CHARMing Clinical Pathways
Modeling of Clinical Pathways based on the Goal-Oriented Ontological Framework CHARM

Satoshi Nishimura[1], Genma Nishijima[1], Yoshinobu Kitamura[1], Munehiko Sasajima[1,2], Toshihiro Takeda[3], Yasushi Matsumura[3] and Riichiro Mizoguchi[4]

[1]*The Institute of Scientific and Industrial Research, Osaka University, 8-1 Mihogaoka, Ibaraki, Osaka, 567-0047, Japan*
[2]*YMP-Mundus Corporation, YMP Tanimachi Building Minami-kan 10F, 1-1-14 Izumi-cho, Chuoh-ku, Osaka, 540-0019, Japan*
[3]*Department of Medical Informatics, Graduate School of Medicine, Osaka University, 2-15 Yamada-oka, Suita, Osaka, 565-0871, Japan*
[4]*Japan Advanced Institute of Science and Technology, 1-1 Asahidai, Nomi, Ishikawa, 923-1292, Japan*

Keywords: Action Model, Clinical Pathways, Knowledge Representation, Ontology Engineering.

Abstract: Much procedural knowledge in the medical domain, such as clinical practice guidelines, nursing manuals, and clinical pathways (abbreviated to CPs), is documented and shared. This paper concentrates on the CP, which represents a standard time-sequence of actions carried out by clinical staff for each disease. With the aim not of replacing the conventional form of CPs in a clinical setting but of facilitating description and revision of knowledge by knowledge managers, we have proposed CHARM, which is a goal-oriented, tree-structured model based on an ontology of actions. The aim of the work described in this paper is to confirm the practical ability of CHARM to represent medical actions in CPs in a computer-interpretable way, using eight real CPs in Osaka University Hospital. CHARM trees in terms of actions defined clearly in the ontology explicitly represent goals of actions, i.e., why the actions should be needed, and so on, which are implicit in the conventional CPs. We also confirmed the benefits of CHARM for describing/revising CPs by the knowledge mangers in a comparison of the actions in CPs, such as finding commonality among CPs, easy comparison of CPs from a goal-oriented perspective, and explanation of the reasons for differences.

1 INTRODUCTION

In the medical domain, large amount of procedural knowledge is documented in clinical practice guidelines, nursing manuals, and clinical pathways (abbreviated to CP hereafter). CPs and clinical practice guidelines describe standard (prescriptive) actions, unlike the record of real actions performed on a patient, which is descriptive. In this research, we currently focus on the former.

The ultimate goal of this research project is to manage procedural knowledge about medical practice in a unified framework in which these several kinds of knowledge are stored. We attempt to use CHARM as the unified modeling framework, which has been proposed by the authors. (Nishimura et al., 2013). We aim to integrate the similar knowledge in nursing manuals, clinical practice guidelines, and CPs into CHARM trees (hereinafter called as knowledge model) to systematically handle it in a consistent manner. We expect that the framework will be used as follows.

(1) Knowledge managers describe the knowledge models in CHARM trees and revise them for their improvement by comparing the trees. They are leading medical doctors for medical informatics in hospitals, experienced nurses, and/or experts in medical societies with knowledge engineers in information science.

(2) Clinical staff read the knowledge models in a clinical setting. They, especially, novice nurses, consult the models as standard actions to be performed in practical clinical situations.

(3) Novice nurses as learners read the knowledge models as right sequences of actions to be performed in education and/or training situations.

This research aims mainly at the use cases of (1) and (3). In these use cases, we expect the benefits of

Nishimura S., Nishijima G., Kitamura Y., Sasajima M., Takeda T., Matsumura Y. and Mizoguchi R..
CHARMing Clinical Pathways - Modeling of Clinical Pathways based on the Goal-Oriented Ontological Framework CHARM.
DOI: 10.5220/0004747002110221
In *Proceedings of the International Conference on Health Informatics* (HEALTHINF-2014), pages 211-221
ISBN: 978-989-758-010-9

CHARM trees in describing, revising and learning the knowledge as described below. In the use case (2) which is not our main aim and not discussed in this paper, the unified model is transformed into the conventional representation forms (e.g., the table-style form of CPs). Thus, in clinical practice, the medical staff can read the unified knowledge in the conventional forms familiar to them.

CHARM is a modeling framework of procedural knowledge based on ontology engineering, aimed at promoting knowledge sharing and knowledge inheritance among medical workers (Nishimura et al., 2013). CHARM, which is an abbreviation of Convincing Human Action Rationalized Model (Nishimura et al., 2013), is designed to represent human actions in a goal-oriented manner. A CHARM tree clarifies the goal of actions. The terms used in a CHARM tree are defined based on an ontology of actions and make the meaning of actions computer-understandable to some extent. A CHARM tree explicates the reason for performing the action by clarifying the goal. Alternative ways of achieving the goal are also made explicit.

The authors have confirmed the practical benefits of CHARM for describing and learning the nursing actions, which corresponds to the use cases of (1) and (3) above. In the collaborative study involving nurses, several nursing manuals in a certain hospital were described based on CHARM. As the knowledge managers in the use case (1), the experienced nurses confirmed the benefits of CHARM in integration of the nursing guidelines in different hospitals (Nishimura et al., 2013). Moreover, for the learners in the use case (3), software designed to browse CHARM trees on tablet computers has been developed and has been applied to the training of novice nurses in hospitals (Sasajima et al., 2013).

There have been some research efforts for modeling the knowledge of medical procedures in computer interpretable manner, such as Asbru (Shahar et al., 1998), PROforma (Sutton and Fox, 2003), GLIF (Boxwala et al., 2004), and SAGE (Tu et al., 2007). They aim to assist doctors in making decisions by automatic reasoning based on computer interpretable models. The aim of our research project is not the same as theirs, but promoting knowledge sharing and knowledge inheritance through using CHARM trees.

In this paper, as the first step to build the management framework, we discuss description of existing CPs in the CHARM trees. We also demonstrate the benefits of CHARM in the use case (1) above. We try to show that the use of CHARM helps the knowledge managers compare the CPs when they want to revise CPs for improvement.

A CP provides a standard medical procedure to optimize length of hospital stay (Pearson et al., 1995), to minimize delays and excessive resource-consumption and to maximize the quality of care (Zander K., 1988, Coffey et al., 2005). There are some reports about improvement of outcomes and reduction of the length of stay thanks to CPs (Hauck et al., 2004, Madan et al., 2006). Every et al. have recommended the use of CPs in clinical settings (Every et al., 2000). Compared with other representation methods, a CP in a tabular form has two features. One is a clear representation of time points (days) on the X axis and the kinds of actions on the Y axis. The other is representation of the goal of actions within one day or several days as an "outcome". In a CP, however, intermediate goals of each action are not described.

The authors aim not at replacing the conventional CP forms with CHARM in the clinical setting but at facilitating the creation and revision of CPs by the CP authors as the knowledge manager. We do not suppose that the doctors and the nurses use the CHARM trees in the clinical setting.

CPs work well for doctors and nurses who understand the goal of their actions in clinical settings. However, some problems may occur to CP authors, who create and revise CPs. It is difficult to reuse the parts of a CP when the CP author creates other CP. In CPs, the time points of the actions and the rough goals are represented, but the relationships between actions are not clear. In other words, the dependency between actions is not clear, so it is difficult to reuse the parts of the CP. In order to revise the CPs, it is useful to compare the same medical procedures which are performed in different department of a hospital. It is easy to compare the procedure from a sequence-oriented viewpoint when the CP author uses the CPs. However, the viewpoint may not facilitate the CP author to detect the rational differences because the goals of the actions are not clear in the CPs. Therefore, the CP author needs his/her knowledge about the medical procedures and that takes a load of him/her. The goals of actions should be clear to facilitate reuse of the parts of the CPs and comparison of the CPs. The goal of actions connects the actions to achieve it, so the dependency between actions becomes clear. The goal of actions also decreases the load of the CP authors when they compare the medical procedures in the CPs.

The aim of our study was to describe CPs in the framework of CHARM and to confirm the following

benefits of a CHARM-based representation of medical actions in CPs used as knowledge sources:
(i) To represent the medical actions in CPs in a structured way, with the terms defined clearly.
(ii) To clarify the goals of actions, which are implicit in CPs.
(iii) To compare the medical actions between two CPs using CHARM trees.

In this research, we built CHARM trees from eight real CPs used in a hospital. From the results, the first and second benefits above were confirmed. Then we compared some CHARM trees and identified common structures among the trees. Through this comparison, the third benefit was confirmed.

This paper is organized as follows. In Section 2, we introduce CHARM as a representation framework and describe the contents of real CPs, and we also explain the method used to build CHARM trees from CPs. In Section 3, we confirm the benefits of CHARM. First, we identify commonalities among CPs, and next, we compare CPs using CHARM trees. In Section 4, we discuss the differences between our framework and other related studies. Finally, in Section 5, we conclude this paper and mention some topics of our future work.

2 DESCRIPTION OF CLINICAL PATHWAYS BASED ON CHARM

2.1 Charm

CHARM is a goal-oriented, tree-structured model based on an ontology of actions. Although there is no common definition of "ontology", an ontology in knowledge engineering can be generally defined as "a system (systematic, operational and prescriptive definitions) of fundamental concepts and relationships which shows how a model author views the target world, and which is shared in a community as building blocks for models" (Mizoguchi, 2003). In this project, the roles of the ontology are to define modelling concepts and to provide a controlled vocabulary for actions as discussed below.

A concrete model based on CHARM is called a CHARM tree. An action is interpreted as a state change of an object and is described using one of a number of action terms (verbs) that are defined in the ontology of actions. A single action is realized by a sequence of detailed (fine-grained) actions. In this context, a single action as a state change is interpreted as a goal of the sequence. Hereafter, we use the term "achieve" to mean that the sequence realizes the action as a state change. We conceptualize the reason why the single action can be achieved by the sequence as "a way of action achievement". The crucial point is detachment of "what is achieved (state change caused by the action)" and "how to achieve (way of action achievement)". This detachment of what to achieve and how to achieve it reduces the number of actions to be defined, which allows us to define a small set of actions as a controlled vocabulary. When two or more ways can be applied to achieve an action, those ways are in an OR relationship. A way of action achievement explains the necessary conditions to be applied and a reason why the way is applicable.

The ontology of actions defines an action as a state change of an object. The state change represents only "what is achieved" and excludes "how it is achieved". This definition enables us to detach a way of action achievement from an action. The ontology also provides terms to be used in a CHARM tree. The controlled terms are used as verbs in a CHARM tree and combined with an object (a target thing) to represent a concrete action clearly.

Figure 1 shows a CHARM tree that represents actions for emptying the digestive tract of a patient before a surgical operation on a digestive organ. This goal is described as an action "decrease contents of digestive tract" as the top node of the CHARM tree (node number 1 in Figure 1). This node 1 action can be achieved by a sequence of the

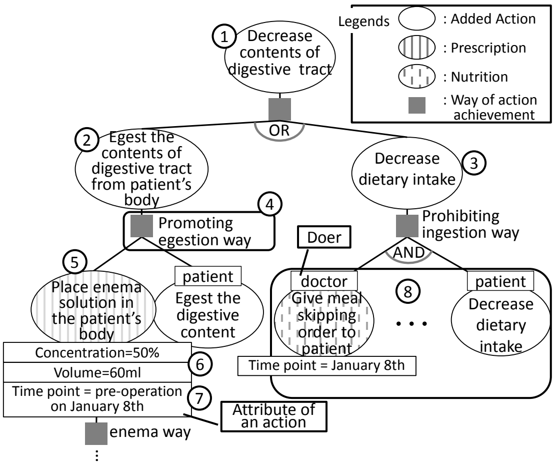

Figure 1: A partial CHARM tree for decreasing contents of digestive tract.

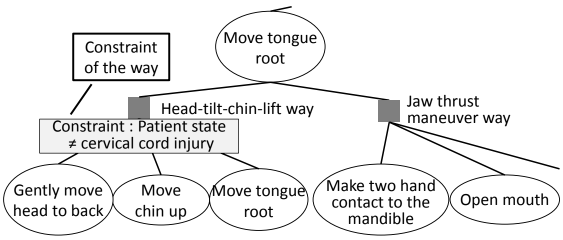

Figure 2: Representation of constrain in a CHARM tree.

actions described in nodes 2 and 3 in Figure 1. Node 1 represents a goal to be achieved by nodes 2 and 3. Node 1 is called the whole action, whereas nodes 2 and 3 are called sub-actions. Furthermore, action 2 can be achieved by using the promoting egestion way (node 4). The promoting egestion way explains that an enema solution helps the body egest the contents of the digestive tract as a reason why the way can achieve the goal. A CHARM tree also represents attributes of actions. For example, the concentration of the enema solution is 50% and its volume is 60 ml, as shown in part 6 of Figure 1. Time points of actions, such as "pre-operation on January 8th" are also represented as attributes of actions as shown in part 7 of Figure 1.

The constraints about (conditions for adopting) a specific way of action achievement can be also represented with the node of the way of actin achievement. For example, the head-tilt-chin-lift way for moving tongue root must not be applied to the patient whose cervical cord is injured. In Figure 2, the rectangle node under the way node denotes this constraint. The constraints about actions are also represented in the same form.

A complex order of actions can be also represented in a CHARM tree. First, we explain how to represent the repetition of actions. Figure 3 shows a part of CHARM tree about chest compression. When s/he compresses a patient's chest, s/he needs

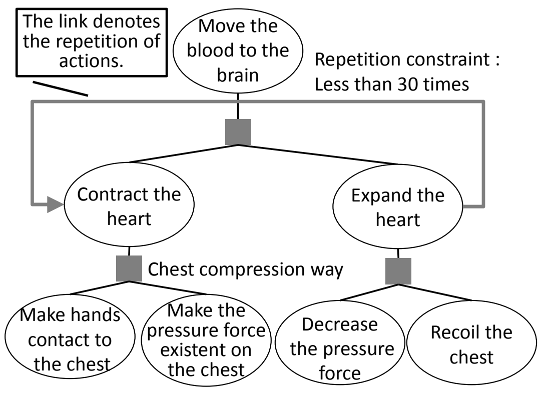

Figure 3: Representation of repetition in a CHARM tree.

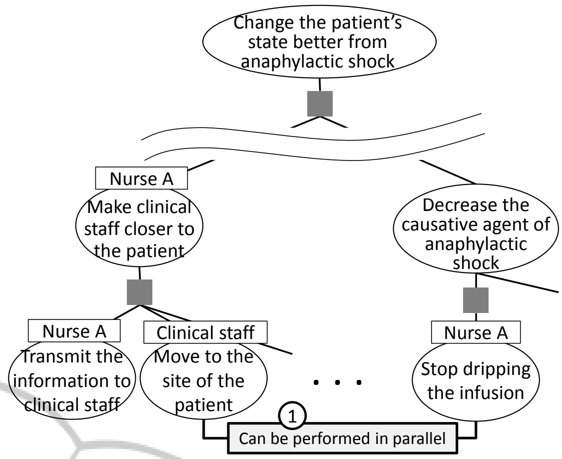

Figure 4: Representation of parallel actions in a CHARM tree.

to repeat 30 times pushing and recoiling the chest as one cycle. In order to represent the repetition, there is a link between the action node "contract the heart" and the action node "expand the heart". The link denotes that the action "contract the heart" should be performed if the actions are not performed less than 30 times. Second, a CHARM tree can also represents medical procedures which are performed in parallel by the link. In Figure 4, a CHARM tree denotes a procedure of clinical staff after anaphylactic shock occurred. The clinical staff receives the emergency call gather and the nurse, who stands by the patient stops dripping infusion which causes anaphylactic shock in parallel. The parallel sequence is represented by the link between the actions as shown in part 1 of Figure 4. The link denotes that the action "move to the site of the patient" and the action "stop dripping the infusion" are performed in parallel.

A CHARM tree can also represent a relationship between actions and side effects. As shown in Figure 5, the "assessing nausea" action is for assessing the side effect of anticancer agents. This relation is represented as a link and clarifies the reason why a member of the medical staff assesses nausea.

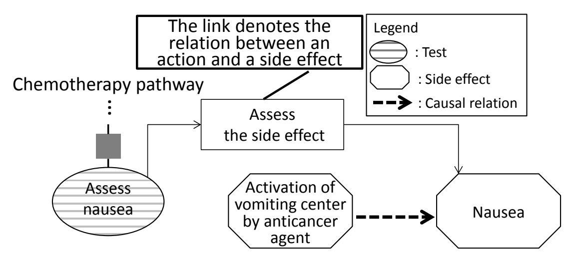

Figure 5: Representation of relationship between action and side effect.

The features of CHARM trees can be summarized as follows.
1) A controlled vocabulary representing actions is clearly defined and makes the meanings of actions clear.
2) CHARM trees can make the goals of actions explicit.
3) CHARM trees can clarify the reason why the way is applied and make it easy to compare alternative ways of action achievement.

The first feature is based on the ontology of actions. The ontology includes controlled action terms. The controlled terms define the meanings of actions and thus help us compare actions. The second feature is making the goals of actions explicit. The whole action is interpreted as the goal of the action. The relationship between an action and other effects also explains why the action is performed. The third feature is based on a way of action achievement. Alternative ways of action achievement may exist, and several ways are shown under the whole action node. This makes it easy to compare the ways. The way of action achievement explains the reason why sub-actions can achieve the goal, so as to make it clear why the way is applied. This feature helps us understand alternative ways and compare CPs easily.

2.2 Clinical Pathway (CP)

A CP represents a standard sequence of actions carried out by doctors, nurses, and other clinical staff members for each disease, and the timing at which the actions should be performed. Basically, CPs are represented in a tabular form. The horizontal axis is a time scale, and the vertical axis is the kind of action (Coffey et al., 2005). The CP methodology is widely deployed in hospitals to minimize delays and excessive resource-consumption and to maintain the quality of care.

Table 1 shows a portion of the Hepatectomy CP, which is used in Osaka University Hospital. A single action is described in a cell, and this CP contains all treatment actions performed in a ward during hospitalization. The date is shown in the uppermost row of the table, and actions described in the same column are performed on the same day. Outcome describes the goal of the event, and this goal is necessary before the next event can be performed. This represents the order relationship between events. Furthermore, kinds of actions are shown on the left side of the table. This indicates that actions in the same row belong to the same kind.

Table 1: A portion of the Hepatectomy CP.

Date		January 7th	January 8th	
Unit name		Previous day of operation	Pre-operation	Post-operation
Event name		Previous day of operation	Operation	Operation
Hospitalization/Ambulatory treatment		Hospitalization		
Outcome		Ready for the operation	No signs of infection disease	No complications
		No signs of infection disease		
Treatment	Prescription	Magcorol P(50g)	Kenei G enema 50% 60ml	
	Injection	DIV Soldem 3A 500ml	DIV Soldem 3A 500ml	IVH1 Soldem 3A 500ml
	General			
Test/ Examination	Laboratory test	Hematologic test		
	Pathological examination			
	Imaging/Physiological test		While operation, Chest X-ray	
Nutrition	Morning		Skip meal	

2.3 Target CPs to Be Described

In this research, we described eight real CPs used in Osaka University Hospital in CHARM trees, as shown in Table 2. These CPs represent treatments for cancer during hospitalization. As shown in Table 2, CPs are created in three departments, such as the digestive surgery department. There are three kinds of affected organs, such as the liver in the case of the Hepatectomy CP. Ways of removing the affected part are also different. We confirmed the representation capability of CHARM through the description of various CPs with medical doctors.

We built eight CHARM trees based on those eight CPs as knowledge sources. Each CHARM tree consists of about 360 action nodes on average. Among them, about 100 actions are explicitly described in the source CPs. The rest (about 260) of the nodes were added as the goals of actions that are implicit in the source CPs, when we built the

Table 2: CPs to be described based on CHARM.

Name of CP	Hospital department	Affected organ	Removal way of affected part
Gastrectomy	Digestive surgery	Stomach	Excision
Hepatectomy		Liver	
Transcatheter arterial chemoembolization (in surgery ward)			Chemoembolization
Transcatheter arterial chemoembolization (in medical ward)	Gastroenterological medicine		
Chemotherapy	Gynecologic	Uterus	Chemotherapy
Laparotomy for malignant disease			Excision
Laparotomy for benign disease			
Radiotherapy			Radiation

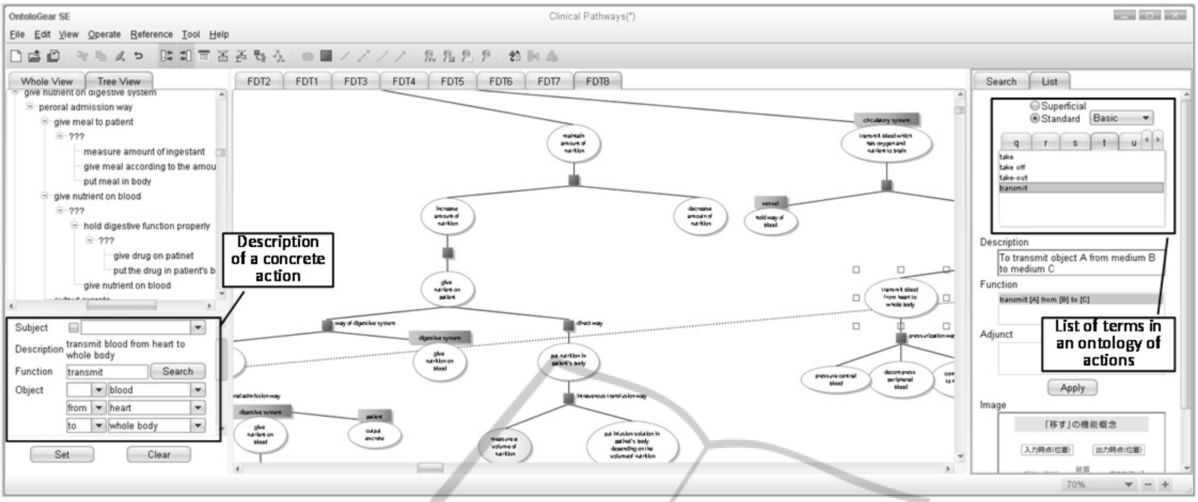

Figure 6: Screen shot of OntoloGear.

CHARM trees.

The CHARM trees were modeled using OntoloGear (as shown in Figure 6), editing software collaboratively developed by MetaMoJi Co. and the authors (MetaMoJi Co., 2009) based on a functional knowledge sharing framework (Kitamura and Mizoguchi, 2003). As shown at the lower left in Figure 6, an action is constructed from a transitive verb and objects. The verb term is controlled in the ontology of actions and a list of the terms is shown at the right side of Figure 6. We can represent an action using the terms. Thanks to the functionality of OntoloGear, the CHARM tree data is stored in a computer interpretable form. In the next sub-section, we describe in detail how to model a CP based on CHARM.

2.4 Building CHARM Trees from CPs

2.4.1 Building Process of CHARM Trees

This section explains how we built CHARM trees from CPs. A team which consists of knowledge engineers and medical doctors built the CHARM trees. First, an action in each cell of each CP was modeled as an action node of a CHARM tree. For example, a cell “Kenei G enema 50% 60ml” appears in the center of Table 1, as shown. We interpreted this cell as an action of placing enema solution in the patient’s body using the enema way shown as node 5 in Figure 1. The concentration and the volume of the enema solution were also described. Moreover, the kind of action was denoted by color (shaded parts in Figure 1).

Second, we added the whole actions (goals) of the actions written in the CP. We added these goal actions by consulting a doctor because they were not described in the CP. An added action is denoted by a white node. For example, we described action 2 in Figure 1, which is to cause the digestive contents to be egested from patient’s body, as the goal of action 5 in Figure 1.

Third, we decomposed the goal action into sub-actions. We checked whether the whole (goal) action node represents the same state change as sub-actions do. If not, we added the missing action nodes. For example, we added action 3 in Figure 1. Action 3 is to decrease dietary intake and is necessary for achieving the goal action, which is to decrease the contents of the digestive tract in the patient’s body. Action 3 was added because the CP does not represent how to achieve its goal. Action 8 in Figure 1, which is for achieving action 3, exists in the source CP, and therefore, action 8 was linked to action 3.

We repeated this process for each cell in the source CP.

In addition, we described side effects related to the actions in a CP, as shown in Figure 5. For example, an action that assesses nausea is described in the CP, and the action is performed to detect a side effect of an anticancer agent. This side effect was not described in the CP. We extracted them from explanation documents given to patients in Osaka University Hospital. The documents contain only typical side effects, so we described only typical side effects in the CHARM trees.

2.4.2 Building an Upper-level Goal Achievement Hierarchy of CHARM Trees

Actions described in CPs are performed during hospitalization. We interpreted the top-goal of the actions as "changing a (diseased or injured) state of a patient to a state in which the patient can leave the hospital". We identified the actions 1 to 5 in Figure 7 through considering what actions are necessary for achieving this goal. Action 1, "maintain daily activity", includes a patient's daily actions or actions taken by staff to support patients, such as taking a meal or cleaning a patient's body. Action 2, "change the state of the patient to a ready state in preparation for the main treatment" indicates an action taken to prepare the patient for the main treatment, such as a surgical operation. For example, the action for assessing a patient, such as measurement of body temperature, in the sub-actions of action 2 is needed to achieve the goal of recording basic data about the patient before the operation. Action 3 "change the state of the affected part to a treated state" indicates a main action of treatment such as a surgical operation and drug administration. An action related to the main treatment is also necessary for achieving this goal. For example, an action that measures the body weight to determine the dose of an anticancer agent achieves action 3. Action 4, "maintain health condition in acute stage", indicates an action to maintain the patient's state against the side effect of the main treatment. Compared with the same "assessing" sub-action of action 2 described above, the assessing sub-actions of action 4 is needed to achieve the goal of finding a variance from the normal value. That is, the CHARM tree represents a difference of the goals to be achieved by the same action. Action 5, "change the state of the patient to a state in which s/he can live after being discharged from the hospital" indicates an action for living after being discharged from the hospital, such as living guidance and mental care.

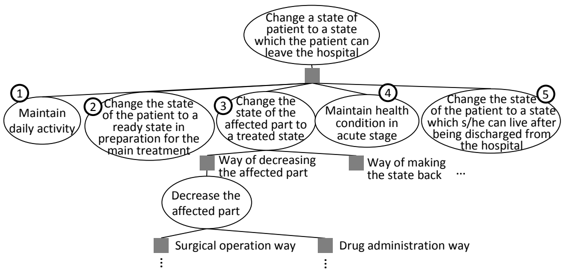

Figure 7: Top section of CHARM tree.

These actions discussed above are not described in CPs. These actions are interpreted as the top-level goals of the actions described in CPs and are made explicit based on CHARM. Explication of such top-level goals differentiates the goals of the same actions, such as the measuring actions above, from a goal-oriented perspective.

We confirmed that CHARM is applicable to model the contents of CPs by building CHARM trees based on real CPs. These CHARM trees have been approved by the co-authors who are medical doctors. We have also confirmed the benefits of CHARM trees, as discussed in the next section.

3 BENEFITS OF CHARM

3.1 Identifying Commonality of Actions in CPs

As a result of modeling the eight CPs based on CHARM, we confirmed that the upper-level goals of the actions in the CPs have commonalities, as discussed in Section 2.4.2. This suggests that actions in CPs have a common goal. We also identified the commonality shown below.

・**Actions for keeping homeostasis**

Actions for keeping homeostasis are described in CPs. For example, the circulatory system of the patient's body acts to keep homeostasis. A patient with a failing of circulatory system must receive assistance. Figure 8 shows a partial CHARM tree for assisting the function of the circulatory system. The tree clarifies which action assists what. In this example, the use a stocking way (point 1) achieves

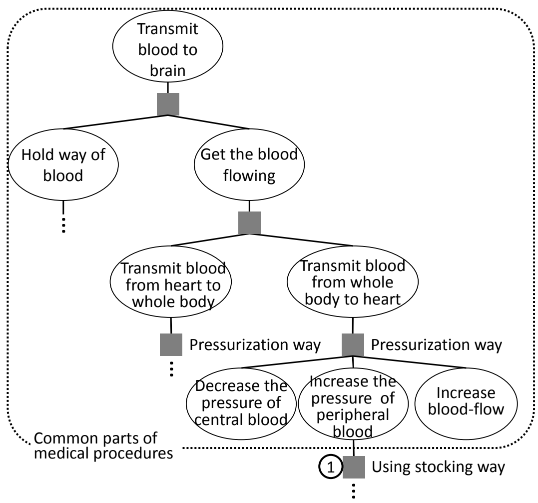

Figure 8: A partial CHARM tree for assisting the function of circulatory system.

Table 3: A list of pairs of CPs that we compared (X in the cell denotes that the combination is finished to compare. Number in parenthesis denotes distances.).

	Gastrectomy	Hepatectomy	Transcatheter arterial chemoemboli-zation (in surgery ward)	Transcatheter arterial chemoemboli-zation (in medical ward)	Chemotherapy	Laparotomy for malignant disease	Laparotomy for benign disease	Radiotherapy
Gastrectomy		X(35)						
Hepatectomy	X		X(127)	X(158)	X(168)	X(122)		
Transcatheter arterial chemoemboli-zation (in surgery ward)		X		X(112)				
Transcatheter arterial chemoemboli-zation (in medical ward)		X	X					
Chemotherapy		X						X(75)
Laparotomy for malignant disease		X					X(139)	
Laparotomy for benign disease						X		X(176)
Radiotherapy					X		X	

Notes:
1. X; finished to compare the CPs
2. (number); distances of the action nodes in the CHARM trees

an action that increases the pressure of the peripheral blood vessels, whose overall goal is to transmit blood to brain. We consider that these actions (as shown in dotted line in Figure 8) will appear in other medical procedures because the actions for keeping homeostasis are not uncommon in medicine. Actually, such actions appear in all eight CPs.

However, it would take a lot of time to describe all actions related to keeping homeostasis because this would be equivalent to describing all functions of the human body. In this study, we described only actions related to the actions in the CPs, and we found that these were enough for representing actions performed during hospitalization.

3.2 Comparison of CPs using CHARM Trees

CHARM trees explicate the knowledge implicit in CPs. We compared CPs using CHARM trees in order to confirm the benefits of CHARM.

Table 3 shows pairs of CPs that we compared. In the uppermost row of the table and the left side of the table, the name of CP is shown. X in a cell shows that the comparison between CPs, whose names are shown in the uppermost row and the left side column, was finished. The number in parenthesis is the number of differences of actions in the CPs. We compared CPs in which treatments were different and which were created by different departments. We calculated the distances (differences) of the action nodes in the CHARM trees using TED (Tree Edit Distance) (Zhang and Shasha, 1989), and these are shown in parentheses in Table 3. TED is a method of describing the distance (difference) between tree-structured data and represents the cost of editing operations that transform one tree into another. The editing operations are renaming, deleting, and inserting.

From the results of the comparison, the CHARM trees explain the reason why there are differences in CPs. Moreover, it is easier to find some differences than with a comparison based on CPs because the goal and the relation of actions can be clarified based on CHARM. The following sub-sections explain such benefits using real examples.

3.2.1 Difference between Ways to Achieve the Same Goal

The goal of actions is described as the whole action node, and the way of action achievement is clearly represented in a CHARM tree. When there are a number of ways to achieve the same goal, these ways are placed under the whole action node and are linked with it. It is not easy to understand whether or not the goals of actions in CPs are the same based on CPs. CHARM trees help us compare actions because CHARM clarifies the goal of actions. Figure 9 shows that a partial CHARM tree represents the difference between ways to achieve the same goal when we compare Hepatectomy CP and Gastrectomy CP.

In order to achieve the same goal of giving nutrition to blood (as shown in 1 of Figure 9), the intravenous transfusion way (as shown in 2 of Figure 9) is applied in the Hepatectomy CP, whereas the intravenous hyper alimentation way (as shown in

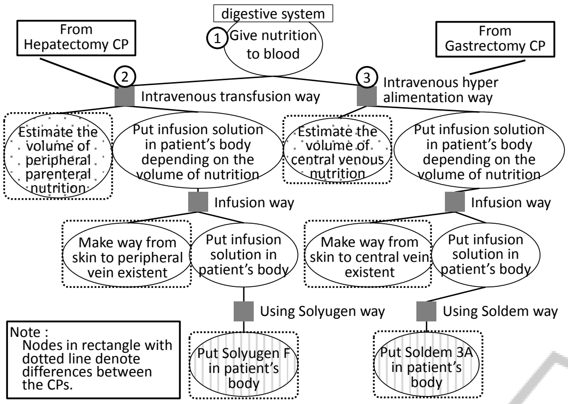

Figure 9: Difference between ways to achieve the same goal based on CHARM tree.

3 of Figure 9) is applied in the Gastrectomy CP. Both way 2 and way 3 in Figure 9 achieve action 1. The action "estimating the required nutrition" and the action "putting infusion solution in the body" are described separately in the CPs. It is not easy to understand the reason why estimating actions are different from each other. Since we built CHARM trees, we could compare the actions from a goal-oriented perspective and understand that the difference between these CPs is the difference of ways of action achievement.

A medical doctor who is one of the co-authors of this paper considers that there is no medical justification for this difference, and that the selection of the ways seems to be done based on only convention. This suggests that there is room to discuss the justification for the selection of the ways of action achievement, and CHARM trees can help us in this point.

3.2.2 Difference of Goals to Be Achieved by the Same Action

The same action in CPs might achieve different goals. Here, we give an example in a comparison between the Transcatheter arterial chemoembolization CP and the Chemotherapy CP. Both CPs contain the "assessing numbness" action (as shown in part 1of Figure 10). A comparison using the CHARM trees of these CPs helps us understand the difference of the goals. As shown in Figure 10, the shaded nodes denote similar actions in different CPs, but goals (as shown in part 2 of Figure 10) of these actions are different. The goals that are implicit in the CPs are made explicit in the CHARM trees. Furthermore, when one revises a CP, the explicitness of the goals of the actions helps him/her understand the intention of the author of the original version.

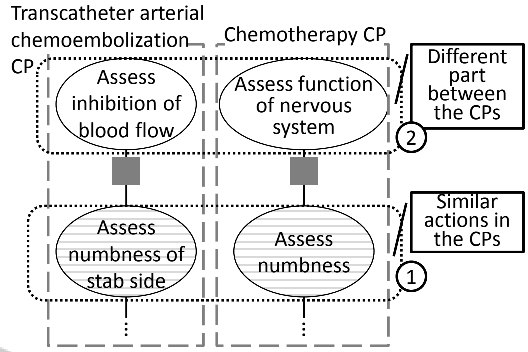

Figure 10: Difference of goals to be achieved by the same action based on CHARM trees.

3.2.3 Difference of Side Effects Related to the Same Action

The same action in CPs might have different reasons why the action should be done. Figure 11 shows an example in a comparison between the Chemotherapy CP and the Radiotherapy CP. Both CPs contain the same "assessing nausea" action. These actions, however, have different side effects related to them. In chemotherapy, a patient may feel nausea as a side effect of an anticancer agent. In radiotherapy, a patient may feel nausea as a side effect of radiation exposure. Each assessing action in the CPs is done in order to detect one of these side effects. The ability of CHARM to clarify the relationship between actions and side effects helps us understand this difference.

In addition to the differences discussed thus far, we found some other differences, such as differences of both the goal and the performed actions. CHARM

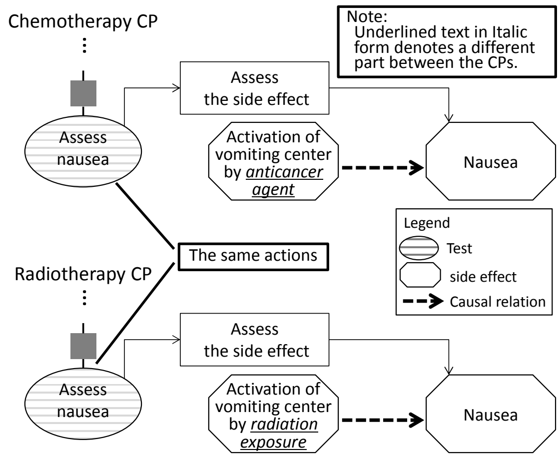

Figure 11: Difference of side effects related to the same action based on CHARM trees.

trees can help us find not only superficial differences of actions in CPs, but also implicit differences, such as differences of the goals and relationships.

4 RELATED WORK

A number of groups have been developing computer interpretable guideline model, such as Asbru (Shahar et al., 1998), PROforma (Sutton and Fox, 2003), GLIF (Boxwala et al., 2004), and SAGE (Tu et al., 2007). They aim to develop guideline-based point-of-care decision support systems. The systems make alerts and reminders to assist doctors in making decisions by automatic reasoning based on computer interpretable models in the flowchart-style form. As discussed in Introduction, we aim at supporting not point-of-care decision by medical staff but knowledge description and revision by the knowledge managers. For such knowledge management, our model has some benefits discussed thus far. In the flowchart models used in the guideline models above, the temporal order of actions is mainly described and the goals of actions are in many cases implicit. Externalizing the implicit knowledge, such as goals can facilitate revision of procedures. CP authors can easily detect the point to revise in a CP.

Hurley et al. have developed a CP ontology in order to represent actions in CPs in a computer interpretable way (Hurley and Abidi, 2007). Hu et al. have also developed a CP ontology and proposed a system connected with a conventional EMR (Electronic Medical Record) system (Hu et al., 2012). Hurley et al. have identified concepts and attributes that appear in CPs and developed a CP ontology. They have confirmed the representation capability by describing five real CPs based on this ontology. Their ontology is specialized for CPs, which are time-sequence-oriented way. Thus, their models based on the ontology are structured in the same way as CPs, that is, time-oriented. On the other hand, our study is based on an ontology of general actions, which is goal-oriented. Thus, our CHARM tree clarifies explicit knowledge, such as goals and relations of actions, which are implicit in CPs. Since our ontology is not specialized for CPs, CHARM can describe medical actions extracted from other knowledge sources, such as clinical practice guidelines and nursing manuals, and can thus handle them seamlessly.

Abidi et al. represented CPs in a computer interpretable way and integrated CPs derived from different institutions (Abidi et al., 2009). They identified the commonalities of three different CPs based on the CP ontology and integrated them into one flowchart. The integrated flowchart can be specialized for each region of the institution. On the other hand, in our study, we identified not differences of regions but differences of goals and the way of action achievement. Abidi et al. claim that their model is convenient for the revision management of CPs. After revision of the common parts of the integrated flowchart that represents CPs, they specialize the flowchart to a CP for each region, and then the revision is reflected. On the other hand, a CHARM tree also helps us manage knowledge. When a conventional treatment method is abolished and a new method is applied, we need only delete the corresponding way of action achievement and add a new one from a goal-oriented perspective. The goals explicitly described in a CHARM tree help us add new knowledge to appropriate parts of the tree.

5 CONCLUSIONS

The work described in paper shows the practical ability of CHARM to describe medical actions in eight real CPs in a computer interpretable way. The built CHARM trees clearly represent knowledge that is implicit in conventional CPs, such as goals of actions and the ways of action achievement. The benefits of CHARM trees include: (1) finding commonalities among CPs, (2) allowing easy comparison of CPs from a goal-oriented perspective, and (3) explaining the reasons for the differences.

We face the following challenges in achieving the ultimate goal, which is to manage procedural knowledge about medical practice based on a unified management framework.

Currently, the controlled vocabulary for actions treats physical actions only. Since medical actions affect human beings, mental health treatment is also important. The definitions of mental actions and their treatment will be tackled in future work.

A CP represents a typical sequence of medical actions for each disease. On the other hand, some treatments consist of an atypical sequence of actions. Treatment may be different at the acute stage and the chronic stage, such as the treatment of cardiac failure. Moreover, the timing of switching the way of treatment is different for each patient. Therefore, it is not easy to create a CP for such treatment. We will try to describe such treatment based on CHARM. Because CHARM is a goal-oriented representation, we expect that such treatments can be modeled successfully.

CPs and clinical practice guidelines describe standard (prescriptive) actions, unlike the record of real actions performed on a patient, which is descriptive. We will develop a method of describing patient records based on CHARM to manage the entire knowledge of actions in hospitals.

REFERENCES

Abidi, S. R., Abidi, S. S. R., Hussain, S., and Butler, L. (2009). Operationalizing Prostate Cancer Clinical Pathways: An Ontological Model to Computerize, Merge and Execute Institution-Specific Clinical Pathways. *Knowledge Management for Health Care Procedures, Lecture Notes in Computer Science*, 5626: 1-12.

Boxwala, A. A., Peleg, M., Tu, S., Ogunyemi, O., Zeng, Q. T., Wang, D., Patel, V. L., Greenes, R. A., and Shortliffe, E. H. (2004). GLIF3: a representation format for sharable computer-interpretable clinical practice guidelines. *Journal of Biomedical Informatics*, 37: 147-161.

Coffey, R. J., Richards, J. S., Remmert, C. S., LeRoy, S. S., Schoville, R. R., and Baldwin, P. J.,(2005). An Introduction to Critical Paths. *Quality Management in Health Care*, 14(1): 46-55.

Every, N. R., Hochman, J., Becker, R., Kopecky, S., and Cannon, C. P. (2000). Critical Pathways: A Review, *Circulation*, 101: 461-465.

Hauck, L. D., Adler, L. M., and Mulla, Z. D. (2004), Clinical pathway care improves outcomes among patients hospitalized for community-acquired pneumonia, *Annals of Epidemiology*, 14(9): 669-675.

Hu, Z., Li, J. S., Zhou, T. S., Yu H. Y., Suzuki, M., and Araki, K. (2012). Ontology-Based Clinical Pathways with Semantic Rules. *Journal of Medical Systems*, 36(4): 2203-2212.

Hurley, K. F., and Abidi, S. S. R. (2007). Ontology Engineering to Modelo Clinical Pathways: Towards the Computerization and Execution of Clinical Pathways. *20th IEEE International Symposium on Computer-Based Medical Systems*, 536-541.

Kitamura, Y., and Mizoguchi, R. (2003). Ontology-based description of functional design knowledge and its use in a functional way server. *Expert Systems with Applications*. 24(2): 153-166.

Nishimura, S., Kitamura, Y., Sasajima, M., Williamson, A., Kinoshita, C., Hirao, A., Hattori, K., Mizoguchi, R. (2013). CHARM as Activity Model to Share Knowledge and Transmit Procedural Knowledge and its Application to Nursing Guidelines Integration. *Journal of Advanced Computational Intelligence and Intelligent Informatics*, 17(2): 208-220.

Madan, A. K., Speck, K. E., Ternovits, C. A., and Tichansky, D. S. (2006). Outcome of a clinical pathway for discharge within 48 hours after laparoscopic gastric bypass. *The American Journal of Surgery*, 192(3): 399-402.

MetaMoJi Co. (2009). http://metamoji.com/en/

Pearson, S. D., Goulart-Fisher, D., and Lee, T. H. (1995), Critical Pathways as a Strategy for Improving Care: Problems and Potential. *Annals Internal Medicine*, 123(12): 941-948.

Mizoguchi, R., Tutorial on ontological engineering - Part 1, 2, 3. (2003), (2004), (2004). *New Generation Computing*, 21(4): 365-384, 22(1): 61-96, 22(2): 193-220.

Sasajima, M., Nishimura, S., Kitamura, Y., Hirao, A., Hattori, K., Nakamura, A., Takahashi, H., Takaoka, Y., and Mizoguchi R. (2013). CHARM Pad: Ontology-Based Tool for Learning Systematic Knowledge about Nursing. *Proceedings of HCI International 2013*, pages 560-567 ISBN 978-3-642-39252-8.

Shahar, Y., Miksch, S., and Johnson P. (1998). The Asgaard Project: A Task-Specific Framework for the Application and Critiquing of Time-Oriented Clinical Guidelines. *Artificial Intelligence in Medicine*, 14(1-2): 29-51.

Sutton D. R., and Fox, J. (2003). The Syntax and Semantics of the PROforma Guideline Modeling Language. *Journal of the American Medical Informatics Association*, 10(5): 433-443.

Tu, S. W., Campbell, J. R., Glasgow, J., Nyaman, M. A., McClure, R., McClay, J., Parker, C., Hrabak, K. M., Berg, D., Weida, T., Mansfield, J. G., and Musen, M. A. (2007). The SAGE Guideline Model: Achievements and Overview, *Journal of the American Medical Informatics Association*, 14(5): 589-598.

Zander K., (1988). Nursing case management: strategic management of cost and quality outcomes. *The Journal of Nursing Administration*, 18(5): 23-30.

Zhang K., and Shasha, D. (1989). Simple Fast Algorithms for the Editing Distance between Trees and Related Problems. *SIAM Journal on Computing*, 18(6): 1245-1262.