# Demonstrating a Linked Data Platform for Finite Element Biosimulations of Cochlear Mechanics

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**Abstract.** Biosimulations employ Finite Element Method (FEM) to simulate complex biological systems in order to understand different aspects of human organs. The applications of FEM biosimulations range from human ear cochlear mechanics, cardiovascular, to neurovascular research. Performing these large Finite Element (FE) simulations, comparison and analysis of multiple simulation experiment results, and visualization of large FEM numerical data is a time consuming hectic job for domain experts - mainly because simulations are performed in an isolated environment. In this paper, we demonstrate a linked data platform to dispatch simulations on biosimulation models for the inner-ear (cochlear) mechanics in an integrated non-isolated environment.

## 1 Introduction & Motivation

The creation of computational biosimulation models plays a fundamental role in the scientific practice with regard to the understanding of biological systems [2]. Finite Element Method (FEM) provides a mathematical and computational framework to simulate dynamic biological systems, with applications ranging from human ear, cardiovascular, to neurovascular research. A FE biosimulation depends on the creation of models which span across multiple, complex and semantically incompatible domains, such as biological models, geometrical structures and mathematical-physical models.

The cochlea (human inner-ear) represents a complex bio-mechanical device and a complete understanding of its behaviour is difficult. The creation of cochlea model, to perform biosimulation experiments depend on integration of heterogeneous models at different scales (e.g. basilar membrane, organ of corti and outer hair cells) and theoretical domains (e.g. mechanical, geometrical, and electrical) [3]. In our observation, performing simulations on a cochlea model is a time-consuming process, mainly because of different and often heterogeneous mathematical parameters. The growing complexity and sophistication of biosimulation models, the effort associated with the creation and analysis of a FE model can grow unmanageable. Due to lack of a well-integrated data infrastructure, the steps involved in the execution and comparative evaluation of a large-scale finite element simulation such as preparing input numerical parameters, solver usages, visualisation and result/output interpretation are time consuming and often performed in isolated environments.

In this paper we present a Linked Data platform aiming to improve the automation in integration, interpretation and visualisation of biosimulations models for inner-ear (cochlea) mechanics. The aim of the proposed platform is to facilitate the reproducibility, reuse, interoperability and automation of FE models with the support of Semantic Web standards and tools. Specifically, to support a domain-expert in performing all isolated tasks of a simulation experiment using a simplified, integrated platform. As most of FE data is numerical, this work explores mechanisms to bridge (link) data on the numerical to the conceptual (ontology) level, facilitating and automating the interpretation of the simulation results. To the best of our knowledge, the proposed linked data platform is a first unified infrastructure that bring together numerical parameters, models, terminologies, storage, querying, visualisation and analysis to conduct a finite element biosimulaion.

Our work is motivated by the need of clinical organisations and labs conducting biosimulation experiments to understand the exact pathophysiological consequences and risk factors of hearing impairment in humans. Our work is conducted in context of the SIFEM EU project[1], which aims at developing an open-source linked data platform for Finite Element multi-scale modelling and biosimulation of the sensorineural hearing loss.

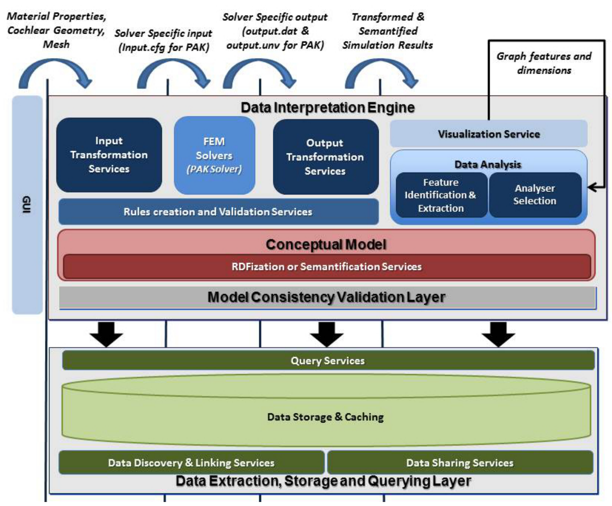


Fig. 1: SIFEM Architecture

***SIFEM Infrastructure:*** In order to achieve the aim and objectives of the proposed Linked Data Platform, we define a SIFEM Architecture as depicted in Figure 1. The proposed linked data platform addresses following challenges in integrating, interpreting and visualising numerical parameters along with simulation results: (i) resolve different data formats (e.g, .dat, unv, .pak, etc.) by transforming them into standard RDF format; (ii) resolve heterogeneous terminologies originating from multiple disjoint domains by building a conceptual model using multiple reference ontologies from biological, geometrical, mathematical, and physical domains; (iii) providing links across input parameters/values and simulations results in-order to reuse relevant data analysis in future experiments; and (iv) visualisation and data analysis over FE simulation results. Further information about SIFEM conceptual model can be found in [1].

[1] `http://www.sifem-project.eu/`

## 2 SIFEM Platform

The SIFEM platform is built as a Web application [2], following the SIFEM architecture. The main screenshot of the platform is depicted in Figure 2, where multiple sub-windows, corresponding to different tasks of a bio-simulation experiment can be seen. Each individual sub-window is invoked using a SIFEM Action Console, given in Figure 3. The SIFEM platform can be accessed on `http://213.249.38.66:7071/Sifem/` [3]. The user provides various inputs related to the simulation experiments [4] through the action console, such as boundary conditions and parameters (damping factor, fluid viscosity etc.) and mesh properties (box model, cochlear model etc.). The user then invokes various services, such as FEM solver, RDFization etc. which process the input data and generates simulation results. The inputs and outputs are RDFized to achieve interoperability among different solvers. The services available through the action console are briefly discussed below (From left-to-right, as shown in Figure 3, e.g. *Material Properties* is the left most action button, while *User Profile* is the right most action button):

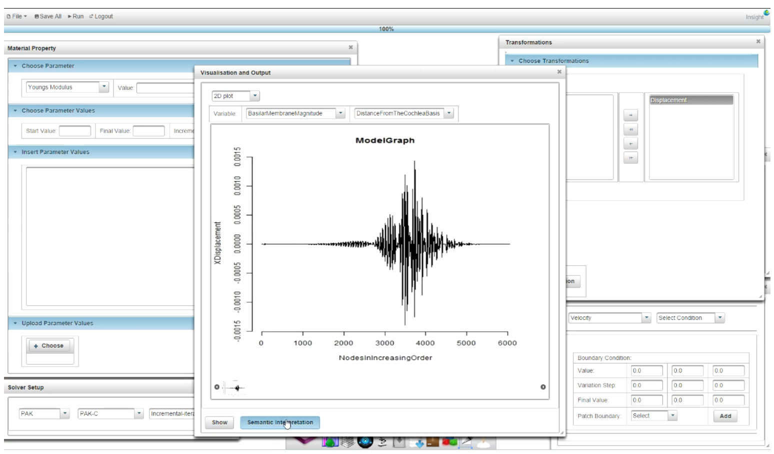


Fig. 2: Screenshot of the SIFEM Platform.

Fig. 3: SIFEM Action Console

**Material Properties:** The material property menu opens a dialog that allows the user to specify the boundary condition types, and allows the user to select and input data for several parameters (such as frequency). This input data is then used by the FEM solver.

[2] The initial version of the platform is released as an open source version, the source code of **beta-version 1** is available at: `https://goo.gl/sxePc8`

[3] SIFEM Platform User-Manual on `https://goo.gl/hbTYZt`

[4] A video, depicting a sample simulation experiment of the running SIFEM platform can be found on `https://goo.gl/wDC0am`

**Mesh Setup:** The mesh setup menu allows the user to specify the mesh file as input for the FEM solver.

**Visualization:** The Visualisation menu visualises the graphs plotted using the simulation experiment data. Both 2D and 3D graphs are generated using the simulation data.

**Knowledge Base Editor:** The knowledge base editor menu opens a new dialog that allows the user to manually enter data in the form of RDF triples into the knowledge base.

**Rules Editor and Validator:** The Rule Editor and Validator menu is used by the experimenter to define and validate rules before running a simulation to validate the results of the simulation automatically. For example, the experimenter can specify a rule, saying the value of frequency should not be greater than 20 kHz as it is maximum frequency limit a human ear can hear. While running the simulation, results will be validated by the rule validator based on the rules specified by the experimenter.

**SPARQL Editor:** The SPARQL editor menu opens a new dialog that allows the user to create SPARQL query and run the query to receive results from the knowledge base.

**Transformations:** The transformation menu lets the user to select the type of transformation for the selected solver, such as displacement, greenwood etc.

**User Profile:** The user profile menu shows the profile of the currently logged in user.

***Summary:*** In this paper, we demonstrate a linked data platform that improves integration, reproducibility and automation of Finite Element (FE) biosimulations. The proposed platform is developed using SIFEM architecture that combines together numerical parameters, models, terminologies, storage, querying, visualisation and analysis to conduct a FE biosimulation experiment. The platform is developed on a use-case to understand the exact pathophysiological consequences and risk factors of hearing impairment in humans. The experimental biosimulation data and models are from scientific and clinical studies about the structure-function relationship in normal and pathological cochlear. A survey evaluating the qualitative attributes of SIFEM platform has been conducted, the complete results of the survey can be seen on `https://goo.gl/PSvvLY`.

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