# Ontologies for Knowledge Modeling and Creating User Interface in the Framework of Telemedical Portal

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**Abstract:** The telemedical portal is an environment that provides a set of communication, storage and decision support services. The telemedical portal is designed to support diversified clinical problems, therefore it should be flexible and extensible. To provide the required flexibility we separated the domain specific knowledge from the generic services. The domain knowledge is represented by ontologies and knowledge bases that describe specific problems. Such separation allows the coupling of services with various knowledge bases. We present the overall architecture of the telemedical portal and use the teleconsultation service and the knowledge base describing the problem of multiple organ injuries to present the separation and coupling. Specifically, we show how the generic teleconsultation service stores information and automatically creates the user interface using the provided knowledge base.

## 1 Introduction

A telemedical portal is an environment that provides telemedical services to its users - physicians, health care professionals and medical students. Telemedical portals are being constructed to support the complex processes of medical treatment and management with the use of the advanced networking tools and technologies. The tools found within such environments range from medical record databases, through image and video transmission, up to clinical decision support systems. The telemedical services built on top of these tools simplify communication between the users, thus improving standards of treatment, administration and training. Examples of telemedical services are: a teleconsultation service that allows one to consult medical cases across different health care units, a teleeducation service that is used in the training of students of medicine, and a reference cases registry service that allows one to find information about treatment strategies that should be applied in difficult medical cases. The domain knowledge on which portal services operate is shared between different services. It is also assumed that generic services operate on knowledge from different medical domains. Therefore, it is crucial for the environment to separate the domain knowledge from the services that use it.

In this paper we present an approach that enables flexible modeling of the domain knowledge that was applied during the development of the “Telemedycyna Wielkopolska” portal [TW]. The main research question to be answered in this paper is how to model domain knowledge to make it applicable to diversified medical domains and usable for different portal services that will operate on it. The telemedical portal offers the set of services that we mentioned above. The first goal of the “Telemedycyna Wielkopolska” portal was to standardize and improve communication between its users, therefore, the initial work was focused on the teleconsultation service and the service has already been introduced into clinical practice. The required flexibility is achieved by separating the domain knowledge from the services and representing the domain knowledge in the form of ontologies and knowledge bases. The domain ontology lists and organizes concepts for a considered problem. It defines classes of concepts and relationships between them. Ontologies are schemas that guide the construction of knowledge bases storing instances of defined classes. Thus, using a database metaphor, an ontology can be seen as the schema of a knowledge base. Separation of the domain knowledge from the services not only improves reusability of system components (a single service can be used with several ontologies and knowledge bases) but also supports automatic customization of services. As an example we present automatic generation of the user interface for the teleconsultation service.

The structure of this document is the following. In section 2 we present the telemedical portal and its architecture. In section 3 we present domain ontologies and knowledge bases. In section 4 we show how the domain knowledge supplemented with interface knowledge can be used to automatically create the user interface. We conclude our presentation in section 5.

## 2 Telemedical Portal “Telemedycyna Wielkopolska”

The architecture of the “Telemedycyna Wielkopolska” portal has been drawn upon the well-established solutions from the grid technology domain. Through the assessment of user requirements we found the challenges set by the need of delivering a complex system providing a set of reliable telemedical services in a form of a telemedical portal very similar to those arising in the grid technology research [GGF]. Grid technology provides some useful models which could be adopted by the constructed telemedical portal. The key element for the success of the complex and diverse regional telemedical portal was an access environment to remote and distributed services such as digital libraries, video streaming services, decision support services and data management systems. Consideration also had to be given to the workflow nature of some of the telemedical processes. The analysis of the telemedical portal requirements led us to the choice of several methodologies for the construction of the telemedical portal environment, selected from the set of solutions developed by Poznan Supercomputing and Networking Center within various grid projects [KMS02, BKM03, KKM04].

Assessment of the user needs showed that the developed telemedical portal had to offer the following services:

- *Teleconsultations* to support the specialized remote consultations for the difficult medical cases that are encountered in regional hospitals and that need to be consulted remotely with experts in a specialized clinic [KOS05],
- *Reference case registry* to manage and provide a database of specially interesting cases that illustrate the procedures to undertake in similar situations found by doctors in their everyday work,
- *Medical teleeducation* to allow the medical personnel to constantly widen their knowledge and thus improve the overall quality of the regional health care,
- *Clinical decision support* to enable semi-automatic decision support in the medical problems faced by doctors in their everyday work.

These high-level telemedical services are shown in Figure 1. They operate on domain knowledge that is modeled as we describe in Section 3 and managed by low-level resource management systems. The specialized resource management systems are available via the interfaces implemented in the form of broker services. In the case of the telemedical portal these low-level systems identified as necessary to carry out the specialized tasks were the Data Management System [KMM05], the Digital Library System [MW05] and the Multimedia Content Delivery System [CKM05].

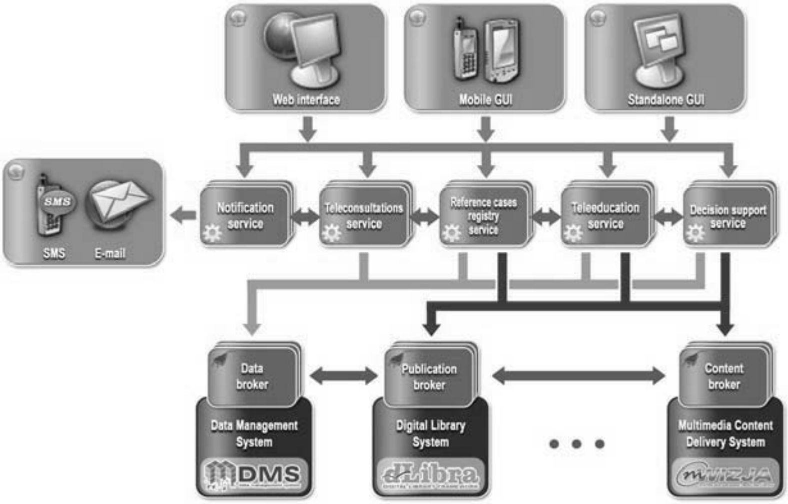


Figure 1 The architecture of the "Telemedycyna Wielkopolska" portal

In addition, the Notification Service designed and developed as a part of the GridLab project was introduced to the telemedical portal. The Notification Service helps to reliably deliver SMS or e-mail notifications of events, for example, to doctors participating in the teleconsultation process [AGK05].

The high-level services are accessed from a diverse set of graphical user interfaces. The main user interface is a web-based application delivered within the GridSphere Portal Framework [NRW03]. In addition, a mobile graphical user interface for 'anytime-anywhere' access and a standalone user interface for more sophisticated access scenarios are planned. To facilitate the construction of specialized telemedical Java-based user interfaces we utilize the capabilities of the PROGRESS Portlet Framework [BKMS04]. The component architecture of the Framework allows one to efficiently reuse parts of the already existing code during the construction of a new portlet and can be efficiently used for the construction of diverse user interfaces. The Framework comprises of four layers, one of which, the Content Generator, is fully dedicated to the generation of user interface screens. This layer is used to define the look and feel of the user interface. It is currently being extended to include ontologies for automatic creation of graphical user interfaces as described in Section 4.

## 3 Ontology for Modeling Domain Knowledge

Our approach to model the domain knowledge for the telemedical portal has been inspired by the research on knowledge-based clinical systems with domain ontologies separated from generic solving methods (solvers) [M98, M99] and by our experience with ontology-driven clinical decision support systems [MSW05, MWF05].

The separation of ontologies (and knowledge bases constructed on their basis) from solvers increases the robustness and reusability of constructed systems – a single ontology can be coupled with various solvers, and on the contrary, a single solver can operate on various ontologies. This separation is not only important from a system engineering perspective, but it results directly from the research in medical informatics. Ontologies represent health-related application areas in the form that is comprehensive for the machine and for the human, while generic solvers represent fundamental algorithms for processing clinical data and knowledge [M99].

The notion of a solver has been usually limited to procedures that solve decision problems (e.g., optimizers or classifiers). However, it can be generalized to include any procedure or service that operates on ontologies and derived knowledge bases, including storage or communication services. Separating the functionality of a system between domain ontologies (and knowledge bases) and generic services adds to the reusability of these components and allows building advanced clinical decision support systems.

The research on ontologies in medical informatics is conducted in three areas: exchange of messages, models of the Electronic Health Record (EHR) and terminologies and vocabularies. So far the major effort has been focused on the first and last area, as they were necessary for assuring inter-operation of various healthcare systems by defining common syntax and content of exchanged messages. The research resulted in emerging such well-accepted standards as HL7 for messages (enhanced by Reference Information

Model that represents semantic and lexical connections between the information in messages) [HL7], SNOMED-CT [SI] for clinical terms, LOINC [RI] for laboratory results and others [HC01]. There are also international efforts that aim at unifying general clinical knowledge (not limited to medical informatics), like the Foundational Model of Anatomy [FMA] or Disease Ontology [DO]. These projects also contribute to supporting efficient exchange of clinical knowledge and information.

Research on modeling the EHR has been intensified recently to further facilitate unification of clinical information across care sites so it can be easily shared and transferred supporting the continuity of care (solutions adopted for messaging may be not effective enough for this purpose). Several standards have been already proposed, e.g., by ASTM Committee E31 [ASTM] or by the openEHR Foundation [OEHR]. However, they are not as widely accepted and applied in practice as standards for messaging and terminologies.

The telelemedical portal offers a set of diversified services that can be used to support various clinical problems. Their efficient use in clinical practice requires the portal to be easily adaptable. To satisfy this requirement we designed an ontology that represents a general schema of clinical knowledge processed by the portal and that closely follows the chacateristics of the portal. The developed ontology is presented in Figure 2. For the sake of clarity we excluded classes of concepts that represent administrative and demographic information (i.e., patient and episode). Moreover, we show only those attributes that are required for comprehensive and concise presentation of the ontology and sample entries in the derived knowledge base. Finally, we use the knowledge base built for the problem of multiple organ injuries as an example.

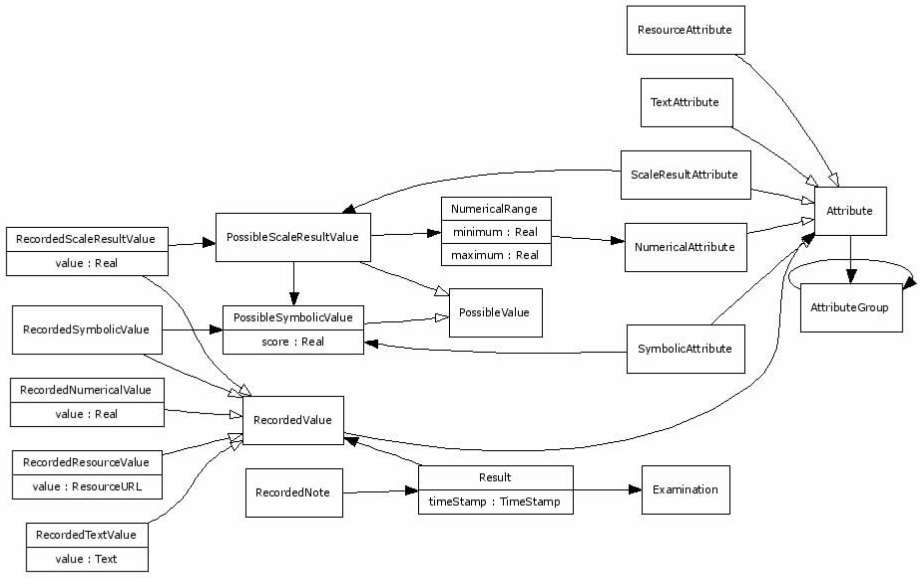


Figure 2: Ontology of the domain knowledge

The ontology relies on the *entity-attribute-value* representation of information [NMC99] that is very well suited for diverse and heterogeneous data. Moreover, this representation eases object-at-a-time queries (e.g., select all examination results for patient X collected his stay in the Emergency Department) that are very frequent in clinical information systems [CNM00]. The ontology is built around three main classes – *Examination, Attribute* and *RecordedValue* that correspond to entity, attribute and value, respectively.

The *Attribute* class represents a clinical attribute. Attributes can be grouped into groups (e.g., attribute describing spine injuries) represented by *AttributeGroup*. We allow multi-level grouping with attribute groups containing subgroups and attributes. In the knowledge base for multiple organ injuries the "injuries of motor organs" are composed of groups related to specific organs (hip, arm, pelvis etc.) that further include attributes representing specific injuries.

*Attribute* is an abstract class further specialized into concrete classes representing attributes of specific types:

- *ResourceAttribute* represents an attribute with values being resources (e.g., images, movies, sounds) managed by the Data Management System.
- *TextAttribute* represents an attribute with values given as texts.
- *NumericalAttribute* represents an attribute with numerical (continuous) values. It is possible to define the range of possible values by linking an instance of the *NumericalRange* that specifies minimum and maximum values, to an instance of *NumericalAttribute*. An example of a numerical attribute is presented in Figure 3.

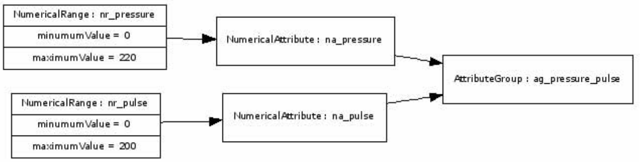


Figure 3. Definition of numerical attributes representing pulse and blood pressure

- *SymbolicAttribute* indicates an attribute with symbolic values. Possible values are provided as instances of the *PossibleSymbolicValue* class. An example of a symbolic attribute is presented in Figure 4.
- *ScaleResultAttribute* indicates an attribute being the aggregated result of a scale (e.g., Glasgow Coma Scale – GCS). The scale can be represented by *AttributeGroup* composed of several attributes from the *SymbolicAttribute* class and a single attribute from the *ScaleResultAttribute* class. Possible values for each symbolic attribute (instances of the *PossibleSymbolicValue* class) can store scores, thus the overall result can be calculated by summing up the scores of se-

lected values. Glasgow Comma Scale mentioned above is defined as a group of three symbolic attributes (eye opening, verbal response and motor response) and a result attribute. The result is calculated as the total of scores bound to selected values for the three symbolic attributes. Usually the score result is augmented by a discretization that translates the score into a categorical description (symbolic value). For Glasgow Comma Scales the following score intervals are considered: 13-15 – mild brain injury, 9-12 – moderate brain injury and 3-8 – severe brain injury. The ontology allows one to define such discretizations by linking appropriate instances of the *PossibleScaleResultValue* class that associate *NumericalRange* with *PossibleSymbolicValue* to an instance of *ScaleResultAttribute*. A definition of Glasgow Coma Scale is given in Figure 5.

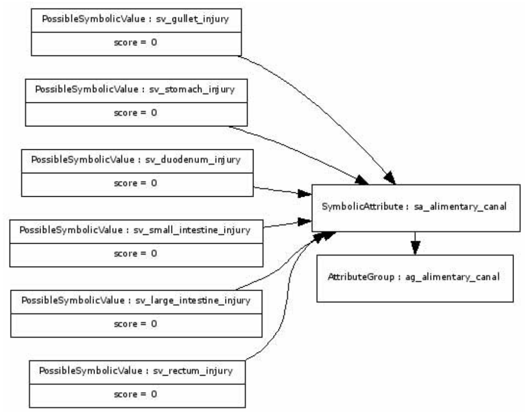


Figure 4. Definition of an attribute representing injuries of the alimentary canal

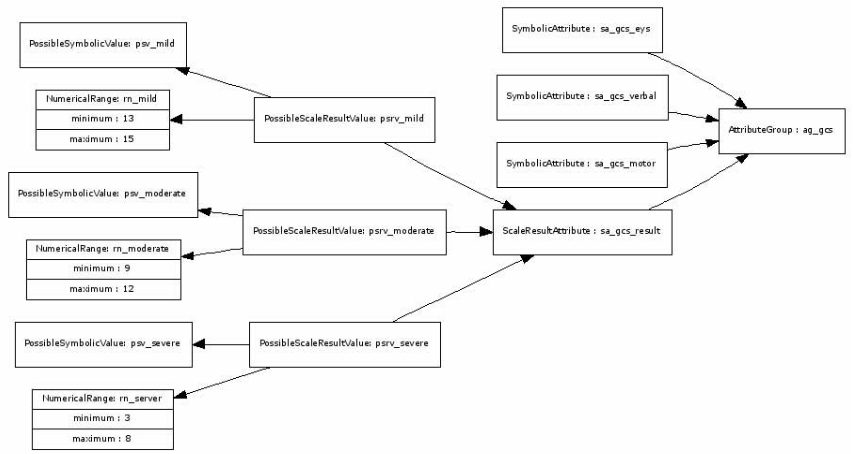


Figure 5. Definition of Glasgow Comma Scale

The value of an attribute is represented by the abstract *RecordedValue* class. The class is further specialized into concrete classes representing specific values. This specialization matched the specialization of the *Attribute* class, i.e., for each attribute class there is a specific value class that is suited for storing information of a specific type:

- *RecordedResouceValue* represents a value of *ResouceAttribute*. The information is stored as the URL of a resource in the Data Management System.
- *RecordedTextValue* represents a value of *TextAttribute* and stores information as text.
- *RecordedNumericalValue* represents a value of *NumericalAttribute* and stores information as a real number.
- *RecordedSymbolicValue* represents a value of *SumbolicAttribute* and stores a link to a selected instance of the *PossibleSymbolicValue* class.
- RecordedScaleResultValue represents a value of *ScaleResultAttribute*. It stores the total score for a scale and the link to an appropriate instance of the *PossibleScaleResultValue*.

*RecordedValue* is linked to an instance of the *Result* class that holds additional information describing the value (e.g., timestamp indicating when the value was recorded). Each instance of *Result* can be annotated with an instance of *RecordedNote* that supplements information stored in *RecordedValue*. Currently, only text notes are supported, but we plan to extend the ontology and introduce voice notes, as they are common in clinical practice. We decided to separate *Result* from *RecordedValue* as we plan to use the ontology for constructing decision models for the decision support service. Decision models will use information in the form of instances of specific *RecordedValue* classes where annotations are superfluous, and thus we will be able to avoid such overload.

Finally, instances of the *Result* class are linked to an instance of the *Examination* class. Thus, a single instance of *Examination* can be associated with multiple instances of *Result*. Moreover, it is also possible to specify several values of the same attribute within a single instance of *Examination*. A samples examination is presented in Figure 6.

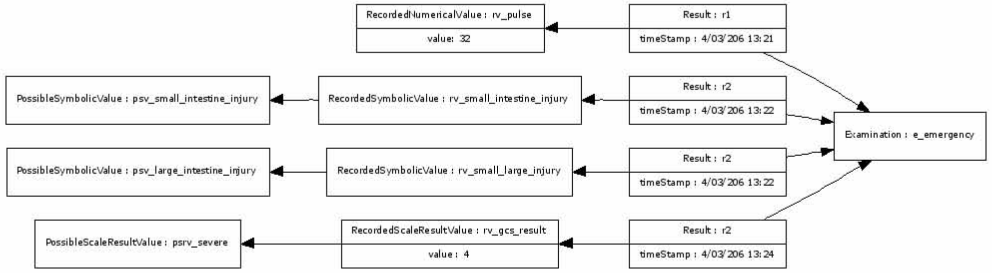


Figure 6. Results of an examination

We use OWL to store the domain ontology and derived knowledge bases. OWL was developed for a semantic web and became a common representation for ontological models and knowledge bases [OWL]. It has been supported by auxiliary technologies, like RDQL – a counterpart of SQL language for querying ontologies. Specifically, we use the Jena library [JENA] to store and process the knowledge represented in OWL.

## 4 Automatic Generation of the User Interface

Ontologies and knowledge bases are not only used to represent and store domain knowledge, but they can also be used for automatic generation of user interfaces [EPM94]. Such interfaces reflect the ontologies and knowledge bases on which they are based, and thus they can adapt whenever the underlying knowledge is modified. The idea of automatically generated interfaces was developed and applied for the knowledge acquisition tools for creating and updating knowledge bases [GMF03] and it can be easily adopted for the telemedical portal.

In order to construct the user interface we had to provide additional information describing the interface, e.g., names of displayed objects (attributes, possible values etc.), their sequence on the screen and additional descriptions. This information forms the interface knowledge. We did not combine the interface knowledge into the domain knowledge as this would have limited the generality of the solution. Now, with the separation of the domain and interface knowledge we can couple several different interfaces with a single domain ontology and knowledge base. In the simple case the interfaces can be in different languages, and in the more complex case we could provide a more advanced interface for the service accessed from a desktop computer, and a simplified one when the service is used from the mobile platform (e.g., a handheld computer or mobile phone).

The interface knowledge is modeled using a simple interface ontology with only one class – *InterfaceItem* that contains information mentioned above. Instances of the *InterfaceItem* class are stored in the interface knowledge base and are linked to appropriate instances in the domain knowledge base. The interface knowledge for Glasgow Coma Scale is presented in Figure 7 (for the sake of brevity we limited the number of presented instances).

The domain knowledge and the interface knowledge are transformed into a running interface following a set of simple rules that bind specific widgets (editing tools) to instances of specific classes from the domain knowledge (e.g., values of *SymbolicAttribute* are entered using selection lists, while values of *TextAttribute* or *NumericalAttribute* are provided via text fields). Then the widgets are rendered using the interface knowledge (e.g., they are labeled with provided descriptions and laid out according to a defined sequence). The rendered interface for Glasgow Coma Scale is presented in Figure 8.

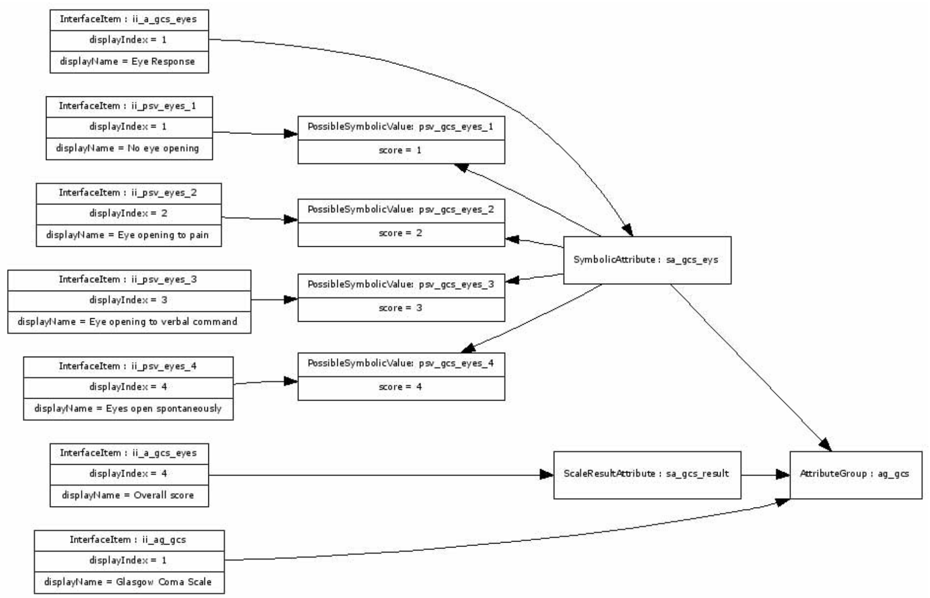
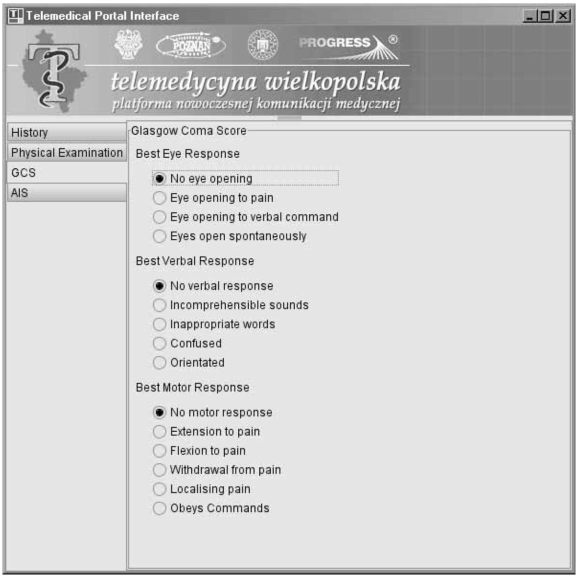


Figure 7. Interface knowledge for Glasgow Coma Scale



Glasgow Coma Score

Best Eye Response

● No eye opening
○ Eye opening to pain
○ Eye opening to verbal command
○ Eyes open spontaneously

Best Verbal Response

● No verbal response
○ Incomprehensible sounds
○ Inappropriate words
○ Confused
○ Orientated

Best Motor Response

● No motor response
○ Extension to pain
○ Flexion to pain
○ Withdrawal from pain
○ Localising pain
○ Obeys Commands

Figure 8. Rendered interface for Glasgow Coma Scale

## 5 Conclusions

We presented the telemedical portal “Telemedycyna Wielkopolska” and described an approach to flexible modeling of the domain knowledge that is stored and processed in the environment of the portal. This approach assumes separation of the domain knowledge and the portal services. We used ontologies and knowledge bases to model the structure of the domain knowledge. This significantly increases the extensibility of the portal as it is very easy to adapt the portal to new medical problems by supplying specialized knowledge bases. We also showed how the domain knowledge augmented with additional interface knowledge can be used for automatic generation of the user interface for the portal. The ontology was developed with the characteristics of the telemedical portal and its services in mind, however, we plan it to combine it with approved models of the EHR, thus easing the integration with existing hospital information systems.

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