Paper:

CHARM as Activity Model to Share Knowledge and Transmit Procedural Knowledge and its Application to Nursing Guidelines Integration

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Japan is no exception among developed countries facing healthcare system problems due to aging and low birthrate as the number of possible patients increases and health care worker numbers shrink. The introduction of high tech medicine has increased the amount of knowledge to be learned by novice nurses. Although vast amounts of implicit knowledge have accumulated among nursing practitioners, this knowledge needs to be communicated when hospitals train younger generations of nurses and integrate nursing guidelines among multiple hospitals. In this paper, the authors have proposed an activity model called CHARM – the Convincing Human Action Rationalized Model. CHARM was developed to resolve the diverse needs of hospitals. CHARM explicates multidimensional purpose-oriented procedure relations often existing as implicit knowledge. For this reason, CHARM supports the training and education of novice nurses. CHARM also is used as a tool to integrate different knowledge and work procedures tacitly existing among different organizations. We developed CHARM models according to nursing guidelines of hospitals and applied them to the integration of nursing procedures at two hospitals. Based on these CHARM models, 12 differences were found among the two guidelines covering the same procedure for different hospitals. CHARM is being evaluated at these hospitals and positive responses are coming from nurses.

1. Introduction

Medical services are essential for people to live healthy and should be provided to all citizens. In developed countries, including Japan, however, the increasing numbers of aging persons in the population, who often suffer from disease, pose a difficult problem for health care workers. The number of health care workers is insufficient in proportion to the number of elderly. Difficulties in maintaining the quality of health care are therefore expected. In spite of this situation, there is a policy that limits the number of doctors who can be trained at one facility. This policy, combined with the increase in medical demand, has resulted in a shortage of physicians [1] and nurses [2]. Under such circumstances, many hospitals have merged in order to ensure efficient use of medical personnel [3]. In order to provide medical services of a sustained quality despite limited numbers of medical personnel, the efficiency of each hospital must be raised.

There are medical guidelines written in natural language that describe standards for medical examination and treatment. When hospitals merge, multiple guidelines have to be integrated, especially guidelines for nurses that describe hospital nursing standards. These nursing guidelines are written both for new nurses and are also used as countermeasures to be taken by experienced nurses against incidents.

The following problems have been identified, however, in conventional guidelines:

(i) Integrating multiple guidelines from different hospitals is difficult. Guidelines are voluminous and even experienced nurses must debate on how to integrate each procedure. This integration task costs time and manpower, yet properly integrating such guidelines is crucial for improving hospital efficiency.

(ii) Some of the nurses who have learned using these guidelines lack flexibility in a changing situation. In order to improve the efficiency of medical care, it is therefore important to train nurses to be able to deal properly with unforeseen incidents.

In this paper, we aim to solve both of these issues surrounding the integration of guidelines and the training of nurses. Specifically, we explicated the implicit knowledge that nurses have.

One of the problems during the integration of guidelines and the training of nurses may be the implicit knowledge that nurses have. Nurses decide on how to integrate guidelines through discussions. Nurses are able to integrate guidelines because they have knowledge that goes beyond contents of guidelines. This additional knowledge can be externalized and used to support the integration of additional guidelines. If the purpose of an action is explicitly written in a guideline, for example, a certain action can be compared with another action from purpose-oriented perspective. The externalization of implicit knowledge will also encourage more nurses to externalize their own implicit knowledge.

The externalization of implicit knowledge will also solve problems that occur in the training of nurses. One of the reasons that nurses become inflexible in changing situations is that guidelines do not contain enough information and that the contents of a guideline lack correlation. Such knowledge is usually learned empirically. Externalizing implicit knowledge can, however, make the training of nurses more efficient. If the purpose of the action is written in guidelines, for example, even if the procedure is not applicable to a certain situation, nurses can work toward achieving the purpose by some other means. In addition, if more than one procedure is written in guidelines with enough visibility, nurses can choose the procedure that best applies to the situation at hand.

In the field of engineering design, knowledge pertaining to functions that express design rationale – this is called functional knowledge – is shared and used. Research pertaining to the improvement of sharing and reusing knowledge is known as ontology engineering [4]. The authors have used a framework based on ontology engineering to explicitly state functional knowledge, hereafter called a functional knowledge sharing framework [5, 6]. This framework is based on the device ontology that defines devices as a modeling perspective. Device ontology was used to describe function decomposition trees for expressing individual functions. The function decomposition tree also demonstrates the purpose of the function. Because the tree describes the purpose of the function from its mechanics, the use of the device can be changed to suit different situations. This framework has also been put to practical use, for example, in daily work in production technology at Sumitomo Electric Industries, Ltd. [6]. In this example, the framework succeeded in enabling implicit knowledge to be externalized and shared.

In this paper, we focused on similarities of function between nursing actions. The functional knowledge sharing framework was used to externalize implicit knowledge that is not contained explicitly in guidelines. We propose a knowledge representation model called CHARM – the Convincing Human Action Rationalized Model – that expresses such implicit knowledge. CHARM is used to model nursing guidelines. We investigate the practicality of this model through the integration of the guidelines which occur during hospital integration.

This paper is organized as follows: In Section 2, we discuss the nursing procedures that will be analyzed and modeled. The models will be used as examples to explain the proposed model CHARM. In Section 3, we report on the use of CHARM to support the integration of guidelines. In Section 4, we introduce related work. In Section 5, we conclude this paper and look at future prospects.

2. Using CHARM to Identify Nursing Procedures

2.1. Content Analysis of Guidelines

In this research, we use clinical practice guidelines that are published by various medical societies. We also use nursing guidelines and manuals that explain standard procedures for nurses in the hospital. Here, guidelines pertaining to medical procedures will be called medical guidelines and guidelines that focus on procedures for nurses will be called nursing guidelines.

Medical guidelines were analyzed first. The aim of this analysis is to share and pass on practical knowledge by adequately describing written procedures. Analyzed guidelines are following six examples:

1. airway management methods [7],

2. inspections for obtaining visual data [8–10],

3. medical procedures for reduce drunkenness,

4. treatment of malaria [11],

5. Parkinson's disease treatment [12],

6. osteoporosis treatment [13–15].

The 6 examples presented were separated so that each example is a subset of different type of procedure. Procedures can be separated, for example, into procedures for surgery, inspection, neurodegenerative disease treatment, poisoning treatment, infection medication, and metabolic disease treatment.

Analysis of guidelines revealed that the following descriptions are contained within guidelines:

(1) Procedures for health care workers

This includes surgical actions by doctors such as skin incisions, lesion removal, and suturing. It also includes actions by nurses such as taking X-rays, giving injections, and using echography.

(2) Procedures for patients

This refers to actions by patients such as taking medicine. Other examples are patient movement during

rehabilitation and agreements to undergo medical treatment.

(3) Biological functions of patients

This refers to functions of the patient's body. Examples are functions of organs, the effect of digestive enzyme on medication, immune function when pathogens enter the body, functions of neurotransmitters, and so on.

(4) Effect of drugs

This refers to effects of drugs on pathogens or patients, for example, reducing pathogens or improving the patient's immune system.

(5) Processes that adversely affect patients

One example of this is the effect of pathogens on patients. This refers to not only effect of bacteria and viruses, however, but also to pain caused by bone fractures. Observable processes that adversely affect patients, for example, such as frozen gait and tremors in Parkinson's disease are also included.

2.2. Interpreting Medical Procedures

In order to describe these medical procedures for sharing and reuse, actions must be interpreted from a consistent perspective. In this study, medical actions are interpreted in the same way as functions of mechanical units.

In proposed interpretation of medical actions, there is a doer of the action that affects an object (a target thing). Such an action is described as a transitive action. A state of the object therefore changes with the medical action. A single action results in a single change of state, and these actions are performed in series. Actions are correlated with each other according to object input and output. The goal of medical action is defined as an intended change of state. Individual actions can be described, furthermore, by a series of subactions, creating a hierarchical structure.

In the functional knowledge sharing framework, the function of a device is defined as "a result of teleological (purpose-oriented) interpretation of a behavior (change of state) of a device under an intended goal" [5]. Furthermore, "micro-macro relations among functions represent that the macro-function is achieved by the sequences of sub(micro)-functions."

When interpretation and modeling processes of medical actions are compared to those of the functional knowledge sharing framework, the following two similarities are observed:

(i) First, purposes of individual actions are correlated with state changes of objects. When viewed in this manner, actions of doctors cutting off skin and functions of the cutting device are interpreted as the same type of action, which is interpreted as a change of an object into two separated objects (as shown in **Figs. 1**① and **2**①).

(ii) Second, both actions can be interpreted similarly as detailed series of actions. For cutting devices, for example, the cutting sequence is decomposed into the
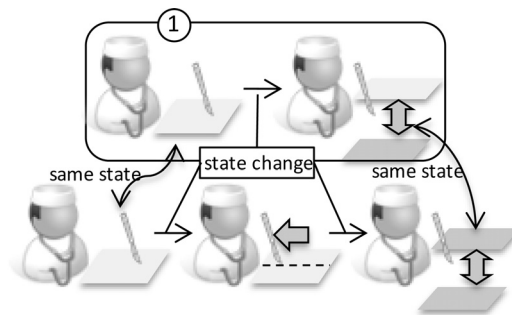

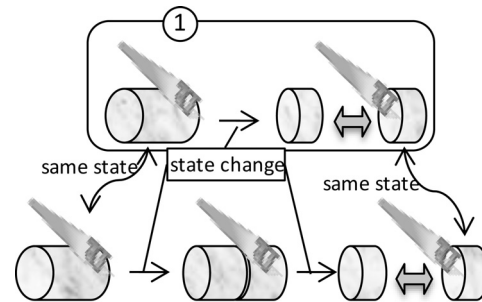**Fig. 1.** A hierarchical structure for the doctor's procedure for cutting skin.

Fig. 2. A hierarchical structure of functions of a cutting device.

function of decreasing bonding force and that of severing the ingots (**Fig. 2**).

The doctor's action can be decomposed in the same manner (**Fig. 1**). In this way, doctors and devices are interpreted as the doers and patients and ingots as objects. The two actions have a striking similarity in this interpretation, so the functional knowledge sharing framework can be used to interpret and model medical actions.

The procedural model of this framework is also known to explicate implicit knowledge and describe correlations between methods. We propose CHARM [16] because the model explicates the purposes of actions.

2.3. Using CHARM to Model Nursing Guidelines

We used CHARM to model a nursing guideline for an actual hospital. First, the extent of the guideline and CHARM will be described. Next, the features of CHARM will be explained from the resulting nursing guideline.

2.3.1. Extent of the Guideline

CHARM was used to model around 40 different guidelines.

(1) Preliminary experiment

In order to test the applicability of CHARM to medical procedures, the 6 types of guidelines mentioned in Section 2.1 were modeled. These modeled guidelines were accepted by medical experts of our colleagues. The 6 types of guidelines were (i) surgical procedures, (ii) inspections procedures, (iii) neurodegenerative disease treatment, (iv) poisoning treatment, (v) infection treatment, and (vi) metabolic disease treatment. We confirmed that CHARM was able to describe these various
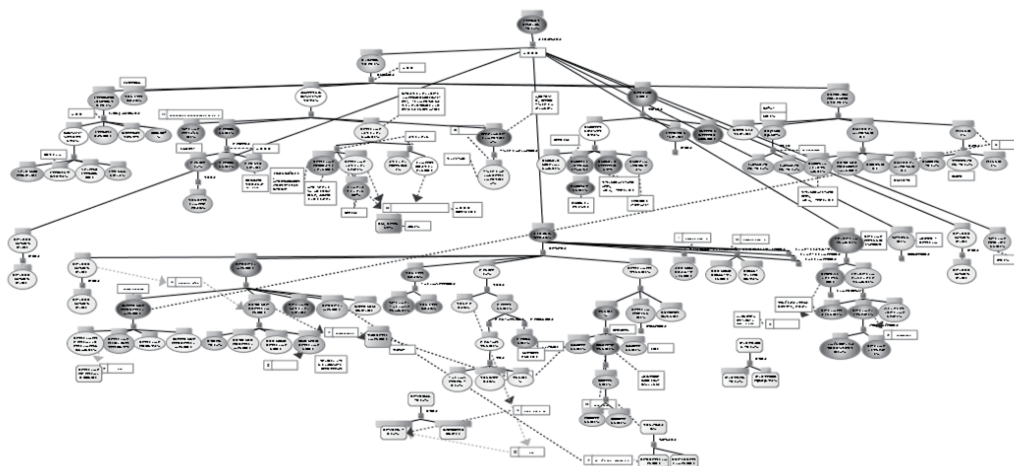
Fig. 3. CHARM for assisted endotracheal intubation.

medical procedures. CHARM was also applicable to expert material, such as medical textbooks, medical research papers published in academic journals, guidelines published by medical societies, and non-expert material such as "Medicine for Households."

(2) Nursing guidelines for Miki City Hospital

The following 4 nursing guidelines that describe standards for nursing procedures were modeled for Miki City Hospital:

1. cardiopulmonary resuscitation [17],

2. assisted endotracheal intubation,

3. tracheostomy and replacement of tracheal cannulas,

4. steps taken in anaphylactic shock.

Miki City Hospital will merge with Ono Municipal Hospital in October 2013, and the merger will reopen as Kita-Harima Medical Center. The hospital therefore requires the integration of nursing guidelines. Specifically, emergency medical care starts immediately after the hospital is integrated, so this area requires the integration of knowledge as soon as possible. Nursing guidelines modeled at this time pertain to emergency medical care. Specifically, we chose to organize cardiopulmonary resuscitation (1., 2., and 3.) and anaphylactic shock (4.) because these procedures will be required with high probability. Guidelines 2., 3., and 4. were modeled with CHARM based on nursing guidelines from Miki City Hospital. For guideline 1., we used CHARM to rewrite a 123-page textbook used by all health care workers, i.e., the table of contents, foreword, and confirmation tests were removed and the 70 pages pertaining to cardiopulmonary resuscitation were used. Validity of these CHARM models was confirmed by nurses.

(3) Nursing guidelines for Osaka Koseinenkin Hospital

CHARM was applied to nursing guidelines used for the ICU training of newcomers at Osaka Koseinenkin Hospital. The target was all 30 nursing procedures contained in ICU training. Procedures are written in the new nursing staff training guidelines provided by the nursing department in Osaka Koseinenkin Hospital. These guidelines cover a half of the technical items of the guideline, which targets all new nursing staffs within the first year and are provided by the Ministry of Health, Labor, and Welfare [18]. In other words, CHARM pertains to all new nursing staff and therefore the model can be potentially used in other hospitals. A total of 54 CHARMs were modeled with 4600 nodes. The modeling procedure took about 3.2 man-months. Validity of content was confirmed by the members of the Kobe City College of Nursing and nurse-educators of the ICU department who coauthored those CHARM models. Guidelines outside of the scope of ICU training were also modeled in CHARM in case other departments decided to use CHARM model.

2.3.2. CHARM Modeling Procedure

Those CHARMs were modeled using OntoloGear, a commercialized product provided by MetaMoJi Co. [19] based on the functional knowledge sharing framework [5]. **Fig. 3** shows the entire CHARM model for assisted endotracheal intubation, and **Fig. 4** describes the top section of the CHARM.

Medical actions are interpreted using the method described in Section 2.2. Outlines of the entire medical action are modeled, then the actions are decomposed. We start by considering the state change caused by endotracheal intubation. The purpose of endotracheal intubation is to secure an airway: in other words, the state of the airway is changed from closed to open. The state change is described as an elliptical node "make the airway existent" as shown in **Fig. 4**①. Describing actions using term provided by the functional knowledge sharing framework makes the action clear. In this case, "make something existent" is functional term. The doer performing an action is written as a rectangular node above the elliptical node. Next, the action of "make the airway existent" is decomposed into smaller actions according to the way of action achievement. The way of action achievement describes the series of actions required to achieve the purpose of
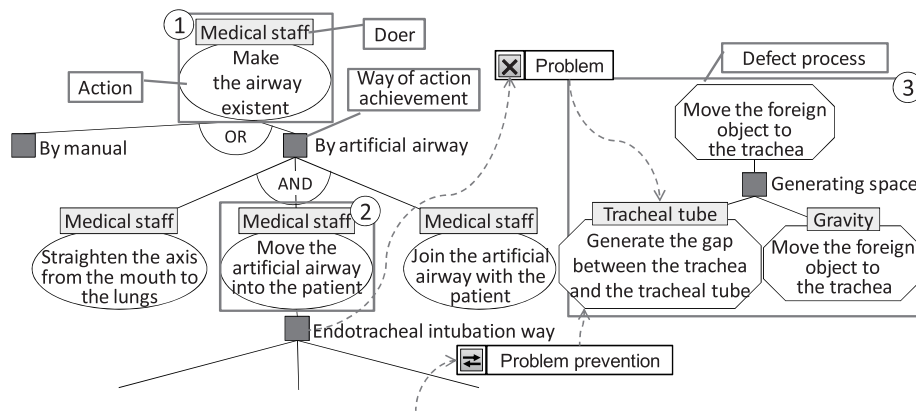
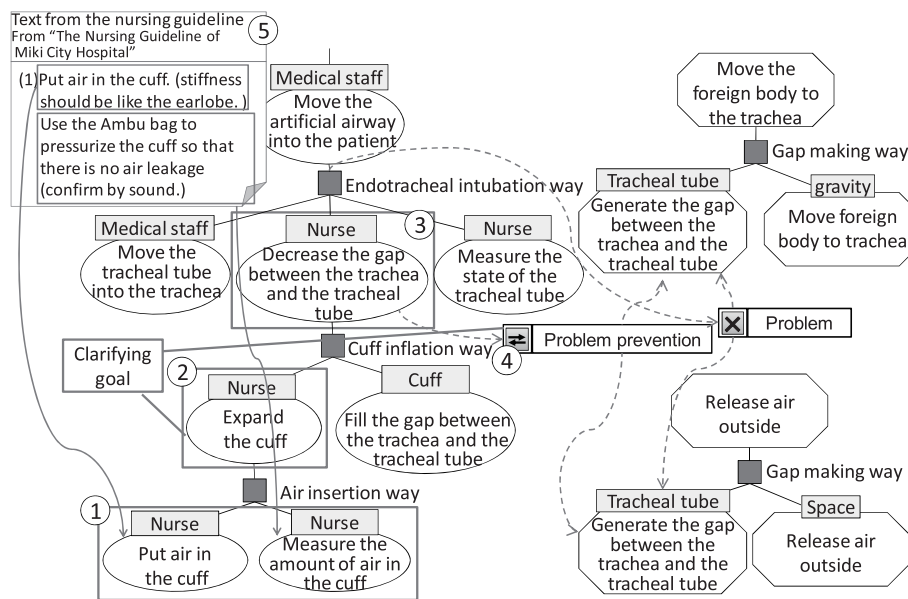**Fig. 4.** Top section of CHARM for assisted endotracheal intubation.

Fig. 5. Middle section of CHARM for assisted endotracheal intubation.

the entire action. In this case, two ways were described, the first using the natural airway and the second inserting an artificial airway into the trachea, and they achieves "making the airway existent" as their purpose. The artificial airway method was described as a chain of 3 actions connected by AND operator that achieves "make the airway existent." Decomposition was reiterated to describe a CHARM model.

Anticipated problems that may arise during the procedure are also written down in the CHARM. In the endotracheal intubation way (**Fig. 4②**), for example, a gap may be created between the tube and the trachea that may cause pulmonary aspiration. Anticipated problems of procedures are described as octagon nodes (**Fig. 4③**). Problems are also decomposed in the same way as actions. Medical actions and anticipated problems are clearly connected by nodes, showing their relationships. Preventive actions for these problems are connected by nodes, too.

As mentioned above, CHARM creates tree structures of procedures by continually decomposing and connecting actions and anticipated problems.

2.3.3. Features of CHARM

As the result of modeling of the guidelines in CHARM, we confirmed that CHARM is a model that provides logical explanations for procedures and that externalizes implicit knowledge.

(1) Explication of purpose

Knowledge written in CHARM explicates the implicit knowledge that nurses have. CHARM describes achievements in a hierarchical structure and describes the purpose of each action series. In **Fig. 5**, for example, the actions of "the nurse puts air in the cuff" and of "the nurse measures the amount of air in the cuff" (**Fig. 5①**) are combined to achieve the purpose of the entire action, which is "the nurse expands the cuff" (**Fig. 5②**). The relation between the medical action and anticipated problems is also explicated. The action of "decrease the gap between the trachea and the tracheal tube" (**Fig. 5③**) is achieved by the action of "expand the cuff" (**Fig. 5②**) and prevents pulmonary aspiration caused by "generate the gap between the trachea and the tracheal tube" (**Fig. 5④**). In this way,
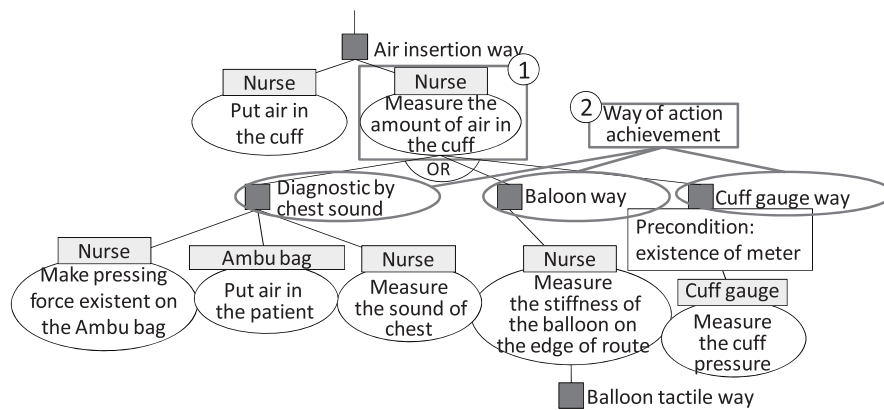
Fig. 6. Bottom section of CHARM for assisted endotracheal intubation.

the relationship between individual actions and their purposes is defined clearly using CHARM.

Nurses using CHARM may realize that some implicit knowledge in the guidelines still needs to be externalized. While CHARM shown in **Fig. 5** is being modeled, for example, the nursing guideline at Miki City Hospital only stated "put air into the cuff (its stiffness should be like the earlobe). Use the Ambu bag to pressurize the cuff so that there is no air leakage (confirm by sound)." In other words, the guideline only described the expanding the cuff with air and observing the amount of air (**Fig. 5⑤**). The purpose of the action was therefore not stated clearly in the guideline. When CHARM was written for this action, the purpose "expand the cuff" was extracted from the advanced life support course guide [17] that is used in training at Miki City Hospital. Anticipated problems due to this action also were not stated clearly in guidelines. We obtained information on anticipated problems from interviews with nurses. In the CHARM, the relations were described as shown in **Fig. 5④**. CHARM was thus able to explicate the purpose of the medical action and help in realizing and identifying implicit knowledge.

(2) Explication of multiple procedures with the same purpose

Procedures written in CHARM describe multiple procedures with the same purpose consistently while explicating the applicability of each procedure. In **Fig. 6①**, for example, the action to "measure the amount of air in the cuff" that is given to prevent overinflation by air can be done several ways (**Fig. 6②**). The first way, written in nursing guidelines, uses an Ambu bag to feed air into the patient and to check for the sound of air leaking. For second way not written in guidelines and actually often used by nurses, the nurse checks the stiffness of the balloon attached to the tracheal tube. In a third way, also not written in guidelines, a cuff pressure gauge is used. The above ways were named diagnostic by chest sound, balloon way, and cuff gauge way. All achieve the purpose of measuring the amount of air in the cuff. All of these ways aim to achieve a single purpose, as was explicated by the use of CHARM. Preconditions for the cuff gauge way require that the cuff gauge be available on site. CHARM

states that other ways can be used if there is no cuff gauge available. The relationship between ways and their applicability preconditions were therefore explicated by using CHARM.

By structuring nursing guidelines using CHARM, purposes of actions were explicated and implicit knowledge accumulated by veteran nurses was externalized. Actions and anticipated problems were then written in correlation with one another with high consistency.

2.4. Comments Regarding CHARM Efficiency

We obtained comments on CHARM from nurses who are coauthors of this paper and from member of the College of Nursing faculty. Their comments suggested that CHARM is a valid method for describing medical procedures.

Because CHARM is able to explicate relationships between actions, there are high expectations for its applicability in nursing training. Nursing staff members who are responsible for educating newcomers at Miki City Hospital commented that CHARM is useful in educating students and inexperienced newcomers. They also commented that CHARM explicates multiple possible procedures and makes optimal decisions easier to make. They further commented that although it may be difficult to use CHARM in a clinical setting, the method is useful in basic and postgraduate training.

Comments from nurses such as "(CHARM) explicated possible choices of procedures" indicate that CHARM has ability to represent the procedures with consistency. Comments such as "(CHARM) explicated purposes of actions" indicated that CHARM was able to describe relationships between actions and purposes or actions and anticipated problems. We expect that CHARM will help learners to optimize decision making.

Members of the College of Nursing faculty commented that CHARM externalized implicit knowledge that was not available in guidelines. In conventional guidelines, the relationship between actions and causes of anticipated problems was not described clearly, making it difficult for nurses to understand guidelines. Faculty members stated that CHARM made it possible for even new nurses to understand procedures.

3. Integration of Nursing Guidelines from Multiple Hospitals

The features of CHARM described in Section 2 makes it useful for integrating guidelines consistently. In this paper, we describe the integration of guidelines using CHARM from an integration aiding perspective.

As we mentioned in Section 2.3.1, Miki City Hospital and Ono Municipal Hospital will be integrated in October 2013, reopening as Kita-Harima Medical Center. CHARM can be used to integrate guidelines for these hospitals.

Nursing guidelines for each hospital are written in natural language. In order to integrate guidelines, the integrator must understand each guideline and compare their contents. Formats for guidelines are different at each hospital, however, and it is difficult to compare procedures. There are, moreover, different procedures written in different guidelines, which make it difficult to recognize that they have the same purpose. It makes difficult to integrate procedures.

CHARM explicates implicit knowledge underlying guidelines and assists users in integrating them. CHARM uses a tree structure to relate purposes and procedures, and the format is consistent. Thus, by modeling guidelines in CHARM, formats of guidelines are made consistent, avoiding the above-mentioned problems. Using CHARM, furthermore, implicit knowledge and purposes of actions become explicit. Because each procedure is modeled according to its purpose using CHARM, different methods with the same purpose can be compared, and discussions of the similarities and differences of each procedure are facilitated. Resulting CHARM can also be used by nursing staffs of more than one hospital because it is written in a consistent format.

3.1. Integration of Guidelines

Using CHARM, we integrated guidelines for assisted endotracheal intubation. This emergency medical procedure was chosen because of the high possibility for its need immediately after reopening of the hospital. We therefore explicated the purpose of assisted endotracheal intubation in cardiopulmonary resuscitation. The relation among all medical personnel in this procedure was explicated furthermore by integrating guidelines not only from Miki City and Ono Municipal Hospitals but also from the world standard guideline for cardiopulmonary resuscitation for advanced life support [17] and guideline for doctors [7]. Four guidelines were thus modeled and integrated using CHARM.

3.2. Integrating Guidelines for Doctors and Nurses

Upon integration of guidelines, we first integrated the world standard guideline [17] and the guideline for doctors [7], then integrated the nursing guideline used at Miki City Hospital. The purpose of this integration was to confirm any differences between the world standard guideline and the guideline used at Miki City Hospital and to

Table 1. Differences in assisted endotracheal intubation guidelines between 2 hospitals.

	Parameter	Miki City Hospital	Ono Municipal Hospital
1	Sniffing position	O	X
2	Confirming size of tracheal tube	X	O
3	Use of stopper for stilet	O	X
4	Bending stilet	X	O
5	Complication with stilet	X	O
6	Region of lubricant application	Tip of tube	From tip of tube to cuff
7	Detailed description of how to put laryngoscope in	O	X
8	Suction during and after tube insertion	O	X
9	Detailed description of how to put tracheal tube in	O	X
10	Ventilation after tube insertion	X	O
11	Confirmation of cuff air	Amount of cuff air	Leakage of cuff air
12	Bite block	Introduced as complication	Explains methodologies of use

Notes:
1. O; included
2. X; excluded

relate procedures in nursing and doctor guidelines. When integrated by using CHARM, we confirmed that the two guidelines complemented each other. Surgical procedures for the laryngeal expose, for example, were extracted from the doctor guideline and world standard guideline, but many of the preparatory procedures were extracted from the nursing guideline used at Miki City Hospital. The contents of Miki City Hospital's nursing guideline therefore agree with the world standard guideline [17] and complement the doctor guideline [7]. CHARM helped explication of this relation because the knowledge sources are clarified thanks to the rule which CHARM describes one action as one node.

3.3. Integration of Nursing Guidelines Between Hospitals

Next, we integrated CHARM introduced in Section 3.2 (called "a" hereafter) and CHARM modeled from the nursing guideline used at Ono Municipal Hospital (called "b" hereafter). The purpose of this integration was to integrate both of the nursing guidelines for hospital merger. Integrated CHARM is used to identify and discuss differences between the two guidelines. The 12 identified differences between the guidelines are listed in **Table 1** [20]. The main types of differences were accidental omission, description in detail, and disease complication problems. The identification procedures for the 3 types of differences are explained in detail below.
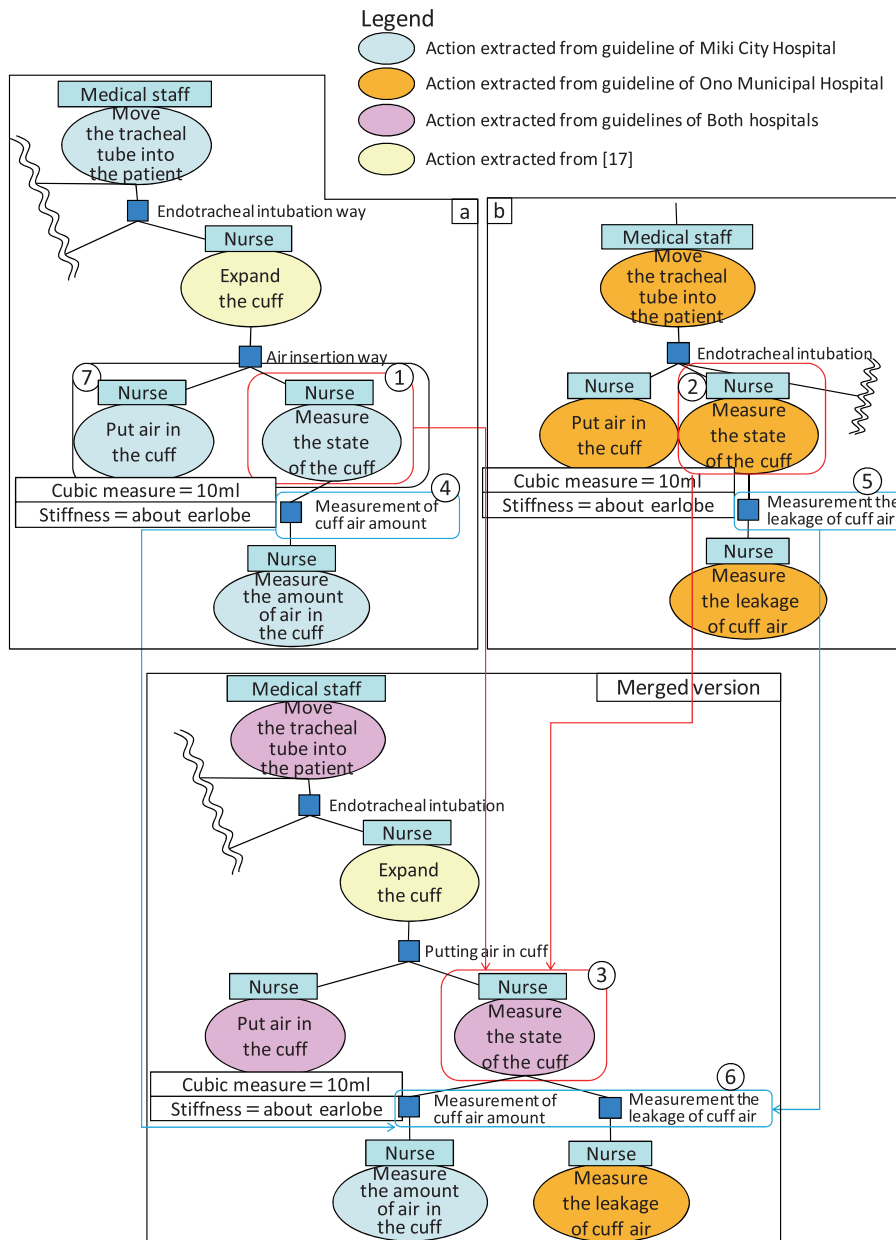
Fig. 7. Integration of action nodes and way of action achievement nodes.

3.4. Integration Method Using CHARM

We investigated common nodes between the 2 CHARMs first. As shown in **Figs. 7**① and ②, for example, the node "measure the state of the cuff" exists in both CHARMs. The common purpose was identified because both of the actions were written in consistent term. In other words, the node "measure the state of the cuff" in "a" and "b" both imply the same state change and therefore can be integrated into a single node (**Fig. 7**③).

Furthermore, as shown in **Figs. 7**④ and ⑤, the action "measure the state of the cuff" can be performed by the ways written in CHARM "a" and CHARM "b." The difference between the ways is that one observed the amount of air in the cuff while the other checked for air leakage. In this case, as shown in **Fig. 7**⑥, both of the ways are written in CHARM after integration. Both of the ways

written in "a" and "b" have the same purpose and the purposes are written in consistent term. In other words, both of the ways can be used to achieve this purpose after integration. The explication of the relation between the two ways helps to create a discussion of which way to select or not. Actual discussions took place on differences of methodologies between the nursing staff at Miki City Hospital and Ono Municipal Hospital. As shown in **Table 1**, differences 2, 3, 5, 8, and 10 existed in one guideline but not in the other. This was only due, however, to accidental omissions in guidelines. The actions were therefore added to the integrated guideline. The actions were omitted because of differences in priorities of actions at each hospital. CHARM clarified priorities for both hospitals by clarifying the knowledge sources. Furthermore, as shown in **Fig. 7**⑥, consistency in format explicitly differentiated procedures with the same purpose.
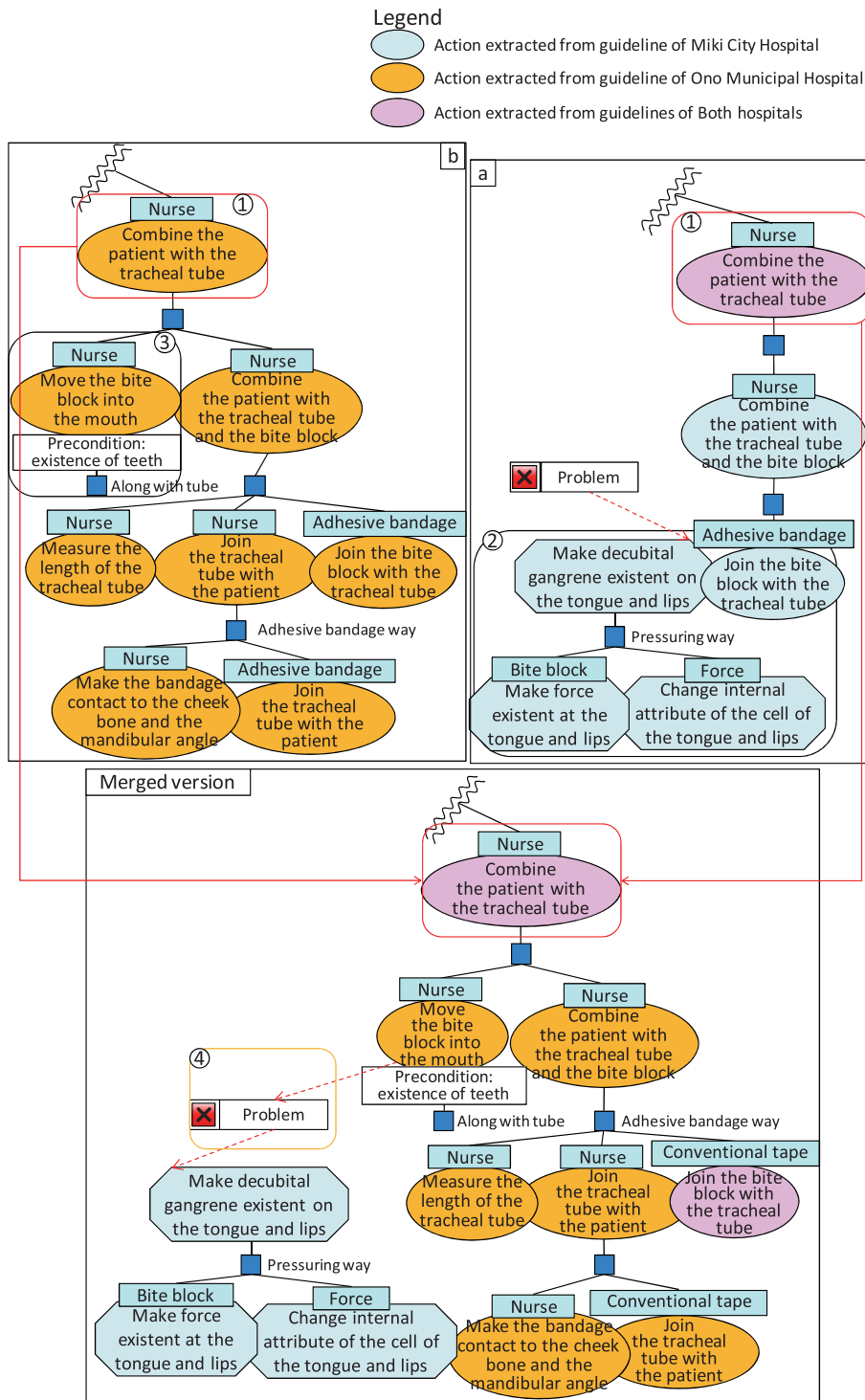
Fig. 8. Complimentary integration of procedures for nurses and problem processes.

An example of this is number 11 in **Table 1**.

Differences in the priority of purposes were clarified also by focusing on the interpretation of actions in each guideline. As shown in **Fig. 7⑦**, in "a," action "put air in the cuff" and "measure the state of the cuff" leads to achieving the purpose "expand the cuff." In "b," however, these actions were not stated clearly. Both guidelines included the higher purpose "move the tracheal tube into the patient." This difference shows that the guideline used at Ono Municipal Hospital omitted intermediate purpose

such as "expand the cuff." Differences due to features of CHARM were clarified. Differences 1, 7 and 9 listed in **Table 1**, were due to differences in details in guidelines. We were therefore able to identify implicit knowledge for intermediate purposes.

As shown in **Fig. 8①**, both "a" and "b" contain the action "combine the patient with the tracheal tube." The common action was identified using CHARM. "a," however, explicated that "make decubital gangrene existent on the tongue or lips" may cause a anticipated problem

(**Fig. 8②**, octagon node). "b," while, does not explicate the anticipated problem in detail but explicate the cause (**Fig. 8③**). CHARM identifies anticipated problems and presents them consistently. Differences in anticipated problems between nursing guidelines at Miki City Hospital and at Ono Municipal Hospital were therefore clarified (**Fig. 8④**). An example of this is written in number 12 of **Table 1**. The clarification of problems facilitated integration and discussion of procedures and also emphasized the importance of omitted knowledge.

Differences 4 and 6 in **Table 1**, in addition, were identified before the modeling of CHARMs. These differences were found by careful examination of guidelines. Number 4 in **Table 1** explains procedures that require a device that was not used at one of the hospitals. Number 6 explains a procedure that was not performed at one of the hospitals. The hospital that omitted the procedure confirmed its importance.

CHARM can be used to explicate implicit knowledge and to explicate relations between purposes and actions. These features make CHARM a useful tool in assisting guideline integration between hospitals. Nurses commented that CHARM allowed them to understand rationale behind actions and procedures. This suggests that implicit knowledge that was omitted from conventional guidelines was recognized by the use of CHARM.

4. Related Research

Research presented in this paper is compared with research pertaining to computer interpretable modeling of medical guidelines.

Boxwala et al. have proposed a model called GLIF that is used to standardize and share guideline models from different organization and different medical systems [21]. GLIF was used to model 12 different procedural guidelines, which included injections for influenza and examinations of lower back pain [22]. GLIF was also used in writing guidelines for nurses [23]. GLIF uses flowcharts to describe procedures. Nodes of flowcharts are defined into 5 types: Patient_State_Step, Action_Step, Decision_Step, Branch_Step, and Synchronization_Step. Patient_State_Step describes the state of a patient such as "in a state of suffering from a chronic cough" and "cough condition was cured." Action_Step describes a recommended action such as "get cough history," which describes the obtaining of information from an electronic medical record, or "take an X-ray of the chest," which describes action taken by a health care worker. Decision_Step describes the process of deciding on treatment. As in Action_Step, Decision_Step nodes describe actions pertaining to systems such as "Is the pH of the esophagus above or below normal values?" and actions taken by health care workers such as "do you suspect that the cough is caused by gastroesophageal reflex disease?" Links for the Decision_Step node branch into 2 or more directions, which differentiates this node from the Action_Step node. Branch_Step and Synchronization_Step
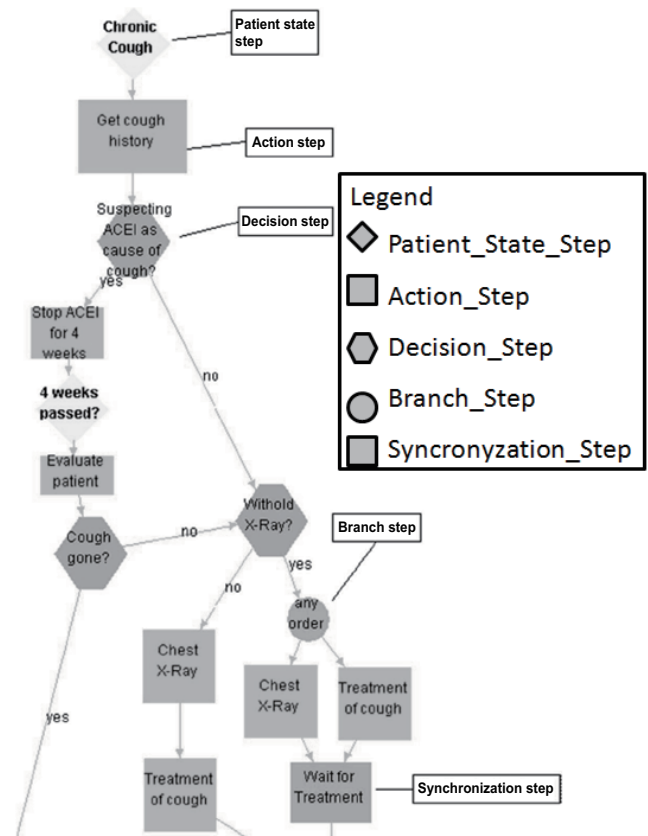

Fig. 9. Description of a guideline according to GLIF ([21]. Common examples were added by the authors).

nodes show actions following in parallel. Branch_Step is the origin of multiple parallel methods and Synchronization_Step is the end point at which parallel methods reintegrate. The node structure of this flowchart clarifies, for the modeler, knowledge that needs to be extracted from guidelines. **Fig. 9** shows a flowchart for chronic cough treatment modeled using GLIF. The beginning of the flowchart shows the assumed patient state. GLIF uses UMLS, which is a system of medical term, in order to share information with other systems. Action_Step describes the obtaining of cough history after a patient arrives at the hospital. The doctor determines if ACEI is the cause of the cough, and actions thereafter branch off according to examination results. In this way, GLIF models procedural guidelines, and then it is computer interpretable.

CHARM as proposed by the authors focuses on modeling purposes of procedures. Models that focus on the flow of procedures, like GLIF, are useful for knowledge builder because he/she needs to understand only the flow of procedures. From the aspect of use in knowledge management and education, however, our model is more efficient. Externalizing the implicit knowledge of veteran staff members can increase the understanding of procedures, thereby facilitating guideline integration. Newcomers can also easily understand purposes behind procedures. These are the differences between GLIF and CHARM.

5. Conclusions

In this paper, we have proposed CHARM, a model for explicating purposes of actions, and have applied the model to nursing guidelines. First, we have discussed the possibilities of using CHARM in the nursing field by comparing medicine and mechanical engineering. Then, based on preliminary discussions, we have proposed CHARM as a model for modeling medical guidelines. CHARM was used to model standard medical guidelines published by medical societies and nursing guidelines used in hospitals. We confirmed the resulting models are able to represent knowledge of various procedures such as surgery, inspection, and cardiopulmonary resuscitation action. Knowledge for nursing procedures covers topics in training guideline for new nurses recommended by the Ministry of Health, Labor, and Welfare of Japan. CHARM has been applied to integrate guidelines between hospitals. Nurses and members of the College of Nursing faculty who were involved in this project commented on the applicability of CHARM.

In the future, the ways of action achievement accumulated in this research will be organized according to their principles. The way of action achievement is the minimum unit of structured knowledge in CHARM. Thus, accumulating these units and connecting them assist in the creation of new CHARM. Systemized ways can be referenced while modeling CHARM and help clarify procedures from a purpose-oriented perspective. New nurses also can refer to ways of action achievement to deepen their understanding of nursing procedures.

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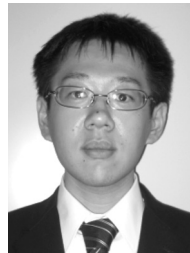
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