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An Implementation of a Decision-Making Algorithm Based on a Novel Health Status Transition Model of Epilepsy

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Abstract. Epilepsy is one of the most common and dangerous neurological disorders, affecting millions of people around the world every year. Its symptoms are quite subtle and the transition from one phase of the disorder to another can go undetected and end to a life threatening situation, if the patient is not carefully monitored. In this paper we propose a novel health status transition model in epilepsy, as well as an implementation scheme suitable to be used in health telemonitoring systems. This model is able to monitor the patient and detect abnormalities providing a time margin for him/her to take actions and for his/her caregivers to be prepared to help and act. Based on whole model's transitions information we created a health-caring ontology. Finally, we used Java in order to develop an appropriate decision-making telemonitoring algorithm based on the proposed model.

Keywords: epilepsy, status transition model, health-caring ontology, Protégé, decision-making algorithm, telemonitoring algorithm

1 Introduction

Epilepsy is one of the most risky chronical medical conditions [1],[2]. Nowadays, 65 millions of people worldwide suffer from epilepsy and most of them live a normal and healthy life. However, we should be aware that epilepsy can be deadly. Epilepsy is a neurological malfunction which affects the nervous system and causes various seizures. Very long seizures or seizures successively occurring, while patients don't recover between them, are dangerous incidents. So, it is important that these seizures are fast detected, identified and treated.

A modern approach of that is by building a telemonitoring system providing personalized services to patients, who have been previously diagnosed with epilepsy. These services allow patients to detect the anticipated seizures and take the necessary precautions. Actually, preventing patients from seizures is

impossible while well treating of them is the target. Patients receive early warnings about the anticipated seizure gaining time for treating their condition. In parallel, other entities, like their caregivers, their doctor, or even a hospital are informed about the patient's critical condition and act accordingly.

In this paper, we organized the different phases that an epileptic patient can enter in a model. We gathered and classified various trigger factors and symptoms that are likely to lead to a seizure and according to them we identify its kind and risk level. Subsequently, and based on the proposed model we developed an event-driven epilepsy telemonitoring algorithm using ontologies in Java [3]. Finally, we evaluated the performance of this algorithm using the data of a specific medical case.

The paper is structured as follows. In Sect. 2, the proposed Transition Model of Epilepsy is presented. In Sect. 3, the implementation of the proposed model's decision making algorithm is presented. Section 4 and 5 include the evaluation of the implemented algorithm and the discussion, and conclusions, respectively.

2 Transition Model of Epilepsy

In this study, physicians and engineers worked together in order to map the evolution of the health status of subjects (patients) suffering from epilepsy [5],[6],[7],[8], and [9]. The aim of this study was to create an appropriate health caring algorithm suitable to be adopted by advanced epilepsy telemonitoring systems. For this purpose, we considered the following as model's primitives:

- a subject suffering from epilepsy can be characterized by fourteen (14) different health statuses, named as: Normal, Predisposition to Epilepsy, High Predisposition to Epilepsy, Generalized Absence Seizure, Generalized Myoclonic Seizure, Generalized Clonic Seizure, Generalized Atonic Seizure, Generalized Tonic Seizure, Generalized Tonic-Clonic Seizure, Partial Seizure, Complex Partial Seizure, Simple Partial Seizure, Status Epilepticus, Post Seizure
- in each health status the subject is being cared by a specific group of caregivers (nurse, volunteers, relatives)
- the subject moves from one health status to another (Transition Phase), whenever a specific symptom presents (Fig. 1).
- within each Transition Phase the model poses specific actions to be performed by both the telemonitoring algorithm and the caregivers. These actions should be strongly coupled with the health record and profile of the subject, in cases of personalized telemonitoring services.

In this section we analyze every possible Transition Phase while moving from one health status to another. Each one of these phases is activated by specific Trigger Factors or symptoms, as it is subsequently analyzed.

Transition Phase 1 This phase declares the beginning of the health caring algorithm, posing the subject to the "Normal status". In this situation no action is required.

Transition Phase 2 Transition from “Normal status” to the “Predisposition to Epilepsy status”. It occurs whenever one or more of the following eleven (11) Trigger Factors $\{TF_i, i = (1, \dots, 11)\}$ are presented:

1. Interruption of antiepileptic drugs
2. Alcohol abuse (drunkenness)
3. Lack of alcohol or benzodiazepines
4. Lack of sleep
5. Physical exhaustion
6. Mental stress (stress)
7. Interruption of drugs acting on the central nervous system (e.g., barbiturates, benzodiazepines)
8. Febrile illness
9. Menstruation
10. Metabolic disorders (hypoglycemia, hyponatremia)
11. Photosensitivity-discontinuous and rhythmically repetitive light stimulation

Actions: In this transition, increased attention is required by the subject for a possible future occurrence of one or more of the general symptoms of “High Predisposition to Epilepsy status”. The algorithm undertakes the responsibility to keep aware about this risk, both the subject and the authorized caregivers by sending regularly to them electronic notification messages. The type and the frequency of these messages are strongly tied with the subjects Electronic Health Record (EHR) and epileptic profile.

Transition Phase 3A Transition from “Normal status” to “High Predisposition to Epilepsy status”. It occurs whenever one or more of the following eleven (11) General Symptoms $\{GS_j, j = (1, \dots, 11)\}$ are presented:

1. Aura - usually aesthetic (visual disturbances or dysesthesias)
2. Stomach discomfort
3. Feeling of fear or panic
4. Nausea or headache
5. Breathing problem
6. Tachycardia
7. High Blood Pressure
8. Dizziness
9. High body temperature
10. Strange smell
11. Pleasant or unpleasant sensation

Actions: The algorithm takes over to send often to the subject as well as to another authorized caregiver electronic notification messages. The type and the frequency of these messages are specified in accordance with the epileptic medical history and profile of the subject, as well as his/her active context (home, work, road, driving, etc.). In addition, the algorithm takes over to call a caregiver in the current subjects place. The caregiver is in charge of recording all symptoms that are likely to happen to the subject during the forthcoming seizure, given the fact that the subject will not be able to perceive and include these symptoms in the algorithm by himself.

Transition Phase 3B Transition from “Predisposition to epilepsy status” to “High Predisposition to epilepsy status”. It occurs whenever one or more of the above eleven (11) General symptoms $\{GS_j, j = (1, \dots, 11)\}$, are presented. The actions remain the same as in Phase 3A.

Transition Phase 4A Transition from “High Predisposition status” to “Generalized Absence Seizure status” occurs whenever unconsciousness with mild motor activity (patient’s gaze freezes, does not answer, does not react), called in our model Absence symptom $\{AS_1\}$, is presented.

Transition Phase 4B Transition from “High Predisposition to epilepsy status” to “Generalized Myoclonic Seizure status” occurs whenever sudden involuntary muscle contractions, called in our model Myoclonic symptom $\{MS_1\}$, are presented.

Transition Phase 4C Transition from “High Predisposition status” to “Generalized Atonic Seizure status” occurs whenever Drop attack (suddenly the muscle tone is lost throughout the body and the subject collapses like a sack on the ground), called in our model Atonic symptom $\{ATS_1\}$, is presented.

Transition Phase 4D Transition from “High Predisposition status” to “Generalized Clonic Seizure status” occurs whenever clonic convulsions, called in our model Clonic symptom $\{CS_1\}$, are presented.

Transition Phase 4E Transition from “High Predisposition status” to “Generalized Tonic Seizure status” occurs whenever tonic convulsions, called in our model Tonic Symptom $\{TonS_1\}$, are presented.

If the subject is in the “Generalized Tonic Seizure status” and the $\{CS_1\}$ is presented, we suppose that the subject moves to “Generalized Tonic-Clonic Seizure status”.

Transition Phase 4F Transition from “High Predisposition status” to “Generalized Partial Seizure status”. It occurs whenever one or more of the following ten (10) Partial Symptoms $\{GPS_u, u = (1, \dots, 10)\}$ are presented:

1. Tonic involuntary movements of one (upper end or lower) end or of the shank
2. Face deformation
3. Sensory disorders - numbness and tingling in any part of the body
4. Visual disturbances e.g. flashes, zig zag
5. Auditory disorders, such as simple sounds or even music
6. Difficulties in speaking, tangle, halting speech, salivation, chewing sounds and movements, teeth grinding
7. Olfactory disorders e.g. feeling bad smell
8. Nausea
9. Affective disorders - sudden change of sentiment
10. Other rare forms, like deja vu

In this Phase, if the subject has his/her consciousness lost, he/she moves to “Complex Partial Seizure status”. Correspondingly, if the subject has his/her consciousness he/she moves to “Simple Partial Seizure status”.

Common Actions for Phases 4A to 4F: Based on the epileptic history/profile of the subject and the symptoms that led to the finding of the seizure, the caregiver communicates with the doctor who is treating the subject and

describes the whole course of the seizure. As far as the algorithm is concerned, it will enter in a standby mode (Delay), whose duration is equal to three (3) minutes. This delay is necessary in order to determine whether the subject suffers from successive attacks without acquiring consciousness.

Transition Phase 4G However, if the subject does not go into any of the above six (6) seizure statuses while he is in the “High Predisposition to Epilepsy status”, then we believe that the algorithm will enter in a waiting state (Delay), whose duration depends on the epileptic medical history of each subject, and then make a new display control of one (or more) new $\{RF_i\}$.

Transition Phase 5 Transition from one of the seizure statuses to “Status Epilepticus” occurs whenever the subject is in the same seizure status for duration of at least three (3) minutes.

Actions: In this Phase, the caregiver takes over to notify an ambulance of a nearby hospital because the situation is extremely serious and dangerous since the patient can even die. As far as the algorithm is concerned, it will enter in a standby mode (Delay), whose duration depends on the epileptic medical history of each patient and the particular seizure status. Then, the algorithm will take control of the restoration of patient’s full consciousness.

Transition Phase 6A Transition from “Status Epilepticus” to “Post Seizure status”. It occurs whenever the subject’s consciousness has been fully restored and one or more of the following eleven (11) Post Seizure symptoms $\{PS_v, v = (1, \dots, 11)\}$ are presented:

1. Sleep
2. Memory deficit the person does not remember what had happened
3. Dizziness
4. Drowsiness
5. Headache
6. Fear
7. Confusion
8. Feeling of Shame
9. Difficulty in speaking
10. Weakness
11. Thirst

Transition Phase 6B Transition from one of the eight (8) seizure statuses to “Post Seizure status” occurs whenever one or more of the above eleven (11) $\{PS_v\}$ are presented.

Actions: In this Phase, we suppose that the algorithm will enter in a Standby mode (Delay), whose duration depends on the epileptic medical history of each subject and the $\{PS_v\}$ that were presented in each case. Then, the algorithm will carry out a display control of one (or more) new $\{PS_v\}$.

Transition Phase 7A Transition from “Status Epilepticus” to “Normal status” occurs whenever the subject’s consciousness has been fully restored and none of the above eleven (11) $\{PS_v\}$ are appeared.

Transition Phase 7B Transition from “Post Seizure status” to “Normal status” occurs whenever none of the above eleven (11) $\{PS_v\}$ are presented.

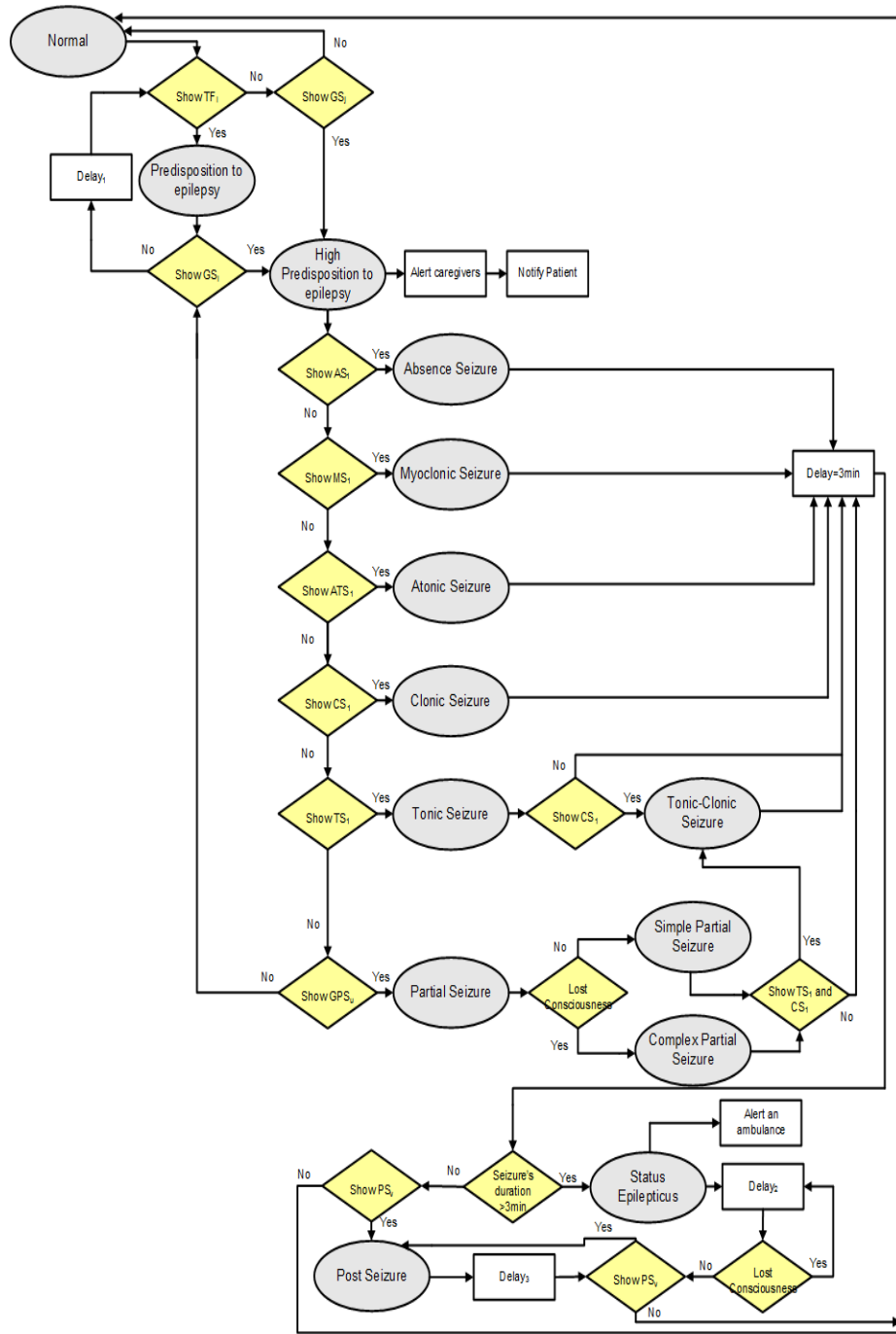


Fig. 1. Epileptic patient's status transition diagram in the proposed telemonitoring algorithm

3 The Implementation of the Model's Decision-Making Algorithm

3.1 The Applied Implementation Method

In order to organize the medical terms, events and actions of previously described mapping, we developed a health-caring ontology [10]. An ontology is defined as an explicit, formal specification of shared conceptualization. So, it is an abstract model of concepts and relationships that exist in a certain knowledge domain and it can be represented in an unambiguous, computer-readable and understandable way. Especially for medical expert systems, ontology is the de facto engineering artifact to develop, process and exchange such models.

An ontology uses a common language to formalize its knowledge domain. The most recognizable are the **Resource Description Framework (RDF)** and the **Web Ontology Language (OWL)**, for which World Wide Web Consortium (W3C) [11] developed a standard.

To develop our domain ontology we chose to use Protégé [12], in its latest stable version 4.3. It is a free, open source editor which helps us build knowledge-based systems. In Protégé, we can model the concepts and relationships of our world and by using reasoners, such as Pellet, Hermit, etc. we can provide semantic classification of the medical terms, combine the defined ones and infer new information of the world. Reasoners, also, check for ontology inconsistencies. Moreover, it is important to mention that Protégé is based on **Java**. So, we can easily import our **.owl** file in **Java** via a **Java Application Programming Interface (API)**.

Finally, in order to provide services to a specific patient we implemented a personalized telemonitoring algorithm based on our ontology using **Java**. We chose that programming language mostly due to the ease of Protégé's integration to it. For the development we used as **Java Integrated Development Environment (IDE)** Eclipse and the **API** of our choice - which will import the ontology - was **Jena** [13]. One of the main reasons for the choice of Jena was that it has plenty of libraries that can be used to create and manipulate **RDF** graphs. Ontology's **OWL** language can be saved in a **RDF/XML** format in Protégé, in order to be understandable by **Jena**.

3.2 Ontology Engineering for Epilepsy

In this work, we developed a knowledge-based ontology for people diagnosed with epilepsy. We acquired the knowledge, necessary for the creation of the ontology, from field experts and based on it we build a model using Protégé. First of all, we defined all the required classes as well as the object and data properties for the representation of all the phases before, after, and in the course of an epileptic seizure. We set some exact cardinality restrictions on classes and axioms on properties, such as domain and range, in order to make the reasoner's inference more accurate. In the end, we added some individuals on the defined classes.

For example, some of them are the symptoms of all the different categories of seizures, which are individuals of the corresponding class.

In Fig.2, we represent the main classes used in our ontology. This visualisation was created by OntoGraf plugin that can be integrated in Protégé.

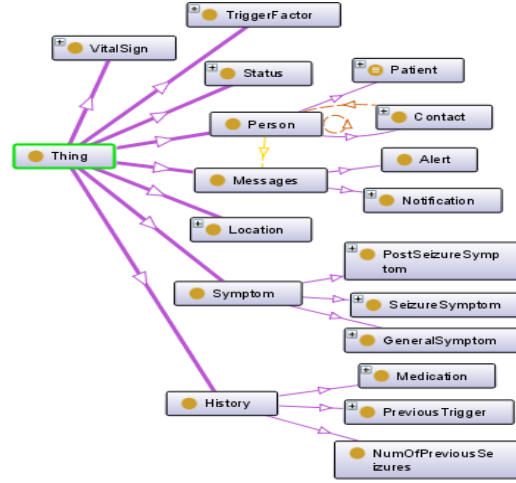


Fig. 2. The main classes in the implemented ontology

3.3 Implementation of the Decision-Making Algorithm

The aim of the ontology is not to contain information that can be updated and changed without changing the ontology itself. Basically it is the blueprint that an algorithm has to be based upon in order to provide personalized and decision-making services to a specific patient. That algorithm in our case is developed using the **Java** programming language with which we coded the rules and conditions so the algorithm can make the correct, in each case, decisions and take actions based on the new inputs. As far as the decisions are concerned, the algorithm will decide in which medical status the patient has been transited to. If the patient does not have any symptoms, the algorithm decides that his/her status will be “Normal status”, otherwise it decides according to the symptoms that he/she exhibits. Regarding the actions, the algorithm will proceed to notify and alert the subject as well as contact his/her caregivers based on his/her health status.

After we imported the ontology via the Jena API, we added the new individuals such as our main subjects along with their properties, for instance the symptoms that he/she exhibits each moment. Finally, Java has to interpret the new inputs as part of the ontology, change the necessary parameters - like the values of the properties which our patient has - make the necessary decisions, and save it as an ontology file that can be opened again and visualized by Protégé.

3.4 Input Data to the Decision-Making Algorithm

The data that need to be inserted in the algorithm must be obtained via many ways. There are data that come from smart sensors. Wearable sensors are placed non-invasively on the patient's body and continuously collect and transmit vital signs measurements. Nowadays, these sensors can be tiny, flexible and embedded in everyday accessories like a watch. In our model, the vital signs that need to be measured are ECG (heart rate), body temperature, respiratory rate and blood pressure, etc. In addition, other data need to be input manually by the patient or the caregiver, but that is implemented in a non distracting and disturbing (for the patient) way. In case of epilepsy, most trigger factors and symptoms are by their nature quite fuzzy and cannot be monitored via an autonomous way. So, the algorithm request people to keep it updated regarding the patient's condition.

4 Evaluation of the Proposed Model

The evaluation of the proposed model is made by means of a specific medical case study [4]. In this case study, we personalize the ontology based on a female patient, named Kate.

4.1 Kate's Epileptic Medical History and Profile

Kate had a normal birth, without perinatal complications and a normal psychosocial growth. There are no significant health issues in her life. Her father seemed to have had Absence seizures as a child but he was never treated for that. In the age of 20, Kate had her first seizure. She first felt disturbed by the lights of a club she was out with her friends and then felt weak and her vision blurred. She lost consciousness, presented urinary incontinence and when she woke up her tongue was bleeding. Her friends mentioned that her limbs and body were stroking for less than a minute. Laboratory tests and Magnetic Resonance Imaging (MRI) exams produced no results. Electroencephalogram (EEG) exam was impaired only under strong pulsative light but no seizure was induced. She was not diagnosed as epileptic and she didn't take any medication. Three months later, she had another seizure while watching television, with the same characteristics. Kate then mentioned she was tired because of exams and then was diagnosed with epilepsy and was prescribed medication. Since then, there was no other epileptic incidence.

Now, Kate is 27 years old, right-handed, with a history of symptomatic epilepsy with Tonic-Clonic seizures and under a 500mg dosage of Depakine 1/day therapy since she was 20 years old.

4.2 Kate's Telemonitoring Through the Proposed Algorithm

One year ago, our research team selected Kate's case as the appropriate case in order to evaluate the proposed model. In our implemented algorithm, we

added three different individuals, Kate, her husband (caregiver) and her doctor. The algorithm took as a fact that her current status is “Normal”. Moreover, we asked Kate and her husband to notify her current active context in order the algorithm to be aware, whenever specific Trigger Factors or symptoms were detected. Some months later, Kate visited her neurologist with the request of stopping her medication in order to get pregnant. Her doctor decided to reduce the dose of medication, a fact that algorithm recognized as a Trigger Factor, then it activated the Transition Phase 2 and finally it decided that Kate transited from “Normal status” to “Predisposition to Epilepsy status”. In parallel, notifications were sent regularly to her husband and to herself about her status.

Three days later, she experienced menstruation. So now she entered as an input in the algorithm the second Trigger Factor and she was notified twice a day, one in the morning and one in the afternoon to avoid stress and lights. Stress and lights were chosen by the algorithm according to her epileptic medical history (Previous Trigger Factors). Her status remained as it is, “Predisposition to Epilepsy”.

Four days later, Kate visited some friends at a restaurant. The algorithm, being informed about the strong lights existing in that place, sent a warning message to her. Fifteen minutes later, when the algorithm asked her again, she felt uncomfortable, tired and her vision impaired. So, she entered her symptoms, but now she had additionally one General Symptom, Aura. Our patient transited from “Predisposition to Epilepsy status” to the “High predisposition to Epilepsy status”. Notifications were sent to her and to her husband in order to check up on her.

While heading to the toilet but before reaching her destination, she lost consciousness and tonic along with clonic convulsions occurred. When her husband reached her he removed the sharp items, to prevent her from hurting herself, and he entered the new symptoms in order for the doctor to be notified and for him to receive updates as to how to proceed. Kate, at this point, transited from “High predisposition to Epilepsy status” to “Generalized Tonic-clonic Seizure status”. Automatically her doctor was notified about Kate’s condition.

Three minutes later she was still having seizures without regaining her consciousness. As three minutes passed Kate transited from “Generalized Tonic-Clonic Seizure status” to “Status Epilepticus” and the nearest hospital was notified and they sent an ambulance.⁵

Fifteen minutes later, the ambulance arrived, the paramedics inserted her with 10mg diazepam IV and she was transferred to the hospital. Ten minutes later the seizures stopped, and she regained consciousness. She was disoriented, she couldn’t speak properly and she was sleepy. In that stage Kate showed Post Seizure symptoms, and after her husband entered them her status was updated to “Post Seizure”.

⁵ In this situation, in order to visualize the relationships that have been created up to this moment, the data were saved and could be again opened in a new ontology file. The results are shown in Fig.3, created with OntoGraf in Protégé.

She woke up four hours later and she was mentally normal. She was feeling good and she wanted to be checked out of the hospital but she had to be kept under supervision for one day. She was prescribed again Depakine of 500mg and after entering this information in the algorithm she transited from “Post Seizure status” to “Predisposition to Epilepsy status” until all the symptoms of this category are gone. To be more exact, she would stay in the above status until menstruation had stopped. Finally, if no other symptoms appeared, she would transit to “Normal status”.

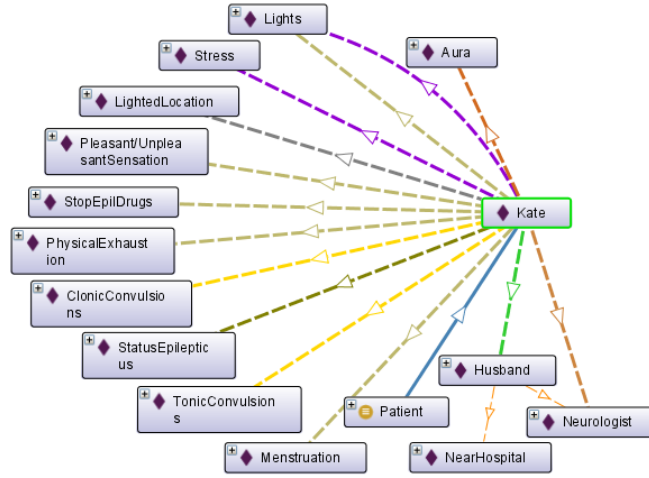


Fig. 3. Kate’s relationships, in the specific case study, when she is in “Status Epilepticus” status based on the proposed algorithm

4.3 Discussion

The above real world case study offered us a chance to evaluate the algorithm’s performance. Despite the fact that we used non full automated data (vital signs, context conditions, etc) acquisition procedures, the algorithm yielded the correct results in any patients living and health condition. The indicated by the algorithm transitions were the appropriate and the predicted health status after each transition was verified by the disorder’s evolution. The doctor and the caregiver were, anytime, well aware about the anticipated seizures. Adopting this algorithm in a telemonitoring system for epilepsy offers advanced capabilities to the patient and the caregivers in order to deal with these seizures.

5 Conclusions

Epilepsy is a dangerous disorder, mainly due to the nature of its symptoms. As we have shown in our model there are a lot of factors that take place and contribute

to its progress - and most of them being fuzzy - the prediction of a seizure is extremely difficult. Being able to identify on time the status of the disorder in which the subject is currently in, is of paramount importance, but it is also very hard to be detected, especially if the patient is not careful, well-informed or not in regular contact with a doctor. Our model offers a viable non-intrusive way to make informed life-saving decisions that will give time to both the patient and his/her doctor (or caregivers) to take action and prevent a situation that could escalate very quickly if it goes undetected. Furthermore the way that we designed and implemented our model, provides a great way to record the status of the patient in regular basis. That log gives him/her the ability to telemonitor his/her condition and also examine in that record, whenever it is necessary, past changes and previous health related events regarding the disorder.

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