Context-Aware Knowledge Modelling for Decision Support in E-Health

Obinna Anya, Hissam Tawfik, Saad Amin, Atulya Nagar and Khaled Shaalan

Abstract—**In the context of e-health, professionals and healthcare service providers in various organisational and geographical locations are to work together, using information and communication systems, for the purpose of providing better patient-centred and technology-supported healthcare services at anytime and from anywhere. However, various organisations and geographies have varying contexts of work, which are dependent on their local work culture, available expertise, available technologies, people's perspectives and attitudes and organisational and regional agendas. As a result, there is the need to ensure that a suggestion – information and knowledge – provided by a professional to support decision making in a different, and often distant, organisation and geography takes into cognizance the context of the local work setting in which the suggestion is to be used. To meet this challenge, we propose a framework for context-aware knowledge modelling in e-health, which we refer to as ContextMorph. ContextMorph combines the commonKADS knowledge modelling methodology with the concept of activity landscape and context-aware modelling techniques in order to morph, i.e. enrich and optimise, a knowledge resource to support decision making across various contexts of work. The goal is to integrate explicit information and tacit expert experiences across various work domains into a knowledge resource adequate for supporting the operational context of the work setting in which it is to be used.**

I. Introduction

THE vision of e-health to provide proactive, patient-centred and knowledge-rich support to collaborative decision making among e-professionals working across organisational and geographical boundaries, makes e-health decision support systems (DSS) of necessity multi-contextual in nature. There are a number of contexts involved, namely context of information resources available for supporting decision making, context of knowledge providers and health professionals working in different organisations, context of patients receiving treatment and context of end-users. Discrepancies exist between the contexts, and both theoretical and empirical studies have shown that such discrepancies may be detrimental to effective use of DSS [1].

On one hand as a result of certain peculiar work settings, experts often use a large amount of domain specific knowledge, which allows them to constrain the problem, to approximate the problem or to reformulate the problem in order to solve a simpler problem efficiently or to use practice-specific heuristics, which reduces the average complexity of the problem [5, 18]. On the other hand, advances in computing have enabled new forms of dynamic and agile collaboration that allow geographically distributed workers to interact with one another independent of time and space in order to harness globally distributed knowledge resources, and leverage collective intelligence and social creativity across organisational and workgroup boundaries for improved decision making.

In this working pattern, individuals will easily utilise information from other sources (e.g. from online communities of professionals and colleagues working in disparate locations) in decision making. There is the need to ensure that a suggestion – information and knowledge – provided by a professional to support decision making in a different, and often distant, organisation and geography takes into cognizance the context of the local work setting in which it is to be used. The emergence of knowledge management as a discipline has highlighted the importance of capturing, operationalising and contextualising knowledge to support decision making, learning and to improve workflows and outcomes [4], and have been well applied in the area of clinical decision making [2, 3].

In this paper, we propose a framework for context-aware knowledge modelling in e-health, which we refer to as ContextMorph. ContextMorph combines the commonKADS knowledge modelling methodology [7] with the concept of activity landscape [8] and context-aware modelling techniques [9] in order to morph, i.e. enrich and optimise, a knowledge resource to support decision making across various contexts of work. The goal is to integrate explicit information and tacit expert experiences across various work domains into a knowledge resource adequate for supporting the operational context of the work setting in which it is to be used.

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II. Background and Related Work

Most research efforts on designing knowledge-based systems for intelligent decision support have, more or less, drawn strength from the knowledge level principle proposed by Alan Newell in his 1982 presidential address to the AAAI [11]. In the proposal, Alan attempted to answer a basic, but critical question – what it is that a system has, when it has knowledge, and how that knowledge can be represented.

Various definitions of the term "knowledge" have emerged from diverse research efforts aimed to elucidate the understanding of knowledge. A common thread among these is that knowledge includes a body of data, information and meta-information that can be applied to carry out tasks and to generate new information [7, 10] Central to this understanding of knowledge is the theory that knowledge has two major components – an explicit component, which has a representation and an tacit part, which is only derivable using some method of inference [12]. A number of knowledge creation theories the Shinayakana Systems Approach [13], the Rational Theory of Fallible Intuition [14], the SECI Model [12], and the Pentagram (I^5) System [15] have aimed to highlight the interplay between tacit and explicit knowledge that lead to knowledge creation. Most of these focus on knowledge creation in corporate decision making. Collaborative e-work, however, presents a different challenge with inherent issues of knowledge elicitation, representation and management in an open and cross-boundary work environment that must be addressed.

The CommonKADS approach [7] is one of the knowledge engineering methodologies for developing knowledge-based systems. The approach allows automatic reasoning of knowledge-intensive task with domain-specific contexts and guidelines. The concept of activity landscape, introduced in [8], enables users to construct a plan for solving a problem based on prevailing context and the resources available to them. Morphing a knowledge resource originating from a provider's context to suit the requirements of the consumer's work context applies the techniques of knowledge morphing, which is central to the work of Abidi in [2, 6].

III. Proposed Conceptual Model

Figure 1 presents an abstract model of our proposed framework. The framework incorporates an explicit model of context between the domain model of an application and the activity landscapes of various individuals, workgroups and organisations collaborating across borders, and between these landscapes and the knowledge resource space model in an intelligent ubiquitous environment. The goal of the framework is to provide a coherent structure, through the use of an explicit context model, for unifying the domain knowledge of an application, the practice-based knowledge used by an expert as a result of a length of time of experience and the Web-based information resources available for supporting work. In other words, it aims to build a ubiquitous creative environment, which will consist of a domain information set (rules and explicit knowledge resources), a tacit knowledge set (experts' ways of 'doing' captured within the activity landscapes) and contextual models for relating these two towards effective cross-organisational problem solving and decision making.

A. Knowledge Resource Space Model

Any system's application of knowledge must specify clearly how the knowledge is to be acquired. Knowledge is basically information with explanation about its value and use. The increasing proliferation of information on the Web has, for many years, led to more research efforts towards efficient techniques for organising information and enabling retrieval of relevant information. Several research avenues have been pursued in the attempt to achieve this goal, and include context-aware retrieval mechanisms, semantic networks and resource organisation models [16, 25]. One of such methods, which influences our concept of a knowledge resource space is the resource space model introduced by Hai Zhuge in his Knowledge Grid research project [25].

We define a knowledge resource space model as a semantic mechanism for conceptually linking heterogeneous information within a ubiquitous environment so as to enable effective generation of knowledge to support problem solving and decision making. The knowledge resource space model uses a mesh network structure to link and organise information resources in a 3D orthogonal knowledge space. The basis of the knowledge resource space model is to enable a systematic and knowledge-driven structure for locating resources in a ubiquitous environment. A resource space is an n-dimensional space where every point uniquely determines one resource or a set of inter-related resources, denoted as RS (X1, X2, …, Xn) or just by name RS in simple. Xi is the name of an axis. Xi = (Ci1, Ci2, …, Cin) represents an axis with its coordinates and the order between them. C denotes the coordinate name in form of a noun or a noun phrase. Any name corresponds to a formal or an informal semantic definition in the domain ontology of the resource [16]. Thus, a resource space provides an n-dimensional space for uniquely locating information resources. We identify three Web-based sources of information for generating knowledge in a knowledge resource space model, namely organisational databases, knowledge networks and online digital libraries. Thus our knowledge resource space model is represented as a 3-dimensional space, where each dimension depicts resources from each of the three sources.

Within a knowledge resource space, we describe the semantics of an information resource as follows:

- Name – this is an identifier for differentiating one information resource from another. Name can be a user-defined identifier, a keyword within the information content or the topic of the information resource
- Type – type represents the kind of information, e.g.

concept information type, task information type or reference information type

- Author – name(s) of the information creator(s)
- Location – the URL or logical address of the piece of information in a ubiquitous environment
- Affiliation – this is a number describing the source of the information resource – organisational database, knowledge network or an online digital library or a URL in the public domain as well as the names of the source database, knowledge network or URL.
- Version – a number that identifies different versions of the same piece of information. Versions are user-assigned.
- Ontological Description – this gives a brief conceptual description of an information resource. This could be a formal description, a natural language description or a template. Ontological descriptions are preferably represented in XML.
- Context of Use – this describes the history of use (if any). This includes the tasks, cases, activities, etc. where the piece of information has been used as well as sources (e.g. information resources) it has referred to, used or cited as well as sources have referred to it, used it or cited it.

The goal of the knowledge resource space model is to create a coherent knowledge-driven information set for supporting context-aware decision making in collaborative e-work. As explained in the next two sub-sections, the activity landscape provides the tacit rules and context-specific guidelines, while the domain model provides the background knowledge necessary to enable the integration of information resources from the information set into the knowledge-intensive heuristics of problem solving in collaborative e-work.

B. Activity Landscape

The next component of our abstract model is the activity landscape. The concept of activity landscape is derived from the idea of a task environment introduced by Simon and Newell [11]. We use activity landscape to capture the unique way in which an expert tackles tasks in his local work setting – applying available information to his experience in relation to contextual constraints. An activity landscape is part mental construct and part physical; it is the space users interactively construct out of the resources they find when trying to accomplish a task [8]. Kirsh [8] uses the concept of activity landscape, along with two other constructs – entry point and coordinating mechanism – to analyse the non-physical setting of an office, namely the state of digital resources, people's concepts, task state, social relations and local work culture.

Activity represents a set of related tasks. In applying activity landscape to analyse an e-work environment, we integrate activity landscape with the concept of activity theory [19, 20]. Activity theory provides a hierarchical structure for our actions and operations. At the highest level, activity acts as a meaningful and goal-directed frame for holding together actions and operations within a context [21], and for providing a coherent view of the interrelationships in a collaborative work environment. Activity theory allows for the modelling of problem solving interactions in an e-work environment from a knowledge level perspective [11]. Several work, such as [22] have attempted to integrate activity theory with other concepts (such as organisational model) for studying context of use. Our approach is to use activity theory to analyse and decompose activity into component tasks so as to depict relevant context variables. Within this process, context is morphed using the technique of ContextMorph (see section V) in order to sufficiently understand the subtle interplays between explicit knowledge and information, an expert's practice-based knowledge and domain rules during decision making within specific activity landscapes. In a collaborative e-work setting, ContextMorph is equally used to analyse the different contexts of work of various organisations in order to enable context-aware support to collaborative problem solving and decision making.

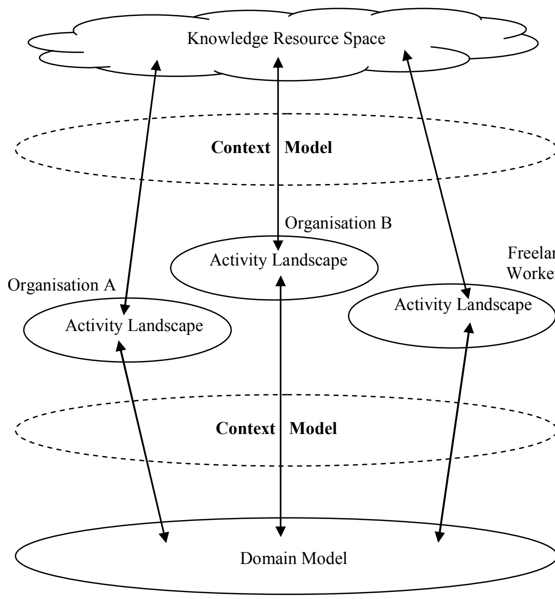

Fig. 1. Abstract model of proposed framework

C. Domain Model

We use the domain model to capture background knowledge of domain of work. Such background knowledge includes knowledge about terminologies, relationships, concepts, theories, rules and facts (e. g. medical guidelines). The domain knowledge model comprises all knowledge required, in principle, to solve a problem or to make a decision. The domain model is built statically during program design time. Owing to the failure of the general problem solver approach in AI, recent approaches in knowledge systems adopt task specific problem solving methods, which focus on the given task [18]. Recently, domain ontologies have been applied to the design of domain models in order to enable reusable model components, which provide conceptualisations of a specific domain and are shareable across different tasks [18, 23].

According to the commonKADS approach [7], the knowledge level description of a knowledge system is called the Model of Expertise [18]. This model separates different kinds of knowledge at three different layers:

• The domain layer contains knowledge about domain-specific concepts, their attributes and their relationships and it contains domain specific problem-solving patterns.

• The inference layer contains knowledge about the functional behaviour of the problem-solving process. This layer indicates which inferences are necessary and which data dependencies exist between them.

• The task layer contains knowledge about the goals of a task and the control knowledge required to perform the task. This layer specifies the sequence of the inferences within the problem-solving process for a specific context of work.

In our proposed system, both the inference and the task layers are represented in the activity landscape. The domain model contains the domain primitives, while the activity landscape contains contextual primitives. Domain primitives describe basic problem guidelines that exist in principle and may be independent of context of work, while contextual primitives describe problem solving heuristics that exist in practice and are dependent on context of work.

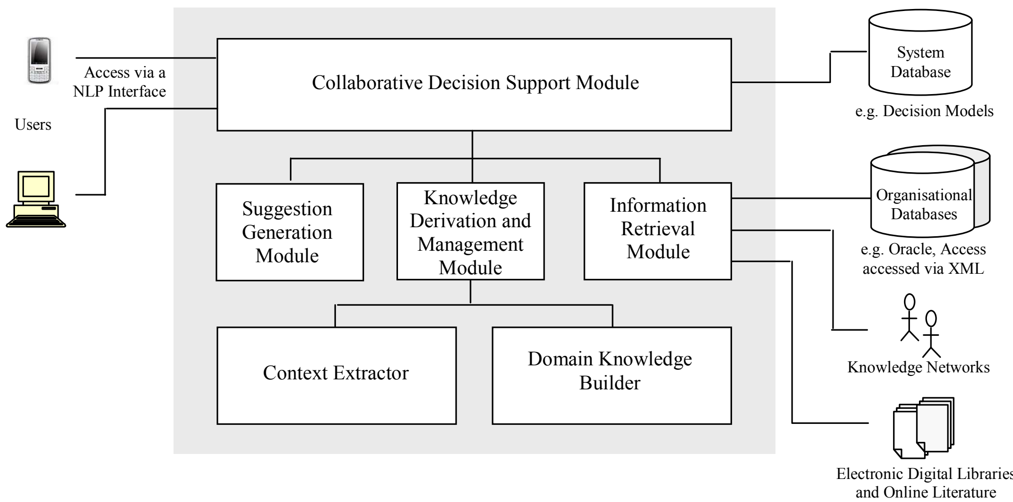

Fig. 2. System architecture

A. Context Model

From the foregoing, the domain knowledge specifies how tasks are carried out in principle, while the activity landscape models how the tasks are carried out in practice. We introduce an explicit context model to represent the relationship between the two during problem solving and decision making. The context component is used to model how experts apply their tacit knowledge and experience to available information (in the knowledge resource space model) in order to tackle problems and make decisions within their context of work.

Different types of context exist in literature; for this research, our focus is on activity context. Context enables us sufficiently understand the various ways, situations and often implied procedures that experts use to create new knowledge during problem solving and decision making, by applying their tacit practice-based knowledge to available information (explicit knowledge) and domain rules. Using the technique of ContextMorph, the context model enables us to analyse different contexts of work of various organisations in order to facilitate context-aware support to collaborative problem solving and decision making.

IV. System Architecture

The system consists of 6 components (see figure 2). The domain knowledge builder is used to generate background knowledge about a certain domain of work. Domain knowledge is statically built. The context extractor derives context information from tasks during collaborative problem solving and decision making. The collaborative decision support module facilitates collaborative decision making among disparate workers. Often, users send a query to the system, which searches for information in response. Retrieved information is augmented using the technique of Suggestion Augmentation and ContextMorph (see figure 3); this is the reactive mode. In the collaborative mode, user suggestions are equally augmented. The learning and knowledge management module is used to accumulate patterns of problem solving and decision making in order to enable proactive suggestions to future decision making tasks. All decision making models are recorded in the system database. The information retrieval module searches the knowledge resource space – organisational databases, knowledge networks and online digital literature for relevant information resources. Suggestion module assists or advises in decision making through a series of decision support functions, which include *consider (), corroborate (), contradict (), query (), make clear (), refute (), acquire ()* and *demonstrate ()*. In other words, these imply actions to consider, support, question or verify suggestions and/or information resources for supporting decision making.

IV. THE CASE FOR CONTEXTMORPH

We define ContextMorph as an intelligent mechanism for augmenting a suggestion, i.e., an idea originating from a particular context of work and consisting of information and knowledge, by automatically fusing and integrating into it more information from explicit and tacit knowledge sources and varying contexts in order to enrich it for supporting decision making in a different context of work. ContextMorph is related to the concepts of medical knowledge morphing and GoalMorph introduced in [6] and [24] respectively. The approach in medical knowledge morphing is to relate knowledge objects that may exist in different representation modalities and formalisms for the purpose of establishing a comprehensive, multi-faceted and networked view of all knowledge pertaining to a domain-specific problem [2]. The concept of GoalMorph was introduced by [24] with reference to context-aware service composition. The focus is on enabling the transformation of failed composition requests into alternatives ones that can be solved based on the system goal.

We use ContextMorph to enable the augmentation, enrichment and optimization of a suggestion – information and knowledge – provided by a professional to support decision making in a different, and often distant, work organisation and geography take into cognizance the context of the local work setting in which the suggestion is to be used. The process of suggestion augmentation using ContextMorph consists of the following key operations:

- Construct and organise a knowledge resource space (see figure 1)
- Acquire knowledge about the domain(s) of collaborative work
- Enrich suggested information or knowledge
- Identify related and relevant contexts
- Identify relevant information and knowledge resources
- Map identified information and knowledge resources to relevant contexts of work

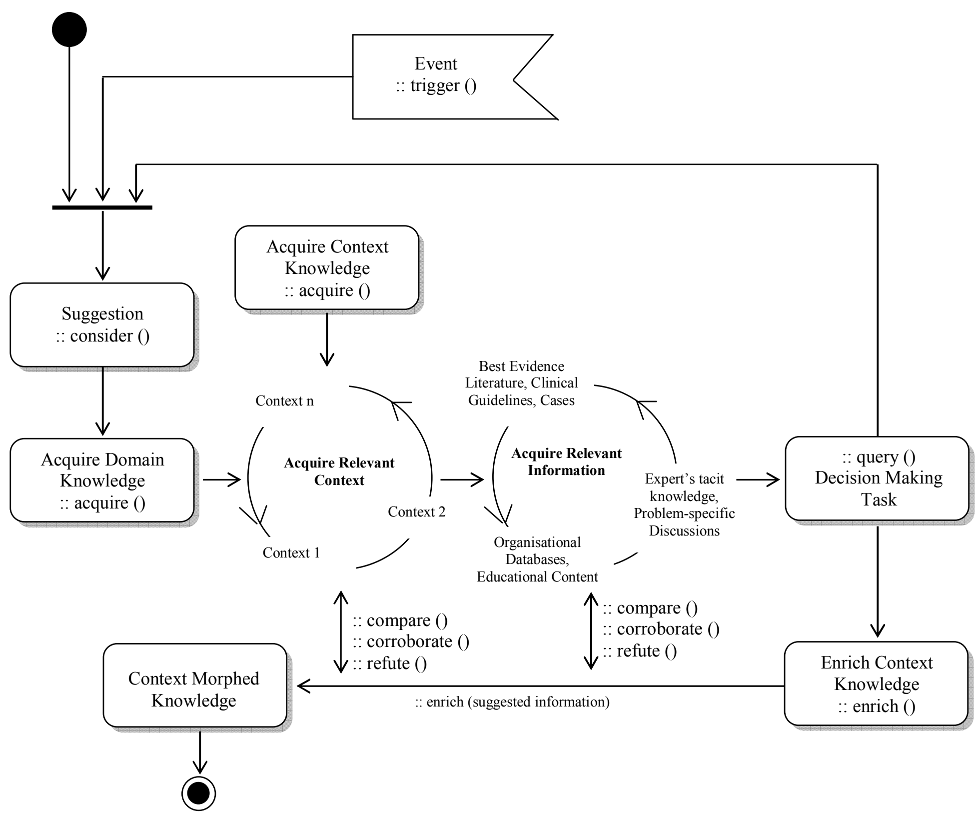

Fig. 3. An activity diagram showing conceptual overview of suggestion augmentation using ContextMorph

Figure 3 shows the conceptual overview of ContextMorph and the process of suggestion augmentation using activity diagram. A suggestion may emerge from a query entered by a user seeking solution to a certain decision making problem (reactive decision support) or could be triggered automatically by the system based on task events (proactive decision support) or explicitly made by a collaborating expert wishing to contribute to decision making. A suggestion is made using the functions *consider ()*. Our suggestion augmentation approach follows the three main stages of the CommonKADS knowledge engineering methodology [7], namely knowledge identification, knowledge specification and knowledge refinement.

1) Knowledge Identification: This stage consists of constructing and organising the knowledge resource space (see figure 1). This involves identifying potential information resources and their sources. As noted in section III, the approach is influenced by the Knowledge Grid resource space model [25], and allows for accurate location of resources within a ubiquitous intelligent environment.

2) Knowledge Specification: During this stage the construction of a specification of the domain knowledge model is carried out. This stage equally involves constructing models of the various activity landscapes (see figure 1) involved in the collaborative e-work. Lastly, information resources, such as portions from text from medical guidelines and case repositories, are modeled. A key function used during this stage is *acquire ()* – to obtain and build models of domain knowledge, work contexts and information resources used for suggestion augmentation.

3) Knowledge Refinement: During this stage, models of knowledge developed during the specification stage are validated using simulations of typical and hypothetical clinical decision making situations. This stage uses, such functions as *compare (), corroborate ()* and *refute ()* to enrich and validate suggested information and knowledge based on context of work leading to context morphed knowledge for supporting decision making in collaborative e-work (see figure 3).

V. EXAMPLE SCENARIO FOR IMPLEMENTATION

The area of breast cancer diagnosis and treatment offers a good scenario for the implementation of our proposed approach. In a certain health organisation in one of the less-technologically developed countries, e.g., Africa or Asia (denoted as Organisation A), a physician will very likely resort to radical mastectomy simply because of the non-availability of the laboratory equipment for detecting the exact location of a lump. Whereas, in countries with more advanced heath systems such as the UK (denoted as Organisation B), a physician will very likely perform simple mastectomy to remove a malignant lump. We use an activity diagram to depict these two scenarios and how a suggestion from a physician in the UK may be adapted to suit the context of work in organisation A using the ContextMorph (see figures 4 and 5).

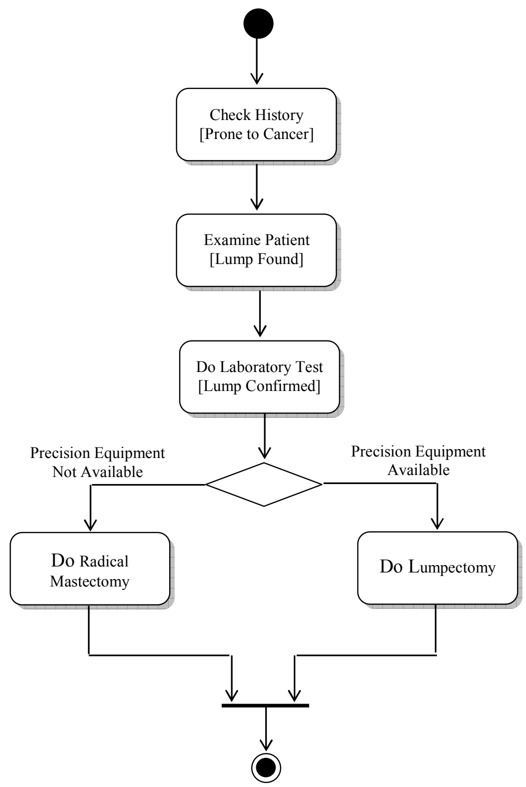

Fig. 4 Breast cancer diagnosis and treatment in two work contexts

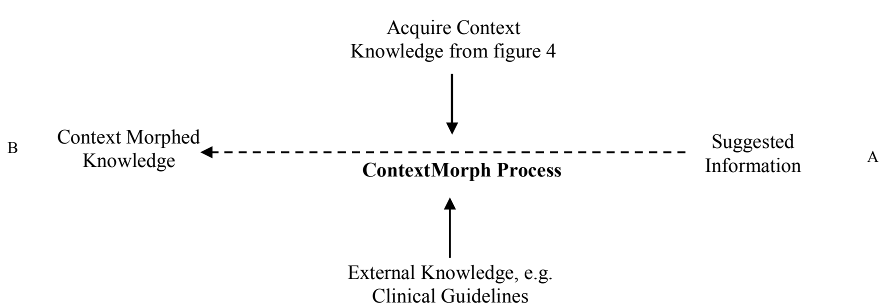

Fig. 5 ContextMorph process

VI. Concluding Remark

This paper presents ContextMorph – a framework for context-aware knowledge modelling in e-health. The research study seeks to contribute new ways of automating the process of providing context-aware knowledge-rich support to decision making in future collaborative e-work environments. This requires 1) constructing and organising an intelligent information environment, 2) enabling systems to acquire knowledge about work and 3) automating the process of context acquisition and reasoning towards effectively and efficiently augmenting human capabilities during problem solving and decision making.

In the context of e-health, professionals and healthcare service providers in various organisational and geographical locations are to work together, using information and communication systems, for the purpose of providing better patient-centred and technology-supported healthcare services at anytime and from anywhere. Ensuring that a suggestion – information and knowledge – provided by a professional to support decision making in a different, and often distant, organisation and geography takes into cognizance the context of the local work setting in which it is to be used, we argue, remains a viable means of achieving the visions of anytime anywhere cross-boundary collaborative e-work.

The research presented here includes preliminary conceptual design and the system architecture of our proposed framework as well as an overview of the application domain. Our future work will consist of detailed implementation of the proposed approach as well as field study evaluation in a real world e-health setting.

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