Towards Knowledge Morphing: A Triangulation Approach to link Tacit and Explicit Knowledge

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Abstract: *Current knowledge management systems are greatly designed to deal with a single knowledge modality. Given the diversity of knowledge modalities that cover any given topic it is quite reasonable to be able to use all available knowledge, irrespective of their representation formalism, to derive a knowledge-mediated solution. For deriving such a solution, there is a need to select all knowledge elements (represented in different modalities) that are relevant to the solution of the problem at hand. Thus here, the author pursues the specification and implementation of such a knowledge management framework that allows for the systematic compilation and organization of such holistic medical knowledge by semi autonomously linking/mapping of contextually and functionally similar medical knowledge originating from different sources and represented in diverse modalities. This tacit-explicit knowledge morphing (TEKM) system/framework supports the extraction of tacit knowledge from past cases stored in a case-base and maps it with corresponding explicit knowledge stored in clinical practice guidelines. The novelty of this approach is inherent in the fact that it uses the explicit knowledge acquired from scientific research in tandem with experiential knowledge found in past cases thus linking/mapping the two modalities of knowledge.*

Keywords: *Knowledge Morphing, Knowledge Modalities, Knowledge Management, Triangulation.*

1. INTRODUCTION

The emergence of knowledge management as a discipline has highlighted the importance of capturing and operationalizing knowledge to support decision support, learning/training and improving operational workflows and outcomes [1][2]. This has precipitated the development of methodologies, tools, and frameworks to capture the different knowledge modalities, given their inherent existential and operational constraints, and an attempt to automate the captured knowledge through knowledge management systems. I note with interest that the current knowledge management systems are largely designed to deal with a single knowledge modality, for instance some variation of explicit knowledge represented as either documents, guidelines/workflows, symbolic rules and so on; or a type of tacit knowledge represented either as cases, scenarios or peer discussions[3,4]. Given the diversity of knowledge modalities that encompass any given topic/problem it is reasonable to demand access and use of all available knowledge, irrespective of their representation modality, to derive a knowledge-mediated solution.

In medicine, the need for leveraging all possible resources of medical knowledge is paramount, as there is the need and realization to give clinical care that is grounded in best evidence. We can find in the literature of medical knowledge management, various initiatives to address the creation, collection, sharing and operationalization of a single medical knowledge modality [5- 7]. The nature of clinical practice is such that is not only quantitative but also very much qualitative. The former is an expression of systematic and critical assessment, continuous experimentation- the ideas based on the critical clinical school and evidence based medicine. On the other hand, the softer side which is the qualitative approach- the tacit knowing held and applied by the practitioner also represents a valuable form of clinical knowledge, which can be gained mainly through experience [8-10]. According to medical knowledge management literature the task at hand of the physician is not only to understand the disease but at the same time to be able to understand the patient. Levenstein et al have argued that there does exist a well tried clinical method for understanding disease but not an equivalent method of understanding patients [11]. A doctor's diagnosis of a disease is not just a matter of objectivity but is also affected by his personal experiences [12].Thus the contention here is that combining qualitative and quantitative approaches can offset the shortcomings of both strategies. "Triangulation", a notion drawn from land surveying implies that a more accurate or adequate account can be provided when a point is described from different perspectives or angles. The validity of clinical evidence can be strengthened when qualitative and quantitative methods complement each other [13].

Thus the argument here is that the morphing of heterogeneous knowledge modalities spanning from tacit to experiential to explicit to data-induced knowledge [14-17] may provide an overall view to practitioners of what solution will work, why it will work, and how to make it work[18].So the problem identified here is that a single modality of knowledge used in isolation may be incomplete and insufficient for best decision making and thus to provide a holistic view of a situation contextually similar modalities of knowledge may be linked and used. The importance of such knowledge morphing activities can be understood by the realization that clinicians need to provide advice in many situations where either (a) strong evidence is lacking or (b) there is a requirement to ascertain that recommended actions adhere to guidelines. In the healthcare setting, where ever there is absence of clinical algorithms based on scientific evidence, clinicians can leverage on intuitive and successful approaches recorded in past clinical cases. In this paper, I firstly introduce the concept of knowledge morphing to characterize the mapping of contextually similar knowledge modalities such as explicit knowledge found in evidence based clinical practice guidelines and tacit experiential knowledge found in past clinical cases. Then I present the system design and implementation details of the system.

2. KNOWLEDGE MORPHING

Knowledge morphing is defined as “the intelligent and autonomous fusion/integration of contextually, conceptually and functionally related knowledge objects that may exist in different representation modalities and formalisms, in order to establish a comprehensive, multi-faceted and networked view of all knowledge pertaining to a domain-specific problem”[18]. Knowledge morphing is a complex modeling activity that establishes a link between apparently different but contextually similar components of knowledge thus to provide an all-embracing solution. Knowledge morphing has been successfully achieved by linking CPG with related clinical evidence published in medical articles at PUBMED [19][20].

In this work, I pursue the concept of knowledge morphing and demonstrate linkages between the CPG and Clinical Case that involve transformation of the knowledge resources into formats that render them computable which have been proposed recently in literature as shown in figure 1.

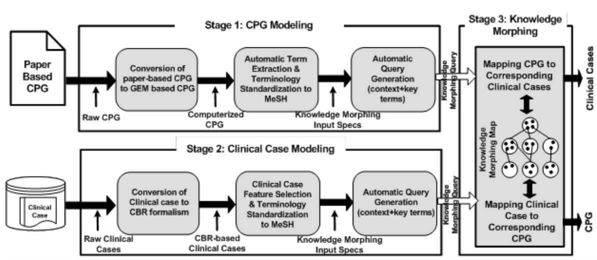

Figure 1: Schematic of Knowledge Morphing Methodology [18]

3. RESEARCH METHODOLOGY AND SYSTEM DESIGN

In this section I present the detailed design of the morphing system proposed in this research work. The explicit modality of knowledge used in this context is clinical practice guidelines and the tacit modality of knowledge which is morphed with the explicit side are past clinical cases. Our goal is to be able to link these two different modalities of clinical knowledge by leveraging upon the contextual similarities of both modalities. The steps of the entire morphing process are given below, followed by a detailed discussion of the process:

1. Convert textual CPG to GEM
2. Verification of GEM-CPG by Domain expert(DE)
3. Workout a generic schema for the Case and convert to XML according to Schema
4. Validation of schema by DE
5. Mapping of GEM-DTD with CC-DTD
6. Validation by DE
7. Present C-CPG or XML-CC to user for text selection
8. Term normalization, Filtering and Expansion
9. Query generation with semantic types and MeSH terms connected using a logical disjunction.
10. Present all hit cases/recommendation to the user
11. Domain expert’s review

3.1 Operationalization of Explicit Knowledge

The explicit modality of knowledge used here are Clinical practice guidelines (CPG) which are textual in nature. To operationalize it, that is to prepare it for knowledge morphing I computerize the textual CPG. There are various guideline representation models which include the Arden Syntax, the Asbru model, the EON model, the GLIF model, the PROforma model, the GUIDE model, the GASTON mode, the GEM model etc [21]. GEM was conceived and built in XML and can therefore take advantage of each of the emerging XML related technologies. The acceptance of GEM can be seen widely in the literature [22-25]. Thus in the work proposed here I use Guideline Element Model (GEM) using GEM Cutter tool. Though the working of GEM and GEM cutter is out of the scope of this paper, it is imperative to understand the meaning of GEM tags and why certain tags are selected for the morphing process while others are not. Table 1 describes all the GEM tags and highlights the ones which are used in the mapping process.

Table 1: GEM tags and their description

No	Field	Description	Used for Mapping
1	Identity	Contains guideline title, citation, availability, adaptation document	No
2	Developer	Contains developer and committee names, funding sources etc	No
3	Purpose	Contains main focus, category, rationale, objective, and implementation strategy	Yes
4	Intended Audience	Contains users and care setting	No
5	Development Method	Contains information about evidence	No
6	Target Population	Contains eligibility like age, sex etc	No
7	Knowledge Components	Contains recommendations which could be conditional or imperative. Conditional tag further contains decision variables and action.	Yes
8	Testing	Contains external review and pilot testing	No
9	Revision Plan	Contains expiration and schedule review	No

The functionality of each tag is evident from the description of tags; the information that we are primarily interested in from these CPG are the knowledge components which I consider as the heart of the guidelines. These knowledge components are a set of recommendations which are statements of appropriate practice that are intended to influence practitioner's behavior. This is the kind of knowledge which needs to be mapped with the similar knowledge inherent in clinical case. Also the tag "purpose" addresses the primary disease/condition, health practice, service, or technology addressed in the guideline.

3.2 Operationalization of Tacit Knowledge

Though the bulk of healthcare knowledge is found in published journal articles, structured reviews, and practice guidelines; still from a knowledge management perspective a significant quantum of important and viable healthcare knowledge exists in the form of tacit working knowledge of healthcare expert [26][27]. Some of the work cited in knowledge management literature in these directions include formal concept analysis[28], the re-use of experiences [29], case-based reasoning based capture of contextualized tacit knowledge as ripple down rules [30][31] and cognitive maps [32].

The operationalization strategy used here is simple but effective which uses the clinical cases as the tacit modality of knowledge. These cases are clinical episodes recorded in textual format. These are tacit in nature because it captures the actual practice scenario as opposed to strict protocols given in evidence based guidelines. These are like live cases provided to us by our domain expert. The personal details are not given in these cases for patient confidentiality; however that does not make a difference because for this research, personal details of a patient are not of interest, only the clinical content is required. Cases are marked up using XML tags to represent case structure described in table 2. In general, any case would, as verified by our domain expert, will contain the following break up described in table below:

Table 2: Case Structure tags and their description

No.	Field	Description	Used for Mapping
1	Case Id	A unique case identifier	No
2	Case Description	Brief description of presenting complaint	Yes
3	General History	Past medical, Surgical, Social History, Known Allergies etc	No
4	Management (multiple instances)	Findings/Diagnosis and Treatment/Therapy	Yes
5	Prognosis	Prediction or course of disease or condition	Yes
6	Etiology	Cause of disease or condition	Yes

I use the above description of cases as the basis for determining the data type definition (DTD) of a generic case. It is evident from the table above that all fields except for case-id and general-history are used in the morphing process. Case-id is simply a numeric field uniquely identifying a case and therefore impertinent to use. The information contained in general history also has no mapping with the CPG because the content of knowledge components of CPG are generic statements about a disease/condition and its management and thus I feel (and verified by domain expert) that I would not benefit by using such a patient specific tag.

3.3 Morphing of explicit and tacit knowledge

Morphing of explicit and tacit knowledge modalities will involve (a) understanding and establishing a conceptual mapping of the schemas (i.e. the DTDs given in the previous section) of the two documents, (b) developing an input module for interfacing with the user, (c) search query generation and execution ; finally (d) displaying resultant output.

3.3.1 Conceptual Mapping of schema of CPG & CC

A conceptual mapping of CPG elements to corresponding CC elements was performed by a domain expert illustrated in figure 2. The idea was to relate corresponding elements of these two different knowledge modalities, both refereeing to the same problem domain, in order to facilitate knowledge morphing. Note that although GEM contains numerous tags, only a few are actually used in this morphing. So I will just discuss the GEM tags and its components which I will use for query generation which are "Purpose" and "knowledge components." Similarly, for cases, the relevant tags are "Case Description", "Management" (which contain finding/diagnosis and therapy/treatment), prognosis and etiology. Note: prognosis and etiology are very seldom used and are matched against the complete text of recommendation description (as suggested by the domain expert).

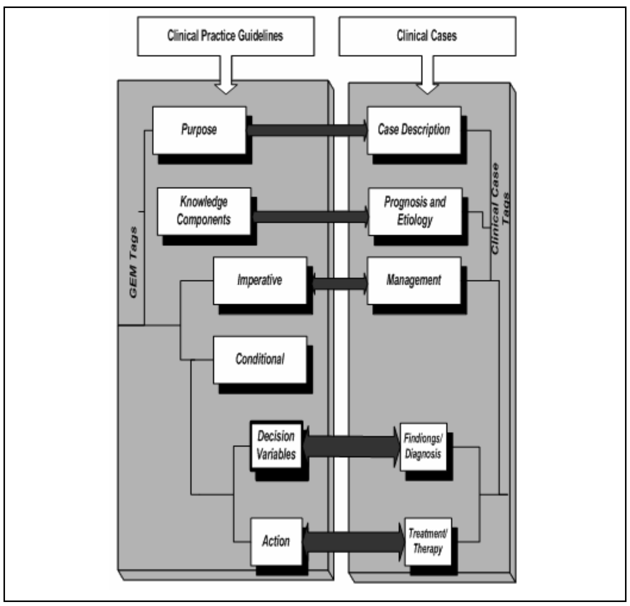

Figure 2: Conceptual Mapping of GEM-CPG and XML-CC Schemas

3.3.2 Selection of text by user from C-CPG or XML-CC

For C-CPG to XML-CC knowledge morphing, the CPG is displayed to the user whereby the user can select parts of

CPG for which advice from past clinical cases is required. However note that only a few tags from the CPG which are involved in the mapping process can be selected which are “purpose and recommendation(s)”. Once the text is selected it is passed on to the next stage of the process which is term normalization. Similarly, for case-to-cpg linkage, the XML case is displayed to the user using XSL style sheets and the tags which can be selected are Case Description, Management, prognosis and etiology.

3.3.3 Normalization of medical terminology

The text selected could consist of terms which are either not part of the biomedical vocabulary (thus meaningless to be used) or terms which are used as a synonym for another medical term. For this reason we need to normalize the selected terms to a uniform biomedical vocabulary and also look up synonyms for such terms. The MMTx tool is used to normalize terms before generating query, that is find synonyms of the MeSH(Medical Subject Headings) terms and find semantic types of the selected terms. Meta Map Transfer tool is developed by the National Library of Medicine (NLM). The output of MMTx would give us the MeSH terms together with semantic types. [www.mmtx.nlm.gov/].

3.3.4 Search Query Generation Strategy

The search query generation strategy is adapted from the original work by Abidi et al with respect to the BiRD system [24]. The BirD search strategy is as follows: (a) categorize queries based on a set of a priori defined query types [33]; (b) the search query is a combination of query type and candidate MeSH terms. Search query should only comprise of MeSH terms thus leading to the generation of optimum search queries [34]. The Search query generation process, illustrated in figure 3, is summarized as follows:

- Parsing the string through MMTx for determining semantic types - query categorization
- Parsing of string through MMTx for identifying synonyms or alternate terms - query expansion
- Filtering out words which are not MeSH terms, i.e. the terms which do not have a definition in the MeSH vocabulary identifying them as extras and stripping them off. Also, terms which have semantic types other than the ones identified earlier are also omitted. – term filtering
- For terms which already have semantic types identified, make query to look up that string in the associated tag (according to semantic type category). In the same fashion synonyms or alternate terms are also used. Thus terms along with its alternate terms are concatenated applying logical disjunction and query generated using XQuery Language composed in XML editor of the XML IDE (a logical conjunction would make the query too rigid and may result in lesser number of hits) - query composer.

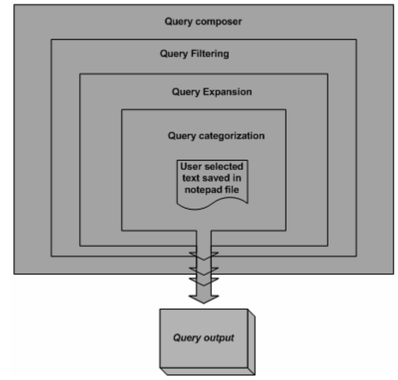

Figure 3: Search Query Generation Strategy

3.3.4.1 Search Query Categorization

From the semantic types generated by MMTx, the categories which we are interested in are Therapy, Diagnosis/finding, etiology, and prognosis. Table 3 below describes the relationship.

Table 3: Relationship between MMTx Semantic types, Case structure and CPG tags

MMTx Semantic Type(MMTx semantic codes)	**Case Structure tag**	**GEM-CPG tag**
Therapeutic or preventive procedure(topp)	Treatment	Action(in case of conditional, otherwise complete text of Imperative knowledge component)
Disease/finding (dsyn/fndg)	Findings	Decision variables (in case of conditional, otherwise complete text of Imperative knowledge component)
Health Care Activity, Intelluctual Product(HLCA/inpr)	Prognosis	Recommendation description
Functional Concept(ftcn)	Etiology	Recommendation description
Other		Not used

3.3.4.2 Term Filtering

Term filtering refers to using selective terms in order to keep the size of the query optimal. All non MeSH terms are omitted and all MeSH terms with semantic types other than the one given in table 3 in section 3.3.4.1 are omitted. The remaining MeSH terms with valid categories (semantic types) are retained and passed on to the next stage.

3.3.4.3 Search Query Expansion

Query expansion refers to using the biomedical meta thesaurus to produce synonyms of the candidate terms. For this purpose, phrase variants are used which are also generated by MMTx. This process expands the query and increases the chances of more hits. This concept can be found in literature in Yikun’s work [35]. For example the phrase “respiratory failure” could also be synonymously used for “respiratory insufficiency” and hence synonyms are used to expand the scope of the query. Thus the remaining MeSH terms with valid categories of semantic types and its variant terms (synonyms) are retained and formed as part of a query connecting all terms with a logical disjunction.

3.3.5 Search Query Composition and Execution

Once the semantics have been determined, terms filtered and expanded, we are ready to write a query based on the remaining candidate terms. The query composer takes into account the semantic type of each term and uses the semantic type to determine in which tag the text content is to be searched. Table 3 given in section 3.3.4.1 is used for this mapping. The formed query is executed in the XML IDE and the result form output window is captured and displayed to the use. This is illustrated in section 4 with examples which will further clarify the process.

4. IMPLEMENTATION DETAILS AND DISCUSSION

According to the system design and research methodology presented above, here I present the implementation details of the TEKM system along with a detailed discussion of each module and its integration.

4.1 Conversion of CPG to GEM

Working with a textual CPG, I first convert it into computerized CPG (for our model I use GEM which is an XML-based guideline document model). The CPG which I am using here is the evidence-based guideline for weaning and discontinuing ventilatory support. This is a collective task force facilitated by the American College of Chest Physicians, the American Association for Respiratory Care and the American College of Critical Care Medicine. Further guideline details can be found at www.rcjournal.com/online_resources/cpgs/ebgwdscpg.asp.

4.2 Clinical Case Representation & Conversion

Past clinical cases provided by the domain expert are used as the tacit experiential knowledge in this project. These cases are highly textual in nature and need to be structured and represented in such a way that they can be mapped with the explicit knowledge found in CPG. There are a number of case representation techniques available in the world of CBR systems. However, for this particular project, after considerable research, I propose to represent cases using XML schema using any XML IDE. The idea of using XML for representing CBR cases is successfully implemented as Case Base Mark Up Language (CBML) in the literature of CBR [36]. For now I am using Stylus Studio, the same can be achieved using MS Visual Studio .NET or any other XML integrated development environment. It is simple and easy to use, plus since cases are marked up as XML tags, we can make use of it to relate it to XML tags in the GEM representation of the CPG.

4.3 Morphing of GEM-CPG and XML-Based Clinical Cases

As discussed above in section 3.3, here I will show the working of the various modules which are part of the morphing process. These include firstly the CPG/XML-CC visualizer that enables the user to select text. Next I show the working of the query generator in detail followed by the query execution and result visualizar modules.

4.3.1 C-CPG and XML-CC Visualizer

The GEM CPG or XML based Clinical Case are displayed in the browser using XSL style sheets. Using the XSL styles sheets, selection can be indicated using radio buttons and check boxes on the tags. These tags and associated text is captured through java script and saved in a notepad file. This notepad file is passed on as input file to our Term Normalization module.

4.3.2 MeSH Term and Semantic Type Generator

The MMTx program takes as input the notepad file generated by the Visualizer and separates it into phrases, identifies the medical concepts and assigns proper semantic categories to terms according to knowledge embedded in UMLS. The output of MMTx would give us the MeSH terms derived from the C-CPG content together with UMLS semantic types. The variant terms generated by MMTx are used to determine synonyms for query expansion as discussed in section 3.3.

4.3.3 Search Query Composer

At this point we have a text file which contains the candidate terms for query generation which have been categorized according to semantic types, filtered, and expanded (as explained in previous section). So the resultant of this process is actually a table with two columns: tag type and term. Depending on whether this is a mapping from C-CPG to XML-CC or vice versa, the table given in section 3.3.4.1 is referred and then the corresponding tags are searched for the candidate terms in the respective documents. This is where the mapping of the schema is taken into consideration. Queries are generated using XQuery. XQuery is a language developed by the W3C XML Query working group and is executed using stylus studio which is the XML IDE used in this project. The output from the query window is hence displayed to the user.

4.3.4 Query Result Visualizer

The result of the query execution is either the matched cases or matched recommendation which are captured and displayed to the user for reference. So what we are achieving by this Explicit-to-tacit mapping is to see how much of evidence-based CPG is actually put into practice and what does expert opinion have to say about a certain protocol. Both recommendations and hit cases are displayed in a collapsed form and can be expanded by clicking to view complete text.

5. DISCUSSION AND SYSTEM EVALUATION

The working of this proof-of-concept system is shown using the evidence-based guideline for weaning and discontinuing ventilatory support together with numerous cases related to Mechanical Ventilator management.

Demonstration

From C-CPG to XML-CC

Suppose the user selects the following recommendation from the CPG:

Recommendation 5: Patients receiving mechanical ventilation for respiratory failure who fail an SBT should have the cause for the failed SBT determined. Once reversible causes for failure are corrected, and if the patient still meets the criteria, subsequent SBT should be performed every 24 h.

Figure 4: Recommendation 5 selected by user

Parse this passage through MMTx to generate semantic types. Synonyms are used to find any alternate biomedical terms that might be used in the CC and semantic types are determined to identify which tag of the CC to target. After parsing through MMTx, following table is generated (only part of the table is displayed here)

Thus using the table 4, query is generated using the XQuery language in XML editor with the following criteria: "/casebase/case[contains(TAG, "TERM")]", where tag is the mapped tag of CC and terms are all the MeSH terms and alternate terms connected using logical OR. The matched case(s) are pulled up and displayed to the user in the output window. In this demo, the case which is matched is case number 1 from the entire case base (the case base contains the XML converted cases from the textual cases provided to us by the domain expert; the case base is not shown in this paper).

Table 4: Formatted output of MMTx Parser, input from CPG

No	MeSH term	Alternate terms	UMLS Semantic types	Used for Query	Mapped tag of CC
1	Reception		Organ or Tissue Function (ortf)	No	
2	Mechanical Ventilations	Management of Mechanically assisted ventilation,	Therapeutic or Preventive Procedure (topp)	Yes	Treatment
3	Respiratory Failure	Respiratory Insufficiency	Finding (fndg)	Yes	Finding
4	Failure		Functional Concept (ftcn)	Yes	Etiology
5	Causes	Causality, etiology	Functional Concept (ftcn)	Yes	Etiology
6	Patients		Patient or disabled group(podg)	No	

From XML-CC to C-CPG

User is displayed cases and has the option to select text/phrases from the tags finding, therapy, prognosis, etiology. After passing the user selected text through MMTx, a table similar to table 5 is generated (entire working not shown because of space constraints). Thus using that table, query is generated using the XQuery language with the following criteria:

"/guideline.document/guideline.body/knowledge.components/recommendation/conditional[contains((TAG/TERM")]"

where tag is the mapped tag of CPG and terms are all the MeSH terms and alternate terms connected using logical OR. The matched recommendation(s) are displayed to the user in the output window.

5.1 System Evaluation and Domain Expert's Review

For this research, a domain expert, who is a pulmonologist and fellow in critical care medicine, is employed to help us identify/understand the tacit knowledge in the cases, and to validate and evaluate the working of the system.

The evaluation strategy of the system is two-fold. Firstly, an overall subjective review is taken from the domain expert on the usability, acceptability and advantage of such a system. Secondly a more objective review is conducted for the efficacy of the search query generation strategy. Based on the CPG and the clinical cases used here, the two way validation is done, that is from C-CPG to XML-CC and vice versa. The TEKM system generates queries using text from all possible sections of cases and recommendations and produces results. On the other hand, the domain expert is independently requested to do the following: (1) for each case, find a corresponding recommendation from the CPG, and (2) for each recommendation try to point out the closest real life case from the case base that I am using for illustration purposes. Then the results produced by TEKM as given are compared with the matching done by the domain expert and evaluated on a Likert scale.

Table 5: General matching performed by domain expert

Cascase #	R Recommendation
1	Rec 2,3
2	Rec 1,2,3
3	Rec 4
4	Rec 4
5	Rec 7
6	Rec 9
7	Rec 7
8	Rec 10

Table 6: General matching performed by TEKM System

Case #	CP Recommendation
1	Rec 2,3,5,6
2	Rec 1,2,3,4,5,6
3	Rec 4,2,3,9
4	Rec 4
5	Rec 7
6	Rec 9
7	Rec 7
8	Rec 1,2,3,5,9,10,12

Table 7: Domain experts matching compared with TEKM matching

Exact Matched		Extra Matched		No Match	
Number	%	Number	%	Number	%
4	50%	4	50%	0	0%

6. CONCLUSIONS AND FUTURE WORK

This paper presents an interest working of the knowledge morphing concept in order to supplement explicit forms of knowledge with tacit knowledge and vice versa. This can further be extended to morph other modalities of knowledge or even more than two modalities at the same time. The application has been shown in a healthcare setting but the same concept can be applied to the business world where various modalities of knowledge exist and there is a huge demand for managing knowledge for better decision making.

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DISCLAIMER

This paper is summary of the Thesis submitted as part of MS research conducted by the author. This work has already been published and reappears here as part of requirement by the institution.

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