Open Source Software in the Biomedical Domain: Electronic Health Records and other useful applications

Stéphane Meystre, M.D.[1]

Henning Müller, Ph.D.[2]

[1] Department of Medical Informatics, University of Utah, Salt Lake City, Utah, USA.

[2] Service d'Informatique Médicale, Université et Hôpitaux Universitaires de Genève, Genève, Suisse.

Corresponding author:

Stéphane Meystre

Department of Medical Informatics, University of Utah School of Medicine,

Room AB194, Salt Lake City, UT 84132-2913

Telephone: +1 (801) 4082111 Fax: +1 (801) 5814297

E-mail: s.meystre@utah.edu

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Abstract

There are few subjects in computer science where the discussion is more emotional than Open Source Software (OSS). People are either strongly favoring its use or are straightforward against it, often without knowing the details of available software or the licensing conditions.

This article gives an overview of available OSS in the medical domain, mainly centered on available open source Electronic Health Records. Much of the software for a hospital infrastructure can be obtained free of charge, but the main costs in a hospital environment are on adaptations of software for a particular setting and on maintenance. These costs also apply to open source software, which is therefore not without cost.

The article also outlines the advantages and problems of OSS through a review of the literature to de-emotionalize the debate and concentrate rather on the facts, with mention of the potential of OSS, for example in developing countries.

Keywords:

Open Source Software

OSS

Free Software

Libre Software

FOSS

FLOSS

Medical Records Systems, Computerized

Introduction

Medical errors and patient safety have become very timely topics in healthcare since a few years, especially after the U.S. Institute of Medicine (IOM) Report estimating that medical errors were the cause of 44’000 to 98’000 deaths every year in the U.S. [1] In a later report, Paul C. Tang, Chair of the IOM Committee on Data Standards for Patient Safety said that "electronic health records that allow care providers to gather, store, and use health information more efficiently could increase the effectiveness of care and greatly reduce errors and costs."[2]. Several barriers to the wide adoption of Electronic Health Records (EHR) remain. In primary care, barriers like excessive cost, instability of vendors, and lack of common data standards have been mentioned [3].

Free and Open Source Software (FOSS) is software with openly published source code, usually available at no charge, and often developed by voluntary effort and participation of a large number of people [4]. FOSS reduces ownership and development costs. It also avoids the vendor “lock-in”, and improves the use of data standards, FOSS being known for embracing standards. As Kantor et al. mention it, FOSS may turn out to be the force that helps overcome barriers to the use of the EHR in primary care and in the rest of the health care system [5]. The FOSS movement is gaining growing interest among scientific communities and among healthcare and public administration organizations. The possibilities offered by FOSS are also important for developing countries [6], where licensing and cost issues have encouraged many to adopt open source products, to the point that whole countries such as Peru have mandated the use of FOSS in their administration. Australia and the state of Massachusetts in the U.S. have strongly encouraged the use of FOSS in public services. The WHO plans to use FOSS to monitor AIDS patients in countries where there is not enough money to even buy basic medication [7]. In Europe, the FLOSS Survey and Study commissioned by the European Commission in 2001-2002 [8] popularized the movement. Cities like Munich and Paris are encouraging their public services to migrate to FOSS. The European Commission is regularly funding projects through its research frameworks. The fifth Framework (1998-2002) placed a strong emphasis on

projects yielding FOSS as one of the outputs. It funded projects like SPIRIT[1] with the aim to accelerate the use of open source software in healthcare, disseminating best practice in FOSS and news about FOSS projects. In the UK, the NHS (National Health Service) Information Authority encouraged development and research in the open source field, and co-sponsored the 2001 annual meeting of the OSHCA (Open Source HealthCare Alliance) in London. Despite interest in open source solutions by the NHS, a recent licensing agreement was signed with Microsoft to provide most of the software needed across the British healthcare system, locking all users into Windows and Microsoft Office for nine years. The deal mentioned that Microsoft would develop "a health specific user interface for clinical systems" at "no charge" to the NHS [9].

Another important aspect in Europe is the support of several languages in software. Whereas the most popular software products such as Windows are translated into languages that have a major market, specialized software is often only available in its original language, most often English. Open source licenses allow translating the software into any other language, which is not possible for closed source software. Rare languages can thus be supported by FOSS like OpenOffice that exists in many languages. For health-related software, we will mention in the text when the software is available in a German or French version. Several open source software packages have a description of how to perform a translation easily.

Background

FOSS is also named Open Source Software (OSS), Free Software, Libre Software, or Free/Libre and Open Source Software (FLOSS). These names are used for freely modifiable and redistributable software, and do not refer to zero-cost software. Free Software was the name originally used, and “Open Source” is a name created to avoid confusion over the term “free” in the English language. Both names refer to a similar sort of software but emphasize different rationales. Free Software is advocated

[1] http://www.euspirit.org/

by the Free Software Foundation (FSF[2]) as a more ethical and social movement, emphasizing the freedom to run, study, redistribute, and improve the software, as detailed in the Free Software Definition [10]. Open Source Software has a more practical definition [11] as defined by the Open Source Initiative. The main concepts of the definition are the free redistribution of software that includes source code, certain authorizations or prohibitions of derived works, and prohibition of discrimination against persons, groups, or fields of endeavor. FOSS and FLOSS are hybrid terms for both the Free Software movement as well as Open Source Software. The name "Libre Software" was created by the European Commission in 1992, to avoid the English ambiguity with "Free Software" and the misunderstandings of "Open Source" alike. All those names should not be confused with Freeware or Shareware. Availability of source code and cost can be used to classify software into four groups (Figure 1).

	Open source (source code freely available)	Closed source (source code not available)
No or limited cost to the user	Non-commercial FOSS	Freeware Shareware[3]
Some cost to the user	Commercial FOSS	Commercial/Proprietary software

Figure 1: Classification of software [8].

Short history of FOSS

In the 1960s and 1970s, revenues in computer business were generated through hardware products, the latter usually having their own operating system. UNIX was developed by the AT&T Laboratories to be deployed on multiple hardware platforms. It was available at low cost for academic institutions, often including the source code for direct changes by scientists. In the 1980s, UNIX became restricted to paid licenses and was delivered without source code. Other hardware companies started developing proprietary UNIX operating systems. At that time, Richard Stallman started a project to develop a free alternative to the UNIX operating system called GNU (GNU's Not UNIX). He established a fairly

[2] http://www.fsf.org/
[3] No cost during the initial evaluation period.

restrictive license using the term copyleft to protect the rights of open source software and their derivations and created the Free Software Foundation (FSF) in 1985 to support his project. In the 1990s, many open source projects emerged. The most prominent example is Linux, a UNIX-like operating system developed to run on personal computers. Linus Torvalds, a now famous Finnish computer scientist, developed the kernel for an open source operating system he called Linux. He released an early version as open source and asked for help and feedback. In 1991, a modified version of UNIX was released as freely downloadable source code by the University of California at Berkeley. It was called BSD (Berkeley Software Distribution) and is now an open source version of UNIX used by many others. In 1997, Eric Raymond and Bruce Perens founded the Open Source Initiative (OSI[4]) in order to establish a more pragmatic approach to software licensing. They developed the Open Source Definition to promote FOSS in the business world. The history of FOSS is described in details in two books, "The Cathedral and the Bazaar" [12], and "Open Sources - Voices from the Open Source Revolution" [13].

In the healthcare domain, the COSTAR ambulatory medical record was one of the first FOSS in the late 1970s, even before the definition of FOSS existed [14]. The U.S. Veteran's Administration system called VistA was also a pioneering healthcare FOSS but the use of FOSS in healthcare has received more attention only since a few years. Organizations to promote the use of FOSS in healthcare have been created, such as OSHCA[5] and working groups in the International Medical Informatics Association (IMIA) and the American Medical Informatics Association (AMIA). The O|B|F[6] (Open Bioinformatics Foundation) has contributed to the rapid development of FOSS that has occurred in our sister field of bioinformatics. In other medical domains like Radiology, FOSS played an important role to create standards: DICOM (Digital Imaging and Communication in Medicine, standardized since 1995) became the standard for communication between imaging modalities, archives and Radiology

[4] http://www.opensource.org/
[5] http://www.oshca.net/
[6] http://www.open-bio.org/

Information Systems (RIS). From the start on, the Radiological Society of North America (RSNA) helped creating open source software to promote the standard and ease development based on this software[7]. This open source software is still used by many vendors in their software and modalities and was the basis for the success of this standard.

FOSS licenses

Open Source does not mean public domain, which implies no copyright or license limitations and allows others to copyright and impose their own restrictions on derived material. Open source licenses share two characteristics: the source code has to be made available, and license fees are typically waived. The most common license is called GPL (GNU General Public License), and is used in the GNU project and by Linux. It does not restrict copying and redistribution, but source code must be made available to the user, and the license has to be enclosed with the distributed software. Modifications are allowed and derivative work is permitted but has to be published under the GPL again. This "viral" effect makes GPL not very business-friendly. To answer this problem, the FSF also offers the LGPL (GNU Lesser General Public License). This license allows commercial software to use FOSS without being "contaminated" by the GPL. This allows creating part of a project in GPL but the libraries in LGPL to ease commercial add-ons to software. Many open source projects created their own licenses, often based on the GPL or LGPL and containing only small modifications.

The MPL **(**Mozilla Public License) was developed by Netscape to release the code of its Netscape web browser. The main difference with the GPL is the possibility to incorporate software under MPL into software products that can be licensed without "contamination". The BSD License and the Apache Foundation's licenses are similar to the LGPL or MPL license, but do not require derived work to be free again. There is no "viral" effect. The large number of licenses for open source software creates a lot of confusion. A project to reduce this and create a flexible license framework is the Creative

[7] http://dicom.offis.de/dcmtk.php.en

Commons initiative[8]. Creative Commons contains licenses for software but also for digital art and music. The toolbox of licenses allows a flexible use of licensing, always having in mind to promote the distribution of content in a free way.

Open Source in healthcare

The academic literature about FOSS in healthcare is very limited. In 2000, Douglas Carnall published a letter advocating the use of FOSS in healthcare [15], with a more complete electronic version also [16]. In 2002, Graham Wright and Peter Murray published a paper to propose the creation of the IMIA open source working group [17]. An interesting white paper about the use of FOSS by the UK NHS was published, but then removed in 2004 when the NHS finally contracted with Microsoft. In 2003, Clement McDonald and colleagues have described open source, its use in healthcare, and the FOSS developed at the Regenstrief Institute for Health Care in Indianapolis (Indiana, U.S.) [18], and Gareth Kantor and colleagues published a letter to support the use of FOSS in primary care [5]. Other articles talk about various aspects in which open source can help the health systems [19,20].

Methods

An extensive literature and electronic information search was conducted at the end of 2004, using the following terms: open source, free software, FOSS, FLOSS, OSS, free medical record, free electronic medical record, free EMR, free EHR, free CBPR, free CPR, and free record. Documents that were retrieved came from academic literature, MEDLINE, library databases, conference proceedings, and Internet websites. This collection of literature and electronic information was then reviewed for its value and for the development of a global view of FOSS in healthcare, with an emphasis on EHRs. Several programs were installed and tested locally to get a better idea of the quality of available software and problems.

[8] http://creativecommons.org/

Results

In general, tens of thousands of FOSS applications exist and are available on Internet websites, such as freshmeat[9], Sourceforge[10], and OSDIR[11]. Some of the most common and famous FOSS projects are described below, starting with general projects and following with projects really focused on the medical domain.

General open sources software usable in a medical context

Apache is the most widely used web server in the world, with a current market share of almost 70% [12]. It was developed by the U.S. National Center for Supercomputer Applications. Since 1999, the Apache Software Foundation is responsible for its development [21]. It can be used for all web-based applications and user interfaces and works on a large number of computer platforms.

Linux is a famous operating system kernel. It provides basic functionalities of the operating system. The Linux kernel, when combined with other components of an operating system (GNU, X-Windows windowing system, gcc compiler, etc.) results in a so-called "Linux distribution", like the well-known Red Hat, SUSE, or Mandrake products. Many people refer to this combination as just "Linux", and others refer to it as "GNU/Linux" for GNU-based distributions. It is a stable server platform that is gaining in market share and importance. Most large companies already use Linux and it is also used in hospitals, often as file or print server. It represents about 25% of the server operating systems, and 4% of the desktop operating systems worldwide. *Knoppix* is a Linux Distribution that can be run on a CD-ROM and that does not need any installation. It also contains other FOSS like OpenOffice, enabling a full working desktop system to be run from the CD-ROM. *OpenOffice*[13] is the open source version of

[9] http://www.freshmeat.net/
[10] http://sourceforge.net/
[11] http://osdir.com/
[12] http://news.netcraft.com/archives/web_server_survey.html
[13] http://www.openoffice.org/

StarOffice, an office suite product from Sun Microsystems, similar to Microsoft Office. *FreeBSD*[14] was released in 1993, and was initially built on the Berkeley Software Distribution (BSD). It is the most popular open source project built on the BSD. Other similar products exist, like NetBSD and OpenBSD. Solaris, the operating system developed by Sun Microsystems, will be released in 2005 as FOSS under the name *OpenSolaris*[15]. GNOME[16] and *KDE*[17] are graphical user interfaces that run on top of Linux, providing user-friendly computing to the non-programmer open source community. *Mozilla*[18] is an open source project initiated by Netscape, including a web browser, an e-mail client, and a webpage design application. Its first version was released in 2002 and different versions now exist. Most popular is the web browser, *Firefox*, released in 2004 and the e-mail client *Thunderbird*.

MySQL[19] is a relational database server initially developed in 1994 and released under the GPL in 2000. Payable versions also exist to allow its use in commercial solutions. *MySQL* is used by many large companies and organizations like Motorola, Yahoo!, NASA, the U.S. Department of Defense, Associated Press, and as background database server for many web-based applications.

Different open source programming languages have been developed, especially for dynamic web pages. *Perl* (Practical Extraction and Report Language) was developed in 1987 for text manipulation, and is now used for a wide range of tasks including system administration, web development, network programming, etc. A great number of Perl modules are available at the *CPAN* (Comprehensive Perl Archive Network), including modules for creating HL7 (Health Level 7) medical applications. *PHP* (PHP Hypertext Preprocessor) started in 1995 as a set of Perl scripts called "Personal Home Page Tools". It is the most popular open source scripting language for web applications. *Python*[20] is another language released in 1991 that evolved quickly into a powerful interpreted object-oriented language. For dynamic Internet websites, one of these programming languages and other FOSS are typically

[14] http://www.freebsd.org
[15] http://www.opensolaris.org
[16] http://www.gnome.org/
[17] http://www.kde.org/
[18] http://www.mozilla.org/
[19] http://www.mysql.com/
[20] http://www.python.org/

combined to form a "LAMP" system. It contains Linux as the operating system, Apache as the web server, MySQL for the database, and PHP/Perl/Python for the middleware programming language.

Open Source in healthcare

FOSS applications in healthcare are only a little fraction of all FOSS, and are listed in various websites. A quite comprehensive list of FOSS projects in healthcare can be found on Yves Paindaveine's homepage[21]. Good sources of information are LinuxMedNews[22], the OpenHealth[23], and AAFP CHIT[24] (American Association of Family Physicians' Center for Health IT) websites. Health Informatics Europe[25] has some useful information. In French, the Médecine libre website[26] is a good information source. An electronic journal on FOSS in healthcare has been created, the "Journal of Open Source Medical Computing"[27].

Open Source Health Records

Most open source EHRs are intended for small physician practices, but some are specifically developed for hospitals such as *OpenVistA* and *care2x*. *OpenVistA*[28] is the open-source version of VistA, a very complete Computer-Based Patient Record (CBPR) using the MUMPS programming language. It is probably the largest healthcare FOSS collection worldwide. It was developed by the U.S. Department of Veteran's Affairs (VA), and has been used throughout this organization since 1982. It was first known as DHCP (Decentralized Hospital Computer Program) [22]. Many other organizations have adopted VistA worldwide, like hospitals in the U.S., Malaysia, India, Finland, Germany, Egypt, Uganda, Nigeria, Colombia, and Pakistan. The source code was made available under the U.S. Freedom of Information Act (FOIA), and is in the public domain. Despite the availability of source code, it is

[21] http://homeusers.brutele.be/ypaindaveine/opensource/inventory.html
[22] http://www.linuxmednews.com/
[23] http://www.minoru-development.com/en/healthcare.html
[24] http://www.centerforhit.org/x135.xml
[25] http://www.hi-europe.info/library/opensource/default.htm
[26] http://medecinelibre.nuxeo.org/
[27] http://www.josmc.org
[28] http://www.worldvista.org/openvista/index.html

difficult to set up a working installation, mostly due to the knowledge needed in the MUMPS language and the complexity of the application. Medsphere[29] provides a commercially supported version of *OpenVistA*. A fully open source version is also available using an open source version of MUMPS called GT.M running on Linux. We tried installing the software but the installation of GT.M was already difficult, and only a bootable CD version supplied by VistA was finally tested.

Care2x[30] is a complete software package for hospitals and health care organizations (available in German and several other languages, with a description on how to perform a translation). It is designed to integrate data, functions and workflows in a healthcare environment. It is currently composed of four major components: hospital/health service information system, practice management (for general practice), central data server, and health eXchange protocol. Each of these components can work individually. *Care2x* is used in Italy since December 2004, at the "Policlinico Umberto I di Roma" in Rome. The system also exists as a Mac OS X version. Live demonstrations of the modules are available on *Care2x* website. The system is based on Linux, MySQL and PHP. The interface is based on web technologies and can be used with any web browser. Input screens can easily be adapted to a hospital's needs and installation is easy.

FreeMED[31] is a practice management and EHR system based on MySQL and PHP, working well on a Linux system. It is HIPAA-compliant (Health Insurance Portability and Accountability Act), and provides billing with a separate application called *FreeB*. It is "Episode of Care"-based, and allows the tracking of detailed medical data, with preservation of the diagnosis and reasons for medical encounters. Outcome data can be abstracted locally. Commercial support for FreeMED is available. It is easy to install and to customize for a local environment. *OpenEMed*[32] is a Java application developed at Los Alamos National Laboratory. It is an intuitive patient record system with multimedia support and remote sharing of medical data. It uses a platform independent language (Java), distributed objects, and

[29] http://www.medsphere.com/
[30] http://www.care2x.com/
[31] http://www.freemed.org/
[32] http://www.openemed.org/

distributed databases, with public key encryption. A prototype has been released as FOSS. *OSCAR*[33] (Open Source Clinical Applications and Resources) is a web-based office management and medical record system for family practice developed and used at McMaster University (Hamilton, Ontario, Canada.). It provides registration, scheduling, medical records, and a Canadian billing component. It also offers a patient portal. It is open source at all levels, running on a Linux or BSD system and based on Zope and MySQL. Installation and changes are easy. *GEHR*[34] (Good Electronic Health Record) is a framework for developing medical record systems, derived from a European research project [23]. It is not a medical record or office practice system per se, but an international attempt to develop open standards for record interchange between different systems. Systems based on *GEHR* have been developed, and work is underway in Australia to make the system available in the entire country. *Access GP*[35] is a general practice EHR based on MS Access and Word. It provides patient registration and records with multimedia content, calculators, scheduling, billing, and other administrative tasks. *FreeEHR* is based on FileMaker, designed by physicians and used in the U.S. and developing countries. Developed on Mac OS, it also runs on Linux and Windows, providing a patient record with multimedia content, growth charts, practice statistics, scheduling, prescribing, and billing. Running on a proprietary database management system, it is not fully open source. The *GNUMed*[36] group is developing a system for general practice, but is not ready for clinical use yet. It uses Python for programming, is based on PostgreSQL, and is cross-platform. A German version is developed at the same time as the English version.

OIO (Open Infrastructure for Outcomes[37]) is an EHR and Quality Assurance System aiming to facilitate data portability. Major components of the *OIO* system are the web-accessible Server and Library. The *OIO* Server is a flexible web-based data management system that manages users, patients, and

[33] http://www.oscarmcmaster.org/
[34] http://www.gehr.org/
[35] http://www.accessgp.com/
[36] http://www.gnumed.org/
[37] http://www.txoutcome.org/

information about patients. The *OIO* Library is a metadata repository that facilitates sharing of metadata between users and *OIO* Servers. The *OIO* Library also hosts a database of open source medical software projects and related documents. *OpenEMR*[38] is a practice management and EHR application with e-prescribing and billing functions enhanced by *FreeB*. *OpenEMR* also exists for Mac OS X. In the Netherlands, *OpenKaart*[39] (in Dutch and English) is a general practice system developed incrementally, with preliminary parts being available such as OpenSDE, a patient data entry tool. *SQL Clinic*[40] is a multi-specialty EHR that is HIPAA-compliant. It offers administrative tools, alerting functions, and quality assurance features. The system is fully open source and programmed in Perl. It uses the Apache server on a Linux or FreeBSD system, with PostgreSQL or MySQL. A Windows version is also available. *SQL Clinic* is in use in the U.S. and South Africa. *Tkfp*[41] is an EHR for small practices in family practice, pediatrics, internal medicine, or primary care, with billing features. It has been in use in two small physician practices in the U.S. since 5 years. It is based on Tcl/Tk, but also C,C++, Python, and Perl, running on Linux and Windows XP. *TORCH*[42] (Trusted Open source Records for Care and Health) is a multi-specialty application derived from FreePM and based on Zope. It is a web-enabled EHR application. TORCH is usable in single practitioner and multi-site practices.

Some promising open source EHRs are currently in development, like *Res Medicinae*[43], a German project using CYBOL (Cybernetics Oriented Programming*)*, an XML-based programming language and as such completely platform-independent (available in German). *OpenEHR*[44] is a British foundation developing open-source specifications, software and knowledge management resources. An interoperable, life-long electronic health record is projected, but only specifications are available yet that are already used in some ER projects [24]. *X-Sys Life Record*[45] is a web-based EHR already

[38] http://www.openemr.net/
[39] http://www.openkaart.org/
[40] http://www.sqlclinic.net/
[41] http://tkfp.sourceforge.net/
[42] http://www.openparadigms.com/
[43] http://resmedicinae.sourceforge.net/
[44] http://www.openehr.org/
[45] http://www.liferecord.com/

available for testing and scheduled for release in February 2005.

Other medical open source applications

Other open source applications developed for healthcare range from decision support tools, to terminological resources. A Linux distribution for healthcare has even been developed - *Debian-Med*[46] - to ensure smooth integration of third party medical software into Debian. It is distributed via the well-known Debian Linux distribution and includes a very large number of programs with an *official*, *unofficial*, or *not yet a Debian package* status. Packages are listed in categories, like practice management, hospital management, imaging, pharmacy and research. All packages are included and tested in the distribution.

BolinOS[47] (also available in French and German) is a Content Management System developed with medical web-based applications in mind. It uses standard FOSS: PHP, Apache, MySQL. A version for healthcare is available: BolinOS Med. This medical online authoring software and web-based system is suited for many configurations in internal medicine, radiology, surgery and research, from individual healthcare professionals to large hospital structures. It provides a DICOM viewer and other image formats, XML compatibility, coding (ICD-10) modules and options like synchronization with Palm OS handheld devices. It is used at the radiology of the University Hospitals of Geneva to manage the Intranet and personal pages. *iPath*[48] is a general-purpose telemedicine platform, more focused on telepathology. The core functionality is the "iPath-Server" with specialized modules developed on top of it. The most important module is a microscope controller, a combination of a client application for a remote workstation and a Java applet allowing controlling a microscope remotely over the Internet. *TeleMedMail* is another telemedicine application developed to allow telemedicine in developing countries where network connections are often of poor quality. It includes text entry, image processing and compression, and encryption, and uses email to transmit data with images [25].

[46] http://debian.org/devel/debian-med
[47] http://www.bolinos.com/
[48] http://ipath.sourceforge.net/

DOCS4DOCS is being developed at the Regenstrief Institute for Health Care in Indianapolis as a report distribution system for delivering clinical documents such as laboratory reports, discharges summaries, and radiology reports. In these reports, the system captures reports as HL7 messages or print streams and stores them as PDF fragments. The office practices subscribe to the service for their physicians, and define the kind of report they want to receive. The reports are stored as PDF fragments that can be combined into a PDF document in any sort order for printing or archiving. This system is written in Java, uses PostgreSQL as its database, and runs on the Apache web server, all open source applications. This program has been delivering reports to more than 100 office practices in Indianapolis in 2003 already, and is planned to be made available under the Apache open source license [18].

Some medical controlled vocabularies and ontologies are available as open source, like *LOINC* and *OpenGALEN* [26]. *Protégé* is a famous ontology and knowledge-base editor [27]. For decision support, the Arden Syntax allows the encoding and exchange of medical knowledge [28], and CLIPS[49] allows developing rule-based expert systems. Finally, MedNotes[50] is a decision support resource with many decision support tools for various platforms.

Discussion

Even if many FOSS solutions exist for the medical domain, they are only seldom used in big hospitals in Europe or North America, because budget for large proprietary software is often available and the responsibility of persons responsible for information systems is important. Barriers to the open source movement in the healthcare industry are numerous. Almost all software is currently more or less proprietary. The health information technology leadership tends to be conservative, and senior management has been eliminating the in-house technical and developmental teams that could best leverage FOSS to the advantage of the institution. Furthermore, healthcare systems operate large,

[49] http://www.ghg.net/clips/CLIPS.html
[50] http://www.smartie-ist.org/en/

complex, and 24-hours nonstop operations, face heavy and changing regulatory burdens, and have strong implementation, support and maintenance requirements. All these needs are not always fulfilled by FOSS. Vendors will need to be convinced by open source software to make it a success as only few hospitals still have real development teams that could customize and maintain an open source solution.

In the related field of bioinformatics, a large proportion of the software used is open source. Numerous FOSS for microarray analysis, genome annotation, visualization, clustering, and other tasks have been developed and are widely used in this young community where commercial software was far less present than in the healthcare domain. This successful development of FOSS could be a good example for the healthcare domain.

In the general domain, the level of use of FOSS varies widely between countries. In a survey conducted in Europe in 2001-2002, 43.7% of the German establishments were using FOSS, but only 17.7% of the Swedish establishments [8]. A study commissioned by the UK Government in 2001 [29] predicted that within five years, FOSS could take 50% of the volume of the software infrastructure market, and that in the developing world, FOSS on the desktop may soon become a significant competitor to Microsoft.

During the FLOSS survey [8], the most frequent reasons to use FOSS were: higher stability and better protection against unauthorized access, also with higher performance; low or zero license fees; indirect cost savings from using FOSS, for installation, administration, and customization; only fourth came the open and modifiable source code. Another reason frequently mentioned was “because we want to be more independent from the pricing and licensing policies of the big software companies”.

FOSS has many advantages, but also disadvantages. There is a lack of formal scientific evaluation to show evidence of most of the benefits seen by users of FOSS, but users consistently report some advantages. Reliability and security are important qualities of FOSS. Source code can be inspected by many, and can be maintained even if the original developers are no longer available. The quality builds on many high quality already available components. Developers can build on them and spend their time exploring new and unsolved problems rather than duplicating efforts [12]. Frequent and close peer

review of source code results in software being better engineered, more secure and less "buggy" than commercial products. About 120'000 programmers worldwide contribute to the development of Linux. As Linus Thorvalds said, "given enough eyeballs, all bugs are shallow". There is no evidence yet, that FOSS applications are more reliable than commercial products, but availability of source code makes immediate fixes for identified problems possible.

FOSS has generally a lower total cost of ownership than proprietary software, which is its largest economic advantage. The absence of licensing cost is a major attraction, but for most organizations, licensing is only a fraction of the total cost: customization, implementation, training, maintenance, and upgrading cost far more. Dependence from vendors is reduced, avoiding the "lock-in" with its related problems when vendors disappear or decide to stop supporting proprietary software. Many healthcare organizations have made the painful experience of a supplier going bankrupt, leaving them with the need to change the system. Some happy few had source code kept with a third party escrow, a way to reduce the risks of vendor lock. For many other reasons, vendors can demand high prices, knowing that changing the system or the vendor would be even more expensive to the client.

FOSS has a higher compatibility with open standards than proprietary software. It runs on a wide range of hardware, and interoperates with most operating systems. FOSS also has other benefits, ranging from the fact that user needs are often a major driving force behind the development of solutions, to the flexible development process with rapid reactivity and innovation spread. A major quality is the improved accessibility to products in developing countries. The use of FOSS has become a central issue in strategies to reduce the digital divide, the growing technological and commercial gap separating industrialized rich countries from developing poor countries. Cost is the first argument, knowing that few developing countries can afford the cost of proprietary software (not talking about maintenance contracts). For example, in Vietnam, the cost of Microsoft Windows XP and Office is higher than the average annual income! National sovereignty is another argument against proprietary software (often American like Microsoft's products) from public administration in other countries. Minorities remain at

the mercy of large multinational companies regarding support for their culture and language when using proprietary software, while FOSS gives them the freedom to modify all software according to their needs.

In healthcare, FOSS would provide healthy competition to the existing closed source commercial market, encouraging innovation whilst promoting compatibility and interoperation. This ultimately will lead to systems that are lower cost, better quality, and more responsive to changing clinical and organizational requirements [4].

A disadvantage of FOSS is the problem of accountability in the case of errors, since FOSS does not have any established line of accountability, but vendors should step in here. Another potential disadvantage could arise when FOSS vendors have support as their main revenue stream. They could then have a perverse incentive to increase the number of support calls.

Initiatives to encourage the use of FOSS are developing, particularly in Europe and in Asia. In Europe, the European Commission's initiative called "eEurope 2005: An Information Society", set the target "to promote the use of open source software in the public sector and e-Government best practice through exchange of experience across the European Union". The UK Government has issued a policy for use of FOSS within the UK Government [30]. This policy states that the UK Government will consider OSS solutions alongside proprietary ones. But it also says that it will only use products that support open standards, that it will seek to avoid lock-in to proprietary IT products, and that it will consider obtaining full rights to bespoke software code, all three requirements suggesting that the use of FOSS is obviously wanted. The French Agency for Information and Communication technology was given the assignment in 2001 to ensure governments projects use FOSS whenever possible. In 2004, the administration of Paris announced that it was considering replacing its proprietary Microsoft systems with FOSS such as Linux, OpenOffice, and Mozilla. In Germany, the city of Munich had taken this decision in 2003 already and has installed the first working test desktops.

Around the world, many countries have adopted laws or are discussing laws about the use of FOSS in

their government. The state of Rio Grande do Sul in Brazil was the first administration to make FOSS use mandatory in government agencies and non-government-managed utilities. In China, the government decided that the nation should not be subject to another nation's software. An important effort is put into a national version of Linux, called "Red Flag Linux". To fight in the desktop area, China has teamed up with South Korea and Japan to develop a Linux-based system for their countries [31]. The Peruvian government has introduced a bill in 2002 regarding the use of FOSS in its government and saying that companies could charge for software and support, but that the source code must be open source to be used in any government application. In Malaysia, the public sector open source masterplan made available in 2004 states that "in situations where advantages and disadvantages of OSS and proprietary software are equal, preference shall be given to OSS." [32]. Besides these countries, many others are actively looking at having legislations regarding the use of FOSS, including South Africa, Ukraine, Portugal, and Bulgaria.

To accelerate an open source movement in healthcare, most helpful would be a policy to encourage or require that all software developed with public funds be released under an open source license. Leaders in the bioinformatics field have argued that in the U.S., all federally funded bioinformatics software should be licensed under the open source model [33]. Public funding agencies should also require the use of widely deployed health informatics standards in all funded development. They should encourage the use of existing low level open source building blocks as the foundation for building the next level open source software. Finally, having a mechanism to promote awareness of the potentials of FOSS among the medical community can be extremely helpful. The AAMC (American Association of Medical Colleges) is currently considering a proposal to maintain an open source web site. Their initial aim is to educate university medical centers about the benefits of general open source software. To advocate the use of FOSS in healthcare, different organizations have been created in the last years, like OSHCA and the IMIA and AMIA working groups in open source. To stimulate the adoption of EHRs by doctors in the U.S., the Center for Medicare and Medicaid Services (CMS) is developing a version

of VistA, called VistA-Office in conjunction with VA officials. This new system is targeted to small medical practices that have one to eight doctors. It will provide them with a number of modules adapted from VistA, including the CBPR. It will also have new modules for pediatricians and gynecologists and a patient registration system. The system is planned to be available in July 2005. A license fee will be needed for the underlying Caché programming language, a language based on MUMPS [34].

The development of FOSS also depends on economic and organizational factors that will have to be taken into account. Organizations developing and/or providing FOSS can be profitable by selling products or services. Products can be packages easing the installation and use of FOSS, like Linux distributions, or proprietary products including FOSS. Different services can be sold like consulting, application implementation and integration, customization, training, support, and application management, ensuring that the software is continuously performing in the way desired. Large companies developing open source products such as IBM or Sun Microsystems have motivations like standardizing alternative operating systems, therefore reducing costs due to multiple software versions. They also lower the cost of software bundles by integrating FOSS, and improve compatibility of their own hardware or software products when making it compatible with FOSS. Finally, some strategic considerations motivate open source developments, to weaken competitors or enhance the popularity of their own products.

In the long run, any successful open source application will need an organizational structure to allow the process to grow and also money to finance further development. Linux and Apache are successful examples. The Linux model uses a centralized control organization model largely controlled by the original author and a group of close colleagues. Proposals for new applications are rigorously screened on the basis of the program code quality, and the extent of current use of the proposed addition. Less than 1 in 50 proposals is adopted. The Apache consortium is based on a loose confederation in which the participating organizations vote on proposals for new directions.

The development of FOSS also depends on the acceptance and use of standards. Linking open source

modules to independently developed commercial software packages is facilitated by a strong underpinning of deployed standards. Standard interfaces between knowledge sources, communication tools, and patient records, together with interpersonal communication skills, will enable the presentation of new material, and revision of the old, to proceed in real time in the consultation, enabling doctors to be better guides and teachers for those whom they serve [16].

This article can only highlight a small fraction of the open source projects that are usable in the medical field. The field is in constant movement and new projects are created regularly, which is also one of the problems with open source software. Although there are a few well-known projects with high visibility and very good quality, there are a large number of projects for which the quality is very hard to estimate. It is not sufficient to just create a project and make it open source to attract programmers and users. Quality criteria will need to be defined before making the decision to employ any open source software and the activity and possibility to obtain help quickly will have to be assured.

Conclusion

This article gives an overview of the large amount of available FOSS that is usable in the medical domain. Although currently only rarely used in hospitals, open source has a lot of potential to help control the rising cost of our specialized health care and health system by sharing source code and knowledge, and by avoiding redevelopment and overprizing by companies. There are also several problems of open source including:

- Difficulty to judge the quality and completeness of an open source project that is available on the Internet;
- Lack of support by vendors and lack of a guaranteed quality of service and responsibility in case of errors;
- Fear that third parties can include malicious code into software subsequently being used.

On the other hand, there are a number of undeniable advantages including:

- Vendor independence through the availability of source code;
- Reduced risk for the user in case of bankruptcy or change in direction of the software producer;
- Reduced total cost of ownership, including maintenance, software adaptation and user training;
- Ease of adapting the software for special needs;
- Reduction of the risk to loose data when migrating to a new software solution;
- Help through a large user community.

In many Western European hospitals, FOSS will remain in small areas of the market for a while, most likely as a server operating system and for specialized application for another couple of years. In several countries in Asia or Africa, there is actually no alternative to using open source operating systems and patient records on old hardware, as no money is available to buy and maintain expensive medical software. In this scenario, it is important to teach the use of FOSS in these countries so that it can be maintained in a sustainable way in the future, without creation of dependence.

For a brighter future of OS medical software, it is important to create quality criteria, so that a user can possibly judge the quality of available projects and exchange information with hospitals already running the software. It is equally important to motivate vendors to use and support FOSS in a similar way as RedHat and IBM do in the Linux field. Only this can help convince large hospitals to adopt an open source strategy because responsibility for failures and guaranteed service quality are needed.

One of the important future developments of FOSS is the definition and development of small building blocks for a health information system that can subsequently be combined to a larger system through standard communication interfaces. This possibility to create a large system made of small components was one of the reasons for the success of FOSS (Linux, Apache, PHP, MySQL, etc.) in the Internet field, and it could also become a success factor in the medical domain.

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