SEMANTIC WEB-BASED REPRESENTATION OF COGNITIVE BEHAVIOURAL THERAPY: APPLYING ONTOLOGICAL KNOWLEDGE MODELLING AND REASONING TO GENERATE PERSONALIZED BEHAVIOURAL PLANS FOR THE TREATMENT OF MILD DEPRESSION

by

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This thesis is dedicated to my sun and my moon, my grandparents, my Ammuma and my Appupa. I love you. I miss you.

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Abstract

Cognitive Behavioural Therapy (CBT) is an action-oriented psychotherapy that uses a combination of cognitive and behavioural techniques—i.e. guided discovery and behavioural activation—as a psychosocial treatment for depression. CBT intervention is considered complex since it includes multiple components that need to be personalized to the patient's beliefs, barriers, lifestyle and expected outcomes. CBT has been computerized to assist therapists develop CBT action plans for mild to moderate depression. However, most computerized CBT initiatives do not include a patient-centered and evidence-based CBT personalization component.

In this thesis, we take a knowledge management approach to semantically model the core CBT concepts and their relationships in terms of an ontological CBT knowledge model that can be reasoned over, with patient data, to generate personalized action plans for treating mild depression. We synthesized and computerized CBT knowledge from multiple sources in terms of the CBT ontology that was validated by a domain expert. We have developed an OWL based CBT ontology and a number of logic-based action plan personalization rules using Semantic Web Rule Language (SWRL) . Using the CBT ontology and logical rules, we operationalized the guided discovery process such that a therapist working with a patient can systematically identify the negative thought processes that lead to depression, and can then apply behavioural activation principles to recommend personalized CBT action plans to alleviate mild depression. We developed a two-tiered personalized CBT action planning approach using logical reasoning to personalize a CBT action plan, whereby at the first level we infer the relevant patient profile attributes and at the second level we infer the most effective action plans for a specific patient. We performed a formative evaluation of the CBT ontology in terms of its completeness, consistency, and conciseness. Case-studies are presented to demonstrate the working of our personalized CBT action planning for treating mild depression.

List of Abbreviations and Symbols Used

APA American Psychological Association

BA Behavioural Activation

BDI-II Beck Depression Inventory-II

CBT Cognitive Behavioural Therapy

CCBT Computerized CBT

DL Description Logic

DSM V Diagnostic and Statistical Manual of Mental Disorders

eCBT Electronic CBT

FBA Functional Behavioural Assessment

GBD Global Burden of Disease

GD Guided Discovery

iCBT	Internet CBT
IPT	Interpersonal Therapy
KBS	Knowledge-Based System
KE	Knowledge Engineering
MDD	Major Depressive Disorder
mHealth	mobile health
MOUMT	Multi-layered Ontological Ubiquitous Monitoring and Treatment framework
OIL	Ontology Interchange Language
OWL	Web Ontology Language
PDT	Psychodynamic Therapy
RDF	Resource Description Framework
RDFS	RDF Schema

SHOE	Simple HTML Ontology Extension
SWRL	Semantic Web Rule Language
TKB	Therapy Knowledge Base
W3C	World Wide Web consortium
WHO	World Health Organization
XOL	XML-based Ontology exchange Language

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Chapter 1

Introduction

The World Health Organization (WHO) states that individuals develop depression as a result of social, psychological and biological factors [165]. As reported by the National Institute of Mental Health in May 2018, depression is a mood disorder that goes beyond normal sadness or grief. It is a clinical syndrome with a group of symptoms associated with it [122]. Symptoms of depression include feelings of worthlessness, hopelessness, helplessness, guilt, lack of interest in daily activities, irritability, loss of energy, loss of appetite, sleep problems, self-loathing, thoughts of suicide [122]. It is considered a leading cause of disability worldwide with more than 300 million people of all ages affected by it. It usually begins in adolescence and may progress into adulthood if left untreated [74].

The Diagnostic and Statistical Manual of Mental Disorders (DSM V) [3] classifies depression into following types: Major Depressive Disorder (MDD) , Dysthymia, Bipolar Disorder, Substance-Induced Mood Disorder, and other psychiatric conditions in which depression can be a primary symptom. MDD is considered to be the most common and prevalent mental disorder [173]. MDD is further classified as: mild, moderate and severe depression. Mild Depression is noticeable, yet it can be hard to diagnose unless individuals seek therapy [63]. As stated by [82] and [104] it has been observed that people hesitate to visit therapists for treating their depressive symptoms. When left alone, mild depression can progress to more severe forms [63].

Cognitive Behavioural Therapy (CBT) is one of the most frequently used psychosocial treatment for depression [173]. It aims at enabling patients to cope with problems in cognition (such as belief and thought) and behaviour [173]. CBT was found to be effective in the prevention of a new depressive episode for MDD patients in remission at both short and long term follow up [173].

The Global Burden of Disease (GBD) Study was conducted in 2018 for the period of 1990 to 2017 of data on premature death and disability from over 350 diseases and injuries in 195 countries by age and sex. It allowed for comparisons to be made over time, across age groups, and among populations [75, 76]. The study found that depressive disorders were the third-leading cause of disability globally in 2017, thereby rising by one spot from the fourth-leading cause in 1990 [43]. These findings substantiate the global need for increased mental health resources [81].

WHO stated that between 76% and 85% of people in low and middle-income countries receive no treatment for their mental disorder [165]. As stated in [65], fewer than 20% of people seeking help for their depressive symptoms receive CBT. They [65] proposed the development of internet based CBT and mobile phone applications as alternatives to clinical practice.

1.1 Problem Statement

CBT uses two main techniques, the cognitive technique involves the Guided Discovery (GD) concept and the behavioural technique involves the Behavioural Activation (BA) concept. GD is used to encourage patients to target dysfunctional thinking, while BA is to engage in activities that increase one's mastery [37]. Computerized CBT (CCBT) has shown a predominantly positive effect on the self-management of mild to moderate depression, yet there is a challenge in terms of developing a clear operationalization of well-defined CBT concepts [136]. Some of the existing CCBT solutions have been deemed ineffective due to the inappropriate application of the GD and BA concepts [74]. CBT interventions are considered complex since it includes multiple components and can be delivered in different ways [101].

CCBT solutions should focus on the theoretical knowledge of CBT so as to maintain the clinical correctness and integrity of the therapy while operationalizing it [74]. In order to address this gap of a lack of sound theoretical proof of CBT in CCBT solutions, we adopted a knowledge-modelling approach by constructing an OWL ontology that can be evaluated for logical correctness [153].

Mental health care must allow for patients to identify their perceived barriers in treatment, which could be in terms of either psychological aspects such as stigma, logistical aspect such as availability of services or illness-related such as depression severity [164]. Current CCBT solutions face an issue of patients withdrawing from support due to a lack of focus on identifying barriers to treatment [91].

1.2 Research Motivation and Objectives

As stated by Huguet et al. [74] constructing a self-management tool for depression as a means for individuals to overcome a lack of resources associated with mental health must focus on adhering to the basic principles of CBT interventions [74].

On a global scale, depression affects roughly 300 million people and has an impact on personal, social and economic morbidity, loss of functioning and productivity, and an increased usage of health-care services [101]. WHO identifies depression as becoming the leading cause of disease burden by the year 2030 [96]. Hence, developing accessible and convenient ways to overcome depression must be made a priority for people the world over [32].

The primary objective of this thesis is to develop a knowledge model based on the core CBT concepts of Guided Discovery (GD) and Behavioural Activation (BA).

GD is a key cognitive activity focused on pragmatic thinking, which asks the patient to provide evidence that supports/does not support their assumptions [37]. GD aims to help patients identify their negative thought processes by questioning its evidence [12].

BA is a behavioural technique that focuses on skill activation to stimulate a greater sense of enjoyment in life [37]. This is done by encouraging patients to schedule activities on a daily or weekly basis in order to reduce depressive symptoms [12].

Our research objective was to develop an OWL ontology that represents the core principles of CBT while maintaining the clinical validity of the therapy. The proposed knowledge driven CBT-based model operationalizes GD so patients can identify the negative thought processes associated with barriers that inhibit them from working towards achieving a treatment goal, and operationalizes BA to promote scheduling activities that elicit feelings of mastery or pleasure in a patient. The proposed OWL ontology instantiates illness-related barriers to treatment goals and associates the selected barrier with the negative thought processes selected.

1.3 Solution Approach

The proposed solution uses an ontology-based knowledge model to provide knowledge representation of the concepts pertaining to CBT. We have used Semantic Web technologies, specifically OWL ontology, to design a Knowledge-Based System (KBS) [80]. Adopting a knowledge-modelling approach allows for the creation of a model representing a particular domain by defining entities within the domain and the relationships among them [84]. Ontologies are developed for the purpose of knowledge modelling [115] and may be constructed for the purpose of information sharing and specification of the vocabulary of a domain [84]. Ontologies can be expressed using OWL to represent rich and complex knowledge about concepts and the relationships between them [126]. Ontologies are used to describe concepts and their hierarchical relationship, concept attributes and constraints put on the concepts. In doing so, ontologies have become modern knowledge bases [50]. OWL can be used with an OWL reasoner to conduct consistency checks [126].

KBS consists of domain knowledge encoded in a knowledge representation formalism and a reasoning engine. For this purpose we have used OWL ontology to represent the domain knowledge in a machine-interpretable manner [80]. It is interpreted by a reasoning engine that supports automated reasoning where new facts are deduced from previously asserted facts. This is called reasoning [80]. We have used Pellet reasoner for this purpose [80]. The new facts are called inferred facts [89]. The main purpose of representing knowledge in a machine-interpretable format such as OWL ontology is to allow for automated reasoning to take place [89].

OWL is a knowledge representation formalism based on description logics [126]. Owing to the ties OWL has to the Web platform, it has emerged as the preferred choice for knowledge representation since it promotes knowledge sharing, dissemination and reuse [144].

CBT proposes a Cognitive Model that says dysfunctional thinking that affects one's thoughts and behaviour is common to all psychological disturbances but there is a way for people to experience improvement in both their emotional state and behaviour that can be achieved through learning to think in a realistic and adaptive way [12].

David et al. [28] reported that CBT supercedes all other therapies for psychosocial treatments thereby making it a first line treatment for many disorders. It has also been noted by both the National Institute for Health and Care Excellence's [71] guidelines and American Psychological Association [70] to be the gold-standard psychological treatment. David et al. [28] pointed out the following reasons as to why this might be the case, firstly, CBT is the most researched form of psychotherapy. Secondly, they state that CBT is systematically superior to other forms of psychotherapy [28].

Our solution approach is mainly focused on the two core concepts of CBT, Guided Discovery (GD) and Behavioural Activation (BA) and the subsequent relationships linking the concepts to a patient. Subsequent chapters present further information on these two techniques. The model instantiates questions associated with GD to encourage patients to identify the evidence of a negative thought process [12]. Alongside monitoring the confidence of adopting action plans it is important to monitor responses to GD. This is usually done in a journal in traditional face-to-face CBT [26]. BA is modelled in a way that involves scheduling of activities that can be done on a weekly basis to increase a sense of mastery or pleasure in an individual [12]. It involves monitoring the activity the individual will undertake for a week, along with the expected and achieved sense of mastery or pleasure [12].

Figure 1.1 shows the conceptualization of our solution approach.

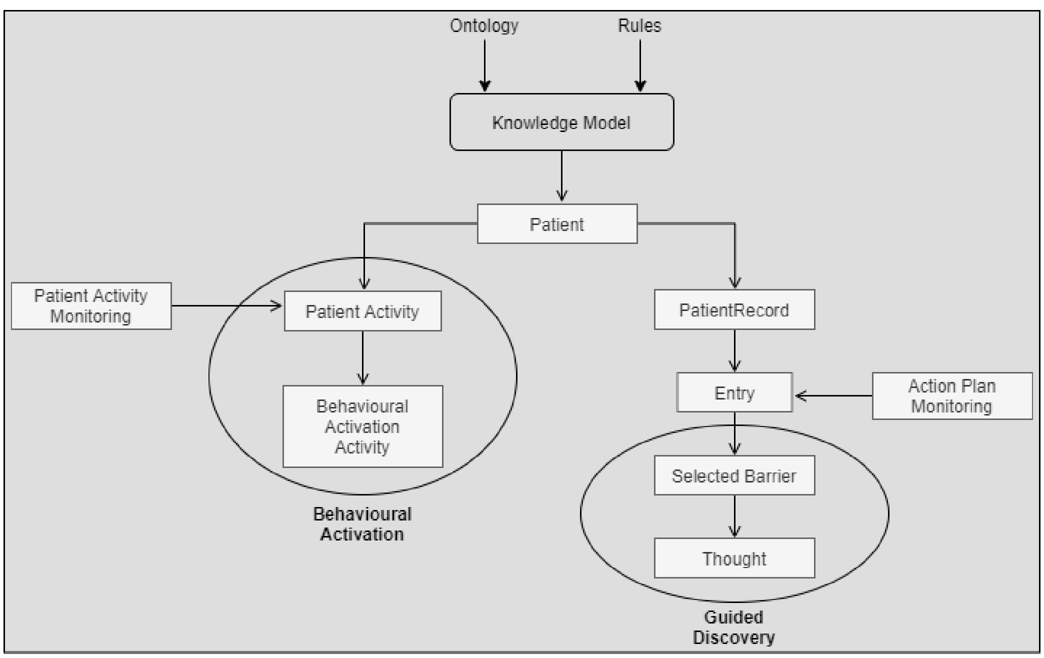


Figure 1.1: Conceptualization of solution approach

Our solution approach is developed after inspecting the key concepts of CBT and how they relate to one another, this is further elaborated in chapter 4. The knowledge model has a Patient class to instantiate a patient, the activities for BA fall under Activity class, and PatientActivity class shows the patients selection of a particular activity. The expected and achieved levels of mastery are modelled as data type properties. The PatientActivity class instantiates monitoring the patients progress. As shown in Figure 1.1, class PatientRecord instantiates a particular record of the treatment goal selected by the patient and selected treatment goal and entry in the record. The Entry class instantiates the barrier to the goal, the action plan selected by the patient and action plan monitoring. The selected barrier to the goal is linked to the thought and the cognitive distortions associated with it. The cognitive distortions are questioned using the GD question instances. Action Plan monitoring involves asking the patient if they followed the action plan for a week and how they felt post it.

The scope of this work will be limited to demonstrating the applicability of this knowledge driven approach in the context of pre-selected treatment goals towards the self-management of mild depression. Knowledge validity was evaluated by a domain expert while the model is evaluated for its consistency, conciseness and correctness.

1.4 Research Challenges

The task of designing and operationalizing a CBT-driven self-management framework for mild depression brings forth numerous challenges, some of which are enumerated below:

1. Functional Challenges

    - Content Gathering: The content gathering exercise required sourcing various resources that included human experts, psychological literature and online resources for accessible theoretical information on CBT and content related to generating action plans.

    - Treatment Goal-Action Plans Matching: Our knowledge model is intended to match treatment goals to action plans based on the users' selection of treatment goal and in some cases, user context.

2. Modelling Challenges

- Operationalizing Guided Discovery and Behavioural Activation: Even though Guided Discovery and Behavioural Activation are viewed as effective techniques to promote rational thinking and reduce depressive symptoms by increasing mastery or pleasure levels in an individual, it is important to specify the mechanism through which they will affect thoughts based on evidence in order to justify the subsequent knowledge modelling efforts.
- Risk analysis - A process to handle unforeseen events must be provided such as if the action plans presented leads to the user feeling worse or shows no signs of improvement in the tracked progress.

3. Technical Challenges

    - Representational adequacy of the knowledge model: The knowledge model must contain domain specific knowledge represented in a semantically rich, computer-interpretable form. It must satisfy the intentions of creating the model while staying true to the theoretical proof of the concepts and the relationships between the concepts modelled. This was ensured by using the semantic web technologies, in particular, the Web Ontology Language (OWL) .

1.5 Thesis Contribution

We developed a knowledge driven CBT model that exploits the Semantic Web technology, in particular OWL ontology towards knowledge modelling. The model was built by implementing CBT components for guided discovery and behavioural activation, monitoring, and rule/reasoning based action plan generation.

The relevant contributions are as follows:

1. Gathering knowledge of complex theory - Gathered knowledge on the basic components of CBT and how they co-relate with one another from domain experts and literature.

2. Based on aforementioned findings and using a knowledge modelling approach we propose an OWL ontology-based knowledge model for CBT. We verify the consistency of the knowledge model using competency questions.

3. Development of a strategy to enhance Guided Discovery and Behavioural Activation - we formulated a strategy focused on GD and BA to technologically facilitate questioning negative thoughts and enhancing levels of mastery towards reducing depressive symptoms.

4. Content generation and adaptation - We have modelled the content gathered into action plans for different treatment goals. They are formulated in such a way to allow users to derive a concrete plan out of them depending on the Treatment Goal selected.

5. Monitoring of activities and negative thought processes - Monitoring these aspects of one's progress in the self-management of depression is important to reflect on. The ontology has the means to monitor each treatment goal selected by a patient along with the associated action plans and feedback from a patient. The SWRL rules created work towards connecting the patients' profile with the negative thought processes selected along with the associated Guided Discovery questions.

To summarize, the aim of this research is to develop a knowledge-based CBT model based on Semantic Web technology that models treatment goals and links them to respective action plans as well as identifying barriers and the negative thought processes associated with them. The model will also incorporate BA in order to increase patient activity that will elicit pleasure and/or mastery. The theoretical foundation for our framework is built on CBT. We present a novel approach of computerizing CBT constructs, by (1) modelling the theoretical knowledge of CBT in terms of an OWL ontology, (2) instantiating standard treatment goals using this ontology, and (3) generating suitable action plans for patients based on treatment goal selected.

1.6 Thesis Organization

The rest of the thesis is organized as follows:

- Chapter 2 presents the reasoning for choosing to model Cognitive Behavioural Therapy (CBT) and an overview on its computerization along with a review of Computerized CBT apps and highlights the addressable gaps found.

- Chapter 3 highlights the importance of a knowledge-based approach and presents a review of the related work that has been pursued in computerization of CBT based approaches for the self-management of mild depression. It presents an account on knowledge engineering, the role of ontologies in Knowledge Engineering and OWL.

- Chapter 4 outlines the core concepts of CBT.

- Chapter 5 outlines our research methodology and describes the steps taken to create the OWL ontology based on CBT with an emphasis on Guided Discovery and Behavioural Activation.

- Chapter 6 gives an account of the evaluation of the implemented module, and finally

- Chapter 7 concludes this thesis with a reflection on our approach, while revisiting the problem statement, highlighting the limitations of this work and future scope.

Chapter 2

Cognitive Behavioural Therapy

This chapter outlines CBT and the role of computerized CBT in the treatment of mild depression. The purpose of this review is to clarify why CBT is well-suited as a subject of a knowledge model as a way to operationalize it for the treatment of mild depression.

2.1 Therapies available for the treatment of mild depression

CBT is one of many types of therapy for people with mild depression. Some other types are Supportive Therapy, Psychodynamic Therapy and Interpersonal Therapy [149].

CBT is an action-oriented, pragmatic treatment approach that is a widely used psychotherapy for mental disorders [167]. CBT focuses on identifying negative thought processes that are automatic thoughts one has regarding themselves, their world or other people [12, p. 3].

The first time CBT was compared to medication in achieving desirable results for patients diagnosed with depression was in 1977 when Dr Aaron T. Beck, the founder of CBT and chief resident John Rush conducted a controlled randomized study with depressed patients to demonstrate the efficacy of CBT. They found that CBT was as effective as imipramine, a common anti-depressant [12].

Beck [12] devised a structured, short-term psychotherapy to treat depression that is directed towards solving the patients current problems and modifying dysfunctional, inaccurate and/or unhelpful thinking and behaviour. CBT focuses on cognitive change and modification in the patient's thinking and belief system to bring about enduring emotional and behavioural change. CBT has been adapted for patients with diverse levels of education and income as well as a variety of cultures and ages, from young children to older adults [12, p. 2]. Beck's cognitive model [12] proposes that dysfunctional thinking influences the patient's mood and behaviour and is common to all psychological disturbances. And when people learn to evaluate their thinking in a realistic and adaptive way, they experience improvement in their emotional state and behaviour [12, p. 3]. CBT focuses on identifying distorted, negative cognition since it was discovered as being a primary feature of depression [12, p. 1].

Figure 2.1 shows the cognitive model that connects thought, emotion and behaviour.

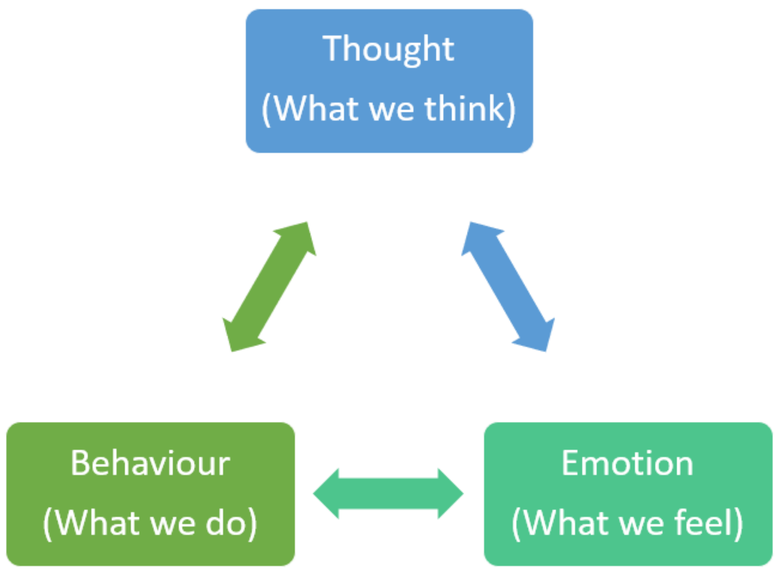


Figure 2.1: Cognitive Model

CBT works at a deeper level of cognition to modify the patient's basic beliefs about themselves, their world, and other people by questioning the evidence of their thoughts [12, p. 3].

Supportive Therapy is any non-directive therapy, typically based on principles such as expressing empathy and establishing a therapeutic relationship between the patient and therapist [149]. The therapist serves as a model for what is considered to be proper and appropriate behaviour. Since it is a non-directive form of therapy, the therapist implicitly conveys to the patient an ideology about the way that life ought to be led [106].

Another form of therapy called Psychodynamic Therapy (PDT) lays emphasis on uncovering unconscious conflicts, personality dynamics, or working through transference reactions [149]. Fonagy [41] states that PDT lacks scientific credibility and has little evidence to suggest that PDT is superior to other therapeutic approaches. Interpersonal Therapy (IPT) focuses on patients understanding interpersonal conflicts and developing adaptive ways to relate to others [149].

Tolin [149] conducted a meta-analysis to evaluate the relative efficacy of CBT across a variety of disorders. This meta-analysis conducted direct comparisons of CBT to other treatments intended to be therapeutic. CBT was found to be superior to other therapies for depression [5]. And so for patients with depressive disorders and anxiety, CBT can be used as a first-line of psychosocial treatment of choice [149].

Tolin [149] classified a treatment as CBT if it contained any of the following components: -

- relaxation training (including progressive muscle relaxation, meditation, or breathing retraining),
- exposure therapy (including flooding and implosive therapy),
- behaviour rehearsal (behavioural training in social skills, habit reversal, or problem solving),
- cognitive restructuring (including direct strategies to identify and alter maladaptive thought processes), or
- operant procedures (systematic manipulation of reinforcers including behavioural activation).

Wright et al. [167] explain a two-way relationship that exists between cognition and behaviour in which cognitive processes can influence behaviour, and behavioural change can influence cognitions. Encouraging adaptive responses to cognitive distortions is a practical method of breaking the cycle [167]. For people with depression, cognitive distortions typically center on negativity, low self-esteem and ineffectiveness that are riddled with errors in logic. CBT for depression frequently uses behavioural interventions namely, activity scheduling to reactivate the patient. Patients suffering from depression have seen an improvement in their symptoms such as lack of interest and low energy when behavioural techniques have been incorporated in their therapy [167].

2.2 Why we chose to model Cognitive Behavioural Therapy?

Seeing as the number of people affected by depression are so high, there is a need to address this issue and give it utmost priority [165]. In most cases, the symptoms of depression go unnoticed and before long it turns from mild depression to severe depression which has devastating impacts on an individual's social and professional life [73]. Depression can destroy one's social life as it affects the functioning of the person suffering from it as well as those who care about them [73].

Hu et al. [73] pointed out that CBT has been widely recognized as an effective psychosocial treatment to cure or alleviate psychological disorders namely, depression, anxiety and eating disorders. Studies show that CBT is significantly more effective in the treatment of depression when compared with other psychological therapies. As a result, the American Psychological Association (APA) recommends CBT as the treatment for several mental disorders, e.g. anxiety disorders, major depression and eating disorders [73].

Reviews and meta-analyses [35, 25, 71, 101, 87, 88, 149, 152, 173, 74, 66, 5] of the voluminous literature on CBT outcome studies have concluded that this treatment approach is highly effective for depression and anxiety disorders.

CBT was compared to Supportive Therapy, IPT, PDT and other forms of therapy such as hypnosis and spiritual counselling [149]. Tolin [149] states that patients who received CBT, regardless of the specific techniques used, exhibited lower primary symptom severity at post-treatment than those patients who received other psychotherapies, especially psychodynamic therapy. According to [149] the advantages of CBT are not time-limited since the superiority of CBT is equally or more evident 6 months and 1 year after treatment discontinuation.

Our review of the existing literature shows that CBT outperforms other forms of psychotherapy and reduces depressive symptoms when it contains any one or more of the components identified by Tolin [149], for this reason we have chosen CBT while focusing on cognitive restructuring through Guided Discovery (GD) and listing cognitive distortions, as well as Behavioural Activation (BA).

2.3 Role of Internet CBT/Computerized CBT in the treatment of depression

Internet CBT (iCBT) is Cognitive Behavioural Therapy (CBT) that is delivered via the internet. Also known as internet-delivered CBT, online CBT, Computerised CBT(CCBT), or Electronic CBT (eCBT) . CCBT can be delivered via desktop websites, or through dedicated apps on mobile devices [148].

Computers and computing devices such as handheld mobile phones are used to aid CCBT [119, 112, 111, 78, 24, 77, 98, 62, 99, 60]. Hu et al. [73] state the following tasks are suitable for computer-based automation:

1. Scheduling homework outside of sessions in therapy so as to enable patients to practice skills learned in therapy and to generalize such skills to real world situations.

2. Scheduling therapy session activity by setting an agenda, utilizing pre-planned techniques at specific times during the session, and directing the patient towards specific topics or tasks.

3. Impinging on a patient's illogical or irrational thoughts or beliefs testing, challenging and changing a patients' beliefs.

4. Training skills to cope with symptoms in a psycho-educational role to enable patients to self-manage their symptoms.

5. Focusing on the patients' present and future experiences and not their past or childhood experiences.

6. Providing relatively simple textual information/description/ explanation regarding a patients' disorder and their symptoms [73].

Ebert et al. [35] conducted randomized controlled trials in which a computer-, Internet- or mobile-based cognitive behavioural intervention targeting either depression, anxiety or both in children or adolescents up to the age of 25 were compared to a control condition where the participants were on wait list. The results obtained provided evidence for the efficacy of CCBT in the treatment of anxiety and depressive symptoms in youth. Hence, such interventions may be a promising treatment alternative when evidence-based face-to-face treatment is not feasible [35].

CCBT is effective in the treatment of depressive symptoms in adults as well. A systematic review of 19 randomized controlled trials was conducted to evaluate Internet-based and other computerized interventions for adult depression symptoms in N = 2996 individuals and showed a mean effect size of 0.56 [35].

A general problem observed with people suffering from depressive symptoms is they do not wish to seek help [21]; in such cases it becomes difficult for well-resourced health care systems to find enough therapists to offer psychological intervention [87]. Due to several barriers to psychotherapy, such as high cost of treatment and fear of stigmatization, a significant number of individuals with depressive symptoms are left untreated [21]. To overcome this barrier, self-guided iCBT without therapist support can permit physicians to provide easy and affordable access to psychological treatments and reduce the cost of such treatments [87]. Eirini K. et al. [87] defined the term self-guided iCBT as CBT delivered via the internet, which may involve automated feedback but does not provide support related to the therapeutic content. They conducted individual participant analysis to find that self-guided iCBT could potentially be an alternative to first step treatment approaches for depressive symptoms in patients. They also noticed the advantage this sort of treatment would have for patients who are not keen on having therapeutic contact. Another advantage was it helped a large number of individuals by providing them with the ability to get treatment at low cost [87].

Hobbs et al. [69] conducted a randomized controlled trial to determine the efficacy of iCBT on 1288 patients over the age of 18 years. For the purpose of conducting the study, the patients were prescribed iCBT for their depression from ThisWayUp.org.au. [148], which is a non-profit provider of online treatment services for depression and anxiety jointly managed by St Vincent's Hospital, Sydney and the University of New South Wales. The results of the trial showed that all age groups including those experiencing late-life depression made substantial improvements in their mental health [69]. The trial showed patients experienced large effect size reductions in depressive symptom severity, psychological distress and moderate reductions in functional impairment irrespective of their age [69].

Hedman et al. [66] conducted a systematic review to identify randomized controlled trials investigating CBT delivered via the internet for adult patient populations. They found that iCBT can be regarded as a well-established treatment for depression, panic disorder and social phobia and that iCBT is as effective as conventional CBT for these clinical disorders [66]. Hedman et al. [66] stated that Internet-based treatments for depression, social phobia and panic disorder were classified as well-established, that is, meeting the highest level of criteria for evidence.

Twomey et al. [152] investigated the effectiveness of a freely available CCBT programme called MoodGYM [110] for depression (primary outcome), anxiety and general psychological distress in adults. They reported comparisons from 11 studies that demonstrated MoodGYM's effectiveness for depressive symptoms in individuals at post-intervention [152].

Lan et al. [93] state that mobile health (mHealth) apps developed for CBT mainly focus on only patient engagement, and lack the functionality necessary to help patients adhere to their treatment within the larger health system. They further state that research demonstrates patient interest in using mHealth apps for self-management, clinician interaction and health system integration as important factors for patient confidence and ultimate behaviour change. There is no evidence of apps developed on evidence-based principles of CBT [93].

Reviews and meta-analyses of the voluminous literature on CCBT outcome studies for the treatment of depression have concluded that CCBT as a treatment approach is highly effective for depression [167].

2.4 Review of a selection of CBT applications and CCBT technologies

Porras et al. [131] state that the application of mobile phone technology to healthcare settings known as m-health, is increasing in popularity. They found that over three quarters of mental health patients own a smartphone, and approximately 90% declare they use mobile apps regularly. Due to this widespread usage of smartphones m-health represents an approach towards management of mental disorders [131]. However, research by Shen et al. [139] revealed that applications available lacked theoretical framework for the therapy they are based on. Their research involved identifying depression apps on the app stores of the five major mobile phone platforms: Android, iPhone, BlackBerry, Nokia, and Windows. They included apps that focused on depression and were available to people who self-identify as having depression [139].

Shen's [139] work included identifying CBT apps for tracking, screening, and providing psycho-education to users. It did not focus on the CBT concepts used to build the app, instead they identified the apps based on the function in focus, which range from eBooks, behaviour training, mood tracker and positive affirmation to name a few [139]. Building on Shen's [139] work, we searched for "CBT depression apps" on Google Play Store and reviewed the top 10 results that focused on CBT concepts- GD and BA. The findings of the review are listed in the table below.

Table 2.1 provides a review of the top 10 CBT apps available on Google Play Store with a focus on GD and/or BA.

Table 2.1: Review of Top 10 CBT apps available on Google Play Store

App	Description	Advantage	Disadvantage	CBT Concept focused on
Cognitive Behavioural Therapy: Depression, Anxiety [119]	Set of strategies listed for different disorders – Depression, Anxiety, Social Anxiety, and Separation and Loss. For depression, has self-help methods to learn helpful ways of thinking.	Lists coping strategies for multiple mental health disorders.	Not designed to treat clinical levels of depression.	Guided Discovery
CBT Thought Diary (by MoodTools) [112]	Document negative emotions and re-evaluate negative thoughts.	Lists cognitive distortions for thoughts entered.	The MoodTools kit has two separate apps for different CBT principles.	Guided Discovery
Activity Mood Tracker (by MoodTools) [111]	Tracks the user's moods before and after following an activity.	Can add custom activity.	Focuses on the Behavioural Activation principle alone.	Behavioural Activation
CBT Companion - CBT for Anxiety, Depression, Anger, Stress, OCD and PTSD [78]	Has video lessons explaining different modules of the app, namely, what is CBT, cognitive distortions and problems, solutions and goals.	Provides visual aid.	Focuses on the Guided Discovery principle alone.	Guided Discovery

Continues...

App	Description	Advantage	Disadvantage	CBT Concept focused on
CBT Diary [24]	Records entries of thoughts, emotions and behaviours.	Creates diagrammatic representation of overall emotions for specified period.	Focuses on making entries of thoughts-emotions-behaviours alone.	Listing automatic thoughts
Sanvello [77]	Focuses on understanding feeling and changing them based on CBT, Mindfulness Meditation and Mood & Health Tracking.	Implements clinically validated techniques.	Focuses on the Guided Discovery principle alone.	Guided Discovery
Mood Fit – Stress & Anxiety [98]	Created to enable users to manage symptoms of stress, anxiety and depression by incorporating CBT.	Thought records are maintained. Along with mood tracking and sleep duration.	Focus on only Guided Discovery by maintaining thought record.	Guided Discovery
Moodpath - Depression & Anxiety Test [62]	Answer 3 questions pertaining to feeling sad, hopeless and pleasure doing things thrice a day for 2 weeks.Receive assessment at the end of 2 weeks. Then repeat process. Can monitor progress.	Developed by experts. User can listen to audio lessons on tackling overwhelming emotions, building self-confidence, etc., or read about understanding depression, mindfulness, sleep, emotions, etc.	Lacking CBT principles Guided Discovery and BA.	Tracking moods.
Feel better – Mood & CBT Therapy to manifest goals [99]	Applies principles found in CBT, vision boards, law of abundance, manifestation, journaling and personal development coaching to set daily goals and track moods. Has a section for inspirational videos from leaders and regular people doing awesome things	Focused on manifesting goals while monitoring emotions and encouraging gratitude in user.	Does not explicitly mention what principles of CBT are followed.	Inconclusive
Happify [60]	Created for users to learn to gain control of their thoughts and feelings	Based on findings of CBT, positive psychology and mindfulness	Focuses on only one principle of CBT.	Guided Discovery

To summarize, a review of the top 10 applications incorporating the CBT concepts - Guided Discovery and Behavioural Activation, available on Google Play Store reveal that there is a lack of an all-encompassing solution to overcome depression that incorporates both GD and BA. [119] was not designed to treat clinical levels of depression and it was not validated domain experts. The MoodTools kit [112] [111] has two separate apps for the CBT principles GD and BA respectively. The user

has to switch between different apps to make entries for negative thoughts [112] and tracking of achieved and expected mastery levels associated with an activity [111]. A number of apps focused on GD alone [78, 77, 98, 60].
Another app [24] focused on making entries of thoughts-emotions-behaviours but does not question the negative thoughts a user can have via GD. [62] focuses on tracking a user's mood pertaining to sadness, hopelessness and pleasure doing things over 2 weeks and then it repeats the process so as to monitor the user's progress. [99] focusses on users manifesting goals while monitoring their emotions and encouraging gratitude in users, but it does not mention what principles of CBT they focus on.

[112, 111, 78, 77, 98, 62, 99, 60] are available on Google Play Store and App Store.

[119, 24] are available only on Google Play Store.

CCBT apps do not typically provide an entire course of CBT, instead they deliver a specific component of treatment, stress management, or skill (e.g., breathing exercises, relaxation, mindfulness, thought diaries, mood tracking) [168]. Our knowledge model instantiates thought records by linking the barrier associated with a treatment goal to the thought process associated with it.

Moberg et al. [108] conducted a randomized wait list controlled trial of Pacifica, now called Sanvello, a mobile app integrating CBT and Mindfulness for the treatment of stress, anxiety, and depression and reported that it was effective in reducing self-reported symptoms of depression, anxiety, and stress among individuals who utilize thought records and are not taking psychiatric medication.

In line with the observations on the nature of interactive apps for the self-management of depression, Huguet et al. [74] identified 81 apps available for android phone users in Canada and found that only a handful of those, only 12 identified as delivering CBT/Behavioural activation interventions. Their review showed a lack of effectiveness/efficacy studies and low adherence to principles of CBT interventions in these apps [74].

Another review conducted by [162] to find the extent to which popular m-health apps incorporate depression and anxiety treatment elements revealed an absence of core treatment elements being implemented in the apps.

In contrast to the findings mentioned above, our knowledge model is based on the CBT concepts of GD and BA, with a focus on identifying thoughts and associated cognitive distortions along with monitoring activities that elicit mastery or pleasure.

We also reviewed some web based CBT interventions available for depression. ThisWayUp [148] is a web based iCBT that offers 6 treatment lessons that are focused on:

- psycho-education about depression and how cognitive and behavioural factors can maintain the cycle of depression,
- behavioural activation,
- identifying and challenging unhelpful thinking patterns (including challenging meta-cognitive beliefs that may maintain rumination),
- structured problem solving,
- graded exposure and assertiveness skills training, and
- relapse prevention [148].

Beating The Blues [19] is an iCBT intervention for individuals with mild to moderate depression. The online CBT programme enables individuals to work through modules to learn about and apply the principles of CBT [147]. The intervention is delivered online for patients with depression or anxiety and consists of eight weekly sessions of 50 minutes each, during which patients are taught to identify symptoms and set goals [51].

MoodGYM [110] is another iCBT intervention that uses live animation, downloadable relaxation recordings, and interactive exercises. It is set up into five modules that each require 30 to 45 minutes to complete. Each module builds from the previous. It allows users to examine and overcome dysfunctional thinking, assess life and stressful events, and engage in problem solving [147].

The above overview of the applications reviewed shows a lack of description of the computerization methods adopted towards the creation of the apps. We outline our contentions from a knowledge management perspective. Most of the applications developed for CBT did not outline details of how they modelled the patient education content incorporating CBT strategies. If they did so, it was not explicitly mentioned. Although several apps are available for the self-management of depression only a handful were identified as delivering Cognitive Behavioural Therapy (CBT) and Behavioural Activation (BA) interventions [91]. There is a lack of uniformity in the descriptions and labelling in m-health apps designed to treat depression [91]. Hence, solutions should focus on the theoretical knowledge of CBT. We identified the scope for the creation of a knowledge model based on CBT that is validated by domain experts that focuses on the core concepts of CBT.

To overcome what [93] stated in their review with regards to having found no evidence of apps developed on evidence-based principles of CBT, building an application on a knowledge model that incorporates basic CBT principles and can be integrated into the larger mental healthcare system. Gratzer et al. [51] state that patients adhere to therapy with some therapist involvement since self-management of depression with some therapist involvement yields better outcomes [51]. Care can be initiated under the supervision of a therapist if they deem the depressive symptoms as aligning with those of mild depression. Therapists can recommend patients suffering from mild depression use an application built on a knowledge-model that incorporates GD and BA in the treatment of mild depression.

A modelling approach would encompass the concepts of the theory and the linking of the concepts thereby utilizing the theoretical aspects via the links specified [115]. In particular, a knowledge modelling approach allows for the domain knowledge to be adapted such that it can used as a basis for inference [73]. The reviewed literature on the CBT apps did not utilize any such modelling or knowledge modelling approach. Considering this, this thesis aims at taking a knowledge modelling approach and creating an ontology for CBT with a focus on the core principles of BA and GD.

2.5 Concluding Remarks

In this chapter, we gave an overview on the origins of CBT and the role of CCBT in the treatment of depression. We also gave a review of CCBT apps currently available and identified the gaps that we would like to address. The next chapter delves into the knowledge management approach to knowledge modelling while looking into the related works of using semantic web technologies, specifically ontologies to design a knowledge based system for CBT.

Chapter 3

Knowledge Management Approach to Knowledge Modelling

We will now look into the knowledge-management approach to knowledge-modelling and the reasoning behind choosing an OWL ontology to model domain knowledge. As stated by [31], Knowledge Management is organization- or business-focused and defines the framework within which knowledge engineering activities are carried out to facilitate the creation, access and reuse of knowledge. Ontologies constitute as an important aspect of knowledge management systems [31]. Developing an ontology constitutes taking a knowledge management approach to knowledge modelling [31]. The following review assesses existing published literature based on the usage of a knowledge modelling approach as well as having a cognitive behavioural theoretic foundation in the design of their intervention. The aim is to highlight existing work and the addressable gaps.

3.1 Related Work

The context of this literature review is knowledge modelling. A knowledge modelling approach signifies the importance of organizing knowledge in terms of interconnected relations between concepts governed by rules and axioms [80]. Knowledge representation formalisms offer flexibility and expressiveness when modelling a domain. One of the biggest advantages of adopting a modelling approach is the possibility of future model improvement [157].

Knowledge modelling offers the following advantages:

1. Representing domain knowledge in a formalism such that domain experts may further improve and subsequently validate the contained knowledge.

2. Ability to reason over knowledge by means of appropriate reasoning algorithms.

3. Allows for knowledge re-usability and sharing across different systems. Given an appropriate process model, domain knowledge models can be shown in a

different context thereby promoting knowledge reuse.

4. Extensibility and incorporating of new facts and information in a model lends to improvement of the model [157].

Omerovic et al. [125] state that a majority of cited authors are in widespread agreement that uniform knowledge representation is achievable by using ontologies populated with concepts.

There have been several studies conducted over the years to understand how a knowledge modelling approach using ontologies can assist in the digitization and computation of information in various fields. One such study was done by Richesson and Andrews [107] to examine how clinical processes can be automated by knowledge representation via the use of ontologies [107]. Researchers in the biomedical field developed the Gene Ontology and the Open Biomedical Ontologies initiative to create a repository of controlled vocabularies regarding the functions of genes and gene products [17, 143]. Meanwhile in the field of clinical psychology, researchers explored the use of ontologies to build knowledge models on different mental disorders. Some of the ontologies developed are - Mental Disease Ontology [61], Mental Health Ontology [58], Mood Disorder Ontology [59], Autism Phenotype Ontology [105], Ontology of Schizophrenia [150], and Ontology to monitor mental retardation rehabilitation process [102] [107].

There exist several ontologies for healthcare domains that cover varying levels of granularity [68]. A search of the current literature revealed some related ontologies in the area of CBT and mental disorders.

We present a quick overview of the studies reviewed in Table 3.1, which is then followed by a discussion.

Table 3.1: Related Works

Paper	Description	Classes	Evaluation (consistency check)	Ontology intention
Ontologies for intelligent e-therapy: application to obesity [172]	Models patient context in a mental health application for obesity treatment	Patient, Agent, Professional, Evaluation, Treatment, Alarm	Not mentioned	Created for the treatment of obesity using CBT
Development and Validation of a Functional Behavioural Assessment Ontology to Support Behavioural Health Interventions [107]	Supports behavioural health interventions	FBA, Method, ABC, Antecedent, Behaviour, Consequence, Function	Pellet Reasoner, Domain Expert	Created for one method adopted in CBT that is used to determine problematic behaviours

Continues...

Paper	Description	Classes	Evaluation (consistency check)	Ontology intention
Ontology-Based Approach to Social Data Sentiment Analysis: Detection of Adolescent Depression Signals [83]	Analytical framework for the analysis of SNS data	Entity, Diagnosis, Subtype, Intervention, Risk_factors, Signs&Symptoms	Description logics	Provides a semantic foundation for analyzing social media data on adolescent depression
Ontology-based ubiquitous monitoring and treatment against depression [73]	Ontology for classifying the domain knowledge of mental disorders	Person, Patient, Doctor, Status, Record, Activity, Schedule, Diagnosis, Treatment_Diary	Inference engine (not mentioned)	Interpret the patients situation and clinician's involvement
Toward a ubiquitous model to assist the treatment of people with depression [129]	Detects the need to contact the caregivers of a depressed person	Depression, Person, PersonType, User, Activity, Symptom, Email, SocialNetwork	System evaluated by users and domain experts	Identify the symptoms of the depressive disorder
Development of clinical ontology for mood disorder with combination of psychomedical information [59]	Ontology for mood disorders with psycho-medical information	Mood_disorder, Associated_problems, Biomedical_view, Psychological_view, Cause	Inference engine (not mentioned)	Improve the quality of diagnosis and appropriate treatment for psychiatric disorders
Depression Diagnosis Based on Ontologies and Bayesian Networks [22]	Utilize the ontology and Bayesian network to propose a framework of depression diagnosis	Thing, Disease, Depression, Patient, Depression_Symptom	SMILE	Build a terminology of depression

Zaragozá et al. [172] present an ontology for modelling patient context in a mental health application for obesity treatment [172, 68]. They developed a re-usable Therapy Knowledge Base (TKB) that is accessible by therapists around the world. They created an ontology on CBT aimed at treating obesity. Different ontologies can extend TKB and be built upon further [172].

Merlo et al. [107] developed an ontology for Functional Behavioural Assessment (FBA) to support behavioural health interventions by capturing the concepts and the relations between them in an effort to gather information about behaviour to determine its function and effective intervention plans. FBA is a method in CBT used to identify the variables that help determine a problematic behaviour in a patient. They based their work on the use of modern technologies that can encourage the collection, sharing, and gathering of statistical evidence on antecedents and the consequences of clusters of problem behaviours and subsequent effective intervention strategies. Merlo et al. [107] define an ontology as a taxonomic description of the concepts in an application domain and the relationships among them that are intended to assist knowledge generation, organization, reuse, integration and analysis [107]. The

FBA-Ontology comprises of classes and properties used to describe the assessment process and includes the definition of a target behaviour along with the collection of behavioural data, the hypothesis about target behaviour functions, and the planning of a behavioural intervention [107]. In order to verify the ontology semantically and syntactically, Merlo et al. [107] performed a machine-based validation using the Pellet reasoner and a human-based assessment to validate the FBA Ontology [107].

Jung et al. [83] developed an ontology to provide a semantic foundation in order to analyse social media data on adolescent depression [83]. The ontology developed expresses shared concepts and their relationships and was used as a semantic framework for social media data analytics [83].

Hu et al. [73] developed a multi-layered ontological ubiquitous monitoring and treatment framework (MOUMT) to assist people in overcoming the challenges of mental disorders. They developed an ontology to collect, manipulate and reason patients' data by incorporating the domain knowledge of mental disorders as the basis for inference. Further, they implemented a mobile version of online CBT for depression with modules for messaging services between the patient and psychotherapists. The framework allows the therapist to record logs, statistics and treatments, and run queries. The authors presented a context ontology for mental disorders as the basis upon which semantics-enhanced methods are developed for gathering, formalising and manipulating patients' data. The proposed framework facilitates online CBT for treating depression and combines talk/chat/messaging services, helps in retrieving neurofeedback, and supports collaborative diagnosis when necessary [73]. Merlo et al. [107] adopted human evaluation as a strategy and interviewed domain experts to check the formal structure of the ontology ranging from the taxonomy, relationships, and axioms to assess whether the ontology definition was consistent with the knowledge domain. In order to do this, they composed a questionnaire of 13 questions aimed to evaluate the issues of the ontology [107]. The questionnaire uses a 5-point Likert scale (from strongly agree to strongly disagree) so experts can rate how much they agree or disagree with the definitions [107].

Petry et al. [129] proposed a model to assist in the treatment of people suffering from depression that detects the need to contact the caregivers of a depressed person, based on the users' historical context. The model, named Hígia, constantly evaluates patients' characteristics on different social networks, emails, and interactions with smartphones, computers, or other devices. They developed an ontology for depression to standardize the information and gain a sound understanding of the concepts and model organization [129].

Haghighi et al. [59] developed the "Haghighi-Koeda Mood Disorder Ontology" that involved both medical and psychological approaches for mood disorders aimed at promoting the exchange of information between psychiatrists and psychologists. Furthermore, they developed a web-based interface system that implements the ontology as well as an online scale for the automated diagnosis of mood disorders. They used Protégé Version 3.4 beta to create an ontology on 4 main categories of mood disorders, namely Bipolar disorder, Cyclothymia, Dysthymia, and Major Depression, by classifying them into classes and subclasses in an ontological structure. Their primary focus was to improve the quality of diagnosis and appropriate treatment for psychiatric disorders. The team of researchers describe ontology as a methodology by which to promote knowledge processing in order to provide systematic semantic links between a collection of related concepts [59].

Chang et al. [22] proposed an inference model that utilizes ontologies and Bayesian networks techniques to infer the probability of depression in individuals. The researchers used Protégé to build the depression ontology model and used inference rules to add Bayesian probability. Their ontology model consists of a vocabulary of terms and the specification of their meaning. The proposed model is an enhancement on the OntoBayes model by Yi et al. [170, 22].

To conclude, we reviewed literature related to ontologies built for mental disorders as well as those built for CBT. The existing ontologies focus on a part of CBT called FBA [107], another was created towards the treatment of obesity [172], another for analysing social media data on adolescent depression [83], an ontology based ubiquitous system focused on interpreting patient's situation alone [73], yet another ubiquitous system was built to identify the symptoms of depression [129].

This review was helpful in highlighting the usage of computing technologies with regards to CBT. On looking through the current works on this front we found the scope to build an ontology on the basic concepts of CBT and to identify barriers to treatment. We contend that a knowledge modelling approach can be adopted to build an ontology by implementing CBT components for GD and BA, identify barriers to treatment, and rule/reasoning-based action plan generation.

In the next section, we present an account of knowledge modelling and engineering and knowledge based systems before proceeding to our research methodology.

3.2 Knowledge Engineering

Knowledge Engineering (KE) is defined as "the process of integrating knowledge into computer systems that are designed to imitate problem solving that normally requires human experts..." [80]. It is the development of a Knowledge-Based System (KBS) in any field [80]. Computing systems that integrate knowledge are known as KBSs. KBS consists of domain knowledge encoded in a knowledge representation formalism and a reasoning engine [80].

3.2.1 Knowledge

Knowledge is "The explicit functional associations between items of information and/or data" [30]. Knowledge can be used by a human or non-human agent to reason over and solve a problem [80]. In order for humans to reason over a problem, they require an internal cognitive representation of the external world. Similarly, a knowledge model is equivalent of the internal cognitive representation in case of non-human agents. So as to enable non-human agents to reason over this model, they require appropriate processes to algorithmically reason over the embedded knowledge to simulate intelligent behaviour [157].

The different types of knowledge are:

1. Declarative knowledge - This type of knowledge tells us facts about things. For instance, the statement 'A light bulb requires electricity to shine' is factually correct [80].

2. Procedural knowledge - This provides us with the skill to do something. For example, an individual will normally check the amount of water in a kettle before turning it on; if there is insufficient water in the kettle, then more will be added [80].

3. Meta-knowledge - This is knowledge about knowledge. It helps us understand how experts use knowledge to make decisions. For example, knowledge about planes and trains might be useful when planning a long journey and knowledge about footpaths and bicycles might be useful when planning a short journey [80].

It is important to understand this distinction since the type of knowledge determines the choice of adopting a knowledge representation formalism in order to develop a KBS [80].

3.2.2 Steps in Knowledge Engineering

The end product of Knowledge Engineering is KBS, which involves capturing knowledge, modelling and subsequently representing it appropriately so it can be used in the system [89].

Knowledge engineering constitutes of the following phases: -

1. Knowledge Acquisition

   The process of extracting, structuring and organizing knowledge obtained from various sources to be used in knowledge-based systems is referred to as knowledge acquisition [80]. Sources include human experts, books, videos and existing computer sources of data such as databases and the Internet [89]. The aim of knowledge acquisition is to acquire and structure data to that can be modelled to automate problem-solving for a particular domain and provide results similar to those provided by domain experts [80].

2. Knowledge Modelling

   The data gathered in the knowledge acquisition phase can be represented, for example, in the form of diagrams or annotated documents. This structured data can be used to build a knowledge model once it is validated, this process is called Knowledge Modelling. Knowledge is organized in terms of interconnected relations between concepts governed by rules and axioms. Recent advances in knowledge representation formalisms offers flexibility and expressiveness in modelling a domain [80]. In order to enable knowledge to be interpreted by a reasoning engine, it must be stored in a knowledge base by using a knowledge representation formalism [80, p. 55].

3. Knowledge Representation

   Knowledge representation is the process of expressing the knowledge model using a symbol system that is non-ambiguous, formalized, and structured. Ontologies are considered the heart of every knowledge representation since they provide a set way to represent reality by using a set of terms [80, p. 49].

   Knowledge representation can either be a rule-based model or a network-based model [137]. The main methods of knowledge representation for a knowledge formalism for a rule-based model is rules and theorems, whereas for a network-based model it is relationships between concepts [137].

   There are several other computer-friendly formalisms with varying levels of expressiveness when it comes to representing knowledge, such as, semantic networks, frames, description logics, conceptual graphs, and fuzzy logic [7].

The knowledge representation formalism selected to create a KBS dictates its expressiveness and whether it promotes or restricts knowledge sharing and reasoning [89].

Lomax et al. [100] have stated the complexity within CBT arises due to the interactions between different elements of CBT that influence one another. By adopting a knowledge modelling approach we computerize CBT in a bid to define the key concepts and the relations between them. In the next section, we will briefly discuss logic-based representation formalisms that can be used to create a KBS and our reasoning for choosing OWL which is a knowledge representation formalism based on description logics.

3.3 Knowledge Representation Formalisms

A knowledge model can be represented through natural languages but this causes ambiguity in interpretation due to high expressiveness. Using automated non-ambiguous formalisms allow only one interpretation of the knowledge contained within the model [80]. Some of the logic-based formalisms used to represent organized knowledge are semantic networks, frames, description logics and conceptual graphs [80]. These logic-based formalisms enable the representation of knowledge in varying levels of expressiveness with no ambiguity [80].

Semantic networks are graphs constructed using set of vertices (or nodes) representing concepts and a set of directed and labelled edges that represent semantic relations between the concepts [138]. Frames are a simplified version of a semantic network that utilizes only 'is a' relationships to associate concepts [89]. Conceptual graphs are a logical formalism based on existential graphs and semantic networks that denotes concepts and conceptual relations to represent classes and roles respectively [4, 80]. Since they lack the representation of knowledge using a formal semantics, it tends to makes these formalism too flexible to work with, hence it makes it difficult to represent complex cases [54].

This led to the emergence of ontologies that are a formal and explicit specification of conceptualization [54]. Description Logic (DL) denotes sets of individual concepts (classes), roles (relations) and individuals (objects) and is a logic-based knowledge representation formalism [80]. Both semantic networks and frames lack formal semantics, hence DL was introduced to overcome this deficiency [155].

A prominent application of DL is within ontology language applications [155]. OWL is a semantic web ontology language that can express knowledge such that it may be reasoned over to verify its consistency by DL reasoners such as Pellet, RACER or FaCT [161] [155]. The basis for designing OWL on DL was the ability of DL reasoners to provide reasoning services to OWL applications [155]. OWL helps to extract and express domain-specific knowledge in a user-friendly and machine-readable form [90]. OWL has three increasingly-expressive sub-languages which are OWL Lite, OWL DL, and OWL Full [161]. OWL Lite supports only simple class and property hierarchies and constraints on the classes and properties. OWL Full is highly expressive yet does not guarantee decidability, which means it lacks computational guarantee. OWL DL on the other hand supports maximum expressiveness similar to OWL Full, yet retains computational completeness and decidability [160]. For this purpose, we have chosen OWL DL as our knowledge representation formalism.

3.4 Ontologies

Owing to the rise of the semantic web, ontologies have emerged as the dominant knowledge representation formalism that is used to facilitate the creation of knowledge models that can be understood by both humans and computing systems [146].

3.4.1 Definition

Musen et al. [118] define ontology as a taxonomic description of the concepts in an application domain and the relationships among them. The three primary uses of ontologies in knowledge-intensive software systems have been identified as follows:

- "they provide a formalism that can facilitate clarification and description of the fundamental concepts in a domain through consensus of experts;
- they can facilitate interchange of information among diverse systems by describing, at various levels of detail, the kinds of data entities that can be exchanged, independent of the particular names the entities are given in each system; and
- they can promote reuse of software components through the development of ontologies of the components themselves (descriptions of what the components do) and the data entities they operate on [15]."

According to the [146], ontologies are defined according to four key aspects:

1. Ontologies are conceptualizations - They are abstract models consisting of concepts that are relevant for describing the real world. As such, ontologies represent concepts belonging to the real world.
2. Ontologies are explicit - The concepts, relations and other components of ontology are to be defined explicitly.
3. Ontologies are formal - Since ontologies are a non-ambiguous, formalized, and structured way to represent knowledge, they are expressed in a formal manner. The use of natural language is not appropriate due to its ambiguousness, inconsistency and incomplete specification.

4. Ontologies are shared - They are used to capture consensual knowledge established by a group of interested users. Consequently, by choosing a specific ontology, the user makes a commitment to a set of terms, or ontological commitments, which determine how and what to perceive in the reality [146].

Ontologies are used to group concepts of a specifically defined purpose. They are mainly developed to organize concepts under a common specification, often covering a complete domain, thereby facilitating knowledge sharing [80, p. 28].

The components of ontologies typically include the following:

- concepts, classes, collections, sets or types;
- objects, individuals, instances or entities;
- attributes, properties, or features of concepts or objects;
- attribute values;
- relations among classes and/or objects [49, 80].

The main advantage of ontologies lies in its ability to facilitate knowledge sharing and the fact that they are intended for organizing concepts under a common specification, often covering a complete domain [80, p. 29].

3.4.2 Ontology development

A search of the current literature revealed the core elements that constitute ontology development. Merlo et al. [107] formulated a series of competency questions used for ontology creation as well as validation, furthermore they discerned the main elements as well as relationships within the selected domain. These questions assisted them to identify the constraints related to the concepts they defined in the ontology. The ontology was modelled using Protégé, a tool that produces an OWL ontology. Merlo adopted Uschold and King's methodology to develop the FBA ontology. The methodology consists of 4 separate steps namely:

- Identification of the ontology purpose,
- capturing the concepts and the relations between the concepts,

- coding the ontology using a formal language, and
- evaluating the ontology from a technical point of view [107].

Larsen KR et al. [94] outlined three core elements that constitute the creation of an ontology. They are, creating a controlled vocabulary that defines classes, specifying the inter-relationships between classes, and lastly, coding in a computer readable format to enable knowledge generation, reuse, integration and analysis [94].

They divide ontology development into an incremental and iterative process with 5 steps: -

- Decide on the scope of the ontology.
- Develop a controlled vocabulary of classes and their properties.
- Develop a taxonomy that defines the parent–child relationships between classes.
- Expand on the single parent–child relationships described in the taxonomy to define all relevant relationships between the various classes including the parent–child relationships described by the taxonomy.
- Codify the ontology in a computer readable format [94].

Ontologies can be created manually using software tools or automatically from various existing information resources. Some well-known software tools for creating ontologies are Protégé [154], TERMINAE [16], KAON [86], DogmaModeler [33], HOZO [72] and OntoStudio [29] [80].

3.4.3 Types of Ontologies

Ontologies can be classified according to the subject of the conceptualisation [80] as well as the different levels of generality [146]. They are as follows:

1. Generic Ontologies These are used to describe general and domain-independent concepts such as events, time, space, matter, objects, actions, processes, causality and behaviour. They are also known as general, upper, foundational, top-level, or core ontologies since these concepts are common across all domains [80].

2. Specific Ontologies This type of ontology is used to represent concepts in a particular domain, application, task, activity, method, etc. They are further categorized as follows:

    (a) Domain Ontologies - They are re-usable in a particular domain, such as, medical, pharmaceutical, automobile, engineering, law, enterprise, etc.

    (b) Task or Method Ontologies - They are used to represent concepts of a particular task or activity, such as diagnosing a patient.

    (c) Application Ontologies - This is a combination of both domain ontology and task ontology, thus creating an ontology that can be used for application ontology [80].

3.4.4 Role of Ontologies in Knowledge Engineering

By itself, an ontology is a schema, but when combined with instances it becomes a knowledge-base. A KBS comprises of domain and problem-solving knowledge. It involves capturing, modelling, and appropriately representing the knowledge to be used in the system [89].The level of reasoning carried out by a KBS is dependent on the expressiveness and limitations of the knowledge representation formalism adopted [80]. The main role of ontologies in the knowledge engineering process is to allow the capture of domain knowledge in domain ontologies and problem solving expertise in task or method ontologies [146].

3.5 Ontology languages

Ontology languages allow for machine-processing of information since it allows users to create explicit, formal conceptualizations of domain models [144]. Ontologies must be encoded in formal ontology languages so as to be able to process them using reasoning rules [80]. Ontology languages can be classified on the basis of the system of logic a particular language is based on [80]. They are as follows:

1. Ontology languages based on description logic - originate from the field of artificial intelligence. Examples include KL-ONE [20] and LOOM [103].

2. Based on first-order logic - Examples include CYCL [36], KIF [46], Ontolingua [55] and Common Logic [23].

3. Ontology languages for the web - Examples include XML-based Ontology exchange Language (XOL) [128], Simple HTML Ontology Extension (SHOE) [67], Ontology Interchange Language (OIL) [38] and Web Ontology Language (OWL) [53].

OWL has emerged as the dominant choice for knowledge representation owing to its ties to the Web platform, and since it enables knowledge sharing, dissemination and reuse [80]. We will discuss OWL in detail in the next section.

3.6 Web Ontology Language (OWL)

Ontologies are coded in a computer readable format using ontology languages like OWL which is a broadly accepted ontology language of the Semantic Web [144]. The Semantic Web addresses the key goals of linking and meaning of data over the web [121]. Similar to the web, semantic web has technologies addressing the linking and meaning of data, that is Resource Description Framework (RDF) and Web Ontology Language (OWL) respectively. RDF is a web-native data model that incorporates hyperlinking [144]. OWL is a language derived from description logics, and offers more constructs over RDF Schema (RDFS) . It is built upon RDF and RDFS and has a similar syntax [144]. OWL allows automated reasoning of the knowledge contained in an ontology and addition of useful annotations to describe the knowledge model [144]. OWL 2 Second Edition, published in 2012, is the latest as of this writing.

OWL promotes the Semantic Web vision and is endorsed by the World Wide Web consortium (W3C) . An OWL ontology contains of individuals that indicate the objects of a specific field or domain. Relationships between two individuals are represented by properties. A collection of many individuals is called a Class [89].

3.6.1 Syntax

The primary syntax used to store OWL 2 ontologies and to exchange them among tools and applications is RDF/XML which must be supported across all OWL 2 tools

[161]. Another syntax used by several ontology editing tools to lend a more readable format is Manchester syntax [161].

3.6.2 Semantics

OWL 2 has Direct Semantics and RDF-Based Semantics that are used to assign meaning to OWL 2 ontologies [161]. In Direct Semantics, the ontology structure is used for reasoning using the SROIQ Description Logic. OWL 2 DL ontologies are interpreted using the direct semantics [161].

The RDF-Based Semantics assigns meaning to the ontology structure indirectly via mapping to RDF graphs first [161]. In this case, it is the RDF graphs that are used for reasoning [161].

3.7 Concluding Remarks

This chapter introduced the reader to a knowledge-based approach the self-management of depression using CBT and the advantages of using a knowledge representation formalism to do the same. We presented an overview of the related works on ontologies developed for CBT and highlighted the addressable gaps. Lastly, we talked about the Web Ontology Language (OWL) which is the predominant knowledge representation language in use today. The next chapter focuses on understanding some key concepts required to build a knowledge model of CBT.

Chapter 4

Core Principles of CBT Used in CBT Knowledge Modelling

This chapter will delve into some of the key concepts we must understand in order to build a knowledge model on CBT. We will highlight what depression is and the core principles of CBT that we will focus on while developing a knowledge model for CBT, namely, cognitive distortions, guided discovery, behavioural activation and self efficacy.

4.1 Depression

Kanter et al. [85] define depression as an emotional state that appeared as early on as 1665 where the core experience in psychiatric terms is dysphoric or "feeling down". This comes from the Latin word 'depressare' and the classical Latin work 'deprimere', which literally means "pressed down". They further say that people are irritable and deny being depressed can still meet the criteria for being depressed [85].

Bachmann [6] conducted a study of the epidemiology of suicide and the psychiatric perspective and observed that in the beginning of the 21st century, depression was the leading cause of death by unnatural reasons globally. Bachmann's study [6] concluded that the majority of suicides worldwide are related to psychiatric diseases among which depression constitutes one of the most relevant risk factors along with substance abuse and psychosis.

As mentioned in Depression Statistics Everyone Should Know [114], depression creates a dent in the financial stability of individuals, families, organizations and thereby society as a whole. Furthermore, it can result in affected individuals leading a poor quality of life that falls short of their potential due to reduced educational attainment, lower earning potential, and higher rates of unemployment [114]. Depression is of significant economic cost to society as a whole and is named as one of the top leading causes of disability worldwide [74, 114].

As of March, 2019 the total economic burden of depression has been estimated to be $210.5 billion per year [114]. Depression in working professionals leads to decreased productivity and absences from work in the workplace which attributes to 48% to 50% of the economic costs. Medical expenses take up 45% to 47% of the costs owing to outpatient and inpatient treatment as well as costs of medication [114]. The Global Burden of Disease (GBD) Study [43] found depressive disorders as the third-leading cause of disability globally in 2017.

As stated by [122], depression is characteristic of negative thoughts, moods and behaviour along with specific changes in bodily functions such as eating, sleeping, energy and sexual activity, as well as potentially developing aches or pains. There can be some differences in signs and symptoms of depression depending on age, gender and ethnicity [122].

CBT has been deemed as an effective treatment for depression [167]. The concepts ascertained from the sources [12], [27] and [52] as being integral to CBT are Treatment Goals, Action Plan, Barriers, Behavioural Activation, Cognitive Distortions, Guided Discovery, Self Efficacy.

A brief description of each concept can be found in Table 4.1 below. Figure 4.1 shows how the concepts listed are related to CBT.

Table 4.1: List of CBT concepts and their description

Concept	Description
Treatment Goal	Defined as guides to treatment to overcome a specific barrier [135].
Action Plan	The treatment goal is the target outcome, in order to achieve the target outcome, individuals focus on performing procedures that are small, realistic steps or objectives. This is called Action Plan [57].
Barriers	Obstacles that hinder an individuals performance when working on a goal [109].
Behavioural Activation	A core concept of CBT that encourages individuals to partake in activities to reduce depressive symptoms by increasing levels of mastery or pleasure [12].
Cognitive Distortions	Errors in thinking are called cognitive distortions [12].
Guided Discovery	A core concept of CBT used to encourage individuals to address cognitive distortions in a realistic and adaptive way [12].
Self Efficacy	Defined as the mediator that can determine an individuals' behaviour [134].

As can be seen from Figure 4.1, CBT is built on a cognitive model that shows one's thoughts, feelings and behaviour are inter-related [12]. Negative thoughts that

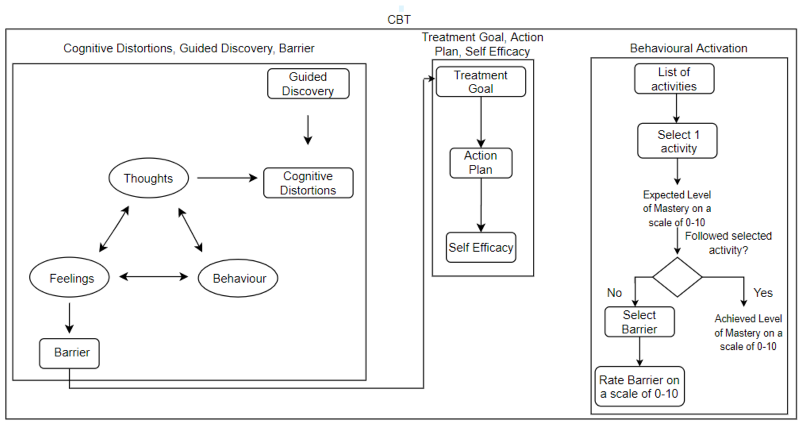


Figure 4.1: Core concepts of CBT

result in cognitive distortions are questioned by Guided Discovery (GD). Barriers are feelings one may have that hinders their progress to work towards a treatment goal. Treatment goals in CBT are linked to action plans. Behavioural Activation (BA) is a separate component that encourages patients to undertake activities.

4.2 Treatment Goal

CBT places focus on setting a treatment goal as it is associated with improving treatment compliance and adherence of the therapy [145]. Battle et al. [11] found patients with MDD listed treatment goals related to improving family or other social relationships, increasing positive health behaviours, finding a job, or organizing their home [11]. Researchers found that setting treatment goals showed an improvement in the outcome studies conducted for CBT amongst populations diagnosed with MDD [145].

4.3 Barrier

Weinberger et al. [164] state that perceived barriers to mental health care may be conceptualized as psychological (ie, stigma, social attitudes, beliefs about depression and its care), logistical (ie, transportation, availability of services) or illness-related that are either modifiable or not (eg, comorbid anxiety, depression severity, cognitive status) [164].

Dr Aaron T. Beck [142] developed self-assessment measures of depression called the Beck Depression Inventory-II (BDI-II) . BDI-II is one of the most widely used psychometric tests administered to patients in order to measure the severity of depression. It is a 21 item test scored on a value of 0-3 [142]. BDI-II evaluates 21 symptoms of depression, 15 of which cover emotions, four cover behavioural changes, and six somatic symptoms [124].

BDI-II lists illness-related concepts and these are potential barriers to working towards treatment goals [164].

4.4 Action Plan

An action plan stipulates the way to work towards attaining a specific treatment goal to be obtained [26]. Action plans convey a sense of taking control and being proactive in the self-management of one's depressive symptoms [12].

4.5 Cognitive Distortions

Depressed people interpret the world in an unrealistically pessimistic way and judge themselves in a harsh and unfair manner. The emotions they feel are based in large part on a negative way of interpreting their lives, this occurs due to distorted ways of thinking. If their thoughts about the world are unrealistic and negative, then their emotions will also be unrealistic and negative [27].

Dan Bilsker [27] explain distorted thinking as follows:

1. Unrealistic, negative thoughts about the situation - A depressed individual sees a situation in an unrealistic pessimistic way, and emphasize on its negative or threatening aspects while ignoring more positive or promising aspects.

2. Unfair, negative thoughts about oneself - The depressed individual thinks of themselves in a critical and unfair manner.

3. Unrealistic, negative thoughts about the future - The depressed individual anticipates negative outcomes in their future [27].

Taken together, this is called the Negative Triad: thinking in an unfair and unrealistic, negative way about your current situation, yourself, and your future [27].

Beck [12, p. 179] explains patients suffering from depression tend to make consistent errors in their thinking wherein there is a negative bias in the way they perceive themselves, their future and a situation. These errors in thinking are called Cognitive Distortions. Some common cognitive distortions are [12, p. 180]: -

1. All-or-nothing thinking: Viewing situations in only two categories instead of as a continuum. Example: “If I’m not a total success, I’m a failure.”

2. Catastrophizing: Predicting the future without considering other more likely outcomes. Example: “I’ll be so upset, I won’t be able to function at all.”

3. Mental filter: Paying attention to only the negative aspects of a situation instead of seeing the whole picture. Example: “Because I got one low rating on my evaluation [which also contained several high ratings] it means I’m doing a lousy job.”

4. Mind reading: When an individual thinks they know what others are thinking while failing to consider more likely possibilities. Example: “My room-mate doesn’t want to be bothered with me”

5. Disqualifying or discounting the positive: When an individual tells themselves that positive experiences, deeds, or qualities do not count. Example: “I did it once well but that doesn’t I can do it well. I just got lucky [12, p. 181].”

In order to tackle depression, both psychosocial as well as pharmacological treatments have been developed, this includes CBT, IPT and antidepressant medication [11].

4.6 Guided Discovery

It is important for patients to identify and respond to dysfunctional cognitions, in order to do this they must respond to their inaccurate or unhelpful ideas: - their automatic thoughts, images (mental pictures) and/or underlying beliefs [12, p. 22]. In order to do this, CBT incorporates Guided Discovery.

Guided Discovery usually has the following questions: -

- "What is the evidence that your thought is true? What is the evidence on the other side?"
- "What is an alternative way of viewing this situation?"
- "What is the worst that could happen and how could you cope if it did? What's the best that could happen? What's the most realistic outcome of this situation?"
- "What is the effect of believing your automatic thought and what could be the effect of changing your thinking?"
- "If your friend or family member were in this situation and had the same automatic thought, what advice would you give him or her?"
- "What should you do? [12, p. 23]"

4.7 Behavioural Activation

CBT places focus on behavioural activation which suggests that when a patient is relatively inactive it contributes to their low mood due to a paucity of opportunities to gain a sense of either mastery or pleasure hence it leads to negative thinking that ultimately brings about increased dysphoria and inactivity, leading to the patient getting caught up in a vicious cycle [13, p. 81].

Depression usually has a significant impact on a person's behaviour and the main areas affected are usually the following [27]: -

- Not doing rewarding activities - Most depressed individuals suffer from anhedonia, which is a reduced ability to enjoy the things they once used to owing to feeling tired or unmotivated. As a result, inactivity can become a habit in depressed individuals.
- Not taking care of yourself - Depressed individuals often tend to neglect looking after themselves. This could result in neglecting activities designed to maintain one's body and appearance such as personal grooming, exercising and disrupted eating habits.

- Not doing small duties - Small, necessary duties such as cleaning the house can be neglected as well. This can lead to adding stress to the individuals relationships.

- Withdrawing from family and friends - Depression impacts one's social life and can lead to social isolation [27].

If individuals increase the frequency of certain behaviours such as staying in bed, watching television and sitting around that could maintain or further increase their dysphoria, it can be tackled by incorporating lifestyle changes in their daily routine [13, p. 80].

The core of Behavioural Activation (BA) is to gradually identify activities and problems that the depressed patient avoids so as to establish valued directions to be followed. BA encourages individuals to start activity scheduling with short-term goals and to treat it as a series of appointments with themselves. Further, it encourages them to include activities that are soothing and pleasurable. Veale [156] states the importance of individuals monitoring the effects of their scheduled activities (and deviations from their plan) on their mood [156].

4.8 Self Efficacy

According to Albert Bandura, self-efficacy is "the belief in one's capabilities to organize and execute the courses of action required to manage prospective situations." In other words, self-efficacy is a person's belief in his or her ability to succeed in a particular situation. Bandura described these beliefs as determinants of how people think, behave, and feel [9].

Self-efficacy is an important element of CBT since positive changes in perceived self-efficacy are linked to an improved adaptive emotional and behavioural response to treatment [174].

Self-efficacy attainment has been shown to influence an individuals' motivations, accomplishments, self-regulation, and efforts to perform self-care actions [1].

Enhancing self-efficacy, that is, the ability to successfully perform a task or specific behaviour or change one's state of mind, is the driving force behind the self-management of one's depression [34]. Individuals using self-management have reduced depressive symptoms, lower relapse rates of depression, improved quality of life and psychosocial well-being, better adherence with medications, and a greater sense of self-efficacy [34]. Whereas low self-efficacy expectations have been shown to be associated with low task performance [2].

The "Decision Self-Efficacy Scale" measures self-confidence or belief in one's ability to make decisions, including participation in shared decision making. [79]

4.9 Concluding Remarks

This chapter lay emphasis on the core principles of CBT that we will focus on while developing a knowledge model for CBT, namely, cognitive distortions, guided discovery, behavioural activation and self efficacy. The next chapter delves into the research methodology we adopted to develop an OWL ontology based on CBT.

Chapter 5

Methodology

This chapter presents our research methodology wherein we discuss in detail the construction of an ontology-based knowledge model using a knowledge-based approach and the semantic web technology OWL. The knowledge-based solution approach is divided into three stages, which are listed below along with their corresponding knowledge engineering phase. They are as follows: -

1. Content Gathering — Knowledge Acquisition phase
2. Conceptual Modelling — Knowledge Modelling phase
3. Ontology Engineering — Knowledge Representation phase

5.1 Content Gathering - Knowledge Acquisition

In order to build a knowledge model of CBT, the first step would constitute gaining knowledge of the therapy. This constituted gathering the relevant content to be modelled. Therefore, it was essential to first gather information on the basic concepts of the theory. In order to do this, we read and scrutinized [12], [27] and [52] as well as referred to a domain expert to understand the main components of CBT.

The following concepts were ascertained from the sources [12], [27] and [52] as being integral to CBT: -

- Treatment Goals
- Action Plan
- Behavioural Activation
- Negative Thought Processes
- Guided Discovery

- Barriers
- Self Efficacy

We will take a closer look into each of these concepts.

5.1.1 Treatment Goals and Action Plans

Goal setting is considered an important and ongoing part of the CBT intervention. Treatment goals once set, require assessment to monitor the progress made [92].

Lam et al. [92] state that treatment goals are mostly identified in relation to illness but also in terms of specific targets relevant to work, leisure or family issues.

While reviewing online sources (blogs,websites) and the existing published literature to find relevant treatment goals and action plans, we followed the criteria as stated below: -

1. Inclusion Criteria:
   - Searched for papers and online sources using the following keywords: "Treatment goals set in CBT", "Most common goals set in CBT", "How to improve social skills", "Tips to improve non-family relations", "How to improve relationship with partner".
   - Included blogs that had mention of using CBT to treat depressive symptoms.
   - Included blogs that listed proven ways to address specific treatment goals, a search example of this is -"Ways to improve physical health".
2. Exclusion Criteria:
   - Blogs that had no mention of ways to improve depressive symptoms using CBT.
   - Papers that did not elaborate on goals addressed in CBT.
   - Blogs that did not list known ways to improve social relationships.

The literature points to goals listed in the treatment of chronic pain using CBT as being those related to Physical Activity, House/Yard Work, Recreational Activities, and Wellness goals [64]. Other than symptom reduction, many patients in therapy have other aims or goals they would like to achieve such as improved functioning, personal growth, and enhanced quality of interpersonal relationships [130].

Research shows that substantial functional impairments at home, work and school and in social relationships have led to depression ranking as the leading psychiatric disorder [116].

The preferences of treatment goals of depressed patients are rarely studied by means of observation or experience. Battle et al. [11] held a trial of behaviourally oriented psychotherapy to conduct a preliminary qualitative investigation to examine treatment goals by depressed outpatients. They found that the most common goals articulated by patients included improving social and family relationships, increasing physical health behaviours, finding a job and organizing one's home. The results of the study conducted by Battle et al. [11] helped determine that depressed individuals view functional improvements as key treatment goals in addition to improvements in the symptoms of depression. After reviewing the literature found on the most common treatment goals for depressive symptoms, we have adopted the following [11]: -

1. Social/family
    - Improve or increase number of non-family social relationships
    - Improve family (non-spouse/significant other) relationships
    - Improve spouse/significant other relationship
2. Occupational/financial
    - Improve existing work situation
3. Other
    - Improve physical health (e.g., increase physical exercise)
    - Organize or clean home

The knowledge model lists adapted treatment goals listed by Battle et al. [11] and the respective action plans for each goal.

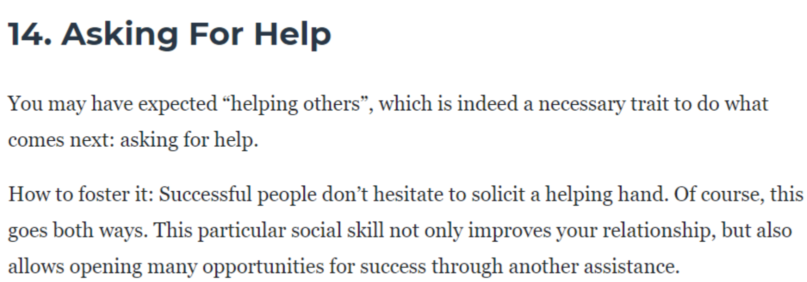
We listed some public health agencies (both governmental and non-governmental) that had material to support ways to address the treatment goals we listed above. We further scrutinized the websites' content and gathered all the content related to addressing the different broad categories of the treatment goals (Social/family, Occupational/financial, Other).

Table 5.1 provides a list of the online sources used to create action plans.

Table 5.1: List of online sources used to collect action plans

Source	Web Address
University of Delaware	https://www.udel.edu/[120]
Lifehack	https://www.lifehack.org/[97]
Focus On The Family	https://www.focusonthefamily.com/ [40]
PsychCentral	https://psychcentral.com[132]
Research Paper - Spouse "Together Time": Quality Time Within the Household	Glorieux, Ignace and Minnen, Joeri and van Tienoven, Theun Pieter [47]
Web MD	https://www.webmd.com[163]
Psychology Today	https://www.psychologytoday.com [133]
Workopolis Blog	https://careers.workopolis.com [18]
Interskills Training	http://www.interskills.edu.au [151]
Skills You Need Training	https://www.skillsyouneed.com [141]
The Muse	https://www.themuse.com[117]

An example of an action plan taken from [97] for the treatment goal 'Improve or increase number of non-family social relationships' in shown in Figure 5.1.


14. Asking For Help

You may have expected "helping others", which is indeed a necessary trait to do what comes next: asking for help.

How to foster it: Successful people don't hesitate to solicit a helping hand. Of course, this goes both ways. This particular social skill not only improves your relationship, but also allows opening many opportunities for success through another assistance.

Figure 5.1: An excerpt from www.lifehack.org

5.1.2 Behavioural Activation

Furukawa et al. [45] examined the aspects of expected or achieved mastery or pleasure in behavioural activation for depression. They conducted a randomized controlled trial to compare the effects of antidepressant medication along with CCBT against medication alone among patients with antidepressant-resistant depression [45]. The CCBT app used for the study was Kokoro which consists of eight sessions - one welcome session, two sessions each on self-monitoring, behavioural activation, cognitive restructuring, and an epilogue focusing on relapse prevention [45].

Furukawa et al. [45] categorized activities by the usual time they require to complete into - less than 5 seconds, less than 5 minutes, less than 60 minutes, and 60 minutes or more.

All the interactions of the patient with the Kokoro-app [45] include the chosen activity, expected mastery or pleasure levels, and achieved mastery or pleasure levels once the behavioural experiment is completed [45]. The researchers found that the expected and continued sense of pleasure in planning activities is what the participants found meaningful and rewarding. They state their finding as what contributes to the efficacy of BA [45].

Bardram et al. [10] conducted a study where they gathered paper-based behavioural activation forms from 5 patients, covering a total of 18 weeks, 115 days, and 1,614 hours of self-reported activity data to utilize patient generated activity data to develop a system that recommends activities to users. They extended their research and designed a system called Moribus to address depression in individuals by encouraging BA [10].

They developed six distinct activity categories to cover all types of activities based on the following [113]:

1. “Movement – Running, biking, taking a walk, swimming, dancing”

2. “Work & education – Updating CV, doing volunteer work, at the office”

3. “Sparetime & “hygge” (the Danish word for feeling cozy [166]) – Reading a book, watching TV, shopping”

4. “Daily living – Sleeping, getting up, eating, taking a bath, planning”

5. “Practical things – Vacuum cleaning, buying groceries, cooking, gardening”

6. “Social – Cup of coffee with a friend, cinema with mom, with guests”

The data collected from patients showed that the categories used in Moribus were sufficient to cover all 1,614 registered hours of activity. The data analysis revealed patients tend to focus on professional, social, and physical activities [10].

Bardram et al. [10] found that it took patients a little over 3 minutes to plan one day and around 20 minutes to plan a 7-day week.

The researchers [10] noted that most participants chose Saturday to undertake an activity, so we have adopted BA within our model such that the user can select an activity they would like to do once a week and rate their expected mastery/pleasure on a scale of 0 (no mastery/pleasure expected) to 10 (greatest mastery/pleasure expected) [45]. At the end of the week the user will be asked to rate their achieved mastery level on a scale of 0 (no mastery/pleasure achieved) to 10 (greatest mastery/pleasure achieved). This will be recorded in order to monitor the user's progress and to maintain a record of activities that were helpful in reducing depressive symptoms.

For the purpose of listing activities to enhance skill mastery for BA, the following two resources were used: -

1. Centre for Clinical Interventions - Behavioural Strategies for Managing Depression [42]

2. University of Michigan - Behavioural Activation for Depression [123]

We divided the activities into two categories based on the categories listed by [45] as: less than 60 minutes and greater than 60 minutes. Some of the activities taken from the two resources for BA are: -

1. Lesser than 60 minutes

    - Repairing things around the house
    - Playing musical instruments
    - Organising my wardrobe
    - Lighting scented candles, oils or incense

2. Greater than 60 minutes

    - Going on a picnic
    - Redecorating my home
    - Going to the beach
    - Doing arts and crafts

In cases where the user does not undertake an activity they selected, they will be shown a list of barriers and asked to select a barrier applicable to them [12] and rate their feeling on a scale of 0-10 [10].

As validated by the domain expert, once the user rates the feeling for a particular barrier selected, if the rating is less than or equal to 8, the model suggests an alternate activity the user can try in the following week. If the feeling rating is greater than 8 the model will suggest the user move out of the system and contact a therapist since their symptoms might have progressed into moderate or severe depression.

5.1.3 Negative Thought Processes

Labelling errors in thinking have been known to help patients identify and spot a pattern and are referred to as Cognitive Distortions [12]. The cognitive distortions were taken from Cognitive Behavior Therapy Basics and Beyond, Second Edition by Judith S. Beck [14].

Some of the common cognitive distortions we have incorporated in the knowledge model have been listed in Section 4.5.

5.1.4 Guided Discovery

This core concept of CBT ascertains which cognition or cognitions are most upsetting to the patient and through a series of questions, helps the patient gain distance so they may see their cognitions as ideas and proceed to validate the utility of such cognitions and/or decatastrophize their fears [12, p. 22].

For this purpose we have incorporated the following two questions that have been validated by the domain expert: -

- If someone I loved had this thought what would I tell them?

- If someone I loved knew I was thinking this thought, what evidence would they point out to me that would suggest that my thoughts were not 100% true?

5.1.5 Barriers

Our KM uses the concepts of BDI-II to list barriers to treatment goals that a user can select to work on.

Table 5.2 shows the barriers implemented in the KM.

Table 5.2: List of Barriers implemented in the KM

S.No	Barriers
1	I feel sad
2	I feel pessimistic
3	I feel like a failure
4	I feel guilty
5	I feel loss of pleasure
6	I feel I am being punished
7	I feel unlikeable
8	I blame myself for what has happened
9	I feel suicidal
10	I feel like crying
11	I feel agitated
12	I feel loss of interest
13	I feel indecisive
14	I feel worthless
15	I feel I am unable to do anything
16	I can't fall asleep
17	I feel tired
18	I don't have much of an appetite
19	I have difficulty concentrating
20	I am worried about my physical health
21	I have no interest in sex

5.1.6 Self Efficacy

We adopted the self efficacy values from the "The Decision Self-Efficacy Scale" which measures self-confidence or belief in one's ability to make decisions, including participation in shared decision making [79]. The Decision Self efficacy scale can be used over time or before and/or after an intervention is provided [79]. We have incorporated it within the model post providing the intervention to the user.

The Decision Self-Efficacy Scale has 5 response categories, from 0 to 4, ranging from "Not at all confident" to "Very confident" [79]. There is a modified 3 point version wherein items are given the following score values [79]:

- 0 - "Not Confident"

- 2 - “A Little Confident”
- 4 - “A Lot Confident” [79].

We have adopted a 3-point scale as follows: -

- 0 - Not confident
- 1 - Unsure
- 2 - Confident

Adopting from the Anti-depression skills workbook [27] where the authors speak about solving problems realistically. In order to do this one must look at the advantages and disadvantages of action plans. We have incorporated Decisional Balance Exercise that lists the pros and cons of following an action plan for the treatment goal selected by the user depending on the self efficacy value selected [79]. The pros and cons will be listed for options - “Not confident” and “Unsure”.

We gathered knowledge on Treatment Goals, Action Plans, Behavioural Activation, Negative Thought Processes, Guided Discovery, Barriers and Self Efficacy to be implemented in a KM for CBT that focuses on the two main principles of GD and BA. This culminates the knowledge acquisition phase and the gathered knowledge is now ready to be modelled [80].

5.2 Conceptual Modelling - Knowledge Modelling

Conceptual modelling is the process of organizing, shaping and transforming the acquired knowledge in a way that it is accurate yet can be represented by a knowledge representation formalism [80].

Figure 5.2 depicts the conceptualization of the knowledge model based on the acquired knowledge.

In order to construct an ontology we must define class concepts, their hierarchy, and the relationships among class concepts [83]. This process is called conceptualization, where the concepts, relations among defined concepts and constraints are set [83]. It represents a common understanding of a domain that can be shared by a larger community of domain experts [7].

Let’s take a closer look at the conceptualization of the CBT ontology.

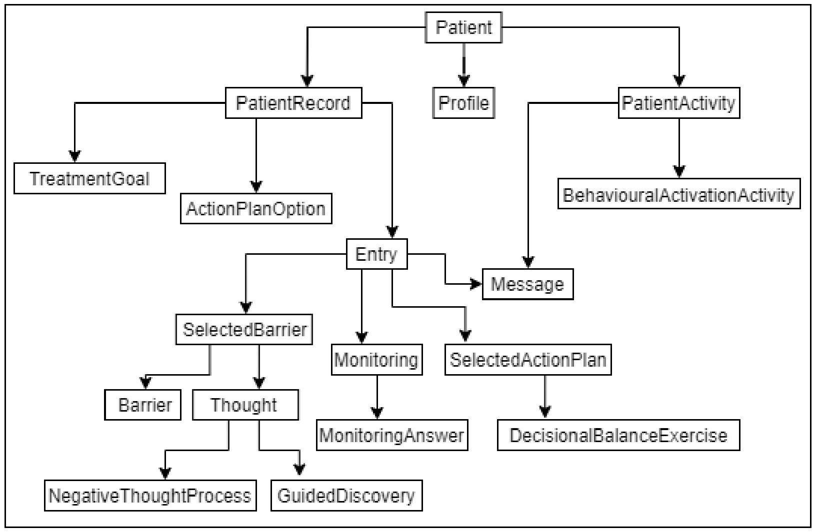


Figure 5.2: Conceptualization of knowledge model

5.2.1 Identify and define the concepts

The primary goal of CBT is to question the evidence of an individuals negative thoughts [12, p. 1]. It has been adapted in such a way that it is accepted and relevant for patients with diverse levels of education and income as well as a variety of cultures and ages ranging from young children to older adults [12, p. 3].

Battle et al. [11] investigated the treatment goal preferences of depressed patients and our solution approach incorporates their findings as the treatment goal options. Further research was conducted to link the treatment goals to their respective action plans.

As stated by Hu et al. [73] one of the tasks suitable for computer based automation of CBT has been implemented in our model namely impinging on a user's illogical or irrational thoughts by listing them in the 'NegativeThoughtProcess' class and subsequently challenging those beliefs through the 'Guided Discovery' class.

We identified the concepts from the knowledge gathered in the content gathering step. Table 5.3 lists the concepts identified in and its definition as intended to be used in our model.

Table 5.3: List of concepts identified along with their definition

Concept	Definition
Patient	Represents the individual

Continues. . .

Concept	Definition
Profile	Record patient profile that can change over time, such as marital status, living environment, occupation, distance to mall, time spent watching TV
Patient Record	Records treatment goal selected and entry instance
Entry	Records action plan options for selected treatment goal, selection of barrier to treatment goal and selected action plan
Treatment Goal	Represents the most common treatment goals that a depressed individual would address
Barrier	Lists barriers to addressing a treatment goal
Selected Barrier	To show actual selection of barrier by the individual
Thought	To handle multiple negative thought processes (cognitive distortions) for a particular barrier to treatment goal selected by an individual
Negative Thought Process	Represents cognitive distortions associated with barriers to treatment goal
Guided Discovery	Represents questions to ask for the evidence of negative thoughts
Action Plan	Represents action plan options categorized according to the Treatment Goal selected by the user
Patient Activity	To record activities selected by the individual for the purpose of Behavioural Activation
Behavioural Activation Activity	Lists activities for Behavioural Activation
Behavioural Activation Duration	To specify duration of Behavioural Activation activities
Decision Balance Exercise	Represents the pros and cons of action plans
Monitoring	To monitor whether user followed the selected action plan or not
Monitoring Answer	To maintain a record of whether the user wants to follow the same Action Plan for the coming week or try another action plan for the same treatment goal

Next, we will identify and define the relationships between the concepts.

5.2.2 Identify and define the relationships between concepts

An individual has a profile to record their personal information as well as patient activity to represent their selection of activities for behavioural activation and a patient record to record the treatment goal selected. To model this requirement, the concept Patient is related to the concept Profile, Patient Activity and Patient Record though *hasProfile*, *hasPatientActivity* and *hasPatientRecord* relationships respectively. Further, the concept PatientRecord is related to the concept Entry that records action plan options for the selected treatment goal, selection of barrier to the treatment goal and the selected action plan through *hasEntry* relationship.
A particular PatientRecord for an individual has a selected treatment goal and action

plan option. To model this requirement, this concept is related to the concepts Treatment Goal and Action Plan Option by *hasTreatmentGoal* and *hasActionPlanOption* respectively.

The Entry concept relates to the concepts SelectedBarrier, Monitoring, SelectedActionPlan and Message with the *hasSelectedBarrier*, *hasMonitoring*, *hasSelectedActionPlan* and *hasMessage* relationships.

In order to model the actual selection of a barrier by the individual we relate the concept SelectedBarrier to the concept Barrier with the *hasBarrier* relationship. It is related to the concept Thought with the *hasThought* relationship.

Thought concept has relations *hasNegativeThoughtProcess* and *hasGuidedDiscovery* to relate it to concepts NegativeThoughtProcess and GuidedDiscovery respectively.

The Monitoring concept is related to the MonitoringAnswer concept by the *hasMonitoringAnswer* concept. The SelectedActionPlan concept is related to DecisionBalanceExercise concept by the relations *hasPro* and *hasCon*. The PatientActivity concept relates to the BehaviouralActivationActivity concept by the relation *hasBAActivity*.

Table 5.4 summarizes the conceptualized relationships along with the domain and ranges set for each of them. It also specifies whether a particular relationship is inferred by the knowledge model or not.

Table 5.4: List of conceptualized relationships

Name of relation	Domain	Range	Inferred
hasProfile	Patient	Profile	No
hasPatientActivity	Patient	PatientActivity	No
hasPatientRecord	Patient	PatientRecord	No
hasEntry	PatientRecord	Entry	No
hasTreatmentGoal	PatientRecord	TreatmentGoal	No
hasActionPlanOption	PatientRecord	ActionPlanOption	Yes
hasSelectedBarrier	Entry	SelectedBarrier	No
hasMonitoring	Entry	Monitoring	No
hasSelectedActionPlan	Entry	SelectedActionPlan	No
hasMessage	Entry & PatientActivity	Message	No
hasBarrier	SelectedBarrier	Barrier	No
hasThought	SelectedBarrier	Thought	No

Continues...

Name of relation	Domain	Range	Inferred
hasNegativeThoughtProcess	Thought	NegativeThoughtProcess	No
hasGuidedDiscovery	Thought	GuidedDiscovery	Yes
hasMonitoringAnswer	Monitoring	MonitoringAnswer	No
hasPro	SelectedActionPlan	DecisionalBalanceExercise	Yes
hasCon	SelectedActionPlan	DecisionalBalanceExercise	Yes
hasBAActivity	PatientActivity	BehaviouralActivationActivity	No

5.2.3 Identify and define constraints to be imposed upon the concepts and relationships

Once the concepts and the relationships between have been identified, the next step is to identify the constraints to be imposed upon them [107].

Merlo et al. [107] formulated a series of competency questions related to the concepts used for ontology creation as well as validation. Furthermore they discerned the main elements as well as relationships within the selected domain. These questions assisted in identifying the constraints related to the concepts they defined in the ontology. Competency questions are expressed using natural language. They are requirements that are stated as questions [107]. The domain and scope of the ontology are defined using competency questions [80].

The competency questions and constraints set for our CBT ontology were validated by the domain expert.

Table 5.5 lists the competency questions formulated for the CBT ontology and the constraints set on them.

Table 5.5: List of competency questions formulated for the CBT Ontology and its relative constraints

Competency Questions	Constraints
How many profiles can a patient have?	Many-to-one
How many patient records per patient?	Many-to-one
How many instances of patient activity per patient?	Many-to-one
How many treatment goals can a patient record have?	One-to-one
How many action plan options per treatment goals?	Many-to-one
How many entries can a patient record have?	Many-to-one

Continues...

Competency Questions	Constraints
How many barriers can an entry have?	One-to-one
How many negative thoughts can be associated with a barrier?	Many-to-one
How many GD questions are associated with a negative thought?	Many-to-one
How many instances of monitoring can an entry have?	One-to-one
How many instances of decisional balance exercise can action plan have?	One-to-one
How many instances of patient activity can a patient have?	Many-to-one
How many behavioural activation activities per patient activity?	One-to-one

The explanation for the constraints defined are as follows: -

1. A patient can have multiple profiles that contain information that can vary over time. A timestamp property is used in order to maintain the record of the latest instance.

2. A patient can have multiple patient records to record the treatment goal selected, action plan options and selection of barrier and action plan.

3. A patient can try several activities for behavioural activation, hence can have multiple instances of patient activities to maintain a record of the activity selected.

4. A treatment goal is linked to multiple action plan options to be given to the user.

5. The patient record consists of different action plans attempted by the user, along with the self efficacy values. For this purpose it is linked to multiple entries. Each entry is subsequently monitored to check whether the user followed the particular action plan or not.

6. A user can select a barrier to the treatment goal post selecting the action plan. There can be multiple negative thought processes associated with a particular barrier.

7. Each negative thought is questioned by the Guided Discovery questions.

8. An action plan is linked to its respective pro and con that relates to the Decisional Balance Exercise.

9. For the purpose of BA, a user can select an activity they want to address for a week. So an instance of patient can be related to multiple instances of patient activity that record the expected and achieved levels of mastery along with whether the user followed the activity.

Figure 5.3 shows an example of the constraints set for SelectedBarrier, Thought, NegativeThoughtProcess and GuidedDiscovery in the form of an ER diagram using Crow's Foot notation to show the constraints on the relations set.

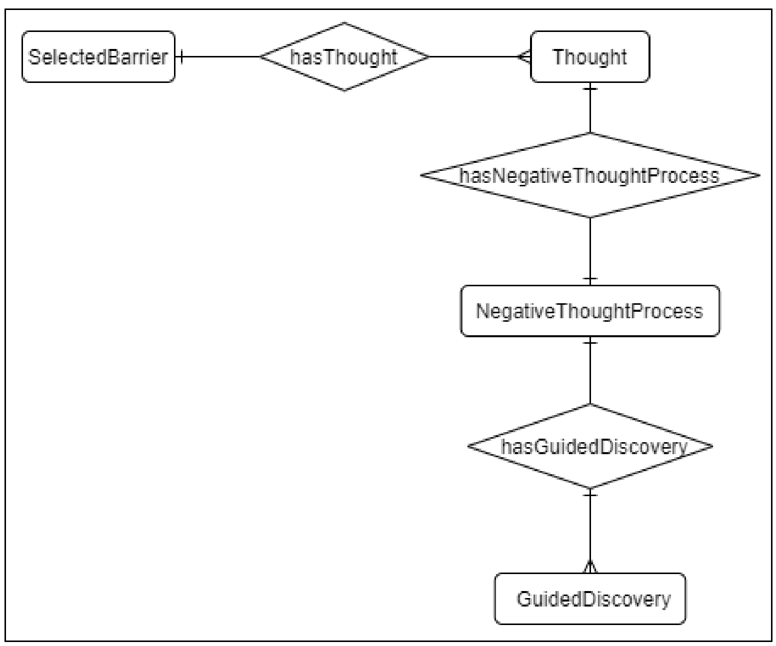


Figure 5.3: Relation between Selected Barrier, Thought, Negative Thought Process and Guided Discovery

It is important to note that the process of knowledge modelling is never complete. There is room for further improvement in a knowledge model since it is only an approximation of the real world [146].

Knowledge modelling is carried out in a number of iterations and the current version of the model serves as a starting point for each iteration. Further refinements, modifications or addition of new acquisition of knowledge can be added [80].

Hence, once acquired knowledge is modelled it can be represented in a machine-interpretable formalism so as to serve the purpose of automated reasoning [7]. We have used the OWL formalism to create a knowledge model.

5.3 Ontology Engineering - Knowledge representation

Ontology Engineering refers to the set of activities related to the ontology development process, the ontology life cycle, the methodologies, tools and languages for building ontologies [50, p. 5].

In order to construct the CBT ontology model, we exploited Protégé version 5.5, a free, open source ontology editor and knowledge-base framework as well as creating inference rules [154]. This section describes the model and the rules created.

After ontology development, information about concrete individuals (users) can be entered. [102]

5.3.1 Classes

Jakus et al. [80] explain a class as being used to define the properties and methods that can be used to manipulate the properties of all the objects that are instances of a particular class. Objects within a class have their state and behaviour defined by the properties within the particular class. Classes are abstractions of concrete objects, hence they correspond to concepts while objects correspond to instantiations of concepts. Classes are viewed as concepts since they combine a set of individual resources or objects with common properties [80].

The formal structure of the ontology regarding taxonomy, relationships, and axioms was validated by the domain expert.

The classes were constructed according to the concepts identified in Section 5.2.

A snapshot of the classes in the CBT ontology is shown in Figure 5.4.

5.3.2 Properties

The relationships between classes are represented by OWL properties. There are two types of properties, Object properties and Datatype properties. Object property connects two individuals thereby relating a class to another class. Data type property

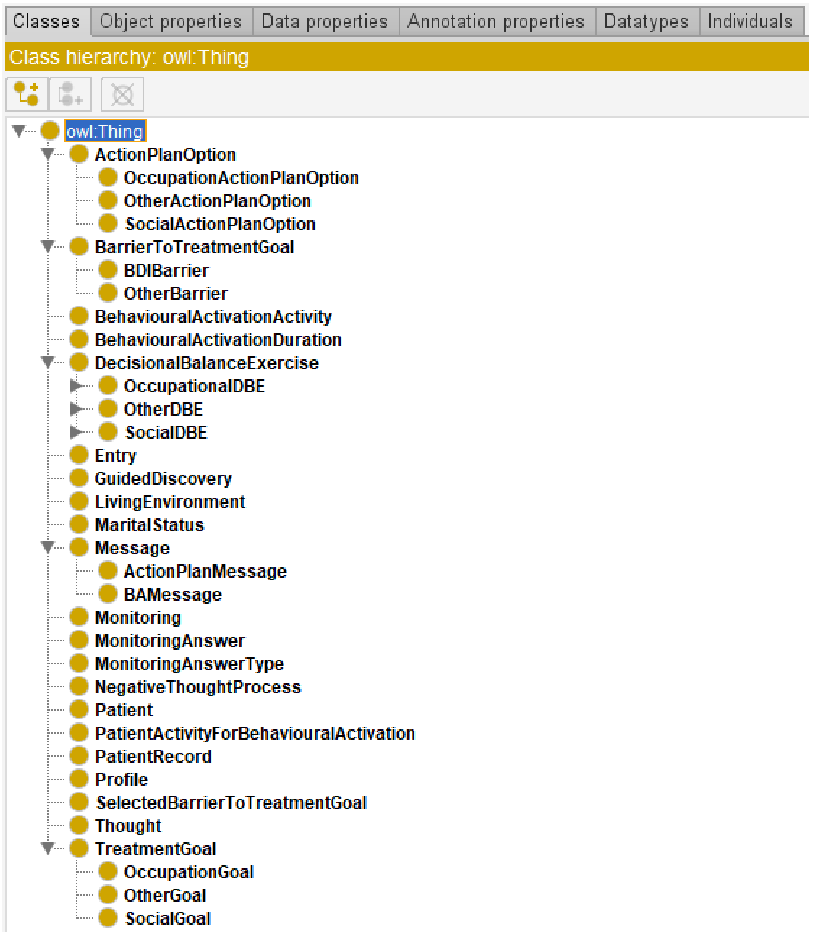


Figure 5.4: OWL Classes

connects an individual to an XML Schema Data type value or an RDF literal like numbers and strings [95]. Every property has a domain and range (codomain) to specify the constraints [171]. Object properties have classes in both their domain and range (codomain). Data type properties have classes in their domain and the range can be either a built in datatype or a data range expression [171].

For easy recognition of the domain and range of properties, the following naming convention was adopted [7]:

<concept>— <relationship>— <concept>OR <class>— <property>— <class>

The class on the left side indicates the domain of the object property and the class on the right indicates the range (codomain).

For example, consider the property patientHasProfile. This implies that the property has the domain “Patient” and the range “Profile”.

Translating the conceptualized relationships of the knowledge model into an OWL model resulted in the following properties. Tables 5.6 and 5.7 list the object properties and data type properties respectively, along with their domain, range and whether a property is inferred by the knowledge model or not.

Table 5.6: List of object properties in CBT ontology

Object Property	Domain	Range	Inferred
apOptionHasCon	ActionPlanOption	DecisionalBalanceExercise	No
apOptionHasPro	ActionPlanOption	DecisionalBalanceExercise	No
apOptionHasTreatmentGoal	ActionPlanOption	TreatmentGoal	No
baActivityHasDuration	BehaviouralActivationActivity	BehaviouralActivationDuration	No
entryHasMonitoring	Entry	Monitoring	No
entryHasSelectedActionPlan	Entry	ActionPlanOption	No
entryHasSelectedBarrier	Entry	SelectedBarrierToTreatmentGoal	No
entryShowCon	Entry	DecisionalBalanceExercise	Yes
entryShowPro	Entry	DecisionalBalanceExercise	Yes
hasMessage	Entry or PatientActivityForBehaviouralActivation	Message	Yes
monitoringHasAnswer	Monitoring	MonitoringAnswer	No
monAnsShowAnswer	MonitoringAnswer	MonitoringAnswerType	Yes
paHasBAActivity	PatientActivityForBehavioural Activation	BehaviouralActivationActivity	No
paHasBarrier	PatientActivityForBehavioural Activation	BarrierToTreatmentGoal	No
patientHasPatientActivity	Patient	PatientActivityForBehavioural Activation	No
patientHasPatientRecord	Patient	PatientRecord	No
patientHasProfile	Patient	Profile	No
patientRecordHasAPOption	PatientRecord	ActionPlanOption	No
patientRecordHasEntry	PatientRecord	Entry	No
patientRecordHasTreatment Goal	PatientRecord	TreatmentGoal	No
profileHasLivingEnvironment	Profile	LivingEnvironment	No
profileHasMaritalStatus	Profile	MaritalStatus	No
sbHasBarrier	SelectedBarrierToTreatmentGoal	BarrierToTreatmentGoal	No

Continues...

Object Property	Domain	Range	Inferred
sbHasThought	SelectedBarrierToTreatmentGoal	Thought	No
thoughtHasGD	Thought	GuidedDiscovery	Yes
thoughtHasNTP	Thought	NegativeThoughtProcess	No
treatmentGoalHasAPOption	TreatmentGoal	ActionPlanOption	No

Table 5.7: List of data type properties in CBT ontology

Data type Property	Domain	Range	Inferred
entryHasSEV	Entry	xsd:int[>="0"xsd:int,<="2"xsd:int]	No
monAnsHasFollowedAP	MonitoringAnswer	xsd:boolean	No
monAnsHasSameActionPlan	MonitoringAnswer	xsd:boolean	No
monitoringHasMonitoring TimeS-tamp	Monitoring	xsd:dateTimeStamp	No
paHasFeelingRating	PatientActivityForBehavioural Activation	xsd:int[>="1"xsd:int ,<="10"xsd:int]	No
paHasFollowedActivity	PatientActivityForBehavioural Activation	xsd:boolean	No
paHasMastery	PatientActivityForBehavioural Activation	xsd:int[>="1"xsd:int ,<="10"xsd:int]	No
patientHasDoB	Patient	xsd:dateTime	No
profileHasProfileProperty	Profile	-	No
profileHasMallCloseBy	Profile	xsd:boolean	No
profileHasOccupation	Profile	xsd:string	No
profileHasPropertyTimeStamp	Profile	xsd:dateTimeStamp	No
profileTimeSpentWatchingTV	Profile	xsd:float	No

A snapshot from Protégé 5.5 properties tabs are shown in Figures 5.5 and 5.6.

5.3.3 SWRL Rules

All the constraints imposed on the concepts and relationships in the conceptualization of our knowledge model were translated to some SWRL rules.

The Semantic Web Rule Language (SWRL) is an ontological language based on OWL-DL and on the Rule Markup Language (RuleML) that allows for expression and rules generation within a knowledge model [44].

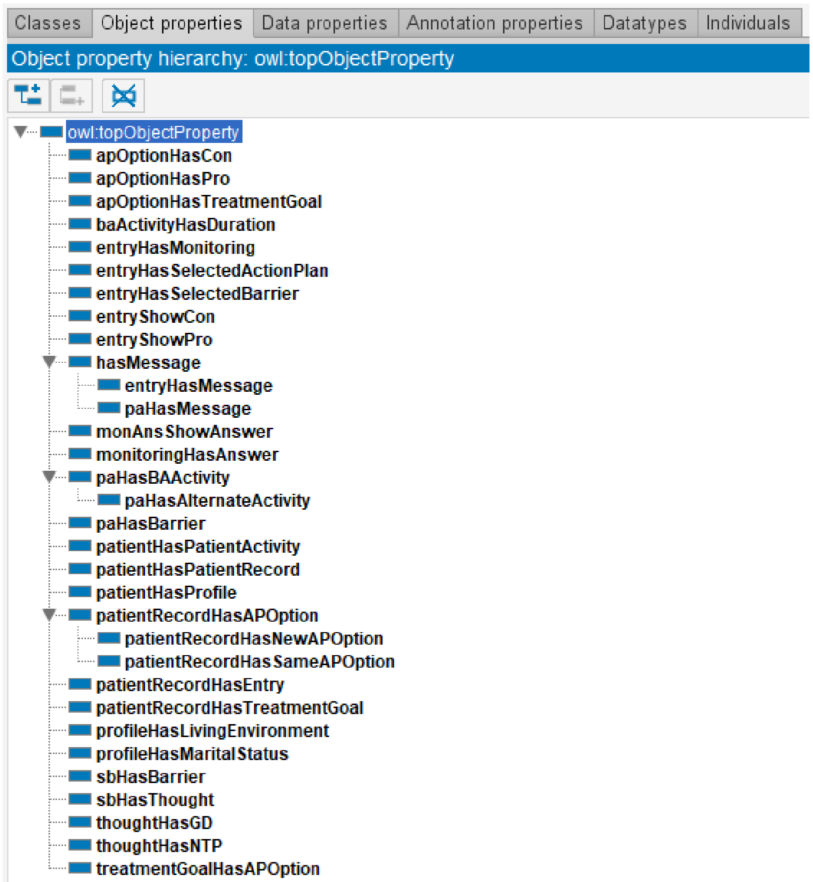


Figure 5.5: Object properties

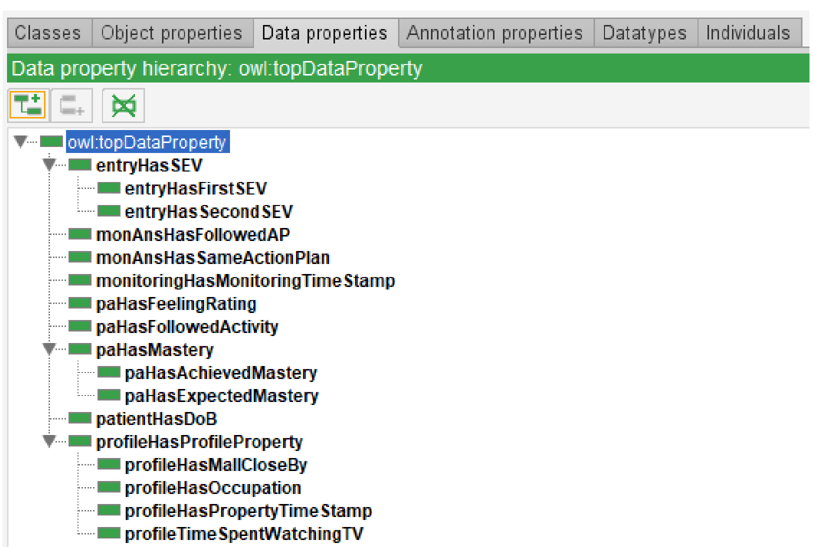


Figure 5.6: Data type properties

SWRL rules are implication rules. Hence, the syntax is as follows [44]:
antecedent → consequent

This syntax implies that the consequent must be true when the antecedent is satisfied. OWL expressions can occur in both the antecedent and consequent [44]. The part of the rule to the left of the arrow is the antecedent (body of the rule) and the part on the right is the consequent (head of the rule). The antecedent consists of multiple atoms delimited by the logical conjunction operator ∧. The consequent is evaluated to either true or false and is true if the antecedent holds — meaning all the atoms in the antecedent evaluate to true [44].

As stated by Fiorentini [39], SWRL allows for the usage of association rules, and to associate instances to new classes as well as create properties between instances [39].

Consider the following SWRL rule. The intent of this SWRL rule is to show the Guided Discovery questions to a patient for the negative thought processes listed so as to encourage pragmatic thinking.

Rule: Patient(?p), patientHasPatientRecord(?p, ?pr), patientRecordHasEntry(?pr, ?ap), entryHasSelectedBarrier(?ap, ?sb), sbHasThought(?b, ?t), thoughtHasNTP(?t, ?ntp) → thoughtHasGD(?t, 'If someone I loved had this thought what would I tell them?'), thoughtHasGD(?t, 'If someone I loved knew I was thinking this thought, what evidence would they point out to me that would suggest that my thoughts were not 100% true?')

Given the above rule, the atom thoughtHasNTP(?t, ?ntp) evaluates to true if there exists an asserted property thoughtHasNTP between some thought - denoted as ?t — and some negative thought process — denoted as ?ntp — in the instantiated ontology. In the same vein, all other atoms are evaluated to either true or false.

We will take a look at the sequence the above rule is executed in. Table 5.8 lists the OWL axioms that help us achieve the inferred output associated with the particular rule.

Table 5.8: List of OWL Axioms

Type	Axiom
ClassAssertion	(:Patient :patient1)

ObjectPropertyAssertion	(:patientHasPatientRecord :patient1 :patientRecord1_1)
ObjectPropertyAssertion	(:patientRecordHasEntry :patientRecord1_1 :entry1_1_1)
ObjectPropertyAssertion	(:entryHasSelectedBarrier :entry1_1_1 :selectedBarrier1_1)
ObjectPropertyAssertion	(:sbHasThought :selectedBarrier1_1 :thought1_1_1)
ObjectPropertyAssertion	(:thoughtHasNTP :thought1_1_1 :ntp4)

The axioms in table 5.8 can be diagrammatically represented as follows.

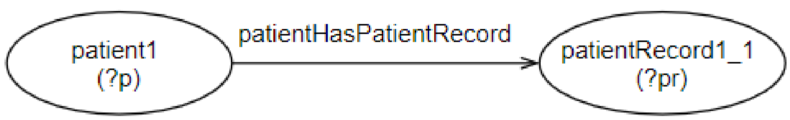


Figure 5.7: Diagrammatic representation of OWL Axiom 1

Figure 5.7 shows the axiom that infers the relationship between instances of Patient and PatientRecord classes.

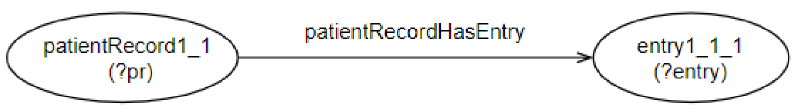


Figure 5.8: Diagrammatic representation of OWL Axiom 2

Figure 5.8 shows the relationship inferred for patientRecord and an instance of Entry class. Similarly figures 5.9, 5.10 and 5.11 show the axioms that infers the relationships between two instances belonging to different classes responsible for achieving GD in the CBT ontology.

If the five situations hold true in the instantiated ontology, then the consequent would evaluate to true resulting in entailment of thoughtHasGD relationship between the thought and GD question.

We saw how GD is achieved in the model, next, we look at how the SWRL rules achieve BA in the ontology.

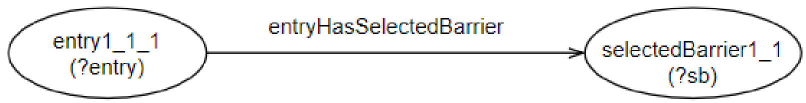


Figure 5.9: Diagrammatic representation of OWL Axiom 3

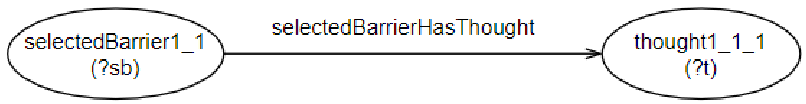


Figure 5.10: Diagrammatic representation of OWL Axiom 4

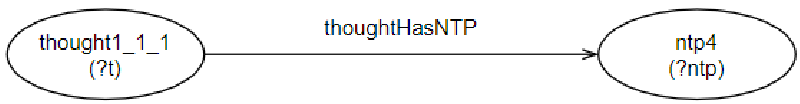


Figure 5.11: Diagrammatic representation of OWL Axiom 5

We implemented BA in the knowledge model as explained in Section 5.1.2. The SWRL rule responsible for listing an alternate activity to the patient is:
Rule: Patient(?p), patientHasPatientActivity(?p, ?pa), paHasBAActivity(?pa, ?act1), baActivityHasDuration(?act1, ?dur), paHasFollowedActivity(?pa, false), paHasFeelingRating(?pa, ?rate), lessThanOrEqual(?rate, 8), BehaviouralActivationActivity(?act2), DifferentFrom (?act1, ?act2), baActivityHasDuration(?act2, ?dur) → paHasAlternateActivity(?pa, ?act2)

The axioms of this rule are shown diagrammatically below. Figure 5.12 shows the

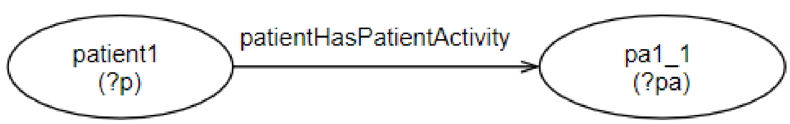


Figure 5.12: Diagrammatic representation of OWL Axiom 1

axiom that infers the relationship between instances of Patient and PatientActivity classes.

As seen in Figure 5.13, we used lessThanOrEqual, a swrl built-in property to check if the feeling rating of the barrier selected is less than 9, if so, the knowledge model must list an alternate activity.

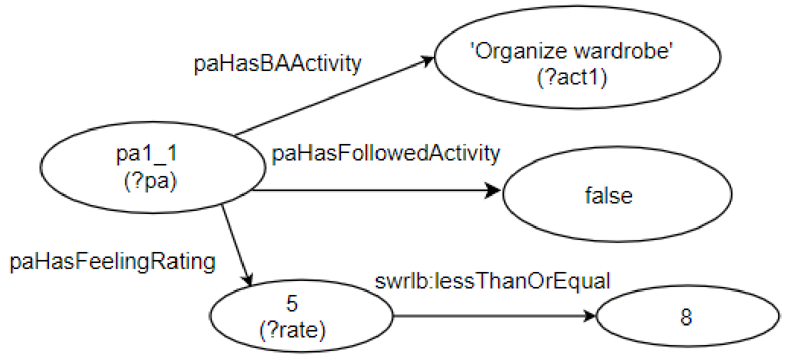


Figure 5.13: Diagrammatic representation of OWL Axiom 2

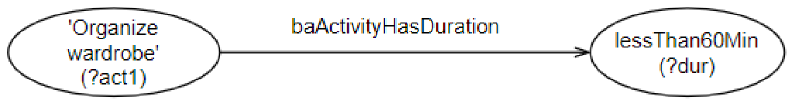


Figure 5.14: Diagrammatic representation of OWL Axiom 3

Figure 5.14 shows the axiom that infers the relationship between instances of PatientActivity and BehaviouralActivationDuration classes.

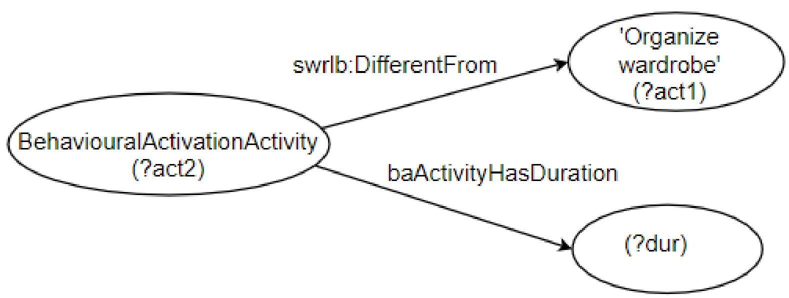


Figure 5.15: Diagrammatic representation of OWL Axiom 4

We use a swrl built-in property called DifferentFrom that checks if the specified URI references refer to different individuals [53]. In the above rule we use this property to check whether the activity selected by the patient, act1, is different from the suggested activity, act2.

If the above situations hold true, then the consequent is inferred resulting in the knowledge model suggesting the patient an alternate activity for the purpose of BA.

The knowledge model lists pros and cons of the selected action plan when the value of FirstSEV is 'Not confident' or 'Unsure', i.e when the value is less than 2.

The swrl rule responsible for doing this is:

Rule: Patient(?p), patientHasPatientRecord(?p, ?pr), patientRecordHasEntry(?pr, ?entry), entryHasSelectedActionPlan(?entry, ?plan), apOptionHasPro(?plan, ?pro), apOptionHasCon(?plan, ?con), entryHasFirstSEV(?entry, ?val), lessThan(?val, 2) → entryShowPro(?entry, ?pro), entryShowCon(?entry, ?con)

Given the above rule, the atom lessThan(?val, 2) checks if the instance of Entry class has a FirstSEV (Self Efficacy Value) value of 0 or 1. If this evaluates to true then the consequent infers the pro and the con associated with selected action plan. The atom entryShowPro(?entry, ?pro) denotes the inferred property entryShowPro between an instance of Entry class - denoted as ?entry and the pro associated with the action plan - denoted as ?pro. The atom entryShowCon(?entry, ?con) works similarly for the con.

Table 5.9 lists the SWRL Rules created in the knowledge model.

Table 5.9: List of SWRL Rules in CBT ontology

Description	SWRL Rule
Display message after selecting SEV	
	Patient(?p), patientHasPatientRecord(?p, ?pr), patientRecordHasEntry(?pr, ?entry), entryHasFirstSEV(?entry, ?sev), equal(?sev, 2) → entryHasMessage(?entry,'Go ahead with your action plan :)')
	Patient(?p), patientHasPatientRecord(?p, ?pr), patientRecordHasEntry(?pr, ?entry), entryHasSecondSEV(?entry, ?sev), equal(?sev, 2) → entryHasMessage(?entry, 'Go ahead with your action plan :)')
	Patient(?p), patientHasPatientRecord(?p, ?pr), patientRecordHasEntry(?pr, ?entry), entryHasSecondSEV(?entry, ?sev), equal(?sev, 0) → entryHasMessage(?entry, 'We understand you need some time, please feel free to try again in a couple of days :)')
Display message for BA activities	
	Patient(?p), patientHasPatientActivity(?p, ?pa), paHasFollowedActivity(?pa, true) → paHasMessage(?pa, 'Thank you for trying this activity! You can try the same activity or pick another one for the next week :)')
	Patient(?p), patientHasPatientActivity(?p, ?pa), paHasFollowedActivity(?pa, false), paHasFeelingRating(?pa, ?rate), lessThan(?rate, 9) → paHasMessage(?pa, 'Try these alternate activities instead.')
	Patient(?p), patientHasPatientActivity(?p, ?pa), paHasFollowedActivity(?pa, false), paHasFeelingRating(?pa, ?rate), greaterThanOrEqual(?rate, 9) → paHasMessage(?pa, 'I understand you are not feeling your best. I suggest moving out of the system and contacting a therapist so you can get the care you deserve :)')

Continues...

Description	SWRL Rule
Display Guided Discovery questions	Patient(?p), patientHasPatientRecord(?p, ?pr), patientRecordHasAPEntry(?pr,?ap), apEntryHasSelectedBarrier(?ap, ?sb), sbHasThought(?b, ?t), thoughtHasNTP(?t, ?ntp) → thoughtHasGD(?t, 'If someone I loved had this thought what would I tell them?'), thoughtHasGD(?t, 'If someone I loved knew I was thinking this thought, what evidence would they point out to me that would suggest that my thoughts were not 100% true?')
List Decision Balance Exercise for action plans where first self efficacy value = 0 or 1	Patient(?p), patientHasPatientRecord(?p, ?pr), patientRecordHasEntry(?pr, ?entry), entryHasSelectedActionPlan(?entry, ?plan), apOptionHasPro(?plan, ?pro), apOptionHasCon(?plan, ?con), entryHasFirstSEV(?entry, ?val), lessThan(?val, 2) → entryShowPro(?entry, ?pro), entryShowCon(?entry, ?con)
Monitoring of action plans	Monitoring(?m), monitoringHasAnswer(?m, ?a), monAnsHasFollowedAP(?a, true) → monAnsShowAnswer(?a, feelingAfterAP) Rule: Monitoring(?m), monitoringHasAnswer(?m, ?a), monAnsHasFollowedAP(?a, false) → hasMessage(?a, 'We understand you need some time, please feel free to try again in a couple of days :)')
Display action plan options for different treatment goals	Patient(?p),patientHasPatientRecord(?p, ?pr),patientRecordHasTreatmentGoal(?pr, 'Improve non family social relations') → patientRecordHasAPOption(?pr, 'Ask others for help'), patientRecordHasAPOption(?pr, 'Use words such as "please", "thank you", "sorry" and "excuse me"'), patientRecordHasAPOption(?pr, 'Think twice before speaking') Patient(?p),patientHasPatientRecord(?p, ?pr),patientRecordHasTreatmentGoal(?pr, 'Improve relationship with spouse/significant other')→ patientRecordHasAPOption(?pr,'Will show physical affection to my partner by hugging them every day'), patientRecordHasAPOption(?pr,'Will establish a time each day to spend quality time together') Patient(?p), patientHasPatientRecord(?p, ?pr), patientRecordHasTreatmentGoal(?pr, 'Improve family (non-spouse/significant other) relationships') → patientRecordHasAPOption(?pr, 'Use "I" sentences instead of "You" sentences'), patientRecordHasAPOption(?pr, 'Spend time with family by having atleast one meal together every day'), patientRecordHasAPOption(?pr, 'Spend time with family by going on a walk post dinner every alternate day'), patientRecordHasAPOption(?pr, 'Actively listen to my family members') Patient(?p), patientHasPatientRecord(?p, ?pr), patientRecordHasTreatmentGoal(?pr, 'Improve physical health'), patientHasProfile(?p, ?profile), profileTimeSpentWatchingTV(?profile, ?tv), greaterThanOrEqual(?tv, 0.25) → patientRecordHasAPOption(?pr, 'Exercise while watching TV'), patientRecordHasAPOption(?pr, 'Run for 15 minutes everyday')

Continues...

Description	SWRL Rule
	Patient(?p), patientHasProfile(?p, ?profile), patientHasPatientRecord(?p, ?pr), patientRecordHasTreatmentGoal(?pr, 'Improve physical health'), profileTimeSpentWatchingTV(?profile, ?tv), lessThan(?tv, 0.25) → patientRecordHasAPOption(?pr, 'Run for 15 minutes everyday')
	Patient(?p), patientHasProfile(?p, ?profile), profileHasMallCloseBy(?profile, true), patientHasPatientRecord(?p, ?pr), patientRecordHasTreatmentGoal(?pr, 'Improve physical health') → patientRecordHasAPOption(?pr, 'Walk indoors at local shopping mall'), patientRecordHasAPOption(?pr, 'Run for 15 minutes everyday')
	Patient(?p), patientHasProfile(?p, ?profile), patientHasPatientRecord(?p, ?pr), patientRecordHasTreatmentGoal(?pr, 'Improve physical health'), profileHasMallCloseBy(?profile, false) → patientRecordHasAPOption(?pr, 'Run for 15 minutes everyday')
	Patient(?p), patientHasPatientRecord(?p, ?pr), patientRecordHasTreatmentGoal(?pr, 'Organize or clean home') → patientRecordHasAPOption(?pr, 'Put away 5 things every time I get up from my chair'), patientRecordHasAPOption(?pr, 'Make my bed every morning as soon as I wake up')
	Patient(?p), patientHasPatientRecord(?p, ?pr), patientRecordHasTreatmentGoal(?pr, 'Improve existing work situation') → patientRecordHasAPOption(?pr, 'Take 5 minute breaks every hour to walk around the office'), patientRecordHasAPOption(?pr, 'Practice deep breathing for 30 seconds when taking a break')
List BA Activities if feeling rating is <=8 depending on duration of selected activity	
	Patient(?p), patientHasPatientActivity(?p, ?pa), paHasBAActivity(?pa, ?act1), baActivityHasDuration(?act1, ?dur), paHasFollowedActivity(?pa, false), paHasFeelingRating(?pa, ?rate), lessThanOrEqual(?rate, 8), BehaviouralActivationActivity(?act2), DifferentFrom (?act1, ?act2), baActivityHasDuration(?act2, ?dur) → paHasAlternateActivity(?pa, ?act2)
Follow same action plan or try a new one	
	Patient(?p), patientHasPatientRecord(?p, ?pr), patientRecordHasAPEntry(?pr, ?entry), apEntryHasSelectedActionPlan(?entry, ?plan1), apEntryHasMonitoring(?entry, ?mon), monitoringHasAnswer(?mon, ?ans), monAnsHasFollowedAP(?ans, true), monAnsHasSameActionPlan(?ans, true), ActionPlanOption(?plan2), SameAs(?plan1, ?plan2) → patientRecordHasSameAPOption(?pr, ?plan2)
	Patient(?p), patientHasPatientRecord(?p, ?pr), patientRecordHasTreatmentGoal(?pr, ?tg), patientRecordHasEntry(?pr, ?entry), entryHasSelectedActionPlan(?entry, ?plan1), entryHasMonitoring(?entry, ?mon), monitoringHasAnswer(?mon, ?ans), monAnsHasFollowedAP(?ans, true), monAnsHasSameActionPlan(?ans, false), ActionPlanOption(?plan2), apOptionHasTreatmentGoal(?plan2, ?tg) → patientRecordHasNewAPOption(?pr, ?plan2)

5.4 Concluding Remarks

This chapter highlighted the research methodology adopted to develop an ontology-based knowledge model and the three steps - (1) Content Gathering, (2) Conceptual Modelling and (3) Ontology Engineering that were undertaken to build the CBT ontology.

Chapter 6

Evaluation and Results

In order to assess the CBT ontology on the grounds of whether it correctly implements the ontology requirements and answers the competency questions set forth in the design phase, we validated the model by a domain expert as well as conducted an evaluation to check the completeness, consistency and conciseness of the model.

6.1 Validation by Domain Expert

The domain expert validated the concepts and the relationships between the concepts along with which properties should be inferred by the knowledge model.

For BA, the domain expert suggested we show one alternate activity if the barrier feeling rating is between 0 and 8. Whereas if it is greater than 8, then we should suggest the user move out of the system and contact their therapist. Initially the model only recorded the feeling rating of the barrier if the user did not go through with an activity selected for behavioural activation.

Messages displayed by the model to the patient were changed to show empathy and understanding. Some examples of validated changes are: -

1. "Go ahead" changed to "Go ahead with your action plan" The word "your" was added since it gives the patient a sense of ownership.

2. "Try again in a couple days" changed to "We understand you need some time, please feel free to try again in a couple of days :)" to show empathy and understanding towards the patient.

3. Decision Balance Exercise Pro for the action plan "Walk for 20 minutes every alternate day", was initially "Helps to reduce depressive symptoms", this was changed to "Helps to feel happier by reducing depressive symptoms" so as to emphasize "happiness".

4. Decision Balance Exercise Con for "Walk for 20 minutes every alternate day", was initially "Lack of exercise tends to increase depressive symptoms due to reduction in the release of endorphins", this was changed to "Lack of exercise causes an increase in depressive symptoms" to keep it simple and straightforward.

For DBE, the domain expert suggested listing the pros and cons for Self Efficacy values - "Not confident" and "Unsure". Earlier, the question was "Are you confident to go ahead with this action plan?", and the options were "Yes" and "No".

6.1.1 Case Studies

Our case studies demonstrate that the CBT ontology is complete since the concepts, relationships and SWRL rules result in achieving inferred output that answer the competency questions correctly.

Each case study takes the patient's profile information that was validated by the domain expert as input. It takes the patient record that instantiates selected treatment goal, barrier and negative thought process. As well as patient activity that instantiates BA as validated by the domain expert. We wanted to showcase how the knowledge model personalizes the action plan options given as inferred output based on the treatment goal selected. Furthermore, it covers the different messages displayed based on the SEV value selected and BA activity monitoring. It also shows scenarios wherein DBE need to be listed as inferred output.

Table 6.1 lists the case studies validated by the domain expert. It lists the input, expected output and inferred output for three case studies.

Table 6.1: Case Studies

Case Study	Input	Expected Output	Inferred Output
1	Occupation: Student Home: Apartment Living Environment: Urban Marital Status: Single		
	Treatment Goal: Improve number of non family social relationships	List action plan options for selected treatment goal	Ask others for help Think twice before speaking Use words such as "please", "thank you", "sorry" and "excuse me"
	Selected action plan: Ask others for help Barrier: I feel shy		

Continues...

Case Study	Input	Expected Output	Inferred Output
	Negative Thought Process: Mind reading	List Guided Discovery Questions	If someone I loved had this thought what would I tell them? If someone I loved knew I was thinking this thought, what evidence would they point out to me that would suggest that my thoughts were not 100% true?
	1st Self Efficacy Value (SEV): 0	List DBE associated with selected action plan if 1st SEV = 0	Pro - Gives opportunity for success through assistance by others Con – Negative impact on your confidence
	2nd SEV: 2	Display message for 2nd SEV = 2	Message: “Go ahead with your action plan :)”
	Selected Activity for BA: Going out to dinner		
	Expected Level of Pleasure: 5		
	Followed BA Activity?: Yes		
	Achieved Level of Pleasure: 8	If BA activity was followed, display message	Message: “Thank you for trying this activity! You can try the same activity or pick another one for the next week :)”
2	Occupation: Marketing Manager		
	Home: Apartment		
	Living Environment: Urban		
	Marital Status: Married		
	Treatment Goal: Improve relationship with spouse	List action plan options for selected treatment goal	Will establish a time each day to spend quality time together Will show physical affection to my partner by hugging them everyday
	Selected action plan: Will show physical affection to my partner by hugging them everyday		
	Barrier: I feel guilty		
	Negative Thought Process: Mental filter	List Guided Discovery Questions	Same as Case Study 1
	1st SEV: 2	Display message for 1st SEV = 2	Message: “Go ahead with your action plan :)”
	Selected Activity: Organising my wardrobe		
	Expected Level of Pleasure: 7		
	Did you do the activity? No		
	Selected Barrier: I am unable to do anything		
	Feeling Rating: 5	Show message and alternate activity matching duration of selected activity if feeling rating <9	Message: “Try this activity instead”
3	Occupation: Home maker		Make a list of things you are grateful for
	Home: Bungalow		
	Living Environment: Urban		
	Marital Status: Married		
	Treatment Goal: Improve physical health	List action plan options for selected treatment goal	Run for 15 minutes everyday Walk indoors at local shopping mall
	Selected action plan: Run for 15 minutes everyday		
	Barrier: I don’t have time to exercise		

Continues. . .

Case Study	Input	Expected Output	Inferred Output
	Negative Thought Process: Disqualifying or discounting the positive	List Guided Discovery Questions	Same as Case Study 1
	1st SEV: 1	List DBE associated with selected action plan if 1st SEV = 1	Pro- Helps to feel happier by reducing depressive symptoms Con – Lack of exercise causes an increase in depressive symptoms
	2nd SEV: 0	Display message for 2nd SEV = 0	Message: "We understand you need some time, please feel free to try again in a couple of days :)"
	Selected Activity: Go on a picnic with friends Expected Level of Pleasure: 7 Did you do the activity? No Selected Barrier: I feel worthless		
	Feeling Rating: 9	Show message if feeling rating >= 9	Message: "I understand you are not feeling your best. I suggest moving out of the system and contacting a therapist so you can get the care you deserve :)"

The properties inferred by the knowledge model for instances of PatientRecord, Entry and PatientActivity for each case study shows the inferred output match the expected output.

The SWRL rule listed in Table 5.9 for listing action plan options based on the selected treatment goal lists the options as output. This can be seen in Figure 6.1 that shows the PatientRecord instance for Case Study 1.

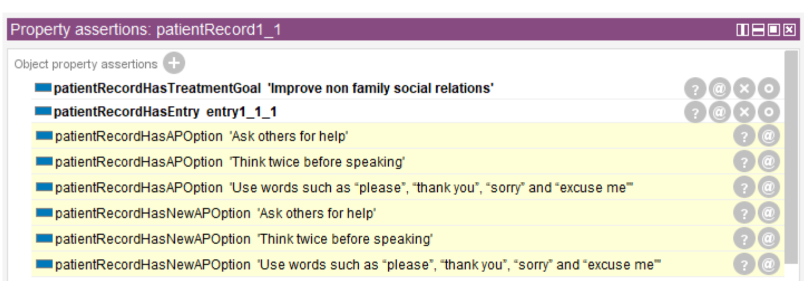


Figure 6.1: Showing inferred properties for PatientRecord instance for Case Study 1

The SWRL rule listed in Table 5.9 displays the decisional balance exercise when the first self efficacy value is 0 or 1, this lists the pro and con of following an action plan as the output. This can be seen in Figure 6.2 that shows the Entry instance for Case Study 1.

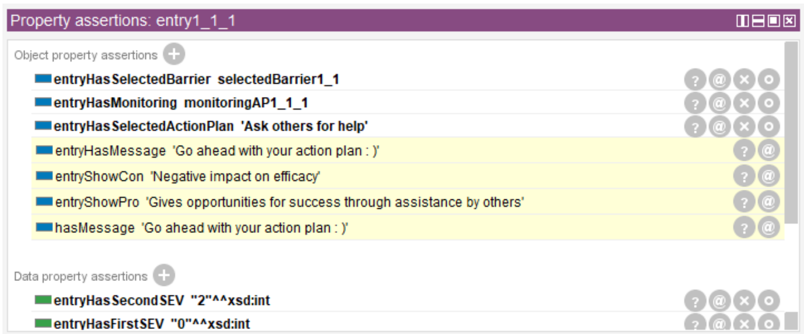


Figure 6.2: Showing inferred properties for Entry instance for Case Study 1

The PatientActivity class instantiates the Behavioural Activation concept of CBT. Patient can select an activity for the purpose of BA, then state the expected level of pleasure. If the activity was completed, the achieved level of pleasure is taken as input.

The SWRL rule listed in Table 5.9 displays the message for BA activities when patient follows the selected BA activity and can be seen in Figure 6.3 that shows the PatientActivity instance for Case Study 1.

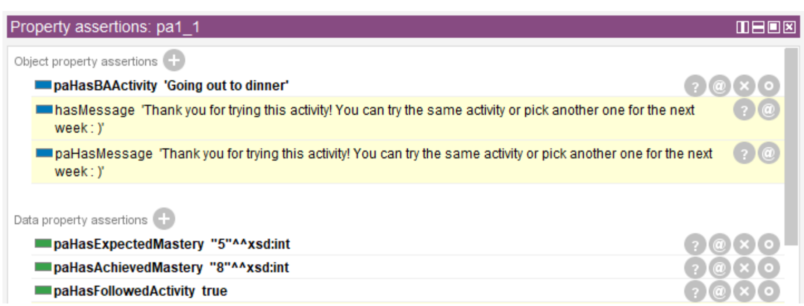


Figure 6.3: Showing inferred properties for PatientActivity instance for Case Study 1

The SWRL rule listed in Table 5.9 for listing action plan options based on the selected treatment goal lists the options as output. This can be seen in Figure 6.4 that shows the PatientRecord instance for Case Study 2.

Figure 6.5 shows the DBE for action plan that shows the Entry instance for Case Study 2.

The SWRL rule listed in Table 5.9 displays the message for BA activities when

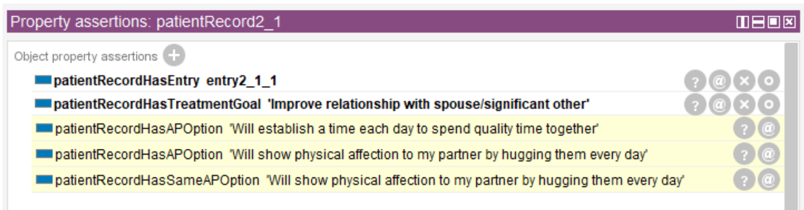


Figure 6.4: Showing inferred properties for PatientRecord instance for Case Study 2

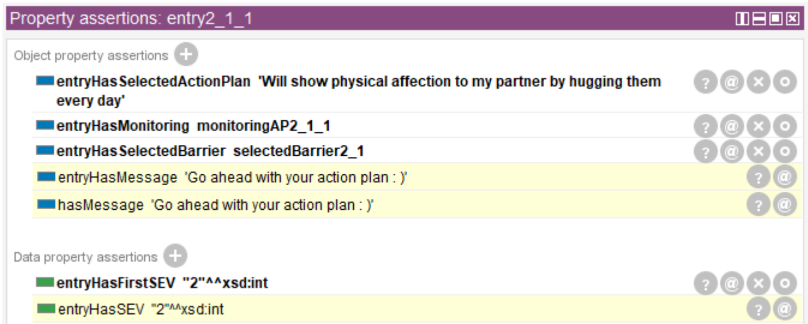


Figure 6.5: Showing inferred properties for Entry instance for Case Study 2

patient does not follow the selected BA activity and selects a barrier and lists a feeling rating less than 9. This can be seen in Figure 6.6 that shows the PatientActivity instance for Case Study 2.

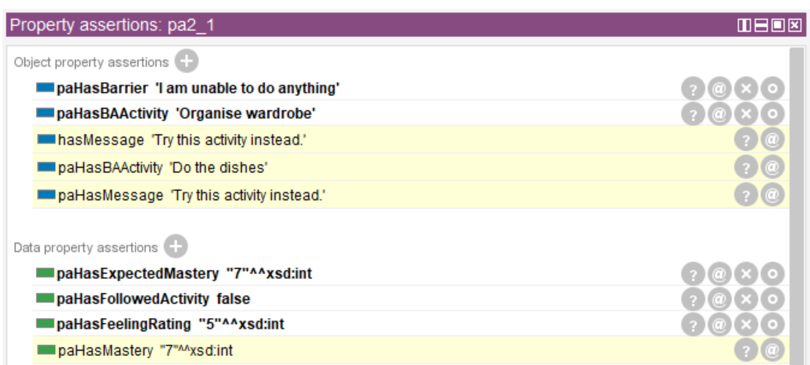


Figure 6.6: Showing inferred properties for PatientActivity instance for Case Study 2

The SWRL rule listed in Table 5.9 for listing action plan options based on the selected treatment goal lists the options as output. This can be seen in Figure 6.7 that shows the PatientRecord instance for Case Study 3.

Figure 6.8 shows the DBE for action plan that shows the Entry instance for Case

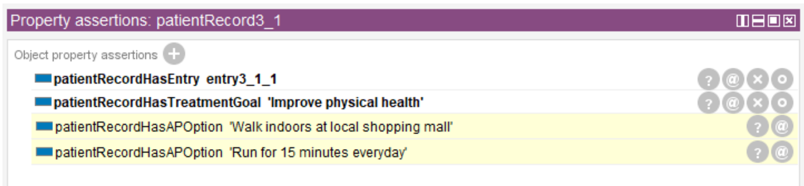


Figure 6.7: Showing inferred properties for PatientRecord instance for Case Study 3

Study 3.

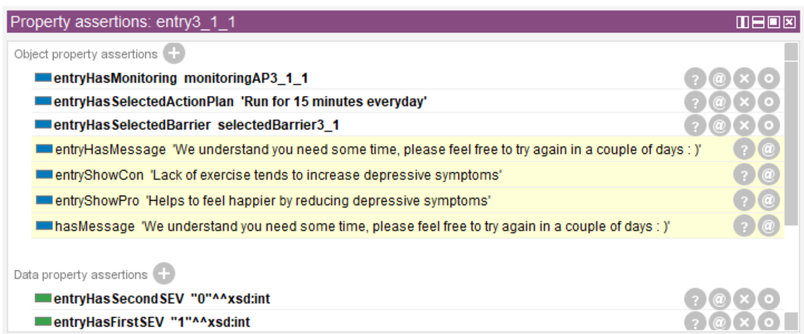


Figure 6.8: Showing inferred properties for Entry instance for Case Study 3

The SWRL rule listed in Table 5.9 displays the message for BA activities when patient does not follow the selected BA activity and selects a barrier and lists a feeling rating greater than or equal to 9. This can be seen in Figure 6.9 that shows the PatientActivity instance for Case Study 3.

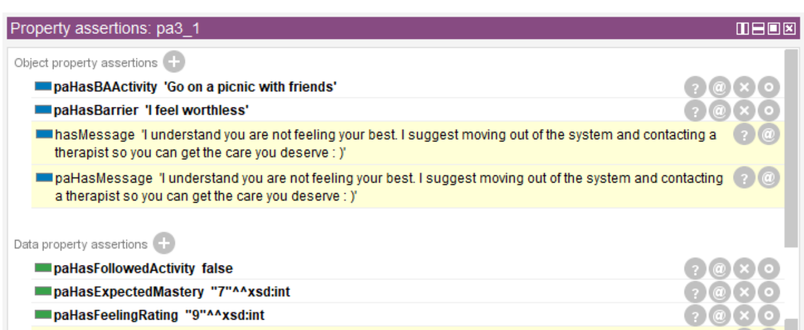


Figure 6.9: Showing inferred properties for PatientActivity instance for Case Study 3

OWL has object and datatype properties that have URIs and literals as values respectively. Datatype properties are often referred to as attributes while object properties are often referred to as relations [159].

Table 6.2 lists different datatype properties and the subsequent values associated with it for each case study.

Table 6.2: Profile attributes and values for Case Studies

Profile attribute (datatype property)	Case Study 1	Case Study 2	Case Study 3
patientHasDob	1990-10-26T21:32:45Z	1922-04-17T22:45:57Z	1974-06-19T03:35:14Z
profileHasProperty TimeStamp	2020-02-20T03:45:12Z	2020-02-25T21:32:52Z	2020-02-28T14:05:16Z
profileHasOccupation	Student	Marketing Manager	Homemaker
profileTimeSpent WatchingTV*	90 minutes	40 minutes	10 minutes
profileHasMallCloseBy*	False	True	True
entryHasFirstSEV*	0	2	1
entryHasSecondSEV*	2	NA	0
monitoringHasMonitoring TimeStamp	2020-02-27T13:20:00Z	2020-03-03T22:05:15Z	2020-03-06T18:20:15Z
monAnsHasFollowedAP*	True	True	False
monAnsHasSame ActionPlan*	False	True	True
paHasExpectedMastery	5	7	7
paHasAchievedMastery	8	NA	NA
paHasFollowedActivity*	True	False	False
paHasFeelingRating*	NA	5	9

Table 6.3 lists the object properties and the objects associated with it for each case study.

Table 6.3: Object properties and associated objects for Case Studies

Relations (object property)	Case Study 1	Case Study 2	Case Study 3
patientHasProfile	profile1_1	profile2_1	profile3_1
profileHasLiving Environment	Urban	Urban	Urban
profileHas MaritalStatus	Single	Married	Married
patientHas PatientRecord	patientRecord1_1	patientRecord2_1	patientRecord3_1
patientRecordHas TreatmentGoal*	Improve number of non family social relationships	Improve relationship with spouse/significant other	Improve physical health
patientRecord HasEntry	entry1_1_1	entry2_1_1	entry3_1_1
entryHas SelectedBarrier	selectedBarrier1_1	selectedBarrier2_1	selectedBarrier3_1
entryHas Monitoring	monitoringAP1_1_1	monitoringAP2_1_1	monitoringAP3_1_1
entryHasSelected ActionPlan*	Ask others for help	Show physical affection to partner by hugging them everyday	Run for 15 minutes everyday
sbHasBarrier	I feel shy	I feel guilty	I can't find the time to exercise
sbHasThought	thought1_1_1	thought2_1_1	thought3_1_1
thoughtHasNTP*	Mind reading	Mental filter	Disqualifying the positive
monitoringHas Answer	ans1_1_1	ans2_1_1	ans3_1_1
patientHas PatientActivity	pa1_1	pa2_1	pa3_1

Continues...

Relations (object property)	Case Study 1	Case Study 2	Case Study 3
paHasBAActivity	Going out to dinner	Organize wardrobe	Go on a picnic with friends
baActivity HasDuration	greaterThan60Min	lessThan60Min	greaterThan60Min
paHasBarrier	NA	I am unable to do anything	I feel worthless

The datatype and object properties marked with an * in tables 6.2 and 6.3 respectively, specify the properties that have a direct impact on the inferred output. We can draw from the above two tables the similarities and the dissimilarities across the three case studies.

Datatype properties such as patientHasDob, profileHasPropertyTimeStamp, profileHasOccupation, monitoringHasMonitoringTimeStamp, paHasExpectedMastery and paHasAchievedMastery are similar across the case studies since they do not have a direct impact on the inferred output. Properties such as profileTimeSpentWatchingTV, profileHasMallCloseBy, entryHasFirstSEV, etc., are labeled with an * and highlight some of the crucial dissimilarities across the case studies as the values for each of these datatype properties differs across the case studies.

Object properties such as patientHasProfile, profileHasLivingEnvironment, profileHasMaritalStatus, etc., are similar across the case studies as the objects associated with them do not impact the inferred output. The object properties marked with an * result in inferred output.

We evaluated the case studies based on the properties that impact the inferred output for instances of Profile, PatientRecord, PatientActivity, Entry and MonitoringAnswer.

Table 6.4 shows a cross-sectional comparison of the case studies and lists profile attributes, values and relations along with inferred outputs.

Table 6.4: Comparison of Case Studies

Profile Attribute	Value	Relation	Inferred Output	Case Study 1	Case Study 2	Case Study 3
profileTimeSpent WatchingTV	>15 minutes		Lists Action Plan Options:			
			Exercise while watching TV	✗	✗	✗
			Run for 15 minutes everyday	✗	✗	✗
	<= 15 minutes		Run for 15 minutes everyday	✗	✗	✔

Continues...

Profile Attribute	Value	Relation	Inferred Output	Case Study 1	Case Study 2	Case Study 3
profileHasMall CloseBy	True		Walk indoors at local shopping mall Run for 15 minutes everyday	✗	✗	✔
	False		Run for 15 minutes everyday	✗	✗	✗
entryHasFirstSEV	<= 1		List DBE associated with the selected action plan	✔	✗	✔
	2		Display Message: "Go ahead with your action plan :)"	✗	✔	✗
entryHasSecondSEV	<= 1		Display Message:"We understand you need some time, please feel free to try again in a couple of days :)"	✗	✗	✔
	2		Display Message: "Go ahead with your action plan :)"	✔	✗	✗
monAnsHas FollowedAP	True		Show feelingAfterAP instance associated with monAnsShowAnswer property	✔	✔	✗
	False		Show message "We understand you need some time, please feel free to try again in a couple of days :)"	✗	✗	✔
monAnsHasSame ActionPlan	True		patientRecordHasSameAPOption property is inferred with associated action plan	✗	✔	✔
	False		patientRecordHasNewAPOption property is inferred with associated action plan options	✔	✗	✗
paHasFollowed Activity	True		Display Message: "Thank you for trying this activity! You can try the same activity or pick another one for the next week :)"	✔	✗	✗
paHasFeeling Rating (paHasFollowedActivity = False)	<9		Display Message: "Try this activity instead"	✗	✔	✗
	>=9		Display Message: "I understand you are not feeling your best. I suggest moving out of the system and contacting a therapist so you can get the care you deserve :)"	✗	✗	✔
		thoughtHasGD	List Guided Discovery Questions: If someone I loved had this thought what would I tell them? If someone I loved knew I was thinking this thought, what evidence would they point out to me that would suggest that my thoughts were not 100% true?	✔	✔	✔
		patientRecordHas APOption	Lists the associated instances of action plan options for the particular treatment goal	✔	✔	✔
		entryShowPro entryShowCon	Lists the associated pro and con for the particular action plan option	✔	✗	✔

As seen in the table above, all the case studies list the Guided Discovery questions for each negative thought process selected. They are also similar in the sense that each treatment goal is associated with action plan options. Some of the crucial dissimilarities arise in listing the DBE, this is done for case studies 1 and 3 since their entryHasFirstSEV property has a value <=1. The messages displayed for each case study vary depending on the self efficacy values, following BA activity and feeling rating of the selected barrier. Each case study lists action plan options based on the treatment goal selected. Each treatment goal is directly associated with specific action plan options. For the treatment goal “Improve physical health”, the SWRL rules specify certain action plan options based on the values of the profileTimeSpent-WatchingTV and profileHasMallCloseBy properties. This is inferred for Case Study 3 as the goal selected matches the SWRL rules.

Tables 6.2 and 6.3 showed how the profiles for each case study were built while table 6.4 shows how the system responds to different and similar profiles.

Next, we look at how the model personalizes the action plan options based on profile attributes profileHasMallCloseBy and profileTimeSpentWatchingTV for current and different scenarios of case studies.

Table 6.5: Personalization of action plan options based on values of profile attributes - profileHasMallCloseBy and profileTimeSpentWatchingTV for current and changed scenarios

Case Study	Goal:Improve physical health	profileHas Mall CloseBy	profile Time SpentWatchingTV (in minutes)	Exercise while watching TV	Run for 15 minutes everyday	Walk indoors at local shopping mall
Current Scenarios						
1	✗	NA	NA	✗	✗	✗
2	✗	NA	NA	✗	✗	✗
3	✔	True	10	✗	Inferred	Inferred
Changed Scenarios						
1	✔	True	10	✗	Inferred	Inferred
2	✔	True	15	✗	Inferred	Inferred
1	✔	False	20	Inferred	✗	✗
2	✔	False	30	Inferred	✗	✗
3	✔	False	40	Inferred	✗	✗

Table 6.5 shows that the action plan options listed are irrelevant for case studies 1 and 2 since they do not have the treatment goal associated with the action plan options listed. The two profile attributes responsible for listing action plan options are not relevant to case studies 1 and 2 either. Whereas, if the scenarios are modified, such that the treatment goal for case studies 1 and 2 is set to “Improve physical health”, then for different values of profileHasMallCloseBy and profileTimeSpentWatchingTV

properties, the inferred output is similar to what was drawn for Case Study 3.

The model also personalizes the action plan options based on the treatment goal selected. Table 6.6 shows this personalization for both the current and different case study scenarios.

Table 6.6: Personalization of action plan options based on selected treatment goal for current and changed scenarios

Case Study	Goal:Improve number of non-family relations	Ask others for help	Think twice before speaking	Use words such 'please', 'thank you', 'sorry' often
Current Scenarios				
1	✔	Inferred	Inferred	Inferred
2	✗	NA	NA	NA
3	✗	NA	NA	NA
Changed Scenarios				
1	✗	NA	NA	NA
2	✔	Inferred	Inferred	Inferred
3	✔	Inferred	Inferred	Inferred

As can be seen from Table 6.6 for Case Study 1, model infers the associated action plan options for the selected treatment goal. Since case studies 2 and 3 do not have this particular treatment goal, the listed action plan options are not inferred.

Whereas if the scenarios are modified such that the selected treatment goal is changed for the case studies, the inferred output is similar to the output obtained for the current scenario.

Tables 6.5 and 6.6 show that the model personalizes action plan options at two levels, one is the selected goal determines which profile attributes are relevant to the inferred action plan options and the second is the treatment goal alone determines the inferred output.

The action plan selected by the patient is monitored in order to maintain a record of whether they followed through with it or not. The patient is asked if they want to work on the same action plan for the following week. This results in the personalization of action plan options once the patient has followed them for a week. Table 6.7 shows us the profile attribute responsible for this.

Table 6.7: Personalization of action plan options post monitoring

Profile attribute	Value	patientRecordHasSame APOption	patientRecordHasNew APOption
monAnsHasSameActionPlan	True	Inferred	✗

Continues...

Profile attribute	Value	patientRecordHasSame APOption	patientRecordHasNew APOption
	False	✗	Inferred

The working of the SWRL rules responsible for this particular personalization of action plans can be explained with case studies 1 and 2 as follows:

Case Study 1:

- monHasSameActionPlan = False
- patientRecordHasTreatmentGoal = Improve number of non-family social relationships
- apEntryHasSelectedActionPlan = Ask others for help

Inferred properties:

- patientRecordHasNewAPOption = Ask others for help
- patientRecordHasNewAPOption = Think twice before speaking
- patientRecordHasNewAPOption = Use words such as “please”, “thank you”, “sorry” and “excuse me”

Case Study 2:

- monHasSameActionPlan = True
- patientRecordHasTreatmentGoal = Improve relationship with spouse or significant other
- apEntryHasSelectedActionPlan = Will show physical affection to my partner by hugging them everyday

Inferred property:

- patientRecordHasSameAPOption = Will show physical affection to my partner by hugging them everyday

Lastly, we list the commonalities and differences found in profile attributes and their values for different treatment goals in table 6.8.

Table 6.8: Attribute values for treatment goals

Profile Attribute	Value	Improve family relationships	Improve non-family social relationships	Improve relationship with spouse/significant other	Improve physical health	Organize or clean home	Improve existing work condition
entryHasFirstSEV	<=2	✔	✔	✔	✔	✔	✔
entryHasSecond SEV	<=2	✔	✔	✔	✔	✔	✔
monAnsHasFollowedAP	True	✔	✔	✔	✔	✔	✔
	False	✔	✔	✔	✔	✔	✔
monAnsHasSameActionPlan	True	✔	✔	✔	✔	✔	✔
	False	✔	✔	✔	✔	✔	✔
profileTimeSpentWatchingTV	>15	✗	✗	✗	✔	✗	✗
	<=15	✗	✗	✗	✔	✗	✗
profileHasMallCloseBy	True	✗	✗	✗	✔	✗	✗
	False	✗	✗	✗	✔	✗	✗

The table above shows that different treatment goals have common attribute values for all the profile attributes except profileTimeSpentWatchingTV and profileHasMallCloseBy. These two profile attributes and their subsequent values impact only one treatment goal, i.e., 'Improve physical health'.

Next, we will look at the qualitative evaluation of the OWL ontology.

6.2 Qualitative Evaluation

6.2.1 Completeness

Grüninger et al. [56] proposed formal and informal competency questions as a way to capture the questions the ontology should be able to answer. By doing this, we can assess the completeness of the model in a measurable way. Competency questions are to be set forth prior to ontology development and help to capture the domain knowledge as the questions that must be answered by the ontology model [7].
Grüninger et al. [56] define the completeness of an ontology model as the state of the ontology when it can answer all the competency questions set forth initially i.e. fulfil all the competencies. Hence, the competency questions listed in section 3.0.2 guide the ontology construction and become a means to evaluate the completeness of

the ontology. The knowledge model can contain either explicit or inferred knowledge that is inferred by an inference engine [56].

Our case studies claim to demonstrate the competency questions put forth prior to ontology development and show the CBT ontology is complete because all the concepts, relationships and rules answer the competency questions.

6.2.2 Consistency

Gómez-Pérez et al. [49] state an ontology is regarded as consistent if both asserted and inferred contradictions are absent. These are of both logical and non-logical consistency, the difference being that logical consistency can be established by a reasoner whereas non-logical consistency is harder to determine through software agents or automated means and requires human expertise [49].

Ontology debugging is the detection of unsatisfiable concepts. Pellet reasoner is an inbuilt inference engine in Protégé 5.5 that provides support for ontology debugging as it can pinpoint to axioms in the ontology that are responsible for an inconsistency as well as relations between unsatisfiable classes [127]. By doing this, Pellet can give the explanation as to why an error occurs in an ontology and ensures that an ontology does not contain any contradictory facts [127]. OWL consistency checker takes a document as input, and returns one word being Consistent, Inconsistent, or Unknown [140].

We used the Pellet reasoner to check the consistency and satisfiability of our ontology. The results of running the reasoner indicated that there were no conflicting rules and contradictions were not inferred [158]. This established the logical consistency of the ontology model.

6.2.3 Conciseness

Gómez-Pérez et al. [49] state an ontology can be considered concise if it void of irrelevant definitions and redundancies cannot be inferred from the asserted definitions. According to [48], an ontology is concise when the information contained is useful and precise. Ontology axioms that represent knowledge pertaining to a domain ensure conciseness and prevents unnecessary knowledge within the ontology [8]. We used axioms within the ontology to represent the meaning of concepts as well as answer questions on the capability of the built ontology using the ontology concepts [8]. These were validated by the domain expert.

6.3 Concluding Remarks

This chapter presented an evaluation of the CBT ontology. We highlighted the validation by domain expert along with the case studies that were validated wherein three separate cases were made and screenshots of the model in Protégé 5.5 are provided showing the inferred properties based on the SWRL rules developed. Additionally, we also carried out the qualitative evaluation wherein focus was laid on the completeness, consistency, and conciseness of the CBT ontology.

Chapter 7

Discussion

This chapter summarizes the key findings of our research by revisiting the research problem, and documents the summary of our solution approach by highlighting the strengths and weaknesses, and the future scope.

7.1 Revisiting the problem statement

A lack of m-health apps based on CBT that are focused on the theoretical knowledge of CBT motivated us to develop a knowledge model that would be uniform in labels and descriptions [91]. This would be validated by a domain expert as well as evaluated by an inference engine for completeness, conciseness and consistency.

Kumar et al. [91] conducted an analysis of m-health apps and found that the lack of focus on identifying barriers to treatment led to patient withdrawal [91]. This motivated us to create a model wherein emphasis on the barriers to treatment goals is placed.

We adopted OWL ontologies as the knowledge representation formalism to create our knowledge model since they are extensible, reusable and can be used to disseminate knowledge [15].

Our review of the related work found that there was room for an ontology that focused solely on operationalizing CBT for the treatment of mild depression while focusing on Guided Discovery and Behavioural Activation.

7.2 Summary of our Solution Approach

To summarize, this thesis demonstrated the applicability of a knowledge-engineering approach in designing a knowledge model for the self-management of CBT. We used a three-step knowledge engineering approach consisting of steps: content gathering, conceptual modelling, and ontological engineering.

The scope of this work is limited to demonstrating the applicability of a knowledge-driven approach in the context of treating mild-depression using CBT techniques and generating personalized behavioural plans. The strengths and limitations of this approach are: -

1. Strengths:

    (a) Using an ontological approach - Ontologies support the extensibility, reusability and dissemination of knowledge. This proves useful since a knowledge model is never complete and further additions or modifications can be made to a model at any given time [80].

    (b) Model based on theoretical proof - The knowledge model is based on two basic theoretical aspects of CBT, namely Guided Discovery and Behavioural Activation and can be extended to add more aspects of CBT such as Homework Assignments [12].

    (c) Creation of a knowledge base - A KBS has two components, a knowledge base and an inference engine. Our approach has resulted in the creation of a knowledge base that contains expert knowledge represented in the form of an ontology [80].

2. Limitations:

    (a) We have listed restricted treatment goals that can be addressed by a patient. If our model is utilized to create a mobile application, it will require additions to treatment goals that can be addressed. This could be done after discussions with domain experts, such as therapists.

    (b) We utilized illness-related barriers from the BDI [169] [164] as barriers to addressing treatment goals. The action plans were developed on the basis of treatment goals alone. Apart from a few which were subject to change based on the patient information, the rest were mapped as 1:many between treatment goal to action plans. Another way to list action plans could have been to look at systematic reviews to find out the most common barriers to the different treatment goals listed and then collect action plan suggestions for them.

7.3 Future Scope

Our work on creating an ontology-based knowledge model can be extended in the following ways: -

1. Currently the knowledge model suggests all the action plan options inferred by the SWRL rules depending on the treatment goal selected by the user. In the future, the model could suggest action plan options to the user based on records of self efficacy values from previous monitoring instances of treatment goals already addressed.

2. The knowledge model lists one alternate activity for the purpose of BA to the user. In the future, it could suggest Behavioural Activation activities to the user based on the record of previous achieved levels of mastery.

3. The model can be extended to support homework assignments and take the results into account when showing a list of action plan options to the user for the following week. It can be extended to incorporate other components of CBT, namely, relaxation training [149] by instantiating suggestions for relaxation activities and monitoring similar to how the model incorporates BA activities.

4. Data collected though an application developed on the model can be displayed to the therapist diagrammatically through charts such that the therapist may view relevant information regarding the patient. This can be used to monitor the progress of the patients' treatment.

7.4 Conclusion

This thesis presented that a knowledge-based OWL ontology can be modelled on the theoretical aspects of CBT and would presumably be more effective in the self-management of mild depression owing to a strong theoretical foundation.

CBT interventions are considered complex due to multiple components that are inter-connected and hence make it difficult for CCBT solutions to be clinically correct [101, 74]. Some of the existing solutions were deemed ineffective due to the inappropriate application of the two main techniques of CBT, that are GD and BA

[74]. Furthermore, we noted that mental health care must take into consideration an individuals' perceived barriers to treatment [164], Kumar et al. [91] found that current CCBT solutions have a lack of focus on identifying barriers to treatment.

We addressed the above problems by adopting a knowledge-modelling approach by constructing an OWL ontology that consists of relationships between core CBT concepts that can be checked for logical consistency and correctness. We created an OWL ontology to represent rich and complex knowledge about CBT concepts and the relationships between them [126].

We used a three-step knowledge engineering approach wherein we described the content gathering, conceptual modelling, and ontological engineering steps undertaken. In order to do this, we identified and defined the concepts, the relationships between concepts and the constraints to be imposed upon the concepts and relationships. The knowledge modelled in the OWL ontology was validated by a domain expert using case studies. Finally we presented a formative evaluation of the OWL ontology in terms of its completeness, consistency and conciseness. We used Pellet Reasoner to conduct the consistency checks [126].

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