HAL
open science

Towards a Generic Framework for Evaluation and Comparison of Soft Tissue Modeling.

Aurélien Deram, Yohan Payan, Emmanuel Promayon

To cite this version:

Aurélien Deram, Yohan Payan, Emmanuel Promayon. Towards a Generic Framework for Evaluation and Comparison of Soft Tissue Modeling.. MMVR'2012, Feb 2012, Newport Beach, United States. pp.1-7. hal-00642269

HAL Id: hal-00642269

https://hal.science/hal-00642269v1

Submitted on 17 Nov 2011

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Towards a Generic Framework for Evaluation and Comparison of Soft Tissue Modeling

Aurélien DERAM [a] Yohan PAYAN [a] Emmanuel PROMAYON [a]
[a] *UJF-Grenoble 1 / CNRS / TIMC-IMAG UMR 5525, Grenoble, F-38041, France*

Abstract. Numerous models have been developed to describe the mechanical behavior of soft tissue in virtual reality medical environments. Very high credibility must be established before clinicians trust these simulations for diagnostic or treatment. Validating models to obtain the right compromise between accuracy and computational efficiency for the targeted medical application is a long, costly and time-consuming task. We have developed a freely available open-source framework for helping scientists in the difficult problem of evaluating and comparing biomechanical models in a more systematic and automatic manner.

Keywords. Soft tissue model, Verification, Validation, Comparison.

Introduction

In virtual simulators, deformable models can be assessed by matching a reasonable degree of visual realism. However, for medical application where diagnostics or treatments are involved, it is necessary to move from subjective validation to objective and quantified error assessments. Verification and validation (V&V) methods produce evidences that a computerized model is sufficiently accurate for its intended use. These methods have gained momentum these last years in the domain of biomechanical simulation as shown by the number of recent reviews [1,2,3]. The verification phase determines if a model implementation accurately represents the developer's mathematical representation of the problem whereas the validation phase determines the degree to which the model is an accurate representation of the reality [1]. In the modeling cycle, the mathematical model includes all mathematical modeling data and equations needed to describe the reality of interest and the computational model is the implementation of the mathematical model (see Figure 1). As V&V in soft tissue modeling mainly concern validation, this paper will focus on this problem. The V&V tasks addressed in this paper are in bold in Figure 1. For a more complete description of the V&V tasks please refer for example to [1,2]. As shown in Figure 1, validation assessments are always made on the computational model. In the remaining, the term "model" refers to the computational model which contains not only the code but also all

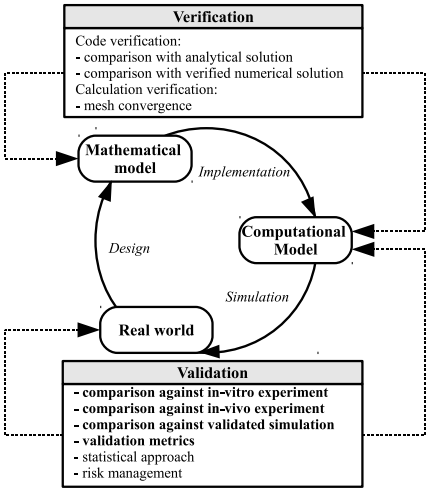

Figure 1. Modeling cycle and V&V tasks.

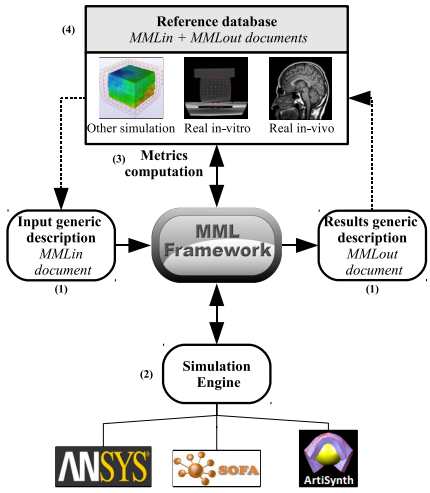

Figure 2. Framework overview.

the modeling assumptions of the mathematical model. Validation is performed by comparing verified simulation results to real data. Real data can be obtained in-vitro (e.g. Truth Cube [4]) or in-vivo (e.g. post-operative data). In-vitro data, even if very difficult to obtain, are easier to collect and allow a better control of boundary conditions compared to in-vivo data. In-vivo data are the closest approach to medical reality but are extremely difficult to obtain. One of the main challenge of validation is to collect good references (control of boundary conditions, material, accuracy of the experiment). Due to the lack of real references, validation studies are often incomplete. As these references are quite rare, validation is also often performed by comparing in-house computations to commercial software (e.g. ANSYS, Abaqus, Comsol) which can be considered as "silver" standards [5]. These commercial software are considered verified because they were tested against large database of analytical benchmark problems and are known to accurately represent reality.

There are numerous implementations of deformable models. These codes can be developed in-house, by other scientists (e.g. SOFA [6] or Artisynth [7]) or by commercial software. In the remaining, software and libraries containing soft tissue models implementations are named "simulation engine". The heterogeneity of these simulation engines together with the heterogeneity of modeling techniques (discrete modeling, e.g. mass-spring, or continuous modeling, e.g. continuum mechanics with Finite Element Method (FEM) resolution) makes it difficult to compare models. Nevertheless, comparisons between models are crucial for determining the relevance of a model for a given medical application depending on a targeted level of compromise between computational efficiency and accuracy.

This paper presents a generic framework to help evaluation and comparison of soft tissue modeling techniques. It is based on a practical analysis of the validation process: as validation mainly concerns comparisons between computational models and references, we propose to consider the model globally and test the simulation results against different types of references (accurate simulations or

real experiments). As implementations of models can be found in different simulation engines, one of the aims of our framework is to ease the access to these simulation engines, so that researchers can compare and choose the one that best fit their needs. The second main objective is to simplify sharing of real references and simulations results.

1. Methods and Material

Our framework has four key concepts (see Figure 2): (1) constitutive elements of a simulation and simulation results are described by a set of generic XML languages to achieve interoperability between different simulation engines and modeling techniques, and also to ease sharing of simulation and experimental results; (2) simulations are computed by simulation engines thanks to a plug-in mechanism; (3) a large set of quantitative metrics can be automatically computed to test models against references or against themselves; (4) a reference database is built from references (simulation results or real experiments). These key concepts are described in the next subsections.

1.1. Generic Description

In order to build a comparison framework which can be used for all types of simulation and biomechanical models we built a generic and extensible description of a simulation. This description is based on the generic languages defined in [8] to describe physical model (PML) and loads (LML). PML stands for Physical Model markup Language. It is an XML language designed to describe soft-tissue and structures as physical objects independently of the method (discrete, continuous, ...). LML stands for Load Markup Language. It is an XML language designed to describe forces or displacements applied to a model for a given time, direction and intensity. A new XML language is introduced in this paper, named MML for Monitoring Markup Language. MML is composed by two distinct parts, MMLin and MMLout. MMLin is a generic description of a simulation. It encapsulates PML and LML and add description for monitored quantities, simulation parameters (e.g. integration step) and stability criterion (see section 1.3). MMLin documents are used as inputs for our framework. MMLout is a generic description for both simulation and real experiments outputs. This common description allows results of a simulation to be included in the database in order to be used as reference for other simulations. Comparison can therefore be made against validated simulation results or real experiments for validation or against previous versions of the currently tested model (for example in order to test the effect of a given change). MML description of a reference can then be simply and easily shared.

Figure 3 represents a single hexahedron under gravity as an example of a simple MML description. Position of nodes, elements and constitutive law are described in the PML document. The fixed bottom nodes and gravity force are described in the LML document. The MMLin document contains these two documents, simulation parameters, the chosen simulation engine (e.g. SOFA), the monitored quantities (only position of nodes here) and stability criterion (thresh-

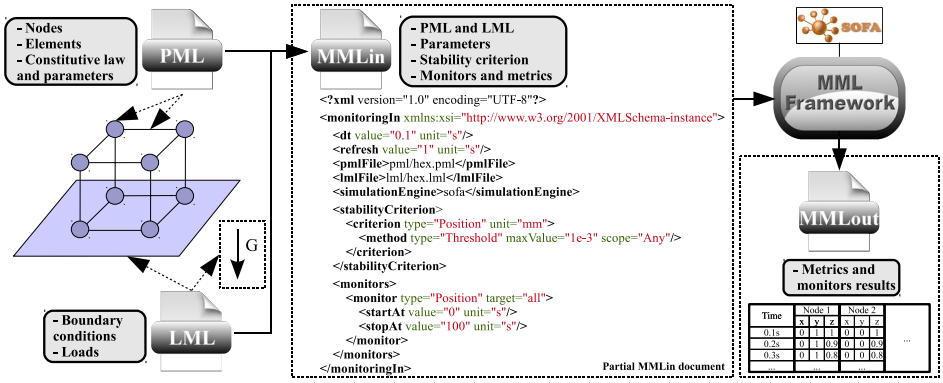

Figure 3. MML description of a simple hexahedron under gravity.

old on the displacement of nodes between two iterations). Simulations results (position of nodes for each time step) are described by the MMLout document.

1.2. Simulation Engines

Simulation steps are computed by external libraries or software. This allows our framework to test models implemented on various platforms. We have currently developed a rather complete plug-in for SOFA which can not only compute simulations from MML description for various model types but can also export SOFA files to MML. This helps to reduce time for creating the generic description when a simulation is already available in SOFA format. A simpler ANSYS plug-in have also been developed which can launch a simulation from MML description.

1.3. Metrics

Soft tissue deformation models have to be tested in term of accuracy and/or computational cost. Therefore, two groups of metrics can be distinguished: accuracy and computational efficiency metrics.

Accuracy metrics have to quantify errors between a computational model and a reference (numerical or from real data). Soft tissue models generally are 3D points linked together by a mesh. Only a few examples of possible metrics are given here. In order to quantify the difference with a reference, point to point comparisons can be used if the two objects have the same structure (e.g. Relative Energy Norm (REN) [3]). If structures are different, points set comparisons can be used (e.g. Hausdorff distance). If a mesh exists, surface and volume differences as well as surface distances can be used.

In order to evaluate the computational cost, we currently use three quantities: The Frame Per Second (FPS), the time to reach stability and the total computation time. FPS is a common indicator largely used in the Computer Graphics community to assess the computational efficiency and, especially, if a model can compute real time deformations. Even if the simulation is computed at a high FPS rate, a model cannot be used for constant interactions if it needs a high number of iterations to reach stability. Therefore, a stability criterion has to be defined and the time to reach stability has to be tested.

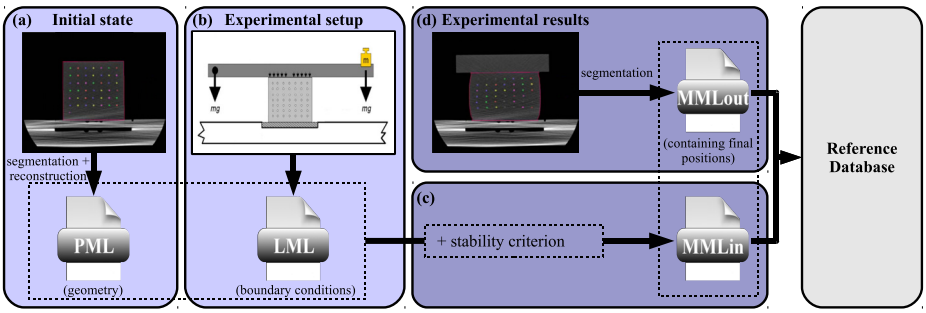

Figure 4. Workflow to add the Truth Cube [4] experiment in the database. a) PML generation from initial CT image. b) LML generation from experimental setup. c) MMLin generation with stability criterion added. d) MMLout generation from final CT image.

1.4. Implementation

MML framework current version contains approximately 30k lines of C++ code including two simulation plug-ins (SOFA and ANSYS), and a graphical user interface. It is freely available as part of the CamiTK open-source project under LGPL license (http://camitk.imag.fr).

2. Results

This section will describe how to add a real reference into the database and how to use it to perform a validation study on various models from different simulation engines.

2.1. Integration of a New Reference

In this section, the Truth Cube [4] experiment is considered as an example to explain how a new reference can be integrated in the database. The Truth Cube is a silicon cube of known constitutive law and rheology where 7x7x7 teflon spheres are embedded. The CT scan imaged experience consists in fixing the base of the cube whereas the top is compressed with a 14.6 mm displacement. The workflow to add the new reference from the experimental setup and medical imaging is described in Figure 4. Initial image of the cube is segmented and reconstructed in 3D in order to capture the initial geometry (PML document, Figure 4.a). Experimental setup is analyzed to describe boundary conditions (LML document Figure 4.b). MMLin document is generated (Figure 4.c) using a threshold on displacements between two iteration times as stability criterion. The deformed positions, segmented from the final CT, are integrated into the simulation results description (MMLout document, Figure 4.d) and will be used for comparison purpose. The same workflow can be used for other types of references.

2.2. Validation and Comparison Study

The new reference is used to perform an example of validation study on various models computed from different simulation engines. The MMLin document gener-

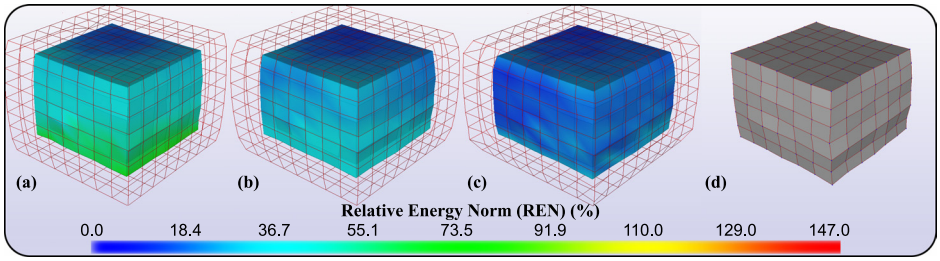

Figure 5. 3D color scale of a the REN metric displayed in our framework. (a) SOFA mass-spring. (b) SOFA Hexahedra FEM. (c) ANSYS. (d) Reference, deformed Truth Cube internal data. Unused external surface is displayed in wire-frame.

Table 1. Quantitative metrics automatically computed from the three simulations. (a) SOFA mass-spring, (b) SOFA Hexahedra FEM, (c) ANSYS. The table shows: average Frame Per Second (FPS), time to reach stability, total computation time, Relative Energy Norm (REN) against reference and point to point distance to reference.

Model	**FPS**	**Time to stability (s)**	**Comp. time (s)**	**REN (%)**			**Distance (mm)**		
				min.	max.	avr.	min.	max.	avr.
(a)	52.3	19.4	3.71	7.50	146.33	38.83	0.61	6.00	2.90
(b)	21.3	12.2	5.73	7.68	43.56	22.19	0.18	4.63	1.89
(c)	n.a.	n.a.	21.1	6.24	43.71	16.79	0.24	3.77	1.42

ated in the previous section is used as input to describe the same exact simulation for all models. The two simulation engines used are: SOFA (version 1.0, November 2, 2011 public svn version) and ANSYS (version 12). SOFA is used to compute two different biomechanical models: a FEM hexahedra corotational algorithm [9], and a more classic discrete mass-spring network, both using an implicit conjugate gradient integration method. In ANSYS, the FEM hexahedra are modeled using the SOLID45 element and default solver and parameters were used. For both FEM simulations, the Young's Modulus was set to 15.3kPa and the Poisson ratio to 0.49. As reference and models have the same structure, point to point metrics are used. Figure 5 shows the REN between models and reference. The external surface is not used because the Truth Cube experiment only provides data for the internal beads. More quantitative measurements of various metrics are shown on Table 1. FPS and time to reach stability are not relevant for ANSYS as equilibrium is independently determined inside the software. The quantitative measurements show the importance of comparing methods in term of accuracy and computational efficiency as FEM based models used in this example are more accurate but slower than mass-spring. Nevertheless, even if mass-spring is faster, it is also less stable as shown by the time to reach the chosen stable state.

3. Conclusion

In this paper we proposed a generic framework for comparing and evaluating different modeling techniques. Comparisons are possible against (1) validated software and in-vitro or in-vivo experiments for validation, (2) other development

versions of the model for testing assumption changes and (3) between models. The framework helps comparisons of models from different simulation engines by wrapping a comparison layer on top of them.

The common description of simulation outputs and references makes it possible to add new simulation results or real experiments in the reference database. These descriptions can be easily shared between research teams. We hope this can help to fill the lack of references for V&V. Adding simulation results in the database also allows scientists to test improvements of their models against previous versions. The Truth Cube experiment is a good illustration of how a real experiment can be added from medical imaging in spite of the fact that this reference is not perfectly suitable for accurate validation because its boundary conditions are not well controlled. We encourage researchers to add their own experiments in the database.

We also presented how a validation and comparison study can be performed using our framework. This simple study shows the usability of the framework for comparing different modeling techniques from different platforms. Even though verification tasks were not addressed here, comparisons of numerical results with verified commercial software based on the same mathematical model are also possible.

Future works will include improving the MMLout description to take experimental uncertainty into account and including metrics reflecting this uncertainty.

References

[1] A.E. Anderson, B.J. Ellis, and J.A. Weiss. Verification, validation and sensitivity studies in computational biomechanics. *Computer Methods in Biomechanics and Biomedical Engineering* **10**(3) (2007), 171–184

[2] H. Henninger, S. Reese, A. Anderson and J. Weiss. Validation of computational models in biomechanics. In *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine* (2010), 801–812

[3] M. Marchal, J. Allard, C. Duriez and S. Cotin. Towards a Framework for Assessing Deformable Models in Medical Simulation. In *Proceedings of International Symposium on Biomedical Simulation* (2008), 176–184

[4] A. Kerdok, S. Cotin, M. Ottensmeyer, A. Galea, R. Howe and S. Dawson. Truth cube: Establishing physical standards for soft tissue simulation. *Medical Image Analysis* **7** (2003), 283–291

[5] I. Stavness, J. Lloyd, Y. Payan and S. Fels. Coupled hard-soft tissue simulation with contact and constraints applied to jaw-tongue-hyoid dynamics. *International Journal for Numerical Methods in Biomedical Engineering* **10** (2011), 367–390

[6] J. Allard, S. Cotin, F. Faure, P.J. Bensoussan, F. Poyer, C. Duriez, H. Delingette and L. Grisoni. SOFA an Open Source Framework for Medical Simulation. *Studies in Health Technology and Informatics* **125** (2007), 13–18. Published by IOS Press.

[7] S. Fels, F. Vogt, K. Van Den Doel, J. Lloyd, I. Stavness and E. Vatikiotis-Bateson. Artisynth: A biomechanical simulation platform for the vocal tract and upper airway. In *Proceedings of International Seminar on Speech Production*, Ubatuba, Brazil, (2006)

[8] M. Chabanas and E. Promayon. Physical model language: Towards a unified representation for continuous and discrete models. In *Proceedings of International Symposium on Biomedical Simulation* (2004), 256–266

[9] M. Nesme, M. Marchal, E. Promayon, M. Chabanas, Y. Payan and F. Faure. Physically Realistic Interactive Simulation for Biological Soft Tissues. *Recent Research Developments in Biomechanics* **2** (2005), 117–139