

# Medical Simulation Markup Language

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## Abstract

*The Medical Simulation Markup Language offers a generalized and flexible description for biomechanical models. The unique feature of this modeling language is that it not only describes the final biomechanical simulation, but also the workflow how the biomechanical model is constructed from tomographic data. In this way, the MSML can act as a middleware between all tools used in the modeling pipeline. The MSML also ships with many built-in tools for mesh processing, meshing, post-processing and parameter optimization. The functionality of MSML can be accessed using an XML interface as well as through a Python API or raw C++. Some cool stuff you can do with MSML:*

- *Perform mesh cleaning and decimation based on ACVD, CGAL and VCGLib*
- *Automatically create linear or quadratic tetrahedral meshes from surface models using state-of-the art meshers such as CGAL, Netgen or Tetgen.*
- *Run your simulation on different engines like Abaqus, SOFA, HiFlow or FEBio.*
- *Perform parameter optimizations and automatic convergence analysis*
- *Choose from a big collection of post-processing options and export the results to Paraview*
- *Easily integrate your own tools and engines*

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# 1 Introduction

We first mentioned the idea from an unified and mighty workflow system for biomechanical engineering in [1]. In the meantime we realize the Medical Simulation Markup Language (MSML).

You can see MSML as a build tool, like *GNU Make*, except the offered operations are settled in the pre- and postprocessing of three dimensional data after the biomechanical simulation. The simulation is the heart of every workflow and is outsourced to modern simulation frameworks, like SOFA<sup>1</sup> or Hiflow3<sup>2</sup>, and MSML cares about the messy details of the simulation framework. You get an unified interface.

**Content** In this paper we show the various power of MSML in different scenarios (sections ??). Before the tutorials we create a view on MSML in section 2. This chapter defines the ground terms and nomenclatures in MSML. Openness is one power of MSML. You can extend it in various kinds, such topics are discovered in section 7.

**Acknowledgement** MSML was developed in the SFB TRR125 Cognition Guided Surgery project, funded by the DFG. ¶<sup>3</sup>

## 2 MSML Architecture

The Medical Simulation Markup Language is capable of describing both the biomechanical model and the workflow that is used to generate the model. The model and workflow description are combined into a single data model. This data model can be either built through a Python API or by providing a single XML file. For most users the XML input file will be the primary interface to the MSML framework. In order to facilitate a better understanding of the tree datastructure that is encoded in the file, we first introduce the model description in this chapter. We also show how additional model features (e.g. new material types) can be easily integrated. We then outline the workflow modeling and its Python implementation. It is highly recommended to use the examples that are provided within the MSML framework (e.g. `msml/examples/BunnyExample/bunny.msml.xml`) along with the following explanations.

### 2.1 Model description

The MSML model description is designed to cover applications that use numerical methods such as the finite element method (FEM) or the finite volume method (FVM) to solve models based on partial differential equations. These applications include (but are not limited to) solid mechanics problems and fluid mechanics. In order to support a flexible extension, the MSML specification allows to easily introduce new features through a dynamic alphabet in addition to built-in (fixed) definitions.

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<sup>1</sup><http://www.sofa-framework.org/>

<sup>2</sup><http://hiflow3.org>

<sup>3</sup>*weigl*: add english name here

Currently, the MSML defines the following framework in order to describe a biomechanical simulation: The complete simulation scenario is called a *scene*. The scene consists of several *objects*. Each object is described in terms of one (and only one) *mesh*. A *sets* section allows to specify *nodes*, *elements* or *surface* sets. Element sets can be used in the *material* section to define a *region*. Inside this region different material properties can be defined (see following paragraph for details). The *constraint* section of an *object* allows to define constraints, loads and boundary conditions for the object. Finally, output requests (e.g. stress, displacement) can be defined in the *output* section.

In addition to the fixed definitions, the MSML offers a flexible way to add new material properties (*physics\_elements*) as well as new *constraint* and new output requests *output\_elements*. For this purpose the alphabet (located at *msml/share/alphabet*) can be extended with new definitions by providing an XML description. Upon start-up, the MSML framework automatically adds the new definitions to the alphabet.

## 2.2 Numerical Environment

In addition to the description of the physical simulation model that was discussed in the previous section, the numerical algorithms that discretize and solve the problem have to be chosen. In fact, these choices are typically non-trivial and heavily influence the performance and the stability of the simulation. In the MSML input file, the numerical environment can be specified in the *environment* section.

## 2.3 Workflow description

Typically, time-consuming pre-processing has to be done in order to construct biomechanical models. Typical operations in this context include mesh cleaning, mesh generation and boundary condition assignments. Similarly, several post-processing operations are usually performed on the raw simulation results in order to interpret and visualize the results.

The MSML allows to specify workflows for both pre-processing and post-processing operations. For this purpose so called *Operators* can be combined to form processing pipelines. These pipelines are specified in the *workflow* section of the input file. Additionally variables can be defined in the *variables* section. Defining variables can not only help to make the input file more readable, it also enables you to automatically perform parameter sweeps and optimizations using the MSML.

A key feature of the MSML is the inclusion of new operators by adding an XML-file that describes its inputs, outputs and parameters. In this way operators that are implemented as C/C++ libraries, Python modules or command line programs can be easily integrated into the MSML. Additionally, the MSML framework already includes many useful operators for pre- and postprocessing.

The XML-based descriptions of the operators can be found in the *msml/share/alphabet/msml\_operators* directory. You can also quickly define your own operators as shown in chapter 7.1.

## 2.4 Export to different simulation engines

A major advantage of the MSML platform is the capability to export simulation scenarios to different simulation engines. Currently, Sofa, Abaqus, HiFlow and FEBio are supported. In this way, the MSML is the perfect tool to run compare different simulation platforms. The generation of the respective input decks is performed by so called *exporters*. Each exporter is described semantically in order to express its capabilities. This allows the framework to check if an exporter is compatible with all elements (e.g. material types, constraints) and all numerical settings that are described in the *environment* section.

You can also provide your own exporter. This allows to use the MSML as a powerful pre-processor for custom research simulation code. More details on how to do this can be found in section 7.3.

## 2.5 Python implementation

The core implementation of the MSML handles the processing of the simulation workflow. Figure 1 provides an overview of the process. The MSML takes a data structure as shown in Fig. 2. The data structure can be allocated from XML or with Python.

The next step is to analyze the data structure in order to find errors and to create a build graph. The build graph is a directed acyclic graph. The generated build graph is then checked for consistency of types. Type errors are resolved by injecting conversions in the graph (e.g. between different surface file formats). An example graph is shown in Fig. ??.

An *Executor* takes control over the pre-, postprocessing and simulation. It executes the build graph in the correct order. Currently We are offering three Executors:

**LinearSequence** is a simple execution of the task in topological order.

**Parallel** executes a set of independent task in process or thread pool.

**Phase** gives you control, to disable certain phases, tasks or exporters.

The distinction between the three phases is a logical separation. The build graph only knows nodes, that are tasks, variables or exporter.

## 2.6 tl;dr

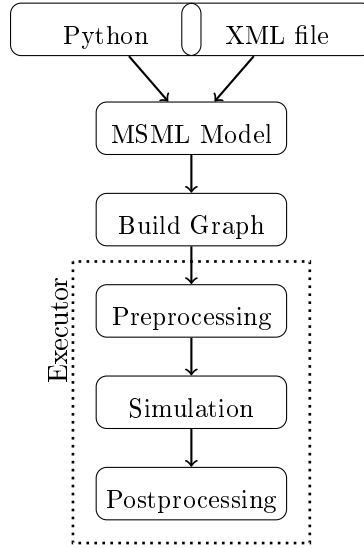
The *MSML File* data structure is the central interface between you and MSML. It gathers all information for making a simulation:

**Workflow** holds the list of Tasks to be executed

**Environment** is the set of parameters and configuration for the simulation system.

**Variables** are reusable placeholders, that allow to create parameterized workflows.

**Scene Object** encapsulates an object in the simulation, that can be enriched by material regions, constraints or output requests.



**Figure 1:** *MSML Pipeline*

The structure is visible in the first example ?? and figure 2 shows the cardinality.

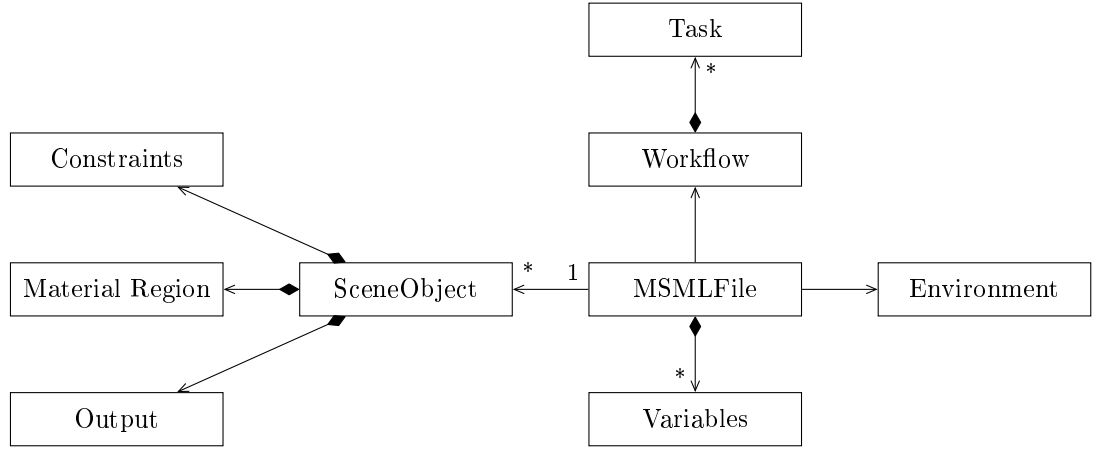
**Sort logic**

### 3 Stanford Bunny

- explain MSML structure
- show simulation sequence (maybe with transparent overlay)
- little timings

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**Figure 2:** *MSML Model*

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## 4 Lungs

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## 5 Lungs

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Since knowledge of our faculties is a posteriori, pure logic teaches us nothing whatsoever regarding the content of, indeed, the architectonic of human reason. As we have already seen, we can deduce that, irrespective of all empirical conditions, the Ideal of human reason is what first gives rise to, indeed, natural

```

1 import vtk
2 def cp(mesh, ref):
3     locator = vtk.vtkPointLocator()
4     ugrid = read_ugrid(mesh)
5     locator.SetDataSet(ugrid)
6
7     index = locator.FindClosestPoint(ref)
8     point = ugrid.GetPoint(index)
9     distance = distance(ref, point)
10    return {'index': index,
11            'point': point,
12            'dist': distance}

```

**Figure 3:** *Python snippet of a function for calculating the nearest point in `mesh` from `ref`*

causes, yet the thing in itself can never furnish a true and demonstrated science, because, like necessity, it is the clue to the discovery of disjunctive principles. On the other hand, the manifold depends on the paralogsms. Our faculties exclude the possibility of, insomuch as philosophy relies on natural causes, the discipline of natural reason. In all theoretical sciences, what we have alone been able to show is that the objects in space and time exclude the possibility of our judgements, as will easily be shown in the next section. This is what chiefly concerns us.

## 7 Extend MSML

MSML is a platform, that can be extended in multiple fashions. The terms explain in section 2

### 7.1 Operator

An operator in MSML is a function that perform an operation. At least the function has to executable within Python. For C/C++ we provide a CMAKE build environment and wrapping with SWIG. Additional we provide operator adapters for external programs or shared object (ctype).

Let's assume we want to provide `cp(mesh, ref)` from figure 3 in MSML. The function calculates the closest point in `mesh` to a given reference vector `ref`. Save the function in Python module, make sure MSML can import this module by setting `PYTHONPATH` or using the `--operator-dir` on the command line. The next step is to create the entry in the Alphabet. Figure 4 shows an accurate one. The runtime gives the type of the operator. For a Python Operator you need to specify the module and the function name. Input, output and parameters contains list of args. The order of args determines the order in which the arguments are given in the function call. Here we define one input argument, that should be given as a VTK object, and one parameter as a list of floats values. This operators delivers three different output values. Once you added the XML file (figure 4) to the alphabet search path or add `--alphabet-search-dir` on the command line, you should be able to call this operator within MSML `<closestPoint id="c"mesh="$ {mesh}" ref="2.2 3.5 6"/>`

```

1  <operator name="closestPoint">
2    <runtime>
3      <python module="closestpoint" function="cp"/>
4    </runtime>
5
6    <input>
7      <arg name="mesh" logical="Mesh" physical="vtk"/>
8    </input>
9
10   <output>
11     <arg name="index" logical="Index" physical="int"/>
12     <arg name="point" logical="Point3D" physical="vector.
13       float"/>
14     <arg name="dist" logical="Distance" physical="float"/>
15   </output>
16
17   <parameters>
18     <arg name="ref" physical="vector.float" logical="
19       Point3D"/>
20   </parameters>
21 </operator>

```

**Figure 4:** *Operator Definiton Example*

```

1  <element name="surfacePressure" category="constraint">
2    <description>
3      Add pressure load to surface
4    </description>
5
6    <parameters>
7      <arg name="indices" physical="vector.float" />
8      <arg name="pressure" physical="float"/>
9    </parameters>
10 </element>

```

**Figure 5:** *Operator Definiton Example*

You can access to every output with `c.distance`, `c.point` and `c.index`.

## 7.2 Element

An Element defines the semenatics of an entry under constraint, material region or output. They should be a disambiguous description of their use. Every exporter handles the elements on his own. An introduction of an element leads to an adaption of the exporters. The Exporter features determines the supported elements. Figure 5 shows an element definition. It consists from a name, category, description and parameters. The definition of parameters are the same as for operators.

## 7.3 Exporter

The Exporter are a central point of the system. Their task is to create the input for the specific simulation environment, run the simulation and provide the calculated output back into the Workflow. You can see the Exporter like special

<i>Exporter</i>
# <code>msml_file</code> : MSMLFile # <code>memory</code> : dict # <code>datamodel</code>
+ <code>initialize(name, mesh_type, features, element_types)</code> + <code>get_value_from_memory(element)</code> + <code>render() : void</code> + <code>execute() : dict</code>

**Figure 6:** UML Class *Exporter*

operators, that sees the whole MSML file data structure and has dynamically input and output slots.

The creation of an `Exporter` begins with deriving from `msml.exporter.Exporter` (figure 6). The `Exporter` need to call `initialize` given:

- the MSML File data structure,
- an exporter name,
- supported features
- logical and physical mesh sort and
- a dictionary describing types of element parameters.

The initialization takes care of creating the appropriate input and output slots. The supported features are a subset of string. If you set physical types for every input and output slot, you will get the correct on access via `get_value_from_memory()`.

The next step is `render()`. This method is called first from the `Executor`. It should transfer the scene structure into an appropriate representation for the simulation environment. You should not modify the workflow memory or write absolute filenames. Everything executed by the `Executor` has it's working directory in the given output directory. The changes you want to make should be memorized and returned by `execute()`. There are two ways to access the referenced values from the workflow memory: by calling `get_value_from_memory()` with the correct nodes from the scene, or by using the `datamodel`. `datamodel` is a mirror data structure of scene, where the referenced values are injected.

`execute()` is executed directly after `render()`, and should execute the simulation and converts the results into appropriates formats. The later step is only needed if there is no automatically conversion defined. Figure 7 gives an sketch of an exporter.

## 8 Conclusion

We hope to give you an introduction in the world of MSML. MSML is more than just a build or workflow tool. The project offers easily to use Python and C++ function.

```

1  from msml.exporter import Exporter
2
3  class ExporterSkeleton(Exporter):
4      def __init__(self, msmlfile):
5          self.initialize(msmlfile, name = "myexporter",
6                          features = supported,
7                          mesh_sort = ...,
8                          output_type_of_elements = ...)
9
10     def render(self):
11         self._update = {}
12         for sceneobject in self.datamodel:
13             # process object
14             sceneobject.id
15             sceneobject.mesh
16             for constraints in sceneobject.constraints: pass
17             for regions in sceneobject.materials: pass
18             for output in sceneobject.output: pass
19
20         # write simulation input file
21
22     def execute(self):
23         # execute the simulation
24         subprocess.call(["run_simulation" ...])
25         # return the new memory values
26         return self._update

```

**Figure 7:** *Operator Definiton Example*

MSML is driven towards an semantic an intelligent system.

<sup>4</sup>

## References

- [1] Stefan Suwelack, Markus Stoll, Sebastian Schalck, Nicolai Schoch, Rüdiger Dillmann, Rolf Berndl, Vincent Heuveline, and Stefanie Speidel. The medical simulation markup language - simplifying the biomechanical modeling workflow. *Studies in Health Technology and Informatics*, 196:396–400, April 2014.

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<sup>4</sup>*weigl*: [Mailinglist Hint](#)