# Interfaces for Modular Surgical Planning and Assistance Systems

PhD Thesis of Dipl.-Inform. Michael Gessat,
born April 6, 1979 in Bad Friedrichshall, Germany

# Summary

## Introduction and Motivation

Modern surgery of the 21st century relies in many aspects on computers or, in a wider sense, digital data processing. Department administration, OR scheduling, billing, and – with increasing pervasion – patient data management are performed with the aid of Surgical Information Systems (SIS) or, more general, Hospital Information Systems (HIS).

Computer Assisted Surgery (CAS) summarizes techniques which assist a surgeon in the preparation and conduction of surgical interventions. Today still predominantly based on radiology images, these techniques include the preoperative determination of an optimal surgical strategy and intraoperative systems which aim at increasing the accuracy of surgical manipulations.

In contrast to the usually distributed and well-integrated information systems which are used for hospital and department administration as well as patient data management, CAS systems lack mechanisms and interfaces for data exchange among different devices or between one CAS device and a patient data repository, e.g. a radiology image database. Between 1990 and 2004, several publications and interdisciplinary workshops analyzed the problems of every-day use of CAS systems in clinical practice. Thereby, increasing attention was given to the lack of an infrastructure for the integration of intraoperative CAS systems as well as the lack of interfaces for transferring information between intraoperative and perioperative systems, e.g. planning systems or reporting systems. It has been reported that this situation leads to ergonomic, logistic, and economic limitations in hospital work: perioperatively, processes are prolonged by the manual installation and configuration of an increasing amount of technical devices; intraoperatively, a large amount of the surgeons' attention is absorbed by the requirement to monitor and operate disparate systems.

The need for open infrastructures which enable the integration of CAS devices from different vendors in order to exchange information as well as commands among these devices through a network has been identified by numerous experts with backgrounds in medicine as well as in engineering.

## Methods

The requirements for systems integration in perioperative and intraoperative CAS applications are analyzed based on surgical workflow models and dataflow models. The need is identified for the integration of preoperative and postoperative CAS systems into the hospital-wide information systems (HIS, PACS, etc.) as well as for an intraoperative communication

infrastructure through which real-time data can be exchanged and which includes features such as auto configuration of device connections in an *ad-hoc* network.

## Results

Standards for Perioperative Data Exchange

In all regarded use cases, preoperative procedures include the analysis of medical images. Postoperative reporting usually includes the archival of medical images which were acquired during the intervention. This motivates the inclusion of perioperative data processing in CAS into existing networks for archival and exchange of medical imagines. The DICOM (Digital Imaging and Communication in Medicine) standard is wide spread in radiology and other medical imaging based fields of application. It regulates the encoding of images, their archival and retrieval from archives as well as their exchange between diagnostic workstations. Picture Archiving and Communication Systems (PACS) are a class of information systems which are utilized for the exchange and archival of radiology images and image-related information. Most PACS are based on the DICOM standard. In order to facilitate the exchange of information between PACS and perioperative image-based planning and reporting systems, a DICOM working group was installed which aims at extending the DICOM standard to fulfill the needs of surgical applications.

The thesis reports on the classification of data flow in CAS with respect to the question whether the DICOM standard contains data structures and services to realize the information which is exchanged. Several, specifically surgical, information objects are identified for which DICOM does not specify viable data structures. Two of these information objects are further investigated:

- For the exchange of surface models of structures in patient space, the surface segmentation Information Object Definition (IOD) is presented.
- For the integration of implantation planning procedures into PACS, three IODs are presented which enable the representation of implant template catalogues.

An Open Infrastructure for Intraoperative Systems Integration

The thesis further reports on the functional and non-functional requirements to an infrastructure for the integration of intraoperatively used CAS systems, such as navigation systems, intraoperative image sources, data processing units, or multi-functional displays. A software library, the *TiCoLi*, is presented which was developed according to these requirements. The *TiCoLi* is implemented as a c++ class library which enables the following functionalities:

- Auto-configuration and automatic service discovery (“surgical plug-and-play”)
- Session-based application level communication interface for exchange of data and control messages.
- Application level interface to a streaming framework for real-time exchange of continuously acquired measurements which are sampled at regular intervals.
- Application level interface for remote access to attributes and methods of peer applications.

The *TiCoLi* is based on open standards and open source software libraries and is intended to be released into the public domain as an open source project. The *TiCoLi* will be the first freely available software library which implements the listed functionalities and is dedicated for integration of CAS systems.

Experiments are presented which were conducted in order to investigate the efficiency and reliability of the information exchange with the *TiCoLi* under real-time conditions.

## Clinical Applications and Discussion

In order to demonstrate the suitability of the presented specifications and their implementation, two modular CAS applications are presented which utilize the proposed DICOM extensions for perioperative exchange of surgical planning data as well as the *TiCoLi* for establishing an intraoperative network of autonomous, yet not independent, CAS modules.

- For cardiac valve surgery, a planning system is presented which utilized the surface segmentation IOD as well as the implant template IOD in a procedure for computer assisted selection of a transcatheter valve implant. It is shown how this system could interact with an intraoperative CAS system which facilitates accurate placement of the valve.
- For brain tumor surgery an early prototype of a setup is presented which combines preoperative surface segmentation with intraoperative navigation and neurophysiology measurements in order to acquire a 3D model of a surgically important anatomical landmark on the cerebral cortex, the sulcus centralis.

Both DICOM IODs and the services which were defined for storage and exchange of instances of the IODs proofed viable for the handling of planning information in both applications. Nevertheless, practical tests showed the need for a mechanism which facilitates the identification of those patient datasets which are intended to be used during surgery among all available datasets of one patient. In the presented prototypes, only a weak scheme based on indicating instance names was applied which neither is interoperable with third-party devices nor can be secured against falsely labeled instances.

The *TiCoLi* services were found to offer sufficient reliability and performance for the presented application in neurosurgery. Streaming of tracking coordinates as well as exchange of event notifications among several autonomous modules was possible through an Ethernet network without any considerable delays. Regarding the exchange of device descriptions and service descriptions during auto-configuration, the technical specifications proofed viable. Limitations were identified regarding the identification of peer devices. Due to the lack of a standardized terminology for CAS devices, the identification of devices and services had to be based on proprietary codes.

## Conclusion and Outlook

The presented specifications facilitate data exchange during perioperative as well intraoperative CAS procedures. The introduction of DICOM IODs aiming at surgical use cases is an ongoing process to which's initiation the presented work was an important factor. The surface segmentation IOD was accepted as a standard supplement in 2009 and added to the DICOM standard publication in 2010. The implant template IODs are as of February 2010 still receiving a finishing touch by DICOM working group 6 ("Base Standard") before they are presented to the DICOM voting committee. It will be important for the future progress of DICOM in CAS that the pervasion of these new data types is promoted and that researchers, clinicians, and industry representatives continue with the identification of additional work items and the specification of appropriate data types.

The *TiCoLi* was developed as a proof of concept for the integration of intraoperative CAS via an Ethernet based network. Furthermore, it was intended from the beginning of the development process to release the library into the public domain to motivate other researchers and developers to use it in their projects and to add to its code base. Thereby, the

*TiCoLi* has the potential to facilitate the exchange of modules between institutions as well as the extension of a third-party system by additional modules in research projects.

Besides the technical specifications of data structures and services for perioperative and intraoperative data exchange, there is a requirement to define standardized terminologies for the identification of the content of data objects, the identification of services, and the description of their properties and capabilities. The thesis identifies a number of coded terminologies which are available in pathology, anatomy, laboratory and intensive care unit integration and could provide good starting points for the definition of a standardized CAS terminology.