Nursing Informatics 2014
K. Saranto et al. (Eds.)

doi:10.3233/978-1-61499-415-2-452

Automatic Generation of Nursing Narratives from Entity-Attribute-Value Triplet for Electronic Nursing Records System

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Abstract. The aim of this study is to develop and evaluate a natural language generation system to populate nursing narratives using detailed clinical models. Semantic, contextual, and syntactical knowledges were extracted. A natural language generation system linking these knowledges was developed. The quality of generated nursing narratives was evaluated by the three nurse experts using a five-point rating scale. With 82 detailed clinical models, in total 66,888 nursing narratives in four different types of statement were generated. The mean scores for overall quality was 4.66, for content 4.60, for grammaticality 4.40, for writing style 4.13, and for correctness 4.60. The system developed in this study generated nursing narratives with different levels of granularity. The generated nursing narratives can improve semantic interoperability of nursing data documented in nursing records.

Keywords. Computerized medical record systems, nursing records, natural language generation, semantics, nursing process

Introduction

To maximize the benefits of the electronic nursing records (ENR) system such as sharing and reusing data, structured data entry is strongly recommended [1]. One approach is to document narrative data using pre-coordinated nursing statements mapped to terminology. However, the terminology-based nursing documents cannot ensure full semantic interoperability of data due to the great variation in structure and granularity in nursing narratives used [2].

Another approach is to document nursing records using data model such as detailed clinical model (DCM) [3, 4]. A DCM consists of Entity-Attribute-Value (EAV) triplets

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where an entity is a core or focus concept of a datum, an attribute is a qualifier that represents the entity in more detail, and a value set is a uniquely identifiable set of valid concept representing an attribute. Nursing documentation using the EAV triplets of DCMs allows nurses document nursing records with different levels of granularity and ensures semantic interoperability of nursing records [5]. However, if a nurse document nursing records by selecting an appropriate entity, then attribute, and finally value from a set of pick-list, it will take longer to document and resulting documents are not as natural as narrative text. To solve this problem, a natural language generation (NLG) system to populate nursing narratives using the EAV triplets of DCMs is proposed. This system will generate nursing narratives that are more natural and easier for humans to understand, and facilitate easier and faster documentation.

Nursing narratives describing the status and problems of the patient, and nursing activities provided have different levels of granularity with more attributes and value sets. For example, the presence of pain or its intensity can be an important piece of information in one nursing unit, whereas the character of the pain or its clinical course can be more important information in another nursing unit. Therefore, it is necessary to generate nursing narratives with different levels of granularity with different attributes and value sets according to the user's needs.

This study is to develop a system generating nursing narratives using NLG technology. For this, we identified semantic, contextual, and syntactic knowledges as system components, developed a NLG system linking these knowledges. Then, we evaluated the NLG system in terms of the quality of generated nursing narratives. The study was limited in scope to the nursing narratives describing nursing assessment, nursing diagnosis, planning, and nursing evaluation for perinatal nursing care in acute care setting.

1. System description

The NLG system for generating nursing narratives developed in this study produces natural language text from DCMs. This system is one of the modules of ENR system. Other components of the ENR system include the nursing documentation system, the International Classification for Nursing Practice (ICNP) terminology system, and data warehouse.

The ICNP terminology system manages ICNP concepts. The nursing documentation system displays the nursing narratives generated from the NLG system by nursing process. Nurses can select appropriate nursing narratives to document nursing records. The documented nursing records are stored in a data warehouse for later use.

Overall functional diagram of the NLG system generating nursing narratives is presented in Figure 1. The system accepts an entity and attributes of the DCM as input and produces nursing narratives as output. The generator in the middle processes semantic, contextual, and syntactic knowledges according to the input.

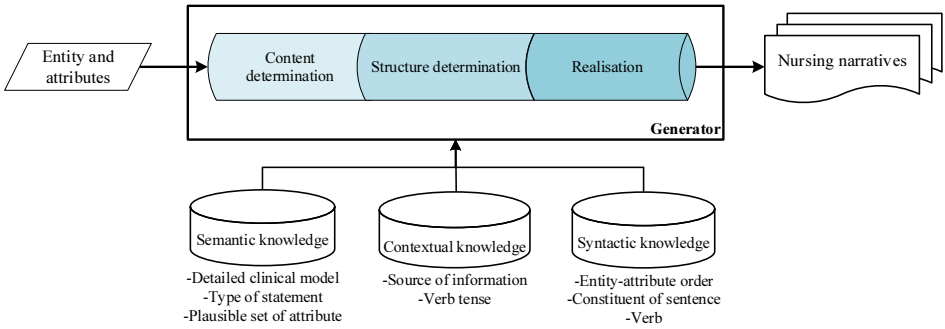

Figure 1. An overview of a natural language generation system for nursing narratives.

The NLG system has semantic, contextual, and syntactic knowledges as its components. Semantic knowledge includes DCM, type of statement, and a plausible set of attributes. Entity and attributes of a DCM determine the structure of nursing narratives, while terms describing an entity and possible values of attributes determine the surface representation of the nursing narratives. Type of statement determines plausible set of attributes and a verb used in the nursing narratives, where a plausible set of attributes is a valid combination of attributes in a nursing narrative. Syntactic knowledge includes sequence of the entity, attributes, and verb in a nursing narrative and case markers. Contextual knowledge includes tense of the verb and the source of information. The NLG consists of three phases: identifying the type of statement and plausible set of attributes to determine the content of the narratives; determining the sequence of the terms and case markers to refine the narratives; and generating grammatically correct narratives with different levels of granularity by assigning values to an attribute and removing the ambiguity of the narratives.

2. Methods

2.1. Extraction of semantic knowledge

We selected DCMs developed and validated in a previous research conducted by the authors of this paper [6]. The DCM included concepts describing sign and symptom, nursing problem, and patient's response to perinatal care.

Type of statement was classified based on an ontology for nursing narratives that was developed in a previous research [7]. Type of the statement is listed as follows with a description of their role: 'patient's verbal' statement represents subjective data such as perceptions or feelings that were experienced and expressed only by the patient in the phase of nursing assessment or evaluation; 'observation' statement represents objective data observed by the nurse, patient, or caregiver in the phase of nursing assessment or evaluation; 'measurement' statement represents objective data measured by the nurse using a device or a tool in the phase of nursing assessment or evaluation; and 'judgment' statement represents the nurse's analysis or clinical judgment on subjective and objective data collected in the phase of nursing assessment to determine the patient's actual and potential health problems in the phase of nursing diagnosis or planning.

We extracted a plausible set of attributes by reviewing nursing narratives used in the nursing records and literatures, and consulting nurse experts. Specifically, we first combined entity with one or more attributes to produce multiple different sub-sets of attributes. We then reviewed whether a subset of attributes was semantically ambiguous either at the attribute level or the value level.

2.2. Extraction of contextual knowledge

Regarding the source of information, when the nurse is the primary informant of the patient status, the subject was omitted in the generated nursing narratives, provided doing so caused no ambiguity in meaning.

Regarding the tense of the verb, since nurses are supposed to document nursing records when they assess the patient and provide nursing care, the generated nursing narratives use the present tense reflecting this.

2.3. Extraction of syntactic knowledge

The sequence of entity and its attributes was such that the subject and the verb of the nursing narrative were placed foremost, other attributes were then arranged according to the grammatical relationship between them. With the addition of a new attribute, the order of the attributes in the narrative was reviewed for ambiguity in meaning. For example, the sentence "reports there is labor pain every five minutes" means the patient status informant reports the patient is in pain every five minutes, whereas "reports every five minutes that there is labor pain" means the informant reports every five minutes about the patient's labor pain. This example shows differences in how attributes are arranged may alter the meaning of the sentence, although included attributes are the same.

The case markers such as nominative case marker or adverbial case marker were extracted from the Korean grammar. Type of the verb was chosen by reviewing the existing nursing records, based on the type of the informant and the type of nursing statement.

2.4. Generation of nursing narratives

The NLG in this study consisted of three phases. In the first phase, the system provided valid types of statement and plausible sets of attributes for the entity entered. In the next phase, the sequence of the entity and attributes were determined by the type of statement. Type of the verb and its tense were provided in accordance with the type of statement and the source of information. In the final phase, attributes are replaced by value, and nursing narratives with entity and different values are generated. The generated nursing narratives are then refined with case markers for the entity (nominative case marker) and case markers for the attributes (adverbial case markers).

The NLG system was developed and implemented on the Microsoft Window platform. Microsoft Visual Studio .NET 2010, C#, Windows Server 2008, Microsoft .Net framework 4.0, and Oracle 11 g were used to design the website and implement the data storage and management system.

3. Quality Evaluation of generated structured narratives

Three domain experts evaluated the quality of the nursing narratives generated from the NLG system. These domain experts were nurses with more than five years of clinical nursing experience in perinatal care or research experience in nursing documentation.

The nursing narratives for quality evaluation consisted of 498 sentences, covering all possible combination of attributes using the eight most frequently recorded DCMs in the nursing documentation for one month.

After reading the generated nursing narratives, the domain experts were asked to rate their overall quality (a global assessment of the overall quality of the descriptions generated by the system), content (the extent to which the delivered information is adequate and focused), grammaticality (the extent to which the information is grammatically well-formed), writing style (the quality of the prose), and correctness (the extent to which the descriptions are in accordance with the established nursing knowledge) by five-point rating scale ranging from 'strongly disagree' to 'strongly agree'. The questionnaire was a modification of one used to evaluate KNIGHT, a biology knowledge base, in the domain of botanical anatomy, physiology, and development [7]. The scores for each item were analyzed using descriptive statistics such as frequencies, means, and standard deviations.

4. Results

4.1. Extraction of semantic knowledge

The DCMs used in this study included 82 entities, 105 attributes, 242 values, 416 entity-attribute relationships, and 257 attribute-value relationships. We identified 429 Korean terms representing 82 entities such as abdominal distension and after pain, 105 attributes such as severity and intensity, and 242 values such as severe and strong.

Out of 82 DCMs, 26 DCMs such as 'abdominal distention' can have observation-type statement, 30 DCMs such as 'body temperature' DCM can have measurement-type statement, 27 DCMs such as 'febrile sense' DCM can have patient's verbal statement, and 36 DCMs such as 'pain' DCM can have judgment-type statement. A DCM can have more than one statement types. For example, 'pain' DCM has three statement types such as patient's verbal statement, measurement, and judgment-type statements.

At the attribute level, it was impossible to combine attributes pertaining to an isolated episode and those pertaining to recurring episodes. The attributes relevant to an isolated episode were 'episodic duration' and 'amount' attributes, while those relevant to repeated episodes were 'frequency', 'occurrence', and 'onset' attributes. At the value level, it was impossible to combine 'irregular' value of 'regularity' attribute and values of 'episodic duration' or 'interval' attributes, and to combine 'absence' value of 'presence' attribute and values of other attributes.

4.2. Extraction of contextual knowledge

If only one type of informant was valid for a type of statement, the subject was omitted from the narrative. For example, because only the patient can be the informant for verbal statement, the subject was not expressed explicitly in the nursing narratives. In

cases where multiple informants were involved, only nurses were not expressed explicitly. For observation-type statement, the informant may be the patient, the caregiver, or the nurse. If the informant was the patient or the caregiver, the subject was expressed in the narratives. If the informant was the nurse, the subject was omitted in the narratives.

As a rule, the present tense was used throughout the narratives. In contrast, if the nurse collected information from the patient or the caregiver, the narratives describing such a case had the past tense.

4.3. Extraction of syntactic knowledge

For patient's verbal statement, 20 attributes could be used, 12 before the entity and two after the entity. For measurement-type statement, 49 attributes could be used, 13 before the entity and ten after the entity. For observation-type statement, 48 attributes could be used, 17 before the entity and three after the entity. For judgment-type statement, 11 attributes could be used, five before the entity and one after the entity.

Twelve case markers were extracted for patient's verbal statement, measurement, observation, and judgment-type statements. The nominative caser marker such as 'i/ga (이/가),' adverbial case markers expressing time, instrument, and place such as 'from,' 'to,' 'with,' 'at,' and proposition of noun such as 'of' were identified as case markers.

Verbs 'complained/not complained,' 'measured/not measured,' 'observed/not observed,' and 'be present/be absent' were used for patient's verbal statement, measurement, observation, and judgment-type statements, respectively.

4.4. Generation of nursing narratives

The NLG system generated 66,888 nursing narrative using 82 DCMs. The number of the generated nursing narratives was 26,204 for observation-type statement, 10,234 for measurement-type statement, 29,705 for patient's verbal statement-type, and 745 for judgment-type statement. The number of attributes within each nursing narrative ranged from zero to nine.

One example of the generated nursing narratives included an entity 'pain(통증)' coded E000057, three values for three attributes such as 'abdomen(복부)' coded V900911, 'severe(심한)' coded V000190, and 'present(있음)' coded V000167, and the adverbial case marker, 'e(에)', coded M000007 and the nominative case marker, 'i (이)', coded M000013 (Figure 2). The generated nursing narrative, along with the associated metadata such as nursing narrative ID, type of statement, EAV triplet and case markers, was stored into a relational database. This generated nursing narrative example was expressed with codes 'S00001012; SC00004: {A000005=V900911, M000007, A000083=V000190, E000057, M000013, A000074=V000167}'.

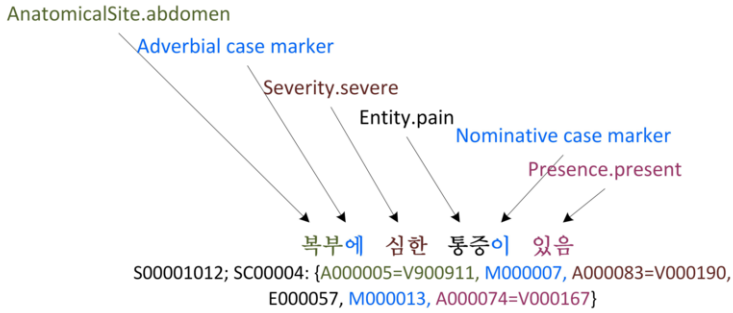

Figure 2. An Example of a generated nursing narrative.

5. Quality Evaluation of generated structured narratives

The mean score for overall quality was 4.66, for content 4.60, for grammaticality 4.40, for writing style 4.13, and for correctness 4.60. For grammaticality and writing style, 18.3% and 22.7% responded with scores 1 or 2.

As the number of attributes within a nursing narratives increases, the mean score of evaluation item were decreased. For overall quality, content, and correctness, the mean score of nursing narratives with 6 or more attributes was lower than the mean score of each evaluation item. For grammaticality and writing style, the mean score of nursing narratives with 5 or more attributes was lower than the mean score of each evaluation item.

6. Discussion

Nursing narratives were first classified into observation, patient's verbal, measurement-type statements based on their data collection method. For instance, narratives describing observable data are classified as observation-type statement in this study, regardless of the types of the observer. Observation type statements are then sub-classified by the observers. In this study, the type of statement determines the sequence of words and type of verb. Therefore, nursing narratives were classified based on both the source of information and method of data collection.

In this study, structure of narratives such as plausible set and sequence was mainly determined by the attributes of DCM. This approach is also used in other natural language processing (NLP) project [9]. This approach allows the system generate large number of narratives with small number of data models with different set of attributes.

The most common ambiguity problem in NLP and NLG has to do with attributes expressing time-oriented information [10]. In this study, the ambiguity problem with time-oriented attributes was solved by categorizing these attributes into two groups of attributes, that is, one group of attributes expressing an isolated episode such as 'episodic duration', and another group of attributes expressing recurring episode such as 'frequency'.

There were cases where the values of a certain attributes could not be combined with any values of another attribute. For instance, a value 'irregular' for the attribute 'regularity' cannot be combined with any values of the attributes 'episodic duration'

and 'interval'. In such a case, restriction on value of an attribute-another attribute combination was processed in the realization phase.

In this study, the quality of nursing narratives generated by NLG system was evaluated by the human rating and judgments. There are different ways of evaluating texts generated by NLG systems in literature such as human ratings and judgments, task-based evaluation, or evaluations based on automatic metrics which compare computer-generated texts to human-authored corpus texts. Among these evaluation methods, human-based quantitative evaluation with free-text comments was found to be the most helpful method in diagnosing and fixing problems in generated text, although human evaluation is relatively time-consuming [11].

The result of the evaluations on the quality of narratives generated in this study showed while each evaluation item received positive response, grammaticality and writing style received many comments particularly on sequence of words and terms. The number of comments increased as the number of attributes increased. In detail, narratives with more than six attributes were found to have comprehension problem. Considering existing nursing narratives use less than four attributes per sentence, unfamiliarity with the narrative employing six or more attributes may be responsible for this result. Therefore, alternative methods of generating narratives with more than six attributes should be explored, such as generating short multiple sentences rather than a long and simple sentence.

7. Conclusion

We tried to develop a system to generate nursing narratives using data model and NLG technology. Narratives generated from the data model allow structured data entry even though they look as natural as human language. Structured data entry will not only enable ease data capture and but also ease reuse of data captured in the future.

Acknowledgments

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT & Future Planning (No. 2012-012257).

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