

Managing Data in Help4Mood

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Abstract. Help4Mood is a system that supports the treatment of people with major depression through collecting a wealth of cognitive, psychomotor, and motor data, which can then be summarised and analysed further. Data is stored in functional units that correspond to treatment relevant entities using a custom XML DTD. As far as possible, observations and findings are coded using SNOMED CT to ensure interoperability with other applications such as Electronic Health Records.

1 Help4Mood—Avatar-Based Support for People with Major Depression

Depression is the main cause of disability worldwide [1]. It is characterised by a persistent and intense change of mood which affects behaviour, cognition, and physiology.

There are various forms of depression [2]. Here, we focus on major unipolar depression, which is mostly treated in the community. The core symptoms are persistent low mood and loss of interest. Figure 1 summarises the definitive diagnostic criteria for an episode of major depression, which includes activity and sleep symptoms.

As the DSM-IV definition suggests, depression also greatly affects psychomotor function [3, 4]. Two types of major depression can be distinguished, a melancholic form where patients' movements are significantly slowed down, and a non-melancholic form, where movements are not affected or agitated. Slowed movements are reflected in both gross motor function, such as gait, and fine motor function, such as movement initiation and reaction times. They also contribute to a reduced speech rate and a flat intonation [5, 6].

At the moment, recovery is monitored infrequently through self-reported patient questionnaires that require the person with depression to remember over a period of time that can be as long as two weeks (e.g., PHQ-9 [7]). Those self-reports can be unreliable, especially if the patient is not keeping regular notes or a diary.

The Help4Mood system is intended to support the treatment of people with major unipolar depression in the community. In addition to monitoring through questionnaires and sensors, the patient interacts with Help4Mood through an avatar interface. Help4Mood consists of three components, a **personal monitoring system**, a **virtual agent**, which implements the avatar interface, and a **decision support system**.

- A. Five (or more) of the following symptoms have been present during the same 2-week period and represent a change from previous functioning; at least one of the symptoms is either (1) depressed mood or (2) loss of interest or pleasure:
- (1) depressed mood most of the day, nearly every day, as indicated by either subjective report (e.g., feels sad or empty) or observation made by others (e.g., appears tearful).
 - (2) markedly diminished interest or pleasure in all, or almost all, activities most of the day, nearly every day (as indicated by either subjective account or observation made by others)
 - (3) significant weight loss when not dieting or weight gain (e.g., a change of more than 5% of body weight in a month), or decrease or increase in appetite nearly every day.
 - (4) insomnia or hypersomnia nearly every day
 - (5) psychomotor agitation or retardation nearly every day (observable by others, not merely subjective feelings of restlessness or being slowed down)
 - (6) fatigue or loss of energy nearly every day
 - (7) feelings of worthlessness or excessive or inappropriate guilt (which may be delusional) nearly every day (not merely self-reproach or guilt about being sick)
 - (8) diminished ability to think or concentrate, or indecisiveness, nearly every day (either by subjective account or as observed by others)
 - (9) recurrent thoughts of death (not just fear of dying), recurrent suicidal ideation without a specific plan, or a suicide attempt or a specific plan for committing suicide
- B. The symptoms do not meet criteria for a Mixed Episode.
- C. The symptoms cause clinically significant distress or impairment in social, occupational, or other important areas of functioning.
- D. The symptoms are not due to the direct physiological effects of a substance (e.g., a drug of abuse, a medication) or a general medical condition (e.g., hypothyroidism).
- E. The symptoms are not better accounted for by Bereavement, i.e., after the loss of a loved one, the symptoms persist for longer than two months or are characterised by marked functional impairment, morbid preoccupation with worthlessness, suicidal ideation, psychotic symptoms, or psychomotor retardation.

Fig. 1. DSM-IV criteria for major depressive episode.

The sensors of the personal monitoring system assess sleep and activity patterns using sleep sensors and a wrist actigraph. The virtual agent asks questions, sets tasks, and summarises the results of each session. Some of these tasks will yield cognitive data, such as relevant negative automatic thoughts, others are designed to capture relevant neuropsychomotor symptoms of depression, such as speech changes and slowed reaction times [3]. The decision support system plans and controls sessions with the virtual agent and converts data about the patient's sleep, motor, speech, and other psychomotor patterns into graphical, textual, and conceptual summaries that can be communicated to clinicians, patients, and electronic health records.

In this paper, we describe our approach to data management in Help4Mood. We focus on the high-level data structures that form the basis for communicating with clinicians, patients, and other stakeholders; the personal monitoring system and the virtual

agent have internal structures for storing the fine-grained, detailed data which is analysed by the decision support system. The basic elements of the high-level Help4Mood data structures are described in Section 2. Provisions for interoperability are outlined in Section 4, and future work plans are summarised in Section 5.

2 Overview of Help4Mood

Help4Mood is structured around patients' sessions with the Virtual Agent. Ideally, patients interact with their Virtual Agent daily. While content and length of a session can be varied depending on the patient's current mood and stamina, a default session consists of five parts: welcome and daily mood check, diary, documenting negative thoughts, speech task / game, summary feedback and closing.

The daily mood check is a validated four-item questionnaire, the CES-VAS-VA [8]. In the diary entries, patients reflect on a specific prompt. These entries are stored internally in the VA; patients will be able to discard them or save them for rereading. All that is stored for the DSS is their length. Next, patients document negative thoughts relating to this diary entry, and Help4Mood provides guidance for challenging these thoughts. Then, patients perform a speech task or a cognitive game. Finally, the session is briefly summarised in a final screen, and the virtual agent bids the patient goodbye.

While sleep data is collected every night, the wrist actigraph will only be worn for 72 hours at a time. Sessions with the virtual agent can include summaries of activity and sleep patterns. In addition to the daily mood check, patients fill in a formal screening questionnaire, the PHQ-9 [7], every fortnight; this task is added to the session at the appropriate time.

3 Core Data Structures

All data structures are described using XML. We chose this solution over a relational database, because Help4Mood has a highly modular architecture, and almost all inter- and intra-module communication is based on XML. Elements are extensively cross-indexed to ensure flexible access to data.

The XML elements that are used to store relevant data are summarised in Table 1. They fall into four main categories, high-level tracking of patient and Help4Mood use, storing monitoring results, managing the interaction between patient and virtual agent, and storing the data collected during the interaction. Each set of elements is briefly explained below.

High Level Tracking. The three high-level tracking elements summarise relevant information about the patient and system usage and store the regular reports generated by the system. Patient information includes basic demographics (occupation, gender, age) as well as current depression scores. As for reports, only official reports that are sent to the clinicians and can be discussed in patient/clinician meetings are stored. The feedback given to the patient at the end of each session is not saved, because it can be reconstructed deterministically from the data collected in each session.

Table 1. Basic Elements of the Help4Mood data structure. Each one is defined using XML.

Element	Description
<i>High-Level Tracking of Patient and Help4Mood Usage</i>	
User Model	high-level summary of information about the patient
Adherence	adherence of patient to Help4Mood; can refer to sessions, tasks, and monitoring schedules
Report	summary report generated for clinician
<i>Managing the Results of Monitoring</i>	
Monitor Data	set of measures that are collected during a session
Measure	high-level measure computed from a given set of monitoring data
Score	score on a standardised questionnaire
<i>Managing the Interaction with the Virtual Agent</i>	
Session	content and results of a session with the Virtual Agent
Event	event triggered by the decision support system during a session
Task	task that is performed by the patient during a specific session
Emotion	emotion used by virtual agent while patient performs task
<i>Storing Information Collected During Interaction with the Virtual Agent</i>	
Diary	information related to diary entries
Speech	changes in relevant speech parameters
Games	changes in reaction times and scores
Negative Thought	frequency of specific negative automatic thoughts

Monitoring. The next two elements are used to describe high-level monitoring data. While the measure element covers specific analysis results, the monitoringdata element collects a set of measures obtained during a given session.

Managing the Interaction with the Virtual Agent. The Decision Support System controls the Virtual Agent's interaction with the user through events (event element). Events are triggered when their preconditions are fulfilled. They are implemented as interaction tasks (task element). Each task is associated with an emotion (emotion element) that controls the affective behaviour of the Virtual Agent.

The sequence of of events and task/emotion pairs that occurred during a session and the data that was generated during a session is stored in a session element for easy reference.

Table 2 shows the structure of an event element. Each event is linked to a session, a patient, and a specific time within the session. A range of auxiliary elements is used to specify events. Descriptors link Events to a formal code that describes the underlying procedure and can be exported to external systems (c.f. Table 3). Preconditions and postconditions are described using condition elements that consist of ⟨Property, Operator, Value⟩-tuples (c.f. Table 4).

Data Collected During Interaction. During most tasks, the system collects rich information about the patient's cognition and current psychomotor functioning. Relevant high-level data is encoded in the diary, speech, games, and negative thought elements.

Table 2. The *Event* class.

Attribute	Value	Description
⟨Type⟩	{1,2,3,4}	Event type as classified by data source
⟨Session⟩	timestamp	Session ID
⟨Patient⟩	alphanumerical code	Patient ID
⟨Description⟩	descriptor	Formal description of the event
⟨Generated⟩	timestamp	time at which the event was generated
⟨Preconditions⟩	list of conditions	pre-conditions that trigger the event.
⟨Postconditions⟩	list of conditions	findings or observable entities

Table 3. Structure of Descriptors.

Attribute	Values	Definition
⟨Code⟩	9-digit integer	Numerical identifier. If the attribute is a concept taken from the SNOMED-CT classification, the code is its corresponding ID
⟨Snomed⟩	Yes/No	Yes if the attribute is a SNOMED-CT concept, otherwise no
⟨Name⟩	String	SNOMED-CT description if attribute is a SNOMED-CT concept, otherwise internal description

Table 4. Structure of Conditions.

Attribute	Value	Description
⟨Property⟩	Descriptor	Property or action in the VA's world that is tested in the precondition.
⟨Operator⟩	<, >, =, !=	A string that specifies the operator used to determine the truth value of the condition. The first two operators are defined for numerical values, the last two are defined for numerical and strong values
⟨Value⟩	descriptor	Value used to compare the property to.

4 Communication and Interoperability

4.1 Clinician

Clinicians can access a patient's history through a web interface to a special clinician-side version of the decision support system, which generates textual and graphic summaries to support treatment planning. In addition, Help4Mood generates a regular report for each patient / clinician meeting. All relevant health care professionals as well as the patient can see this report; clinician and patient may discuss specific findings when they meet.

4.2 Patient

The patient receives textual and / or graphical summaries at the end of each session that are generated dynamically. The Virtual Agent stores detailed information about

performance on speech tasks and games which can be exported for further refinement of measures. Patients can choose to save their diary entries for later perusal. The entries themselves are not passed on to the clinician. Patients will be made aware that diary entries are private every time they use the system. In addition to their diary entries, patients have access to the shared reports, which are stored patient-side.

4.3 EHR Integration

As far as possible, we use the international Core Release of SNOMED CT [9] to describe our findings and observations. SNOMED CT is a highly complex, extendable clinical vocabulary that can be integrated with standards such as HL7 [10], which Help4Mood will support.

Most of the SNOMED-CT concepts used in Help4Mood come from the *Clinical Finding* hierarchy. Clinical findings are the outcome of assessments, observations, or judgements. For example, if the sleep sensor data indicate that the patient tossed and turned frequently at night, this can be encoded as the Clinical Finding “restless sleep”.

Other concepts are *Procedures*, i.e., activities that occur at a specific time and involve the patient. Procedures include education and administration activities. For example, showing the patient a list of activities that were identified as comforting could be a procedure. Another example of a procedure would be guiding the patient through a relaxation exercise.

Most of the relevant information about a patient’s social context is modelled using concepts from the *Social Context* hierarchy, such as occupation.

A question or a procedure that produces a result is an *Observable Entity*. For example, “gender” is an observable entity, while “female gender” is a finding. Questionnaire scores are modelled as observable entities; the associated finding is their interpretation. The questionnaire instruments themselves are part of yet another hierarchy, *Staging and Scales*. For example, the Beck Depression Inventory [11]

When extending Help4Mood to provide medication education, we may also include concepts from the hierarchy *Pharmaceutical/biological product*, which correspond to the type of medication being given.

We defined our own codes only if the relevant findings, observable entities, or procedures were not included in SNOMED-CT. In all cases, these codes are linked to a parent concept in SNOMED-CT. For example, unlike the Beck Depression Inventory, neither of our depression measures are modelled explicitly in SNOMED-CT. Therefore, we assigned the resulting scores system-specific codes and linked them to relevant parent concepts. Hence, the PHQ-9 score is an Observable Entity which is in an *is-a* relation with the SNOMED CT concept *Mental state, behaviour / psychosocial function observable*.

If necessary, relevant data is mapped onto SNOMED CT categories by the Decision Support System. While information such as questionnaire scores can be stored more or less directly, concepts such as “restless sleep” will be derived from sensor data using validated algorithms.

Table 5. Anchoring New Concepts in SNOMED-CT.

SNOMED CT Concept Type	Description	is-a relation to SNOMED-CT
		Code Description
Procedure	999991011 Assessment using VAS-VS	CES-D- 445536008 Assessment using assessment scale
Observable Entity	999991012 CES-D-VAS-VS score	363870007 Mental state, behavior / psychosocial function observable (observable entity)
Procedure	999991021 Assessment using PHQ-9	445536008 Assessment using assessment scale
Observable Entity	999991022 PHQ-9 score	363870007 Mental state, behavior / psychosocial function observable (observable entity)
Finding	999992011 Change of Score on Cognitive Game SIMON	248536006 Finding of functional performance and activity

5 Future Work

The data management approach outlined here provides a detailed, systematic representation of all of the relevant high-level information that Help4Mood collects about a patient with major unipolar depression. It was designed for easy maintenance and maximum interoperability with EHRs.

We are currently implementing the first version of Help4Mood based on the data structures outlined in this paper. In future versions, we plan to add HL7 integration, refine the elements and clinical vocabulary described here to provide a more detailed ontology for interoperability, and extend Help4Mood with reminder functionality and patient education through tailored health information presentation.

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