The iPath Telemedicine System

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Telemedicine for Improving Access to Health Care in Resource-Constrained Areas – from Individual Diagnosis to Strengthening Health Systems,

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The original chapter has been re-formatted to fit this document.

Since the mid 1990s, the Department of Pathology at the University of Basel has been researching in the field of telepathology. Early applications included remote frozen section diagnosis with the regional hospital in Samedan [114, 115, 137]. Like many other telepathology systems [112, 133, 151, 156], this application was focused on a point-to-point interaction using specific hardware and software to allow remote collaboration. With fast development of the Internet, a common and relatively inexpensive network has become available almost anywhere in the world. Additionally, modern web browsers have developed to a standard way of accessing information over the Internet, and they provide enough functionality to allow complex applications such as e.g. the remote control of a microscope [16, 62, 122].

In 2000 it was decided to replace the telemicroscopy system at the Department of Pathology in Basel (a point-to-point solution) by an open, web based solution that allows collaboration between any interested pathologists without the need to acquire and install any specific hardware or software. Though some commercial solutions had been available, none met these requirements. The new system was designed as a web based platform on the basis of the PHP programming language and was released to the general public in 2001 in form of the open source iPath telemedicine platform.

The scope of application of the iPath software changed significantly, when we were approached in 2001 to provide pathology support for a hospital in Solomon Islands. In contrast to the original project, targeting to pathologists in Europe where internet connectivity was not an issue, we were now suddenly confronted with the problems of resource-constrained areas, where infrastructure is minimal and internet connectivity slow and often unreliable. While some projects tried to address this problem by developing solutions that target specifically at low resource settings [49, 140] we decided to integrate the collaborations with partners in developing countries into the same framework that we had started to develop for our own purpose. Although this approach was technically more challenging, the decision was based on the assumption that the most limiting factor will not be technology itself but the availability of volunteering medical specialists. Our intention was to lower the threshold for recruiting new specialists by developing a comprehensive and functional platform that lends itself as a useful tool also for collaboration within groups of specialists.

The following chapters will give an overview of design of iPath and on possible applications. Chapter 5 summarises the functionality and architecture of the iPath telemedicine platform, chapter 6 analyses the technical details of the telemicroscopy module, chapter 7 will describe the major applications of the server in Basel and chapter 8 illustrates some examples from developing countries in more detail.

This part is focusing on the methodological aspects of the software infrastructure developed and refined throughout my PhD thesis. The specific methods of the concrete telemedicine applications such as laboratory equipment and image capturing devices are provided separately by each chapter in part III.

5. Description of the iPath Telemedicine Platform

5.1. Technical Background of the iPath-Server

During the scope of the project a web-based telemedicine platform was developed. The platform was named iPath – Internet Pathology Suite – in the initial phase when the applications where exclusively from the field of pathology. In the first version, iPath was basically a set of web dynamic web pages written in the PHP language[1] that had grown out of some preliminary projects at the Department of Pathology. This original version was intended as a proof of concept. Due to its user-friendliness and its ability to accommodate the needs of doctors in developing countries as well as the needs of specialists in western Europe it found good acceptance.

Unfortunately, the original version was not developed following a clear development model and it did not have a good separation of data and visualisation layer. Furthermore, with the steady increase of users and applications utilising iPath, the original version had become very slow. In early 2005 it was decided to develop a completely new version of iPath. This version 2 of iPath includes now an API (Application Programming Interface) which provides a set of classes and functions to access all data stored in the database. In addition, there is now a well-defined concept for splitting the code into independent modules. This greatly facilitates the development of additional modules without changing any of the core code.

A modular and extensible concept is important to allow other organisations to extend and adapt iPath to their own needs. iPath is released under the General Public License (GPL) as Free and Open Source Software (FOSS or OSS) and is thus available to others for usage as well as for modification under the condition that all modifications and improvements are again made available under GPL. Hence, if iPath lends itself to modification and adaptation by others, there is an increased chance that iPath will continue to be developed on a larger scale and by a broader team of developers even after the termination of this very project.

5.1.1. Basic Functionality of iPath

iPath was designed to facilitate consultations and collaboration between different specialists and health care providers. Essentially, iPath offers a collaboration environment for groups of people working together. The basic model for collaboration in iPath is that of a virtual community – a closed user group in which participants can present and discuss medical cases and problems. Every community or group has one or more members that act as moderator who can grant other users access to the group.

Within a group users can create and present content such as a case with a clinical description and attach documents such as images, video clips or forms for capturing alpha-numerical data. Once a case is presented inside a group, other group members can add their comment to the case. Comments are essentially text messages that are attached to a case. In a typical consultation the diagnosis of the experts are inserted as comments. In contrast to other data types, comments cannot be altered by users. Once saved a comment cannot be changed. Only system administrators have the possibility to delete a specific comment. This is important to ensure a certain carefulness from the side of the experts and to make the process of finding a diagnosis transparent. In contrast to email based consultations or video conferences, iPath records the whole diagnostic process and makes it transparently available to all group members.

5.1.2. Application Layers

The new iPath-2 is built in a modular way to ensure that it can easily be extended and adapted to new situations. At the core of iPath is a relational database storing all alpha-numerical information. iPath uses a database

[1] http:/www.php.net

abstraction layer (adodb[2]) to ensure compatibility with different databases. At present the open source RDBMS MySQL[3] and PostgreSQL[4] are supported (c.f. fig.5.1).

Most data stored in the database can be accessed using an object oriented API. This API consists of a set of classes which represent users, groups, cases, images, annotations, etc. All classes are derived from a base class (ipath_Object) and the API is extensible in a modular way so that new classes for new data objects can be dynamically added without the necessity to change anything in the core code base. Besides access to data, the API also includes abstraction for general functionality such as registering events (e.g. new case received) with specific alerting methods (e.g. sending an email). A partial documentation of the API is available on the iPath website[5].

5.1.3. The Data Model

iPath is storing four basic types of data objects: users, groups, data objects (cases, images, etc.) and annotations. Technically the iPath API offers a base class (ipath_Object) from which all data classes are derived. This base class takes care of storing and retrieving data from the database and is handling access control.

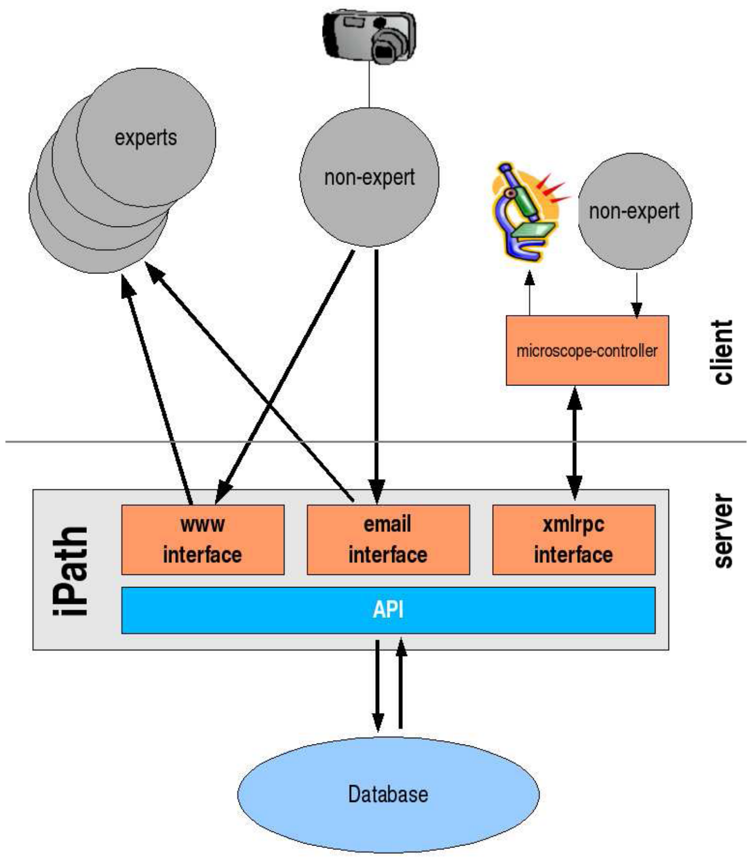

Figure 5.1.: Illustration of the application layers of iPath. At the core is a relational database. User access to the database is provided through different application interfaces (web, email, telemicroscopy). All these interfaces use the iPath API, which provides a set of classes to access data stored in the database.

2 http://adodb.sourceforge.net
3 http://www.mysql.com
4 http://www.postgresql.org/
5 http://ipath.ch/

For the “data objects”, only information about the relation between objects are stored as fields in the relational database. The medical content is encoded as XML (eXtensible Markup Language) and is stored in the database as a text field. This guarantees a maximum flexibility for creating new data types for representing medical data and findings without the necessity to change the underlying database scheme. The visualisation of medical data on the web interface is done through XSL (eXtensible Stylesheet Language) by applying an XSL stylesheet on the data XML. Thus, new data objects can be created basically by writing a new XSL stylesheet.

Additionally, it is possible to collate several XML objects into a larger XML file. This makes it easy to recursively concatenate all objects representing a medical case (case data, images, folders with images) into one XML file that can be exported. Similarly it is possible to concatenate all cases within a group with all their data into a large XML file which can then be further processed for statistics and analyses using standard XML tools.

All data is stored in UTF-8 character encoding to ensure data input in non-European languages.

Custom Forms

A peculiar data object is the “custom forms” module. This module was developed to provide a very easy way of creating forms for capturing and storing arbitrary alpha-numerical data in iPath. A plain HTML form is used as template for the graphical representation of data. The custom forms module of iPath can automatically transform such an HTML form into an XSL stylesheet. iPath can then use this stylesheet to display a form on the web interface. Data entered by the user is stored as XML in the database. In addition, the form module allows to export data from all forms of a certain type for a whole group in form of a text or HTML table that can be opened with a standard statistical software package or a spreadsheet (e.g. MS Excel) for statistical analysis.

5.1.4. Visualisation

Web Interface

On top of the API there are a number of interfaces to access the data stored in iPath (fig.5.1). The most prominent and frequently used is the web interface that allows access to the data over the web. The web interface offers the most complete set of functionality and is the only way to access the administrative functions. For transforming medical data stored in the data objects into HTML, iPath uses XSL stylesheets which transform the XML coded data into HTML – a procedure termed XSL transformations (XSLT). Other parts of the user interface, mainly administrative pages and settings, are directly rendered as HTML. The advantage of using XSLT is that the stylesheets (XSL) and data representations (XML) are completely independent of programming language and allow utilisation and manipulation of data by external processes written in other programming languages (e.g. Java).

Multi-Lingual User Interface

The user interface is available in multiple languages. A module for on-line translation of the user interface is included in iPath. The translated strings are stored in an XML file which is included by the XSLT process when data objects are rendered. Additionally, the XML files with the translated strings can easily be copied from one server to another, thus translations can be prepared on a test instance and then copied to a productive environment when they are finished. At the moment translations exist for English, German, Spanish, French, Italian, Ukrainian, Lithuanian, Russian, Georgian and Rumantsch. Of course, users can enter content like case descriptions or comments in any language which is supported by the UTF-8 standard.

Email Interface

Besides the web interface, iPath offers an email interface which makes a limited subset of the functionality available over ordinary email. A registered user can submit consultations via email and iPath will import it into the database so that the consultants can access it over the web. The email interface also offers users the possibility to subscribe to email notifications on specific events. Alerts can be defined specifically for each group on iPath. Optionally, the emailed alerts include a full text report with case description and comments of other group members. These reports also contain specially coded “mailto:” links which can be used to trigger a replying email through which the user can 1) retrieve the images for that case or 2) add a comment to the case or 3) if permitted, even add another image to that case by plain email. These emails contain a control hash that identifies the action to be triggered by this email and iPath will securely import data from such emails and add it automatically to the appropriate object in the database.

In contrast to other telemedicine systems developed especially for developing countries that use email for data transmission [49, 169], iPath is a full fledged web application that can handle large amounts of users, organised in many different virtual communities, and large amount of data (100’000 or more images). It is not routing emails to the most appropriate specialist, but imports all cases and comments submitted by email into the same database that can also be accessed over the web interface. Users that have access to email only can still actively participate in the same virtual communities that other users access over the web. While a physician from a remote hospital may chose email to submit cases and receive comments, the consultants in the same group can access the full functionality available – for example, duty plan, drawing applet for annotations in images, web-meetings for the on-line discussion of cases, etc.

An optional module for importing email from the TeleMedMail [49] application is available.

XMLRPC

While the web and email interfaces are intended for human interaction with the database, iPath also offers an interface for interaction with other computer applications. This interface is based on XMLRPC – remote procedure calls (RPC) encoded in XML. This interface offers an API for other modules on iPath to publish certain functions as remote procedure calls accessible to applications running on a distant computer and which can be written in any programming language that support XMLRPC (e.g. JAVA or python). The XMLRPC interface is used e.g. by the telemicroscopy module and also by some specific application to import data into iPath. For example, there is an external application (ImageDrop) which allows importing large amounts of images by drag and drop (current web browser unfortunately do not offer drag and drop functionality).

5.1.5. Modular Design

To encourage further development and adaptation of iPath to other needs, the new version is designed in a very modular way. Almost all functionality is encapsulated into concise modules. The most prominent modules are the content modules that contain the data objects like for example case, image, file, folder, video clip, drawing, etc. Another type of modules are the work flow modules which allow users to simplify a certain task like email alerts or the virtual institute module with its duty plan.

There is a basic set of modules which are essential for the functioning of iPath. These modules are included with the basic distribution of iPath. Other modules that do not include any essential functionality can be optionally enabled through the administrative interface. In addition to the modules bundled with the base distribution, there is a growing number of additional modules which can be added to an iPath installation on an individual basis.

Enabling Modules Group-specifically

One of the most important design considerations for iPath was to keep its user interface as simple as possible. While it is nice to have a lot of optional functionality, medical specialists are often rather deterred by too many buttons and options. In order to provide unrestricted extensibility for some users whilst keeping the user interface simple for others, it is possible to enable certain modules only specifically for certain groups.

5.1.6. Security

All users must first register a user account on the server by filling out a on-line form. When the registration form is saved, iPath will create a user account but mark it as inactive. An activation email is sent to the email address specified by the user. This email contains a special link through which the user must then activate the newly created account by logging in with the password chosen on registration. This procedure ensures that registration is only possible with a correct email address and that the user can receive email on this address.

There are three types of users on iPath. *System administrators* are users that are members of a special admin group. They can access a special system administration interface for configuring and monitoring the system and they can edit almost all data, except comments which can be deleted, but not modified. Besides system administrators there are *moderators* who have some administrative permission for the groups that they moderate – most importantly they can grant and revoke access to the group to other users and the can delete unwanted content from the group. One user can be moderator of multiple groups and one group can have multiple moderators. Normal users finally have access to the groups to which they were granted access by a group moderator and they can only edit or delete content which they have created themselves.

To improve security for data transmission we offer access to our server over https (encrypted http). This feature is not part of iPath itself but can be configured on the web server that iPath is installed on. However, it is possible to configure iPath in a way that iPath switches automatically to encrypted mode, if encryption is available on the web server.

All modifications to content objects are logged to ensure that the full history of changes can be reconstructed at any time. Most administrative requests such as user registrations, password reset requests or granting access to a group are logged by the “watchdog” module. This module also logs every attempted access to content to which a user does not have permission. The watchdog logs the IP address of the remote user, the URL which he tried to access as well as all data submitted via GET or POST requests. Other modules can use the watchdog module to register their own errors and other messages. System admins can access the watchdog entries from the system administration interface.

5.1.7. Advanced Functionality

Beyond the basic functionality of a multi-media discussion forum with closed user groups, iPath offers a number of additional functionality designed especially for telemedicine. Most of this functionality is encapsulated into separate modules in order to make future extensions and adaption easily possible. The most important functionality specifically designed for telemedicine is described in this section.

Virtual Institute / Duty Plan

The virtual institute is a module that enables the organisation of diagnostic consultations. The module itself provides the functionality for the organisation of a duty plan which can then be attached to an expert group. In addition it can create a list of all cases that are not yet closed from an arbitrary number of groups. The usage for this module for the organisation of a virtual institute is illustrated in fig.5.2. A description of its application is provided in chapter 9.

Telemicroscopy

The telemicroscopy module allows real-time remote control of a microscope through the iPath- Server. Routing the remote control through an external server rather than a point-to-point connection offers the advantage that the session can be automatically archived into the database on the server. In addition it eliminates the need to configure firewalls in order to allow access from a workstation outside of a hospital to an microscope which is located inside a hospital. This functionality is described in detail in chapter 6.

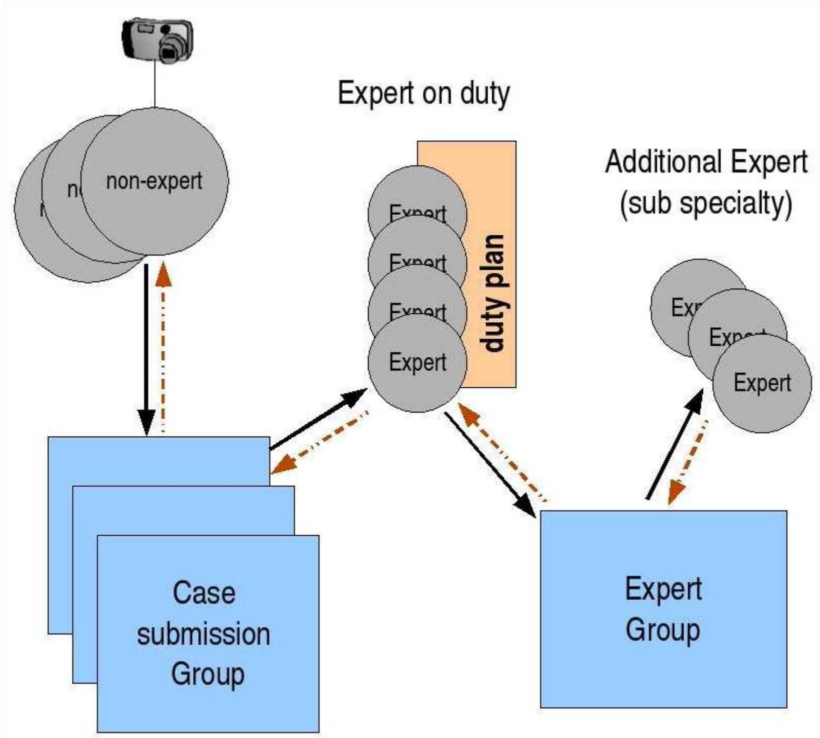

Figure 5.2.: Illustration of the organisation of a virtual institute. The virtual institute consists of one or more case submission groups to which the original consultations are submitted. The expert on duty is automatically notified and can, if possible, write a diagnosis immediately on the original case. If consultation of additional (sub-) specialists is desired, the case can be referred to the expert group. In this case all additional experts are notified and can contribute their diagnosis and comments. Finally, the expert on duty summarises the opinions of the experts and states this as a "final diagnosis" on the original case.

The functionality of this module has been extended since the publication of this article and now includes support for several other types of microscopes, e.g. Leica DM Family and the Nikon CoolScope.

Data Export and Import

iPath offers several possibilities for exporting and importing object data. iPath offers the possibility to export any data object in its XML representations. If an object export is requested, iPath will create a full XML of the object and all its child objects recursively. This XML is bundled together with binary data files (e.g. images) into a zip file which is passed to the user. Conversely it is possible to re-import such exported zip files into another group or even into another iPath server. The only potential problem can be that on the target instance some optional object modules are not installed and the import will be aborted.

The import/export system is easily extensible and developers can write their own import or export plug-ins. Plug-ins can be made part of an add-on module and then a system administrator can enable them group-specifically. Custom export modules developed at the University of Basel include export of a case as pdf file or the export of all comments or data stored in custom forms.

Web-Meeting and Distributed Presentations

The distributed presentation module allows publication and real-time discussion of a case over Internet. The module offers the synchronised viewing of a case using a text chat and a shared pointer. Cases can be discussed within the closed user group or can also be published so that the audience need not necessarily log in on the server. The synchronisation of text messages, image display and position of the shared pointer is implemented using AJAX technology.

Any object that is stored in iPath can be presented through the distributed presentations module. For large audiences with more then 20 participants it is useful to cache the content of a presentation for faster loading and to decrease the database activity during a presentation. iPath offers the possibility to cache the presentation, in that situation, however, only images can be presented. Other objects such as custom forms, drawings or text slides will not work with a cached presentation.

This module can be used for real-time discussion of a case (web-meeting) as well as for distance presentations. There is an option to combine the distance presentation with an audio streaming server for the live transmission of the voice of the presenter. On our server we have implement audio transmission as low bandwidth MP3 streaming using the open source IceCast2 streaming server software[6]. The distance presentations are useful for distance education and are used by the

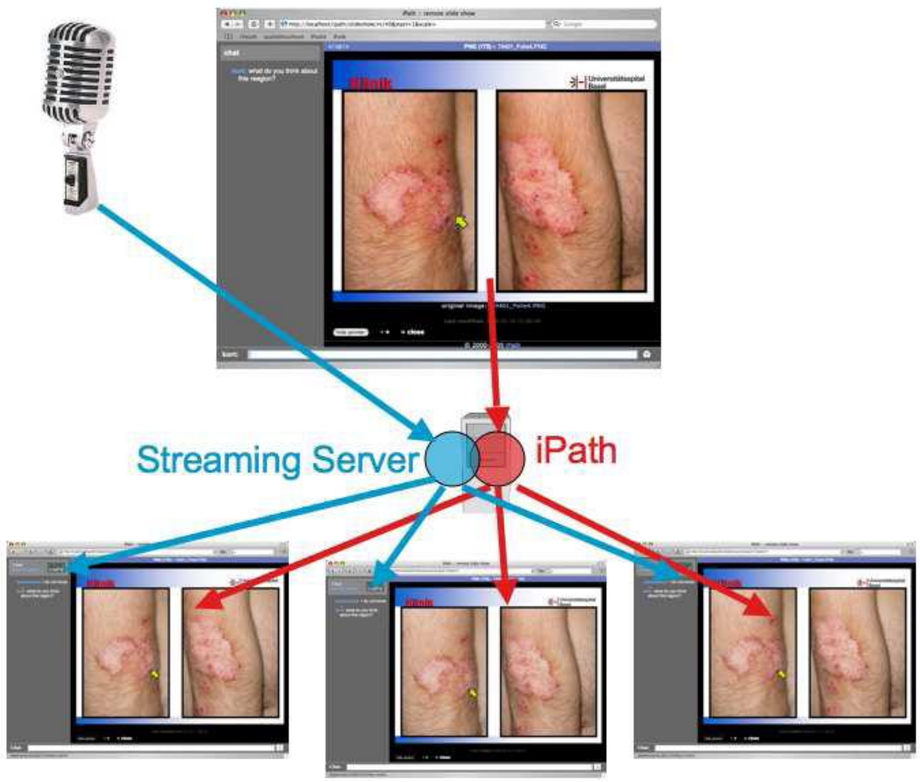

Figure 5.3.: Illustration of a distributed presentations through iPath. The images, chat and shared pointer are distributed directly by the iPath server software. The optional voice data is transmitted with the help of an audio streaming server which was originally developed for Internet radio. The playback of the voice is embedded into the iPath user interface in form of either a JAVA Applet or a RealPlayer Plugin. Thus, for the audience there is no extra software required. The broadcaster of the presentation needs an additional piece of software for recording and broadcasting the voice. Multiple software packages for broadcasting voice are available for most computer systems (Windows, Mac, Linux). With appropriate settings, live audio streaming is possible at relative low bandwidth (4-32KB/s) which makes this also a feasible option for collaboration with developing countries [53].

[6] http://www.icecast.org/

Swiss Society of Dermatology to transmit presentations from continuous medical education seminars to practitioners who cannot attend the seminar physically. The slides are typically exported from PowerPoint and then imported as cases to iPath. A similar system has been used for the past four years by the French African Telemedicine Network (RAFT) to broadcast presentations to multiple locations in French speaking Africa [53].

Teaching

iPath includes a number of features that allow its application in teaching. In a normal discussion group all material is by default sorted by the date of submission to the server. In a teaching group, the sorting can be predefined by the author of content by providing a "sort number" for every object in a group.

The option to link objects from one group to other groups offers teachers the possibility to separate their pool of material from the actual course that is accessed by the students. Teachers can store all basic material like diagrams, text documents, images or example cases to a specific group that serves as "pool of material". The actual layout of a course is implemented in a separate group to which also the students have access. Original material from the pool is then linked to the specific place within the course. This greatly simplifies the re-use and sharing of material for different courses. While the pool of material can be continuously extended over time, the courses can be easily adapted and re-done according to the teacher's needs.

For practical teaching there are two applications of iPath. 1) Teachers can use e.g. the slide show or the dual projection mode of iPath during the actual lecture as blackboard or slide projector – this can be live in a class room, but also at a distance using the distributed presentations module of iPath. 2) Teachers can grant students access to the information for later review and reference.

5.2. Distribution of iPath

5.2.1. Requirements for Installation of an iPath-Server

iPath is split into several parts. The most important part is the iPath-Server which is a web application written in PHP running on Apache or Microsoft Internet Information Server (IIS). The minimal requirements for installing an iPath instance are:

- Web server: Apache (version 1.3 or 2) or an IIS web server
- PHP: version 5+ with the DOM and XSL modules enabled
- Database: MySQL version 4 or 5 or Postgres version 7 or 8
- Image Processing: preferable ImageMagick or alternatively the gd2module for PHP. With the gd2 module iPath currently supports only a limited number of image formats.

Optional requirements for all advanced functions:

- The automatic email import requires the php_imap module
- The custom forms module is preferably used with the htmltidy[7] utility for cleaning html form templates and with the iconv (php module) utility for character set conversion when exporting data to excel spreadsheets.

[7] htmltidy for automatically cleaning html code: http://tidy.sourceforge.net/

5.2.2. Helper Applications

In addition to the iPath-Server there are several external applications that facilitate working with iPath. The ImageDrop module consists of a Java application that connects to iPath using its XMLRPC interface. Users can drag and drop images and other files from their Desktop to ImageDrop and they will automatically be uploaded and attached to the specified case on an iPath-Server. Similar applications for direct uploading from a TWAIN compatible scanner or from a video camera have been implemented. A more complex external helper is iMic, a Java application that provides an interface between an iPath-Server and a Nikon CoolScope microscope (cf. chapter 6).

5.2.3. Licensing and Availability

iPath is released under GPL, which implies that iPath with the complete source code is freely available to anyone. Anyone may use, redistribute and also modify iPath provided that any modification which are redistributed are again made publicly available under GPL. The source code repository of the iPath server code is hosted on Savannah[8], the software development platform of the Free Software Foundation. The rest of the code which includes all optional server modules as well as the external tools for microscope control and image upload are hosted on sourceforge, another open source software development environment. The code is made available for download in the form of several packages which are all available at http://ipath.sourceforge.net/

A project documentation is available on-line at http://ipath.ch/ and includes the user manuals and installation manuals as well as the API documentation for software developers who want to extend the iPath-Server. Besides the technical documentation there is also a section with documentation of different projects using iPath. The project site is also the web site of the iPath association (“Verein iPath”) which was founded in order to promote a sustainable continuation of the projects and services started throughout this initiative.

[8] http://savannah.gnu.org/

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Part II. The iPath Telemedicine System (pp. 28-42) Selections only

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