2009

TOWARDS A CONTEXT-ORIENTED DYNAMIC MEDICAL INFORMATION SYSTEM SUPPORTING THE DIFFERENTIAL DIAGNOSIS PROCESS

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Abstract

eHealth strategies promote the emergence of national EHR patient records so that for the first time a patient is represented as a whole. This information aggregation is the basis to which this work tries to provide access to but also include additional medical information sources or services. To prevent information overload, relevance and context are explored to leave the clinician with information he actually needs, given his particular situation. A preliminary framework comprising of a context-sensitive CBR learning-algorithm is introduced and based on that a prototype build.

1. Introduction

Global networking and changes in health care delivery are just two of many environmental forces that are changing values and practises in the health domain [3]. Health care practise involves gathering, synthesising, and acting on information and therefore poses a great challenge to ongoing research and development for general frameworks and standards. Structured data and processable information are technically possible but still a rarity, especially when it comes to shared usage of interlinked information sources. Thinking about e.g., patient data with medications and known allergies, and drug-drug interactions, a lack of interlinking can result in insufficient data about a patient, which in turn, makes repeated data gathering necessary in the best case, or prescription of an allergic drug in the worst.

As a response, new information systems are emerging which promise to satisfy the demands imposed by those changes, i.e. the availability of patient specific data way across the place they once were created. Initiatives like Infoway, Canada, NHS CRS, United Kingdom, or ELGA in Austria are each part of this new infrastructure, connecting patient information from regional hospitals on a national level.

From an information systems point of view, the "changing face" can best be explained through to the connecting of formerly unconnected dots becoming visible in the information space, as more and more information is available, then build into services which then provide additional value. The benefit is a more complete picture of the patient, thus representing him as a whole, ideally with all medical reports that are available. But still, this should not be the limit, as a doctor may also need

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additional information like pollen counts or drug-drug interactions. This should also be accessible through his interface within the process patient treatment.

The ability to gather information from multiple sources and merging them to create something new is also known as the concept of information synthesis [21]. Together with contextual retrieval they state two grad challenges in health informatics, and as Shepherd has put it, are not isolated from each other. But this also includes a drawback. The negative aspect also referred to as the phenomenon of information overload introduces a low signal to noise ratio to the process, as not everything is useful in the situation the patient and the doctor are currently undergoing. Furthermore, every medical user is given more or less the same view from his hospital information system (HIS), regardless his personal preferences or needs, thus fragmenting information with catastrophic impact on the respective workflow. Locating the needed medical report can be similar to the situation of finding the needle in a haystack, as the presented overview conditions relevant information to be hidden within.

Providing a mechanism for pre-selecting (i.e. filtering) of information preventing information flood would leave the doctor with what he is actually looking for and thus, more time spent on patient treatment and not on sorting information. This leads to the assumption that the context in which the process takes place is of great importance to the actual information which should be retrieved, actually deciding on which information should be retrieved at all.

Generally, specialised systems that might assist in routine medical care remain scarce. Reasons range from low user acceptance [7], lack of workflow integration and inflexibility, lack in the consideration of the medical context [10] and the mapping of decision-making process to computational approaches [22], to incompatibility with legacy applications [7]. Generally speaking, most systems introduce more effort then they are worth, implying that a social perspective [17] has not been fully recognised.
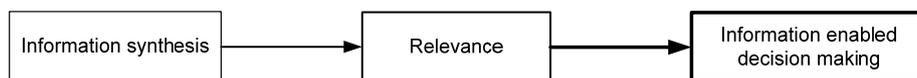
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┌──────────────────────┐       ┌──────────────┐       ┌──────────────────────┐
│ Information synthesis │ ────▶ │  Relevance   │ ────▶ │  Information enabled  │
│                      │       │              │       │   decision making    │
└──────────────────────┘       └──────────────┘       └──────────────────────┘
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Figure 1. Approach to informed decision making

Information portals might offer a solution, as they aggregate information in a user perspective manner. This work as seen in Figure 1 will try to approach and evaluate the concept of medical relevance and explore how information synthesis can be utilized in order to facilitate information enabled decision making. The vision now becomes clearer, constructing future eHealth systems to establish better control and/or access to available resources, or in other words, offer the right information at the right time to the right place.

2. Related Work

Information overload has long been a problem for users utilizing the internet for information aggregation. If useful information was found it normally was contained in many different sites. To stay informed, all these sites had to be constantly monitored. Early information portals tried to solve this problem by providing more and more information of all kinds of branches, but never succeeded in obtaining a reasonable cost-effective strategy. It was only after the 2001 dot.net crash when information portals were reborn and now pose a promising concept for information aggregation and visualisation. It could be seen [26] that information, which was stored at different sources, now was consolidated and made accessible though a single access point. Further on, sites

such as netvibes are now fully adjustable to the needs and perceptions of its users. As a consequence, big search portals like google or yahoo are now also partly configurable and a user can select from a vast abundance of services which are then bundled into his personal website, creating a *mashup* of different information of different sources.

But still, simple provision of information is not enough. Bates et al. [1] emphasise that clinicians might miss important information due to the sheer volume of information, calling for systems which can make associations between information elements. In addition, there is broad consensus that any new system must fit within the users workflow [20], [1], [7], [16], [17]. Kaplan [10] states that in order to become involved and feel as active participants, users must have the ability to modify their system. By following this principle, personalisation is seen as key to aid to the concept of workflow integration, as it provides means necessary to shape the interface along the needs.
Thus, workflow integration also requires an adaptive system which can utilise knowledge about the users' task to calculate the probability of steps following the current one. This directly correlates to Bates et al. [1] and Wetter's [27] statement about 'to anticipate needs', which adds ease-of-use and real benefit by reducing necessary interaction time [20], [16]. As Perreault and Metzger [18] put it, it is necessary to enhance systems usefulness by integrating and presenting information in different ways depending on the medical context. For his routine work a clinician knows what information about a patient he needs to perform an adequate diagnosis [17]. In order to make that diagnosis, he does not need all information but rather the information for that certain situation, which appear relevant in his context.

When reviewing literature, the notion of relevance is always accompanied by the concept of context. Following Wetter's statement above, Shepherd [21] concludes that needs always occur 'in a given situation'. Dey et al. [5] also call for paying more attention to the context, which in turn will completely redefine the basic notions of interface and interaction [22]. Although most literature about context is concerned about ambient intelligence, mobile or ubiquitous computing, their concepts can still be applied to non location based applications. Several works tried to define context [5], [19], [13], [9] by listing entities of the environment the human and the human-computer interaction is taking place. This often includes the cognitive state of the user as well. All agree that context can be seen as implicit input to a system [5], [19], [13], [2], [9], in a way of command switches altering the outcome [2], ideally automatically inferred, because the user's objective is difficult to determine directly [9] and therefore context cues can be used to help infer this information and to inform an application on how to best support the user. If information from a system is considered to be relevant, the system must be aware of the context [5].

Information retrieval considers relevance as a basic notion. When following Saracevic [24] it is understood as a relation, having a number of properties and criteria (e.g., strength) but with many manifestations. Also Hartner [8] and Maglaughlin [11] state that it exhibits a certain duality, two braches in which it can de divided: topicality (system) or objective, meaning it can be obtained by experts in that discipline and situation (human) or subjective, and therefore personal, meaning it must be assessed by the user himself. Harter [8] further interpreted the theory of psychological relevance presented by Sperber and Wilson [23] as an occurrence when retrieved information suggests new connections, increases or decreases the strength in a belief, thereby changing the cognitive state of the requester. Thus, it can be seen as the actual output an information system must produce in order to be beneficial.

Information needs are central to the rendering of relevance judgements, and therefore are central to the conduct of information searches [8]. Consequently, this all leads to a form of basic decision support offering easy access to general and patient-specific clinical information with adjustable and

adaptive behaviour aimed at delivering the right information at the right time [20], [4], i.e. in the correct context [9], and is thereby regarded crucial for carrying out informed clinical decision making [10].

3. Analysis and Scope

In order to build a concept around medical relevance, relevance has to be brought in relation with the process of diagnosis and prerequisites have to be found:

Common ground A requirement for relevance is common ground [6], which stands for any shared concepts, vocabulary or even ontology. In the medical area, some standards have evolved, like Mesh, Snomed, LOINC, UMLS, and ICD-10. Its benefit is the decisiveness, the definite relation and identification of clinical studies (medical reports or tests) for proper semantic identification.

Medical context Relevance is also comprised [19] of the actual context which is defined by a combination of the environment within the clinical situation or setting (e.g., outpatient encounter in a particular medical unit like general internal medicine) and the type of disease the patient indicates, as well as the user who is interacting with the system [25]. In order to provide relevant information, the context within the user interacts with the system has to be known a priori.

Informativeness For medical documents, relevance always adds to the findings a doctor seeks. If a document does not indicate a particular disease and is perceived informative, it is still relevant, as he can exclude the diagnosis leading to this disease.

Prediction Further on, a relation between medical reports and their diagnosis has to exist, in that for any suspected diagnosis there are required tests to prove if the hypothesis is verified. This can be achieved either by incorporating knowledge into the system or deriving it from user interaction and building pathways from diagnosis to studies by putting learning-algorithms (case-based, CBR) in place. Either solution alone is insufficient, as rules don't allow adaptation, and without them, no new medical studies are taken into consideration, as nobody might know about them.

The importance of context becomes clearer, when e.g., considering patient characteristics from the electronical health record (EHR), some diagnoses and therefore medical studies are less likely to occur given certain circumstances (e.g., breast-cancer for men). Context is key to medical relevance and requires careful consideration. Table 1 shows factors (context elements [14]) influencing context.

Table 1. Factors influencing medical context

Patient (demographics, history, constitution, allergies, medication etc)
Actual health problem, affected body areas, possible disease
Clinical user
Medical unit (internal, orthopaedics etc)
Environmental variables (current season, climate etc)

It has been argued by Kaplan [10] and Peleg [17], that providing advice concerning the decision process outcome can have negative impact, as clinicians might fear dependency [7] toward the system, or even feel that their sense of autonomy [20], [10] is omitted, rendering them useless. Of course, no system could or should actually replace a clinician, but most certainly it is important to respect social roles [17] and not alter their perception of being in control. As a matter of fact, to

judge a person's health by examining his signs and symptoms is probably the most important capability a doctor must develop, and by providing him with relevant information to judge upon empowers him to perform informed clinical decision making. Information synthesis therefore leaves the user to interpret the information correctly.

Combined findings from the previous chapters, literature, and interviews conducted with clinical personal rendered several factors important, as can be seen in Table 2. This is complemented by a study on implications for visualisation of different types of hospital medical data [15].

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Table 2. Requirements for information enabled decision making

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Factors	Implications
Present relevant information first	Provide view for timely patient data
Provide access to all available information on request	Provide current patient overview of medical information (audio, video, text, images)
Reduce time to find information needed	Provide tabular view of measured values e.g.,
Be adjustable and adaptive	enzyme values from blood tests

Compared with the nearby concept of clinical decision support systems (CDSS), information enabled decision making would classify at Bates scale of 'degrees of computerisation' [1] as level 3 by providing relevant patient information as recommendation but without intention to influence the users' cognitive thinking process.

4. Framework

To incorporate the key factors from the previous chapter and further develop necessary concepts for medical assistant applications, the DMIS (dynamic medical information system) project was launched. This initial stage of the project is being undertaken at the University of Innsbruck to investigate possibilities for medical unit-related information portals. The primary goal of DMIS is to provide a better cockpit for clinicians [1], assisting clinicians by offering relevant information/appropriate services [13] at first sight though an adjustable and adaptive graphical user interface, thereby reducing information overload (see Figure 2).
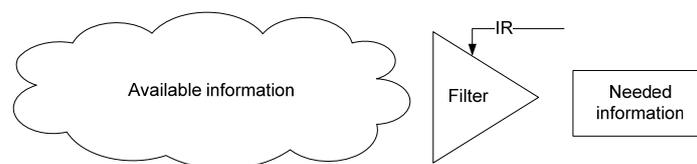

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Figure 2. Relevance as filter-mechanism

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The intention of DMIS is to act as a composition on top of already existing HIS with EHR capabilities and is thus not meant to replace them. The scenario has been set to the following: the environment considered is the outpatient setting, it is assumed that clinical data are already semantically annotated (LOINC-codes for examinations, ICD-10-codes for diagnoses) and security as an issue is recognised, however methods and techniques are not yet dealt with and proper authentication is presupposed.

Figure 3 shows how DMIS is intended to operate. It requires the clinician to make 3 to 5 suspected diagnoses using hypothetico-deductive reasoning [15] and enter them in to the system. From these

possible diagnoses entered, DMIS starts to show relevant clinical examinations already available in the EHR or suggests ordering them, as relevance not only requires display of what is available, but also what is necessary. Studies indicated that for similar diagnoses also similar tests are ordered, which leads to a converging number of possible tests, even if more suspected diagnoses are entered.
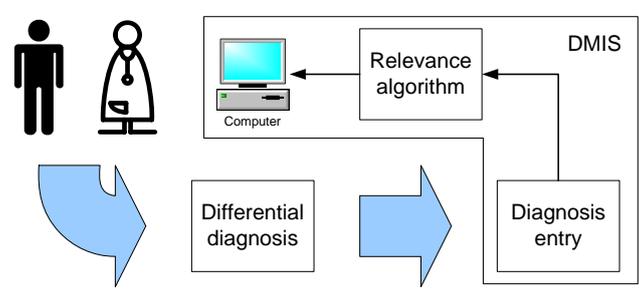

Figure 3. Diagnosis process with DMIS

Figure 4 shows the approach which was taken so far. When the patient first comes to the doctor the so-called clinical situation or clinical encounter begins and a new session is started. This is the origin to which every resulting action/information (ordering examinations, treatment, medication etc) will relate. To be able to distinct between situations [2], a context-triple (patient, doctor, medical unit) is introduced and together with the differential diagnoses (hypotheses) from table 1 is used to describe the situation [19].
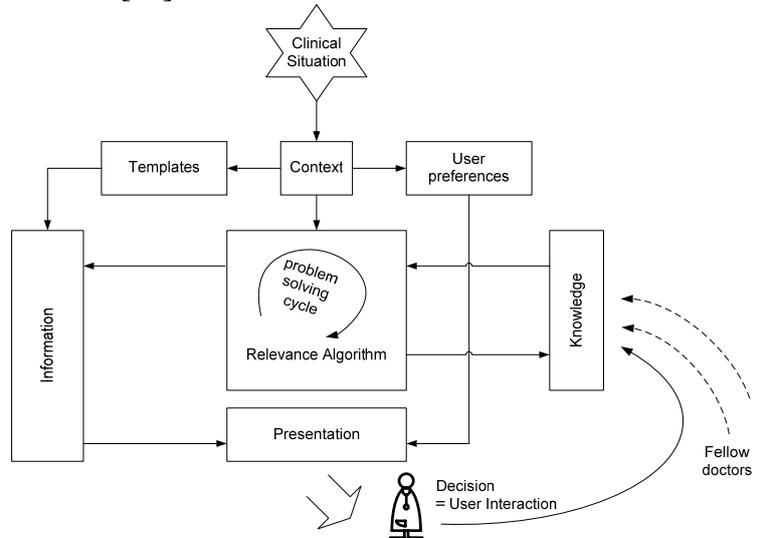

Figure 4. Framework of DMIS

Relevance uses this context to compute a list of recommendations for examinations which are indicated in the current situation. As seen in Figure 4, those recommendations can be computed either on the basis of the current doctor, but also on other doctors experiences as well. As to start with, only certain simple and pre-defined features of the context-triple (e.g., patient age, gender) can be used for description. These features are hereby seen as meta-data, which are required to get to the actual needed information (see Figure 5). As Montani [12] put it, it is hard to distinguish where context starts and ends. Still, if those exact features which are relevant for a case can be derived, it will provide the relevance-algorithm with the intelligence to distinct between equal situations requiring different examinations (e.g., due to patient age), and thereby producing more appropoirate results. Figure 5 shows how these context-features can be seen as binary switches to select between possible solutions.

As mentioned above, manual context entry is required [5] to inform the system which diagnoses the doctor is currently considering. Relevance is then inferred by putting a CBR-learning algorithm in place for recording user interaction to capture tacit knowledge used in selecting information (e.g., examinations) for particular diagnoses and by that be able to learn from previous choices [2] to show medical reports with a high probability of being ordered in that particular context in the past.

So far, three different case-base types within the diagnosis process have been identified, from where relevance to a new given situation can be derived. These are:

- Templates (Initially stated or derived and approved by domain expert)
- Inference (Pathways from current user or other users pathways during a session)
- Diagnoses (Decisions made from annotated previous cases)

Templates represent reliable knowledge, kind of prototypes, defined by an expert on which medical reports and/or information is relevant for a given diagnosis. Inference refers to the user interaction occurring during the diagnosis process, where some reports or information are requested but the actual reason is still not directly clear. Diagnoses represent the end product of the process and therefore the final decisions made by the clinical user.
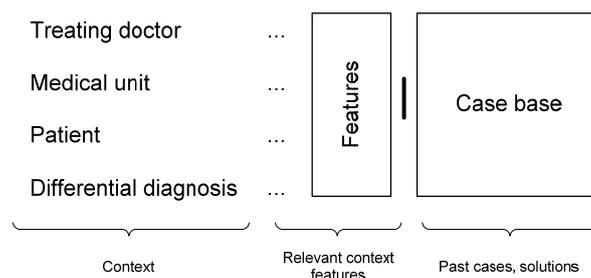

Figure 5. Context features and CBR-cases

5. Prototype

In order to realise the proposed framework and to further develop ideas, a prototype was build to incorporate those ideas. A web-based front-end was chosen which utilizes Web 2.0 technologies (AJAX) to provide both flexibility, extensibility, and facilitate ease-of-use. Figure 6 shows the user interface implemented so far.

Diagnoses are entered at the left together with the reason the patient is seeking treatment (initial problem). The structure above represents the patients EHR. By pushing the <Befunde Anfordern> button, a new window appears presenting which type of information is considered relevant in this case, and if it is already present within the EHR. Additional information can be requested as well.
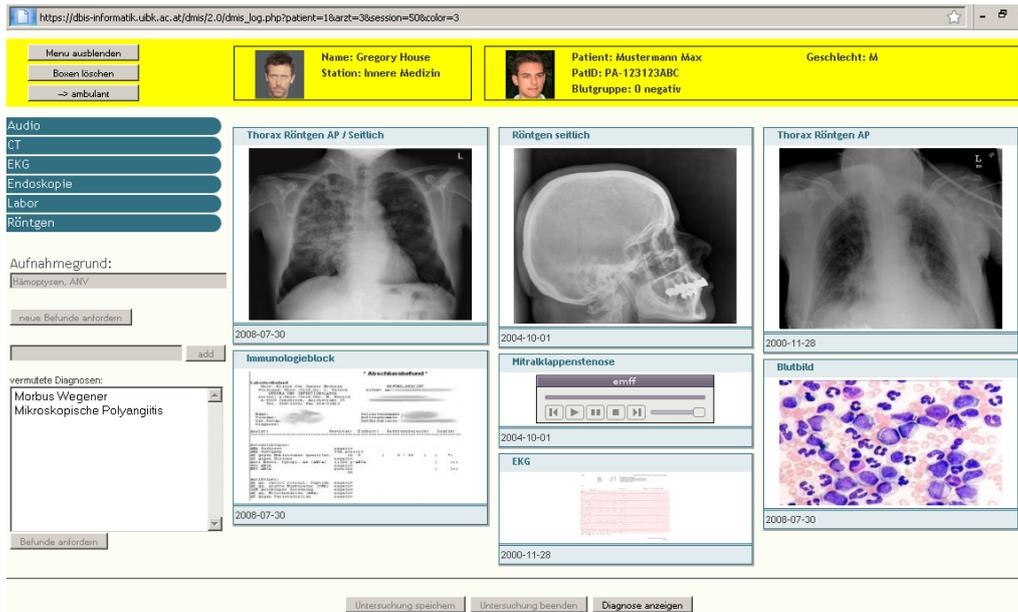
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Figure 6. Screenshot of the DMIS prototype

Currently the prototype is able to visualise various clinical data (audio, video, images, pdf, text). Each examination process produces medical data combined with semantic medical information, e.g., a CT image of the patients head. Such an item is hereby referred as a clinical element. These items can be adapted (arranged) with drag-and-drop functionality according to the users preferences, e.g., the CT image always at the right top. Clinical elements are grouped into classes, each class having its own methods and properties. Every displayed element therefore belongs to exactly one class. An instance as a representation of such a class is realised through widgets. They act as sort of mini-applications providing basic functionality like e.g., printing, but can encompass also more high-level functions like navigation if needed. To provide also access to not only the EHR but to external sources, RSS-Feeds, Web-Services, and other XML-based services are also possible classes for clinical elements.

6. Summary

This paper describes on-going work towards a framework for providing medical patient information needed for a clinician involved in the diagnosis process. To this end, the process of medical diagnosis was analysed, a basic framework was introduced, containing a context-triple driven retrieval mechanism. Based on that a prototype was build to actually create a relation between diagnoses and medical information (e.g., reports) used in particular contexts, and therefore relevant, described by their respective codes (ICD-10 for diagnoses, LOINC for medical reports, and a not yet defined ID for additional information sources) which is sensitive to the context of the actual clinical situation taking place.

So far, only the patient-at-a-glance mode is implemented and further development of the clinical element classes to represent timely-view for selected clinical data, and a tabular view of laboratory values is necessary. The navigational structure within the EHR also needs further reconsideration. Most importantly, evaluations on how the relevance algorithm is best equipped with have to be conducted. The notions of relevance and context have to be defined more clearly. More certainty has to be reached to narrow down the concept of context according to the context-triple, e.g., what information about a patient can or should be included in the context as well as how this context

affects GUI elements will have be of future consideration. How and in what manner the user interaction stream can be bundled to gain knowledge has to be carefully studied. Also, elements to definitely exclude from reasoning therefore reducing output possibilities could improve filtering. In general, field studies at clinics have to be conducted to reveal the user side of relevance and type of information or services required.

7. Literature

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