some set of observed inputs by inferring a causal matrix able to give rise to that very structure."

thus prediction error ensues. If, however, the brain ignores the prediction error and persists with the initial prediction, then the higher-level prediction will come to entrain the activity of lower-level neural regions. Eventually, the very lowest layers in the hierarchy will be forced to adopt the patterns of activity that would normally be driven by proprioceptive receptors. At this point, the triggering of reflex arcs brings about the actual movement—your arm reaches, and the sensory situation is changed so as to conform to the prediction. An erstwhile incorrect prediction now becomes a veridical representation of reality. As with perception, the goal of action is to minimize prediction error. But whereas perception focuses on the adjustment of predictions to match sensory input, action is concerned with changing sensory input to match predictions.

Note that the predictive processing account of action relies on predictions that are in some sense 'optimistic'. By this we mean that the brain simply assumes that a given prediction is correct, even though (prior to the implementation of the action) the prediction is not an accurate reflection of the current sensory reality. Optimistic predictions are important, for they lie at the heart of recent efforts to accommodate motivated and goal-directed behaviour within the predictive processing framework (e.g., Clark, 2020; Pezzulo et al., 2018; Smith et al., 2022; Van de Cruys et al., 2020). To help us get to grips with this idea, consider how predictive processing might be applied to thermoregulatory processes (see Tschantz et al., 2022). According to predictive processing, the human brain harbors an in-built (i.e., evolved) prediction pertaining to normal body temperature. This prediction is 'optimistic' in the sense that the brain simply assumes (or expects) the human body to be at a given temperature (i.e., 37 °C). Now suppose that one is exposed to a heat source, such that one's body temperature begins to rise. This increase in temperature will be signalled by perceptual processes that adjust sensory predictions to coincide with the current sensory data. But such shifts need not affect the aforementioned optimistic prediction. Indeed, there are good reasons to think that such (optimistic) predictions are fixed (within certain bounds), for they denote the basic set of environmental conditions that an organism must be in if it is to survive. Perceptual processes can thus reduce one sort of prediction error (the error pertaining to the present sensory situation), but they cannot minimise the error associated with the optimistic prediction. Indeed, there is inevitable tension here: The more perception-oriented predictions succeed in minimizing one sort of error (by accurately signalling the rise in body temperature), the more they elevate another sort of prediction error (the mismatch between the present sensory situation and the optimistic encoding of body temperature). In such cases, the only way to minimise global prediction error is to implement actions that alter the sensory situation in line with the optimistic prediction. This could be via a visceromotor route, as when we perspire, or it could be via a somatomotor route, as when we open a window or remove an item of clothing.

The notion of an optimistic prediction thus helps us understand how a variety of processes (some physiological, some behavioural) might be coordinated with an overarching imperative to minimize prediction error. In the case of thermoregulation, the optimistic prediction refers to a specific set of sensory conditions that signal the presence of a target thermal state. There is, however, no reason why optimistic predictions cannot refer to other survival-relevant conditions, such as those associated with blood acidity, the absence of nociceptive input, the availability of metabolic substrates, etc. More generally, optimistic predictions serve as the basis for predictive processing accounts of conative mental states, such as states of wishing, hoping, wanting, desiring, and so forth (Clark, 2020; Smith et al., 2022). Indeed, from a predictive processing standpoint, a conative mental state is, at root, nothing more than an optimistic prediction of what the future should be. It is then the job of actions to fulfil the prediction (i.e., to transform the world so as to conform to the prediction). Much the same applies to what we

typically understand as goals or objectives. Friston (2010, p. 134), for example, suggests that "goals can be considered as prior expectations that an action is obliged to fulfil."

All this, we suggest, informs our understanding of the distinction between preferred and non-preferred processes. Preferred processes can now be understood as processes that succeed in bringing us progressively closer to our goals, which is to say, preferred processes are processes that bring about the states-of-affairs denoted by optimistic predictions. Non-preferred processes, by contrast, are processes that disrupt or undermine our capacity to bring about these predicted states-of-affairs. In essence, non-preferred processes lead to a predicted state-of-affairs in which one or more optimistic predictions are likely to go unfulfilled, thereby leading to prediction error. The sense of being burdened, we suggest, is tied to the fact that our brains predict the presence of this *future* prediction error given our participation in non-preferred processes.[16] In essence, we appraise ourselves as being burdened when we are obliged to participate in processes that reduce our chances of fulfilling optimistic predictions.

To see how this sort of account might apply to symptom burden, consider someone who is experiencing persistent fatigue as the result of chronic fatigue syndrome.[17] Quite plausibly, the fatigue (*qua* symptom) may be perceived as burdensome, and we thus have a case of symptom burden. According to the Atlassian view, what makes this symptom burdensome is not so much the idea that fatigue is, in itself, aversive or unpleasant; it is more that the persistent presence of fatigue is perceived to be interfering with one's capacity to bring about states-of-affairs that one optimistically expects oneself to be in (e.g., a situation in which one fulfils expectations pertaining to a social role). In this case, the object of burden is the situation in which one perceives oneself to be a participant in a certain sort of process (a symptom process). And yet, at the same time, one acknowledges that one's continued participation in this process is apt to be a source of future prediction error. At the very least, the continued presence of fatigue is unlikely to diminish the prediction error to which one is currently exposed.

Now consider treatment burden. In cases of treatment burden, one is 'obliged' to participate in treatment processes (i.e. processes that are intended to treat, or at least manage, a disease). What makes these processes burdensome, we suggest, is that one's participation in the processes is predicted to lead to an increase in future prediction error. This is typically because the treatment process is interfering with the performance of other processes/activities. Either that, or the treatment process is consuming resources (time, money, energy, etc.) that limit one's action-oriented paths into the future.

The BBO is, as far as we can tell, the first attempt to incorporate aspects of the predictive processing framework within a BFO-conformant ontology. It does this by building on existing ontologies, most notably, the MFO and CPO. Consider, first, the **CONATIVE REPRESENTATION** class (see Figure 5). **CONATIVE REPRESENTATIONS** are a type of **MENTAL REPRESENTATION** and thus a type of **MENTAL QUALITY**. In contrast to **COGNITIVE REPRESENTATIONS**, **CONATIVE**

[16] It is important to note that burden is tied to predictions of prediction error (in the future); it is not, as we might think, the presence of prediction error in the here-and-now. Pain, for example, is quite plausibly associated with an increase in prediction error. According to the present account, however, what makes the pain burdensome is not so much the presence of prediction error (in the present); it is more the way in which one's continued participation in a pain-related process is expected to lead to prediction error in the future.

[17] Note that the chronicity of the symptom (i.e., fatigue) is important. There is little reason to think that ephemeral or fleeting episodes of fatigue will be perceived as particularly burdensome, for there is no reason to think that these episodes are particularly injurious to our capacity to minimise future prediction error. Add to this the fact that the persistent presence of a symptom alters our view of the future. If a symptom has continued unabated for a year or more, then what reason do we (or rather our brains) have to infer that this symptom will not continue into the future?

REPRESENTATIONS have a world-to-mind direction of fit, meaning that they represent the world not as it is, but as how it 'should' be (see Searle, 2001, chap. 2).[18]

To capture the expectation- or prediction-oriented flavour of predictive processing accounts, the BBO introduces an **EXPECTATION** class, which is asserted as a subclass of the **CONATIVE REPRESENTATION** class (see Figure 5). The **EXPECTATION** class has two subclasses: **POSITIVE EXPECTATION** and **NEGATIVE EXPECTATION**. **POSITIVE EXPECTATIONS** refer to states-of-affairs an organism (optimistically) expects itself to be in (e.g., a state-of-affairs in which one's body is at a temperature of 37 °C); **NEGATIVE EXPECTATIONS**, by contrast, denote states-of-affairs that an organism (optimistically) expects itself *not* to be in (e.g., a state-of-affairs characterised by the presence of nociceptive input). As with the earlier appraisal-related classes, **EXPECTATIONS** denote or refer to worldly states-of-affairs via their links with **ICEs**. In particular, **EXPECTATIONS** ***concretize*** **OBJECTIVES**, which are a type of **DIRECTIVE INFORMATION CONTENT ENTITY** (**DICE**). **OBJECTIVES** then ***prescribe*** **SITUATIONS**, which are the states-of-affairs to which **EXPECTATIONS** refer (see Figure 5). The BBO then makes a distinction between preferred and non-preferred situations. **PREFERRED SITUATIONS** are those denoted by **POSITIVE EXPECTATIONS**, while **NON-PREFERRED SITUATIONS** are denoted by **NEGATIVE EXPECTATIONS**. In short: **POSITIVE EXPECTATIONS** refer to states-of-affairs that an organism (optimistically) expects itself to be in, while **NEGATIVE EXPECTATIONS** refer to states-of-affairs that an organism (optimistically) expects itself *not* to be in.

As shown in Figure 5, **CONATIVE REPRESENTATIONS** are associated with two additional **MENTAL QUALITIES**. These are **SUBJECTIVE LIKELIHOOD** and **SUBJECTIVE IMPORTANCE**. **SUBJECTIVE LIKELIHOOD** corresponds to the subjective (i.e., perceived) probability of an expectation being fulfilled, while **SUBJECTIVE IMPORTANCE** denotes the subjective importance of the expectation (and thus the subjective importance/significance of the corresponding situation).[19]

The earlier notion of a **NEGATIVE EFFECT** (see Figure 3) can now be understood in relation to the perceived impact of one's participation in a non-preferred process. In particular, a **NEGATIVE EFFECT** can be defined as follows:

> **NEGATIVE EFFECT** $=_{def.}$ An **EFFECT** that either 1) increases the **SUBJECTIVE LIKELIHOOD** of a **NEGATIVE EXPECTATION** or 2) decreases the **SUBJECTIVE LIKELIHOOD** of a **POSITIVE EXPECTATION**

The status of a process as a non-preferred process is then given by its causal relationship to **NEGATIVE EFFECT**. Specifically, non-preferred processes are those processes that lead to **NEGATIVE EFFECTS**. **NEGATIVE EFFECTS**, recall, are the things picked out by the **APPRAISAL OF BURDENSOMENESS** class (see Figure 3)—they are the things that appraisals of burdensomeness are about. Situations are thus appraised as burdensome when:

(1) one is obliged to participate in a process that *decreases* the likelihood of some *preferred situation* materializing, or
(2) one is obliged to participate in a process that *increases* the likelihood of some *non-preferred* situation materializing.

[18] Note that this is not the same as a representation encoding one's prediction of what the future will be. One can optimistically predict one's body to be a temperature of 37 °C while also predicting that one's temperature will rise if one spends too long in a warm environment.

[19] We assume that these two mental qualities are 'fused' with **CONATIVE REPRESENTATIONS**, similar to how confidence values are fused with cognitive representations (see Limbaugh et al., 2020).

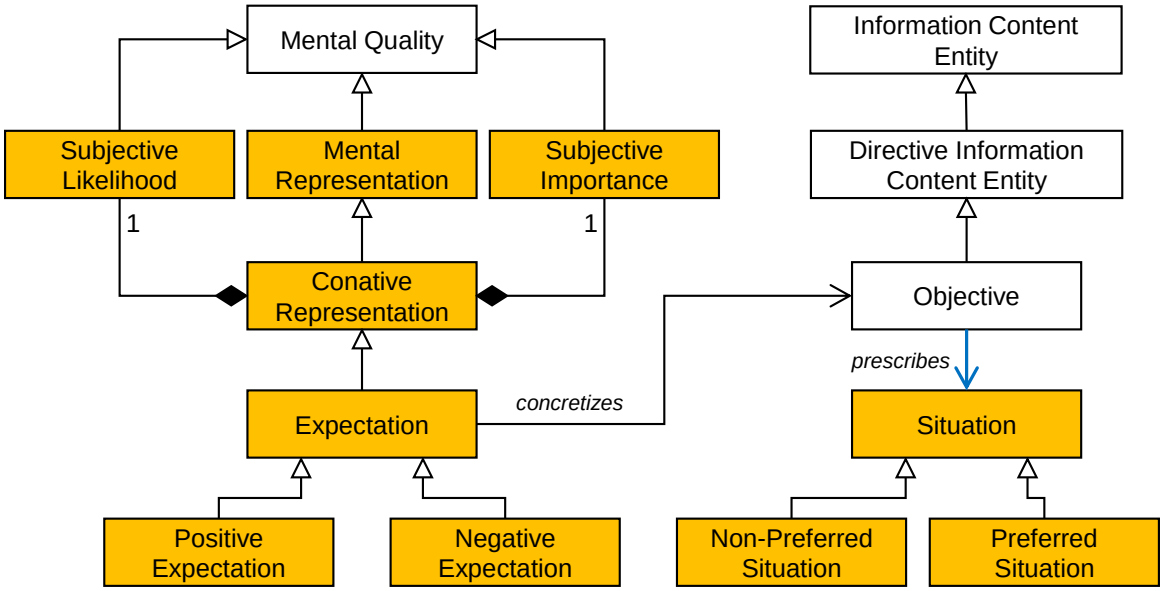


Fig. 5. Positive and negative expectations and their links to preferred/non-preferred situations. Note that the ***prescribes*** relation is rendered in blue font, since the range of the relation is an expected (i.e., future) state-of-affairs. That is to say, the range of the ***prescribes*** relation is a state-of-affairs that does not exist at the present moment.

While talk of expectations and preferred situations is seldom encountered in the burden-related literature, the general idea that biomedical burdens are tied to some sort of disruption or interference with the sort of things we would prefer to do is relatively commonplace. In respect of treatment burden, for example, Demain et al. (2015) discuss the ways in which treatment burdens are experienced as disruptions to biological, psychological, and social functioning.[20] This is perfectly compatible with the BBO approach to burden. What Demain et al. (2015) refer to as a "treatment generated disruption" is (we suggest) simply the perceived impact of an individual's participation in a treatment process relative to states-of-affairs that an individual optimistically expects themselves to be in. The distinction between biological, psychological, and social disruptions can then be understood in relation to the sorts of expectations that are negatively impacted by one's obligatory participation in a process. A biological expectation, for example, can be understood as an expectation pertaining to some physiological state-of-affairs (e.g., one's temperature being at a certain level), while a social expectation can be understood as an expectation pertaining to some social state-of-affairs (e.g., one's position within a social network or one's occupation of a social role). Treatment processes would then be appraised as burdensome to the extent that they interfered with one's capacity to fulfil these expectations. More abstractly, we can say that treatments become burdensome when they interfere with one's capacity (or, perhaps, capability[21]) to bring about future states-of-affairs that are consistent with one's expectations of what the future *ought* to be (given the sort of person one is).

In addition to the notion of disruption, attempts to define treatment burden often refer to the *impact* of treatments. Eton et al. (2017) for example offer the following definition of treatment burden:

[20] See Corns (2022), for a similar (disruption-oriented) view of suffering.

[21] See Beverley et al. (2024), for a recent ontological treatment of capabilities.

> Treatment burden refers to the personal workload of healthcare, including treatment and self-management of chronic health conditions, and the impact of this workload on patient functioning and well-being. Workload identifies the activities that patients are asked or required to do in order to care for their health (e.g., taking medications, maintaining medical appointments, monitoring health status, engaging in physical therapy). Impact refers to a patient's perception of the effect of the workload on role, social, physical, and psychological functioning. (Eton et al., 2017, p. 490)

Again, while this definition makes no reference to expectations, preferred situations, and the like, there is nothing here that is incompatible with the proposed approach to modelling burden via the BBO. The appeal to workload refers to the various healthcare tasks (e.g., treatment processes) in which an individual is obliged to participate. These, recall, are one of the entities referred to by the **APPRAISAL OF BURDEN OBJECT** class (see Section 3). The notion of impact then refers to the way one's participation in treatment processes affects one's perceived capacity to bring about the situations that one optimistically expects themselves to be in. Such impacts are represented by the **NEGATIVE EFFECT** class, and the appraisal of these impacts corresponds to the **APPRAISAL OF BURDENSOMENESS**. In short, then, the foregoing definition of treatment burden can be reduced to the idea that one is obliged to perform treatment-related tasks (i.e., participate in treatment processes) and that such tasks have some sort of negative impact (or effect) on an individual's biological, psychological, and social functioning. In the BBO, these impacts (effects) are just what we have called **NEGATIVE EFFECTS**. In this sense, then, there is no reason to regard the BBO as incompatible with recent efforts to define treatment burden.

Much the same can be said about symptom burden. Consider the following definition of symptom burden:

> Symptom burden is defined as the subjective, quantifiable prevalence, frequency, and severity of symptoms placing a physiologic burden on patients and producing multiple negative, physical, and emotional patient responses. (Gapstur, 2007, p. 673)

At the core of this definition is the idea that patients are experiencing symptoms that are "producing" some sort of (negative) response. In the BBO, symptoms are cast as processual entities, meaning that patients (*qua* independent continuants) participate in symptom processes. The notion of a negative patient 'response' is then tied to the perceived consequences of one's participation in these processes. Once again, it is the perceived impact of one's participation in symptom processes that is central to our understanding of why a given symptom is appraised as burdensome. Burdensome symptoms will thus be those that negatively impact (or effect) one's capacity to bring about the states-of-affairs that one (optimistically) expects oneself to be in.[22] In line with this idea, it is worth noting that when patients were asked to provide their own definition of symptom burden, the most common response—reported by 59% of patients—was an inability to perform usual (i.e., expected) activities (Gill et al., 2012).

While we have emphasised the potential of predictive processing to illuminate the distinction between preferred and non-preferred processes, it is important to stress that the practical use of the BBO does not require a detailed understanding of predictive processing (or active inference). Indeed, the expectation-related classes depicted in Figure 5 can be employed without committing to a predictive processing view of mental functioning—these classes simply denote situations that an individual would desire to bring about or, in the case of negative expectations, to avoid. Likewise, acceptance of the Atlassian view of

[22] Undoubtedly, there will be some variability here. What counts as burdensome to one individual may not count as burdensome to another. These differences can be understood in relation to the importance that individuals assign to particular outcomes. For some folks, a mild motor impairment of the left hand may be of little consequence. But, for a professional piano player, it is an entirely different matter.

burden does not entail a commitment to predictive processing. One could, for example, accept the idea that burdens arise from obligatory participation in non-preferred processes without accepting that predictive processing provides the best account of the nature of non-preferred processes. In addition, the use of expectation-related classes may not be required in all modelling contexts. The representation of burden measurements in Section 5, for instance, does not require their use. At the same time, a consideration of predictive processing remains important for at least two reasons. First, it provides a point of contact with emerging scientific theories of cognitive and affective phenomena, which are increasingly framed in terms of prediction and prediction-error minimization (Fernandez Velasco and Loev, 2021; Hesp et al., 2020; Miller et al., 2022; Smith et al., 2022). Second, it connects the theoretical discussion back to the clinical literature, showing how effects—specifically those relating to one's participation in a process—are relevant to clinical understandings of both symptom and treatment burden.

5. Measuring Burden

In a healthcare context, burden is typically measured using questionnaires administered to either patients or caregivers. One example of a questionnaire that has been used to measure symptom burden is the M. D. Anderson Symptom Inventory (MDASI) (Cleeland, 2007). The MDASI is mostly used with cancer patients. It aims to assess the severity of symptoms (e.g., pain, fatigue, nausea) and their impact on daily functioning (i.e. how the symptoms affect aspects of life such as work, mood, and general activity).

Regarding treatment burden, the Patient Experience with Treatment and Self-management (PETS) and Multimorbidity Treatment Burden Questionnaire (MTBQ) have both been used to assess the burden experienced by patients with chronic conditions (Sheehan et al., 2019). The PETS is a comprehensive (78-item) tool that evaluates multiple dimensions of treatment burden, including the effort required to manage medications, appointments, and lifestyle changes, as well as the emotional and financial impact of treatment (Eton et al., 2017, 2022). The MTBQ is a more concise (10-item) tool that is specifically designed for patients with multimorbid conditions (Hounkpatin et al., 2022; Matthews et al., 2023). It covers issues relating to medication number, medication adherence, collecting prescriptions, monitoring health, arranging appointments, seeing multiple health professionals, attending appointments, disease knowledge, lifestyle changes, and help from family and friends.

Relative to the scope of the present paper, our interest is not so much in the details of these measurement instruments as it is the way in which measurement outcomes (i.e., data) can be linked to terms in the BBO. In the BBO, burden measurements are represented as instances of the **MEASUREMENT INFORMATION CONTENT ENTITY** (**MICE**) class, which is one of the classes included in the CCO suite, specifically, the Information Entity Ontology. These instances are linked to other information-related entities via the relationships shown in Figure 6. Of particular importance is the way that **MICE** instances (as types of information content entities) are linked to their referents via the ***isAbout*** relationship (or one of its sub-properties). In the BBO, burden measurements are understood to be about instances of the **BURDEN PROCESS** class. Accordingly, burden measurements (instances of the **MICE** class) are linked to burden processes via the ***isAMeasurementOf*** relation, which specialises the ***isAbout*** relationship. The actual value of the measurement is then represented via the ***generiticallyDependsOn*** relation, which connects an individual burden measurement to an **INFORMATION BEARING ENTITY** (**IBE**) and thus a particular measurement value (see Figure 6).[23]

[23] In fact, as shown in Figure 6, there are two ways that literal values can be represented in the CCO. The first is via an instance of the **IBE** class; the second is via the ***isTokenizedBy*** relation. The ***isTokenizedBy*** relation provides a simplified

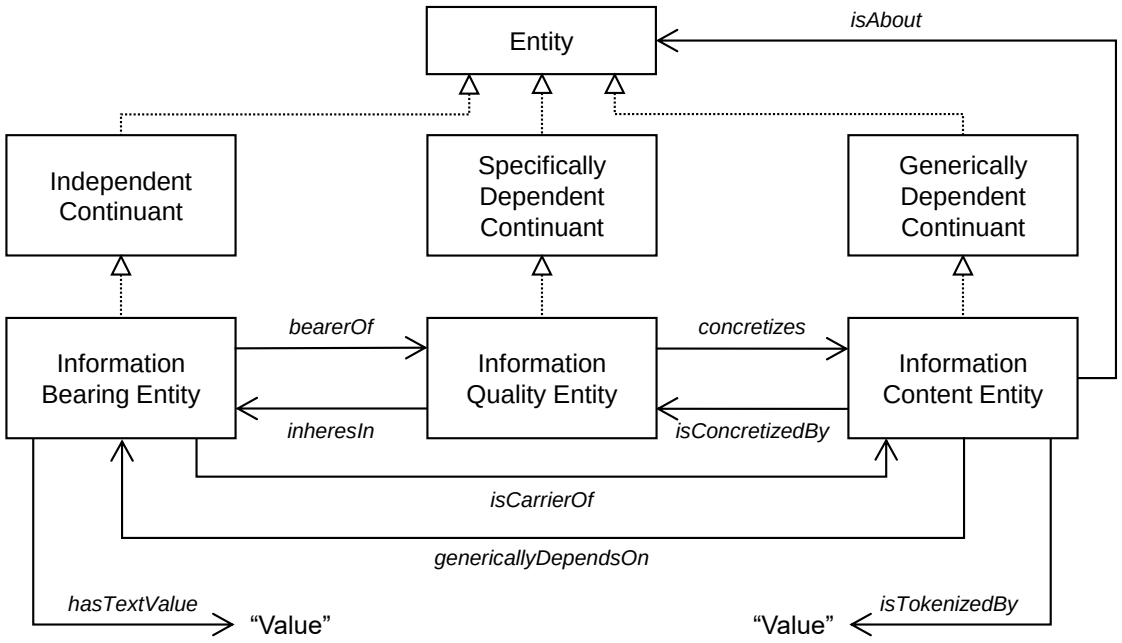


Fig. 6. Information entities in the CCO. For more information on the CCO approach to information modelling, see Jensen et al. (2024) and CUBRC (2020).

As a means of making this clearer, Figure 7 exemplifies how the total score obtained from a particular treatment burden questionnaire (in this case, the MTBQ) would be represented in the BBO. The measurement, itself, is represented by the individual `:O-MICE`, which is an instance of **`ORDINAL MEASUREMENT INFORMATION CONTENT ENTITY`**.[24] The thing (i.e., the entity) that is being measured here is `:BURDEN PROCESS`. `:O-MICE` thus establishes a link to `:BURDEN PROCESS` via the ***`isAMeasurementOf`*** relation. Note that `:O-MICE` is the output of an `:ACT OF MEASURING` that occurs on a particular date, namely, "1/1/2025". One of the participants in this process is `:HUMAN PATIENT`, which reflects the fact that a given patient participated in the measurement process that culminated in the production of a particular burden measurement. Another participant to `:ACT OF MEASURING` is `:MTBQ-IBE`, which is an instance of **`IBE`**. Here, the `:MTBQ-IBE` corresponds to a token instance of the MTBQ questionnaire whose (information) content is given by `:MTBQ-ICE`, where `:MTBQ-ICE` is an instance of an **`ICE`** representing the content of the MTBQ.

Note that this example is based around the MTBQ, but we could just have easily presented an example based around the PETS or MDASI. Crucially, the only thing that need change here is the type of **`ICE`** that specifies the content of the questionnaire that is being used. If, for example, we had opted to use the PETS in lieu of the MTBQ, then `:MTBQ-ICE` (and `:MTBQ-IBE`) would be substituted with `:PETS-ICE` (and `:PETS-IBE`). Aside from these substitutions, however, no further changes to the elements of Figure 7

approach to data representation that avoids the need to create an intermediate information carrier (i.e., **`IBE`** instance).

[24]The choice of ordinal measurements is tied to the way patient responses are scored in the MTBQ. The MTBQ consists of 10 items, with each item scored on a 5-point Likert scale ranging from 0 to 4. The total score is thus a value between 0 and 40.

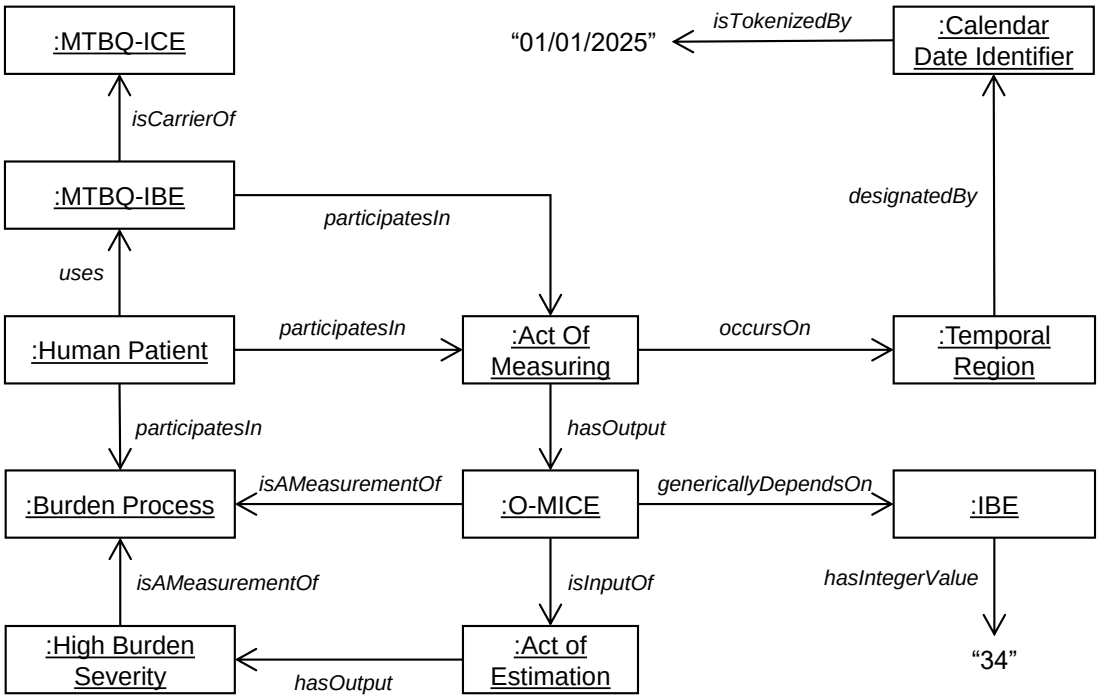


Fig. 7. Measuring treatment burden via the MTBQ.

are needed. This highlights one of the virtues of the CCO design pattern for information modelling (CUBRC, 2020): it enables multiple types of measurement-related data to be represented in a consistent (and thus predictable) manner.

There is one further feature of Figure 7 that is worth commenting on. This relates to the way in which the total score (i.e., 34) serves as the basis for a severity-related classification, denoted by the `:HIGH BURDEN SEVERITY` instance. The BBO includes classes representing three levels of burden severity, all of which are asserted as subclasses of the **`BURDEN SEVERITY`** class. The **`BURDEN SEVERITY`** class is then asserted as a subclass of **`NOMINAL MEASUREMENT INFORMATION CONTENT ENTITY`**, which, as its name suggests, is used to represent nominal measurements that group entities into particular categories according to some shared, possibly arbitrary, characteristic.

6. Burden Indicators

The BBO serves as a comprehensive and theoretically grounded framework designed to represent various types of burdens encountered within a biomedical context. The scope of the BBO is, however, limited to entities that lie at the heart of our current best theoretical understanding of burden. The BBO does not, for example, provide support for the representation of information about specific health conditions, the symptoms experienced by patients, or other forms of patient information (e.g., information about demographic or lifestyle factors). The wider application of the BBO thus relies on the integration of the BBO with other ontologies that form part of the medical ontology landscape. The Human Disease

Table 2
Burden indicator categories.

Burden Indicator Category	# SubClasses	Example Subclass
Adaptation	13	**BEREAVEMENT BURDEN INDICATOR**
Disease Accumulation	6	**AGE AT ONSET OF FIRST CONDITION BURDEN INDICATOR**
Emotion	13	**FRUSTRATION BURDEN INDICATOR**
Financial	3	**UNEMPLOYED BURDEN INDICATOR**
Health Services	9	**ADMISSION BURDEN INDICATOR**
Investigation	7	**PHYSICAL EXAMINATION BURDEN INDICATOR**
Long-Term Condition	93	**PARKINSON'S DISEASE BURDEN INDICATOR**
Medication	7	**ADHERENCE PROBLEMS BURDEN INDICATOR**
Outcome Event	1	**CARDIOVASCULAR EVENTS BURDEN INDICATOR**
Patient Characteristic	1	**BODY MASS INDEX BURDEN INDICATOR**
Symptom	25	**BREATHLESSNESS BURDEN INDICATOR**

Ontology (DOID), for example, provides a structured vocabulary for human diseases (Schriml and Mitraka, 2015), while the Symptom Ontology (SYMP) provides a taxonomy of symptoms (Schriml et al., 2022). There are also a growing number of ontologies that provide specialized support for various long-term conditions, such as cardiovascular conditions (Barton et al., 2014), Parkinson's disease (Younesi et al., 2015), and chronic kidney disease (Cole et al., 2018), all of which have been the focus of burden-related research (Fraser et al., 2015; Gallacher et al., 2018; Tan et al., 2021).

One of the challenges confronting the wider application of the BBO is thus the integration and alignment with existing medical ontologies. One example of this challenge arose during the course of our work on the MELD-B programme, a project exploring the lifecourse determinants of burdensome health conditions.[25] In particular, the challenge was to represent information indicating the possible presence of burden from patient clinical records and other health datasets. Based on a comprehensive review of the burden literature, a team of epidemiologists (at the University of Southampton, UK) identified a total of 178 burden indicators, which were grouped into 11 categories (see Table 2). To support the ontological representation of these indicators, we created an extension to the BBO, dubbed the Biomedical Burden Ontology, eXtended (BBOX).[26] [The BBOX imports the BBO via an `owl:imports` statement.] Burden indicators were then represented as subclasses of the **ICE** class. Specifically, the 11 indicator categories were represented as direct subclasses of a **BURDEN INDICATOR** class, which was itself asserted as a direct subclass of **ICE**. Individual burden indicators were then represented as subclasses of their respective indicator category.

In a general sense, burden indicators indicate the presence of burden given the existence of some 'indicator' entity, such as a particular long-term condition or a particular symptom. The indicators in the long-term condition category, for example, mostly refer to the presence of a disease, such as Parkinson's disease, while the indicators in the symptom category mostly refer to some sort of symptom, such as chronic pain, breathlessness, or a persistent (chronic) cough. The challenge is thus to establish a 'mapping' between each of the burden indicators and some other entity, such as a disease, a symptom, a treatment action, or some aspect of the patient's healthcare context. In the BBOX, this challenge is addressed by

[25]The MELD-B programme is a multidisciplinary initiative involving clinicians, computer scientists, and patient representatives. Clinical collaborators contributed expertise on burden types, indicators, and assessment methods, ensuring that ontology design was informed by relevant stakeholder perspectives.

[26]The BBOX is available at: https://git.soton.ac.uk/meldb/ontologies/.

asserting a closure axiom[27] on the ***isAbout*** relation (see Figure 8). The problem is that burden indicators refer to a complex mix of entities that are distributed across widely disparate parts of the ontological terrain. Consider that the indicators in the long-term condition category map to diseases, while those in the symptom category map to symptoms. In addition, some burden indicators refer to entities that cannot be classified as either diseases or symptoms. Treatment processes, for example, are covered by the Medical Action Ontology (MAXO) (Carmody et al., 2023), while patient-related characteristics are targeted by ontologies such as the Ontology for Modeling and Representation of Social Entities (OMRSE) (Hicks et al., 2016) and the Clinical Measurement Ontology (CMO) (Smith et al., 2013). While these ontologies could be imported into the BBOX via the `owl:imports` statement, the size of the ontologies makes this strategy unwieldy (the DOID for example contains in excess of 18,000 classes).

For this reason, we resorted to an alternative approach to the reuse of ontology content, specifically one that leverages the capabilities of the OntoFox tool (Xiang et al., 2010).[28] OntoFox enables a subset of terms—what we call an ontology fragment—to be extracted from an existing ontology in a manner that adheres to the Minimal Information to Reference an External Ontology (MIREOT) guidelines for the reuse of ontology terms (Courtot et al., 2011). In the case of the BBOX, ontology fragments were extracted with the support of a bespoke software application, called the "BBOX Concept Editor."[29] This application supported the effort to identify relevant Internationalized Resource Identifiers (IRIs) for each of the burden indicators by drawing on the search capabilities of the EBI OLS (Jupp et al., 2015). Once the IRIs were identified, the BBOX Concept Editor was used to generate a collection of OntoFox command files, each of which was programmatically posted to the OntoFox service.[30] The resulting ontology fragments were then combined into a single merged ontology using dotNetRDF,[31] an open-source .NET library for Resource Description Framework (RDF) applications. Finally, the closure axioms for all burden indicator classes were asserted using SPARQL queries executed against a GraphDB repository.[32] Specifically, the BBOX ontology was loaded into a GraphDB repository (with no inferencing). Python routines were then employed to run `INSERT DATA` queries for each of the burden indicators.[33]

As a result of this process, the majority of burden indicators (N=124) were 'mapped' to terms in existing biomedical ontologies. The remaining burden indicators (N=54) required the (manual) addition of classes to the BBOX ontology. Examples of these classes include: **AGE AT ONSET OF FIRST CONDITION**, **DRUG MONITORING PROCESS**, **HEALTHCARE COORDINATION PROCESS**, **NUMBER OF MEDICATIONS**, and **TREATMENT NON-ADHERENCE PROCESS**.

This approach enabled us to limit the number of imported classes while ensuring adequate support for the representation of burden indicators. In total, 1,400 classes were incorporated into the BBOX ontology, many sourced from existing ontologies such as DOID, SYMP, Phenotype And Trait Ontology (PATO), MAXO, and the Ontology of Adverse Events (OAE). While this approach was intended to support the representation of burden indicators, there is no reason why it cannot be adopted for other use cases. The

[27] A closure axiom is expressed using an existential restriction (∃) (stating that at least one value exists) alongside a universal restriction (∀) (stating that no values other than those specified are allowed).

[28] See Halper et al. (2023) for a recent summary of guidelines pertaining to the use of ontology content.

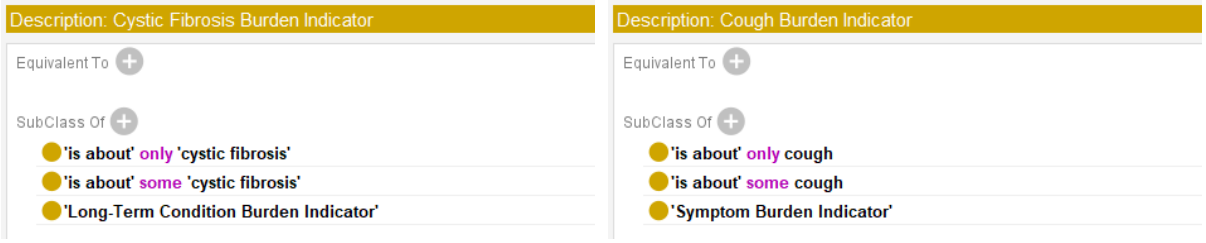
[29] The source code for this editor can be downloaded from the BBOX website: https://git.soton.ac.uk/meldb/ontologies/-/tree/main/bbox.

[30] https://ontofox.hegroup.org/service.php.

[31] See https://dotnetrdf.org/.

[32] https://graphdb.ontotext.com/.

[33] More details on this process, along with code resources, can be found on the BBOX website: https://git.soton.ac.uk/meldb/ontologies/-/tree/main/bbox.



(a) Cystic Fibrosis Burden Indicator

(b) Cough Burden Indicator

Fig. 8. Closure axioms for **CYSTIC FIBROSIS BURDEN INDICATOR** and **COUGH BURDEN INDICATOR**. Screenshots taken from the Protégé ontology editor.

present approach thus demonstrates how existing medical ontologies can be leveraged to extend the BBO for application-specific purposes.

7. Conclusion and Future Work

In recent years, the assessment and management of burden has emerged as a crucial part of patient experience and healthcare delivery. While burden has been the focus of considerable scientific attention, there has been little attempt to subject the burden concept to analytic scrutiny. This has led to a lack of theoretical understanding and the absence of univocal definitions. It is also notable that there is no ontological support for burden. This complicates efforts to integrate burden-related data within the wider biomedical informatics ecosystem.

The present paper describes an ontology of biomedical burdens (the BBO) that is rooted in an analysis of the burden concept. The ontology is based on a novel theoretical account of burden, dubbed the Atlassian view of burden. It provides support for the representation of scientific and clinical data pertaining to multiple types of burden, while adhering to the methodological and representational principles of BFO. Crucially, the BBO builds upon a number of pre-existing ontologies, many of which form part of the OBO Foundry.

As far as we are aware, the BBO is the first attempt to provide an ontological characterization of burden. It also marks the first attempt to accommodate aspects of the predictive processing/active inference framework within a BFO-conformant ontology. This is likely to be important given the recent interest in applying predictive processing to a range of biomedical topics, including biopsychosocial approaches to disease (Smith et al., 2019), treatment adherence (Smith et al., 2021), subjective well-being (Miller et al., 2022; Smith et al., 2022), neuropsychiatric illness (Fabry, 2020; Friston et al., 2014), stress (Arnaldo et al., 2022; Hartwig et al., 2022; Peters et al., 2017), and symptom perception (Kube et al., 2020; Maisto et al., 2021; Van den Bergh et al., 2017). Also important is the recent attempt to apply predictive processing to our understanding of conscious experience (Clark, 2019, 2023; Nave et al., 2022; Ramstead et al., 2023). This dovetails with the phenomenological orientation of the present work. Indeed, we suggest that the BBO provides a springboard for work that seeks to leverage predictive processing for the purpose of developing formal ontologies of human experience, including those tailored for the more specific realm of patient phenomenology.

There are, of course, multiple areas for future work (see Table 3). On the theoretical front, it would help to have a better understanding of the relationship between burden and suffering, especially given the similarities between the Atlassian view of burden and disruption-oriented accounts of mental suffering

Table 3

Summary of future work areas.

Future Work Area	Description
Burden and Suffering	There are reasons to think that burden and suffering are linked at both the conceptual and etymological levels. But what is the nature of the relationship between burden and suffering? Is burden merely an attenuated form of suffering or are the differences more profound?
Objective vs. Subjective Views	The present paper adopts a subjective approach to burden, assuming that biomedical burdens correspond to aspects of patient experience. Our linguistic practices are, however, suggestive of a more objective view of burden. How does this subjective/objective distinction relate to existing debates regarding the (subjective/objective) nature of suffering (see Edwards, 2003)?
Burden Terminology and Medical Ethics	There are anecdotal reports of patients expressing discomfort with the use of burden terminology (see Eton et al., 2017; Ridgeway et al., 2014). Does this mandate a terminological retreat from burden? What are the ethical issues (both pro and con) surrounding the use of burden-related terms to characterise patient experience?
Treatment Entities	Additional work is required to support the ontological characterisation of treatment processes and associated entities (e.g., treatment objectives and treatment plans). Existing ontologies (e.g., the MAXO) provide some support for treatment processes, but the availability of a more refined taxonomy would benefit the ontological characterisation of treatment burden.
Moderating Factors	In addition to treatment entities, ontological characterisations of health literacy, demographic factors, educational background, and early life experiences will help to support scientific efforts to understand the forces and factors that moderate experiences of burden.
Clinical Application and Decision Support	The integration of the BBO into clinical decision support systems promises to improve semantic interoperability among healthcare applications, enhance personalised medicine, and optimise treatment strategies to reduce the burden experienced by both patients and caregivers.

(Corns, 2022; McClelland, 2020). It would also help have a better understanding of the contrast between subjective and objective approaches to burden. In the present paper, we have adopted a subjective approach to burden; viewing burden as an aspect of patient phenomenology (and, more generally, an aspect of human lived experience). Some uses of the term "burden," however, are suggestive of a more objective (or at least non-experiential) view of burden. This is apparent when we (e.g.) talk of trees being burdened by fruit or nation states being burdened by healthcare costs. Interestingly, the distinction between subjective and objective approaches to burden marks a further point of contact with the literature on suffering (see Edwards, 2003).

On the more practical front, the wider application of the BBO will undoubtedly require the development and integration of additional ontologies. Of particular importance is the need for a more refined taxonomy of treatment processes (or perhaps better, healthcare actions). Also important are ontologies that provide support for factors that are deemed to moderate the experience of burden (e.g., Tran et al., 2015). This includes factors such as health literacy, self-esteem, and educational background. Future work will also benefit from deeper engagement with clinical end-users to validate the ontology in applied settings, particularly with respect to the usability and adequacy of the burden indicators represented in the BBOX. Finally, future work should explore the integration of the BBO into computational tools that provide opportunities for both the analysis and mitigation of burden. Progress in these areas will help to support the more general effort to align healthcare interventions with the principles of minimally disruptive medicine and patient-centred care.

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