

# An Information Model for Designing Virtual Environments for Orthopedic Surgery

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**Abstract.** In this paper, the role of an information model in the design of virtual environments for orthopedic surgery is discussed. The engineering Enterprise Modeling Language (eEML) is used to model the relationships and precedence constraints in a specific set of orthopedic surgery activities. Our model focuses on a process referred to as LISS plating surgery (LISS- Less Invasive Stabilization System). This information model serves as a basis to develop two orthopedic surgical environments: a non-immersive virtual reality based environment and a haptic interface equipped virtual environment. These virtual environments can be used for training medical residents in specific orthopedic surgical processes.

## 1 Introduction

The training of medical residents in a given surgical field is an important aspect of their educational process. Before recent decades, the medical training system used to employ the traditional methods for training purposes. These methods of surgical training include the use of cadavers, animals, or synthetic mockups [1]. These traditional methods have some major drawbacks. Animal right activists have criticized the use of animals for surgical training. Use of cadavers creates the possibility of risk of infections. Synthetic mockups for training (for instance, synthetic bones) are expensive and are not patient/human specific. As a result, the interest toward training the surgeons with alternative methods such as Virtual Reality based environments has been increasing over the recent decades [2-6]. The benefits of such environments can vary from providing a long-term low cost training method to enabling a collaborative training system accessible from different geographical locations in the world.

In the literature, there have been few research efforts dealing with creating information models as a basis to develop virtual environments especially in biomedical domains. Cecil and Cruz [7] have presented their work on developing an information model of the micro surgical process. In their work, the detailed information model about this surgical process has been presented. Hirschman et al. [8] has presented their research on developing of a tactile and haptic enabled open

surgery simulator. The objective of their work is to develop a simulator that can effectively simulate the feel for open surgery. Dargar et al. [9] has developed a haptic interface for virtual transluminal endoscopic surgical trainer. Their simulator is a virtual reality haptic interface for training and evaluating new techniques and procedures. Jalote-Parmar et al [10] have elaborated on use of a Work flow integration matrix (WIM) in the design of surgical information systems. WIM uses theories of human behavior in problem solving and investigates the role of evidence-based decision-making for the development of new surgical technologies.

In [13], Jannin highlighted the need for process models in computer assisted surgery. A global methodology is presented which includes the definition of a surgical ontology, the software developed based on this ontology as well as the development of methods for automatic recognition of a surgeon's activities. This discussion of this methodology is in the context of neurosurgery processes. One of the other methods used in surgical task modeling is Hierarchical Task Analysis (HTA), which can be used to analyze and evaluate a surgeon's capabilities for various procedures. A HTA task tree usually contains the primary surgical steps, which are decomposed or divided into various tasks, subtasks and motion level actions [14]. Using this HTA approach, a task analysis of an endoscopic surgical process is discussed in [14]; the surgery process is Hybrid Rigid Scope Natural Orifice Transluminal Endoscopic Surgery (NOTES). Further, motion analysis was also conducted as part of this study. The modeling approach in HTA is very rudimentary as it focuses primarily on the "identification of steps"; a process is divided into a collection of tasks and their children (or sub-tasks). when a time analysis is conducted, the tool used in a specific step (eg: suture needle, etc.) is identified along with the beginning and end of a specific sub-task. However, the HTA approach does not model or capture key attributes such as information or physical inputs, and constraints; modeling such attributes is necessary to obtain a better understanding of functional and process relationships which in turns enables a stronger foundation that is necessary to build a virtual environment.

In general, there is also a lack of emphasis on creation and use of information models in the creation of virtual environments especially for medical process domains (including orthopedic surgery). The information modeling approach discussed in this paper encompasses the major elements of process modeling including capturing the information inputs, constraints, performing mechanisms as well as the intermediate decision outcomes of the various sub-tasks; by modeling such relationships as well as explicitly capturing temporal precedence constraints, it provides a more fundamental basis to understand and analyze a given surgical process.

The objective of this paper is to discuss an information model created to support the design of a VSE for orthopedic surgery. Using this information model, virtual environments for training surgery residents in LISS plating orthopedic processes are being developed. The creation of an information model provides a structure basis not only for understanding and analyzing a given surgical process but also provides a useful communication vehicle between the expert surgical team and the

IT/engineering team (which is building such an environment). As the literature review indicates, there has been a lack of comprehensive approaches for modeling surgical processes including orthopedic surgery. In our research, by adopting such an approach, the interaction and transfer of detailed information between the two teams was also facilitated. The creation of such an information model for orthopedic surgery also provides a structured basis for reasoning and understanding the complex relationships between the various inputs, constraints and performing agents; such an understanding enables a better design of the virtual environment which will be used to train medical residents in orthopedic surgery.

The information modeling language used in this work is called (engineering) Enterprise Modeling Language (eEML), which can be utilized to model the LISS plating surgery at various levels of abstraction [11]. eEML in general can be used as a modeling language to plan activities, design software systems for a given domain, analyze the integration and information exchange needs in a distributed virtual enterprise (VE), and enable understanding of existing, new or changing processes and product development practices [7].

At the highest level, the core activity to be modeled is the Focus Unit (FU) which appears as a verb representing the activity of interest. The Focus Unit (FU) corresponds to the E-0 level which can be decomposed into other levels of abstraction. In an eEML model there are four categories of information attributes: the Influencing Criteria (IC), the Associated Performing Agents (APA), the Decision Objects (DO) and the Task Effectors (TE). Using these attributes, a target set of activities can be modeled, studied and analyzed at various levels of abstraction. Influencing Criteria can be categorized as information inputs (II) and constraints (CO), which directly impact the accomplishment of the target activity (being modeled). The information inputs are the information attributes which are required to accomplish the target process being modeled. The Associated Performing Agents (APAs) refer to the software, personnel and/ or machines/tools agents, which perform the identified tasks. Decision Objects (DO) can be grouped under information and physical objects, which refer to the information or physical outcomes (respectively) of activities performed. The end effectors indicate flow of task accomplishment in either a synchronous or asynchronous manner. Logical AND and OR relationships can also be represented. Consider the eEML diagram in figure 4. This diagram, which represents the highest level of abstraction, illustrates the general layout and use of attributes in eEML (for the LISS plating process context). A modeled (target) activity E-0 (or E0) can be decomposed into a set of related activities E-1, E-2, etc. At various levels, the temporal relationships among these activities can also be captured using appropriate junctions. Subsequently, the tasks that comprise the parent activity can be represented in the decomposition and the process is repeated. This information model discussed in this paper was developed after closely interacting with a orthopedic surgeon (Dr. Pirela-Cruz), which has been lacking in other virtual surgical research initiatives. This developed model is being used as a basis to create a new virtual environment for orthopedic surgery. The outline of this paper is as follows. In

section 3, detailed information regarding eEML models of LISS plating surgery is presented. Then in section 4, a brief overview of virtual LISS plating surgery environment is discussed. Finally, section 5 concludes this paper.

## 2 The Information Model Developed

Less Invasive Stabilization System (LISS) surgery is a specific orthopedic surgery process which is used to deal with fractures on the human femur bone (figure 1). The information model discussed in this paper is restricted to the domain of LISS surgery, which is one of many orthopedic surgical processes. Figure 1 is a view of the LISS plating instruments after completion of such a surgical process.

The main steps in a LISS plate process (or procedure) are shown in Figure 1. After performing the preoperative steps and choosing the proper implants for the observed crack, the surgeon needs to reduce the fracture and put different parts of the cracked bone back to their proper positions. This procedure usually is performed by specific reduction methods [12]. The next step in the surgery is the insertion of the LISS plate into its proper position under the skin and in the constant touch of the femur. The surgeon does this using the insertion guide which is assembled to the LISS plate before this step (figure 1). The next and most important step is to screw the LISS plate to the bone using different types of surgical screws. When the LISS plate is placed properly over the femur, the insertion guide can be detached from the LISS plate (figure 1).

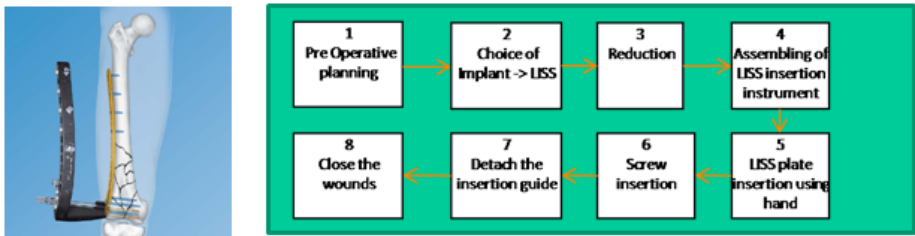


Fig. 1. View of an inserted LISS plate [12] and steps of LISS surgery

We used the eEML modeling language. The tree diagram depicted in Figure 2 shows the whole LISS plating surgery with the decompositions (appearing as child activities in the tree diagram shown). The top level, *E0*, of the process is shown in Figure 3 (using eEML). The elided views are a feature of eEML; it allows a user to obtain a view of the main steps with the main activities and outcomes (figure 4).

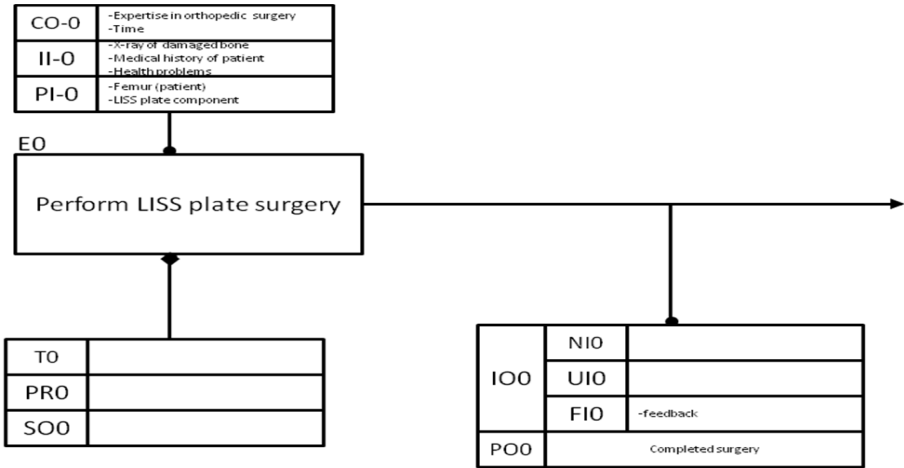


Fig. 2. Top level of LISS plating surgery (EO)

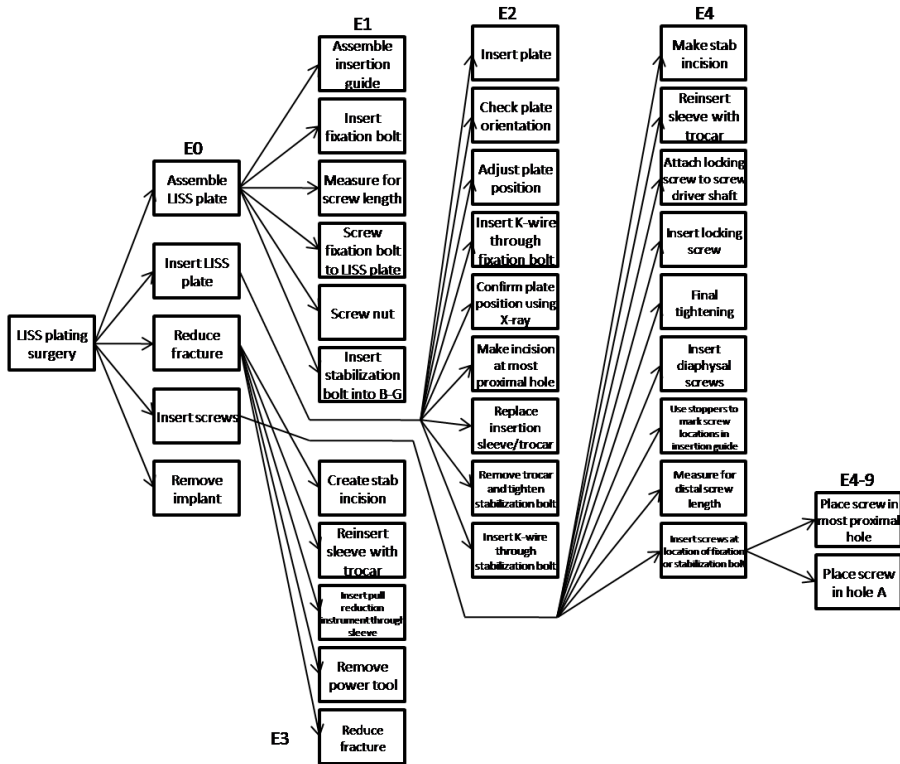


Fig. 3. Tree diagram of LISS plating decompositions

Figures 5 through 8 show the decompositions of the *E0* level diagram.

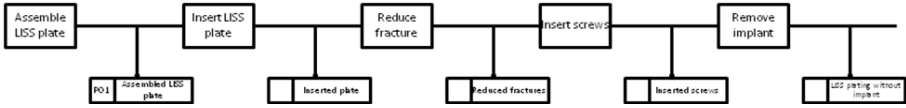


Fig. 4. Elided view of *E0* decomposition

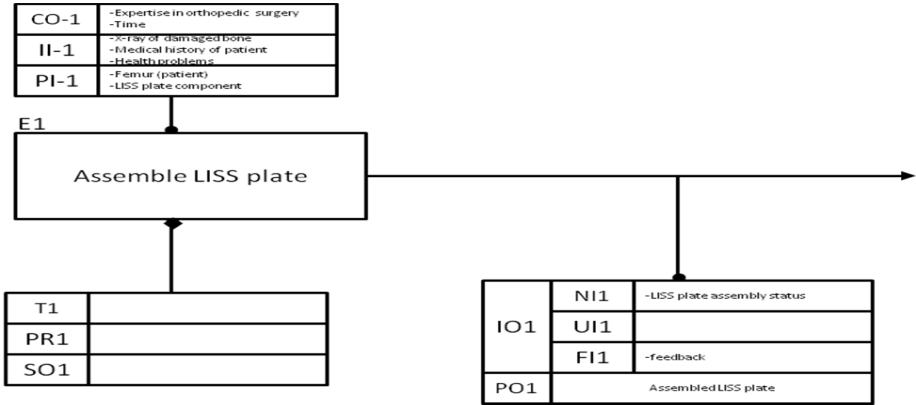


Fig. 5. *E1* decomposition

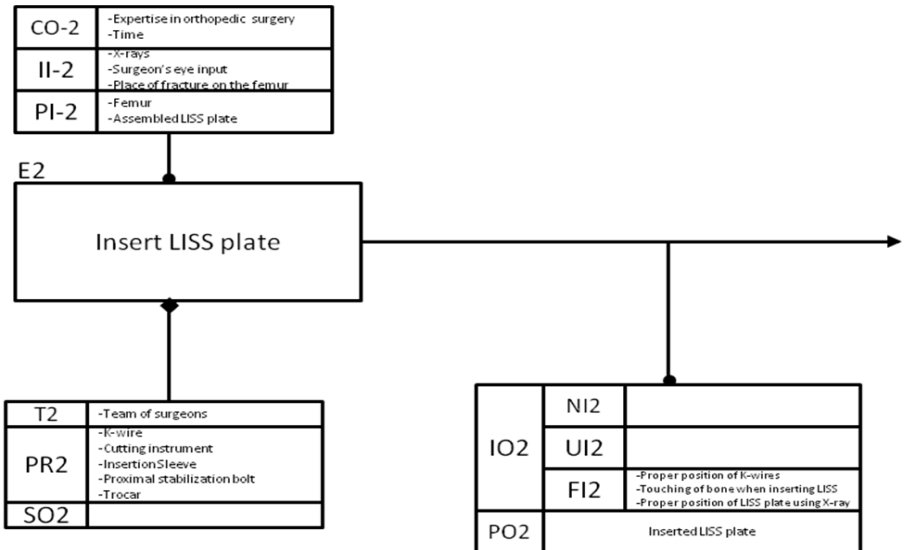


Fig. 6. *E2* decomposition

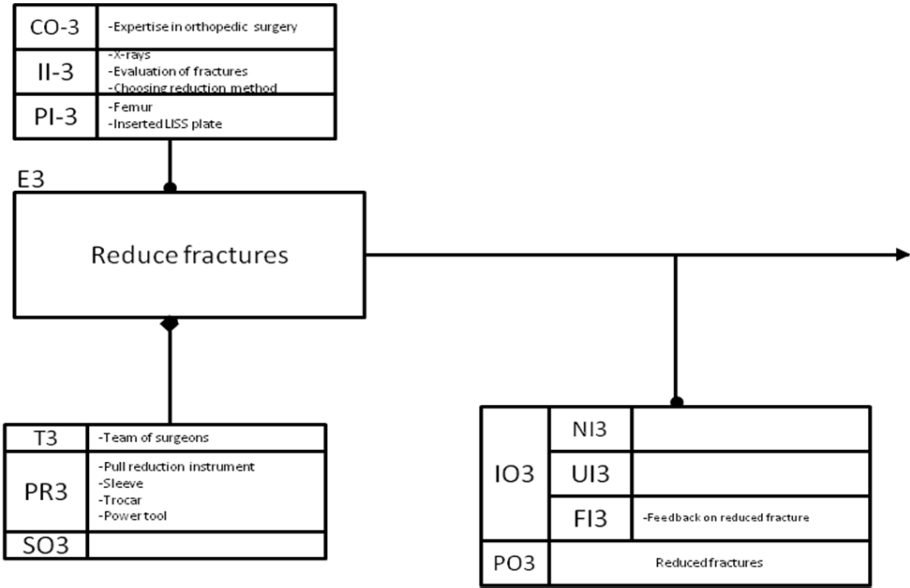


Fig. 7. E3 decomposition

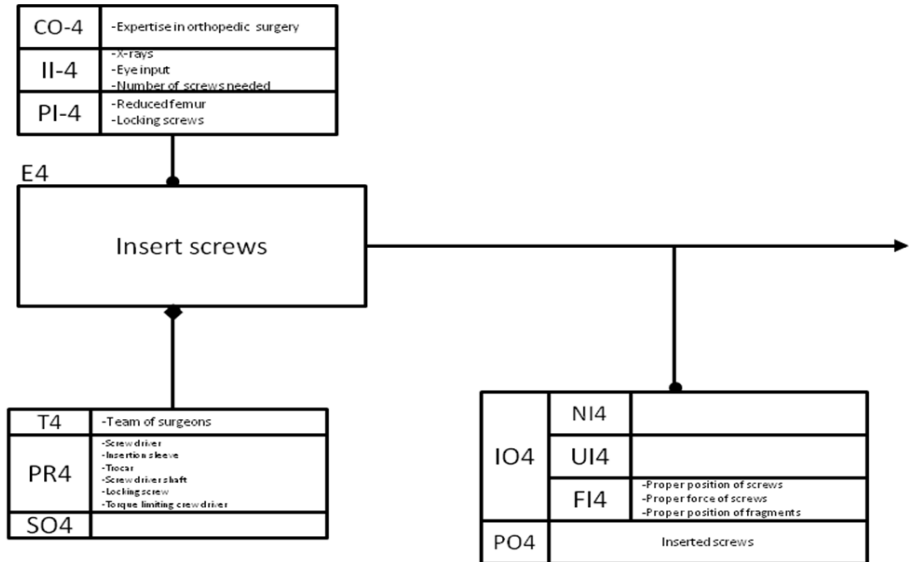


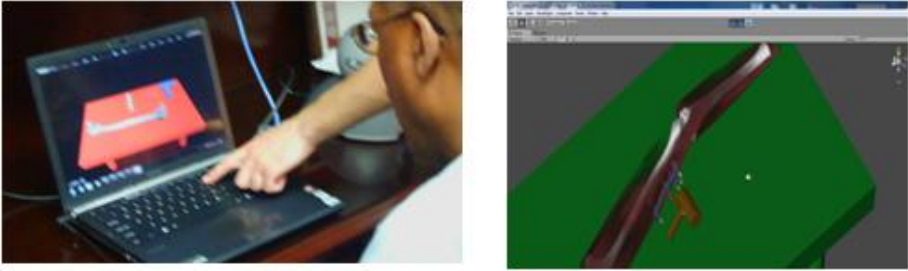
Fig. 8. E4 decomposition

In *E1* decomposition of the surgery, the surgeon assembles different components of insertion guide and LISS plate together. The key constraints in this stage are time and availability of expertise in orthopedic surgery. The information inputs for this process are X-ray of damaged bone, medical history of patient, and health problems. The performing agents are a team of surgeons and the physical resources needed Distal femur LISS insertion guide, radiolucent extension, main component of insertion guide, fixation bolt, 4.5 mm pin wrench, insertion sleeve, and stabilization bolt. The decision objects include the feedback based on proper positioning of assembly components, screw lengths, and proper screwing of the fixation and stabilization bolts. After the plate is assembled and inserted in contact with fractured bone ( shown in *E1* and *E2*), the fracture is then 'reduced' in *E3*. When the fractured pieces are positioned with care by the surgeon back into their normal positions, locking screws are inserted into the bone in different locations of the insertion guide (*E4*). Then, the injury site (in the leg) is 'closed' by the surgeon which completes the LISS plating process. Later, the final step which is removing the implant, can be performed (*E5*). For purposes of brevity, the other decompositions (of *E2* through *E5*) have not been included in this paper.

### 3 Virtual Environments for Orthopedic Surgery

The information models described in the earlier sections are being used as the basis to develop a virtual environment for LISS plating orthopedic surgery process. These virtual environments can be used in different modules such as training or evaluating the performance of surgery students. These implementations (both on PC platforms) are in progress. The first environment is a haptic based environment; C++ and Chai3D open source libraries have been used to build this virtual surgery environment. Figure 9 (a) shows Dr. Cruz interacting with this virtual environment using the haptic device. An initial implementation demonstrated linking multiple environments with haptic devices using a next generation GENI network; users were in Oklahoma and Wisconsin and were able to interact with each other (taking on the role of the expert surgeon and a medical resident); control was able to be transferred between both the environments using these next generation networks.

A second environment is also being developed to simulate the virtual LISS surgery environment using Unity software (Figure 9 b). In this environment, the simulation is non immersive and has no haptic device interface. Using this lower cost non-haptic environment, the surgeon can provide a basic introduction to the LISS plating processes; later, using the surgical simulation, he or she can pause the simulation and ask questions about a specific step in the process. The teaching module of the simulator can use the surgeon's voice or popup text for describing the on-going procedure or as an indicator of the level of accuracy achieved by the user when performing the requested task.



**Fig. 9.** (a) and (b) The two virtual environments for LISS plating under development

The development of both these virtual environments is continuing. The orthopedic surgeon is also interacting with both these preliminary environments and has provided initial feedback including suggested modifications; modifications to the virtual environments has started as part of the next phase of implementation.

## 4 Conclusion

In this paper, an information model of the LISS plating orthopedic surgery was discussed. The engineering Enterprise Modeling Language (eEML) was used to model the relationships and precedence constraints in a specific set of orthopedic surgery activities. This information model is being used to create a virtual reality simulator for the LISS plating surgery process in both haptic and non-haptic based environments. Using the presented eEML model for the LISS plating orthopedic surgery simulator, a better understanding of the overall process and the important relationships between information inputs (or information needed by the surgeon), the constraints (availability of equipment, knowledge of patient medical history, etc) was obtained.

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