

Transcranial Magnetic Stimulation Modeling Tutorial

SCIRun 4.7 Documentation

Center for Integrative Biomedical Computing
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SCIRun software download:

<http://software.sci.utah.edu>

Center for Integrative Biomedical Computing:

<http://www.sci.utah.edu/cibc>

This project was supported by grants from the National Center for Research Resources
(**5P41RR012553-14**) and the National Institute of General Medical Sciences
(**8 P41 GM103545-14**) from the National Institutes of Health.

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Overview

This tutorial demonstrates how non-invasive magnetic brain stimulation, known as transcranial magnetic stimulation (TMS), can be modeled using SCIRun. It describes modeling, setting up TMS simulations as well as how to visualize the results based on a simple geometric model: the label mask data set containing multiple spheres forming a Mickey Mouse head.

1.1 Transcranial Magnetic Stimulation (TMS)

Transcranial Magnetic stimulation (TMS) is a non-invasive technique that influences human brain function. TMS is an FDA-approved tool used in basic and clinical neuroscience. A TMS coil can be freely positioned close to the scalp by the experimenter (often guided by a navigation system) to target a specific brain region of interest (ROI).

1.2 Mathematical Modeling

Modeling TMS involves the computation of magnetic fields generated by the TMS coil for a particular ROIs, such as biological tissues (brain/head). The magnetic field originating at the TMS coil can sufficiently be approximated by a number of magnetic dipoles. Those magnetic dipoles describe the magnetic field that the coil is emitting and depend on shape and other technical specifications of the coil. Typical shapes of TMS coils can consist of a single or a double-ring coil. Each subcoil of the most common double-ring coil (8-shaped coil) is wound in opposite direction, which focuses the stimulation at the mid-point of the entire TMS coil. To compute the current density J that is induced by the TMS coil the following equation needs to be solved:

$$J = -\sigma(\nabla\phi + \frac{dA}{dt}),$$

with $\nabla\phi$ being the gradient of the electrical potential (ϕ) and $\frac{dA}{dt}$ being the time derivative of the magnetic vector potential generated by the coil both being multiplied by $-\sigma$, the electrical conductivity tensor. Firstly, the magnetic vector potential is computed at each node location of the ROI mesh. For each of these node locations, a mean conductivity tensor ($\bar{\sigma}$) of the surrounding mesh elements is computed and multiplied by the magnetic vector

potential. The result can be seen as a *primary current* ($J = \sigma \cdot A$, here: assumed to be constant for the considered time interval) induced at the ROI node location. This primary current depends solely on the position, orientation and magnetic field profile of the TMS coil for a given conductivity distribution in the ROI. Secondly, the induced primary currents (J) modeled as electrical boundary (volumetric source) conditions *secondary currents* can also be computed with SCIRun. However, the computation of secondary currents is rather time consuming and appears to have little impact on the current density J . In order to perform feasible real time simulations (also for machines with low computing power) we neglect the contributions of $\sigma \nabla \phi$ regarding the induced current density J in this tutorial.

Software requirements

2.1 SCIRun Compability

The modules demonstrated in this tutorial are available in SCIRun version 4.7 and are not compatible with any older version of SCIRun. Be sure to update your SCIRun version to the latest built available from the [SCIRun website](#), which will include the latest bug fixes and will make sure that the capabilities demonstrated in this tutorial are up to date.

2.2 Required Datasets

This tutorial relies on several datasets that are all part of the SCIRunData bundle. To obtain these datasets, go to the [SCIRun website](#) and click the **Download** button. Instead of the SCIRun source or binary files, download the SCIRunData archive files. The latter is available as a zip file or as a gzip file.

TMS example: The Mickey Mouse

The Mickey Mouse model was chosen because of its simplicity (compared to a human head model) to be part of a real-time TMS simulation. The example scene contains a TMS coil, which is initially positioned in between the Mickey Mouse and a flat pad meant to depict an ideal TMS response (Figure 3.1). To keep the TMS example scenery simple, the TMS response pad is not activated initially (see for more information Section 3.4).

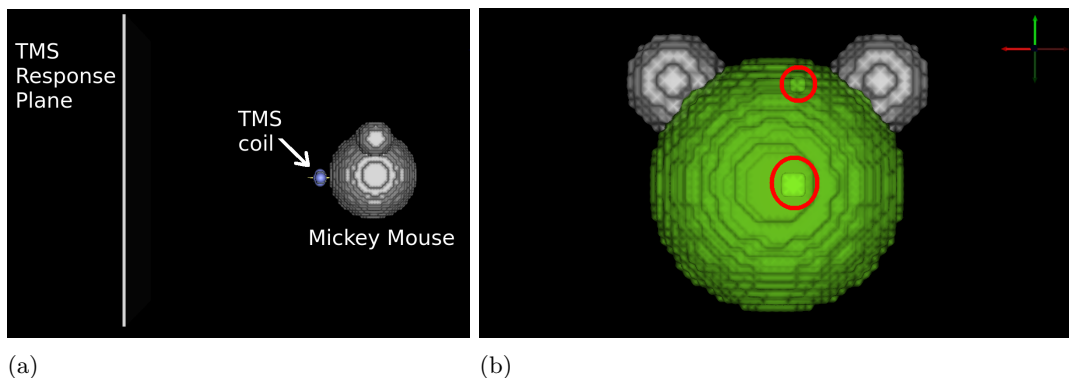


Figure 3.1. (a) the TMS example scenery (TMS response pad, TMS coil, Mickey Mouse Model) (b) the Mickey Mouse is composed of a spherical body, two ears and two target regions (one superficial and one deep inside Mickey's body, circled in red).

3.1 The TMS coil

The 8-shaped TMS coil used in the example is surrounded by a widget frame (gray bars) once clicked (while keeping the shift key pressed) can be used to drag the coil front, back, up, down, left and right. The violet balls are meant to rotate the coil visually around its axis (Figure 3.2(a)). Both subcoils are modeled by 8 magnetic dipoles placed circular around one bigger dipole (magnetic momentum is doubled) in the center of each subcoil depicted as yellow cones (Figure 3.2(b)) approximating the magnetic field.

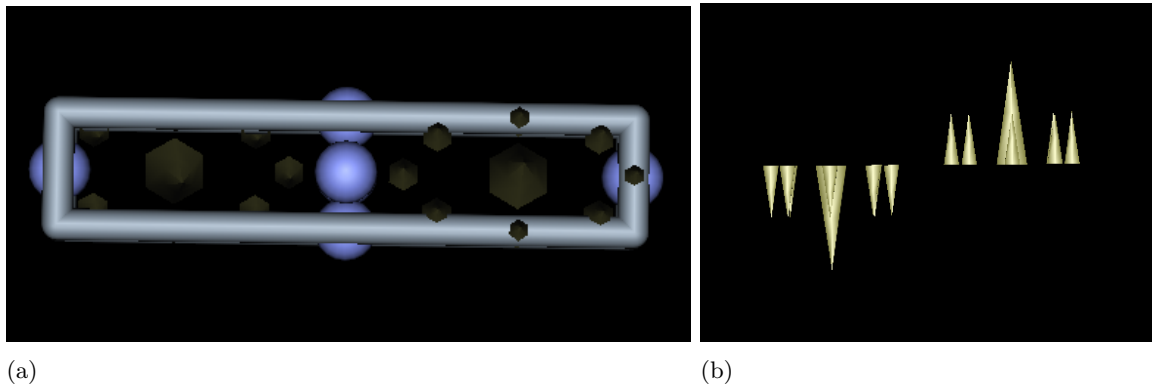


Figure 3.2. (a) TMS coil (dipoles at right coil point towards reader) + GUI frame (b) Magnetic dipoles of TMS coil (side view) for left and right coil.

3.2 The SCIRun4 network

The SCIRun4 network can be found at `Optional/MagneticalBrainStimulation/SCIRUN_TMS_simulation.srn`. In Figure 3.3(a), three important areas of the network are circled in red:

1. Loading the TMS coil and specify the GUI widgets properties (TMS coil appearance) in the `EditMeshBoundingBox` module.
2. Use of the `CreateMatrix` module to set the isotropic electrical conductivities of the Mickey Mouse body.
3. Loading the Mickey Mouse body tetrahedral mesh.

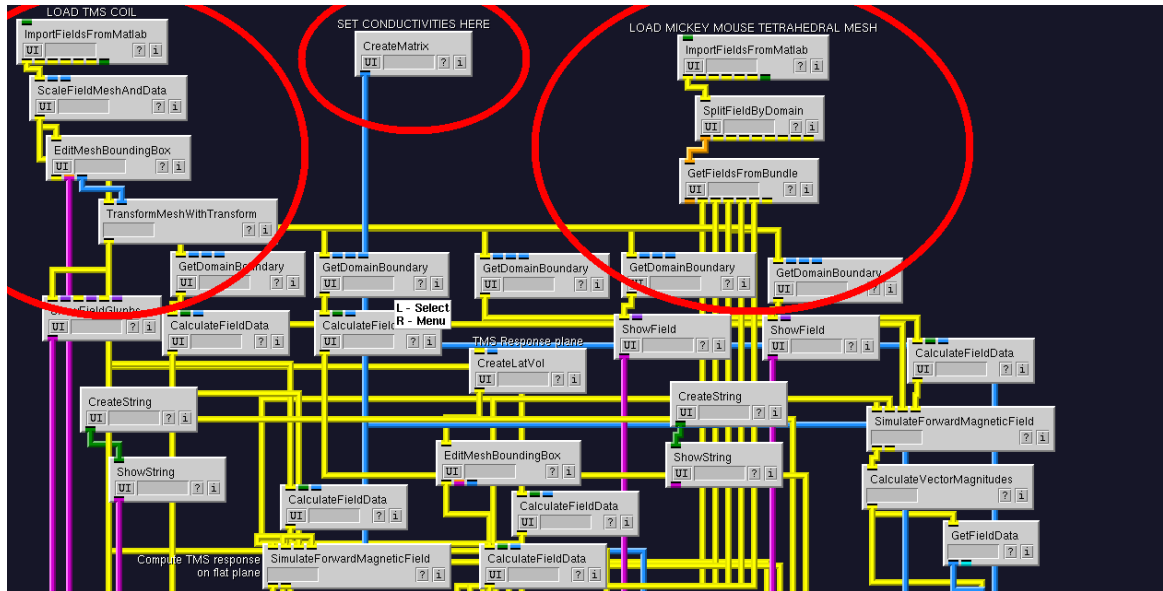
Please check for the correct path in `ImportFieldsFromMatlab` if the network does not execute properly. Modules for computing magnetic fields, determining their maxima and magnetic streamlines as well as their visualization are circled red in Figure 3.3(b).

If you want to visualize magnetic streamlines (the `GenerateStreamLines` module might take some time to complete) based on the last TMS coil position, you need to enable both:

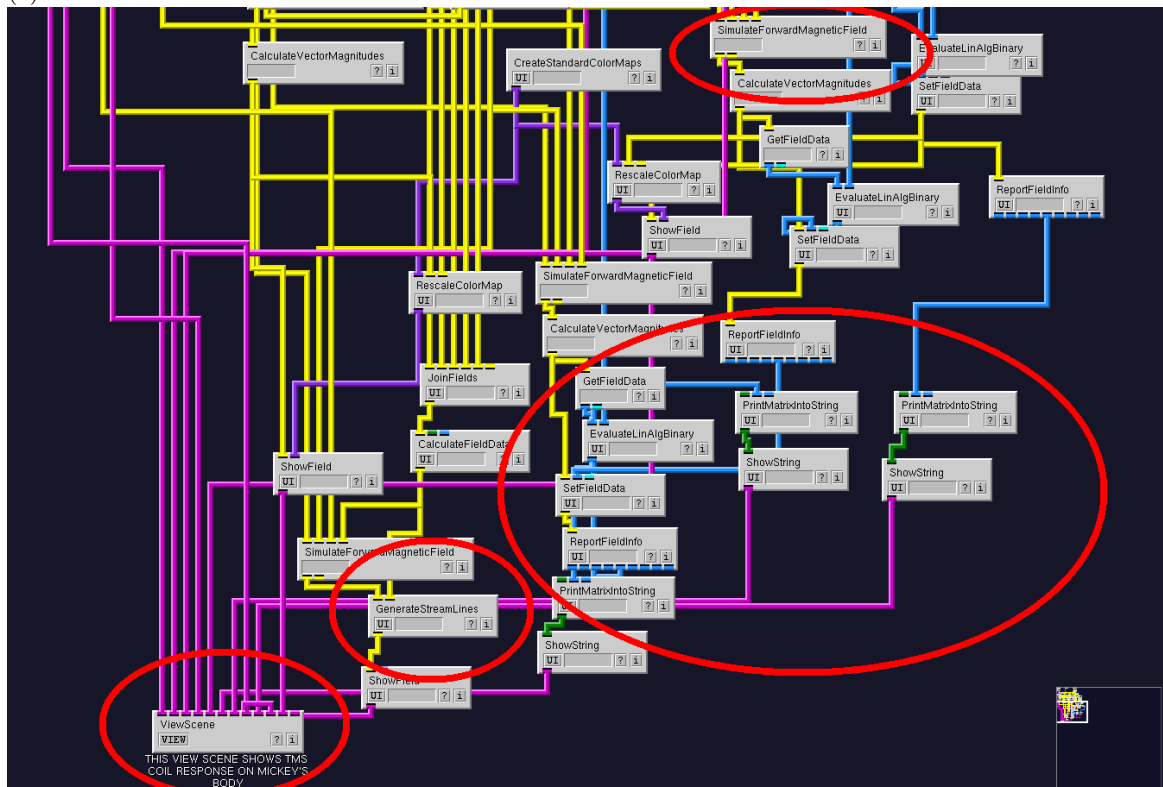
1. the two input fields and the one output field of `GenerateStreamLines` (shown in gray) by making a right click on each and selecting `Enable` and executing the entire network (`Execute all`)
2. make sure that the option `Edges (10)` is checked in your `ViewScene (<Configure> button and Objects tab, Figure 3.4(c))`.

3.3 ViewScene

The `ViewScene` should automatically open up when loading the network. You can execute the entire network by pressing the `Execute All` button in the left lower corner of the SCIRun 4 GUI. After running the network you should be able to see Figure 3.4(a,b). The computed magnetic vector potential magnitude is shown on Mickey's body if you



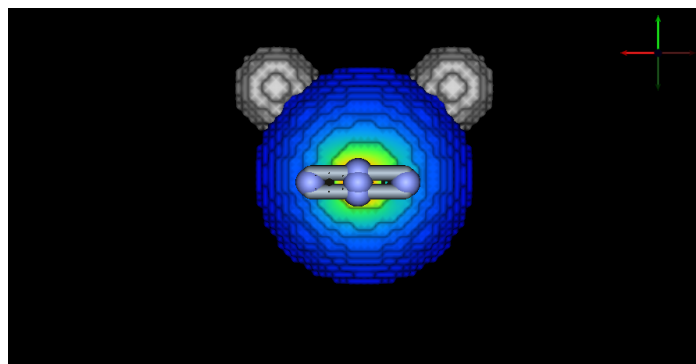
(a)



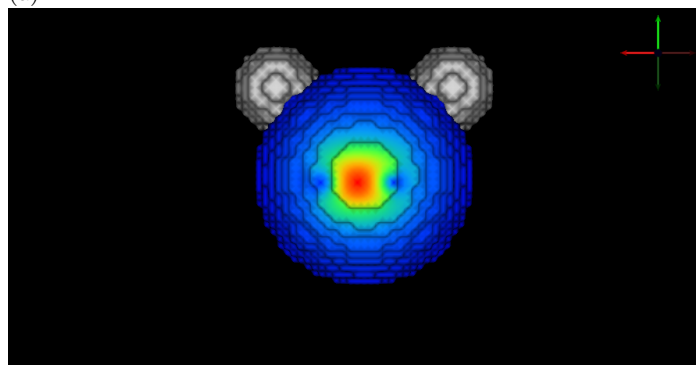
(b)

Figure 3.3. (a) The upper part of the network contains: Loading and setting up the TMS coil; loading Mickey Mouse mesh data and specifying its electrical conductivity (b) The lower part of the network contains magnetic field computations, determining maxima and magnetic streamlines, which are piped to ViewScene

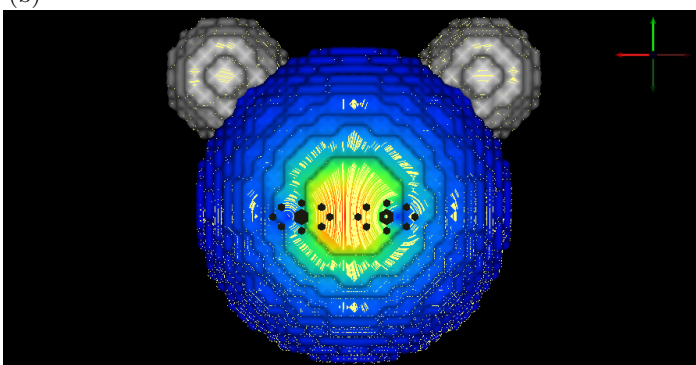
disable the TMS coil (<Configure> button in ViewScene, click on the Objects tab and disable the checkbox `EditMeshBoundingBox Transform` widget (1) and `Field1 Vectors` (8), see Figure 3.4(b)).



(a)



(b)



(c)

Figure 3.4. (a)+(b) Mickey Mouse (frontal view) with and without TMS coil positioned at the “equator” of Mickey’s spherical body surface where the magnetic vector potential magnitude is mapped onto (c) Streamlines generated using the initial TMS coil position (frame disabled)

3.3.1 Interactive Task

Position the TMS coil over the superficial target region between Mickey's ears and maximize magnetic field without touching Mickey's body surface. The superficial region represents a common target in experimental TMS, the human motor cortex. In order to perform efficient TMS stimulation experimentors often try to position a TMS coil as close as possible to the target. You can see the maximum of the magnetic field magnitude for any TMS coil location written at the bottom of the ViewScene (maximal value for surface, superficial and deep region).

3.4 TMS response pad

In order to see an ideal TMS coil response another geometrical object was added to ViewScene, a plane that is here called TMS coil response pad. You can visualize the pad by enabling **Faces** (11) in the ViewScene (<Configure> button, Objects tab).

3.4.1 Interactive Task

Drag the TMS coil away from the Mickey Mouse towards the TMS coil response pad. Evaluate where minimal and maximal magnetic field are located as you go closer to the pad. As you rotate the TMS coil, you will see the pattern change showing the importance of accurate coil positioning and orientation.

In Figure 3.5, the TMS coil is moved closer to the TMS response pad and a classical TMS response pattern can be seen.

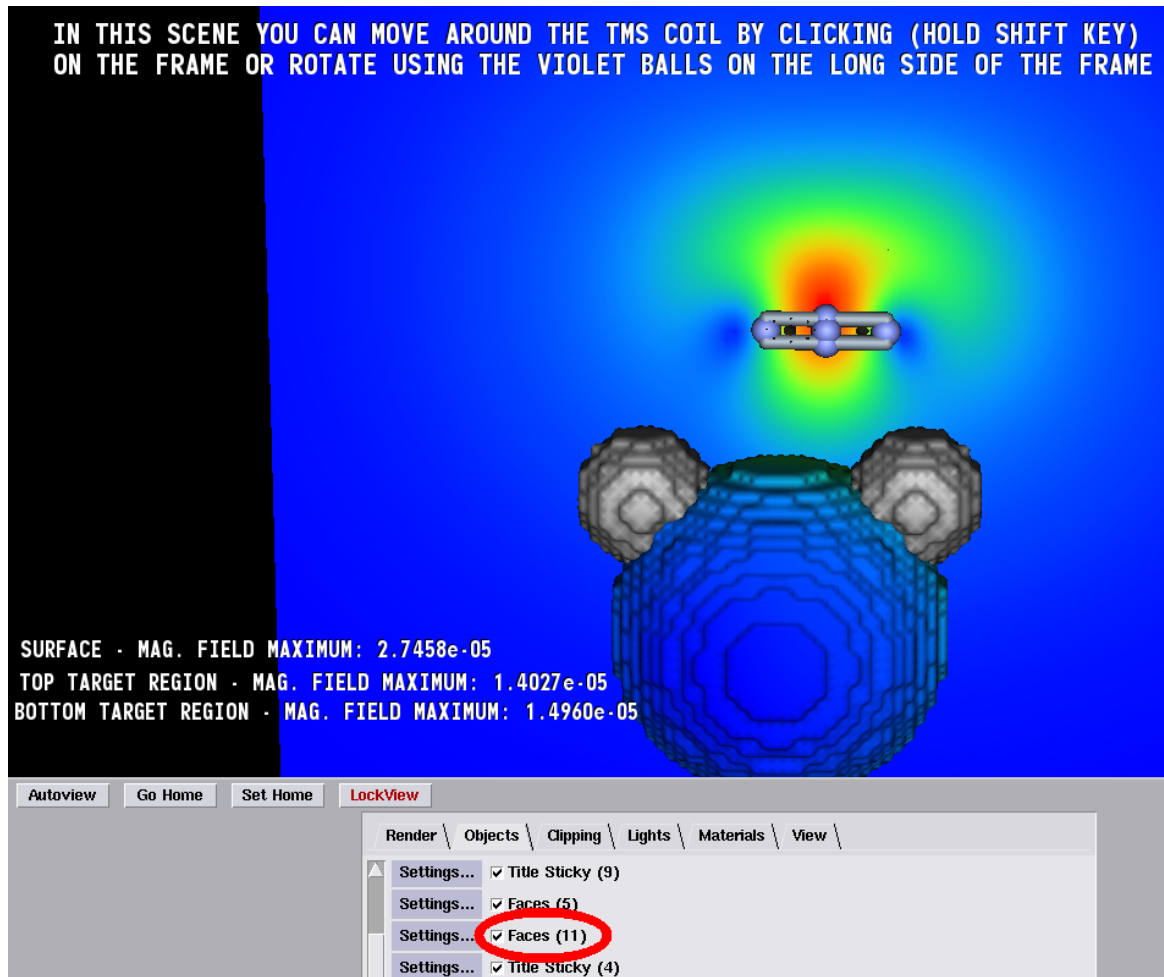


Figure 3.5. Visualizing the magnetic field displayed on a flat surface (TMS response pad)