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ORIGINAL PAPER

MEDWISE: An Innovative Public Health Information System Infrastructure

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Abstract In this paper, we present MedWise, a high level design of a medical information infrastructure, and its architecture. The proposed system offers a comprehensive, modular, robust and extensible infrastructure to be used in public health care systems. The system gathers reliable and evidence based health data, which it then classifies, interprets and stores into a particular database. It creates a healthcare ecosystem that aids the medical community by providing for less error prone diagnoses and treatment of diseases. This system will be standards-compliant; therefore it would be complementary to the existing healthcare and clinical information systems. The key objective of the proposed system is to provide as much medical historical and miscellaneous data as possible about the patients with minimal consultation, thus allowing physicians to easily access Patients' Ancillary Data (PAD) such as hereditary, residential, travel, custom, meteorological, biographical and demographical data before the consultation. In addition, the system can help to diminish problems and misdiagnosis situations caused by language barriers-disorders and misinformation. MedWise can assist physicians to shorten time for diagnosis and consultations, therefore dramatically improving quality and quantity of the physical examinations of patients. Furthermore, since it intends to supply a significant amount of data, it may be used to improve skills of students in medical education.

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Introduction

Generally speaking, the term eHealth refers to solutions that make use of Information & Communication Technologies (ICT) that improves the quality of our health. Many countries consider ICT a crucial enabler in "delivering better and more efficient healthcare services by helping you, your doctor(s), your pharmacist and your hospital take better care of your health" [1]. There is no doubt that ICT is considered to be a very significant catalyst for the health-care system in all countries, and it is widely believed that an efficient, seamless and interoperable healthcare system can be developed only by means of ICT.

The quality of a diagnosis depends on the quality and quantity of patient data. A large data set of patient medical records enables the discovery of patterns in diseases and provides for the development of tools that can help doctors in the diagnosis and treatment of diseases. The data helps medical professionals to choose the best treatment option among many alternatives for a particular disease, to pinpoint deadly drug interactions and to establish links between the patient's disease and certain geographic locations or hereditary information.

A Patient's Ancillary Data (PAD), including hereditary, residential, travel, custom, meteorological, biographical and demographical information should be considered an indispensible part of diagnosis and treatment of the patient. The impact of PAD on clinical decisions has been inadequately explored and is rarely incorporated into health care information systems. This is unfortunate; as the quality of the decisions improves as the diversity of the patient data items increases. Wyatt and Spiegelhalter have stated that a Clinical Decision Support System is an “Active Knowledge System which uses two or more items of patient data to generate case-specific advice” [2].

In this paper we present a comprehensive, robust extensible architecture which collects, classifies, and interprets medical and non-medical data with a goal of aiding the medical community by providing less error-prone diagnoses and treatment of diseases. This architecture will be standards-compliant, and would therefore be complementary to the existing systems.

Literature review and motivation

For many years, European countries have been expending great effort towards making progress on a common eHealth platform [3–5]. In spite of increased efforts to develop a seamless healthcare system, only a small number of countries have been able to achieve the construction of Patient Summaries Database, which was only a part of the original goal.

Despite having the communication infrastructure, eHealth solutions in EU countries are either still at the planning stage, or not working efficiently and effectively due to a number of difficulties, such as political and economical problems. Some difficulties of integrating patient records into eHealth systems stem from interoperability, governmental policies, and privacy and security issues; however, wide-ranging as these problems are, they are not intractable. Nevertheless, even if these issues are overcome, an effective eHealth solution cannot be built without incorporating PAD, since most causes of misdiagnosis and long diagnosis duration are attributed to incomplete PAD or incorrect information provided by patients themselves. These can occur because of difficulties in the consultation process, such as language barriers or language disorders.

It is not uncommon to hear or read about medical misdiagnosis cases. According to a study by [6–8], diagnostic errors in medicine are classified in three broad categories. 1) No-fault errors (e.g. masked or unusual presentation of disease, uncooperative, deceptive patients) 2) System related errors (e.g. Technical failures and equipment problems, organizational flaws) 3) Cognitive errors (e.g. faulty knowledge, faulty data gathering, fault synthesis). Any Health Information System must simultaneously attack the misdiagnosis problem from all three fronts.

Hereditary factors play a role in many diseases, for example, a family history of diabetes, gout, high blood pressure or high blood cholesterol increases the risk of heart disease. It is an established fact that fat accumulation in the arteries can be linked to hereditary factors. In one misdiagnosis case, “Ismail” (an alias given to protect the anonymity of a patient) arrived at a hospital with chest pains, was given a form to fill and also asked by the physician about his symptoms. The answers convinced the doctor that the condition was non-heart related. However, Ismail had failed to provide crucial detailed information about the history of heart problems in his family neglecting to mention that his father suffered two heart attacks, the second of which was fatal. Ismail later went to another doctor with the same symptoms, this time he mentioned his father’s situation, and the doctor then immediately gave him an effort test and diagnosed a severe heart problem.

Although it is difficult to miss severe symptoms of heart attacks, other symptoms are identical to ones seen in other diseases [9, 10]. Symptoms can also vary from patient to patient. Thus a full and complete medical history is extremely important for a correct diagnosis.

Another disease that is known to have links to heredity is Hemochromatosis [11]. It has no early symptoms; however, it is often left undiagnosed until other symptoms appear due to serious organ damage. It is therefore important to have information about major medical conditions and causes of death of the immediate relatives, including the age the disease started and the date of death. Knowing the medical history of first and second degree relatives improves the chances of a faster and more accurate diagnosis.

Several diseases originate or appear in greater proportions in certain locations in the world. A past visit by the patient to such a location is a strong indication of the likely cause of a disease. Knowing the past residential locations is very valuable in diagnosing diseases and determining subtypes (i.e. determining the subtype of influenza: swine or avian).

When a patient visits multiple doctors or health institutions at multiple locations, it is seldom the case that the patient data is consolidated. The disadvantage of this is that there are times when two different illnesses may point to a much more severe (underlying) third illness as shown in the following case, taken from a forum on medical misdiagnoses.

> “*My boyfriend’s mother just died suddenly from an enlarged heart. The medical condition was never detected on her medical record but she had previously visited the hospital for unrelated conditions.*” [12].

It may be the case that information from previous visits to doctors was unavailable to subsequent doctors. Evidently, none of the doctors involved had the complete and full medical history of the patient.

Environmental data such as climate and geographic data can also significantly contribute to a more accurate and faster diagnosis of diseases. People who live in industrial areas have a higher risk of exposure to chemical compounds which can lead to cancer, lung and other diseases. Certain types of skin cancers tend to occur more often in locations which receive longer periods of sunlight all year long [13]. Crimean-Congo Hemorrhagic Fever Disease (CCHFD), a tick-borne disease caused by a virus, occurs more often in certain locations. The Congo hemorrhagic fever virus is localized to certain parts of Asia, Europe and Africa. Even within a particular country, some areas see higher proportions of CCHFD than others. It is evident that the past or present location of a patient provides important evidence, enabling successful diagnosis of the disease caused by Congo hemorrhagic fever virus.

In all cases described above, getting medical data from various and diverse resources improves the chances of a full and accurate diagnosis. Better diagnosis can result from augmenting test data from various sources: for heart diseases and Hemochromatosis, hereditary data from census bureau, for flu, tuberculosis or venereal diseases, travel data from the customs and border office. This ancillary data also enables the medical practitioner to better utilize the time spent with the patient. Having already accumulated a substantial amount of medical and non-medical data, the doctor can concentrate on other fact-finding activities such as inquiring about a patient's psychological condition. Table 1 illustrates some medical conditions and their possible causes, and a data source providing data to help diagnose the condition

Objectives

Our objective is to propose a flexible, robust, comprehensive and standards compliant Medical Information System's infrastructure that will facilitate collection of data from diverse sources, sharing of data with other health information systems and turning raw data into knowledge which can be used by a medical inference engine to aid physicians in their diagnosis and treatment of the diseases.

In order to construct a well-designed healthcare system, as much information as possible about an individual should be stored and this data should be readily available in case of a request. Figure 1 shows several types of data source that may contribute to the successful monitoring of an individuals' lifelong healthcare. Many of the healthcare systems implementations cover information coming from group A, however any weaknesses of data originating from group B and C decreases the system accuracy and occasionally this situation leads to serious errors, which may be even fatal.

The collected medical data must be kept secure and private. In particular the proposed infrastructure will be very sensitive to privacy issues. When it comes to medical data, information security exceeds simple cryptography. Existing technologies provide adequate means to enforce a suitable level of security and privacy. However, major difficulties arise when the source of the medical data involves a range of organizations and institutions with differing privacy and policy rules. A role-based access control mechanism, similar to those present in operating systems will be put in place within each individual organization which owns the data. Thus, the medical records of a patient with a mental disorder would only be accessed by a physician only when the physician assumes the role of a psychologist. This entails the need for patients' explicit permission for the examination of data when it falls outside the physician's domain of expertise.

The infrastructure that we are proposing can easily be customized to different sub areas within the health domain. Pharmacists and nursing professionals also make critical decisions similar to physicians, and thus are also the target users of the system. Such decision making processes are not unique to medical practice, however, and when the scope is widened, this infrastructure can be adapted to any domain which involves decision-making based on large quantities of data. One interesting application area would be the judicial system.

In brief, our objective is to develop a comprehensive health information system that would be seamlessly integrated with other health information systems and government organizations working in harmony. In many countries which have adapted digital record management in government, it can be challenging for different institutions to share their information due to incompatibilities and policy differences. Each governmental organization uses different methods, mechanisms to store, process and share data. In the case of the US, the states may have additional health regulations besides federal regulations. Therefore, while the federal government has set a national floor for

Table 1 Several medical conditions, their possible causes and their data sources [13]

Condition	A possible cause	Data source
Heart attack, Hemochromatosis	Hereditary	Census Bureau
Cancer, lung diseases, CCHFD	Environmental factors	Geographical information systems
Flu, tuberculosis, STD	Travel to high risk destinations	Border control and customs
Skin cancer	Tropical climate	Bureau of meteorology

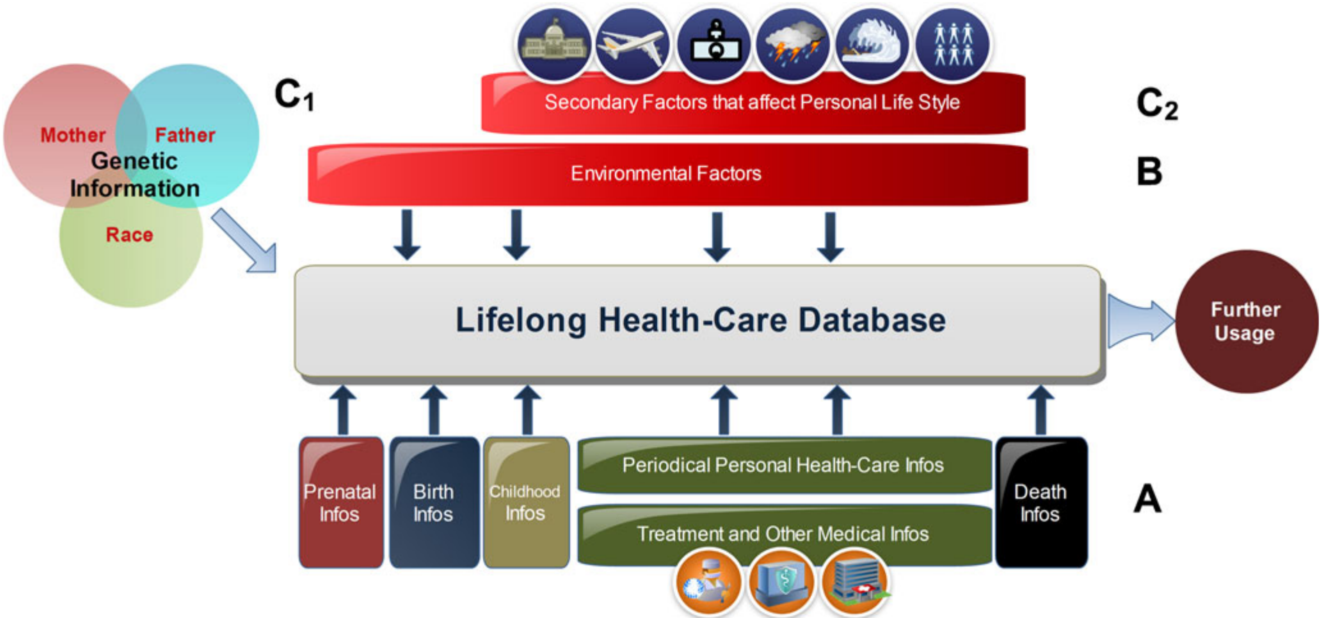


Fig. 1 Lifelong healthcare data of an individual

coordinating the protection and sharing of health information, individual states may create their own initiatives for information exchanges, mandates and privacy rules [14].

Turkey's adaptation of digital technologies was slightly delayed when compared to other developed countries. Ironically, this turned out to be a considerable benefit in the sense that from the very beginning, it enabled the nationwide e-government project to be designed and architected with inter-organization cooperation and collaboration in mind. In other words, Turkey is in a position to benefit from and build on the experience of others [15, 16].

MedWise system

MedWise receives the data and knowledge from providers and converts data into knowledge represented in an appropriate form, and generates meaningful information and advising schema for use by stakeholders (patients, users, administrative, government entities). Since the proposed system presented in this paper (MedWise) is research in progress, it is considered appropriate to explain only the system level (high level) details and contextual descriptions of the system. In the following sections we shall describe MedWise's architecture, its interfaces and features.

MedWise system architecture

Figure 2 illustrates the MedWise system's architecture. The system consists of three main layers: "Providers", "Security and Refinement Ring" and "Three Dimensional Inference Engine". The "Providers" layer is assigned the task of gathering information from data providers (i.e. governments, hospitals, doctors, pharmacies) which supply data and knowledge to the system either continuously or upon a request coming from the Inference Engine. The "Security and Refinement Ring (SRR)" is responsible for providing filtered and reliable data to the inference engine. The last and the innermost layer, the Three Dimensional Inference Engine (3DIE) is based on a hybrid design which employs mechanisms and techniques from Expert Systems and Data-Mining, and provides information or advice to the stakeholders.

Information and data providers layer

This layer is the interface layer of the MedWise, enabling communication with data providers and stakeholders. In this layer, data providers supply the knowledge and raw data necessary for the inference engine to deliver meaningful information to and advise the stakeholders (physicians, nurses etc). Table 2 gives detail of the providers and the data they supply.

Since the primary goal of MedWise is to provide accurate and adequate information about patients, it has to communicate extensively with the environment. Most of the data and knowledge providers have already integrated with e-government solutions such as e-custom. This integration means the providers to be well structured and easily adaptable to other e-systems.

Communication with government organizations enables MedWise to acquire many required and useful patient data items such as family or race, travel to other countries or

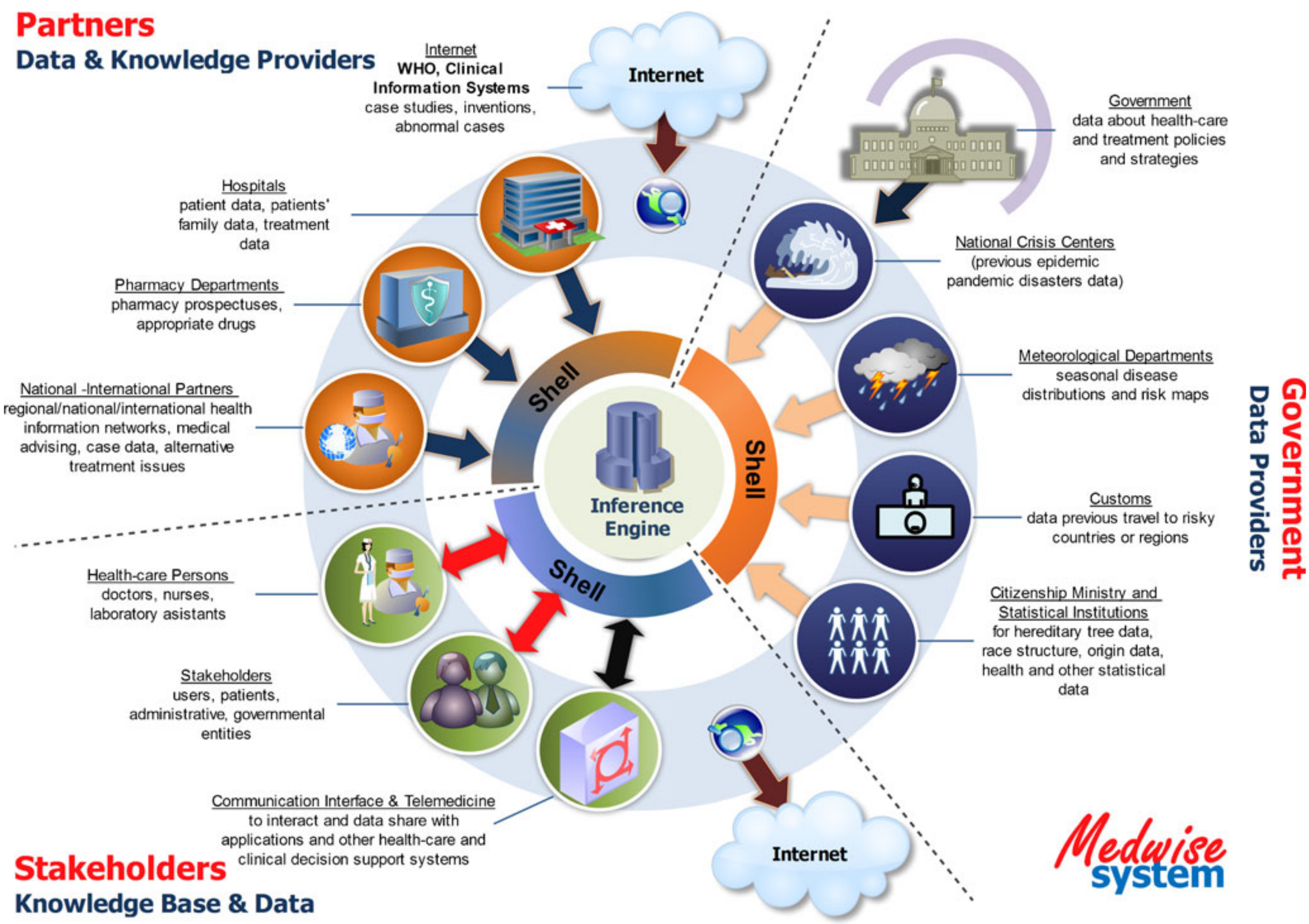


Fig. 2 MedWise system architecture

Table 2 Data providers, descriptions and formats for MedWise

Provider	Data description
Government side (data) data providers	
National crisis center	Data on previous crisis or disasters, survivors, effected regions by years
Meteorological Depts.	Historical and current weather data
Customs	Data on patients' travel data
Citizenship ministry	Hereditary clues for discovering genetic diseases or anomalies
Partners (data and knowledge based) data providers	
Internet-WHO	Data supplied by WHO (Critical info, etc), data on countries who have specific sanitary cordon or quarantine conditions, etc
Hospitals	Patients historical data
Pharmacy Departments	Pharmaceutical data
National/International Partners	Interaction with regional/national/international health information networks
System stakeholders (knowledge based) data consumers	
Healthcare personals	Detailed data on patients (medical history and diagnostic data)
System users	Medical advice to stakeholders through the Internet
Communication interface & telemedicine	Telemedicine applications, data conversion tools, data providing for different applications and other clinical decision support systems
Internet for casual users	General information about the system, formal and legal forms, etc

regions, previously recorded accidents, residential information and weather parameters (average humidity, temperature, air pressure). In addition, the providers of MedWise supply the system with a number of additional patient data, such as new research and innovations in the field of bio-medical and medicine, pharmaceutical data required for treatment advice and alternative treatment strategies.

The data presented in Table 2 undergoes a rigorous filtering by the SRR-Shell, and the data is then converted to knowledge, and stored into a warehouse in 3DIE (3D Inference Engine).

SRR-shell: Security and refinement ring

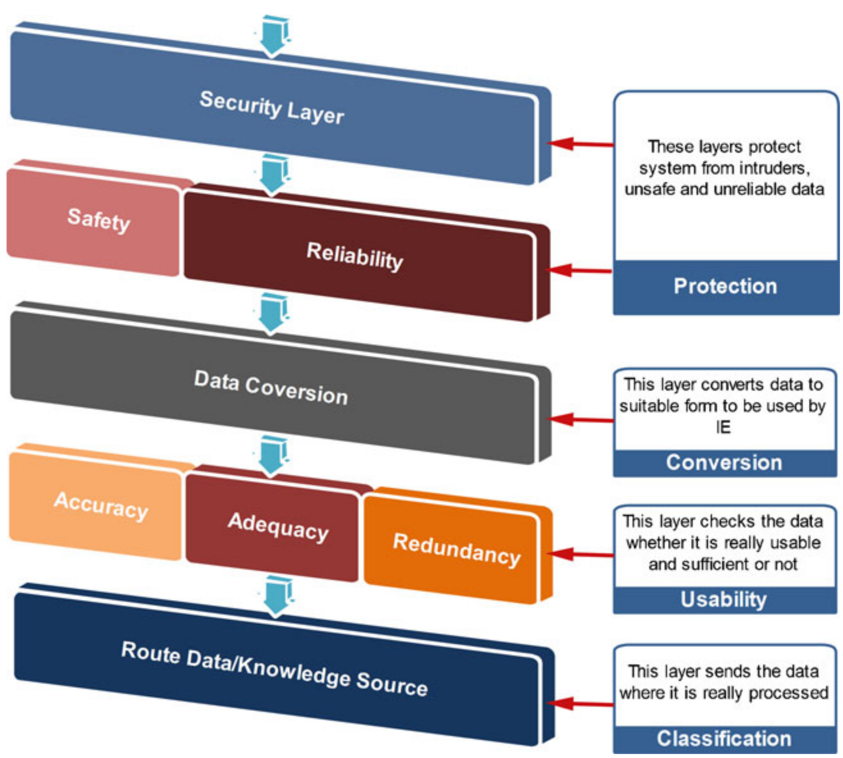
This layer has crucial importance for MedWise, and is responsible for providing sanitized and reliable data to the next layer, 3DIE. Figure 3 illustrates the SRR-Shell structure. The MedWise system communicates and interacts with its environment via the web, making MedWise dependent on the Internet, and consequently vulnerable to intruders. Thus, a security layer is used to protect MedWise against intruders or any other unauthorized access. The security layer incorporates many different security technologies, including but not limited to, IP control, trusted connections, intrusion detection and firewalls.

The next layer is the safety and reliability check layer, responsible for protecting against the inclusion of unsafe and unreliable data into the system. Any data that reaches to this layer is known to be coming from trusted connections. However, these may sometimes provide corrupted or inaccurate data to the system. A reliability level filtering mechanism is, hence, used to promptly reject any incoming data deemed to be unreliable. All information received from external sources is verified and assigned a trust level. According to the trust level attached, the inference engine will deny, fully or partially accept information. The information will also be assigned a privacy level which allows data only to be accessed or used by an entity with the matching clearance level. Information will only be accessed on a need-to-know basis, and those who lack authorization will be denied access. The methods employed will be analogous to the multi-level security techniques used in protecting operating systems based on security clearances.

The data conversion layer is used to convert data obtained from many different institutions into a standard and commonly agreed format, since institutions participating in the system provide different types of information and use different data formats. Furthermore, this layer is also used for integration by other systems, and it supports the de facto medical information exchange protocol HL7 [17, 18].

The next layer filters data, allowing only the relevant, accurate and adequate data to pass to subsequent layers. The accuracy filter is engaged in case the data is not properly measured, or given in incorrect units. If this is the case, it classifies the data as inaccurate, and rejects it. The

Fig. 3 SRR-shell design



adequacy filter is responsible for ensuring that the information contained in minimum health data set is sound and complete. The minimum health data set (MHDS) encompasses the information needed by the medical practitioner to recognize, diagnose, and advise a patient with a particular disease. Should any data be received multiple times or have duplicate or irrelevant content, it would be filtered as per the redundancy constraint that the filter enforces.

The last layer is responsible for directing the data to proper channels in the 3D Inference Engine. Since 3D Inference Engine has three main input channels (Nursing, Medical and Pharmaceutics), the data coming from SRR-shell should, therefore, be directed to the proper channel.

DIE: 3D inference engine

3DIE (3D Inference Engine) uses expert system technologies and data mining methods. The main purpose of 3DIE is to provide information and knowledge about a patient. In addition, it offers several recommendations to uncertainties that are normally one or more human experts would need to be consulted. It uses three methods of knowledge base creation: 1—it uses some knowledge representation formalism to capture the SME (Subject Matter Expert) knowledge, 2—it gathers that knowledge from the SME and codifying it according to the formalism, 3—it mines techniques on data stored by the 3DIE's data-warehouse to provide knowledge and advise [19, 20]. Figure 4 shows the design of 3DIE.

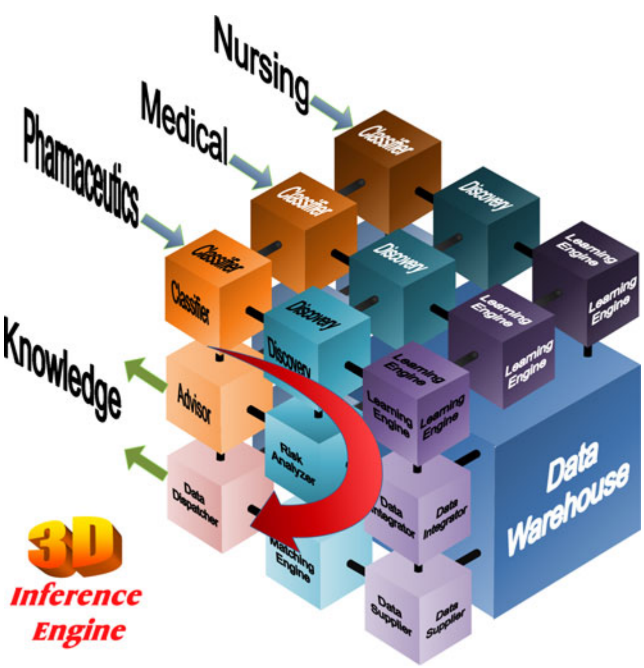


Fig. 4 Design of 3DIE

The main differences between 3DIE and a Classical Inference Engines are that the former gathers data from three different domains separately (nursing, medical and pharmaceutics). Moreover, it offers three distinct and one combined knowledge and advising work-flows, and it provides separate knowledge discoveries and learning methods for each domain. This schema ensures that 3DIE provides all possible advice alternatives for the cure and treatment of a particular disease, if there are alternative treatments inferred from knowledge directly gathered from physician and patient consultations, and indirectly from the learning engine.

The 3DIE work flow is very straightforward: obtain and classify data and discover what kind of knowledge should be learned, then learn and store it. When advice is required by any stakeholder, 3DIE firstly receives and classifies the request, discovers the knowledge required, fetches the knowledge from data warehouse, integrates the knowledge with data, analyzes results, and finally dispatches results to the application layer. In addition, a Health Data Dictionary (HDD) capable of supporting technical words and expressions according to the field of medicine will be used in MedWise. A HDD improves the data understandability for medical practitioners.

MedWise system's interface and features

The two main reasons that a physician may show a lack of willingness to use medical or clinical information systems are firstly, the fact that data entry that is viewed as a clerical task and a burden, and secondly, the presentation of data is often inadequate or ineffective . These two factors and a number of other expectations of physicians were the determinant and key factors influencing the design of MedWise interfaces. In addition, the Graphical User Interfaces (GUIs) of any system must be both intuitive and easy to use, and information must be easy to locate, and categorize accurately so that relevant information is grouped together. MedWise has strong potential to offer very intuitive user interfaces.

In this section, several key interfaces will be introduced using the case of Fever of Unknown Origin (FUO) as an example. This case illustrates how MedWise can assist a physician in the process of determining the cause of fever. When a patient reports to the health care professional with fever, a thorough medical examination is performed for diagnostic purposes. This includes physical examinations, test results and obtaining various kinds of information about past medical history. Table 3 lists a number of workups and examinations used to identify the cause of fever.

MedWise's goal is to automatically provide as many as possible of the items described in Table 3 with minimal

Table 3 Workups and diagnosis examinations and investigations samples for fever [21]

Item	Description
1	Daily documentation of fever, onset, duration
2	Weight loss, diet history, medications, sick contacts
3	Animal or tick exposure, travel, foreign contacts
4	Immune status, history of transfusion, surgery
5	Family history (FH) of autoimmune or neo-plastic diseases
6	Physical exams (Vital signs, growth parameters, Skin, Oral lesions, etc)
7	Labs (CBC, ESR, C-reactive protein, etc.)
8	Radiographic imaging with plain films, ultrasound, bone scan, etc

patient consultation. Patient's data items 1, 2 and 4 can be provided by MedWise using 3DIE (data warehouse of MedWise) as well as visual records of patient.

Items 3 and 5 in Table 3 indicate that a patient's travel and hereditary data must be examined in addition to standard tests and imaging results for FUO. In the following sections we introduce how MedWise presents a patient's hereditary, travel and residential information in such a way as to facilitate the physician's diagnose of the cause of fever.

Hereditary map

Family history is sometimes vital for diagnosis of many diseases, especially for diabetes and cardio-vascular problems [22]. In the MedWise system, a hereditary map is generated automatically from Ministry of Citizenship database, and the map is annotated by parental health data from the participant hospitals. This map can be used to understand the possible genetic factors causing the fever. Thus information supplied by this map can be useful for the 5th item of Table 3. Figure 5 shows a sample hereditary map provided by MedWise that could be effective in identifying the cause of fever.

In this example, the patient has inherited a significant genetic factor for the fever (Familial Mediterranean Fever from the father and Muckle-Wells Syndrome from the mother). If the hereditary map is generated at the beginning stages of workups, subsequent tests would be targeted towards to the diseases indicated in the map and, therefore, no further workups are likely to be necessary.

Customs and travel data

Figure 6 illustrates a sample map which shows a particular patient's journeys over the past 6 months. This map is generated from the travel data provided by the customs control and statistical institute, and risk data from World Health Organization (WHO). This map is extremely important for tracing the patient's travel over the previous 6 months. If the patient has visited a risky location and it is considered that the fever associated with a particular disease might be the result of any of the journeys, the physician would prioritize the workups by first testing for

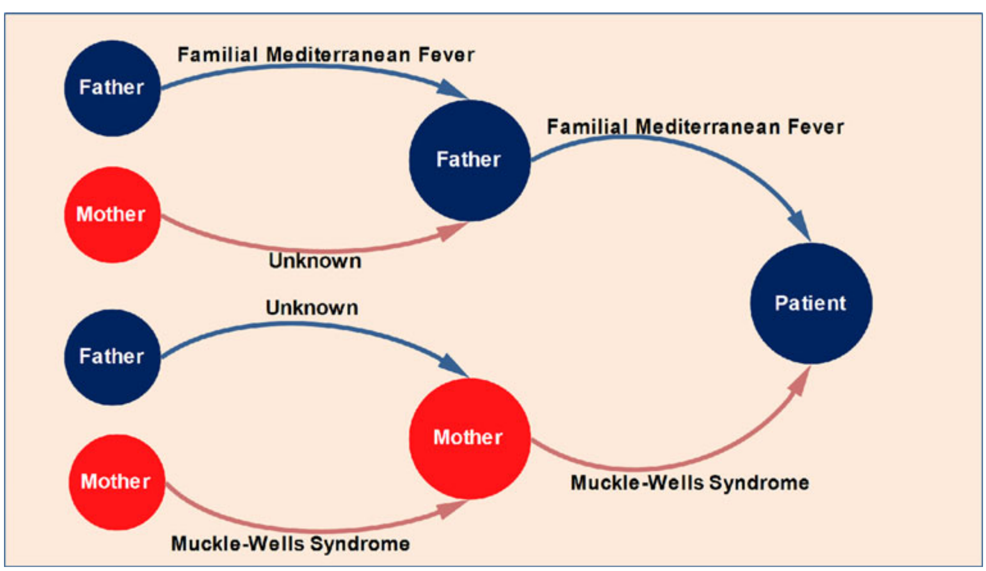


Fig. 5 Sample hereditary map

Fig. 6 A sample travel map of a particular patient

diseases which can be caused by these journeys. Thus, travel, one of the factors in item 3 in Table 3 can be reviewed and a possible reason of fever might be found using this facility.

Residential information

Tick bites can be extremely dangerous, especially for children, and can cause pyrexia (fever), possibly with fatal consequences [23]. Crimean-Congo Hemorrhagic Fever Disease is caused primarily by tick bites. If a patient with a fever resides in a region with dense tick population and the physical examination results indicates a tick bite, then a map showing dangerous tick habitat would be very important in determining the kind of the tick involved and type of tests needed. Figure 7 shows a sample tick population distribution map of Turkey which will be provided by MedWise [24]. Thus, this information is also a part of 3rd item in Table 3.

Discussion and conclusion

Human life is precious and priceless. Medical errors can degrade the quality of life or even cost the life of a person, and are therefore intolerable. Even more intolerable are mistakes caused by incomplete data, quality of data or delay of data. We propose a medical information infrastructure that addresses many issues that physicians frequently face in their diagnoses and treatment of patients.

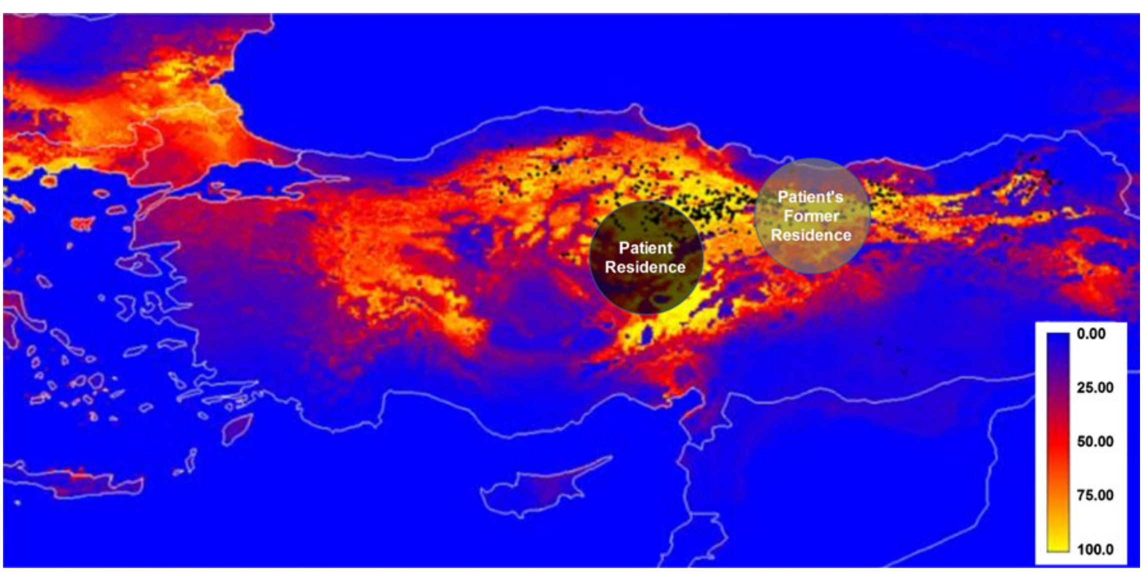


Fig. 7 The distribution of Tick population in Turkey

A number of advantages of the architecture presented in this paper can be listed as follows;

- It provides significant information about the patient to the physicians, who can then interpret condition from a variety of viewpoints.
- MedWise helps to reduce problems caused by language barriers and disorders, because ancillary data about the patients is essentially derived from factual and evidential information rather than patient's own statements or declarations.
- It automatically supplies crucial data about patient to the physicians, thus it helps to reduce time spent on paper-work and therefore physicians are able to allocate more time to physical examination or can examine more patients.
- Physicians can instantly access precise information about patients, without the need to search distinct files for consultations.
- Its modular and flexible design make it easy to integrate with other clinical support systems, and a single feature or combination of several features of the system can be deployed or integrated into a country's e-health system. Thus, if a country has regulative or political difficulties, the authority would activate only the applicable features.
- It supports different data entry interfaces (verbal, paper tablets, templates etc) for physicians, any of which can be used at any time.
- All the institutions regarding healthcare can be incorporated under a single platform and therefore security and reliability problems can dramatically be decreased.
- It can be used for scientific surveys, and it can provide huge data sets to researchers and governmental entities engaged in drafting new policies or improving existing health care systems.

Its disadvantages and drawbacks could be listed as follows;

- This is a long term project, and ten or more years might be required to realize the system, because of regulative and political difficulties, the resistive attitudes of stakeholders, and time requirements for gathering patients' data.
- Physicians often view data entry as a clerical task and a burden and may be reluctant to enter data, making data collection problematic [25].
- Physicians may view the initial versions the proposed system as less effective, and the evolution period of the system might cause strain.
- Physicians can be concerned about possible malpractice lawsuits resulting from the use of clinical decision support systems [26].
- There may be doubts about the reliability of the system due to hardware, software and communication failures.

MedWise is intended to assist physicians to reduce the workload and to shorten time for diagnosis and consultations; therefore both the quality and quantity of the physical examinations of patients will dramatically be increased.

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