

# Medical Knowledge Packages and their Integration into Health-Care Information Systems and the World Wide Web

Klaus-Peter ADLASSNIG<sup>a,b,1</sup> and Andrea RAPPELSBERGER<sup>a,b</sup>

<sup>a</sup>*Section on Medical Expert and Knowledge Based Systems, Medical University of Vienna, Spitalgasse 23, A 1090 Vienna, Austria*

<sup>b</sup>*Medexter Healthcare GmbH<sup>2</sup>, Borschkegasse 7/5, A 1090 Vienna, Austria*

**Abstract.** Software-based medical knowledge packages (MKPs) are packages of highly structured medical knowledge that can be integrated into various health-care information systems or the World Wide Web. They have been established to provide different forms of clinical decision support such as textual interpretation of combinations of laboratory test results, generating diagnostic hypotheses as well as confirmed and excluded diagnoses to support differential diagnosis in internal medicine, or for early identification and automatic monitoring of hospital-acquired infections. Technically, an MKP may consist of a number of inter-connected Arden Medical Logic Modules. Several MKPs have been integrated thus far into hospital, laboratory, and departmental information systems. This has resulted in useful and widely accepted software-based clinical decision support for the benefit of the patient, the physician, and the organization funding the health care system.

**Keywords.** Knowledge-based systems, decision support, internal medicine, laboratory medicine, infection control

## Introduction

In the last few years, it has been possible to extract medical knowledge bases previously contained in the core of medical expert systems, add appropriate knowledge processing algorithms, and integrate these into various health-care information systems. These information systems might be hospital information systems (HISs), laboratory information systems (LISs), intensive-care patient data management systems (PDMSs), medical practice software systems, telemedicine applications, or health-care information or patient record systems in the World Wide Web (WWW). We name these extracted medical knowledge bases together with their corresponding knowledge processing algorithms medical knowledge packages (MKPs). Moreover, we have been

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<sup>1</sup> Corresponding Author: Klaus-Peter Adlassnig, Section on Medical Expert and Knowledge-Based Systems, Core Unit for Medical Statistics and Informatics, Medical University of Vienna, Spitalgasse 23, A-1090 Vienna, Austria; E-mail: klaus-peter.adlassnig@meduniwien.ac.at

<sup>2</sup> Medexter Healthcare GmbH, a spin-off of the Medical University of Vienna, Austria, acts as a vendor of medical decision support systems and services including medical content such as Arden or FuzzyArden MLMs and technical inference frameworks such as Arden or FuzzyArden rule engines ([www.medexter.com](http://www.medexter.com)).

able to render them available in several technical formats such as source code, or in compiled form, together with their corresponding carrier systems. A further option is to place these MKPs on a server and furnish them with standardized input and output structures for on-site or remote access. By means of these MKPs, the corresponding health-care information systems are equipped with knowledge-based medical intelligence.

## 1. Integration into Health-Care Information Systems

*Integration into HIS:* MKPs to support differential diagnosis in internal medicine can be integrated into the process of work-flow-oriented patient care—if necessary with additional input of medical data—and be rendered available in a structured documentation. Explanations will be provided for the eventually confirmed diagnoses, the offered diagnostic hypotheses, and the excluded diagnoses. The clinical user receives a detailed analysis of the patients' data and information about further diagnostic investigations so that each step of the diagnostic decision is traceable and remains transparent. MKPs for automated interpretation of laboratory test results can be useful on the information screen for test results. A simple query click by the user yields an interpretive text that explains the combination of laboratory test results achieved, particularly in cases of rare, complex, or even inconsistent findings.

*Integration into LIS:* MKPs for automated interpretation of laboratory test results can be integrated into the textual report of laboratory test results. A clinically oriented interpretive text—not only for common standard results but also for rare, complex, and unlikely test results—is automatically inserted into the report sent to the ordering physician [1]. This forms an essential quality assurance tool for the laboratory. Moreover, it saves time, avoids error, and provides clinically useful information. In the final analysis, it saves costs.

*Integration into intensive care PDMS:* MKPs such as those for early identification and automated monitoring of hospital-acquired infections can be directly incorporated as alarm modules into intensive-care PDMSs. Through several data-to-symbol conversion steps, existing clinical and microbiological data are prepared in a manner that common definitions of hospital-acquired infections such as those of CDC [2], HELICS [3], or KISS [4] can be assessed for concurrence or non-concurrence in a fully automated fashion.

*Integration into medical practice software systems:* MKPs to support the differential diagnosis at the physician's office—possibly with a separate documentation of additional patient data—serve as add-on modules for medical practice software systems. Thus, these modules provide problem-specific documentation as well as support in terms of differential diagnosis [5].

*Integration into telemedicine applications:* In these systems, continuous monitoring of incoming data streams aimed at accepting normal patient data in an automated fashion and marking only those that need to be reported to a human decision maker has become increasingly important.

*Integration into WWW applications:* Browser-based access to MKPs permits world-wide dissemination and utilization of the medical knowledge contained in these knowledge packages [1, 6, 7]. Decision support systems based on these knowledge packages can be accessed through any WWW browser. One alternative is to make MKPs available on a server that can be directly accessed through a suitable

communication protocol. Data is passed on to data structures such as XML [8], HTTP, or HL7 [9]; the generated results are also passed on, if necessary with an explanatory report.

## 2. Technical Solutions

Technically, the integration of MKPs into health-care information systems and the WWW can be carried out as follows. The respective knowledge base is written in a special syntax format packed together with the knowledge processing system, and provided as a transferable file. This syntax can be processed by a compiler (or an interpreter).

One example is the standard format Arden [10–12] introduced in 1992 and now supervised by a Special Interest Group (SIG) of the HL7 committee [9]. Arden is used to represent medical knowledge in the form of Medical Logic Modules (MLMs). It was primarily intended to develop reminders, alerts, and recommendations [13–17]. The available medical knowledge corresponding to Arden syntax is compiled by an Arden compiler. However, the applicability of this syntax for formal representation of “larger” knowledge bases extends beyond the writing of simple MLMs. This has resulted in strongly inter-connected packages of MLMs which, however, can be processed without difficulty. The intended purpose is fulfilled.

We developed a complete Arden software package (see Figure 1) consisting of an ArdenServer with database, reasoning, and analysis components, an ArdenEngine, and an ArdenCompiler including an integrated Arden development and test environment (ArdenIDE, see Figure 2). Arden as a medical knowledge representation and rule-based inference system was selected because it is the only industry standard and has been further developed by HL7.

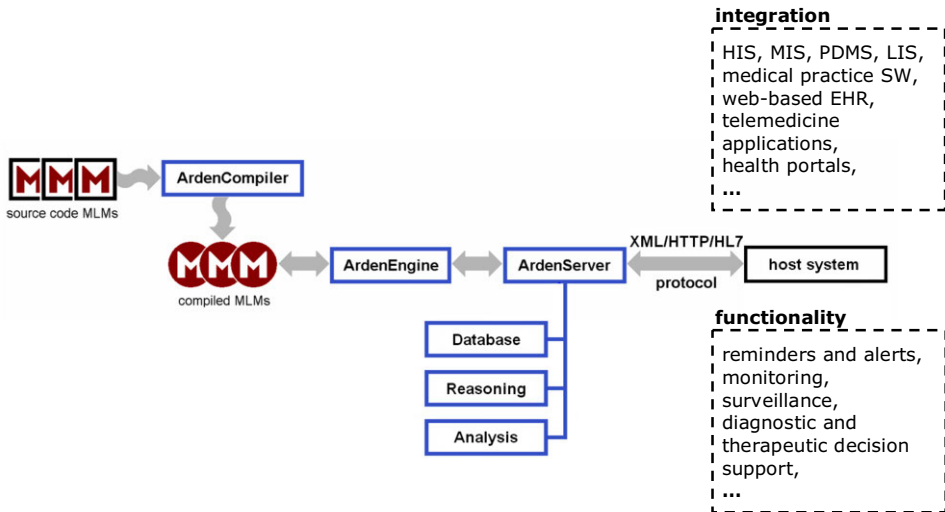
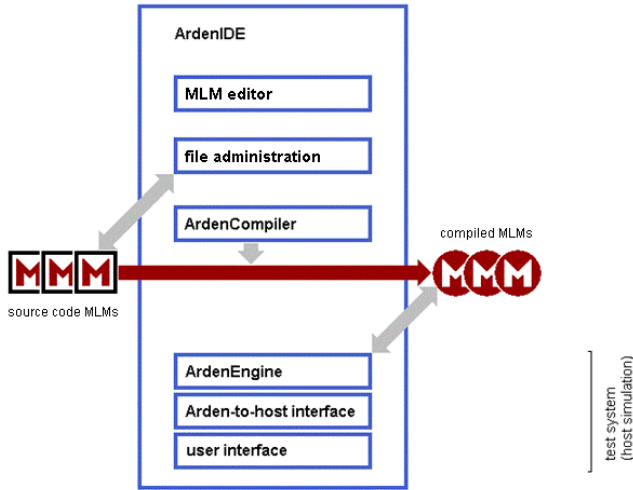


Figure 1. An Arden server that contains the respective MKPs is integrated into a host system.



**Figure 2.** An ArdenIDE (integrated development environment) permits efficient development, testing, and compilation of MLMs for further processing by the ArdenEngine.

The Arden software components were themselves written in Java. They permit writing, compiling, testing, and executing Arden MLMs, which are mounted on an Arden server, controlled by an Arden engine, and connected to and triggered by the respective host health-care information system. The Arden server is equipped with several components: First, a database component to temporarily store data essential for the inference process including consecutive medical data as well as intermediate results of the inference process to allow detailed reasoning of the proposed medical decisions; second, a reasoning component to offer a line of reasoning either on a detailed level providing single data that lead to the results or on an abstracted level summarizing the detailed reasons; and, third, an analysis component to implement a mechanism for logging relevant medical or technical events for software and knowledge maintenance. The communication between the Arden server, which establishes an envelope around the Arden engine that administers the Arden MLMs, is done via data structures (XML, or HTTP, or HL7). The data structures provide access to input and output data. In this case, the so-called curly-braces problem is surmounted in such a way that the read, write, and other Arden statements with curly-braces access the Arden server's database component and not the external host health-care information system. However, we also offer—instead of the Arden server—an Arden-to-host interface. Here the curly-braces problem still exists. In some instances, data for Arden MLMs might just be transferred through the Arden “argument” and “return” statements. Our Arden engine then receives data through an XML structure and passes them on to the “argument” statements (the “return” statement runs the opposite way).

### 3. Present Results

At present we have a number of MKPs in Arden format which are or can be integrated into HISs, LISs, PDMSs, medical practice software systems, telemedicine applications, or the WWW.

- *Hepaxpert/Interpretation*—knowledge-based interpretation of hepatitis A, B, and C serology test results; implementations into the hospital information systems Orbis by AGFA Healthcare and Soarian by Siemens Medical Solutions were carried out successfully; Teleiatros ([www.teleiatros.com](http://www.teleiatros.com)) whose core consists of an Arden server provides both browser-based and direct server access to Hepaxpert/Interpretation; a remote direct server access out of Soarian was established for test purposes. The access time was a few milliseconds. Hepaxpert/Interpretation is able to interpret more than 60,000 combinations of serologic test results. We wrote a total of 7 MLMs (for each language) to carry out the respective interpretations. These contain very densely “compiled” knowledge.
- *Thyrexpert/Interpretation*—knowledge-based interpretation of thyroid hormone test results and *Toxopert/Interpretation*—knowledge-based interpretation of toxoplasmosis serology test results. Again, Teleiatros provides browser-based and direct server access to these two MKPs. Thyrexpert/Interpretation consists of 9 MLMs (per language) and Toxopert/Interpretation of 79 MLMs (per language). For both systems the MLM packages are highly interwoven and densely “compiled”.
- *RheumaDiff/Diagnosis*—medical documentation and support of decisions relating to differential diagnosis in rheumatology and *Moni/Alert ICU*—knowledge-based early identification and automated monitoring of hospital-acquired infections at adult intensive care units. Both systems consist of packages of Arden MLMs (13 for RheumaDiff/Diagnosis per language and 47 for Moni/Alert-ICU per language). In both systems, the extended data-to-symbol conversion is also represented in MLMs. However, parts of the feature extraction in Moni still have to be done by the host health-care information system. Both are accessible through Teleiatros. Moni/Alert-ICU will shortly be integrated in a PDMS.

### 4. Discussion and Conclusion

MKPs are useful to support the physician in his/her medical and organizational decisions in the course of patient care. The prerequisite is that these knowledge packages should be of excellent medical quality and fully integrated into the medical work processes—whether at the clinic, the laboratory, or the physician’s office. They serve the purpose of quality assurance and potentially improve patient care, enhance the efficiency of medical work by accelerating diagnostic and therapeutic decisions, and possibly reduce the cost of care or at least render the costs transparent.

MKPs serve the purpose of clinical decision support for the individual patient by means of medical expert knowledge. The growing complexity of medical knowledge makes the use of such systems increasingly important. When used properly they reduce a large part of the attending physician’s effort in terms of repetitive mental processes

related to his specialty. They provide him time and opportunity to devote his attention to patients and contribute in great measure to the patient's safety.

The achieved results are pervading all fields of application of information systems in medicine. Initial significant steps have been taken; these are steps in the direction of knowledge-based health care for the benefit of the patient, the physician, and the organizations funding the health care system.

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