Contact Information

Visit the Contact COMSOL page at www.comsol.com/contact to submit general inquiries, contact Technical Support, or search for an address and phone number. You can also visit the Worldwide Sales Offices page at www.comsol.com/contact/offices for address and contact information.

If you need to contact Support, an online request form is located at the COMSOL Access page at www.comsol.com/support/case. Other useful links include:

- Support Center: www.comsol.com/support
- Product Updates: www.comsol.com/support/updates
- Discussion Forum: www.comsol.com/community
- Events: www.comsol.com/events
- Support Knowledge Base: www.comsol.com/support/knowledgebase

Part number: CM020008
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Introduction

This guide introduces you to LiveLink™ for MATLAB®, which extends your COMSOL modeling environment with an interface between COMSOL Multiphysics® and MATLAB®. The COMSOL Multiphysics Programming Reference Manual provides additional documentation of the COMSOL API.

In this chapter:

- About this Product
- Help and Documentation
LiveLink™ for MATLAB® connects COMSOL Multiphysics to the MATLAB scripting environment. Using this functionality you can do the following:

**Set Up Models from a Script**
LiveLink™ for MATLAB® includes the COMSOL API, which has all the necessary functions and methods to implement models from scratch. For each operation done in the COMSOL Desktop there is a corresponding command that is entered at the MATLAB prompt. It is a simplified syntax based on Java® and does not require any Java knowledge. The easiest way to learn this syntax is to save the model as an M-file directly from the COMSOL Desktop. Read more about building a model using the command line in the section Building Models.

**Use MATLAB Functions in Model Settings**
Use LiveLink™ for MATLAB® to set model properties with a MATLAB function. For example, define material properties or boundary conditions as a MATLAB routine that is evaluated while the model is solved. Read more in Calling External Functions.

**Leverage MATLAB Functionality for Program Flow**
Use the API syntax together with MATLAB functionality to control the flow of your programs. For example, implement nested loops using for or while commands, implement conditional model settings with if or switch statements, or handle exceptions using try and catch. Some of these operations are described in Running Models in a Loop and Handling Errors and Warnings.

**Analyze Results in MATLAB**
The API wrapper functions included make it easy to extract data at the command line. Functions are available to access results at node points or arbitrary locations. You can also get low level information about the extended mesh, such as finite element mesh coordinates, and connection information between the elements and nodes. Extracted data are available as MATLAB variables ready to be used with any MATLAB function. See Extracting Results and Retrieving Xmesh Information.

**Create Custom Interfaces for Models**
Use the MATLAB Guide functionality to create a user-defined graphical interface that is combined with a COMSOL Multiphysics model. Make your models available for others by creating graphical user interfaces tailored to expose settings and parameters of your choice.
Connect to COMSOL Server™

LiveLink™ for MATLAB® has the ability to connect to COMSOL Server™ as well as COMSOL Multiphysics Server. This means that MATLAB scripts and GUIs that utilize COMSOL functionality can be distributed to and used by any user that have access to COMSOL Server™.
**Help and Documentation**

In this section:

- **Getting Help**
- **Where Do I Access the Documentation and the Application Libraries?**

**Getting Help**

COMSOL Multiphysics and LiveLink™ for MATLAB® have several sources of help and information.

**THE INTRODUCTION TO LIVELINK™ for MATLAB®**

To get started with LiveLink™, it is recommended that you read the *Introduction to LiveLink™ for MATLAB®*. It contains detailed examples about how to get you started with the product.

**ONLINE DOCUMENTATION AND OTHER RESOURCES**

- Read this user’s guide to get detailed information about the different parts of the model object and how these are accessed from MATLAB. In the section Command Reference the function available for use with LiveLink™ for MATLAB® are described.

- The *COMSOL Multiphysics Programming Reference Manual* contains reference documentation that describes the methods in the model object.

You can access the online documentation directly at the MATLAB prompt using the function `mphdoc`.

To open the COMSOL Documentation Help Desk enter:

```
mpdhoc
```

To open the help window for a specific entry node enter:

```
mpdhoc(node)
```

where `node` is the model object node (for instance, `model.geom`).

To view the help of a specific feature of a node enter:

```
mpdhoc(node, <fname>)
```
where `<fname>` is a string defining the feature name in the COMSOL API, e.g. `mphdoc(model,'Rectangle')`.

It is of course also possible to use MATLAB's own help function such as

```matlab
help mphinterp
```

and

```matlab
doc mphinterp
```

**M-FILES**

You can save COMSOL Multiphysics models as M-files. Use the COMSOL Desktop to get your first model implemented using the COMSOL API.

Set up the model using the graphical user interface, then save the model as an M-file. Next go to the File menu and select Save, in the save window locate Save as type list and select Model File for MATLAB (*.m). This generates an M-function that can be run using COMSOL with MATLAB.

Since version 5.3 a new syntax closer to the structure in the Model Builder is available. This new syntax includes the component node as in the example below:

```matlab
model.component(<cTag>).geom(<geomTag>)
```

In the previous syntax to access the geometry node you need to enter:

```matlab
model.geom(<geomTag>)
```

Both versions are fully supported, and the new syntax is used by default when saving a model in the M-file format. To save a model M-file using the old syntax, you need to change the preferences settings as described in the steps below:

1. In the COMSOL Desktop, go to the File menu and click Preferences.
2. In the Preferences window, click Methods. In the Code generation settings clear the option Use component syntax.
3. Click OK.

At the MATLAB prompt use `mphsave` to save the model object `model` in the *.m format as in the command below:

```matlab
mphsave(model,<filename.m>)
```
where <filename.m> is the name of the file with the *.m extension.

The component syntax is not used by default.

To save the model object in the *.m format using the component syntax enter:

```matlab
mphsave(model, <filename.m>, 'component', 'on');
```

Models created with older versions than COMSOL 5.3 cannot be saved using the component syntax unless File>Compact History is used.
THE APPLICATION LIBRARIES WINDOW

Study the LiveLink™ for MATLAB® Application Library

LiveLink™ for MATLAB® includes an Application Library with detailed example models. Use the function mphapplicationlibraries at the command line to start a GUI for viewing the Application Libraries.

The following are some models that can help you get started.

Model Examples

- Learn how to activate and deactivate domains alternatively during a transient analysis. See the model Domain Activation and Deactivation (model name domain_activation_llmatlab).
- Homogenization in a Chemical Reactor (model name homogenization_llmatlab) shows how to simulate a periodic homogenization
process in a space-dependent chemical reactor model. This homogenization removes concentration gradients in the reactor at a set time interval.

- **Convective Heat Transfer with Pseudo-Periodicity** (model name pseudoperiodicity_llmatlab) simulates convective heat transfer in a channel filled with water. To reduce memory requirements, the model is solved repeatedly on a pseudo-periodic section of the channel. Each solution corresponds to a different section, and before each solution step the temperature at the outlet boundary from the previous solution is mapped to the inlet boundary.

- **Temperature Distribution in a Vacuum Flask** (model name vacuum_flask_llmatlab) shows how to use the MATLAB function callback. This example solves for the temperature distribution inside a vacuum flask with hot coffee.

- **Electrical Heating of a Busbar Solved with LiveLink™ for SOLIDWORKS® and LiveLink™ for MATLAB®** (model name busbar_llsw_llmatlab) performs geometry optimization using COMSOL Multiphysics, MATLAB, and SOLIDWORKS®.

Where Do I Access the Documentation and the Application Libraries?

A number of internet resources have more information about COMSOL, including licensing and technical information. The electronic documentation, topic-based (or context-based) help, and the application libraries are all accessed through the COMSOL Desktop.

---

| If you are reading the documentation as a PDF file on your computer, the blue links do not work to open an application or content referenced in a different guide. However, if you are using the Help system in COMSOL Multiphysics, these links work to other modules (as long as you have a license), application examples, and documentation sets. |

---

**THE DOCUMENTATION AND ONLINE HELP**

The *COMSOL Multiphysics Reference Manual* describes all core physics interfaces and functionality included with the COMSOL Multiphysics license. This book also has instructions about how to use COMSOL Multiphysics and how to access the electronic Documentation and Help content.
**Opening Topic-Based Help**

The Help window is useful as it is connected to many of the features on the GUI. To learn more about a node in the Model Builder, or a window on the Desktop, click to highlight a node or window, then press F1 to open the Help window, which then displays information about that feature (or click a node in the Model Builder followed by the Help button (❓)). This is called *topic-based (or context) help*.

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<th>To open the <strong>Help</strong> window:</th>
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</thead>
<tbody>
<tr>
<td>• In the <strong>Model Builder, Application Builder, or Physics Builder</strong> click a node or window and then press F1.</td>
<td></td>
</tr>
<tr>
<td>• On any toolbar (for example, <strong>Home, Definitions, or Geometry</strong>), hover the mouse over a button (for example, <strong>Add Physics</strong> or <strong>Build All</strong>) and then press F1.</td>
<td></td>
</tr>
<tr>
<td>• From the <strong>File menu</strong>, click <strong>Help (❓)</strong>.</td>
<td></td>
</tr>
<tr>
<td>• In the upper-right corner of the COMSOL Desktop, click the <strong>Help(❓)</strong> button.</td>
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<th>Mac/Linux</th>
<th>To open the <strong>Help</strong> window:</th>
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<tbody>
<tr>
<td>• In the <strong>Model Builder</strong> or <strong>Physics Builder</strong> click a node or window and then press F1.</td>
<td></td>
</tr>
<tr>
<td>• On the main toolbar, click the <strong>Help (❓)</strong> button.</td>
<td></td>
</tr>
<tr>
<td>• From the main menu, select <strong>Help&gt;Help</strong>.</td>
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**Opening the Documentation Window**

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<tr>
<td>• From the <strong>File menu</strong> select <strong>Help&gt;Documentation (📑)</strong>.</td>
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### THE APPLICATION LIBRARIES WINDOW

Each application includes documentation with the theoretical background and step-by-step instructions to create a model application. The applications are available in COMSOL as MPH-files that you can open for further investigation. You can use the step-by-step instructions and the actual applications as a template for your own modeling and applications. In most models, SI units are used to describe the relevant properties, parameters, and dimensions in most examples, but other unit systems are available.

Once the Application Libraries window is opened, you can search by name or browse under a module folder name. Click to view a summary of the application and its properties, including options to open it or a PDF document.

---

#### Opening the Application Libraries Window

To open the Application Libraries window ( ):

- **Mac**
  - Press Ctrl+F1.
  - On the main toolbar, click the **Documentation** button.
  - From the main menu, select **Help>Documentation**.

- **Linux**
  - Press Ctrl+F1.
  - On the main toolbar, click the **Documentation** button.
  - From the main menu, select **Help>Documentation**.

---

**The Application Libraries Window** in the *COMSOL Multiphysics Reference Manual*. 

---

**Opening the Application Libraries Window**

To open the **Application Libraries** window ( ):

- From the **Home** toolbar, **Windows** menu, click **Applications Libraries**.

- From the **File** menu select **Application Libraries**.

**To include the latest versions of model examples**, from the **File>Help** menu, select ( ) **Update COMSOL Application Library**.

---

**Mac**

- Select **Application Libraries** from the main **File> or Windows>** menus.

**To include the latest versions of model examples**, from the **Help** menu select ( ) **Update COMSOL Application Library**.

---

**Linux**

- Select **Application Libraries** from the main **File> or Windows>** menus.

**To include the latest versions of model examples**, from the **Help** menu select ( ) **Update COMSOL Application Library**.
CONTACTING COMSOL BY EMAIL

For general product information, contact COMSOL at info@comsol.com.

To receive technical support from COMSOL for the COMSOL products, please contact your local COMSOL representative or send your questions to support@comsol.com. An automatic notification and case number is sent to you by email.

COMSOL WEBSITES

<table>
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<td><a href="http://www.comsol.com/support/knowledgebase">www.comsol.com/support/knowledgebase</a></td>
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In this chapter:

- The Client-Server Architecture
- Running COMSOL Models at the Command Line
- The COMSOL Apps
- Calling External Function within the Model
The Client-Server Architecture

LiveLink™ for MATLAB® uses the client-server mode to connect a COMSOL server and MATLAB.

The term COMSOL server designates either the COMSOL Multiphysics server or the COMSOL Server™.

When starting COMSOL with MATLAB, two processes are started — a COMSOL Multiphysics server and the MATLAB desktop. The COMSOL Desktop does not have to be started, but it possible to have both MATLAB and COMSOL Desktop connected to the same COMSOL Multiphysics server at the same time.

COMSOL Desktop cannot connect to COMSOL Server™.

The communication between the two processes is based on a TCP/IP communication protocol. You provide login information the first time COMSOL is started with MATLAB. The login information is not related to the system’s username and password. This information is stored in the user preferences file and is not required again when using COMSOL with MATLAB. The same login information can be used when exchanging the model object between the COMSOL server and the COMSOL Desktop.

The communication between the COMSOL server and MATLAB is established by default using port number 2036. If this port is in use, port number 2037 is used instead, and so on.

You can manually specify the port number. See the COMSOL Multiphysics Installation Guide for more information on the COMSOL server start-up properties.
A connection can be local (on the same computer), which is the common case, or remote to a COMSOL server located on a different computer, in the later case you to connect manually MATLAB to the COMSOL server as described in the section Connecting a COMSOL server and MATLAB® Manually.

You can manually specify the port number. See the COMSOL Multiphysics Installation Guide for more information on the COMSOL server start-up properties.
Running COMSOL Models at the Command Line

The command to run COMSOL with MATLAB® automatically connects a COMSOL process with MATLAB. You can also connect the process manually. This section describes this process as well as how to change the MATLAB path in the COMSOL settings.

The System Requirements section in the COMSOL Multiphysics Installation Guide lists the versions of MATLAB supported by LiveLink™ for MATLAB®.

In this section:
- Starting COMSOL® with MATLAB® on Windows®/ Mac OS X / Linux®
- Connecting a COMSOL server and MATLAB® Manually
- Changing the MATLAB® Version

Starting COMSOL® with MATLAB® on Windows®/ Mac OS X / Linux®

To run a COMSOL Multiphysics model at the MATLAB® prompt, start COMSOL with MATLAB:

- On Windows®, use the COMSOL Multiphysics with MATLAB shortcut icon that is created on the desktop after the automatic installation. A link is also available in the Windows start menu under All Programs>COMSOL Multiphysics 5.3a>COMSOL Multiphysics 5.3a with MATLAB.
- On Mac OS X, use the COMSOL with MATLAB application available in the Application folder.
- On Linux®, enter the command `comsol mphserver matlab` at a terminal window.

See the COMSOL Multiphysics Installation Guide for a complete description about how to start COMSOL with MATLAB on these supported platforms.
The first time **COMSOL Multiphysics with MATLAB** is started, login and password information is requested to establish the client/server connection. The information is saved in the user preference file and is not required again.

To reset the login information, add the flag `-login force` to the icon target path.

To reset the login information, enter the command `comsol mphserver matlab -login force` at a system command prompt.

### **RUNNING A MODEL M-FILE FROM TERMINAL PROMPT**

If you want to run an M-file directly at a terminal prompt immediately after having started **COMSOL Multiphysics with MATLAB** enter the startup command as described below:

**Win**

```bash
comslmphserver.exe matlab filename
```

**Mac**

```bash
comsl mphserver matlab filename
```

**Linux**

```bash
comsl mphserver matlab filename
```

where `filename.m` is the file containing both MATLAB and COMSOL API command to be executed using COMSOL with MATLAB.
RUNNING WITHOUT DISPLAY

If you need to run COMSOL with MATLAB on a machine without support for graphics display, add the flags `nodetop` and `mlnosplash` to the startup command as described below:

Win

```
comsolmphserver.exe matlab -nodetop -mlnosplash
```

Mac

```
comsol mphserver matlab -nodetop -mlnosplash
```

Linux

```
COMSOL_MATLAB_INIT='matlab -nosplash'
```

The above command starts MATLAB without splash screen and without the MATLAB desktop.

To avoid the splash screen on the COMSOL Server, you need to create the environment variable `COMSOL_MATLAB_INIT` and set it to `matlab -nosplash`.

Connecting a COMSOL server and MATLAB® Manually

Manually connecting MATLAB® to a COMSOL server can be useful if you want to start a MATLAB standalone and then connect to a COMSOL server, or if you need to connect MATLAB and a COMSOL server running on different computers.

LiveLink™ for MATLAB® provides the function `mphstart` to operate the client/server connection. This section contains the instruction to follow to connect MATLAB to either a COMSOL Multiphysics server or the COMSOL Server™.
CONNECTING MATLAB TO A COMSOL MULTIPHYSICS SERVER

Starting a COMSOL Multiphysics server

- On Windows go to the start menu All Programs>COMSOL 5.3a> Client Server>COMSOL Multiphysics 5.3a server.
- On Mac OS X or Linux enter comsol mphserver at a terminal window.

Connecting MATLAB to the COMSOL Multiphysics Server

1. In MATLAB, add the path of the COMSOL 5.3a/mli directory.
2. Enter this command at the MATLAB prompt:
   ```matlab
   mphstart
   ```
   If the COMSOL Multiphysics server started listening to a different port than the default one (which is 2036) use the `mphstart` function as in the command below:
   ```matlab
   mphstart(<portnumber>)
   ```
   where `<portnumber>` is an integer corresponding to the port used by the COMSOL server.

CONNECTING MATLAB AND A SERVER ON DIFFERENT COMPUTERS

To connect MATLAB and a COMSOL Multiphysics server that are running on different computers, specify the IP address of the computer where the COMSOL server is running in the function `mphstart`:

```matlab
mphstart(<ipaddress>, <portnumber>)
```

`<ipaddress>` can also be defined with the COMSOL server domain name.

The command above assume that the same user login information are set on the server and client machine. In case the login information are not accessible from the client machine, specify manually the user name and password to the COMSOL server with the command:

```matlab
mphstart(<ipaddress>, <portnumber>, <username>, <password>)
```

If the COMSOL Multiphysics installation folder cannot be found automatically, you can specify its location manually as in the command below:

```matlab
mphstart(<ipaddress>, <portnumber>, <comsolpath>)
```
where `<comsolpath>` is the path of the COMSOL installation folder.

You can also specify all the information to connect a COMSOL server within the same command, use the following command:

```matlab
mphstart(<ipaddress>, <portnumber>, <comsolpath>, ...
  <username>, <password>)
```

**MEMORY SETTINGS**
To be able to manipulate the model object and extract data at the MATLAB prompt, you may need to modify the Java® heap size in MATLAB. See Improving Performance for Large Models.

**IMPORTING THE COMSOL CLASS**
Once MATLAB and the COMSOL server are manually connected, import the COMSOL class by entering the following command at the MATLAB prompt:

```matlab
import com.comsol.model.util.*
```

**Disconnecting MATLAB and the COMSOL server**
To disconnect MATLAB and the COMSOL server, run this command at the MATLAB prompt:

```matlab
ModelUtil.disconnect;
```

**Connecting to COMSOL Server™**
When using a COMSOL Multiphysics installation with LiveLink for MATLAB the connected is made between MATLAB and a COMSOL Multiphysics Server. It is also possible to connect MATLAB to a COMSOL Server™ if a COMSOL Server™ is available with a LiveLink for MATLAB License.

When using LiveLink for MATLAB with COMSOL Server™ this way MATLAB is installed on the local computer where the user is executing commands and COMSOL Server™ will most often be on another computer that is handled by an IT-department.

In order to be able to connect from MATLAB to a COMSOL Server™ without having Comsol Multiphysics installed some files must be installed on the computer where MATLAB is installed. This is handled by using the COMSOL Server Client installer.
When installing the COMSOL Server Client it is important to select LiveLink™ for MATLAB© in the installation window.

It is recommended to install Desktop and Start menu shortcuts. If these are not installed, the only way to create a link between MATLAB and COMSOL Server is to use the `mphstart` command as previously described for use with COMSOL Multiphysics Server.

After the installation a shortcut is available.

When clicking on this shortcut MATLAB will start and a dialog box appears that makes it possible to connect to the COMSOL Server™ that is already assumed running.

Fill in the missing information and click OK to connect.
After a connection has been made the LiveLink work in the same way as it does when connected to a COMSOL Multiphysics server with these exceptions:

- Some graphical user interfaces that are included in a regular COMSOL Multiphysics license do not work
- `mphplot` cannot plot on the server but has to plot on a local MATLAB figure.

### Changing the MATLAB® Version

The path of the MATLAB® version connected to COMSOL Multiphysics is defined during the initial COMSOL installation. The MATLAB root path can be changed using the Preferences dialog box:

1. From the File (Windows users) or Options menu (Mac and Linux users), select Preferences ( ).
2. In the Preferences dialog box, click LiveLink products.
3. Set the MATLAB root directory path in the MATLAB installation folder field.
4. Windows OS users also need to click the Register MATLAB as COM Server button; otherwise, the specified MATLAB version does not start when calling external MATLAB functions from the COMSOL model.
5. Click OK.

6. To update the preferences file, close and reopen the COMSOL Desktop.
On Mac OS X, select the **COMSOL with MATLAB** application available in the **Application** folder. The correct path includes the `.app` extension.
The COMSOL Apps

Install apps in the MATLAB desktop for an easy access to COMSOL information and navigation functions that use Graphical User Interfaces.

Installing Apps in the MATLAB Apps Ribbon

The automatic COMSOL installation does not include installation of the COMSOL apps in the MATLAB Apps Ribbon. To install the apps follow the steps below:

1. In the MATLAB Desktop, go to the Apps Tab and select Install App.
2. Browse to the COMSOL Installation directory and go to the folder: COMSOL53a/Multiphysics/mli/toolbox
3. Change File name extension to All Files (*.*) and select the file LiveLink for MATLAB.mltbx
4. Click OK. This opens the Install LiveLink for MATLAB window.

5. In the Install LiveLink for MATLAB window click Install.
Removing Apps in the MATLAB Apps Ribbon.

To remove Apps from the MATLAB Apps Ribbon, right-click on the apps icon and select Uninstall. The operation is individual for each apps and need to be repeated for every apps to be removed.

The COMSOL Apps

The available COMSOL apps that can be installed in the MATLAB Apps ribbon are listed below:

- COMSOL Model Library, opens a GUI for viewing the Model Library, see also The Application Libraries Window.
- COMSOL Model Navigator, opens a GUI for viewing the COMSOL model object defined as model in MATLAB. You can get more information in the section Navigating the Model Object Using a GUI.
- COMSOL Open, opens a GUI for opening recent files, see also Loading a Model from a List of Existing files.
- COMSOL Search, opens a GUI for searching for expressions in the COMSOL model object defined as model in MATLAB. See also Finding Model Expressions.

To run these apps you need a connection between MATLAB and a COMSOL server, either using COMSOL with MATLAB or using manual connection.
Callin g External Function within the Model

Use LiveLink™ for MATLAB® to call MATLAB functions from within the model — for instance, when working in the COMSOL Desktop. The procedure is different than implementing a model using a script as you do not need to run COMSOL with MATLAB.

Start COMSOL Multiphysics as a standalone application. The external MATLAB function needs to be defined in the COMSOL model so that a MATLAB process can automatically start when the function needs to be evaluated. The result of the function evaluation in MATLAB is then sent back to the COMSOL environment.

To run a MATLAB function, enable Allow external MATLAB® functions in the Preferences window; see Allowing External MATLAB functions for more information.
Building Models

This chapter gives an overview of the model object and provides an introduction to building models using the LiveLink™ interface.

In this chapter:

- The Model Object
- Working with Geometries
- Working with Meshes
- Modeling Physics
- Creating Selections
- Computing the Solution
- Analyzing the Results
The Model Object

While working with the LiveLink™ interface in MATLAB®, you work with models through the model object. Use methods to create, modify, and access models.

In this section:

• Important Notes About the Model Object
• The Model Object Methods
• The General Utility Functionality
• The Model History
• Loading and Saving a Model
• Sharing the Model Between the COMSOL Desktop® and the MATLAB® Prompt

Important Notes About the Model Object

Consider the following information regarding the model object:

• All algorithms and data structures for the model are integrated in the model object.
• The model object is used by the COMSOL Desktop to represent your model. This means that the model object and the COMSOL Desktop behavior are virtually identical.
• The model object includes methods to set up and run sequences of operations to create geometry, meshes, and to solve your model.

LiveLink™ for MATLAB® includes the COMSOL API, which is a programming interface based on Java®. In addition, the product includes a number of M-file utility functions that wrap API functionality for greater ease of use.
The Model Object Methods

The model object has a large number of methods. The methods are structured in a tree-like way, very similar to the nodes in the model tree in the Model Builder window on the COMSOL Desktop. The top-level methods just return references that support further methods. At a certain level the methods perform actions, such as adding data to the model object, performing computations, or returning data.

The General Utility Functionality

The model object utility methods are available with the ModelUtil object. These methods can be used, for example, to create or remove a new model object, but also to enable the progress bar or list the model object available in the COMSOL server.

MANAGING THE COMSOL MODEL OBJECT

Use the method ModelUtil.create to create a new model object in the COMSOL server:

```matlab
model = ModelUtil.create('Model');
```

This command creates a model object Model on the COMSOL server and a MATLAB object model that is linked to the model object.

It is possible to have several model objects on the COMSOL server, each with a different name. To access each model object requires different MATLAB variables linked to them and each MATLAB variable must have a different name.

Create a MATLAB variable linked to an existing model object with the method ModelUtil.model. For example, to create a MATLAB variable model that is linked to the existing model object Model on the COMSOL server, enter the command:

```matlab
model = ModelUtil.model('Model');
```

To remove a specific model object use the method ModelUtil.remove. For example, to remove the model object Model from the COMSOL server enter the command:

```matlab
ModelUtil.remove('Model');
```

Detailed documentation about model object methods is in About General Commands in the COMSOL Multiphysics Programming Reference Manual.
Alternatively remove all the COMSOL objects stored in the COMSOL server with the command:

```matlab
ModelUtil.clear
```

List the names of the model objects available on the COMSOL server with the command:

```matlab
mphtags -show
```

**ACTIVATING THE PROGRESS BAR**

By default no progress information is displayed while running COMSOL with MATLAB. To manually enable a progress bar and visualize the progress of operations (such as loading a model, creating a mesh, assembling matrices, or computing the solution), enter the command:

```matlab
ModelUtil.showProgress(true)
```

To deactivate the progress bar enter:

```matlab
ModelUtil.showProgress(false)
```

**Mac OS X does not support the progress bar.**

---

**The Model History**

The model contains its entire modeling history corresponding to every settings added once to the model. When you save a model as an M-file, you get all the operations performed to the model, including settings that are no longer part of the model.

Using the model history is a convenient way to learn the COMSOL API. The latest settings enter in the command Desktop being listed at the end of the M-file.

The model history is automatically enabled when the model is created in the COMSOL Desktop. It is however possible to manually disable the model history recording from the MATLAB prompt with the command:
model.hist.disable

To enable the model history, enter the command:

```
model.hist.enable
```

**COMPACTING THE MODEL HISTORY**

To clean the M-file for the model so that it contains only the settings that are part of the current model you need to compact the model history before saving the model as an M-file.

To compact the model history in the COMSOL Desktop, from File menu (Windows users) or from the toolbar (Mac and Linux users), select Compact History ( ).

To compact the model history at the MATLAB prompt enter the command:

```
model.resetHist
```

**Loading and Saving a Model**

**LOADING A MODEL AT THE MATLAB PROMPT**

To load an existing model saved as an MPH-file use the function `mphopen`. To load the model with the name `<filename>` enter:

```
model = mphopen('<filename>')
```

where `<filename>` is a string. This creates a model object `Model` on the COMSOL server that is accessible using the MATLAB variable `model`.

A shorter form is to simply use

```
mphopen '<filename>
```

that will load the model with the given filename and use the variable name `model` for accessing the model later. Any existing variable `model` will be overwritten without warning.

The function `mphload` can also be used with the same property. In the following documentation the commands also work with `mphload`. 

---

The functions `mphload` and `mphopen` automatically disable model history when loading a model.
Once the model is loaded, the file name and its associated model object tag are displayed in the COMSOL server window.

If there is already a model object Model in the COMSOL server, mphopen overrides the existing model object unless the model is also open in a COMSOL Multiphysics Client. In the later case, an index number is appended to the new model object name, for instance Model1.

If you want to manually specify the model object in the COMSOL server, use the command:

```matlab
model = mphopen(<filename>, <ModelTag>);
```

where `<ModelTag>` is a string defining the tag that defines the loaded model in the COMSOL server.

When using the function mphopen, the model history is automatically disabled to prevent large history information when running a model in a loop. To turn model history on, use the function mphopen:

```matlab
model = mphopen(<filename>, '-history');
```

If the model mph-file is protected using a password, use mphload as in the command below:

```matlab
model = mphopen(<filename>, <ModelTag>, <password>)
```

where `<password>` is a string defining the password protecting the file.

mphload does not store the filename in the recent file list as mphopen does by default.

mphopen and mphload do not look for lock file when opening a model in the COMSOL server.

The history recording can be useful when using the COMSOL Desktop. All the operations are then stored in the saved M-file.

If you do not want to update the recent opened file list with the model you are about to open, use the -nostore flag with the function mphopen as in the command below:

```matlab
model = mphopen(<filename>, <ModelTag>, '-nostore')
```

If the model mph-file is protected using a password, use mphload as in the command below:

```matlab
model = mphopen(<filename>, <ModelTag>, <password>)
```
If you want to get the full filename of the loaded file, add a second output as in the command below:

\[ \text{[model, filenameloaded]} = \text{mphopen(}<\text{filename}>\text{, ...)} \]

LOADING A MODEL FROM A LIST OF EXISTING FILES

You can use a GUI where to load the model from a list files corresponding to the recent opened file or the files in a specified directory.

At the MATLAB prompt enter the command:

\text{mphopen}

This starts a GUI with a list of the recent opened files.

If you have installed the COMSOL apps in the MATLAB Apps ribbon, click the COMSOL Open icon ( ).

For each selected files, the model information is available in the **File Info** section.

Click the **Recent** button to get the list of the recent opened file. Click the **Search** button to search for a file using file pattern. Click the **Browse** button to browse the directory where to get filename list.
To clear the recent opened file list enter the command:

`mphopen -clear`

To open the GUI with the list of files in a specific directory `<dirpath>`, enter the command:

`mphopen -dir <dirpath>`

**SAVING A MODEL**

Use the function `mphsave` to save the model object linked to the MATLAB object model:

`mphsave(model,<filename>)`

where `<filename>` is a string. If the filename specified `<filename>` does not provide a path, the file is saved relative to the current MATLAB path. The file extension determines the format to use (*.mph, *.m, *.java, or *.vba).

Alternatively, use the save method:

`model.save(<filename>)`

If `<filename>` does not provide a path, the file is saved relative to the local server path.

Any files saved in the MPH format can be loaded by COMSOL Desktop. In addition, the model can be saved as an M-file:

`model.save(<filename>, 'm')`

When saving the model as an M-file `mphsave` does not automatically use the component syntax to save model using the COMSOL API, to enable this syntax run the command below:

`mphsave(model,<filename>, 'component', 'on')`

The models are not automatically saved between MATLAB sessions.

**SET A MODEL THUMBNAIL**

Before saving your model, you may want to include a model thumbnail to quickly identify your model in your own Application Library or when using `mphopen`. To set the model thumbnail enter the command:
mphthumbnail(model,<filename>)

where <filename> is the image file name.

You can also use a MATLAB figure to set the thumbnail. The following command will set the thumbnail to the image of the current figure:

mphthumbnail(model,gcf)

Note that the thumbnail is stored in memory. In order to save the thumbnail in the model file the model must be saved.

You can extract the image and image filename for the thumbnail stored in model, enter the command:

[image, imagefilename] = mphthumbnail(model)

**Example**

The code below shows how to get the model thumbnail as MATLAB image data, show the image in a MATLAB figure and store the new image as thumbnail in the model.

mphopen model_tutorial_llmatlab
im = mphthumbnail(model);
imshow(im)
mphthumbnail(model, gcf)

**Sharing the Model Between the COMSOL Desktop® and the MATLAB® Prompt**

It is possible to connect a COMSOL Desktop to the COMSOL Multiphysics Server that is already connected with MATLAB and then access the model from both client (the COMSOL Desktop and MATLAB). The change performed from either client are directly accessible from the other one; for instance, type a command at the MATLAB prompt and see the resulting modification in the Model Builder window, or extract data at the MATLAB prompt from a model set up in the COMSOL Desktop.

**CONNECT THE COMSOL DESKTOP TO THE COMSOL MULTIPHYSICS SERVER WITH MPH LAUNCH**

Use `mphlaunch` to start a COMSOL Desktop, connect it to the same COMSOL Multiphysics Server to which MATLAB is connected to, and import a model.

Run the command below:

mphlaunch
This starts a new COMSOL Desktop, connect it to the COMSOL Multiphysics Server that is already connected with MATLAB, and import the model available in the server. In case several model are available in the server you can specify which one to import by running the command below:

```
mphlaunch ModelTag
```

where `ModelTag` is the tag of the model to import.

List the tags of the application loaded in the server with the command `mphtags`.

You can also specify the MATLAB object name that is link to the application to be imported in the COMSOL Desktop, enter the command:

```
mphlaunch(model)
```

If a COMSOL Multiphysics client is already connected to the COMSOL Multiphysics server you will be asked to disconnect the connected client and connect the new one or cancel the operation.

`mphlaunch` sets automatically a timeout to make MATLAB wait 0.5 second until the COMSOL server is free again. If you need to increase the timeout run the command below:

```
mphlaunch(model,<timeout>)
```

where `<timeout>` is the time in milliseconds to wait for the server to be free again.

**CONNECT THE COMSOL DESKTOP TO THE COMSOL MULTIPHYSICS SERVER MANUALLY**

Connect the COMSOL Desktop to a COMSOL Multiphysics server manually using the `Connect to Server` dialog box:

1. From the File (Windows users) or Options menu (Mac and Linux users), select COMSOL Multiphysics Server>Connect to Server ( ).

2. In the `Connect to Server` window, you specify the Server configuration and the user settings. In the `Server` section enter the COMSOL Multiphysics Server name (the default name is `localhost`) and the Port number (the default is 2036). This number corresponds to the port that the COMSOL Multiphysics Server is listening to, the number is displayed at the COMSOL Multiphysics Server window.

3. In the User section enter a Username and a Password (if they are empty); these are defined the first time you are connected to the COMSOL Multiphysics Server.
4 Click OK.

The first time you connect the COMSOL Desktop to the COMSOL Multiphysics Server no model is loaded to the GUI. See Import An application from the COMSOL Multiphysics Server to the COMSOL Desktop to know how connect the GUI to a model loaded in the COMSOL Multiphysics Server.

**IMPORT AN APPLICATION FROM THE COMSOL MULTIPHYSICS SERVER TO THE COMSOL DESKTOP**

Once you have the COMSOL Desktop connected to the COMSOL Multiphysics Server you can import the model in the GUI:

1. From the File (Windows users) or Options menu (Mac and Linux users), select **COMSOL Multiphysics Server>Import Application from Server**.

2. In the **Import Application from Server** window, specify the application you want to import.

**IMPORT A MODEL FROM THE COMSOL MULTIPHYSICS SERVER TO MATLAB**

To access a model stored in the COMSOL Multiphysics Server from the MATLAB prompt enter the command:

```matlab
model = ModelUtil.model(<ModelTag>)
```

where `model` is the variable in MATLAB used to access the model stored on the COMSOL server and `<ModelTag>` is the tag of the COMSOL Model.

You can get the list of the models stored in the COMSOL Multiphysics server with the command:

```
mphtags -show
```
Set up a time-out in MATLAB
To prevent MATLAB sending command to the COMSOL Multiphysics server while it is busy to update the COMSOL Desktop, you need to set up a time-out in MATLAB and specify how long to wait the COMSOL Multiphysics Server to be free again. Enter the command:

```
ModelUtil.setServerBusyHandler(ServerBusyHandler(<timeout>))
```

Where `<timeout>` is the time in millisecond to wait the server to be free again.
Working with Geometries

This section describes how to set up and run a geometry sequence. In this section:

- The Geometry Sequence Syntax
- Displaying the Geometry
- Working with Geometry Sequences
- Retrieving Geometry Information
- Modeling with a Parameterized Geometry
- Images and Interpolation Data

The Geometry Sequence Syntax

Create a geometry node using the syntax:

```
model.component(<ctag>).geom.create(<geomtag>, sdim)
```

where `<geomtag>` is a string used to refer to the geometry and `<ctag>` is the string defined when the component is created. The integer `sdim` specifies the space dimension of the geometry and it can be either 0, 1, 2, or 3.

To add an operation to a geometry sequence, use the syntax:

```
geometry.feature.create(<ftag>, operation)
```

where `geometry` is a link to the geometry node. The string `<ftag>` is used to refer to the operation.

In the COMSOL Multiphysics Programming Reference Manual:

- For a list of geometry operations, see About Geometry Commands.
- For a property list available for the geometry features see Geometry.

Geometry Modeling and CAD Tools in the COMSOL Multiphysics Reference Manual

To set the feature property with different values than the default, use the `set` method:

```matlab
geometry.feature(<ftag>).set(property, <value>)
```

where `<ftag>` is the string defined when creating the operation.

To build the geometry sequence, enter:

```matlab
geometry.run
```

Alternatively, to build the geometry sequence up to and including a given feature `<ftag>` enter:

```matlab
geometry.run(<ftag>)
```

**Displaying the Geometry**

Use the function `mphgeom` to display the geometry in a MATLAB figure:

```matlab
mphgeom(model)
```

To specify the geometry to display, enter:

```matlab
mphgeom(model, <geomtag>)
```

Adding a `view` property will add some view settings from the COMSOL model such as axes labels (units) and grid and supports hiding of geometric entities. Usually it is sufficient to use the `auto` value for the view property:

```matlab
mphgeom(model, <geomtag>, 'view', 'auto')
```

If the model only contains a single geometry the `<geomtag>` can be left empty.

When running `mphgeom` the geometry node is automatically built. Set the `build` property to specify how the geometry node is supposed to be built before displaying it. Enter:

```matlab
mphgeom(model, <geomtag>, 'build', build)
```

where `build` is a string with the value: 'off', 'current', or the geometry feature tag `<ftag>`, which, respectively, does not build the geometry (off), builds the geometry up to the current feature (current), or builds the geometry up to the specified geometry feature node (ftag).

Use the `parent` property to specify the axes handle where to display the plot:

```matlab
mphgeom(model, <geomtag>, 'parent', <axes>)
```
The following properties are also available to specify the vertex, edge, or face rendering:

- `vertexmode`
- `edgemode`
- `facemode`
- `vertexlabels`
- `edgelabels`
- `facelabels`
- `domainlabels`
- `edgecolor`
- `vertexlabelscolor`
- `edgelabelscolor`
- `facelabelscolor`
- `domainlabelscolor`
- `facealpha`

Use `mphgeom` to display a specified geometry entity. To set the geometry entity, enter the `entity` property and set the geometry entity index in the `selection` property to:

```
mphgeom(model, <geomtag>, 'entity', entity, 'selection', <idx>)
```

where `entity` can be either 'point', 'edge', 'boundary', or 'domain', and `<idx>` is a positive integer array that contains the list of the geometry entity indices.

**Working with Geometry Sequences**

This section shows how to create geometry sequences using the syntax outlined in The Geometry Sequence Syntax. This section has these examples:

- Creating a 1D Geometry
- Creating a 2D Geometry Using Primitive Geometry Objects
- Creating a 2D Geometry Using Boundary Modeling
- Creating a 3D Geometry Using Solid Modeling

For more information about geometry modeling, see the Geometry chapter in the COMSOL Multiphysics Reference Manual.

**Creating a 1D Geometry**

From the MATLAB command prompt, create a 1D geometry model by adding a geometry sequence and then adding geometry features. The last step is to run the sequence using the run method.
First create a model object:

```matlab
model = ModelUtil.create('Model');
```

Then continue with the commands:

```matlab
model.component.create('comp1',true);
geom1 = model.component('comp1').geom.create('geom1',1);

i1 = geom1.feature.create('i1','Interval');
i1.set('intervals','many');
i1.set('p','0,1,2');
geom1.run;
```

This creates a geometry sequence with a 1D solid object consisting of vertices at $x = 0$, 1, and 2, and edges joining the vertices adjacent in the coordinate list.

Then enter:

```matlab
p1 = geom1.feature.create('p1','Point');
p1.set('p',0.5);
geom1.run;
```

to add a point object located at $x = 0.5$ to the geometry.

To plot the result, enter:

```matlab
mphgeom(model,'geom1','vertexmode','on');
```

![Geometry plot](image)

*Code for use with MATLAB®*

```matlab
model = ModelUtil.create('Model');
model.component.create('comp1',true);
```
WORKING WITH GEOMETRIES

```plaintext
geom1 = model.component('comp1').geom.create('geom1',1);
i1 = geom1.feature.create('i1','Interval');
i1.set('intervals','many');
i1.set('p','0,1,2');
geom1.run;
p1 = geom1.feature.create('p1','Point');
p1.set('p',0.5);
geom1.run;
mpgeom(model,'geom1','vertexmode','on')
```

CREATING A 2D GEOMETRY USING PRIMITIVE GEOMETRY OBJECTS

Creating Composite Objects
Use a model object with a 2D geometry. Enter:

```plaintext
model = ModelUtil.create('Model');
comp1 = model.component.create('comp1',true);
geom2 = comp1.geom.create('geom2',2);
```

Continue by creating a rectangle with side length of 2 and centered at the origin:

```plaintext
sq1 = geom2.feature.create('sq1','Square');
sq1.set('size',2);
sq1.set('base','center');
```

The property `size` describes the side lengths of the rectangle and the property `pos` describes the positioning. The default is to position the rectangle about its lower left corner. Use the property `base` to control the positioning.

Create a circular hole with a radius of 0.5 centered at (0, 0):

```plaintext
c1 = geom2.feature.create('c1','Circle');
c1.set('r',0.5);
c1.set('pos',[0 0]);
```

The property `r` describes the radius of the circle, and the property `pos` describes the positioning.

```plaintext
c1 = geom2.feature.create('c1','Circle');
c1.set('r',0.5);
c1.set('pos',[0 0]);
```

The property `pos` could have been excluded because the default position is the origin. The default is to position the circle about its center.

Drill a hole in the rectangle by subtracting the circle from it:

```plaintext
c1 = geom2.feature.create('c1','Circle');
c1.set('r',0.5);
c1.set('base','center');
```

```plaintext
c1 = geom2.feature.create('c1','Circle');
c1.set('r',0.5);
c1.set('pos',[0 0]);
```

Drill a hole in the rectangle by subtracting the circle from it:

```plaintext
c1 = geom2.feature.create('c1','Circle');
c1.set('r',0.5);
c1.set('base','center');
```
A selection object is used to refer to the input object. The operators +, *, and - correspond to the set operations union, intersection, and difference, respectively.

The Compose operation allows you to work with a formula. Alternatively use the Difference operation instead of Compose. The following sequence of commands starts with disabling the Compose operation:

```cpp
co1.active(false);

dif1 = geom2.feature.create('dif1', 'Difference');
don1.selection('input').set({'sq1'});
don1.selection('input2').set({'c1'});
```

Run the geometry sequence to create the geometry and plot the result:

```cpp
geom2.run;
mpgeom(model, 'geom2');
```

Trimming Solids

Continue with rounding the corners of the rectangle with the Fillet operation:

```cpp
fil1 = geom2.feature.create('fil1', 'Fillet');
fil1.selection('point').set('dif1', [1 2 7 8]);
fil1.set('radius', 0.5);
```

Run the sequence again:

```cpp
geom2.run;
```

The geometry sequence is updated with rounded corners. To view the result, enter:
WORKING WITH GEOMETRIES

Code for use with MATLAB®

```matlab
model = ModelUtil.create('Model');
comp1 = model.component.create('comp1',true);
geom2 = comp1.geom.create('geom2',2);
sq1 = geom2.feature.create('sq1','Square');
sq1.set('size',2);
sq1.set('base','center');
c1 = geom2.feature.create('c1','Circle');
c1.set('r',0.5);
c1.set('pos',[0 0]);
co1 = geom2.feature.create('co1','Compose');
co1.selection('input').set({'c1' 'sq1'});
co1.set('formula','sq1-c1');
co1.active(false)
dif1 = geom2.feature.create('dif1','Difference');
dif1.selection('input1').set({'sq1'});
dif1.selection('input2').set({'c1'});
geom2.run;
```

CREATING A 2D GEOMETRY USING BOUNDARY MODELING

Use the following commands to create six open curve segments that together form a closed curve:

```matlab
model = ModelUtil.create('Model');
comp1 = model.component.create('comp1',true);
```
```javascript
const g1 = comp1.geom.create('g1',2);
w=1/sqrt(2);
c1 = g1.feature.create('c1','BezierPolygon');
c1.set('type','open');
c1.set('degree',2);
c1.set('p',[-0.5 -1 -1;-0.5 -0.5 0]);
c1.set('w',[1 w 1]);
c2 = g1.feature.create('c2','BezierPolygon');
c2.set('type','open');
c2.set('degree',2);
c2.set('p',[-1 -1 -0.5;0 0.5 0.5]);
c2.set('w',[1 w 1]);
c3 = g1.feature.create('c3','BezierPolygon');
c3.set('type','open');
c3.set('degree',1);
c3.set('p',[-0.5 0.5;0.5 0.5]);
c4 = g1.feature.create('c4','BezierPolygon');
c4.set('type','open');
c4.set('degree',2);
c4.set('p',[0.5 1 1;0.5 0.5 0]);
c4.set('w',[1 w 1]);
c5 = g1.feature.create('c5','BezierPolygon');
c5.set('type','open');
c5.set('degree',2);
c5.set('p',[1 1 0.5;0 -0.5 -0.5]);
c5.set('w',[1 w 1]);
c6 = g1.feature.create('c6','BezierPolygon');
c6.set('type','open');
c6.set('degree',1);
c6.set('p',[0.5 -0.5;-0.5 -0.5]);
```

The objects \(c_1, c_2, c_3, c_4, c_5,\) and \(c_6\) are all curve2 objects. The vector \([1 \ w \ 1]\) specifies the weights for a rational Bézier curve that is equivalent to a quarter-circle arc. The weights can be adjusted to create elliptical or circular arcs.

Convert the curve segments to a solid with the following conversion command:

```javascript
const csol1 = g1.feature.create('csol1','ConvertToSolid');
csol1.selection('input').set(['c1' 'c2' 'c3' 'c4' 'c5' 'c6']);
```

Then issue a final run command:

```javascript
g1.run;
```
mphgeom(model,'g1');

ModelUtil.create('Model');
comp1 = model.component.create('comp1',true);
g1 = comp1.geom.create('g1',2);
w=1/sqrt(2);
c1 = g1.feature.create('c1','BezierPolygon');
c1.set('type','open');
c1.set('degree',2);
c1.set('p',[-0.5 -1 -1;-0.5 -0.5 0]);
c1.set('w',[1 w 1]);
c2 = g1.feature.create('c2','BezierPolygon');
c2.set('type','open');
c2.set('degree',2);
c2.set('p',[-1 -1 -0.5;0 0.5 0.5]);
c2.set('w',[1 w 1]);
c3 = g1.feature.create('c3','BezierPolygon');
c3.set('type','open');
c3.set('degree',1);
c3.set('p',[-0.5 0.5;0 0.5 0.5]);
c4 = g1.feature.create('c4','BezierPolygon');
c4.set('type','open');
c4.set('degree',2);
c4.set('p',[0.5 1 1;0.5 0.5 0]);
c4.set('w',[1 w 1]);
c5 = g1.feature.create('c5','BezierPolygon');
c5.set('type','open');
c5.set('degree',2);
c5.set('p',[1 1 0.5;0 -0.5 -0.5]);
c5.set('w',[1 w 1]);
c6 = g1.feature.create('c6','BezierPolygon');
c6.set('type','open');
c6.set('degree',1);
CREATING A 3D GEOMETRY USING SOLID MODELING

This section shows how to create 3D solids using work planes and Boolean operations.

Create a 3D geometry with an \( xy \) work plane at \( z = 0 \):

```matlab
model = ModelUtil.create('Model');
comp1 = model.component.create('comp1',true);
geom1 = comp1.geom.create('geom1', 3);
wp1 = geom1.feature.create('wp1', 'WorkPlane');
wp1.set('planetype', 'quick');
wp1.set('quickplane', 'xy');
r1 = wp1.geom.feature.create('r1', 'Rectangle');
r1.set('size',[1 2]);
geom1.run;
fil1 = wp1.geom.feature.create('fil1', 'Fillet');
fil1.selection('point').set('r1', [1 2 3 4]);
fil1.set('radius', '0.125');
geom1.runCurrent;
ext1 = geom1.feature.create('ext1', 'Extrude');
ext1.set('distance', '0.1');
```

Add another \( yz \) work plane, at \( x = 0.5 \):

```matlab
wp2 = geom1.feature.create('wp2', 'WorkPlane');
wp2.set('planetype', 'quick');
wp2.set('quickplane', 'yz');
wp2.set('quickx', '0.5');
b1 = wp2.geom.feature.create('b1', 'BezierPolygon');
b1.set('type', 'open');
b1.set('degree', [1 1 1 1]);
b1.set('p',
    {'0.75','1','1','0.8','0.75';'0.1','0.1','0.05','0.05','0.1'});
b1.set('w', {'1','1','1','1','1','1','1','1'});
```
Revolve the triangle from the yz work plane:

```plaintext
rev1 = geom1.feature.create('rev1', 'Revolve');
rev1.selection('input').set({'wp2'});
rev1.setIndex('pos', '1', 0);
```

Add the difference operation that computes the final 3D geometry:

```plaintext
dif1 = geom1.feature.create('dif1', 'Difference');
dif1.selection('input').set({'ext1'});
dif1.selection('input2').set({'rev1'});
```

To run the sequence, enter:

```plaintext
geom1.run;
```

To view the geometry enter:

```plaintext
mphgeom(model);
```
geom1.runCurrent;
ext1 = geom1.feature.create('ext1', 'Extrude');
ext1.set('distance', '0.1');
wp2 = geom1.feature.create('wp2', 'WorkPlane');
wp2.set('planetype', 'quick');
wp2.set('quickplane', 'yz');
wp2.set('quickx', '0.5');
b1 = wp2.geom.feature.create('b1', 'BezierPolygon');
b1.set('type', 'open');
b1.set('degree', [1 1 1 1]);
b1.set('p', {'0.75', '1', '1', '0.8', '0.75'; '0.1', '0.1', '0.1', '0.05', '0.05', '0.1'});
b1.set('w', {'1', '1', '1', '1', '1', '1'});
wp2.geom.feature.create('csol1', 'ConvertToSolid');
wp2.geom.feature('csol1').selection('input').set({'b1'});
rev1 = geom1.feature.create('rev1', 'Revolve');
rev1.selection('input').set({'wp2'});
rev1.setIndex('pos', '1', 0);
dif1 = geom1.feature.create('dif1', 'Difference');
dif1.selection('input').set({'ext1'});
dif1.selection('input2').set({'rev1'});
geom1.run;
mphgeom(model);

Retrieving Geometry Information

To retrieve the detailed information about the geometry in a model, see Geometry Object Information Methods in the COMSOL Multiphysics Programming Reference Manual.

First create a simple 3D geometry:

model = ModelUtil.create('Model');
comp1 = model.component.create('comp1', true);
geom1 = comp1.geom.create('geom1', 3);
geom1.feature.create('blk1', 'Block');
geom1.feature.create('con1', 'Cone');
geom1.run;

To visualize the geometry in a MATLAB figure window enter:
The model object contains general geometry information methods. For example, to determine the space dimension of the geometry, enter:

```
geom1.getSDim
```

There are also methods to determine the number of geometrical entities. For example, to inquire about the number of domains and the number of boundaries:

```
geom1.getNDomains
geom1.getNBoundaries
```

Another group of geometry information methods concern adjacency properties of the geometric entities. For example, the number of up and down domain information on each boundary:

```
geom1.getUpDown
```

There are also methods for evaluating properties such as coordinate values and curvatures on faces and edges. For example, to evaluate coordinates on face 1 for the face parameters (0.2, 0.5), enter:

```
geom1.faceX(1,[0.2,0.5])
```

To get the range of the parameters of a given face, use the method `faceParamRange(N)`, where N is the face number. For example:

```
geom1.faceParamRange(1)
```

returns a 4x1 array following the given format: \([s1min; s1max; s2min; s2max]\) where \(s1min\) and \(s1max\) are the minimum, and maximum respectively, of the first surface.
parameter. \( s_{2\text{min}} \) and \( s_{2\text{max}} \) are the minimum, and maximum respectively, of the second surface parameter.

To get the parameter range of an edge, use the `edgeParamRange(N)` method. For example, to get the length of edge number 3, enter:

```
geom1.edgeParamRange(3)
```

To get the coordinate and the curvature data along a specified edge, enter:

```
geom1.edgeX(2,0.5)
geom1.edgeCurvature(2,0.5)
```

There are also methods for getting information about the internal representation of the geometry. For example, the coordinates of the geometry vertices:

```
geom1.getVertexCoord
```

To fetch geometry information from elements in the geometry sequence, enter:

```
geom1.obj('blk1').getNBoundaries
```

**Code for use with MATLAB®**

```matlab
model = ModelUtil.create('Model');
comp1 = model.component.create('comp1',true);
geom1 = comp1.geom.create('geom1', 3);
geom1.feature.create('blk1','Block');
geom1.feature.create('con1','Cone');
geom1.run;
mphgeom(model)
SDim = geom1.getSDim
NDomains = geom1.getNDomains
NBoundaries = geom1.getNBoundaries
UpDown = geom1.getUpDown
faceX = geom1.faceX(1,[0.2,0.5])
faceParamRange = geom1.faceParamRange(1)
edgeParamRange = geom1.edgeParamRange(3)
edgeX = geom1.edgeX(2,0.5)
edgeCurvature = geom1.edgeCurvature(2,0.5)
VertexCoord = geom1.getVertexCoord
objNBoundaries = geom1.obj('blk1').getNBoundaries
```

**Modeling with a Parameterized Geometry**

COMSOL Multiphysics has built-in support for parameterized geometries. Parameters can be used in most geometry operations. To exemplify parameterizing a geometry, the following script studies the movement of a circular source through two adjacent rectangular domains:
model = ModelUtil.create('Model');
model.param.set('a',0.2);
comp1 = model.component.create('comp1',true);

geom1 = comp1.geom.create('geom1',2);

r1 = geom1.feature.create('r1','Rectangle');
r1.set('size',[0.5 1]);
r1.set('pos',[0 0]);

r2 = geom1.feature.create('r2','Rectangle');
r2.set('size',[0.6 1]);
r2.set('pos',[0.5 0]);

c1 = geom1.feature.create('c1','Circle');
c1.set('r',0.1);
c1.set('pos',{'a','0.5'});

mphgeom(model);

Change the position of the circle by changing the value of parameter a:

model.param.set('a',0.5);
Create a loop that changes the position of the circle in increments:

```matlab
for a=0.2:0.1:0.5
    model.param.set('a',a);
    geom1.run;
end
```

Create a mesh:

```matlab
comp1.mesh.create('mesh1');
```

Add a Weak Form PDE interface:

```matlab
w = comp1.physics.create('w', 'WeakFormPDE', 'geom1');
w.feature('wfeq1').set('weak', 1, '-test(ux)*ux-test(uy)*uy');

dir1 = w.feature.create('dir1', 'DirichletBoundary', 1);
dir1.selection.set([1 2 3 6 7]);

src1 = w.feature.create('src1', 'SourceTerm', 2);
src1.set('f', 1, '1');
src1.selection.set([3]);
```

Then, create a stationary study step:

```matlab
std1 = model.study.create('std1');
stat1 = std1.feature.create('stat1', 'Stationary');
```

Create a parametric sweep feature:

```matlab
p1 = model.batch.create('p1','Parametric');
p1.set('pname', 'a');
p1.set('plist', 'range(0.2,0.1,0.8)');
```
Alternatively, you can run the parametric sweep using a MATLAB for loop:

```matlab
for a = 0.2:0.1:0.8
    model.param.set('a', a);
    std1.run;
end
```

**Code for use with MATLAB®**

```matlab
model = ModelUtil.create('Model');
model.param.set('a', 0.2);
comp1 = model.component.create('comp1', true);
geom1 = comp1.geom.create('geom1', 2);
r1 = geom1.feature.create('r1', 'Rectangle');
r1.set('size', [0.5 1]);
r1.set('pos', [0 0]);
r2 = geom1.feature.create('r2', 'Rectangle');
r2.set('size', [0.6 1]);
r2.set('pos', [0.5 0]);
c1 = geom1.feature.create('c1', 'Circle');
c1.set('r', 0.1);
c1.set('pos', {'a', '0.5'});
mphgeom(model);
model.param.set('a', 0.5);
for a = 0.2:0.1:0.5
    model.param.set('a', a);
    geom1.run;
end
comp1.mesh.create('mesh1');
w = comp1.physics.create('w', 'WeakFormPDE', 'geom1');
w.feature('wfeq1').set('weak', 1, '-test(ux)*ux-test(uy)*uy');
dir1 = w.feature.create('dir1', 'DirichletBoundary', 1);
dir1.selection.set([1 2 3 6 7]);
src1 = w.feature.create('src1', 'SourceTerm', 2);
src1.set('f', 1, '1');
src1.selection.set([3]);
std1 = model.study.create('std1');
stat1 = std1.feature.create('stat1', 'Stationary');
p1 = model.batch.create('p1', 'Parametric');
p1.set('pname', 'a');
p1.set('plist', range(0.2, 0.1, 0.0));
```

After updating a parameter that affects the geometry, COMSOL detects this change and automatically updates the geometry and mesh before starting the solver. The geometry is associative, which means that physics settings are preserved as the geometry changes.
```matlab
p1.run;
for a=0.2:0.1:0.8
    model.param.set('a',a);
    std1.run;
end
```

**Images and Interpolation Data**

This section describes how to generate geometry from a set of data points by using interpolation curves and how to create geometry from image data.

- Creating a Geometry Using Curve Interpolation
- Creating Geometry from Image Data

**Creating a Geometry Using Curve Interpolation**

Use the interpolation spline feature to import a set of data points that describe a 2D geometry. To create an interpolation spline feature, enter:

```matlab
model.component(<ctag>).geom(<geomtag>).feature.create(<ftag>, 'InterpolationCurve')
```

Then specify data points in a table:

```matlab
ftag.set('table', <data>)
```

where `ftag` is the curve interpolation node and `<data>` can either be a 2xN cell array or a 2xN array.

Control the type of geometry generated by the operation with the command:

```matlab
ftag.set('type', type)
```

where `type` can either be 'solid' to generate a solid object, 'closed' to generate a closed curve or 'open' to generate an open curve.

**Example: Curve Interpolation**

Create a set of data points in MATLAB, then use these to construct a 2D geometry.

1. Create data points that describe a circle, sorted by the angle, and remove some of the points:
   ```matlab
   phi = 0:0.2:2*pi;
   phi([1 3 6 7 10 20 21 25 28 32]) = [];
   p = [cos(phi);sin(phi)];
   ```

2. Add some noise to the data points:
   ```matlab
   randn('state',17)
   p = p+0.02*randn(size(p));
   ```
3 Create a 2D geometry with a square:
   model = ModelUtil.create('Model');

4 Add a square geometry:
   comp1 = model.component.create('comp1', true);
   geom1 = comp1.geom.create('geom1', 2);

   sq1 = geom1.feature.create('sq1', 'Square');
   sq1.set('base', 'center');
   sq1.set('size', '3');

5 Add an interpolation curve feature:
   ic1 = geom1.feature.create('ic1', 'InterpolationCurve');

6 Use the variable \( p \) for the data points:
   ic1.set('table', p');

7 Specify a closed curve:
   ic1.set('type', 'closed');

8 Plot the geometry with the \texttt{mphgeom} command:
   mphgeom(model)

\begin{center}
\begin{tikzpicture}
\begin{axis}[
    title={Geometry (geom1)},
    xlabel={x},
    ylabel={y},
    xmin=-2.5,
    xmax=2.5,
    ymin=-1.5,
    ymax=1.5,
]
\end{axis}
\end{tikzpicture}
\end{center}

\textit{Code for use with MATLAB}\textsuperscript{®}
\begin{verbatim}
model = ModelUtil.create('Model');
comp1 = model.component.create('comp1', true);
geom1 = comp1.geom.create('geom1', 2);
sq1 = geom1.feature.create('sq1', 'Square');
sq1.set('base', 'center');
sq1.set('size', '3');
phi = 0:0.2:2*pi;
\end{verbatim}
\[ \phi([1\ 3\ 6\ 7\ 10\ 20\ 21\ 25\ 28\ 32]) = [] \]
\[ p = [\cos(\phi); \sin(\phi)] \]
\[ \text{randn('state',17)} \]
\[ p = p + 0.02 \times \text{randn(size}(p)) \]
\[ \text{ic1 = geom1.feature.create('ic1', 'InterpolationCurve');} \]
\[ \text{ic1.set('table', p);} \]
\[ \text{ic1.set('type', 'closed');} \]
\[ \text{mphgeom(model);} \]

**Creating Geometry from Image Data**

Use the function `mphimage2geom` to create geometry from image data. The image data format can be \( M \)-by-\( N \) array for a grayscale image or \( M \)-by-\( N \)-by-3 array for a true color image. This section also includes an example (see Example: Convert Image Data to Geometry).

If you specify the image data and the level value that represents the geometry contour you want to extract, the function `mphimage2geom` returns a model object with the desired geometry:

\[ \text{model = mphimage2geom(}<\text{imagedata}, <\text{level}>)} \]

where `imagedata` is a C array containing the image data, and `level` is the contour level value used to generate the geometry contour.

Specify the type of geometry object generated:

\[ \text{model = mphimage2geom(}<\text{imagedata}, <\text{level}, 'type', \text{type}>)} \]

where `type` is 'solid' and generates a solid object, 'closed' generates a closed curve object, or 'open' generates an open curve geometry object.

Use the property `curvetype` to specify the type of curve used to generate the geometry object:

\[ \text{model = mphimage2geom(}<\text{imagedata}, <\text{level}, 'curvetype', \text{curvetype}>)} \]

where `curvetype` can be set to 'polygon' to use a polygon curve. The default curve type creates a geometry with the best suited geometrical primitives. For interior curves it uses interpolation curves, while for curves that are touching the perimeter of the image a polygon curve is used.

To scale the geometry use the `scale` property where `scale` is a double value:
model = mphimage2geom(<imagedata>, <level>, 'scale', scale)

Set the minimum distance (in pixels) between coordinates in curve with the mindist property where mindist is a double value:

model = mphimage2geom(<imagedata>, <level>, 'mindist', mindist)

Set the minimum area (in square pixels) for interior curves where minarea is a double value:

model = mphimage2geom(<imagedata>, <level>, 'minarea', minarea)

In case of overlapping solids, the function mphimage2geom automatically creates a Compose node in the model object. If you do not want this geometry feature, set the property compose to off:

model = mphimage2geom(<imagedata>, <level>, 'compose', 'off')

To create a rectangle domain surrounding the object generated use the property rectangle:

model = mphimage2geom(<imagedata>, <level>, 'rectangle', 'on')

mphimage2geom returns a model object with the created geometry stored in a geometry node. The default geometry node has the tag geom1, to specify manually the geometry tag use the function as below:

model = mphimage2geom(<imagedata>, <level>, 'geom', <geomtag>)

where <geomtag> is a string corresponding to the tag of the geometry node.

It is also possible to create a geometry object and include it in an existing model object, to proceed use the command below:

mphimage2geom(<imagedata>, <level>, 'geom', <geomnode>)

where <geomnode> is the geometry node object where to include the newly generated geometry.

To manually specify the tag of the model object created in the COMSOL server use the command below:

model = mphimage2geom(<imagedata>, <level>, 'modeltag', <Modeltag>)

where <Modeltag> is a string defining the tag of the model object in the COMSOL server.
Example: Convert Image Data to Geometry

This example shows how to create geometry based on gray scale image data. First generate the image data in MATLAB and display the contour in a figure. Then, create a model object including the geometry represented by the contour value 40.

At the MATLAB prompt enter these commands:

```matlab
p = (peaks+7)*5;
[c,h] = contourf(p);
clabel(c, h);
model = mphimage2geom(p, 40);
figure(2)
mpgeom(model)
```

Use the property `type` to create closed or open curves. For example, to create a geometry following contour 40 with closed curves, enter:

```matlab
model = mphimage2geom(p, 40, 'type', 'closed');
```
To scale the geometry, use the `scale` property. Using the current model scale the geometry with a factor of 0.001 (1e-3):

```matlab
model = mphimage2geom(p, 40, 'scale', 1e-3);
mphgeom(model)
```

To insert a rectangle in the geometry that has an outer domain surrounding the created contour, set the property `rectangle` to `on`:

```matlab
model = mphimage2geom(p, 40, 'rectangle', 'on');
```
Only include the interior curves with an area larger than 100 square pixels:

```matlab
model = mphimage2geom(p, 40, 'minarea', 100);
mphgeom(model)
```

Insert the geometry in an existing geometry object:

```matlab
model = mphopen('model_tutorial_llmatlab');
geom1 = model.component('comp1').geom('geom1');
wp1 = geom1.feature.create('wp1', 'WorkPlane');
wp1.set('quickz',1e-2);
mphimage2geom(p, 50, 'scale', 1e-3, 'geom', wp1.geom);
```
Code for use with MATLAB®

```matlab
p = (peaks+7)*5;
[c,h] = contourf(p);
clabel(c, h);
model = mphimage2geom(p, 40);
figure(2)
mphgeom(model)
model = mphimage2geom(p, 40, 'type', 'closed');
mphgeom(model)
model = mphimage2geom(p, 40, 'scale', 1e-3);
mphgeom(model)
model = mphimage2geom(p, 40, 'rectangle', 'on');
mphgeom(model)
model = mphimage2geom(p, 40, 'minarea', 100);
mphgeom(model)
model = mphopen('model_tutorial_llmatlab');
geom1 = model.component('comp1').geom('geom1');
wp1 = geom1.feature.create('wp1', 'WorkPlane');
wp1.set('quickz',1e-2);
mphimage2geom(p, 50, 'scale', 1e-3, 'geom', wp1.geom);
mphgeom(model)
```
Working with Meshes

This section describes how to set up and run meshing sequences in a model.

- The Meshing Sequence Syntax
- Displaying the Mesh
- Mesh Creation Functions
- Importing External Meshes and Mesh Objects
- Measuring Mesh Quality
- Getting Mesh Statistics Information
- Getting and Setting Mesh Data

The Meshing Sequence Syntax

Create a meshing sequence by using the syntax:

```python
model.component(<ctag>).mesh.create(<meshtag>, <geomtag>)
```

where `<meshtag>` is a string that you use to refer to the meshing sequence. The tag `<geomtag>` specifies the geometry to use for this mesh node.

To add an operation to a sequence, use the syntax:

```python
mesh.feature.create(<ftag>, operation)
```

where `mesh` is a link to a mesh node and the string `<ftag>` is a string that you use to refer to the operation.

To set a property to a value in an operation, enter:

```python
mesh.feature(<ftag>).set(property, <value>)
```
To build the mesh sequence, enter:

mesh.run

To run the mesh node up to a specified feature node \(<ftag>\), enter:

mesh.run(\<ftag\>)

Displaying the Mesh

To display the mesh in a MATLAB figure, use the function \texttt{mphmesh}. Make sure that the mesh is built before calling this command:

\texttt{mphmesh(model)}

If there are several meshes in a model, specify the mesh to display using the command:

\texttt{mphmesh(model, \<meshtag\>)}

Adding a \texttt{view} property will add some view settings from the COMSOL model such as axes labels (units) and grid and supports hiding of mesh entities. Usually it is sufficient to use the \texttt{auto} value for the view property:

\texttt{mphmesh(model, \<meshtag\>, 'view', 'auto')}

If the model only contains one mesh then the \<meshtag\> may be left empty.

Use the \texttt{parent} property to specify the axes handle where to display the plot:

\texttt{mphmesh(model, \<meshtag\>, 'parent', \<axes\>)}

The following properties are also available to specify the vertex, edge, or face rendering:

- \texttt{vertexmode}
- \texttt{edgemode}
- \texttt{facemode}
- \texttt{vertexlabels}
- \texttt{edgelabels}
- \texttt{facelabels}
- \texttt{meshcolor}
- \texttt{edgecolor}
- \texttt{edgelabelscolor}
- \texttt{vertexlabelscolor}
- \texttt{facelabelscolor}
- \texttt{facealpha}
Mesh Creation Functions

Several mesh features are discussed, with examples in this section:

- Mesh Sizing Properties
- Creating a 2D Mesh with Triangular Elements
- The Free Meshing Method
- Creating a 2D Mesh with Quadrilateral Elements
- Creating Structured Meshes
- Creating a Structured Quadrilateral Mesh
- Building a Mesh Incrementally
- Revolving a Mesh by Sweeping
- Extruding a Mesh by Sweeping
- Combining Unstructured and Structured Meshes
- Creating Boundary Layer Meshes
- Refining Meshes
- Copying Boundary Meshes
- Converting Mesh Elements

Mesh Sizing Properties

The **Size** attribute provides a number of input properties that can control the mesh element size, such as the following properties:

- Maximum and minimum element size
- Element growth rate
- Curvature factor
- Resolution of narrow regions

These properties are available both globally and locally. The following examples are included: Creating a 2D Mesh with Triangular Elements and Creating a 2D Mesh with Quadrilateral Elements. Also discussed is The Free Meshing Method.
There are several predefined settings that can be used to set a suitable combination of values for many properties. To select one of these settings, use the property \texttt{auto} and pass an integer from 1 to 9 as its value to describe the mesh resolution:

- Extremely fine (1)
- Extra fine (2)
- Finer (3)
- Fine (4)
- Normal (5) (the default)
- Coarse (6)
- Coarser (7)
- Extra coarse (8)
- Extremely coarse (9)

For details about predefined mesh size settings and mesh element size parameters, see \texttt{Size} in the \textit{COMSOL Multiphysics Programming Reference Manual}.

**CREATING A 2D MESH WITH TRIANGULAR ELEMENTS**

Generate a triangular mesh of a unit square:

```plaintext
model = ModelUtil.create('Model');
comp1 = model.component.create('comp1', true);
geom1 = comp1.geom.create('geom1',2);
geom1.feature.create('r1','Rectangle');

mesh1 = comp1.mesh.create('mesh1');
ftri1 = mesh1.feature.create('ftri1','FreeTri');
mesh1.run;
```
Figure 3-1: Default mesh on a unit square.

The default size feature is generated with the property `hauto` set to 5, that is:

```plaintext
mesh1.feature('size').set('hauto',5);
```

To override this behavior, set `hauto` to another integer. Override this by setting specific size properties, for example, making the mesh finer than the default by specifying a maximum element size of 0.02:

```plaintext
mesh1.feature('size').set('hmax',0.02);
mesh1.run;
mphmesh(model)
```
This value corresponds to 1/50 of the largest axis-parallel distance, whereas the default value is 1/15.

Figure 3-2: Fine mesh (maximum element size = 0.02).

Sometimes a nonuniform mesh is desirable. Make a mesh that is denser on the left side by specifying a smaller maximum element size only on the edge segment to the left (edge number 1):

```plaintext
mesh1.feature('size').set('hauto',5);
size1 = ftri1.feature.create('size1','Size');
size1.set('hmax',0.02);
size1.selection.geom('geom1',1);
size1.selection.set(1);
mesh1.run
```
CHAPTER 3: BUILDING MODELS

Figure 3-3: Refined mesh on boundary 1 (maximum element size = 0.02).

Code for use with MATLAB®

```matlab
model = ModelUtil.create('Model');
comp1 = model.component.create('comp1', true);
geom1 = comp1.geom.create('geom1',2);
geom1.feature.create('r1','Rectangle');
mesh1 = comp1.mesh.create('mesh1');
ftri1 = mesh1.feature.create('ftri1','FreeTri');
mesh1.run;
mphmesh(model)
mesh1.feature('size').set('hauto',5);
mesh1.feature('size').set('hmax',0.02);
mesh1.run;
mphmesh(model)
mesh1.feature('size').set('hauto',5);
sizel = ftri1.feature.create('sizel','Size');
sizel.set('hmax',0.02);
sizel.selection.geom('geom1',1);
sizel.selection.set(1);
mesh1.run
mphmesh(model)
```

THE FREE MESHING METHOD

The default method to generate free triangle meshes in 2D is based on an advancing front algorithm. To switch to a Delaunay algorithm use the value `del` for the `method` property. Start by creating a geometry:

```matlab
model = ModelUtil.create('Model');
comp1 = model.component.create('comp1', true);
```
geom1 = comp1.geom.create('geom1',2);
geom1.feature.create('r1','Rectangle');

c1 = geom1.feature.create('c1','Circle');
c1.set('r','0.5');

co1 = geom1.feature.create('co1','Compose');
co1.selection('input').set({'c1' 'r1'});
co1.set('formula','r1-c1');

geom1.runAll;

mesh1 = comp1.mesh.create('mesh1');
ftri1 = mesh1.feature.create('ftri1','FreeTri');
ftri1.set('method','del');

mesh1.run;

mphmesh(model,'mesh1')

Figure 3-4: Mesh created with the Delaunay method.

Code for use with MATLAB®

model = ModelUtil.create('Model');
comp1 = model.component.create('comp1', true);
geom1 = comp1.geom.create('geom1',2);
geom1.feature.create('r1','Rectangle');
c1 = geom1.feature.create('c1','Circle');
c1.set('r','0.5');
co1 = geom1.feature.create('co1','Compose');
co1.selection('input').set({'c1' 'r1'});
co1.set('formula','r1-c1');
CREATING A 2D MESH WITH QUADRILATERAL ELEMENTS

To create an unstructured quadrilateral mesh on a unit circle, enter:

```matlab
model = ModelUtil.create('Model');
comp1 = model.component.create('comp1', true);
geom1 = comp1.geom.create('geom1',2);
geom1.feature.create('c1','Circle');
mesh1 = comp1.mesh.create('mesh1');
mesh1.feature.create('ftri1','FreeQuad');
mesh1.run;
mphmesh(model)
```

![Figure 3-5: Free quad mesh.](image)

Code for use with MATLAB®

```matlab
model = ModelUtil.create('Model');
comp1 = model.component.create('comp1', true);
geom1 = comp1.geom.create('geom1',2);
geom1.feature.create('c1','Circle');
mesh1 = comp1.mesh.create('mesh1');
mesh1.run;
mphmesh(model)
```
To create a structured quadrilateral mesh in 2D, use the `Map` operation. This operation uses a mapping technique to create the quadrilateral mesh.

**CREATING A STRUCTURED QUADRILATERAL MESH**

Create a structured quadrilateral mesh on a geometry where the domains are bounded by more than four edges:

```plaintext
model = ModelUtil.create('Model');
comp1 = model.component.create('comp1', true);
geom1 = comp1.geom.create('geom1',2);
r1 = geom1.feature.create('r1','Rectangle');
r2 = geom1.feature.create('r2','Rectangle');
r2.set('pos',[1 0]);
c1 = geom1.feature.create('c1','Circle');
c1.set('r','0.5');
c1.set('pos',[1.1 -0.1]);
dif1 = geom1.feature.create('dif1','Difference');
dif1.selection('input').set({r1, r2});
dif1.selection('input2').set({c1});
dif1.run;
geom1圳

mesh1 = comp1.mesh.create('mesh1');
map1 = mesh1.feature.create('map1','Map');
eg1 = map1.feature.create('eg1','EdgeGroup');
eg1.selection.set([1 3]);
eg1.selection('edge1').set([1 3]);
eg1.selection('edge2').set(2);
eg1.selection('edge3').set(8);
eg1.selection('edge4').set(4);
eg2 = map1.feature.create('eg2','EdgeGroup');
```
eg2.selection.set(2);
eg2.selection('edge1').set(4);
eg2.selection('edge2').set([6 9 10]);
eg2.selection('edge3').set(7);
eg2.selection('edge4').set(5);

mesh1.run;
mphmesh(model);

Figure 3-6: Structured quadrilateral mesh (right) and its underlying geometry.

The left-hand side plot in Figure 3-6 is obtained with this command:

mphgeom(model, 'geom1', 'edgelabels','on')

The EdgeGroup attributes specify that the four edges enclosing domain 1 are boundaries 1 and 3; boundary 2; boundary 8; and boundary 4. For domain 2 the four edges are boundary 4; boundary 5; boundary 7; and boundaries 9, 10, and 6.

Code for use with MATLAB®

model = ModelUtil.create('Model');
comp1 = model.component.create('comp1', true);
geom1 = comp1.geom.create('geom1',2);
geom1.feature.create('r1','Rectangle');
  r2 = geom1.feature.create('r2','Rectangle');
  r2.set('pos',[1 0]);
c1 = geom1.feature.create('c1','Circle');
  c1.set('r','0.5');
  c1.set('pos',[1.1 -0.1]);
dif1 = geom1.feature.create('dif1', 'Difference');
  dif1.selection('input').set({r1', r2'});
  dif1.selection('input2').set({c1'});
  geom1.run('dif1');
mesh1 = comp1.mesh.create('mesh1');
map1 = mesh1.feature.create('map1', 'Map');
eg1 = map1.feature.create('eg1', 'EdgeGroup');
eg1.selection.set(1);
eg1.selection('edge1').set([1 3]);
eg1.selection('edge2').set(2);
eg1.selection('edge3').set(8);
eg1.selection('edge4').set(4);
eg2 = map1.feature.create('eg2', 'EdgeGroup');
eg2.selection.set(2);
eg2.selection('edge1').set(4);
eg2.selection('edge2').set([6 9 10]);
eg2.selection('edge3').set(7);
eg2.selection('edge4').set(5);
mesh1.run;

BUILDING A MESH INCREMENTALLY

To build meshes in a step-by-step fashion, create selections for the parts of the geometry that you want to mesh in each step, as in this example:

```plaintext
model = ModelUtil.create('Model');
comp1 = model.component.create('comp1', true);

geom1 = comp1.geom.create('geom1', 2);
geom1.feature.create('r1', 'Rectangle');
geom1.feature.create('c1', 'Circle');
uni1 = geom1.feature.create('uni1', 'Union');
uni1.selection('input').set({'c1' 'r1'});
geom1.runCurrent;
del1 = geom1.feature.create('del1', 'Delete');
del1.selection('input').init(1);
del1.selection('input').set('uni1', 8);
geom1.run('del1');

mesh1 = comp1.mesh.create('mesh1');
dis1 = mesh1.feature.create('dis1', 'Distribution');
dis1.selection.set([2 4]);
dis1.set('type', 'predefined');
dis1.set('method', 'geometric');
dis1.set('elemcount', 20);
dis1.set('reverse', 'on');
dis1.set('elemratio', 20);

dis2 = mesh1.feature.create('dis2', 'Distribution');
dis2.selection.set([1 3]);
dis2.set('type', 'predefined');
dis2.set('method', 'geometric');
dis2.set('elemcount', 20);
dis2.set('elemratio', 20);```
map1 = mesh1.feature.create('map1', 'Map');
map1.selection.geom('geom1', 2);
map1.selection.set(2);
mesh1.feature.create('frt1', 'FreeTri');

mesh1.run;

mphmesh(model)

The final mesh is in Figure 3-7. Note the effect of the Distribution feature, with which the distribution of vertex elements along geometry edges can be controlled.

Figure 3-7: Incrementally generated mesh (right).

The left-hand side plot in Figure 3-7 is obtained with this command:

mphgeom(model, 'geom1', 'edgelabels', 'on')

To replace the structured quad mesh by an unstructured quad mesh, delete the Map feature and replace it by a FreeQuad feature:

mesh1.feature.remove('map1');
mesh1.run('dis1');
fq1 = mesh1.feature.create('fq1', 'FreeQuad');
fq1.selection.geom('geom1', 2).set(2);
mesh1.run;

Analogous to working with the meshing sequence in the Model Builder in the COMSOL Desktop, new features are always inserted after the current feature.

Thus, to get the FreeQuad feature before the FreeTri feature, the dis1 feature needs to be made the current feature by building it with the run method. Alternatively, parts
of a mesh can be selectively removed by using the **Delete** feature. For example, to remove the structured mesh from domain 2 (along with the adjacent edge mesh on edges 3 and 4), and replace it with an unstructured quad mesh, enter these commands:

```matlab
   del1 = mesh1.feature.create('del1','Delete');
   del1.selection.geom('geom1', 2).set(2);
   del1.set('deladj', 'on');
   frq1 = mesh1.feature.create('frq1','FreeQuad');
   frq1.selection.geom('geom1', 2).set(2);
   mesh1.run;
```

For further details on the various commands and their properties see the COMSOL Multiphysics Programming Reference Manual.

**Code for use with MATLAB®**

```matlab
   model = ModelUtil.create('Model');
   comp1 = model.component.create('comp1', true);
   geom1 = comp1.geom.create('geom1',2);  
   geom1.feature.create('r1','Rectangle');
   geom1.feature.create('c1','Circle');
   uni1 = geom1.feature.create('uni1', 'Union');
   uni1.selection('input').set({ 'c1' 'r1' });
   geom1.runCurrent;
   del1 = geom1.feature.create('del1', 'Delete');
   del1.selection('input').init(1);
   del1.selection('input').set('uni1', 8);
   geom1.run('del1');
   mesh1 = comp1.mesh.create('mesh1');
   dis1 = mesh1.feature.create('dis1', 'Distribution');
```
dis1.selection.set([2 4]);
dis1.set('type', 'predefined');
dis1.set('method', 'geometric');
dis1.set('elemcount', 20);
dis1.set('reverse', 'on');
dis1.set('elemratio', 20);
dis2 = mesh1.feature.create('dis2', 'Distribution');
dis2.selection.set([1 3]);
dis2.set('type', 'predefined');
dis2.set('method', 'geometric');
dis2.set('elemcount', 20);
dis2.set('elemratio', 20);
map1 = mesh1.feature.create('map1', 'Map');
map1.selection.geom('geom1', 2);
map1.selection.set(2);
mesh1.feature.create('frt1', 'FreeTri');
mesh1.run;

REVOLVING A MESH BY SWEEPING

Create 3D volume meshes by extruding and revolving face meshes with the Sweep feature. Depending on the 2D mesh type, the 3D meshes can be hexahedral (brick) meshes or prism meshes.

Create and visualize a revolved prism mesh as follows:

model = ModelUtil.create('Model');
comp1 = model.component.create('comp1', true);
geom1 = comp1.geom.create('geom1', 3);
wp1 = geom1.feature.create('wp1', 'WorkPlane');
wp1.set('planetype', 'quick');
wp1.set('quickplane', 'xy');
c1 = wp1.geom.feature.create('c1', 'Circle');
c1.set('pos', [2, 0]);
rev1 = geom1.feature.create('rev1', 'Revolve');
rev1.set('angle2', '60').set('angle1', -60);
rev1.selection('input').set({'wp1'});
geom1.run('rev1');

mesh1 = comp1.mesh.create('mesh1');
mesh1.feature.create('ftri1', 'FreeTri');
mesh1.feature('ftri1').selection.geom(2);
mesh1.feature('ftri1').selection.set(2);
mesh1.runCurrent;

swe1 = mesh1.feature.create('swe1', 'Sweep');
swe1.selection.geom(3);
swe1.selection.add(1);

mesh1.run;
mphmesh(model)

To obtain a torus, leave the angles property unspecified; the default value gives a complete revolution.

![3D prism mesh created with the Sweep feature.](image)

**Figure 3-8: 3D prism mesh created with the Sweep feature.**

**Code for use with MATLAB®**

```matlab
model = ModelUtil.create('Model');
comp1 = model.component.create('comp1', true);
geom1 = comp1.geom.create('geom1', 3);
wp1 = geom1.feature.create('wp1', 'WorkPlane');
wp1.set('planetype', 'quick');
wp1.set('quickplane', 'xy');
c1 = wp1.geom.feature.create('c1', 'Circle');
c1.set('pos', [2, 0]);
rev1 = geom1.feature.create('rev1', 'Revolve');
rev1.set('angle2', '60').set('angle1', -60);
rev1.selection('input').set({'wp1'});
```
EXTRUDING A MESH BY SWEEPING
To generate a 3D prism mesh from the same 2D mesh by extrusion and then to plot it, enter these commands:

```plaintext
model = ModelUtil.create('Model');
comp1 = model.component.create('comp1', true);
geom1 = comp1.geom.create('geom1', 3);
wp1 = geom1.feature.create('wp1', 'WorkPlane');
wp1.set('planetype', 'quick');
wp1.set('quickplane', 'xy');
c1 = wp1.geom.feature.create('c1', 'Circle');
c1.set('pos', [2, 0]);
ext1 = geom1.feature.create('ext1', 'Extrude');
ext1.selection('input').set({'wp1'});
geom1.runAll;
mesh1 = comp1.mesh.create('mesh1');

ftri1 = mesh1.feature.create('ftri1', 'FreeTri');
ftri1.selection.geom('geom1', 2);
ftri1.selection.set(3);
dis1 = mesh1.feature.create('dis1', 'Distribution');
dis1.selection.set(1);
dis1.set('type', 'predefined');
dis1.set('elemcount', 20);
dis1.set('elemratio', 100);
swe1 = mesh1.feature.create('swe1', 'Sweep');
swe1.selection('sourceface').geom('geom1', 2);
swe1.selection('targetface').geom('geom1', 2);

mesh1.run;
mphmesh(model);
```
The result is shown in Figure 3-9. With the properties `elemcount` and `elemratio` the number and distribution of mesh element layers is controlled in the extruded direction.

**Figure 3-9: Extruded 3D prism mesh.**

**Code for use with MATLAB®**

```matlab
model = ModelUtil.create('Model');
comp1 = model.component.create('comp1', true);
geom1 = comp1.geom.create('geom1', 3);
wp1 = geom1.feature.create('wp1', 'WorkPlane');
wp1.set('planetype', 'quick');
wp1.set('quickplane', 'xy');
c1 = wp1.geom.feature.create('c1', 'Circle');
c1.set('pos', [2, 0]);
ext1 = geom1.feature.create('ext1', 'Extrude');
ext1.selection('input').set({'wp1'});
geom1.runAll;
 mesh1 = comp1.mesh.create('mesh1');
ftri1 = mesh1.feature.create('ftri1', 'FreeTri');
ftri1.selection.geom('geom1', 2);
ftri1.selection.set(3);
dis1 = mesh1.feature.create('dis1', 'Distribution');
dis1.selection.set(1);
dis1.set('type', 'predefined');
dis1.set('elemcount', 20);
```

**Distribution** in the COMSOL Multiphysics Programming Reference Manual or at the MATLAB prompt:

```matlab
mphdoc(model.mesh,'Distribution')
```
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COMBINING UNSTRUCTURED AND STRUCTURED MESHES

By specifying selections for the meshing operations, swept meshing can also be combined with free meshing. In this case, start by free meshing domain 2, then sweep the resulting surface mesh through domain 1, as in this example:

```plaintext
dis1.set('elemratio', 100);
swe1 = mesh1.feature.create('swe1', 'Sweep');
swe1.selection('sourceface').geom('geom1', 2);
swe1.selection('targetface').geom('geom1', 2);
mesh1.run;
mphmesh(model);
```

**Figure 3-10:** Combined structured/unstructured mesh.
The left-hand side plot in Figure 3-10 is obtained with this command:

```
mphgeom(model,'geom1','facemode','off','facelabels','on')
```

**Code for use with MATLAB®**

```matlab
model = ModelUtil.create('Model');
comp1 = model.component.create('comp1', true);
geom1 = comp1.geom.create('geom1', 3);
cone1 = geom1.feature.create('cone1', 'Cone');
cone1.set('r', 0.3).set('h', 1).set('ang', 9);
cone1.set('pos', [0 0.5 0.5]).set('axis', [-1 0 0]);
geom1.feature.create('blk1', 'Block');
mesh1 = comp1.mesh.create('mesh1');
ftet1 = mesh1.feature.create('ftet1', 'FreeTet');
ftet1.selection.geom('geom1', 3);
ftet1.selection.set(2);
swe1 = mesh1.feature.create('swe1', 'Sweep');
swe1.selection('sourceface').geom('geom1', 2);
swe1.selection('targetface').geom('geom1', 2);
mesh1.run;
mphmesh(model);
mphgeom(model,'geom1','facemode','off','facelabels','on')
```

**Creating Boundary Layer Meshes**

For 2D and 3D geometries it is also possible to create boundary layer meshes using the `BndLayer` feature. A boundary layer mesh is a mesh with dense element distribution in the normal direction along specific boundaries. This type of mesh is typically used for fluid flow problems to resolve the thin boundary layers along the no-slip boundaries. In 2D, a layered quadrilateral mesh is used along the specified no-slip boundaries. In 3D, a layered prism mesh or hexahedral mesh is used depending on whether the corresponding boundary layer boundaries contain a triangular or a quadrilateral mesh.

If starting with an empty mesh, the boundary-layer mesh uses free meshing to create the initial mesh before inserting boundary layers into the mesh. This generates a mesh with triangular and quadrilateral elements in 2D and tetrahedral and prism elements in 3D. The following example illustrates this in 2D:

```matlab
model = ModelUtil.create('Model');
comp1 = model.component.create('comp1', true);

geom1 = comp1.geom.create('geom1', 2);
r1 = geom1.feature.create('r1', 'Rectangle');
r1.set('size', [10, 5]);
c1 = geom1.feature.create('c1', 'Circle');
c1.set('pos', [3.5 2.5]);
dif1 = geom1.feature.create('dif1', 'Difference');
```
dif1.selection('input').set({'r1'});
dif1.selection('input2').set({'c1'});
geom1.runAll;

mesh1 = comp1.mesh.create('mesh1');

bl1 = mesh1.feature.create('bl1', 'BndLayer');
bl1.feature.create('blp1', 'BndLayerProp');
bl1.feature('blp1').selection.set([2 3 5 6 7 8]);

mesh1.run;
mphmesh(model);

Figure 3-11: Boundary layer mesh based on an unstructured triangular mesh.

It is also possible to insert boundary layers in an existing mesh. Use the following meshing sequence with the geometry sequence from the previous example:

bl1.active(false);

fq1 = mesh1.feature.create('fq1', 'FreeQuad');
fq1.selection.set(1);
mesh1.run;
mphmesh(model)

bl1 = mesh1.feature.create('bl2', 'BndLayer');
bl1.feature.create('blp2', 'BndLayerProp');
bl1.feature('blp2').selection.set([2 3 5 6 7 8]);

mesh1.run;
Figure 3-12: Initial unstructured quad mesh (left) and resulting boundary layer mesh (right).

Code for use with MATLAB®

```matlab
model = ModelUtil.create('Model');
comp1 = model.component.create('comp1', true);
geom1 = comp1.geom.create('geom1', 2);
r1 = geom1.feature.create('r1', 'Rectangle');
r1.set('size', [10, 5]);
c1 = geom1.feature.create('c1', 'Circle');
c1.set('pos', [3.5 2.5]);
dif1 = geom1.feature.create('dif1', 'Difference');
dif1.selection('input').set({r1});
dif1.selection('input2').set({c1});
geom1.runAll;
mesh1 = comp1.mesh.create('mesh1');
bl1 = mesh1.feature.create('bl1', 'BndLayer');
bl1.feature.create('blp1', 'BndLayerProp');
bl1.feature('blp1').selection.set([2 3 5 6 7 8]);
mesh1.run;
mphmesh(model);
bl1.active(false);
fq1 = mesh1.feature.create('fq1', 'FreeQuad');
fq1.selection.set(1);
mesh1.run;
mphmesh(model);
b11 = mesh1.feature.create('b11', 'BndLayer');
b11.feature.create('blp1', 'BndLayerProp');
b11.feature('blp1').selection.set([2 3 5 6 7 8]);
mesh1.run;
```

WORKING WITH MESHES | 95
REFINING MESHES

Given a mesh consisting only of simplex elements (lines, triangles, and tetrahedra) you can create a finer mesh using the feature Refine. Enter this command to refine the mesh:

```matlab
mesh1.feature.create('ref1', 'Refine');
```

By specifying the property tri, either as a row vector of element numbers or a 2-row matrix, the elements to be refined can be controlled. In the latter case, the second row of the matrix specifies the number of refinements for the corresponding element.

The refinement method is controlled by the property rmethod. In 2D, its default value is regular, corresponding to regular refinement, in which each specified triangular element is divided into four triangles of the same shape. Setting rmethod to longest gives longest edge refinement, where the longest edge of a triangle is bisected. Some triangles outside the specified set might also be refined in order to preserve the triangulation and its quality.

In 3D, the default refinement method is longest, while regular refinement is only implemented for uniform refinements. In 1D, the function always uses regular refinement, where each element is divided into two elements of the same shape.

COPYING BOUNDARY MESHES

Use the CopyEdge feature in 2D and the CopyFace feature in 3D to copy a mesh between boundaries.

For stationary or eigenvalue PDE problems you can use adaptive mesh refinement at the solver stage with the adaption solver step. See Adaption in the COMSOL Multiphysics Programming Reference Manual.

It is only possible to copy meshes between boundaries that have the same shape. However, a scaling factor between the boundaries is allowed.

The following example demonstrates how to copy a mesh between two boundaries in 3D and then create a swept mesh on the domain:

```matlab
model = ModelUtil.create('Model');
comp1 = model.component.create('comp1', true);
geom1 = comp1.geom.create('geom1', 3);
```
wp1 = geom1.feature.create('wp1', 'WorkPlane');
wp1.set('planetype', 'quick');
wp1.set('quickplane', 'xy');
c1 = wp1.geom.feature.create('c1', 'Circle');
c1.set('r', 0.5).set('pos', [1, 0]);
rev1 = geom1.feature.create('rev1', 'Revolve');
rev1.set('angle1', 0).set('angle2', 180);
rev1.selection('input').set({'wp1'});
geom1.run('wp1');

mesh1 = comp1.mesh.create('mesh1');

size1 = mesh1.feature.create('size1', 'Size');
size1.selection.geom('geom1', 1);
size1.selection.set(18);
size1.set('hmax', '0.06');

ftri1 = mesh1.feature.create('ftri1', 'FreeTri');
ftri1.selection.geom('geom1', 2);
ftri1.selection.set(10);

cpf1 = mesh1.feature.create('cpf1', 'CopyFace');
cpf1.selection('source').geom('geom1', 2);
cpf1.selection('destination').geom('geom1', 2);
cpf1.selection('source').set(10);
cpf1.selection('destination').set(1);

sw1 = mesh1.feature.create('sw1', 'Sweep');
sw1.selection('sourceface').geom('geom1', 2);
sw1.selection('targetface').geom('geom1', 2);

mesh1.run;
mphmesh(model);
The algorithm automatically determines how to orient the source mesh on the target boundary. The result is shown in Figure 3-13.

![Figure 3-13: Prism element obtained with the CopyFace and Sweep features.](image)

To explicitly control the orientation of the copied mesh, use the **EdgeMap** attribute. The command sequence:

```plaintext
em1 = cpf1.feature.create('em1', 'EdgeMap');
em1.selection('srcedge').set(18);
em1.selection('dstedge').set(2);
mesh1.feature.remove('sw1');
mesh1.feature.create('ftet1', 'FreeTet');

mesh1.run;
mpmesh(model);
```

copies the mesh between the same boundaries as in the previous example, but now the orientation of the source mesh on the target boundary is different. The domain is then meshed by the free mesh, resulting in the mesh in Figure 3-14. In this case it is not possible to create a swept mesh on the domain because the boundary meshes do not match in the sweeping direction.
Figure 3-14: Free tetrahedral mesh after the use of the CopyFace feature.

Code for use with MATLAB®

```matlab
model = ModelUtil.create('Model');
comp1 = model.component.create('comp1', true);
geom1 = comp1.geom.create('geom1', 3);
wp1 = geom1.feature.create('wp1', 'WorkPlane');
wp1.set('planetype', 'quick');
wp1.set('quickplane', 'xy');
c1 = wp1.geom.feature.create('c1', 'Circle');
c1.set('r', 0.5).set('pos', [1, 0]);
rev1 = geom1.feature.create('rev1', 'Revolve');
rev1.set('angle1', 0).set('angle2', 180);
rev1.selection('input').set({{'wp1'}});
geom1.run('wp1');
mesh1 = comp1.mesh.create('mesh1');
size1 = mesh1.feature.create('size1', 'Size');
size1.selection.geom('geom1', 1);
size1.selection.set(18);
size1.set('hmax', '0.06');
ftri1 = mesh1.feature.create('ftri1', 'FreeTri');
ftri1.selection.geom('geom1', 2);
ftri1.selection.set(10);
cpf1 = mesh1.feature.create('cpf1', 'CopyFace');
cpf1.selection('source').geom('geom1', 2);
cpf1.selection('destination').geom('geom1', 2);
cpf1.selection('source').set(10);
cpf1.selection('destination').set(1);
sw1 = mesh1.feature.create('sw1', 'Sweep');
sw1.selection('sourceface').geom('geom1', 2);
sw1.selection('targetface').geom('geom1', 2);
```
mesh1.run;
mphmesh(model);
em1 = cpf1.feature.create('em1', 'EdgeMap');
em1.selection('srcedge').set(18);
em1.selection('dstedge').set(2);
mesh1.feature.remove('sw1');
mesh1.feature.create('ftet1', 'FreeTet');
mesh1.run;
mphmesh(model);

CONVERTING MESH ELEMENTS

Use the Convert feature to convert meshes containing quadrilateral, hexahedral, or prism elements into triangular meshes and tetrahedral meshes. In 2D, the function splits each quadrilateral element into either two or four triangles. In 3D, it converts each prism into three tetrahedral elements and each hexahedral element into five, six, or 28 tetrahedral elements. To control the method used to convert the elements, use the property splitmethod.

This example demonstrates how to convert a quad mesh into a triangle mesh:

```matlab
model = ModelUtil.create('Model');
comp1 = model.component.create('comp1', true);
geom1 = comp1.geom.create('geom1', 2);
geom1.feature.create('c1', 'Circle');
geom1.feature.create('r1', 'Rectangle');
int1 = geom1.feature.create('int1', 'Intersection');
int1.selection('input').set({'c1', 'r1'});
mesh1 = comp1.mesh.create('mesh1', 'geom1');
mesh1.feature.create('fq1', 'FreeQuad');
mesh1.runCurrent;
mphmesh(model);
mesh1.feature.create('conv1', 'Convert');
mesh1.run;
mphmesh(model);
```

For additional properties supported, see Convert in the COMSOL Multiphysics Programming Reference Manual or at the MATLAB prompt: mphdoc(model.mesh,'Convert')
The result is illustrated in the **Figure 3-15:**

![Figure 3-15: Mesh using free quad elements (left) and converted mesh from quad to triangle (right).](image)

**Code for use with MATLAB®**

```matlab
model = ModelUtil.create('Model');
comp1 = model.component.create('comp1', true);
geom1 = comp1.geom.create('geom1', 2);
geom1.feature.create('c1', 'Circle');
geom1.feature.create('r1', 'Rectangle');
int1 = geom1.feature.create('int1', 'Intersection');
int1.selection('input').set({'c1' 'r1'});
mesh1 = comp1.mesh.create('mesh1', 'geom1');
mesh1.feature.create('fq1', 'FreeQuad');
mesh1.runCurrent;
mesh1.feature.create('conv1', 'Convert');
mesh1.run;
mpmesh(model);
```

**Importing External Meshes and Mesh Objects**

It is possible to import meshes to COMSOL Multiphysics using the following formats:

- COMSOL Multiphysics text files (extension .mphtxt),
- COMSOL Multiphysics binary files (extension .mphbin), and
- NASTRAN files (extension .nas or .bdf).

**Importing Meshes**

To import a mesh stored in a supported format use the **Import** feature. The following commands import and plot a NASTRAN mesh for a crankshaft:
model = ModelUtil.create('Model');
comp1 = model.component.create('comp1', true);
comp1.geom.create('geom1', 3);

mesh1 = comp1.mesh.create('mesh1', 'geom1');
imp1 = mesh1.feature.create('imp1', 'Import');
filenamepath = fullfile(COMSOL, 'applications', ...
'COMSOL_Multiphysics','Structural_Mechanics');
model.modelPath(filenamepath);
imp1.set('filename','crankshaft.nas');
mesh1.feature('imp1').importData;

mesh1.run;
mpmesh(model);

Where COMSOL is the path of root directory where COMSOL Multiphysics is installed.
The above command sequence results in Figure 3-16.

Figure 3-16: Imported NASTRAN mesh.

For additional properties supported, see Import in the COMSOL Multiphysics Programming Reference Manual.
For a description of the text file format see the COMSOL Multiphysics Reference Manual.

Code for use with MATLAB®
model = ModelUtil.create('Model');
comp1 = model.component.create('comp1', true);
comp1.geom.create('geom1', 3);
mesh1 = comp1.mesh.create('mesh1');
imp1 = mesh1.feature.create('imp1', 'Import');
filenamepath = fullfile(COMSOL,'applications',...
 'COMSOL_Multiphysics','Structural_Mechanics');
model.modelPath(filenamepath);
imp1.set('filename','crankshaft.nas');
mesh1.feature('imp1').importData;
mesh1.run;
mphmesh(model);

Measuring Mesh Quality

Use the stat method on the meshing sequence to get information on the mesh quality. The quality measure is a scalar quantity, defined for each mesh element, where 0 represents the lowest quality and 1 represents the highest quality.

The following commands show how to visualize the mesh quality for a mesh on the unit circle:

model = ModelUtil.create('Model');
comp1 = model.component.create('comp1', true);
geom1 = comp1.geom.create('geom1', 2);
geom1.feature.create('c1', 'Circle');
geom1.runAll;

mesh1 = comp1.mesh.create('mesh1');
mesh1.feature.create('ftri1', 'FreeTri');
mesh1.run;

meshdataset1 = model.result.dataset.create('mesh1', 'Mesh');
mgdataset1.set('mesh', 'mesh1');
pg1 = model.result.create('pg1', 2);

meshplot1 = pg1.feature.create('mesh1', 'Mesh');
meshplot1.set('data', 'mesh1');
meshplot1.set('filteractive', 'on');
meshplot1.set('elemfilter', 'quality');
meshplot1.set('tetkeep', 0.25);
mphplot(model,'pg1','rangenum',1);
meshplot1.set('elemfilter','qualityrev');
meshplot1.run;
mphplot(model,'pg1','rangenum',1);

These commands display the worst 25% and the best 25% elements in terms of mesh element quality. In Figure 3-17, the triangular mesh elements in the right-hand side plot are more regular than those in the left-hand side plot; this reflects the fact that a
quality measure of 1 corresponds to a uniform triangle, while 0 means that the triangle has degenerated into a line.

![Figure 3-17: Visualizations of the mesh quality: worst 25% (left) and best 25% (right).](image)

**Code for use with MATLAB®**

```matlab
model = ModelUtil.create('Model');
comp1 = model.component.create('comp1', true);
geom1 = comp1.geom.create('geom1', 2);
geom1.feature.create('c1', 'Circle');
geom1.runAll;
mesh1 = comp1.mesh.create('mesh1', 'geom1');
mesh1.feature.create('ftri1', 'FreeTri');
mesh1.run;
meshdset1 = model.result.dataset.create('mesh1', 'Mesh');
meshdset1.set('mesh', 'mesh1');
pg1 = model.result.create('pg1', 2);
meshplot1 = pg1.feature.create('mesh1', 'Mesh');
meshplot1.set('data', 'mesh1');
meshplot1.set('filteractive', 'on');
meshplot1.set('elemfilter', 'quality');
meshplot1.set('tetkeep', 0.25);
mphplot(model, 'pg1', 'rangenum', 1);
meshplot1.run;
mphplot(model, 'pg1', 'rangenum', 1);
```

**Getting Mesh Statistics Information**

Use the function `mphmeshstats` to get mesh statistics and mesh information where `stats` is a structure containing the mesh statistics information. Enter:

```matlab
stats = mphmeshstats(model)
```
The statistics structure has the following fields:

- `meshtag`, the tag of the mesh sequence;
- `geomtag`, the tag of the associated geometry;
- `component`, the tag of the component the mesh belongs to;
- `isactive`, boolean variable that indicates if the mesh feature is active (1) or not (0);
- `hasproblems`, boolean variable that indicates if the mesh feature contains error or warning nodes (1) or not (0);
- `iscomplete`, Boolean variable that indicates if the mesh feature is built (1) or not (0);
- `sdim`, the space dimension of the mesh feature;
- `secondorderelements`, boolean variable that indicates if the mesh has second order elements;
- `contributing`, the contributing physics and multiphysics feature for physics-controlled mesh;
- `types`, the element types present in the mesh. The element type can be vertex (`vtx`), edge (`edg`), triangle (`tri`), quadrilateral (`quad`), tetrahedra (`tet`), pyramid (`pyr`), prism (`prism`), hexahedra (`hex`). The type can also be of all elements of maximal dimension in the selection (`all`);
- `numelem`, the number of elements for each element type;
- `qualitymeasure`, the quality measure used to evaluate the quality of the mesh.
- `minquality`, the minimum element quality;
- `meanquality`, the mean element quality;
- `qualitydistr`, the distribution of the element quality (20 values);
- `minvolume`, the minimum element volume/area;
- `maxvolume`, the maximum element volume/area;
- `volume`, the total volume/area of the mesh;
- `maxgrowthrate`, the maximal growth rate value for the entire selection, regardless of the element type property;
- `meangrowthrate`, the average growth rate value for the entire selection, regardless of the element type property.

If several mesh cases are available in the model object, specify the mesh tag:

```plaintext
stats = mphmeshstats(model, <meshtag>)
```
Set the number of bins in the quality distribution histogram (\textit{qualitydistr}) with the property \textit{qualityhistogram}:

\begin{verbatim}
stats = mphmeshstats(model, <meshtag>, 'qualityhistogram', <num>)
\end{verbatim}

where \textit{<num>} is an integer corresponding to the desired number of bins.

Set the mesh quality measure from for the mesh statistics with the property \textit{qualitymeasure}:

\begin{verbatim}
stats = mphmeshstats(model, <meshtag>, 'qualitymeasure', <quality>)
\end{verbatim}

where \textit{<quality>} is one of 'condition' (condition number), 'growth' (growth rate), 'maxangle' (maximum number), 'skewness' (skewness), 'volcircum' (volume versus circumradius) or 'vollength' (volume versus length).

\begin{table}[h]
\centering
\begin{tabular}{|c|}
\hline
Mesh Element Quality and Size in the \textit{COMSOL Multiphysics} Programming Reference Manual. \\
\hline
\end{tabular}
\end{table}

\section*{GET MESH STATISTICS ON SPECIFIED ENTITY OR SELECTION}

Specify the entity where to evaluate mesh quality with the property \textit{entity} as in the command below:

\begin{verbatim}
stats = mphmeshstats(model, <meshtag>, 'entity', entity)
\end{verbatim}

where \textit{entity} is one of 'domain', 'boundary', 'edge' or 'point'.

Use the selection property to specify the entity number where to get the mesh statistics:

\begin{verbatim}
stats = mphmeshstats(model, <meshtag>, 'entity', entity, 'selection', <selnum>)
\end{verbatim}

where \textit{<selnum>} is an integer array defining the selection number.

It is also possible to use the selection property to define a selection node defined in the model:

\begin{verbatim}
stats = mphmeshstats(model, <meshtag>, 'selection', <seltag>)
\end{verbatim}

where \textit{<seltag>} is the tag of the desired selection node.

\begin{table}[h]
\centering
\begin{tabular}{|c|}
\hline
The properties \textit{entity} and \textit{selection} cannot be set if the mesh data information is returned. \\
\hline
\end{tabular}
\end{table}
**Retrieve Mesh Statistics of a Specific Element Type**

Restrict the mesh statistics information structure a specific element type with the property type:

\[
\text{stats} = \text{mphmeshstats}(\text{model}, \text{<meshtag>}, \text{'type'}, \text{type})
\]

where \(\text{type}\) is one of the mesh element type available: vertex (‘vtx’), edge (‘edg’), triangle (‘tri’), quad (‘quad’), tetrahedron (‘tet’), pyramid (‘pyr’), prism (‘prism’) or hexahedron (‘hex’). \(\text{type}\) can also be a cell array to return the mesh statistics of several mesh element type.

**Getting and Setting Mesh Data**

The function \texttt{mphmeshstats} also returns the mesh data such as element coordinates. Use the function with two output variables to get the mesh data. Enter:

\[
[\text{meshstats}, \text{meshdata}] = \text{mphmeshstats}(\text{model})
\]

where \text{meshdata} is a MATLAB structure with the following fields:

- \text{vertex}, which contains the mesh vertex coordinates;
- \text{elem}, which contains the element data information;
- \text{elementity}, which contains the element entity information for each element type.

---

| `Selection and/or Entity properties cannot be set if the mesh data structure is returned.` |

---

**Extract and Create Mesh Information**

A mesh can be manually created based on a grid generated in MATLAB. However, before inserting this mesh into the model, a default coarse mesh is generated to get the mesh information, which enables you to understand the requested mesh structure to use with the \texttt{createMesh} method. Then a complete mesh can be constructed and stored in the meshing sequence. If the geometry is not empty, the new mesh is checked to ensure that it matches the geometry. In other words, to create an arbitrary mesh, an empty geometry sequence and a corresponding empty meshing sequence need to be created and the mesh is then constructed on the empty meshing sequence.

Start by creating a 2D model containing a square, and mesh it with triangles:

\[
\begin{align*}
\text{model} &= \text{ModelUtil.create('Model')}; \\
\text{comp1} &= \text{model.component.create('comp1', true)}; \\
\text{geom1} &= \text{comp1.geom.create('geom1', 2)};
\end{align*}
\]
geom1.feature.create('sq1', 'Square');
geom1.run;
mesh1 = comp1.mesh.create('mesh1');
mesh1.feature.create('ftri1', 'FreeTri');
mesh1.feature('size').set('hmax', 0.5);
mesh1.run('ftri1');
mphmesh(model);

To get the mesh data information, enter:

```
[meshstats, meshdata] = mphmeshstats(model);
```

```
meshdata =
    vertex: [2x12 double]
    elem: {{[2x8 int32]  [3x14 int32]  [0 5 7 11]}}
    elementity: {{[8x1 int32]  [14x1 int32]  [4x1 int32]}}
```

The mesh node coordinates are stored in the `vertex` field:

```
vtx = meshdata.vertex
```

```
vtx =
    Columns 1 through 7
        0    0.5000    0.3024         0    0.6314    1.0000    0.3511
        0         0    0.3023    0.5000    0.3632         0    0.6397
    Columns 8 through 12
        0    0.6730    1.0000    0.5000    1.0000

1.0000    0.6728    0.5000    1.0000    1.0000
```

In the `elem` field the element information is retrieved, such as the node indices (using a 0 based) connected to the elements:

```
tri = meshdata.elem{2}
```
In the above command, notice that element number 1 is connected to nodes 1, 2, and 3, and element number 2 is connected to nodes 4, 1, and 3.

Then create manually a mesh using a data distribution generated in MATLAB. Enter the command:

```
[x,y] = meshgrid([0 0.5 1], [0 0.5 1]);
coord = [x(:) y(:)]';
```

The node distribution obtained with this command corresponds to the mesh in Figure 3-18.

![Figure 3-18: Mesh with elements (bold) and nodes (italic) indices.](image-url)
Table 3-1 lists the nodes and element connectivity in the mesh.

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>NODES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1, 4, 5</td>
</tr>
<tr>
<td>2</td>
<td>1, 2, 5</td>
</tr>
<tr>
<td>3</td>
<td>2, 5, 6</td>
</tr>
<tr>
<td>4</td>
<td>2, 3, 6</td>
</tr>
<tr>
<td>5</td>
<td>4, 7, 8</td>
</tr>
<tr>
<td>6</td>
<td>4, 5, 8</td>
</tr>
<tr>
<td>7</td>
<td>5, 8, 9</td>
</tr>
<tr>
<td>8</td>
<td>5, 6, 9</td>
</tr>
</tbody>
</table>

To create the elements and nodes connectivity information use the command:

```matlab
new_tri(:,1)=[0;3;4];
new_tri(:,2)=[0;1;4];
new_tri(:,3)=[1;4;5];
new_tri(:,4)=[1;2;5];
new_tri(:,5)=[3;6;7];
new_tri(:,6)=[3;4;7];
new_tri(:,7)=[4;7;8];
new_tri(:,8)=[4;5;8];
```

Assign the element information, node coordinates, and elements connectivity information, into a new mesh. Use the method `createMesh` to create the new mesh:

```matlab
comp2 = model.component.create('comp2', true);
comp2.geom.create('geom2',2);
mesh2 = comp2.mesh.create('mesh2');
mesh2.data.setElem('tri',new_tri)
mesh2.data.setVertex(coord)
mesh2.data.createMesh
```

*Code for use with MATLAB®*

```matlab
model = ModelUtil.create('Model');
comp1 = model.component.create('comp1', true);
geom1 = comp1.geom.create('geom1', 2);
geom1.feature.create('sq1', 'Square');
geom1.run;
mesh1 = comp1.mesh.create('mesh1');
mesh1.feature.create('ftri1', 'FreeTri');
mesh1.feature('size').set('hmax', 0.5);
mesh1.run('ftri1');
mphmesh(model);
[meshstats,meshdata] = mphmeshstats(model);
```
vtx = meshdata.vertex
tri = meshdata.elem{2}
[x,y] = meshgrid([0 0.5 1], [0 0.5 1]);
coord = [x(:) y(:)]';
new_tri(:,1)=[0;3;4];
new_tri(:,2)=[0;1;4];
new_tri(:,3)=[1;4;5];
new_tri(:,4)=[1;2;5];
new_tri(:,5)=[3;6;7];
new_tri(:,6)=[3;4;7];
new_tri(:,7)=[4;7;8];
new_tri(:,8)=[4;5;8];
comp2 = model.component.create('comp2', true);
comp2.geom.create('geom2',2);
mesh2 = comp2.mesh.create('mesh2');
new_tril.data.setElem('tri', new_tri);
new_tril.data.setVertex(coord);
new_tril.data.createMesh;
mphmesh(model, 'mesh2');
Modeling Physics

This section describes how to set up physics interfaces in a model. The physics interface defines the equations that COMSOL solves.

- The Physics Interface Syntax
- The Material Syntax
- Modifying the Equations
- Adding Global Equations
- Defining Model Settings Using External Data File
- Access the User-Defined Physics Interface

The Physics Interface Syntax

Create a physics interface instance using the syntax:

```python
model.component(<ctag>).physics.create(<phystag>,physint,<geomtag>)
```

where `<phystag>` is a string that identifies the physics interface node. Once defined, you can always refer to a physics interface, or any other feature, by its tag. The string `physint` is the constructor name of the physics interface. To get the constructor name, the best way is to create a model using the desired physics interface in the GUI and save the model as an M-file. The string `<geomtag>` refers to the geometry where you want to specify the interface.

To add a feature to a physics interface, use the syntax:

```python
phys.feature.create(<ftag>, operation)
```

where `phys` is a link to a physics node. `<ftag>` is a string that you use to refer to the operation. To set a property to a value in a operation, enter:

```python
phystag.feature(<ftag>).set(property, <value>)
```
where `<ftag>` is the string that identifies the feature.

To disable or remove a feature node, use the methods `active` or `remove`, respectively.

The command:

```matlab
phystag.feature(<ftag>).active(false)
```

disables the feature `<ftag>`.

To activate the feature node you can set the `active` method to true:

```matlab
phystag.feature(<ftag>).active(true)
```

To remove a feature from the model, use the method `remove`:

```matlab
phystag.feature.remove(<ftag>)
```

**EXAMPLE: IMPLEMENT AND SOLVE A HEAT TRANSFER PROBLEM**

This example shows how to add a physics interface and set the boundary conditions in the model object.

Start to create a model object including a 3D geometry. The geometry consists in a block with default settings. Enter the following commands at the MATLAB prompt:

```matlab
model = ModelUtil.create('Model');
comp1 = model.component.create('comp1', true);
geom1 = comp1.geom.create('geom1', 3);
geom1.feature.create('blk1', 'Block');
geom1.run;
```

Add a Heat Transfer in Solids interface to the model:

```matlab
phys = comp1.physics.create('ht', 'HeatTransfer', 'geom1');
```

The tag of the interface is `ht`. The interface constructor is `HeatTransfer`. The physics is defined on geometry `geom1`.

The physics interface automatically creates a number of default features. To examine these, enter:

```matlab
comp1.physics('ht')
```

```matlab
ans =
```

There are alternative syntaxes available. See `model.physics()` in the *COMSOL Multiphysics Programming Reference Manual* or type at the MATLAB prompt: `mphdoc(model.physics)`. 
Type: Heat Transfer in Solids
Tag: ht
Identifier: ht
Operation: HeatTransfer
Child nodes: solid1, init1, ins1, idi1, os1, cib1

The physics method has the following child nodes: solid1, init1, ins1, idi1, os1, and cib1. These are the default features that come with the Heat Transfer in Solids interface. The first feature, solid1, consists of the heat balance equation. Confirm this by entering:

```matlab
solid = phys.feature('solid1')
ans =
  Type: Solid
  Tag: solid1
  Operation: SolidHeatTransferModel
```

The settings of the solid1 feature node can be modified, for example, to manually set the material property. To change the thermal conductivity to 400 W/(m*K) enter:

```matlab
solid.set('k_mat', 1, 'userdef');
solid.set('k', 400);
```

The Heat Transfer in Solids interface has features you can use to specify domain or boundary settings. For example, to add a heat source of $10^5$ W/m³ in the study domain, enter the commands:

```matlab
hs = phys.feature.create('hs1', 'HeatSource', 3);
hs.selection.set(1);
hs.set('Q', 1, 1e5);
```

To create a temperature boundary condition on boundaries 3, 5, and 6, enter:

```matlab
temp = phys.feature.create('temp1', 'TemperatureBoundary', 2);
temp.selection.set([3 5 6]);
temp.set('T0', 1, '300[K]');
```

Then add a mesh and a study feature and compute the solution:

```matlab
comp1.mesh.create('mesh1');
std = model.study.create('std1');
std.feature.create('stat', 'Stationary');
std.run
```

To visualize the solution, create a 3D surface plot group, which is displayed in a MATLAB figure with the function `mphplot`:

```matlab
pg = model.result.create('pg1', 'PlotGroup3D');
pg.feature.create('surf1', 'Surface');
mphplot(model, 'pg1', 'rangenum',1)
```
In addition to changing material properties directly inside the physics interfaces, materials available in the entire model can also be created. Such a material can be used by all physics interfaces in the model.
Create a material using the syntax:

```
model.component(<ctag>).material.create(<mattag>)
```

where `<mattag>` is a string that you use to refer to a material definition.

A *Material* is a collection of material models, where each material model defines a set of material properties, material functions, and model inputs. To add a material model, use the syntax:

```
mat.materialmodel.create(<mtag>)
```

where `mat` is a link to a material node. The string `<mtag>` refers to the material model.

To define material properties for the model, set the property value pairs by entering:

```
mat.materialmodel(<mtag>).set(property, <value>)
```

**EXAMPLE: CREATE A MATERIAL NODE**

The section Example: Implement and Solve a Heat Transfer Problem shows how to change a material property inside a physics interface. This example shows how to define a material available globally in the model. These steps assume that the previous example has been followed. Enter:

```matlab
mat = model.component('comp1').material.create('mat1');
```

The material automatically creates a material model, `def`, which can be used to set up basic properties. For example, use it to define the density and the heat capacity:

```matlab
mat.materialmodel('def').set('density', 400);
mat.materialmodel('def').set('heatcapacity', 2e3);
```

To use the defined material in a model, set the `solid1` feature to use the material node. Enter:

```matlab
solid.set('k_mat',1,'from_mat');
```

---

**Modifying the Equations**

The equation defining the physics node can be edited with the method `featureInfo('info')` applied to a feature of the physics node.
physics(<phystag>).feature(<ftag>), where <phystag> and <ftag> identify the physics interface and the feature, respectively:

info = phystag.feature(<ftag>).featureInfo('info');

Use the method getInfoTable(type) to return the tables available in the Equation View node:

infoTable = info.getInfoTable(type);

where type defines the type of table to return. It can have the value ‘Weak’ to return the weak form equations, ‘Constraint’ to return the constraint types table, or ‘Expression’ to return the variable expressions table.

**EXAMPLE: ACCESS AND MODIFY THE EQUATION WEAK FORM**

This example continues from the Example: Implement and Solve a Heat Transfer Problem and modifies the model equation.

To retrieve information about the physics interface create an info object:

ht = model.component('comp1').physics('ht');
info = ht.feature('solid1').featureInfo('info');

From the info object access the weak form equation by entering:

infoTable = info.getInfoTable('Weak');

This returns a string variable that contains both the name of the weak equation variable and the equation of the physics implemented in the weak form. Enter the command:

list = infoTable(:)

which results in the output:

java.lang.String[]:

'(-(ht.k_effxx*Tx+ht.k_effxy*Ty+ht.k_effxz*Tz)*test(Tx)-(ht.k_eff...

'root.comp1.ht.solid1.weak$1'

'4'

'Spatial'

'Domain 1'

'3'

'-ht.rho*ht.Cp*(ht.ux*Tx+ht.uy*Ty+ht.uz*Tz)*test(T)*ht.d'

'root.comp1.ht.solid1.weak$2'

'4'

'Spatial'

'Domain 1'

'3'

'ht.streamline'
The output shows that the physics is defined with the weak expression available in the variable list(1). Enter:

```
list(1)
```
to get the weak equation as a string variable. The result of this command is:

```
ans = 
(-(ht.k_effxx*Tx+ht.k_effxy*Ty+ht.k_effxz*Tz)*test(Tx)-(ht.k_effyx*Tx+ht.k_effyy*Ty+ht.k_effzy*Tz)*test(Ty)-(ht.k_effzx*Tx+ht.k_effzy*Ty+ht.k_effzz*Tz)*test(Tz))*ht.d
```

To access the equation in the node `root.comp1.ht.solid1.weak$1`; for example, to modify the equation and lock the expression, run the commands:

```
equExpr = '\texttt{200[W/(m*K)]*(T_x*test(T_x)+T_y*test(T_y)+T_z*test(T_z))}';
info.lock(list(2), {equExpr});
```

These commands set the heat conductivity to a constant value directly within the heat balance equation.

### Adding Global Equations

To add a global equation in the model use the command:

```
model.component(<ctag>).physics.create(<odestag>, 'GlobalEquations')
```

To define the name of the variable to be solved by the global equation, enter:

```
ode.set('name', <idx>, <name>)
```

where `ode` is a link to a Global Equations node and `<idx>` is the index of the global equation, and `<name>` a string with the name of the variable.

Set the expression `<expr>` of the global equation with:

```
ode.set('equation', <idx>, <expr>)
```

where `<expr>` is defined as a string variable.

Initial value and initial velocity can be set with the commands:

```
node.set('initialValueU', <idx>, <init>)
ode.set('initialValueUt', <idx>, <init_t>)
```
where \(<init>\) and \(<init>_t\) are the initial value expression for the variable and its time derivative respectively.

**EXAMPLE: SOLVE AN ODE PROBLEM**

This example illustrates how to solve the following ODE in a COMSOL model:

\[ \ddot{u} + \frac{\dot{u}}{2} + 1 = 0 \]

\[ u(0) = 0 \]

\[ u(0) = 20 \]

**Code for use with MATLAB®**

```matlab
model = ModelUtil.create('Model');
comp1 = model.component.create('comp1', true);
ge = comp1.physics.create('ge', 'GlobalEquations');
ge1 = ge.feature('ge1');
ge1.set('name', 1, 1, 'u');
ge1.set('equation', 1, 1, 'utt+0.5*ut+1');
ge1.set('initialValueU', 1, 1, 'u0');
ge1.set('initialValueUt', 1, 1, 'u0t');
model.param.set('u0', 0);
model.param.set('u0t', 20);
std1 = model.study.create('std1');
std1.feature.create('time', 'Transient');
std1.feature('time').set('tlist', 'range(0,0.1,20)');
```
std1.run;
model.result.create('pg1', 1);
model.result('pg1').set('data', 'dset1');
model.result('pg1').feature.create('glob1', 'Global');
model.result('pg1').feature('glob1').set('expr', {'comp1.u'});
mphplot(model, 'pg1')

Defining Model Settings Using External Data File

To use tabulated data from files in a model, use the interpolation function available
under the Global Definitions node or the Definitions node of the model.

To add an interpolation function under the Global Definitions node, enter:

    model.func.create(<functag>, 'Interpolation')

If you have several model nodes in your model and you want to attach it to the
specified component node <ctag>, enter:

    model.component(<ctag>).func.create(<functag>, 'Interpolation')

where <ctag> is the tag of the model node to attach the interpolation function.

Then you can interpolate data specified by a table inside the function (default), or
specified in an external file.

When using an interpolation table, set the interpolation data for each row of the table
with the commands:

    func.setIndex('table', <t_value>, <i>, 1)
    func.setIndex('table', <ft_value>, <i>, 2)

where func is a link to a function node and <t_value> is the interpolation parameter
value and <ft_value> is the function value. <i> is the index (0-based) in the
interpolation table. If the number of rows is large then it takes a long time to create
the table element by element. Instead store all the data as a cell array of strings and
set the values all at once:

    func.set('table', data)

To use an external file change the source for the interpolation and specify the file,
where filename is the name (including the path) of the data file:

    func.set('source', 'file')
    func.set('filename', <filename>)

Several interpolation methods are available. Choose the one to use with the command:

    func.set('interp', method)
The string `method` can be set as one of the following alternatives:

- 'neighbor', for interpolation according to the nearest neighbor method,
- 'linear', for linear interpolation method,
- 'cubicspline', for cubic spline interpolation method, or
- 'piecewisecubic', piecewise cubic interpolation method.

You can also decide how to handle parameter values outside the range of the input data by selecting an extrapolation method:

```matlab
func.set('extrap', method)
```

The string `method` can be one of these values:

- 'const', to use a constant value outside the interpolation data,
- 'linear', for linear extrapolation method,
- 'nearestfunction', to use the nearest function as extrapolation method, or
- 'value', to use a specific value outside the interpolation data.

---

**Access the User-Defined Physics Interface**

Using COMSOL with MATLAB, to run a model made with a user-defined physics interface created with the COMSOL Physics Builder you need to save the compiled archive (.jar) in your user home folder `comsol/<version>/archives`, where you replace `<version>` with the current version of COMSOL. Any compressed archive (with extension .jar) is loaded next time COMSOL with MATLAB starts.
Creating Selections

In this section:
- The Selection Node
- Coordinate-Based Selections
- Selection Using Adjacent Geometry
- Displaying Selections

### The Selection Node

Use a Selection node to define a collection of geometry entities in a central location in the model. The selection can easily be accessed in physics or mesh features or during results analysis. For example, you can refer collectively to a set of boundaries that have the same boundary conditions, which also have the same mesh size settings.

A selection feature can be one of these types:
- explicit, to include entities explicitly defined by their definitions indices,
- ball, to include entities that fall with a set sphere,
- cylinder, to include entities that fall with a set cylinder, and
- box, to include entities that fall within a set box.

Selection can also be combined by Boolean operations, such as Union, Intersection, and Difference.

### Setting an Explicit Selection

Create an explicit selection with the command:

```python
model.component(<ctag>).selection.create(<seltag>, 'Explicit')
```

To specify the domain entity dimension to use in the selection node, enter:

```python
sel.geom(edim)
```
where \texttt{sel} is a link to an Explicit Selection node and \texttt{sdim} is the space dimension that represents the different geometric entities:

- 3 for domains,
- 2 for boundaries/domains,
- 1 for edges/boundaries, and
- 0 for points.

Set the domain entity indices in the selection node with the command:

\begin{verbatim}
sel.set(<idx>)
\end{verbatim}

where \texttt{<idx>} is an array of integers that list the geometric entity indices to add in the selection.

\textbf{Coordinate-Based Selections}

\textbf{DEFINING A BALL SELECTION NODE}

The Ball selection node is defined by a center point and a radius. The selection can include geometric entities that are completely or partially inside the ball. The selection can be set up by using either the COMSOL API directly or the \texttt{mphselectcoords} function. There are different ways to define the ball selections: Ball Selection Using the COMSOL API or Ball Selection Using \texttt{mphselectcoords}.

\textit{Ball Selection Using the COMSOL API}

To add a ball selection to a model object enter:

\begin{verbatim}
model.component(<ctag>).selection.create(<seltag>, 'Ball')
\end{verbatim}

To set the coordinates (\texttt{<x0>}, \texttt{<y0>}, \texttt{<z0>}) of the selection center point, enter:

\begin{verbatim}
  sel.set('posx', <x0>)
  sel.set('posy', <y0>)
  sel.set('posz', <z0>)
\end{verbatim}

where \texttt{sel} is a link to a Ball Selection node and \texttt{<x0>}, \texttt{<y0>}, \texttt{<z0>} are double values.

Specify the ball radius \texttt{<r0>} with the command:

\begin{verbatim}
  sel.set('r', <r0>)
\end{verbatim}

where \texttt{<r0>} is a double floating-point value.

To specify the geometric entity level, enter:

\begin{verbatim}
  sel.set('entitydim', edim)
\end{verbatim}
where \( edim \) is an integer defining the space dimension value (3 for domains, 2 for boundaries/domains, 1 for edges/boundaries, and 0 for points).

The selection also specifies the condition for geometric entities to be selected:

```python
sel.set('condition', condition)
```

where `condition` can be:

- `'inside'`, to select all geometric entities completely inside the ball,
- `'intersects'`, to select all geometric entities that intersect the ball (default),
- `'somevertex'`, to select all geometric entities where at least some vertex is inside the ball, or
- `'allvertices'`, to select all geometric entities where all vertices are inside the ball.

**Ball Selection Using mphselectcoords**

The function `mphselectcoords` retrieves geometric entities enclosed by a ball.

To get the geometric entities enclosed by a ball of radius \( r_0 \), with its center positioned at \((x_0,y_0,z_0)\) enter the command:

```python
idx = mphselectcoords(model, <geomtag>, [<x0>,<y0>,<z0>], ... entitytype,'radius','<r0>')
```

where `<geomtag>` is the tag of geometry where the selection, and `entitytype` can be one of `'point'`, `'edge'`, `'boundary'`, or `'domain'`.

The above function returns the entity indices list. Use it to specify a feature selection or to create an explicit selection as described in Setting an Explicit Selection.

You can also refine the search using several search ball. To do so set the coordinates as a \( N \times M \) array where \( N \) corresponds of the number of point to use and \( M \) the space dimension of the geometry as in the command below:

```python
idx = mphselectcoords(model, <geomtag>, ... [<x0>,<y0>,<z0>; <x1>,<y1>,<z1>;...], entitytype)
```

This returns the geometric entity indices that have vertices near both the given coordinates using the tolerance radius.

To include any geometric entities in the selection that have at least one vertex inside the search ball, set the property `include` to `'any'`:

```python
idx = mphselectcoords(model, <geomtag>, ... [<x0>,<y0>,<z0>; <x1>,<y1>,<z1>], entitytype, 'include', 'any');
```
In case the model geometry is finalized as an assembly, you have distinct geometric entities for each part of the assembly (pair). Specify the adjacent domain index to avoid selection of any overlapping geometric entities. Set the \texttt{adjnumber} property with the domain index:

\begin{verbatim}
idx = mphselectcoords(model, <geomtag>, [<x0>,<y0>,<z0>], ..., entitytype,'radius',<r0>, 'adjnumber',<idx>)
\end{verbatim}

where \texttt{<idx>} is the domain index adjacent to the desired geometric entities.

**Defining a Box Selection Node**

The Box selection node is defined by two diagonally opposite points of a box (in 3D) or rectangle (in 2D). There are different ways to define the box selections: **Box Selection Using the COMSOL API** or **Box Selection Using mphselectbox**

**Box Selection Using the COMSOL API**

This command adds a box selection to the model object:

\begin{verbatim}
model.component(<ctag>).selection.create(<seltag>, 'Box')
\end{verbatim}

To specify the points \((<x0>, <y0>, <z0>)\) and \((<x1>, <y1>, <z1>)\), enter:

\begin{verbatim}
sel.set('xmin', <x0>)
sel.set('ymin', <y0>)
sel.set('zmin', <z0>)
sel.set('xmax', <x1>)
sel.set('ymax', <y1>)
sel.set('zmax', <z1>)
\end{verbatim}

where \texttt{sel} is a link to a Box Selection node and \(<x0>, <y0>, <z0>, <x1>, <y1>, <z1>\) are double values.

To specify the geometric entities levels use the command:

\begin{verbatim}
sel.set('entitydim', edim)
\end{verbatim}

where \texttt{edim} is an integer defining the space dimension value (3 for domains, 2 for boundaries/domains, 1 for edges/boundaries, and 0 for points).

The selection also specifies the condition for geometric entities to be selected:

\begin{verbatim}
sel.set('condition', condition)
\end{verbatim}

where \texttt{condition} can be:

- \texttt{‘inside’}, to select all geometric entities completely inside the ball,
- \texttt{‘intersects’}, to select all geometric entities that intersect the ball (default),

\texttt{CREATE SELECTIONS} | 125
• ’somevertex’, to select all geometric entities where at least some vertex is inside the ball, or
• ’allvertices’, to select all geometric entities where all vertices are inside the ball.

**Box Selection Using mphselectbox**

The function `mphselectbox` retrieves geometric entities enclosed by a box (in 3D) or rectangle (in 2D).

To get the geometric entities of type `entitytype` enclosed by the box defined by the points \((x_0,y_0,z_0)\) and \((x_1,y_1,z_1)\), enter the command:

```matlab
idx = mphselectbox(model,<geomtag>,...,[<x0> <x1>;<y0> <y1>;<z0> <z1>],entitytype)
```

where `<geomtag>` is the geometry tag where the selection is applied, and `entitytype` can be one of ‘point’, ‘edge’, ‘boundary’, or ‘domain’.

The above function returns the entity indices list. Use it to specify a feature selection or to create an explicit selection as described in Setting an Explicit Selection.

By default the function searches for the geometric entity vertices near these coordinates using the tolerance radius. It returns only the geometric entities that have all vertices inside the box or rectangle. To include any geometric entities in the selection that have at least one vertex inside the search ball, set the property `include` to ’any’:

```matlab
idx = mphselectbox(model,<geomtag>,...,[<x0> <x1>;<y0> <y1>;<z0> <z1>],entitytype,'include','any')
```

In case the model geometry is finalized as an assembly (pair), you have distinct geometric entities for each part of the assembly. Specify the adjacent domain index to avoid selection of overlapping geometric entities. Set the `adjnumber` property with the domain index:

```matlab
idx = mphselectbox(model,<geomtag>,...,[<x0> <x1>;<y0> <y1>;<z0> <z1>],entitytype,'adjnumber',<idx>)
```

where `<idx>` is the domain index adjacent to the desired geometric entities.

**Retrieving Point Coordinates Using a Selection**

Use `mphgetcoords` to retrieve coordinates of the points that belong to a given geometry. Run the command below to get the coordinates of the points that belong to the desired geometric entity:

```matlab
c = mphgetcoords(model,<geomtag>,entitytype,<idx>)
```
where `<geomtag>` is the geometry tag where the selection is applied, `entitytype` can be one of `'point'`, `'edge'`, `'boundary'`, or `'domain'` and `<idx>` is a integer array containing the geometric entity indices. `c` is a Nx2 double array containing the point coordinates where N is the number of points.

**Selection Using Adjacent Geometry**

Another approach is to select geometric entities and define the adjacent object. For example, select edges adjacent to a specific domain or boundaries adjacent to a specific point. There are different ways to create an adjacent selection: Adjacent Selection Using the COMSOL API or Adjacent Selection Using mphgetadj

**Adjacent Selection Using the COMSOL API**

This command creates a selection node using adjacent geometric entities:

```plaintext
model.component(<ctag>).selection.create(<seltag>, 'Adjacent')
```

The geometric entity level needs to be specified with the command:

```plaintext
sel.set(edim)
```

where `sel` is a link to an Adjacent Selection node and `edim` is an integer defining the space dimension value (3 for domains, 2 for boundaries/domains, 1 for edges/boundaries, and 0 for points).

The Adjacent selection node only supports the Selection node as an input:

```plaintext
sel.set('Adjacent')
```

and specify the ball radius `<r0>` with the command:

```plaintext
sel.set('input', <seltag>)
```

where `<seltag>` is the tag of an existing Selection node.

Select the level of geometric entities to add in the selection with the command:

```plaintext
sel.set('outputdim', edim)
```

where `edim` is an integer defining the space dimension value (3 for domains, 2 for boundaries/domains, 1 for edges/boundaries, and 0 for points).

If there are multiple domains in the geometry to include in the interior and exterior selected geometric entities, then enter:

```plaintext
sel.set('interior', 'on')
sel.set('exterior', 'on')
```
To exclude the interior/exterior, select geometric entities and set the respective property to 'off'.

Adjacent Selection Using `mphgetadj`
An alternative to the COMSOL API is to use the function `mphgetadj` to select geometric entities using an adjacent domain.

To get a list of entities of type `entitytype` adjacent to the entity with the index `<adjnumber>` of type `adjtype`, enter:

```matlab
idx = mphgetadj(model, <geomtag>, 'returntype', adjtype, <adjnumber>)
```

where `<geomtag>` is the tag of geometry where the selection applies, `returntype` is the type of geometry entities whose index are returned and `adjtype` is the type of input geometry entity. The string variables `returntype` and `adjtype` can be one of 'point', 'edge', 'boundary', or 'domain'.

The list returned by the function can be used to specify the selection for a model feature or to create an explicit selection as described in Setting an Explicit Selection.

Displaying Selections
Use the function `mphviewselection` to display the selected geometric entities in a MATLAB figure. This section also includes sections to Specify What to Display with the Selection and Change Display Color and Transparency.

You can either specify the geometry entity index and its entity type or specify the tag of a selection node available in the model.

To display the entity of type `entitytype` with the index `<idx>` enter:

```matlab
mphviewselection(model, <geomtag>, <idx>, entitytype)
```

where `<geomtag>` is the geometry node tag, and `<idx>` is a positive integer array that contains the entity indices. The string `entitytype` can be one of 'point', 'edge', 'boundary', or 'domain'.

If the model contains a selection node with the tag `<seltag>`, this selection can be displayed with the command:

```matlab
mphviewselection(model, <seltag>)
```

To plot the selection in an existing axes, set the property 'parent' with the axes handle. For instance, the command below displays the selection in the current axis:

```matlab
mphviewselection(model, <seltag>, 'parent', gca)
```
SPECIFY WHAT TO DISPLAY WITH THE SELECTION

- If the selected selection node is a Ball or Box selection, the ball or box selector is display by default, to not show the selector, set the property 'showselector' to 'off'.

\[
\text{mphviewselection(model, <seltag>, 'showselector', 'off')}
\]

- To deactivate the geometry representation, set the property 'geommode' to 'off' as in this command:

\[
\text{mphviewselection(model, <seltag>, 'geommode', 'off')}
\]

- The property 'vertexmode', 'edgemode' and 'facemode' support the value 'on' or 'off' in order to render the vertex, the edge and the face respectively in the figure, as in this example line:

\[
\text{mphviewselection(model, <seltag>, 'facemode', 'off')}
\]

- To include vertex, edge and face number, set the property 'vertexlabels', 'facelabels' and 'edgelabels' respectively to 'on'.

- Change the marker used to represent the vertex with the property 'facemode'. In the example command below the vertex are represented in the figure with a '+' marker instead of the default '•':

\[
\text{mphviewselection(model, <seltag>, 'marker', '+')}
\]

- Specify the size of the marker with the property 'edgelabels', you can specify an integer value corresponding to the number of pixels.

CHANGE DISPLAY COLOR AND TRANSPARENCY

- To change the color of the edge and the face use the property 'edgecolor' and 'facecolor' respectively. Specify the color of the vertex with the property 'markercolor'. Set the property with a character or using a RGB array. In this example the edges are displayed in blue while the faces are displayed in the color defined by the RGB array (0.5,0.5,0.5):

\[
\text{mphviewselection(model, <seltag>, 'edgecolor', 'b',... 'facecolor', [0.5 0.5 0.5])}
\]

- Specify the color for the selected edge and face with the properties 'edgecolorselected' and 'facecolorselected' respectively. Specify the color of the selected vertex with the property 'markercolorselected'. Use a character or specify the color by its RGB array. These commands show how to set the edge to a blue color and the face with the color defined by the RGB array (0.5, 0.5,0.5):

\[
\text{mphviewselection(model, <seltag>, 'edgecolorselected', 'b',... 'facecolorselected', [0.5 0.5 0.5])}
\]
• Specify the color for the vertex, edge, and face labels with the properties 'vertexlabelscolor', 'edgelabelscolor' and 'facelabelscolor' respectively. You can use a character or the RGB array to specify the color.

• Control the transparency of the geometry representation with the property 'facealpha'. Set the property with a double included between 0 and 1. Using this command the geometry is displayed with a transparency of 50%:

  \texttt{mphviewselection(model, <seltag>, 'facealpha', 0.5)}

• Control the transparency of the selector representation with the property 'selectoralpha'. Set the property with a double included between 0 and 1. Using this command, the selector is displayed with plain color:

  \texttt{mphviewselection(model, <seltag>, 'selectoralpha', 1)}
Computing the Solution

This section describes the commands to use to compute the solution at the MATLAB prompt. How to set up and run a study node but also how to set manual solver sequence. This includes the following paragraphs:

- The Study Node
- The Solver Sequence Syntax
- Run the Solver Sequence
- Adding a Parametric Sweep
- Adding a Job Sequence
- Plot While Solving

The Study Node

A study node holds the nodes that define how to solve a model. These nodes are divided into these broad categories:

- Study steps, which determines overall settings suitable for a certain study type,
- Solver sequence, and
- Job configurations for distributed parametric jobs, batch jobs, and cluster computing.

Create a study node by using the syntax:

```matlab
model.study.create(<studytag>)
```

where `studytag` is a string that is used to define the study node.
The minimal definition for the study node consists in a study step that define the type of study to use to compute the solution. To add a study step to the study node, use the syntax:

\[
\text{study.feature.create(\texttt{<ftag>}, \textit{operation})}
\]

where \texttt{study} is a link to the study node. The string \texttt{<ftag>} is a string that is defined to refer to the study step. The string \textit{operation} is one of the basic study types, such as \texttt{Stationary}, \texttt{Transient}, or \texttt{Eigenfrequency}, and more.

To specify a property value pair for a study step, enter:

\[
\text{study.feature(\texttt{<ftag>}).set(\textit{property}, \texttt{<value>})}
\]

where \texttt{<ftag>} is the string identifying the study step.

To generate the default solver sequence associated with the physics solved in the model and compute the solution, run the study node with the command:

\[
\text{study.run}
\]

---

---

### The Solver Sequence Syntax

If you do not want to use the default solver sequence created by the study node, you can manually create one. To create a solver sequence, enter:

\[
\text{model.sol.create(\texttt{<soltag>})}
\]

where \texttt{<soltag>} is a string used to refer to the solver sequence associated to a solution object.

A solver sequence has to be connected to a study node, which is done with the command:

\[
\text{sol.study(\texttt{<studytag>})}
\]

where \texttt{<studytag>} is the tag of the study you want to associate the solver sequence sol.

A solver sequence also requires the definition of these nodes:

- Study Step, where the study and study step is specified for compiling the equations and computing the current solver sequence;
• Dependent Variables, this node handles settings for the computation of dependent variables, such as initial value and scaling settings but also the dependent variables not solved for; and

• Solver node, where the type of solver to use is specified to compute the solution.

Add the nodes to the solver sequence with the command:

```python
sol.feature.create(<ftag>, operation)
```

where `sol` is a link to a solver sequence node. The string `<ftag>` is a string that is defined to refer to the node, for example, a study step. `operation` can be 'StudyStep', 'Variables', or 'Stationary'.

To specify a property value pair for a solver feature, enter:

```python
feat.set(property, <value>)
```

where `feat` is a link to the solver sequence feature node.

---

**Run the Solver Sequence**

There are different ways to run the solver sequence:

• run the entire sequence,

• run up to a specified feature, or

• run from a specified feature.

Use the methods `run` or `runAll` to run the entire solver configuration node:

```python
model.sol(<soltag>).run
model.sol(<soltag>).runAll
```

You can also use the method `run(<ftag>)` to run the solver sequence up to the solver feature with the tag `<ftag>`:

```python
model.sol(<soltag>).run(<ftag>)
```

When you want to continue solving a sequence, use the method `runFrom(<ftag>)` to run the solver configuration from the solver feature with the tag `<ftag>`:

```python
model.sol(<soltag>).runFrom(<ftag>)
```
**Adding a Parametric Sweep**

In addition to the study step that defines a study type, you can add a parametric sweep to the study node. This is a study step that does not generate equations and can only be used in combination with other study steps. You can formulate the sequence of problems that arise when some parameters are varied in the model.

To add a parametric sweep to the study node, enter:

```python
study.feature.create(<ftag>, 'Parametric')
```

where `study` is a link to a valid study node where to include the parametric sweep defined with the tag `<ftag>`.

To add one or several parameters to the sweep, enter the command:

```python
study.feature(<ftag>).setIndex('pname', <pname>, <idx>)
```

where `<pname>` is the name of the parameter to use in the parametric sweep and `<idx>` the index number of the parameter. Set the `<idx>` to 0 to define the first parameter, 1 to define the second parameter, and so on.

Set the list of the parameter values with the command:

```python
study.feature(<ftag>).setIndex('plistarr', <pvalue>, <idx>)
```

where `<pvalue>` contains the list of parameter values defined with either a string or with a double array, and `<idx>` is the index number of the parameter and uses the same value as for the parameter name.

If there are several parameters listed in the parametric sweep node, select the type of sweep by entering:

```python
study.feature(<ftag>).set('sweeptype', type)
```

where `type` is a string defining the sweep type, it can take either the value ‘filled’ or ‘sparse’, referring to all combinations or specified combinations of the parameter values, respectively.

**Adding a Job Sequence**

In the study node you can define a job sequence such as distributed parametric jobs, batch jobs, and cluster computing. To create a batch node enter:

```python
model.batch.create(<batchtag>, type)
```
where `<batchtag>` is the tag of the job sequence and `type` is the type of job to define. It can be either *Parametric*, *Batch*, or *Cluster*.

For a solver sequence you need to attach the job sequence to an existing study node. Enter the command:

```matlab
model.batch(<batchtag>).attach(<studytag>)
```

where `<studytag>` is the tag of the study node.

Each job type, such as parametric, batch, or cluster job, can be defined with specific properties. Use the `set` method to add a property to the batch job:

```matlab
model.batch(<batchtag>).set(property, <value>)
```

To run the batch sequence use the `run` method:

```matlab
model.batch(<batchtag>).run
```

**Plot While Solving**

With the Plot While Solving functionality you can monitor the development of the computation by updating predefined plots during the computation. Since the plots are displayed on a COMSOL Multiphysics graphics window, start COMSOL with MATLAB using a graphics COMSOL Multiphysics Server.

To activate Plot While Solving, enter the command:

```matlab
study.feature(<studysteptag>).set('plot', 'on')
```

where `study` is a link to a valid study node and `<studysteptag>` is a string that refers to the study step.

Specify the plot group to plot by setting the plot group tag:

```matlab
study.feature(<studysteptag>).set('plotgroup', <ptag>)
```
Only one plot group can be plotted during a computation. Use the probe feature instead if you need to monitor several variables.

To activate Plot While Solving for a probe plot, enter the command:

```matlab
study.feature(<studysteptag>).set('probesel', seltype)
```

where `seltype` is the type of probe selection, that can be 'none', 'all', or 'manual'.

In case the probe selection is set to manual you have to specify the list of the probe variable to display. Enter the command:

```matlab
study.feature(<studysteptag>).set('probes', <list>)
```

where `<list>` is the cell array containing the list of the probe to use.
Analyzing the Results

In this section:
- The Plot Group Syntax
- Displaying The Results
- The Data Set Syntax
- The Numerical Node Syntax
- Exporting Data

The Plot Group Syntax

Result plots always appear in plot groups, which are added to the model by the `create` method:

```python
model.result.create(<pgtag>, sdim)
```

Select the string `<pgtag>` to identify the plot group and the integer `sdim` to set the space dimension (1, 2, or 3) of the group.

To add a plot to a plot group, use the syntax:

```python
pg.feature.create(<ftag>, plottype)
```

where `pg` is a link to a plot group node and `plottype` is a string that defines the plot type.

Plots can have different attributes that modify the display. For example, the Deformation attribute deforms the plot according to a vector quantity, the Height Expression attribute introduces 3D height on a 2D table surface plot, and the Filter attribute filters the plot using a logical expression. The type of plot determines which attributes are available. Add an attribute to a plot with the command:

```python
pg.feature(<ftag>).feature.create(<attrtag>, attrtype)
```
where `attrtype` is a string that defines the attribute type.

| Question | For a list of available plot types and corresponding attribute types, see `Results` and `model.result()` in the *COMSOL Multiphysics Programming Reference Manual* or type at the MATLAB prompt: `mphdoc(model.result)`.

**Displaying The Results**

There are different commands available to Display Plot Groups, Extract Plot Data, and to Plot External Data. A practical example of this is included in Example: Plot `mpheval` Data.

**DISPLAY PLOT GROUPS**

Use the command `mphplot` to display a plot group available from the model object.

For example, to display the plot group `<pgtag>` enter:

```
mphplot(model, <pgtag>)
```

This renders the graphics in a MATLAB figure window. In addition you can plot results in a COMSOL Multiphysics Graphics window if you start COMSOL with MATLAB using a graphics COMSOL Multiphysics Server. To do this for a plot group `<pgtag>` enter:

```
mphplot(model, <pgtag>, 'server', 'on')
```

See the section *Starting COMSOL Multiphysics with MATLAB using the Graphics Server* in the *COMSOL Multiphysics Installation Guide*.

Another way to plot in a COMSOL Graphics window is to use the `run` method:

```
model.result(<pgtag>).run
```

Mac OS does not support plotting in a COMSOL Graphics window.

The default settings for plotting in a MATLAB figure do not display the color legend. To include the color legend in a figure, use the property `rangenum`:
mphplot(model, <pgtag>, 'rangenum', <idx>)

where the integer <idx> identifies the plot for which the color legend should be displayed.

**EXTRACT PLOT DATA**

In some situation it can be useful to extract data from a plot, for example, if you need to manually edit the plot as it is allowed in MATLAB. To get a cell array, pd, which contains the data for each plot feature available in the plot group <pgtag> enter:

```
pd = mphplot(model, <pgtag>)
```

The data fields contained in pd returned by mphplot are subject to change. The most important fields are:

- **p**: the coordinates for each point that are used for creating lines or triangles.
- **n**: the normals in each point for the surfaces. These are not always available.
- **t**: contains the indices to columns in p of a simplex mesh, each column in t representing a simplex.
- **d**: the data values for each point.
- **rgb**: the color values (red, green and blue) entities at each point.

If you don’t want to generate a figure when extracting the plot data structure, set the property `createplot` to `off` as in the command below:

```
pd = mphplot(model, <pgtag>, 'createplot', 'off')
```

This is useful for instance on machine without graphics display support.

**Example: Examining the plot data**

Reuse the first on-line example available for mphplot:

```matlab
model = mphopen('model_tutorial_llmatlab');
std = model.study.create('std');
std.feature.create('stat', 'Stationary');
std.run;
model.result.dataset.create('mir', 'Mirror3D');
pg = model.result.create('pg', 'PlotGroup3D');
surf1 = pg.feature.create('surf1', 'Surface');
surf1.set('colortable', 'Thermal');
mphplot(model, 'pg')
surf2 = pg.feature.create('surf2', 'Surface');
surf2.set('data', 'dset1').set('expr', 'ht.tfluxMag');
```

Now plot the result and extract the associated plot data structure:

```
pd = mphplot(model, 'pg');
```
pd is a cell array containing three plot data structure, the first one corresponds the
outline of the geometry, the title, the legend and the color bar information (if any) in
the figure. The second and the third plot data structures correspond to the plot
defined by the features added to the plot group pg: surf1 and surf2 respectively.

To inspect the outline data of the geometry enter:

```matlab
pd1 = pd{1}{1}
```

```matlab
pd1 =
  p: [3x1410 single]
  t: [2x816 int32]
  rgb: [3x1 double]
  type: 'line'
  plottype: 'PlotGroup3D'
  tag: 'pg'
  preserveaspect: 'on'
  title: 'Surface: Temperature (K) Surface: Total heat
  flux magnitude (W/m^{2})'
```

To investigate the plot data information of the second surface plot feature (surf2)
enter:

```matlab
pd3 = pd{3}{1}
```

```matlab
pd3 =
  p: [3x5250 single]
  n: [3x5250 single]
  t: [3x9558 int32]
  d: [5250x1 single]
  colortable: 'Rainbow'
  rgb: [5250x3 single]
  type: 'surface'
  plottype: 'Surface'
  tag: 'surf2'
```

---

**PLOT EXTERNAL DATA**

Using the function `mphplot` you can also plot data that is specified directly as an input
argument. The supported data format is according to the structure provided by the
functions `mphplot`, `mpheval`, and `mphmesh`. This allows you to plot data that has first
been extracted from the model. To plot the structure `<data>`, run the command:

```matlab
mphplot(<data>)
```

If the data structure contains the value of several expressions, set the one to display in
the plot with the index property:

```matlab
mphplot(<data>, 'index', <idx>)
```
where \(<idx>\) is a positive integer that corresponds to the expression to plot.

Using the \texttt{colortable} option to select from several available color tables when visualizing data:

\begin{verbatim}
mphplot(<data>, 'colortable', colorname)
\end{verbatim}

Obtain a list of alternatives for \texttt{colorname} from the on-line help by entering:

\begin{verbatim}
help colortable
\end{verbatim}

To disable the mesh displayed together with the data results, set the property \texttt{mesh} to \texttt{off} as in this command:

\begin{verbatim}
mphplot(<data>, 'mesh', 'off')
\end{verbatim}

\textbf{EXAMPLE: PLOT MPHEVAL DATA}

This example extracts COMSOL data at the MATLAB prompt, modifies it and plots the data in a MATLAB figure.

First load the Busbar model from the COMSOL Multiphysics Applications Libraries. Enter:

\begin{verbatim}
model = mphopen('busbar');
\end{verbatim}

To extract the temperature and the electric potential field, use the command \texttt{mpheval}:

\begin{verbatim}
dat = mpheval(model,{'T','V'},'selection',1);
\end{verbatim}

To display the temperature field, using the \texttt{thermal} color table:

\begin{verbatim}
mphplot(dat,'index',1,'colortable','thermal');
\end{verbatim}
Do a simple scaling of the electric potential then plot it using the default color table:

\[ \text{dat.d2} = \text{dat.d2} \times 10^{-3}; \]

Plot the newly evaluated data without the mesh:

\[ \text{mphplot(dat, 'index', 2, 'rangenum', 2, 'mesh', 'off');} \]

To emphasize the geometry use the function `mphgeom` to display line plot on the same figure:

\[ \text{hold on;} \]
\[ \text{mphgeom(model, 'geom1', 'facemode', 'off')}; \]
**Code for use with MATLAB®**

```matlab
model = mphopen('busbar');
dat = mpheval(model, {'T', 'V'}, 'selection', 1);
mphplot(dat, 'index', 1, 'colortable', 'thermal');
dat.d2 = dat.d2 * 1e-3;
 mphplot(dat, 'index', 2, 'rangenum', 2, 'mesh', 'off');
 hold on;
 mphgeom(model, 'geom1', 'facemode', 'off')
```

**The Data Set Syntax**

Use Data Sets to make solutions and meshes available for visualization and data analysis. You can create Solution Data Sets, Mesh Data Sets, or Visualization Data Sets (such as, for instance, Cut Plane or Edge Data Sets). While Solution and Mesh Data Sets are self defined, Visualization Data Sets always refer to an existing Solution Data Set.

See Data Sets in the section [Commands Grouped by Function](#) of the [COMSOL Multiphysics Programming Reference Manual](#) to get a list of the available Data Sets.

All plots refer to data sets; the solutions are always available as the default data set.

To create a data set at the MATLAB prompt, use the command:
model.result.dataset.create(<dsettag>, dsettype);

where \textit{dsettype} is one of the available data set types.

- Data Sets in the \textit{COMSOL Multiphysics Reference Manual}
- Use of Data Sets in the \textit{COMSOL Multiphysics Programming Reference Manual}

\textbf{The Numerical Node Syntax}

Use the numerical node to perform numerical evaluation from within the COMSOL Multiphysics model. Numerical operations such as computing averages, integrations, maximums, or minimums of a given expression are available. You can also perform point and global evaluations.

To create a numerical node, enter:

\begin{verbatim}
model.result.numerical.create(<numtag>, numtype)
\end{verbatim}

where \textit{numtype} is the type of operation to be performed by the node.

To store the data needed to create a table and associate the table to the numerical node:

\begin{verbatim}
model.result.table.create(<tabletag>, 'Table')
model.result.numerical(<numtag>).set('table', <tabletag>)
\end{verbatim}

where \textit{<tabletag>} is the tag of the table where you want to store the data evaluated with the numerical operations defined with the tag \textit{<numtag>}.

To extract the data stored in MATLAB into a table, use the methods \texttt{getRealRow} and \texttt{getImagRow}, such as:

\begin{verbatim}
realRow = model.result.table(<tabletag>).getRealRow(<idx>)
imagRow = model.result.table(<tabletag>).getImagRow(<idx>)
\end{verbatim}

where \textit{<idx>} is the column index of the table \textit{<tabletag>}.

For a list of the syntax of the numerical results type available, see \textit{About Results Commands} in the \textit{COMSOL Multiphysics Programming Reference Manual}. 

\textbf{Data Sets in the \textit{COMSOL Multiphysics Reference Manual}}

\textbf{Use of Data Sets in the \textit{COMSOL Multiphysics Programming Reference Manual}}
For data evaluation in MATLAB you can also use the functions `mpheval`, `mphevalpoint`, `mphglobal`, `mphint2`, `mphinterp`, `mphmax`, `mphmean` and `mphmin`.

### Extracting Results

**Exporting Data**

Use the `export` node to generate an animation or to export data to an external file (ASCII format). This section includes information about Animation Export, Data Export, and the Animation Player.

**Animation Export**

Animations can be defined as two different types: a movie or an image sequence. The movie generates file formats such as GIF (.gif), AVI (.avi), or flash (.swf); the image sequence generates a sequence of images. Make sure COMSOL with MATLAB using a graphics COMSOL Multiphysics Server to enable plot on server.

To generate an animation, add an Animation node to the `export` method:

```plaintext
model.result.export.create(<animtag>, 'Animation')
```

To change the animation type use the `type` property according to:

```plaintext
animtag.set('type', type)
```

where `animtag` is a link to an animation node and `type` is either `imageseq` or `movie`.

To set the filename and finally create the animation, enter:

```plaintext
animtag.set(typefilename, <filename>)
animtag.run
```

In the above, `typefilename` depends on the type of animation export: `imagefilename` for an image sequence, `giffilename` for a gif animation, `flashfilename` for a flash animation, and `avifilename` for an avi animation.

To learn how to start COMSOL with MATLAB using a graphics COMSOL Multiphysics Server, see the **COMSOL Multiphysics Installation Guide**.
For a movie type animation, it is possible to change the number of frames per second with the command:

```python
animtag.set('fps', <fps_number>)
```

where `<fps_number>` is a positive integer that corresponds to the number of frames per second to use.

For all animation types you can modify the width and the height of the plot with the `set` method:

```python
animtag.set('width', <width_px>)
animtag.set('height', <height_px>)
```

where the positive integers `<width_px>` and `<height_px>` are the width and height size (in pixels), respectively, to use for the animation.

**DATA EXPORT**

In order to save data to an ASCII file, create a Data node to the `export` method:

```python
model.result.export.create(<datatag>, 'Data')
```

Set the expression `expr` and the file name `filename`, and run the export:

```python
model.result.export(<datatag>).setIndex('expr', <expr>, 0)
model.result.export(<datatag>).set('filename', <filename>)
```

Set the export data format with the `struct` property:

```python
model.result.export(<datatag>).set('struct', datastruct)
```

where datastruct can be set to 'spreadsheet' or 'sectionwise'.

See Data Formats in the COMSOL Multiphysics Programming Reference Manual for details about the data formats used in the exported data files.

To export the data in the specified file, run the `export` node:

```python
model.result.export.<datatag>.run
```

**ANIMATION PLAYER**

For transient and parametric studies, an animation player can be generated to create interactive animations.
The player displays the figure on a COMSOL Graphics window. Make sure COMSOL with MATLAB is started using a graphics COMSOL Multiphysics Server.

To create a player feature node to the model enter the command:

```
model.result.export.create(<playtag>, 'Player')
```

Then associate the player with an existing plot group by setting the `plotgroup` property:

```
model.result.export(<playtag>).set('plotgroup', <pgtag>)
```

where `<pgtag>` refers to the plot group, which is animated in the player.

The default frame number used to generate the animation is 25, you can also specify the number of frame with the command:

```
model.result.export(<playtag>).set('maxframe', <maxnum>)
```

where `<maxnum>` is a positive integer value that corresponds to the maximum number of frames to generate with the player.

Use the `run` method to generate the player:

```
model.result.export(<playtag>).run
```
Working With Models

This section introduces you to the functionality available for LiveLink™ for MATLAB® including the wrapper functions and the MATLAB tools that can be used and combined with a COMSOL Multiphysics® model object.

In this chapter:

- Using Workspace Variables in Model Settings
- Extracting Results
- Running Models in a Loop
- Running Models in Batch Mode
- Working with Matrices
- Extracting Solution Information and Solution Vectors
- Retrieving Xmesh Information
- Navigating the Model
- Handling Errors and Warnings
- Improving Performance for Large Models
- Creating a Custom GUI
Using Workspace Variables in Model Settings

LiveLink™ for MATLAB® allows you to define the model properties with MATLAB variables or a MATLAB M-function.

In this section:

- The Set and SetIndex Methods
- Using a MATLAB® Function to Define Model Properties

The Set and SetIndex Methods

You can use MATLAB® variables to set properties of a COMSOL Multiphysics model. Use the set or setIndex methods to pass the variable value from MATLAB to the COMSOL model.

The Set Methods

Use the set method to assign parameter and/or property values. All assignments return the parameter object, which means that assignment methods can be appended to each other.

The basic method for assignment is:

```
something.set(name, <value>)
```

The `name` argument is a string with the name of the parameter/property. The `<value>` argument can for example be a MATLAB integer or double array variable. `<value>` can also be a string, in this case the value or expression is defined within the model object.

When using a MATLAB variable, make sure that the value corresponds to the model unit system. COMSOL can also take care of the unit conversion automatically; in this case convert the MATLAB integer/double variable to a string variable and use the set method as:

```
something.set(property, [num2str(<value>)]['unit'])
```

where is the `unit` you want to set the `value` property.
THE SETINDEX METHODS

Use the setIndex method to assign values to specific indices (0-based) in an array or matrix property. All assignment methods return the parameter object, which means that assignment methods can be appended to each other:

`something.setIndex(name, <value>, <index>)`

The `name` argument is a string with the name of the property, `<value>` is the value to set the property, which can be a MATLAB variable value or a string, and `<index>` is the index in the property table.

When using a MATLAB variable make sure that the value corresponds to the model unit system. COMSOL can automatically take care of the unit conversation; in this case converting the MATLAB integer/double variable to a string variable and using the `set` method as:

`something.setIndex(name, [num2str(<value>)'['unit']'], <index>)`

where `unit` is the unit you want to set the value property.

Using a MATLAB® Function to Define Model Properties

Use MATLAB® Function to define the model property. The function can either be declared within the model object or called at the MATLAB prompt.

CALLING MATLAB FUNCTIONS WITHIN THE COMSOL MODEL OBJECT

LiveLink™ for MATLAB® enables you to declare a MATLAB M-function directly from within the COMSOL Multiphysics model object. This is typically the case if you want to call a MATLAB M-function from the COMSOL Desktop. The function being declared within the model object accepts any parameter, variable, or expression arguments defined in the COMSOL model object. However, to use a variable defined at the MATLAB prompt, the variable has to be transferred first in the COMSOL model as a parameter, for example (see how to set a MATLAB variable in the COMSOL model in The Set and SetIndex Methods).

The function is evaluated any time the model needs to be updated. The model object cannot be called as an input argument of the M-function.

Calling External Functions
CALLING MATLAB FUNCTIONS AT THE MATLAB PROMPT

Use a MATLAB function to define a model property with the `set` method:

```matlab
feature.set('property', myfun('<arg>')
```

where `myfun()` is an M-function defined in MATLAB.

The function is called only when the command is executed at the MATLAB prompt. The argument of the function `<arg>` called can be MATLAB variables. To include an expression value from the model object, first extract it at the MATLAB prompt, as described in Extracting Results.

The function `myfun()` accepts the model object `model` as an input argument as any MATLAB variable.
Extracting Results

Use LiveLink™ for MATLAB® to extract at the MATLAB prompt the data computed in the COMSOL Multiphysics® model. A suite of wrapper functions is available to perform evaluation operations at the MATLAB prompt.

In this section:

- Extracting Data at Arbitrary Points
- Evaluating a Minimum of Expression
- Evaluating a Maximum of Expression
- Evaluating an Integral
- Evaluating an Expression Average
- Extracting Data at Node Points
- Evaluating an Expression at Geometry Vertices
- Evaluating Expressions on Particle/Ray Trajectories
- Evaluating a Global Expression
- Evaluating a Matrix Expression at Points
- Evaluating a Global Matrix
- Extracting Data From Tables

Extracting Data at Arbitrary Points

At the MATLAB® prompt, the function `mphinterp` evaluates the result at arbitrary points. To evaluate an expression at specific point coordinates, call the function `mphinterp` as in the command:

```matlab
[d1,...] = mphinterp(model,{’e1’,...},’coord’,<coord>)
```

where `e1,...` are the COMSOL Multiphysics expressions to evaluate, `<coord>` is a NxM double array, with `N` the space dimension of the evaluation domain, and `M` is the number of evaluation points. The output `d1,...` is a PxM double array, where `P` is the length of the inner solution.

Alternatively, specify the evaluation coordinates using a selection data set:

```matlab
data = mphinterp(model, <expr>, 'dataset', <dsettag>)
```
where `<dsettag>` is a selection data set tag defined in the model, for example, Cut point, Cut Plane, Revolve, and so forth. `<dsettag>` can also be a mesh data set tag, in this case the evaluation is performed on the geometric mesh vertices.

The rest of this section has additional information for the function `mphinterp`:

- **Specify the Evaluation Data**
- **Output Format**
- **Small-Signal Analysis, Prestressed Analysis, and Harmonic Perturbation Settings**
- **Specify the Evaluation Quality**
- **Other Evaluation Properties**

**SPECIFY THE EVALUATION DATA**

The function `mphinterp` supports the following properties to set the data of the evaluation to perform:

- **dataset**, specify the solution data set to use in the evaluation:
  
  ```matlab
  data = mphinterp(model, <expr>, 'coord', <coord>, 'dataset', <dsettag>)
  ```
  
  `<dsettag>` is the tag of a solution data set or a mesh data set. The default value is the current solution data set of the model. When a mesh data set is specified the expression `<expr>` can only be geometry or mesh expression.

- **selection**, specify the domain selection for evaluation:
  
  ```matlab
  data = mphinterp(model, <expr>, 'coord', <coord>, 'selection', <seltag>)
  ```
  
  `<seltag>` is the tag of a selection node to use for the data evaluation. `<seltag>` can also be a positive integer array that corresponds to the domain index list. The default selection is All domains where the expression is defined. If the evaluation point does not belong to the specified domain selection the output value is NaN.

- **edim**, specify the element dimension for evaluation:
  
  ```matlab
  data = mphinterp(model, <expr>, 'coord', <coord>, 'edim', edim)
  ```
  
  where `edim` is one of the strings ‘point’, ‘edge’, ‘boundary’ or ‘domain’. One can also use numerical values instead, which in 3D are the values from 0 to 3. The default settings correspond to the model geometry space dimension. When using a lower space dimension value, make sure that the evaluation point coordinates dimension has the same size.
• **ext**, specify extrapolation control value to define how much outside the mesh the interpolation searches. This ensures you return data for points that are outside the geometry:

```matlab
data = mphinterp(model,<expr>,'coord',<coord>, 'ext',<ext>)
```

where `<ext>` is a double value corresponding to the search distance as a scale in terms of the local element size. The default value is 0.1.

• **solnum**, specify the inner solution number for data evaluation. Inner solutions are generated for the following analysis types: time domain, frequency domain, eigenvalue, or stationary with continuation parameters:

```matlab
data = mphinterp(model,<expr>,'coord',<coord>,solnum',<solnum>)
```

where `<solnum>` is an integer array corresponding to the inner solution index. `<solnum>` can also be a string: ‘end’ or ‘all’ to evaluate the expression for the last inner solution, or all inner solution respectively. By default the evaluation is performed on all inner solution.

• **outersolnum**, specify the outer solution number for data evaluation. Outer solutions are generated with parametric sweeps:

```matlab
data = mphinterp(model,<expr>,'coord',<coord>,... 'outersolnum',<outersolnum>)
```

where `<outersolnum>` is a positive integer corresponding to the outer solution index. `<outersolnum>` can also be a string, ‘all’ or ‘end’, to evaluate the expression for all or the last outer solution respectively. The default settings use the first outer solution for the data evaluation.

• To evaluate the expression data at a specific time use the property `t`:

```matlab
data = mphinterp(model,<expr>,'coord',<coord>, 't',<time>)
```

where `<time>` is a double array. The default value corresponds to all the stored time steps.

• **phase**, specify the phase in degrees:

```matlab
data = mphinterp(model,<expr>,'coord',<coord>, 'phase',<phase>)
```

where `<phase>` is a double value.

**OUTPUT FORMAT**
The function `mphinterp` returns in the MATLAB workspace a double array. It also supports other output formats.

To evaluate several expressions at once, make sure that the same number of output variables are defined as there are expressions specified:
\[ d_1, \ldots \] = mphinterp(model, {'e1', \ldots}, 'coord', coord)

To extract the unit of the evaluated expression, define an extra output variable:

\[ \text{[data, unit]} = \text{mphinterp(model, <expr>, 'coord', coord)} \]

with unit is a 1xN cell array where N is the number of expressions to evaluate.

Returns only the real part in the data evaluation with the property complexout:

\[ \text{data} = \text{mphinterp(model, <expr>, 'coord', coord, 'complexout', 'off')} \]

To return an error if all evaluation points are outside the geometry, set the property coorderr to on:

\[ \text{data} = \text{mphinterp(model, <expr>, 'coord', coord, 'coorderr', 'on')} \]

By default the function returns the value NaN for any points that are outside the domain.

**SMALL-SIGNAL ANALYSIS, PRESTRESSED ANALYSIS, AND HARMONIC PERTURBATION SETTINGS**

For solutions with a stored linearization point, such as harmonic perturbation, small-signal analysis, or prestressed analysis you can specify the evaluation method. Use the mphinterp function with the property evalmethod:

\[ \text{data} = \text{mphinterp(model, <expr>, 'coord', coord, \text{'evalmethod'}, method)} \]

where method can be one of the following value:

- 'harmonic', for harmonic perturbation analysis.
- 'linpoint', the expression is evaluated by taking the values of any dependent variables from the linearization point of the solution.
- 'lintotal', the expression is evaluated by adding the linearization point and the harmonic perturbation and taking the real part of this sum.
- 'lintotalavg', this is the same as evaluating using the lintotal property and then averaging over all phases of the harmonic perturbation.
- 'lintotalrms', this is the same as evaluating using the lintotal property and then taking the RMS over all phases of the harmonic perturbation.
- 'lintotalpeak', this is the same as evaluating using the lintotal property solution and then taking the maximum over all phases of the harmonic perturbation.

If the property evalmethod is set to harmonic, you specify whether the expression should be linearized or not with the property differential as shown below:
data = mphinterp(model, expr, 'coord', coord, ...) 'evalmethod', 'harmonic', 'differential', diffvalue)

The default property value settings ('on') evaluates the differential of the expression with respect to the perturbation at the linearization point. If diffvalue is off, it evaluates the expression by taking the values of any dependent variables from the harmonic perturbation part of the solution.

**Specify the Evaluation Quality**

With the property recover, you can specify the accurate derivative recovery:

\[ \text{data} = \text{mphinterp(model, expr, 'coord', coord, 'recover', recover)} \]

where recover is either 'ppr', 'pprint', or 'off' (the default). Set the property to ppr to perform recovery inside domains or set to pprint to apply recovery to all domain boundaries. Because the accurate derivative processing takes time, the property is disabled by default.

**Other Evaluation Properties**

Set the unit property to specify the unit of the evaluation:

\[ \text{data} = \text{mphinterp(model, expr, 'coord', coord, 'unit', unit)} \]

where unit is a cell array with the same size as expr.

To not use complex-value functions with real inputs, use the property complexfun:

\[ \text{data} = \text{mphinterp(model, expr, 'coord', coord, 'complexfun', 'off')} \]

The default value uses complex-value functions with real inputs.

Use the property matherr to return an error for undefined operations or expressions:

- \[ \text{data} = \text{mphinterp(model, expr, 'coord', coord, 'matherr', 'on')} \]

**Evaluating a Minimum of Expression**

Use the function \text{mphmin} to evaluate the minimum of a given expression over an inner solution list.

To evaluate the minimum of the COMSOL expressions \( e_1, \ldots \) use the command \text{mphmin}:

\[ [d_1, \ldots] = \text{mphmin(model, \{'e_1', \ldots\}, edim)} \]
where \( edim \) is a string to define the element entity dimension: 'volume', 'surface', or 'line'. \( edim \) can also be a positive integer (3, 2, or 1 respectively). The output variables \( d1,...,dP \) are an \( N \times P \) array where \( N \) is the number of inner solutions and \( P \) the number of outer solutions.

The rest of this section has additional information for the function \( \text{mphmin} \):

- **Specify the Evaluation Data**
- **Output Format**

**SPECIFY THE EVALUATION DATA**

The function \( \text{mphmin} \) supports the following properties to set the data of the evaluation to perform:

- **dataset**, specify the solution data set to use in the evaluation:
  
  \[
  \text{data} = \text{mphmin}(\text{model}, \text{expr}, \text{edim}, \text{dataset'}, <\text{dsettag}>)
  \]
  
  \(<\text{dsettag}>\) is the tag of a solution data set. The default value is the current solution data set of the model.

- **selection**, specify the domain selection for evaluation:
  
  \[
  \text{data} = \text{mphmin}(\text{model}, \text{expr}, \text{edim}, \text{selection'}, <\text{seltag}>)
  \]
  
  where \(<\text{seltag}>\) is the tag of a selection node to use for the data evaluation. \(<\text{seltag}>\) can also be a positive integer array that corresponds to the domain index list. The default selection is all domains where the expression is defined. If the evaluation point does not belong to the specified domain selection the output value is NaN.

- **solnum**, specify the inner solution number for data evaluation. Inner solutions are generated for the following analysis types: time domain, frequency domain, eigenvalue, or stationary with continuation parameters:
  
  \[
  \text{data} = \text{mphmin}(\text{model}, \text{expr}, \text{edim}, \text{solnum'}, <\text{solnum}>)
  \]
  
  where \(<\text{solnum}>\) is an integer array corresponding to the inner solution index. \(<\text{solnum}>\) can also be a string: 'end' or 'all' to evaluate the expression for the last inner solution or all inner solutions, respectively. By default the evaluation is performed on all inner solutions.

- **outersolnum**, specify the outer solution number for data evaluation. Outer solutions are generated with parametric sweeps:
data = mphmin(model, <expr>, edim, 'outersolnum', <outersolnum>)

where <outersolnum> is a positive integer array corresponding to the outer solution index. <outersolnum> can also be a string, 'all' or 'end', to evaluate the expression for all or the last outer solution, respectively. The default setting uses the first outer solution for the data evaluation.

• To evaluate the expression data at a specific time use the property t:
  data = mphmin(model, <expr>, edim, 't', <time>)

where <time> is a double array. The default value corresponds to all the stored time steps.

• In case of data series, such as from a parametric or a transient study, an operation can be applied. To perform data series operation use the function mphmin as in the command below:
  data = mphmin(model, <expr>, edim, 'dataseries', <dataoperation>)

where <dataoperation> can be one of the following value: 'none' (no operation performed), 'average' (to compute average of the selected series), 'integral' (to integrate over series), 'maximum' (to evaluate the maximum over series), 'minimum' (to evaluate the minimum), 'rms' (to compute the root mean square), 'stddev' (to compute the standard deviation) or 'variance' (to compute the variance).

**OUTPUT FORMAT**

The function mphmin also supports other output formats.

To extract the unit of the evaluated expression, define an extra output variable:

(data, unit) = mphmin(model, <expr>, edim)

where unit is a 1xN cell array and N is the number of expressions to evaluate.

By default mphmin returns the results as a squeezed singleton. To get the full singleton set the squeeze property to off:

data = mphmin(model, <expr>, edim, 'squeeze', 'off')

Set the property matrix to off to return the data as a cell array instead of a double array:

data = mphmin(model, <expr>, edim, 'matrix', 'off')
Evaluating a Maximum of Expression

Use the function `mphmax` to evaluate the maximum of a given expression over an inner solution list.

To evaluate the maximum of the COMSOL Multiphysics expressions $e_1,\ldots$ use the command:

$$[d_1,\ldots] = \text{mphmax}(\text{model},\{'e_1',\ldots\},\text{edim})$$

where `edim` is a string to define the element entity dimension: 'volume', 'surface', or 'line'. `edim` can also be a positive integer (3, 2, or 1 respectively). The output variables $d_1,\ldots$ are an $N\times P$ array where $N$ is the number of inner solutions and $P$ is the number of outer solutions.

The rest of this section has additional information for the function `mphmax`:

- **Specify the Evaluation Data**
- **Output Format**

**Specify the Evaluation Data**

The function `mphmax` supports the following properties to set the data of the evaluation to perform:

- `dataset`, specify the solution data set to use in the evaluation:
  
  $$\text{data} = \text{mphmax}(\text{model},<\text{expr}>,\text{edim},'\text{dataset}',<\text{dsettag}>)$$

  `<dsettag>` is the tag of a solution data set. The default value is the current solution data set of the model.

- `selection`, specify the domain selection for evaluation:
  
  $$\text{data} = \text{mphmax}(\text{model},<\text{expr}>,\text{edim},'\text{selection}',<\text{seltag}>)$$

  where `<seltag>` is the tag of a selection node to use for the data evaluation. `<seltag>` can also be a positive integer array that corresponds to the domain index list. The default selection is all domains where the expression is defined. If the evaluation point does not belong to the specified domain selection the output value is NaN.

- `solnum`, specify the inner solution number for data evaluation. Inner solutions are generated for the following analysis types: time domain, frequency domain, eigenvalue, or stationary with continuation parameters:
\[ \text{data} = \text{mphmax(model, expr, edim, 'solnum', \text{solnum})} \]

where \text{solnum} is an integer array corresponding to the inner solution index. \text{solnum} can also be a string: 'end' or 'all' to evaluate the expression for the last inner solution or all inner solutions, respectively. By default the evaluation is performed on all inner solutions.

- **outersolnum**, specify the outer solution number for data evaluation. Outer solutions are generated with parametric sweeps:

\[ \text{data} = \text{mphmax(model, expr, edim, 'outersolnum', \text{outersolnum})} \]

where \text{outersolnum} is a positive integer array corresponding to the outer solution index. \text{outersolnum} can also be a string, 'all' or 'end', to evaluate the expression for all or the last outer solution, respectively. The default setting uses the first outer solution for the data evaluation.

- To evaluate the expression data at a specific time use the property \( t \):

\[ \text{data} = \text{mphmax(model, expr, edim, 't', \text{time})} \]

where \text{time} is a double array. The default value corresponds to all the stored time steps.

- In case of data series, such as from a parametric or a transient study, an operation can be applied. To perform data series operation use the function \text{mphmax} as in the command below:

\[ \text{data} = \text{mphmax(model, expr, edim, 'dataseries', \text{dataoperation})} \]

where \text{dataoperation} can be one of the following value: 'none' (no operation performed), 'average' (to compute average of the selected series), 'integral' (to integrate over series), 'maximum' (to evaluate the maximum over series), 'minimum' (to evaluate the minimum), 'rms' (to compute the root mean square), 'stdev' (to compute the standard deviation) or 'variance' (to compute the variance).

**OUTPUT FORMAT**

The function \text{mphmax} also supports other output formats.

To extract the unit of the evaluated expression, define an extra output variable:

\[ [\text{data}, \text{unit}] = \text{mphmax(model, expr, edim}) \]

where unit is a 1xN cell array and N is the number of expressions to evaluate.

By default \text{mphmax} returns the results as a squeezed singleton. To get the full singleton set the \text{squeeze} property to off:
data = mphmax(model,<expr>,edim,'squeeze','off')

Set the property matrix to off to return the data as a cell array instead of a double array:

data = mphmax(model,<expr>,edim,'matrix','off')

Evaluating an Integral

Evaluate an integral of expression with the function mphint2.

To evaluate the integral of the expression over the domain with the highest space domain dimension call the function mphint2 as in this command:

[d1,...] = mphint2(model,{'e1',...},edim)

where e1,... are the expressions to integrate. The values d1,... are returned as a 1xP double array, with P the length of inner parameters. edim is the integration dimension, which can be 'line', 'surface', 'volume', or an integer value that specifies the space dimension (1, 2, or 3).

The rest of this section has additional information for the function mphint2:

• Specify the Integration Data
• Output Format
• Specify the Integration Settings

Specify the Integration Data

The function mphint2 supports the following properties to set the data of the evaluation to perform:

• dataset, specify the solution data set to use in the integration:

data = mphint2(model,<expr>,edim,'dataset','<dsettag>')</dsettag> is the tag of a solution data set. The default value is the current solution data set of the model.

• selection, specify the integration domain:

data = mphint2(model,<expr>,edim,'selection','<seltag>')

where <seltag> is the tag of a selection node to use for the data evaluation. <seltag> can also be a positive integer array that corresponds to the domain index list. The default selection is all domains where the expression is defined. If the evaluation point does not belong to the specified domain selection the output value is NaN.
solnum, specify the inner solution number for data evaluation. Inner solutions are generated for the following analysis types: time domain, frequency domain, eigenvalue, or stationary with continuation parameters:

\[
data = \text{mphint2}(\text{model}, \langle \text{expr} \rangle, \text{edim}, \langle \text{solnum} \rangle, \langle \text{solnum} \rangle)
\]

where \langle solnum \rangle is an integer array corresponding to the inner solution index. \langle solnum \rangle can also be a string: 'end' or 'all' to evaluate the expression for the last inner solution, or all inner solutions, respectively. By default the evaluation is performed on all inner solutions.

outersolnum, specify the outer solution number for data evaluation. Outer solutions are generated with parametric sweeps:

\[
data = \text{mphint2}(\text{model}, \langle \text{expr} \rangle, \text{edim}, \langle \text{outersolnum} \rangle, \langle \text{outersolnum} \rangle)
\]

where \langle outersolnum \rangle is a positive integer corresponding to the outer solution index. \langle outersolnum \rangle can also be a string, 'all' or 'end', to evaluate the expression for all or the last outer solution respectively. The default settings use the first outer solution for the data evaluation.

To evaluate the expression data at a specific time use the property t:

\[
data = \text{mphint2}(\text{model}, \langle \text{expr} \rangle, \text{edim}, \langle \text{t} \rangle, \langle \text{time} \rangle)
\]

where \langle time \rangle is a double array. The default value corresponds to all the stored time steps.

In case of data series, such as from a parametric or a transient study, an operation can be applied. To perform data series operation use the function mphint2 as in the command below:

\[
data = \text{mphint2}(\text{model}, \langle \text{expr} \rangle, \text{edim}, \langle \text{dataseries} \rangle, \langle \text{dataoperation} \rangle)
\]

where \langle dataoperation \rangle can be one of the following value: 'none' (no operation performed), 'average' (to compute average of the selected series), 'integral' (to integrate over series), 'maximum' (to evaluate the maximum over series), 'minimum' (to evaluate the minimum), 'rms' (to compute the root mean square), 'stddev' (to compute the standard deviation) or 'variance' (to compute the variance).

**OUTPUT FORMAT**

The function mphint2 also supports other output formats.

To extract the unit of the evaluated expression, define an extra output variable:

\[
[data, \text{unit}] = \text{mphint2}(\text{model}, \langle \text{expr} \rangle, \text{edim})
\]

with \text{unit} is a 1xN cell array where N is the number of expressions to evaluate.
By default `mphint2` returns the results as a squeezed singleton. To get the full singleton, set the `squeeze` property to off:

```plaintext
data = mphint2(model,<expr>,edim,'squeeze','off')
```

Set the property `matrix` to off to return the data as a cell array instead of a double array:

```plaintext
data = mphint2(model,<expr>,edim,'matrix','off')
```

**SPECIFY THE INTEGRATION SETTINGS**

To specify integration settings such as the integration method, integration order, or axisymmetry assumption using these properties:

- `method`, specify the integration method, which can be either integration or summation:
  ```plaintext
data = mphint2(model,<expr>,edim,'method',method)
```
  where `method` can be `'integration'` or `'summation'`. The default uses the appropriate method for the given expression.

- `intorder`, specify the integration order:
  ```plaintext
data = mphint2(model,<expr>,edim,'intorder',<order>)
```
  where `order` is a positive integer. The default value is 4.

- `intsurface` or `intvolume`, compute surface or volume integral for axisymmetric models:
  ```plaintext
data = mphint2(model,<expr>,edim,'intsurface','on')
data = mphint2(model,<expr>,edim,'intvolume','on')
```

**Evaluating an Expression Average**

Use the function `mphmean` to evaluate the average of a given expression over inner solution lists. To evaluate the mean of the expressions `e1,...` use the command `mphmean`:

```plaintext
[d1,...] = mphmean(model,{'e1',...},edim)
```
where \( edim \) is a string to define the element entity dimension: ‘volume’, ‘surface’, or ‘line’. \( edim \) can also be a positive integer (3, 2, or 1 respectively). The output variables \( d_1, \ldots \) are an \( NxP \) array where \( N \) is the number of inner solutions and \( P \) the number of outer solutions.

The rest of this section has additional information for the function \( mphmean \):

- Specify the Evaluation Data
- Output Format
- Specify the Integration Settings

**Specify the Evaluation Data**

The function \( mphmean \) supports the following properties to set the data of the evaluation to perform:

- **dataset**, specify the solution data set to use in the evaluation:
  
  \[
  \text{data} = mphmean(model, <expr>, edim, 'dataset', <dsettag>)
  \]

  \(<dsettag>\) is the tag of a solution data set. The default value is the current solution data set of the model.

- **selection**, specify the domain selection for evaluation:

  \[
  \text{data} = mphmean(model, <expr>, edim, 'selection', <seltag>)
  \]

  where \(<seltag>\) is the tag of a selection node to use for the data evaluation. \(<seltag>\) can also be a positive integer array that corresponds to the domain index list. The default selection is all domains where the expression is defined. If the evaluation point does not belong to the specified domain selection the output value is NaN.

- **solnum**, specify the inner solution number for data evaluation. Inner solutions are generated for the following analysis types: time domain, frequency domain, eigenvalue, or stationary with continuation parameters:

  \[
  \text{data} = mphmean(model, <expr>, edim, 'solnum', <solnum>)
  \]

  where \(<solnum>\) is an integer array corresponding to the inner solution index. \(<solnum>\) can also be a string: ‘end’ or ‘all’ to evaluate the expression for the last inner solution or all inner solutions, respectively. By default the evaluation is performed on all inner solutions.

- **outersolnum**, specify the outer solution number for data evaluation. Outer solutions are generated with parametric sweeps:
data = mphmean(model,<expr>,edim,'outersolnum',<outersolnum>)

where <outersolnum> is a positive integer array corresponding to the outer solution index. <outersolnum> can also be a string, ‘all’ or ‘end’, to evaluate the expression for all or the last outer solution, respectively. The default setting uses the first outer solution for the data evaluation.

• To evaluate the expression data at a specific time use the property t:
   data = mphmean(model,<expr>,edim,'t',<time>)

where <time> is a double array. The default value corresponds to all the stored time steps.

• In case of data series, such as from a parametric or a transient study, an operation can be applied. To perform data series operation use the function mphmean as in the command below:
   data = mphmean(model,<expr>,edim,'dataseries',<dataoperation>)

where <dataoperation> can be one of the following value: ‘none’ (no operation performed), ‘average’ (to compute average of the selected series), ‘integral’ (to integrate over series), ‘maximum’ (to evaluate the maximum over series), ‘minimum’ (to evaluate the minimum), ‘rms’ (to compute the root mean square), ‘stddev’ (to compute the standard deviation) or ‘variance’ (to compute the variance).

OUTPUT FORMAT

The function mphmean also supports other output formats.

To extract the unit of the evaluated expression, define an extra output variable:

[data,unit] = mphmean(model,<expr>,edim)

where unit is a 1xN cell array and N is the number of expressions to evaluate.

By default mphmean returns the results as a squeezed singleton. To get the full singleton set the squeeze property to off:

data = mphmean(model,<expr>,edim,'squeeze','off')

Set the property matrix to off to return the data as a cell array instead of a double array:

data = mphmean(model,<expr>,edim,'matrix','off')
**SPECIFY THE INTEGRATION SETTINGS**

You can specify integration settings such as an integration method or integration order to perform the mean operation. The available integration properties are:

- **method**, specify the integration method, which can be either integration or summation:
  ```matlab
  data = mphmean(model, <expr>, edim, 'method', method)
  ```
  where `method` can be 'integration' or 'summation'. The default uses the appropriate method for the given expression.

- **intorder**, specify the integration order:
  ```matlab
  data = mphmean(model, <expr>, edim, 'intorder', <order>)
  ```
  where `<order>` is a positive integer. The default value is 4.

**Extracting Data at Node Points**

The function `mpheval` lets you evaluate expressions on node points.

Call the function `mpheval` as in this command:
```matlab
pd = mpheval(model, <expr>)
```
where `<expr>` is a string cell array that lists the expression to evaluate. The expression has to be defined in the COMSOL model object in order to be evaluated.

`pd` is a structure with the following fields:

- **expr** contains the list of names of the expressions evaluated with `mpheval`;
- **d1** contains the value of the expression evaluated. The columns in the data value fields correspond to node point coordinates in columns in the field `p`. In case of several expressions are evaluated in `mpheval`, additional field `d2`, `d3`,... are available;
- **p** contains the node point coordinates information. The number of rows in `p` is the number of space dimensions;
- **t** contains the indices to columns in `pd.p` of a simplex mesh; each column in `pd.t` represents a simplex;
- **ve** contains the indices to mesh elements for each node points; and
- **unit** contains the list of the unit for each evaluated expressions.

The rest of this section has additional information for the function `mpheval`:

- **Specify the Evaluation Data**
- **Output Format**
• Specify the Evaluation Quality
• Display the Expression in Figures

**SPECIFY THE EVALUATION DATA**

The function `mpheval` supports the following properties to set the data of the evaluation to perform:

• **dataset**, specify the solution data set to use in the evaluation:
  ```
  pd = mpheval(model, <expr>, 'dataset', <dsettag>)
  ```
  `<dsettag>` is the tag of a solution data set. The default value is the current solution data set of the model. Selection data sets such as Cut Point, Cut Line, Edge, Surface, and so forth are not supported.

• **selection**, specify the domain selection for evaluation:
  ```
  pd = mpheval(model, <expr>, 'selection', <seltag>)
  ```
  where `<seltag>` is the tag of a selection node to use for the data evaluation. `<seltag>` can also be a positive integer array that corresponds to the domain index list. The default selection is all domains where the expression is defined. If the evaluation point does not belong to the specified domain selection, the output value is NaN.

• **edim**, specify the element dimension for evaluation:
  ```
  pd = mpheval(model, <expr>, 'edim', edim)
  ```
  where `edim` is one of the strings 'point', 'edge', 'boundary', or 'domain'. It is also possible to use the corresponding integer which in 3D is in the range from 0 to 3. The default settings correspond to the model geometry space dimension. When using a lower space dimension value, make sure that the evaluation point coordinates dimension has the same size.

• **solnum**, specify the inner solution number for data evaluation. Inner solutions are generated for the following analysis types: time domain, frequency domain, eigenvalue, or stationary with continuation parameters:
  ```
  pd = mpheval(model, <expr>, 'solnum', <solnum>)
  ```
  where `<solnum>` is an integer array corresponding to the inner solution index. `<solnum>` can also be a string: 'end' or 'all' to evaluate the expression for the last

---

Use the function `mphevalpoint` to evaluate expressions at geometric points (see Evaluating an Expression at Geometry Vertices).
inner solution, or all inner solution respectively. By default the evaluation is performed on all inner solution.

- **outersolnum**, specify the outer solution number for data evaluation. Outer solutions are generated with parametric sweeps:
  
  ```matlab
  pd = mpheval(model, <expr>, 'outersolnum', <outersolnum>)
  ```

  where `<outersolnum>` is a positive integer corresponding to the outer solution index. `<outersolnum>` can also be a string, `'all'` or `'end'`, to evaluate the expression for all or the last outer solution respectively. The default setting uses the first outer solution for the data evaluation.

- To evaluate the expression data at a specific time use the property `t`:
  
  ```matlab
  pd = mpheval(model, <expr>, 't', <time>)
  ```

  where `<time>` is a double array. The default value corresponds to all the stored time steps.

- **phase**, specify the phase in degrees:
  
  ```matlab
  pd = mpheval(model, <expr>, 'phase', <phase>)
  ```

  where `<phase>` is a double value.

- **pattern**, use Gauss point evaluation:
  
  ```matlab
  pd = mpheval(model, <expr>, 'pattern','gauss')
  ```

  The default evaluation is performed on the Lagrange points.

**OUTPUT FORMAT**

The function `mpheval` returns a structure in the MATLAB workspace. You can specify other output data formats.

To only obtain the data evaluation as a double array, set the property `dataonly` to `on`. This is speeds up the call to COMSOL since the coordinate and element information is not retrieved.

```matlab
pd = mpheval(model, <expr>, 'dataonly', 'on')
```

Returns only the real part in the data evaluation with the property `complexout`:

```matlab
pd = mpheval(model, <expr>, 'complexout', 'off')
```

**SPECIFY THE EVALUATION QUALITY**

Define `mpheval` function settings to specify the evaluation quality using these properties:

- **refine**, specify the element refinement for evaluation:
pd = mpheval(model, <expr>, 'refine', <refine>)

where <refine> is a positive integer. The default value is 1 which sets the simplex mesh identical to the geometric mesh. Many model use second order elements for which a refine value of 2 must be used to use all the data in the model.

- smooth, specify the smoothing method to enforce continuity on discontinuous data evaluation:

  pd = mpheval(model, <expr>, 'smooth', smooth)

where smooth is either 'none', 'everywhere', or 'internal' (default). Set the property to none to evaluate the data on elements independently, set to everywhere to apply the smoothing to the entire geometry, and set to internal to smooth the quantity inside the geometry (but no smoothing takes place across borders between domains with different settings). The output with the same data and same coordinates are automatically merged, which means that the output size can differ depending on the smoothing method.

- recover, specify the accurate derivative recovery:

  pd = mpheval(model, <expr>, 'recover', recover)

where recover is either 'ppr', 'pprint', or 'off' (default). Set the property to ppr to perform recovery inside domains or set to pprint to perform recovery inside domains. Because the accurate derivative processing takes time, the property is disabled by default.

**OTHER EVALUATION PROPERTIES**

To not use complex-value functions with real inputs, use the property complexfun:

  pd = mpheval(model, <expr>, 'complexfun', 'off')

The default value uses complex-valued functions with real inputs.

Use the property matherr to return an error for undefined operations or expressions:

  pd = mpheval(model, <expr>, 'matherr', 'on')

**DISPLAY THE EXPRESSION IN FIGURES**

You can display an expression evaluated with mpheval in an external figure with the function mphplot (see Displaying The Results).

**Evaluating an Expression at Geometry Vertices**

The function mphevalpoint returns the result of a given expression evaluated at the geometry points:
\[ [d_1, \ldots] = \text{mphevalpoint}(\text{model},\{',e_1',\ldots\}) \]

where \( e_1, \ldots \) are the COMSOL expressions to evaluate. The output \( d_1, \ldots \) is a \( \text{NxP} \) double array, where \( N \) is the number of evaluation points and \( P \) the length of the inner solution.

The rest of this section has additional information for the function \text{mphevalpoint}:

- Specify the Evaluation Data
- Output Format

**Specify the Evaluation Data**

The function \text{mphevalpoint} supports the following properties to set the data of the evaluation to perform:

- **dataset**, specify the solution data set to use in the evaluation:
  
  \[
  \text{data} = \text{mphevalpoint}(\text{model},<\text{expr}>,'\text{dataset}',<\text{dsettag}>) 
  \]
  
  \(<\text{dsettag}\> \) is the tag of a solution data set. The default value is the current solution data set of the model.

- **selection**, specify the domain selection for evaluation:
  
  \[
  \text{data} = \text{mphevalpoint}(\text{model},<\text{expr}>,'\text{selection}',<\text{seltag}>) 
  \]
  
  where \(<\text{seltag}\> \) is the tag of a selection node to use for the data evaluation. \(<\text{seltag}\> \) can also be a positive integer array that corresponds to the domain index list. The default selection is all domains where the expression is defined. If the evaluation point does not belong to the specified domain selection, the output value is NaN.

- **solnum**, specify the inner solution number for data evaluation. Inner solutions are generated for the following analysis types: time domain, frequency domain, eigenvalue, or stationary with continuation parameters:
  
  \[
  \text{data} = \text{mphevalpoint}(\text{model},<\text{expr}>,'\text{solnum}',<\text{solnum}>) 
  \]
  
  where \(<\text{solnum}\> \) is an integer array corresponding to the inner solution index. \(<\text{solnum}\> \) can also be a string: ‘end’ or ‘all’ to evaluate the expression for the last inner solution, or all inner solution respectively. By default the evaluation is performed on all inner solution.

- **outersolnum**, specify the outer solution number for data evaluation. Outer solutions are generated with parametric sweeps:
data = mphevalpoint(model, <expr>, 'outersolnum', <outersolnum>)

where <outersolnum> is a positive integer corresponding to the outer solution index. <outersolnum> can also be a string, 'all' or 'end', to evaluate the expression for all or the last outer solution respectively. The default settings use the first outer solution for the data evaluation.

• To evaluate the expression data at a specific time use the property t:
  data = mphevalpoint(model, <expr>, 't', <time>)

  where <time> is a double array. The default value corresponds to all the stored time steps.

Perform a data series operation with the dataseries property:

  data = mphevalpoint(model, <expr>, 'dataseries', dataseries)

where dataseries is either 'mean', 'int', 'max', 'min', 'rms', 'std', or 'var'. Depending on the property value, mphevalpoint performs the following operations—mean, integral, maximum, minimum, root mean square, standard deviation, or variance, respectively.

When performing a minimum or maximum operation on the data series, you can specify to perform the operation using the real or the absolute value. Set the property minmaxobj to 'real' or 'abs', respectively:

  data = mphevalpoint(model, <expr>, 'dataseries', dataseries, ...
  'minmaxobj', valuetype)

By default valuetype is 'real'.

**OUTPUT FORMAT**

The function mphevalpoint supports other output formats.

To extract the unit of the evaluated expression, define an extra output variable:

  [data,unit] = mphevalpoint(model, <expr>)

with unit is a 1xN cell array where N is the number of expressions to evaluate.

By default, mphevalpoint returns the results as a squeezed singleton. To get the full singleton set the squeeze property to off:

  data = mphevalpoint(model, <expr>, 'squeeze', 'off')

Set the property matrix to off to return the data as a cell array instead of a double array:

  data = mphevalpoint(model, <expr>, 'matrix', 'off')
Evaluating Expressions on Particle/Ray Trajectories

Evaluate expressions on particle trajectories with the function `mphparticle` and on ray trajectories with the function `mphray`.

`mphray` supports only Ray Trajectories Data sets. `mphparticle` supports both Ray Trajectories and Particle Trajectories Data sets.

In this section you can replace the command `mphparticle` and `mphray` as they support the same properties.

Evaluate expressions on particle and ray trajectories with either the function `mphparticle` or `mphray`.

To evaluate the particle position and the particle velocity run `mphparticle` as in this command:

```matlab
pd = mphparticle(model)
```

`pd` is a structure containing the information about particle position and particle velocity at every time step. The information is stored in the following fields:

- `p` contains the coordinates of the particle position along the trajectories. The data are stored in a NxAxL array where N is the number of time steps, A the number of evaluation point along the particle trajectories, and L the evaluation space dimension.
- `v` contains the value of the particle velocity along the trajectories. The data are stored in a NxAxL array where N is the number of time steps, A the number of evaluation points along the particle trajectories, and L the evaluation space dimension.
- `t` contains the list of evaluation time.

You can also specify expressions to evaluate along the particle trajectories. Run the function `mphparticle` as in this command:

```matlab
pd = mphparticle(model,'expr','e1')
```

where `'e1'` is the expression to evaluate along the particle trajectories. The output structure `pd` contains the fields `p`, `v`, and `t` (described above) with the following ones:

- `unit` contains the unit of the evaluated expression;
• \( d1 \) contains the value of the expression. The data are stored in a \( NxM \) array where 
   \( N \) is the number of time steps and \( M \) the number of evaluation points along the 
   particle trajectories; and 
• \( expr \) contains the list of the evaluated expression. 

Use a string cell array to evaluate several expressions at once. The result of the 
evaluation is then stored in the field \( d1, \ldots \) corresponding to each evaluated 
expression.

**SPECIFY THE EVALUATION DATA**

The function `mphparticle` supports the following properties to set the data of the 
evaluation to perform:

• \( dataset \), specify the solution data set to use in the evaluation: 
  \[ \text{pd} = \text{mphparticle(model, 'expr', '<expr>', 'dataset', '<dsettag>') } \]
  
  \(<dsettag>\) is the tag of a particle solution data set. The default value is the current 
  particle solution data set of the model.
• To evaluate the expression data at a specific time use the property \( t \): 
  \[ \text{pd} = \text{mphparticle(model, 'expr', '<expr>', 't', '<time>') } \]
  where \(<time>\) is a double array. The default value corresponds to all the stored time 
  steps.

**OUTPUT FORMAT**

The function `mphparticle` also supports other output formats.

Set the property \( dataonly \) to \( on \) to return only the data related to the specified 
expression: 

\[ \text{pd} = \text{mphparticle(model, 'expr', '<expr>', 'dataonly', 'on') } \]

The output structure \( pd \) only contains the field \( unit, d\# \), \( expr \), and \( t \) (described 
above).

---

**Evaluating a Global Expression**

Evaluate a global expression with the function `mphglobal`.

To evaluate a global expression at the MATLAB® prompt, call the function 
`mphglobal` as in this command:

\[ [d1, \ldots] = \text{mphglobal(model, '{'e1', \ldots'}) } \]
where \( e_1, \ldots \) are the COMSOL Multiphysics global expressions to evaluate. The output values \( d_1, \ldots \) are returned as a \( P \times 1 \) double array, with \( P \) the length of inner parameters.

The rest of this section has additional information for the function \texttt{mphglobal}:

- **Specify the Evaluation Data**
- **Output Format**
- **Other Evaluation Properties**

### Specify the Evaluation Data
The function \texttt{mphglobal} supports the following properties to set the data of the evaluation to perform:

- **dataset**, specify the solution data set to use in the evaluation:
  
  \[
  \text{data} = \text{mphglobal}(\text{model}, <\text{expr}>, 'dataset', '<\text{dsettag}>')
  \]

  where \(<\text{dsettag}>\) is the tag of a solution data set. The default value is the current solution data set of the model.

- **solnum**, specify the inner solution number for data evaluation. Inner solutions are generated for the following analysis types: time domain, frequency domain, eigenvalue, or stationary with continuation parameters:
  
  \[
  \text{data} = \text{mphglobal}(\text{model}, <\text{expr}>, 'solnum', '<\text{solnum}>')
  \]

  where \(<\text{solnum}>\) is an integer array corresponding to the inner solution index. \(<\text{solnum}>\) can also be a string, 'end' or 'all' to evaluate the expression for the last inner solution or all inner solutions, respectively. By default the evaluation is performed on all inner solutions.

- **outersolnum**, specify the outer solution number for data evaluation. Outer solutions are generated with parametric sweeps:
  
  \[
  \text{data} = \text{mphglobal}(\text{model}, <\text{expr}>, 'outersolnum', '<\text{outersolnum}>')
  \]

  where \(<\text{outersolnum}>\) is a positive integer corresponding to the outer solution index. \(<\text{outersolnum}>\) can also be a string, 'all' or 'end' to evaluate the expression for all or the last outer solution, respectively. The default settings uses the first outer solution for the data evaluation.

- To evaluate the expression data at a specific time use the property \( t \):
  
  \[
  \text{data} = \text{mphglobal}(\text{model}, <\text{expr}>, 't', '<\text{time}>')
  \]

  where \(<\text{time}>\) is a double array. The default value corresponds to all the stored time steps.
**CHAPTER 4: WORKING WITH MODELS**

- **phase**, specify the phase in degrees:
  
  ```
  data = mphglobal(model,<expr>, 'phase',<phase>)
  ```

  where `<phase>` is a double value.

**OUTPUT FORMAT**

The function `mphglobal` also supports other output formats.

To extract the unit of the evaluated expression, define an extra output variable:

```
[data,unit] = mphglobal(model,<expr>)
```

with `unit` is a 1xN cell array where N is the number of expressions to evaluate.

Returns only the real part in the data evaluation with the property `complexout`:

```
data = mphglobal(model,<expr>, 'complexout','off')
```

**OTHER EVALUATION PROPERTIES**

Set the `unit` property to specify the unit of the evaluation:

```
data = mphglobal(model,<expr>, 'unit',<unit>)
```

where `<unit>` is a cell array with the same length as `<expr>`.

Use the property `matherr` to return an error for undefined operations or expressions:

```
data = mphglobal(model,<expr>, 'matherr', 'on')
```

**Evaluating a Matrix Expression at Points**

The function `mphevalpointmatrix` returns the result of a given matrix expression evaluated at the points:

```
M = mphevalpointmatrix(model,<expr>,...) 
```

where `<expr>` is the COMSOL expressions to evaluate. The output `M` is a matrix.

The rest of this section has additional information for the function `mphevalpointmatrix`:

- **Specify the Evaluation Data**
- **Output Format**
SPECIFY THE EVALUATION DATA

The function `mphevalpoint` supports the following properties to set the data of the evaluation to perform:

- **dataset**, specify the solution data set to use in the evaluation:
  
  ```
  M = mphevalpointmatrix(model,<expr>,'dataset','<dsettag>'
  <dsettag> is the tag of a solution data set. The default value is the current solution data set of the model.
  ```

- **selection**, specify the domain selection for evaluation:
  
  ```
  M = mphevalpointmatrix(model,<expr>,'selection','<seltag>'
  where <seltag> is the tag of a selection node to use for the data evaluation. <seltag> can also be a positive integer array that corresponds to the domain index list. The default selection is all domains where the expression is defined. If the evaluation point does not belong to the specified domain selection, the output value is NaN.
  ```

- **solnum**, specify the inner solution number for data evaluation. Inner solutions are generated for the following analysis types: time domain, frequency domain, eigenvalue, or stationary with continuation parameters:
  
  ```
  M = mphevalpointmatrix(model,<expr>,'solnum','<solnum>'
  where <solnum> is an integer array corresponding to the inner solution index. <solnum> can also be a string: 'end' or 'all' to evaluate the expression for the last inner solution, or all inner solution respectively. By default the evaluation is performed on all inner solution.
  ```

- **outersolnum**, specify the outer solution number for data evaluation. Outer solutions are generated with parametric sweeps:
  
  ```
  M = mphevalpoint(model,<expr>,'outersolnum','<outersolnum>'
  where <outersolnum> is a positive integer corresponding to the outer solution index. <outersolnum> can also be a string, 'all' or 'end', to evaluate the expression for all or the last outer solution respectively. The default settings use the first outer solution for the data evaluation.
  ```

- To evaluate the expression data at a specific time use the property `t`:
  
  ```
  M = mphevalpointmatrix(model,<expr>,'t','<time>'
  where <time> is a double array. The default value corresponds to all the stored time steps.
  ```

- Perform a data series operation with the `dataseries` property:
  
  ```
  M = mphevalpointmatrix(model,<expr>,'dataseries', 'dataseries')
  ```
where \texttt{dataseries} is either \texttt{'none'}, \texttt{'average'} or \texttt{'sum'}.

**Evaluating a Global Matrix**

\texttt{mphevalglobalmatrix} evaluates the matrix variable such as S-parameters in a model with several ports activated as a parametric sweep and a frequency-domain study.

**Note:** S-parameters evaluation requires the AC/DC Module or the RF Module.

To evaluate the global matrix associated to the expression <\texttt{expr}>, enter the command:

\[
M = \texttt{mphevalglobalmatrix}(\texttt{model}, \texttt{<expr>})
\]

The output data \(M\) is a \(NxN\) double array, where \(N\) is the number of port boundary condition set in the model.

The rest of this section has additional information for the function \texttt{mphevalglobalmatrix}:

- **Specify the Evaluation Data**
- **Specify Matrix transformation**

**SPECIFY THE EVALUATION DATA**

The function \texttt{mphevalglobalmatrix} supports the following properties to set the data of the evaluation to perform:

- Set the solution data set for evaluation with the property \texttt{dataset}:
  
  \[
  M = \texttt{mphevalglobalmatrix}(\texttt{model}, \texttt{<expr>}, \texttt{'dataset'}, \texttt{<dsettag>})
  \]

  where \texttt{<dsettag>} is the tag of a solution data.

- \texttt{solnum}, specify the inner solution number for data evaluation. Inner solutions are generated for the following analysis types: time domain, frequency domain, eigenvalue, or stationary with continuation parameters:
  
  \[
  M = \texttt{mphevalglobalmatrix}(\texttt{model}, \texttt{<expr>}, \texttt{'solnum'}, \texttt{<solnum>})
  \]

  where \texttt{<solnum>} is an integer array corresponding to the inner solution index. \texttt{<solnum>} can also be a string: \texttt{'end'} or \texttt{'all'} to evaluate the expression for the last inner solution or all inner solutions, respectively. By default the evaluation is performed on all inner solutions.
• **outersolnum**, specify the outer solution number for data evaluation. Outer solutions are generated with parametric sweeps:

\[
M = \text{mphevalglobalmatrix}(\text{model}, \text{"expr"}, \text{"outersolnum"}, \text{"outersolnum"})
\]

where `<outersolnum>` is a positive integer corresponding to the outer solution index. `<outersolnum>` can also be a string, 'all' or 'end' to evaluate the expression for all or the last outer solution, respectively. The default settings use the first outer solution for the data evaluation.

• To evaluate the expression data at a specific time use the property `t`:

\[
dM = \text{mphevalglobalmatrix}(\text{model}, \text{"expr"}, \text{"t"}, \text{"time"})
\]

where `<time>` is a double array. The default value corresponds to all the stored time steps.

• Perform a data series operation with the `dataseries` property:

\[
M = \text{mphevalglobalmatrix}(\text{model}, \text{"expr"}, \text{"dataseries"}, \text{dataseries})
\]

where `dataseries` is either 'none', 'average' or 'sum'.

• Perform a data series operation on outer data with the `outerdataseries` property:

\[
M = \text{mphevalglobalmatrix}(\text{model}, \text{"expr"}, \text{"outerdataseries"}, \text{outerdataseries})
\]

where `outerdataseries` is either 'none', 'average' or 'sum'.

**SPECIFY MATRIX TRANSFORMATION**

To apply a transformation operation to compute the inverse of the matrix variable or to convert between the impedance matrix, `Z`, the admittance matrix, `Y`, and the S-parameter matrix `S`, use the `trans` property:

\[
M = \text{mphevalglobalmatrix}(\text{model}, \text{"expr"}, \text{"trans"}, \text{"trans"})
\]

where `<trans>` can be either: 'maxwellmutual' (from Maxwell to mutual capacitance), 'mutualmaxwell' (from mutual to Maxwell capacitance), 'none' (no transformation), 'inverse' (compute the inverse of the matrix), 'sy' (from `S` to `Y` transformation), 'sz' (from `S` to `Z` transformation), 'ys' (from `Y` to `S` transformation), 'zy' (from `Z` to `Y` transformation).

For `S` to `Y` and `Y` to `S` transformation you need to specify the characteristic admittance, to proceed use the command:

\[
M = \text{mphevalglobalmatrix}(\text{model}, \text{"expr"}, \text{"trans"}, \text{"sy"}, \text{"y0"}, \text{value})
\]

\[
M = \text{mphevalglobalmatrix}(\text{model}, \text{"expr"}, \text{"trans"}, \text{"ys"}, \text{"y0"}, \text{value})
\]
where \(<value>\) is the characteristic admittance in siemens (S). The default value is 1 S.

For S to Z and Z to S transformation you need to specify the characteristic impedance, to proceed use the command:

\[
M = \text{mphevalglobalmatrix}(\text{model},<\text{expr}>, 'trans', 'sz', 'Z0', <value>)
\]

\[
M = \text{mphevalglobalmatrix}(\text{model},<\text{expr}>, 'trans', 'zs', 'Z0', <value>)
\]

where \(<value>\) is the characteristic admittance in ohm (Ω). The default value is 1 Ω.

Extracting Data From Tables

In the Table node you can store the data evaluated with the COMSOL Multiphysics built-in evaluation method (see The Numerical Node Syntax).

Use \text{mphtable} to extract the data stored in the table with the tag \(<\text{tbltag}>\). Enter:

\[
\text{tabl} = \text{mphtable}(\text{model},<\text{tbltag}>)
\]

This creates a structure \(\text{tabl}\) made with the following fields:

- headers for the table,
- tag of the table,
- data of the extracted table, and
- filename when the table is exported to file.

Running Models in a Loop

A common use of LiveLink™ for MATLAB® is to run models in a loop. MATLAB provides several functionalities to run loops, including conditional statements and error handling, and this section shows how to use that functionality together with the COMSOL API syntax to run COMSOL Multiphysics® models in loops.

In this section:

- The Parametric Sweep Node
- Running Model in a Loop Using the MATLAB® Tools

The Parametric Sweep Node

Using the COMSOL API you can run models in loops. See Adding a Parametric Sweep in the section Building Models.

By using the COMSOL built-in function to run models in loops, you can ensure the model is saved automatically at each iteration. COMSOL also offers tools to take advantage of clusters and distributed computer architectures.

Running Model in a Loop Using the MATLAB® Tools

Use MATLAB® tools such as for or while statements to run your model in a loop. The COMSOL API commands can be included in scripts using MATLAB commands. To evaluate such a script you need to have MATLAB connected to a COMSOL server.

To run a model in a loop you do not need to run the entire M-file’s commands from scratch. It is recommended to load a COMSOL model in MATLAB and run the loop only over the desired operations. The COMSOL model is automatically updated when running the study node.
You can run an M-file for a model from scratch if required, for example, to generate the geometry in loop.

The model run inside a MATLAB loop is not automatically saved. Make sure to save the model at each iteration using the command `mphsave` to save the model object.

If you are not interested in saving the entire model object at each iteration, you can extract data and store it in the MATLAB workspace. See `Extracting Results` to find the most suitable function to your model.

When running loops in MATLAB, the iteration progress is taken care of by MATLAB; only the COMSOL commands are executed in the COMSOL server.

You can generate as many nested loops as needed and combine the loop with other MATLAB conditional statements such as `if` and `switch` or error handling statements such as `try/catch`. Or break the loop with `break`, or jump to the next loop iteration with `continue`.

See the MATLAB help for more information about the MATLAB commands `for`, `while`, `if`, `switch`, `try/catch`, `break`, and `continue`.

**GEOMETRY PARAMETRIZATION**

This example shows how to proceed to geometry parametrization using a MATLAB `for` loop. The model consists of the busbar example available in the COMSOL Multiphysics Applications Libraries; see the `Introduction to COMSOL Multiphysics`.

In this example the loop iterates over the busbar’s width, `wbb`. The solution for each parameter value is displayed using the second plot group defined in the COMSOL model. All the results are plotted in the same figure.
The results from the computation display in these plots:

Code for use with MATLAB®

```matlab
model = mphopen('busbar');
w = [5e-2 10e-2 15e-2 20e-2];
for i = 1:4
    model.param.set('wbb',w(i));
    model.study('std1').run;
    subplot(2,2,i);
    mphplot(model,'pg4','rangenum',1);
end
```
Running Models in Batch Mode

Use LiveLink™ for MATLAB® to model in batch mode. At the MATLAB prompt you can execute commands to set up the batch job using the COMSOL Multiphysics® built-in method or run custom scripts directly from a command line. In this section:

- The Batch Node
- Running an M-file in Batch Mode
- Running an M-file in Batch Mode Without Display

The Batch Node

Using the COMSOL API you can run models in a loop. See Adding a Job Sequence.

Running an M-file in Batch Mode

Running COMSOL with MATLAB® in batch mode requires that you have xterm installed on your machine. If this is not the case see Running an M-file in Batch Mode Without Display.

To run in batch an M-script that runs COMSOL Model is required. Start COMSOL with MATLAB at a terminal window with this command:

```
comsol mphserver matlab myscript
```

where `myscript` is the M-script, saved as `myscript.m`, that contains the operation to run at the MATLAB prompt.

COMSOL Multiphysics does not automatically save the model. You need to make sure that the model is saved before the end of the execution of the script. See Loading and Saving a Model.

You can also run the script in batch without the MATLAB desktop and the MATLAB splash screen. Enter this command:

```
comsol mphserver matlab myscript -nodesktop -mlnosplash
```
Running an M-file in Batch Mode Without Display

To connect COMSOL with a MATLAB® terminal requires that xterm is installed on the machine. If this is not the case as it might be for a computation COMSOL server, a workaround is to connect manually MATLAB to a COMSOL server with the function `mphstart`.

These steps describe how to run an M-script that runs a COMSOL model:

1. In a system terminal prompt start a COMSOL Multiphysics server with the command:
   ```
   comsol mphserver -silent &
   ```

2. In the same terminal window change the path to the COMSOL installation directory:
   ```
   cd COMSOL_path/mli
   ```

3. From that location, start MATLAB without display and run the `mphstart` function in order to connect MATLAB to COMSOL:
   ```
   matlab -nodesktop -nosplash -r "mphstart; myscript"
   ```

For more information about how to connect MATLAB to a COMSOL server see Starting COMSOL® with MATLAB® on Windows®, Mac OSX, Linux®.
Working with Matrices

In this section:

- Extracting System Matrices
- Set System Matrices in the Model
- Extracting State-Space Matrices
- Extracting Reduced Order State-Space Matrices

**Extracting System Matrices**

Extract the matrices of the COMSOL Multiphysics linearized system with the function `mphmatrix`. To call the function `mphmatrix`, specify a solver node and the list of the system matrices to extract:

```matlab
str = mphmatrix(model, <soltag>, 'out', out)
```

where `<soltag>` is the solver node tag used to assemble the system matrices and `out` is a cell array containing the list of the matrices to evaluate. The output data `str` returned by `mphmatrix` is a MATLAB® structure, and the fields correspond to the assembled system matrices.

The system matrices that can be extracted with `mphmatrix` are listed in the table:

<table>
<thead>
<tr>
<th>EXPRESSION</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>Stiffness matrix</td>
</tr>
<tr>
<td>L</td>
<td>Load vector</td>
</tr>
<tr>
<td>M</td>
<td>Constraint vector</td>
</tr>
<tr>
<td>N</td>
<td>Constraint Jacobian</td>
</tr>
<tr>
<td>D</td>
<td>Damping matrix</td>
</tr>
<tr>
<td>E</td>
<td>Mass matrix</td>
</tr>
<tr>
<td>NF</td>
<td>Constraint force Jacobian</td>
</tr>
</tbody>
</table>
SELECTING LINEARIZATION POINTS

The default selection of linearization points for the system matrix assembly is the current solution of the solver node associated to the assembly.

If the linearization point is not specified when calling `mphmatrix`, the COMSOL Multiphysics software automatically runs the entire solver configuration before assembling and extracting the matrices.

Save time during the evaluation by manually setting the linearization point. Use the `initmethod` property as in this command:

```
str = mphmatrix(model,<soltag>, 'out', 'out', 'initmethod', method)
```

where `method` corresponds to the type of linearization point—the initial value expression ('init') or a solution ('sol').

To set the solution to use for the linearization point, use the property `initsol`:

```
str = mphmatrix(model,<soltag>, 'out', 'out', 'initsol', <initsoltag>)
```

where `<initsoltag>` is the solver tag to use for linearization points. You can also set the `initsol` property to 'zero', which corresponds to using a null solution vector as a linearization point. The default is the current solver node where the assemble node is associated.
For continuation, time-dependent, or eigenvalue analyses you can set the solution number to use as a linearization point. Use the solnum property:

```matlab
str = mphmatrix(model,<soltag>,'out','solnum',<solnum>)
```

where `<solnum>` is an integer value corresponding to the solution number. The default value is the last solution number available with the current solver configuration.

---

**SPECIFYING WHEN TO ASSEMBLE THE MATRICES IN THE SOLUTION SEQUENCE**

You can specify when in the solution sequence to assemble the system matrices, for instance after computing the solution or if you have a solution sequence combining different solver. By default the system matrices are assembled before running the first solver, just after the first dependent variable node in the solution sequence. To specify the node that precede the matrix extraction use the extractafter property:

```matlab
str = mphmatrix(model,<soltag>,'out','extractafter',<nodetag>)
```

where `<nodetag>` is the tag of a solution sequence node such as dependent variable or solver nodes.

**EIGENVALUE PROBLEMS**

For eigenvalue problems, it is necessary to specify the eigenvalue name and the eigenvalue linearization point. Use the property eigname to specify the name of the eigenvalue and eigref to specify the value of eigenvalue linearization point:

```matlab
str = mphmatrix(model,<soltag>,'out','eigname',<eigname>)
str = mphmatrix(model,<soltag>,'out','eigname',<eigname>,
                'eigref',<eigref>)
```

where `<eigname>` is a string and `<eigref>` a double.

**ROW EQUILIBRATION, MATRIX SYMMETRY AND NULL-SPACE FUNCTION**

The default assembly of the system matrices assumes row equilibration of the system matrices. It is however possible to extract the unscaled matrices, to proceed set the rowscale property to off:

```matlab
str = mphmatrix(model,<soltag>,'out','rowscale','off')
```
Set the symmetry property to specify manually the symmetry type for the matrix evaluation. The symmetry property supports the following values:

\[
\text{str} = \text{mphmatrix}(\text{model}, \langle \text{soltag} \rangle, \text{out}, \text{out}, \text{symmetry}', \text{sym})
\]

where \( \text{sym} \) can be either of one of the following values:
- `'on'`, to assemble and extract the system matrices as symmetric.
- `'off'`, to assemble and extract the system matrices as non-symmetric.
- `'hermitian'`, to assemble and extract the system matrices as hermitian.
- `'auto'`, to let the solver assembly determine the type of the system matrices.

Use the `nullfun` property to specify the method for computation of matrices needed for constraint handling:
- `'flnullorth'`, a method based on singular value decomposition;
- `'flspnull'`, to handle constraint matrices with nonlocal couplings using singular sparse algorithm;
- `'explicitsp'`, to handle constraints by explicitly eliminating the DOFs on the destination side of the explicit constraints. The remaining constraints are handled using the Sparse method.
- `'explicitorth'`, to handle constraints by explicitly eliminating the DOFs on the destination side of the explicit constraints. The remaining constraints are handled using the Orthonormal method.
- `'auto'`, to let the software automatically determine the most appropriate method, which uses an explicit handling of nodal constraints and one of the Orthonormal or Sparse methods for the remaining constraints.

**Complex Function**
If the system contains complex functions, use the property `complexfun` to specify how to handle such a function. Set this property to 'on' to use complex-valued function with real input:

\[
\text{str} = \text{mphmatrix}(\text{model}, \langle \text{soltag} \rangle, \text{out}, \text{out}, \text{complexfun}', \text{'on'})
\]

**Handling Undefined Operations**
It is possible to disable the error for undefined operations during the assembly and matrix evaluation, to proceed set the property `matherr` to 'off' as in the command below:

\[
\text{str} = \text{mphmatrix}(\text{model}, \langle \text{soltag} \rangle, \text{out}, \text{out}, \text{matherr}', \text{'off'})
\]
EXTRACTING THE SYSTEM MATRICES

The following illustrates how to use the mphmatrix command to extract eliminated system matrices of a stationary analysis and linear matrix system at the MATLAB prompt.

The model consists of a linear heat transfer problem solved on a unit square with a $1 \times 10^5$ W/m$^2$ surface heat source and temperature constraint. Only one quarter of the geometry is represented in the model. For simplification reasons, the mesh is made of four quad elements and the discretization is set with linear element.

These commands set the COMSOL model object:

```matlab
model = ModelUtil.create('Model12');
comp1 = model.component.create('comp1', true);
geom1 = comp1.geom.create('geom1', 2);
geom1.run;
mat1 = comp1.material.create('mat1');
def = mat1.materialModel('def');
def.set('thermalconductivity',4e2);
ht = comp1.physics.create('ht', 'HeatTransfer', 'geom1');
ht.prop('ShapeProperty').set('boundaryFlux_temperature',false);
ht.prop('ShapeProperty').set('order_temperature',1);
hs1 = ht.feature.create('hs1', 'HeatSource',2);
hs1.selection.set(1);
hs1.set('Q',1,1e5);
temp1 = ht.feature.create('temp1','TemperatureBoundary',1);
temp1.selection.set([1 2]);
mesh1 = comp1.mesh.create('mesh1');
dist1 = mesh1.feature.create('dist1','Distribution');
dist1.selection.set([1 2]);
dist1.set('numelem',2);
map1.feature.create('map1','Map');
std1 = model.study.create('std1');
std1.feature.create('stat','Stationary');
std1.run;
```

To extract the solution vector of the computed solution, run the function `mphgetu` as in this command:

```matlab
U = mphgetu(model);
```
To assemble and extract the eliminated stiffness matrix and the eliminated load vector, set the linearization point to the initial value expression by entering:

\[
\begin{align*}
\text{MA} &= \text{mphmatrix}(\text{model}, 'sol1', 'Out', \{'Kc', 'Lc', 'Null', 'ud', 'uscale'\}, \{'initmethod', 'sol', 'initsol', 'zero'\}); \\
\text{Uc} &= \text{MA}.Null*\text{MPIKc}\text{MA}.Lc; \\
\text{U0} &= \text{Uc}+\text{MA}.ud; \\
\text{U1} &= \text{U0}.*\text{MA}.uscale;
\end{align*}
\]

Solve for the eliminated solution vector using the extracted eliminated system:

\[
\begin{align*}
\text{Uc} &= \text{MA}.Null*(\text{MA}.Kc\text{MA}.Lc); \\
\text{U0} &= \text{Uc}+\text{MA}.ud; \\
\text{U1} &= \text{U0}.*\text{MA}.uscale;
\end{align*}
\]

Now compare both solution vector \(\text{U}\) and \(\text{U1}\) computed by COMSOL Multiphysics and by the matrix operation, respectively.

**Code for use with MATLAB®**

```matlab
model = ModelUtil.create('Model');
comp1 = model.component.create('comp1', true);
geom1 = comp1.geom.create('geom1', 2);
geom1.feature.create('sq1', 'Square');
geom1.run;
mat1 = comp1.material.create('mat1');
def = mat1.materialModel('def');
def.set('thermalconductivity',4e2);
ht = comp1.physics.create('ht', 'HeatTransfer', 'geom1');
ht.prop('ShapeProperty').set('boundaryFlux_temperature',false);
ht.prop('ShapeProperty').set('order_temperature',1);
hs1 = ht.feature.create('hs1','HeatSource',2);
temp1 = ht.feature.create('temp1','TemperatureBoundary',1);
temp1.selection.set([1 2]);
dist1 = mesh1.feature.create('dist1','Distribution');
dist1.selection.set([1 2]);
dist1.set('numelem',2);
mat1.feature.create('map1','Map');
std1 = model.study.create('std1');
std1.feature.create('stat','Stationary');
std1.run;
U = mphgetu(model);
MA = mphmatrix(model,'sol1',...
          'Out', {'Kc','Lc','Null','ud','uscale'},...
          'initmethod','sol','initsol','zero');
```
\[ U_c = MA.\text{Null}*(MA.Kc \backslash MA.Lc); \]
\[ U_0 = U_c + MA.ud; \]
\[ U_1 = U_0 \cdot MA.uscale; \]

**Set System Matrices in the Model**

Use the function `mphinputmatrix` to set a linear matrix system to a model:

```matlab
mphinputmatrix(model,<str>,<soltag>,<soltypetag>)
```

This command sets the matrices of a linear system stored in the MATLAB® structure `<str>` into the model. The linear system is associated to the solver sequence `<soltag>` and is to be solved by the solver `<soltypetag>`. `mphinputmatrix` only supports the solver types Stationary, Eigenvalue, and Time.

A valid structure `<str>` for a stationary solver includes the following fields:

<table>
<thead>
<tr>
<th>FIELD</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>Stiffness matrix</td>
</tr>
<tr>
<td>L</td>
<td>Load vector</td>
</tr>
<tr>
<td>M</td>
<td>Constraint vector</td>
</tr>
<tr>
<td>N</td>
<td>Constraint Jacobian</td>
</tr>
</tbody>
</table>

A valid structure `<str>` for a time-dependent or an eigenvalue solver includes the following fields:

<table>
<thead>
<tr>
<th>EXPRESSION</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>Stiffness matrix</td>
</tr>
<tr>
<td>L</td>
<td>Load vector</td>
</tr>
<tr>
<td>M</td>
<td>Constraint vector</td>
</tr>
<tr>
<td>N</td>
<td>Constraint Jacobian</td>
</tr>
<tr>
<td>D</td>
<td>Damping matrix</td>
</tr>
<tr>
<td>E</td>
<td>Mass matrix</td>
</tr>
</tbody>
</table>

You can also include the Constraint force Jacobian vector, defined in the field NF.

Once the linear system is loaded in the model, you can directly run the solver.

The system matrices are not stored in the model when it is saved in the MPH-format or loaded to the COMSOL Desktop.
SETTING A MODEL WITH A MODIFIED MATRIX SYSTEM

This example deals with heat transfer in solids physics. The geometry and physics settings are already set in the model and saved in the MPH-format. The Model MPH-file comes with the COMSOL installation.

At the MATLAB prompt you load the model and add an additional line heat source to the model directly in the system matrix by manually changing the load vector. Then compute the solution of the modified system in COMSOL.

Load the base Model MPH-file and display the geometry:

```matlab
model = mphopen('model_tutorial_llmatlab.mph');
mphgeom(model)
```

This results in the following MATLAB figure:

![Geometry (geom1)](image)

Draw the line to be used as a line heat source in the model and plot the modified geometry:

```matlab
comp1 = model.component('comp1');
b1 = comp1.geom('geom1').feature.create('b1', 'BezierPolygon');
b1.set('p', {1e-2 5e-2; 1e-2 5e-2; 1e-2 1e-2});
mphgeom(model, 'geom1', 'edgelabels', 'on', 'facealpha', 0.5);
```
In the figure below you can see that the added line as the index 21:

![Geometry (geom1)](image1)

Generate a mesh with finer mesh settings:

```matlab
mesh1 = comp1.mesh('mesh1');
mesh1.feature.create('ftet1', 'FreeTet');
mesh1.feature('size').set('hauto', 3);
mesh1.run;
mphmesh(model)
```

![Mesh (mesh1)](image2)

Set the solver sequence associated to a stationary study node:

```matlab
std1 = model.study.create('std1');
std1.feature.create('stat', 'Stationary');
so11 = model.sol.create('so11');
so11.study('std1');
st1 = so11.feature.create('st1', 'StudyStep');
st1.set('studystep', 'stat');
```
v1 = sol1.feature.create('v1', 'Variables');
v1.set('control', 'stat');
sol1.feature.create('s1', 'Stationary');

Set the dependent variable discretization with linear shape function:

Shape = comp1.physics('ht').prop('ShapeProperty');
Shape.set('order_temperature', 1, 1);

The heat transfer interface automatically compute for internal DOFs in order to evaluate fluxes accurately at the boundaries. Deactivate the internal DOFs with this command:

Shape.set('boundaryFlux_temperature', false);

Now extract the matrices of the linear system associated to the solver sequence sol1:

ME = mphmatrix(model,'sol1','Out',{'K' 'L' 'M' 'N'},
    'initmethod','sol','initsol','zero');

To retrieve the degrees of freedom that belong to edge 21, you need to get the geometric mesh data:

[stats,data] = mphmeshstats(model);

With the mesh data structure data, you can get the element indices that belong to edge 2. Use the MATLAB find function to list all the indices:

elem_idx = find(data.elementity{1}==21)

With the function mphxmeshinfo, retrieve the finite element mesh information associated to solver sequence sol1:

info = mphxmeshinfo(model,'soltag','sol1','studysteptag','v1');

In the info structure you can get the DOFs indices that belong to the edge element defined with the indices elem_idx:

dofs = info.elements.edg.dofs;
edgdofs_idx = [];
for i = 1:length(elem_idx)
    edgdofs_idx = [edgdofs_idx; dofs(:,elem_idx(i))];
end

edgdofs_idx might contain duplicate DOFs indices. This is because the information is from the element level; the duplicate indices correspond to the connecting node between two adjacent elements.

First remove the duplicate entities:

unique_idx  = unique(edgdofs_idx);
Edit the load vector for the DOF that belong to edge 21, the total applied power is 50 W:

\[ ME.L(\text{unique_idx}+1) = \frac{50}{\text{length(unique_idx)}}; \]

Now that the linear system has been modified, set it back in the model:

\[ \text{mphinputmatrix}(\text{model}, \text{ME}, 'sol1', 's1') \]

**Note:** mphmatrix only assembles the matrix system for the dofs solved in the specified solver configuration. mphinputmatrix insert the matrix system as defined by the user. When inserting matrices in an existing model, the solution format may not be compatible with the inserted system matrices.

In order to have a compatible xmesh solution format compatible with the size of the inserted matrices, add a new equation form physics interface, solving only for one variable.

\[
\text{gForm} = \text{comp1.physics.create('g', 'GeneralFormPDE', {'u'})};
\]

\[
\text{gForm.prop('ShapeProperty').set('order', 1)};
\]

\[
\text{gForm.prop('ShapeProperty').set('boundaryFlux', false)};
\]

Disable the Heat Transfer physics interface.

\[
\text{comp1.physics('ht').active(false)};
\]

Compute the solution of the added system:

\[
\text{model.sol('sol1').runAll};
\]

Display the solution:

\[
\text{pg1 = model.result.create('pg1', 'PlotGroup3D')};
\]

\[
\text{pg1.feature.create('surf1', 'Surface')};
\]
Code for use with MATLAB®

```matlab
model = mphopen('model_tutorial_llmatlab.mph');
mphgeom(model);
comp1 = model.component('comp1');
b1 = comp1.geom('geom1').feature.create('b1', 'BezierPolygon');
b1.set('p', {'1e-2' '5e-2'; '1e-2' '5e-2'; '1e-2' '1e-2'});

mphgeom(model, 'geom1', 'edgelabels', 'on', 'facealpha', 0.5);
mesh1 = comp1.mesh('mesh1');
mesh1.feature.create('ftet1', 'FreeTet');
mesh1.feature('size').set('hauto', 3);
mesh1.run;
mphmesh(model);
std1 = model.study.create('std1');
std1.feature.create('stat', 'Stationary');
sol1 = model.sol.create('sol1');
sol1.study('std1');

st1 = sol1.feature.create('st1', 'StudyStep');
st1.set('studystep', 'stat');
v1 = sol1.feature.create('v1', 'Variables');
v1.set('control', 'stat');
sol1.feature.create('s1', 'Stationary');
Shape = comp1.physics('ht').prop('ShapeProperty');
Shape.set('order_temperature', 1, 1);
Shape.set('boundaryFlux_temperature', false);

ME = mphmatrix(model, 'sol1', 'Out', {'K' 'L' 'M' 'N'},... 
    'initmethod', 'sol', 'initsol', 'zero');

[stats, data] = mphmeshstats(model);
elem_idx = find(data.elementity(1)==21);
info = mphxmeshinfo(model, 'soltag', 'sol1', 'studysteptag', 'v1');
dofs = info.elements.edg.dofs;
edgdofs_idx = [];
for i = 1:length(elem_idx)
```

```matlab
...
```
edgdfs_idx = [edgdfs_idx; dofs(:,elem_idx(i))];
end
unique_idx = unique(edgdfs_idx);
ME.L(unique_idx+1) = 50/length(unique_idx);
mphinputmatrix(model,ME,'sol1','s1')
gForm = comp1.physics.create('g', 'GeneralFormPDE', {'u'});
gForm.prop('ShapeProperty').set('order', 1);
gForm.prop('ShapeProperty').set('boundaryFlux', false);
comp1.physics('ht').active(false);
model.sol('sol1').runAll;
pg1 = model.result.create('pg1', 'PlotGroup3D');
pg1.feature.create('surf1', 'Surface');
mpfplot(model,'pg1','rangenum',1)

Extracting State-Space Matrices

Use state-space export to create a linearized state-space model corresponding to a COMSOL Multiphysics model. You can export the matrices of the state-space form directly to the MATLAB® workspace with the command `mphstate`.

This section includes information about The State-Space System, how to Extract State-Space Matrices and Set Linearization Points and has an Extracting State-Space Matrices.

**The State-Space System**

A state-space system is the mathematical representation of a physical model. The system consistent in an ODE linking input, output, and state-space variable. A dynamic system can be represented with the following system:

\[
\begin{bmatrix}
\frac{dx}{dt}
\end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} x \\ u \end{bmatrix}
\]

An alternative representation of the dynamic system is:

\[
\begin{bmatrix}
\frac{dx}{dt}
\end{bmatrix} = \begin{bmatrix} M_C & A \\ C & D \end{bmatrix} \begin{bmatrix} x \\ u \end{bmatrix}
\]

This form is more suitable for large systems because the matrices \( M_C \) and \( M_CA \) usually become much more sparse than \( A \).

If the mass matrix \( M_C \) is small, it is possible to approximate the dynamic state-space model with a static model, where \( M_Cx = 0 \):
Let $Null$ be the PDE constraint null-space matrix and $ud$ a particular solution fulfilling the constraints. The solution vector $U$ for the PDE problem can then be written

$$U = Nullx + ud + u_0$$

where $u_0$ is the linearization point, which is the solution stored in the sequence once the state-space export feature is run.

**EXTRACT STATE-SPACE MATRICES**

The function `mphstate` requires that the input variables, output variables, and the list of the matrices to extract in the MATLAB workspace are all defined:

```matlab
str = mphstate(model, <soltag>, 'input', <input>, ... 'output', <output>, 'out', out);
```

where `<soltag>` is the solver node tag used to assemble the system matrices listed in the cell array `out`, and `<input>` and `<output>` are cell arrays containing the list of the input and output variables, respectively.

The output data `str` returned by `mphstate` is a MATLAB structure and the fields correspond to the assembled system matrices.

The input variables need to be defined as parameters in the COMSOL model. The output variables are defined as domain point probes or global probes in the COMSOL model.

The system matrices that can be extracted with `mphstate` are listed in the table:

<table>
<thead>
<tr>
<th>EXPRESSION</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>$MA$</td>
<td>$McA$ matrix</td>
</tr>
<tr>
<td>$MB$</td>
<td>$McB$ matrix</td>
</tr>
<tr>
<td>$A$</td>
<td>$A$ matrix</td>
</tr>
<tr>
<td>$B$</td>
<td>$B$ matrix</td>
</tr>
<tr>
<td>$C$</td>
<td>$C$ matrix</td>
</tr>
<tr>
<td>$D$</td>
<td>$D$ matrix</td>
</tr>
<tr>
<td>$Mc$</td>
<td>$M$ matrix</td>
</tr>
<tr>
<td>$Null$</td>
<td>Null matrix</td>
</tr>
<tr>
<td>$ud$</td>
<td>$ud$ vector</td>
</tr>
<tr>
<td>$x0$</td>
<td>$x0$ vector</td>
</tr>
</tbody>
</table>
To extract sparse matrices set the property `sparse` to `on`:

```matlab
str = mphstate(model, <soltag>, 'input', <input>, ...
    'output', <output>, 'out', out, 'sparse', 'on')
```

To keep the state-space feature node, set the property `keepfeature` to `on`:

```matlab
str = mphstate(model, <soltag>, 'input', <input>, ...
    'output', <output>, 'out', out, 'keepfeature', 'on')
```

**SET LINEARIZATION POINTS**

`mphstate` uses linearization points to assemble the state-space matrices. The default linearization point is the current solution provided by the solver node, to which the state-space feature node is associated. If there is no solver associated to the solver configuration, a null solution vector is used as a linearization point.

You can manually select the linearization point to use. Use the `initmethod` property to select a linearization point:

```matlab
str = mphstate(model, <soltag>, 'input', <input>, ...
    'output', <output>, 'out', 'initmethod', method)
```

where `method` corresponds to the type of linearization point—the initial value expression (`'init'`) or a solution (`'sol'`).

To set the solution to use for the linearization point, use the property `initsol`:

```matlab
str = mphstate(model, <soltag>, 'input', <input>, ...
    'output', <output>, 'out', 'initsol', <initsoltag>)
```

where `<initsoltag>` is the solver tag to use for a linearization point. You can also set the `initsol` property to `'zero'`, which corresponds to using a null solution vector as a linearization point. The default is the current solver node where the assemble node is associated.

For continuation, time-dependent, or eigenvalue analyses you can set which solution number to use as a linearization point. Use the `solnum` property:

```matlab
str = mphstate(model, <soltag>, 'input', <input>, ...
    'output', <output>, 'out', 'solnum', <solnum>)
```

where `<solnum>` is an integer value corresponding to the solution number. The default value is the last solution number available with the current solver configuration.
**EXTRACTING STATE-SPACE MATRICES**

To illustrate how to use the `mphstate` function to extract the state-space matrices of the model `heat_transient_axi` from the COMSOL Multiphysics Applications Libraries. To be able to extract the state-space matrices you need to modify an existing model. First, create a parameter `T0` that is set as the external temperature:

```verbatim
comp1.physics('ht').feature('temp1').set('T0', 1, 'Tinput');
```

Then create a domain point probe:

```verbatim
pdom1 = comp1.probe.create('pdom1', 'DomainPoint');
pdom1.setIndex('coords2', '0.2', 0, 0);
pdom1.setIndex('coords2', '0.3', 0, 1);
```

Change the time stepping:

```verbatim
time = model.study('std1').feature('time');
time.set('tlist', 'range(0.5, 0.5e3)');
```

Extract the matrices of the state-space system using `Tinput` as an input variable and the probe `comp1.ppb1` as an output variable:

```verbatim
M = mphstate(model, 'sol1', 'out', {'Mc', 'MA', 'MB', 'C', 'D', 'x0'},
            'input', 'Tinput', 'output', 'comp1.ppb1');
```

Compute the state-space system with the extracted matrices:

```verbatim
u = 1;
T0 = 1273.15;

opt = odeset('mass', M.Mc);
func = @(t,x) M.MA*x + M.MB*u;
[t, x] = ode23s(func, [0:50:2e3], M.x0, opt);
y = M.C*x + M.D*u + T0;
```

Compare the solution computed with the system and the one computed with COMSOL Multiphysics (see Figure 4-1):

```verbatim
plot(t, y)
hold on
Tnum = mphinterp(model, 'T', 'coord', [0.2; 0.3], 't', t);
```
Figure 4-1: Temperature distribution computed with the state-space system (blue line) and COMSOL Multiphysics (red marker).

Code for use with MATLAB®

```matlab
model = mphopen('heat_transient_axi');
model.param.set('Tinput','1000[degC]');
comp1 = model.component('comp1');
comp1.physics('ht').feature('temp1').set('T0', 1, 'Tinput');
pdom1 = comp1.probe.create('pdom1', 'DomainPoint');
pdom1.setIndex('coords2','0.2',0,0);
pdom1.setIndex('coords2','0.3',0,1);
time = model.study('std1').feature('time');
time.set('tlist','range(0,50,2e3)');
M = mphstate(model,'sol1','out',...    'input','Tinput', 'output', 'comp1.ppb1');
u = 1;
T0= 1273.15;
opt = odeset('mass', M.Mc);
func = @(t,x) M.MA*x + M.MB*u;
[t,x] = ode23s(func, [0:50:2e3], M.x0, opt);
y = M.C*x'+M.D*u+T0;
plot(t,y); hold on
Tnum = mphinterp(model,'T','coord',[0.2;0.3],'t',t);
plot(t,Tnum,'r+')
```
**Extracting Reduced Order State-Space Matrices**

COMSOL Multiphysics models often have a large number of degrees of freedom. This leads to large state-space model when exported using `mphstate`. COMSOL Multiphysics provides model reduction functionality, which can reduce the number of states using an eigenvalue (or eigenfrequency) study leading to a low number of states that can be used for simulation and analysis.

The function `mphreduction` can be used to add studies to a model that add a training and model reduction study to a model. The number of eigenvalues can be specified as well as their range. `mphreduction` returns state-space matrices or a MATLAB state-space model using the `ss` function.


**EXTRACTING REDUCED ORDER STATE-SPACE MATRICES**

In this example, a heat transfer model will be constructed. It uses a very simple rectangular geometry and heat flux boundary conditions to keep things simple. The unreduced model has more than 800 DOFs, but the reduced model only has 7 states and a reduced-order model with even fewer states is possible with good results.

The following example sets up a model using commands from MATLAB. If the Heat Transfer Module or MEMS Module is available, then the model can be set up using the Heat Transfer in Solids physics interface. If these modules are not available, the example shows how to set up the model using the Heat Equation from the collection of classical PDEs in COMSOL Multiphysics.

**Geometry**

First the model and its geometry and mesh are constructed. The parameter `Qin` is later used as an input for the reduced state-space model.

```matlab
model = ModelUtil.create('Model');
model.component.create('comp1', true);
model.param.set('Qin', '10000');
model.component('comp1').geom.create('geom1', 2);
model.component('comp1').mesh.create('mesh1');
model.component('comp1').mesh('mesh1').autoMeshSize(3);
model.component('comp1').geom('geom1').create('r1', 'Rectangle');
model.component('comp1').geom('geom1').feature('r1').set('size', [0.1 0.01]);
model.component('comp1').geom('geom1').run;
```
Physics - from the Heat Transfer Module

The physics is set up using the Heat Transfer in Solids heat-transfer physics and using Aluminum as the material.

```model
  model.component('comp1').physics.create('ht', 'HeatTransfer', 'geom1');
  model.component('comp1').physics('ht'). ... feature('solid1').set('k_mat', 'userdef');
  model.component('comp1').physics('ht').feature('solid1').set('k', 238);
  model.component('comp1').physics('ht'). ... feature('solid1').set('rho_mat', 'userdef');
  model.component('comp1').physics('ht').feature('solid1').set('rho', 2700);
  model.component('comp1').physics('ht'). ... feature('solid1').set('Cp_mat', 'userdef');
  model.component('comp1').physics('ht').feature('solid1').set('Cp', 900);
  Flux boundary conditions are set up at the left side (1) and top (3) of the rectangle.
  model.component('comp1').physics('ht'). ... create('hf1', 'HeatFluxBoundary', 1);
  model.component('comp1').physics('ht').feature('hf1').set('q0', 'Qin');
  model.component('comp1').physics('ht').feature('hf1').selection.set(1);
  model.component('comp1').physics('ht'). ... create('hf2', 'HeatFluxBoundary', 1);
  model.component('comp1').physics('ht').feature('hf2').selection.set(3);
  model.component('comp1').physics('ht'). ... feature('hf2').set('HeatFluxType', 'ConvectiveHeatFlux');
  model.component('comp1').physics('ht').feature('hf2').set('h', 100);
```

Skip the next section and continue the model from the Output section below.

Physics - from Classical PDEs

The physics is set up using the Heat Equation and using the material parameters for Aluminum.

```model
  model.component('comp1').physics.create('hteq', 'HeatEquation', 'geom1');
  model.component('comp1').physics('hteq').feature('init1').set('u', 293.15);
  model.component('comp1').physics('hteq').feature('hteq1').set('c', 238);
  model.component('comp1').physics('hteq').feature('hteq1').set('f', 0);
  model.component('comp1').physics('hteq').feature('hteq1').set('da', '2700*900');
  Flux boundary conditions are set up at the left side (1) and top (3) of the rectangle.
  model.component('comp1').physics('hteq').create('flux1', ...
  'FluxBoundary', 1);
  model.component('comp1').physics('hteq').feature('flux1').selection.set(1);
  model.component('comp1').physics('hteq').feature('flux1').set('g', 'Qin');
  model.component('comp1').physics('hteq').create('flux2', ...
  'FluxBoundary', 1);
  model.component('comp1').physics('hteq').feature('flux2').selection.set(3);
  model.component('comp1').physics('hteq').feature('flux2').set('g', ...
  '100*(293.15-u)');
```
Outputs

Outputs from the model are defined using probes. In this example, there is only one output, which is the average temperature on the top of the rectangle.

```plaintext
model.component('comp1').probe.create('bnd1', 'Boundary');
model.component('comp1').probe('bnd1').set('intsurface', true);
model.component('comp1').probe('bnd1').selection.set(3);
model.component('comp1').probe('bnd1').genResult('none');
```

Study and Solver Settings

A transient study and solver are created, and the model is solved. A plot is shown in a MATLAB figure if everything has been set up correctly.

```plaintext
model.study.create('std1');
model.study('std1').create('time', 'Transient');
model.study('std1').feature('time').set('tlist', 'range(0,1,1000)');
model.sol.create('sol1');
model.sol('sol1').createAutoSequence('std1');
model.sol('sol1').feature('t1').set('tstepsbdf', 'intermediate');
model.sol('sol1').runAll;
```

Training Study

For heat transfer problems, it is necessary to manually add a training study, which must be an eigenvalue study. The solver is set up such that it finds 5 eigenvalues.

```plaintext
model.study.create('std2');
model.study('std2').create('eigv', 'Eigenvalue');
model.study('std2').feature('eigv').activate('ht', true);
model.study('std2').feature('eigv').set('neigsactive', true);
model.study('std2').feature('eigv').set('neigs', 5);
```

Calling mphreduction and Simulating

A call to `mphreduction` creates the state-space matrices needed to simulate the reduced-order system.

```plaintext
MR = mphreduction(model, ...
    'out', {'MA' 'MB' 'A' 'B' 'C' 'D' 'Mc' 'x0'}, ...
    'controls', {'Qin'}, ...
    'controlvals', [10000], ...
    'output', 'comp1.bnd1', ...
    'unreducedstudy', 'std1', ...
    'trainingstudy', 'std2')
```

Now the reduced-order system can be simulated using the function `ode23s`.

```plaintext
u = 10000;
func = @(t,x) MR.MA*x + MR.MB*u
tspan = 0:1000;
opt = odeset('mass', MR.Mc);
[t,x] = ode23s(func, tspan, zeros(size(MR.MA,1),1), opt);
```

```plaintext
yt = MR.C*x'; % deviation variables
```
\[ y_0 = MR.C*MR.x_0; \] % initial output value
\[ y = y + y_0; \]
\[ \text{hold on} \]
\[ \text{plot}(t, y, \text{'}r\text{'}) \]

As an alternative to using `ode23s`, you can use functions in the Control System Toolbox, which is an add-on to MATLAB. The matrices stored in `MR` can be used to manually construct a state-space system using the function `ss`, or you can call `mphreduction` using the return option to specify that `mphreduction` should do the conversion.

```matlab
sys = mphreduction(model, ...
    'out', {'MA' 'MB' 'A' 'B' 'C' 'D' 'Mc' 'x0' 'Y0' 'Kr'}, ...
    'controls', {'Qin'}, ...
    'controlvals', [10000], ...
    'output', 'comp1.bnd1', ...
    'unreducedstudy', 'std1', ...
    'trainingstudy', 'std2', ...
    'return', 'ss')
```

The system can, for example, be simulated using the `step` function.

```matlab
opt = stepDataOptions('StepAmplitude', 10000);
figure(2)
step(sys, 1:1000, opt)
```
Notice that the output is using deviation variables.

grid on

Code for use with MATLAB®

```matlab
model = ModelUtil.create('Model');
comp1 = model.component.create('comp1', true);
model.param.set('Qin', '10000');
geom1 = comp1.geom.create('geom1', 2);
r1 = geom1.create('r1', 'Rectangle');
r1.set('size', [0.1 0.01]);
geom1.run;

mesh1 = comp1.mesh.create('mesh1');

ht = comp1.physics.create('ht', 'HeatTransfer', 'geom1');
ht.feature('solid1')...
    .set('k_mat', 'userdef').set('k', 238)...
    .set('rho_mat', 'userdef').set('rho', 2700)...
    .set('Cp_mat', 'userdef').set('Cp', 900);

hf1 = ht.create('hf1', 'HeatFluxBoundary', 1);
hf1.set('q0', 'Qin');
hf1.selection.set(1);

hf2 = ht.create('hf2', 'HeatFluxBoundary', 1);
hf2.selection.set(3);

hteq = comp1.physics.create('hteq', 'HeatEquation', 'geom1');
hteq.feature('hteq1').set('c', 238);
hteq.feature('hteq1').set('f', 0);
```
hteq.feature('hteq1').set('da', '2700*900');
flux1 = hteq.create('flux1', 'FluxBoundary', 1);
flux1.selection.set(1);
flux1.set('g', 'Qin');
flux2 = hteq.create('flux2', 'FluxBoundary', 1);
flux2.selection.set(3);
flux2.set('g', '100*(293.15-u)');

bnd1 = comp1.probe.create('bnd1', 'Boundary');
bnd1.set('intsurface', true);
bnd1.selection.set(3);
bnd1.genResult('none');
std1 = model.study.create('std1');
std1.create('time', 'Transient');
std1.feature('time').set('tlist', 'range(0,1,1000)');
sol1 = model.sol.create('sol1');
sol1.createAutoSequence('std1');
sol1.feature('tt').set('tstepsbdf', 'intermediate');
sol1.runAll;

mphplot(model, 'pg1'); hold on
std2 = model.study.create('std2');
std2.create('eigv', 'Eigenvalue');
std2.feature('eigv').activate('ht', true);
std2.feature('eigv').set('neigsactive', true);
std2.feature('eigv').set('neigs', 5);

MR = mphreduction(model, ...
    'out', {'MA' 'MB' 'A' 'B' 'C' 'D' 'Mc' 'x0'}, ...
    'controls', {'Qin'}, ...
    'controlovals', [10000], ...
    'output', 'comp1.bnd1', ...
    'unreducedstudy', 'std1', ...
    'trainingstudy', 'std2', ...
    'return', 'ss')

u = 10000;
func = @(t,x) MR.MA*x + MR.MB*u
tspan = 0:1000;
opt = odeset('mass', MR.Mc);
[t,x] = ode23s(func, tspan, zeros(size(MR.MA,1),1), opt);
yt = MR.C*x'; % deviation variables
y0 = MR.C*MR.x0; % initial output value
y = yt+y0;
plot(t, y, 'r')

sys = mphreduction(model, ...
    'out', {'MA' 'MB' 'A' 'B' 'C' 'D' 'Mc' 'x0' 'Y0' 'Kr'}, ...
    'controls', {'Qin'}, ...
    'controlovals', [10000], ...
    'output', 'comp1.bnd1', ...
    'unreducedstudy', 'std1', ...
    'trainingstudy', 'std2', ...
    'return', 'ss')
opt = stepDataOptions('StepAmplitude', 10000);
figure(2)
step(sys, 1:1000, opt)
grid on
Extracting Solution Information and Solution Vectors

In this section:

- Obtaining Solution Information
- Retrieving Solution Information and Solution Data Sets Based on Parameter Values
- Extracting Solution Vector

Obtaining Solution Information

Get the solution object information with the function `mphsolinfo`. Specify only the model object to obtain the information of the default solution object:

```plaintext
info = mphsolinfo(model)
```

This section includes information about Specifying the Solution Object and the Output Format.

SPECIFYING THE SOLUTION OBJECT

To retrieve the information of a specific solution object, set the `soltag` property with the solver tag `soltag` associated to the solution object:

```plaintext
info = mphsolinfo(model, 'soltag', <soltag>)
```

If there are several solution data sets attached to the solver, for example, solution data sets with different selections, specify the data set to use to get the solution object information with the `dataset` property:

```plaintext
info = mphsolinfo(model, 'dataset', <dsettag>)
```

where `dsettag` the tag of the solution data set to use.

The function `mphsolinfo` replaces the function `mphgetp`. If you are using the later you can now replace it as it will be removed in a future version.
**OUTPUT FORMAT**

The output info is a MATLAB® structure. The default fields available in the structure are listed in the table:

<table>
<thead>
<tr>
<th>FIELDS</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>soltag</td>
<td>Tag of the solver associated to the solution object</td>
</tr>
<tr>
<td>study</td>
<td>Tag of the study associated to the solution object</td>
</tr>
<tr>
<td>size</td>
<td>Size of the solution vector</td>
</tr>
<tr>
<td>nummesh</td>
<td>Number of mesh in the solution (for automatic remeshing)</td>
</tr>
<tr>
<td>sizes</td>
<td>Size of solution vector and inner parameters for each mesh</td>
</tr>
<tr>
<td>soltype</td>
<td>Solver type</td>
</tr>
<tr>
<td>solpar</td>
<td>Parameter name</td>
</tr>
<tr>
<td>sizesolvals</td>
<td>Length of parameter list</td>
</tr>
<tr>
<td>solvals</td>
<td>Inner parameter value</td>
</tr>
<tr>
<td>paramsweepnames</td>
<td>Outer parameter name</td>
</tr>
<tr>
<td>paramsweepvals</td>
<td>Outer parameter value</td>
</tr>
<tr>
<td>label</td>
<td>Solution node label</td>
</tr>
<tr>
<td>batch</td>
<td>Batch information</td>
</tr>
<tr>
<td>dataset</td>
<td>Tag of the solution data set associated to the solution object</td>
</tr>
</tbody>
</table>

To get the information about the number of solutions, set the property `nu` to on:

```matlab
info = mphsolinfo(model, 'nu', 'on')
```

The `info` structure is added with the following fields:

<table>
<thead>
<tr>
<th>FIELDS</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>NUsol</td>
<td>Number of solutions vectors stored</td>
</tr>
<tr>
<td>Nureacf</td>
<td>Number of reaction forces vectors stored</td>
</tr>
<tr>
<td>NUadj</td>
<td>Number of adjacency vectors stored</td>
</tr>
<tr>
<td>NUfsens</td>
<td>Number of functional sensitivity vectors stored</td>
</tr>
<tr>
<td>NUsens</td>
<td>Number of forward sensitivity vectors stored</td>
</tr>
</tbody>
</table>

The `batch` field is a structure including the following fields:

<table>
<thead>
<tr>
<th>BATCH FIELDS</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>type</td>
<td>The type of batch</td>
</tr>
<tr>
<td>psol</td>
<td>Tag of the associated solver node</td>
</tr>
</tbody>
</table>
Retrieving Solution Information and Solution Data Sets Based on Parameter Values

A model can contain several solution vectors computed with different values of parameters, such as time, eigenvalue, or model parameters. These solution vectors can be available in different solution data sets. Use the function `mphsolutioninfo` to retrieve the solution vector corresponding to a specified study parameter value.

The parameters used in a study can be group in two distinct solution number types:

- The **inner solution**, containing the solution computed with parameters such as eigenvalues, time steps, or continuation parameter combinations.
- The **outer solution**, containing the solution computed with parameters defined in parametric sweep.

To get information about all solution object and solution data set combinations in the model enter the command:

```matlab
info = mphsolutioninfo(model)
```

The output `info` is a structure containing these fields:

<table>
<thead>
<tr>
<th>FIELDS</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>solutions</td>
<td>List of the solution object tags available in the model</td>
</tr>
<tr>
<td>sol#</td>
<td>Substructure containing information related to the solution number #</td>
</tr>
</tbody>
</table>

The substructure `info.sol#` has these fields:

<table>
<thead>
<tr>
<th>FIELDS</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>dataset</td>
<td>List of the tags of the data set associated to the solution</td>
</tr>
<tr>
<td>study</td>
<td>Tag of the study that computed the solution</td>
</tr>
<tr>
<td>sequencetype</td>
<td>Type of solution node</td>
</tr>
<tr>
<td>cellmap</td>
<td>Connections between parameters and inner/outer solution numbers; the field is not available by default.</td>
</tr>
<tr>
<td>values</td>
<td>Values of the parameters used in the solution</td>
</tr>
<tr>
<td>parameters</td>
<td>Names of the parameters used in the solution</td>
</tr>
</tbody>
</table>
You can also retrieve the solution objects and solution data sets related to a specific parameter value with the command:

```
info = mphsolutioninfo(model, 'parameters', {e1, v1, tol1})
```

where e1 is the expression name, v1 the value of the expression.

The property parameters can also be set as a 1xN cell array where N corresponds to the number of parameters to specify.

This section includes information about Specifying the Solution Object and the Output Format. It also includes the section, Retrieving Solution Information.

**SPECIFYING THE SOLUTION OBJECT**

To retrieve the information of a specific solution object, set the soltag property with the solver tag soltag associated to the solution object:

```
info = mphsolutioninfo(model, 'soltag', <soltag>)
```

If there are several solution data sets attached to the solver, for example, solution data sets with different selections, specify the data set to use to get the solution object information with the dataset property:

```
info = mphsolutioninfo(model, 'dataset', <dsettag>)
```

where dsettag the tag of the solution data set to use.

**OUTPUT FORMAT**

To include the cellmap field in the info.sol# substructure set the property cellmap to on:

```
info = mphsolutioninfo(model, 'cellmap', 'on')
```

Improve the visibility of the map table by sorting the row using either the column number or the name in the map header:

```
info = mphsolutioninfo(model, 'sort', <idx>)
```

where <idx> is a positive integer equal to the column number or a string corresponding to the name of the column header.

---

<table>
<thead>
<tr>
<th>FIELDS</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>mapheaders</td>
<td>Headers of the table stored in the map field</td>
</tr>
<tr>
<td>map</td>
<td>Connections between the parameter values and the solution number (inner and outer solutions)</td>
</tr>
</tbody>
</table>
**RETRIEVING SOLUTION INFORMATION**

This example shows how to use the function `mphsolutioninfo` to retrieve solution information in a mode combining a parametric sweep and transient analysis.

Start by loading the base model `model_tutorial_llmatlab` from the COMSOL Multiphysics Application Libraries; this model contains base settings for a thermal analysis:

```matlab
model = mphopen('model_tutorial_llmatlab');
```

Now create a study combining a parametric sweep and a transient study step. The parametric sweep consist by varying the parameters that set the heat source and the bottom temperature. This is done with these commands:

```matlab
std = model.study.create('std');
param = std.feature.create('param', 'Parametric');
param.setIndex('pname', 'power', 0);
param.setIndex('plistarr', '30 60 90', 0);
param.setIndex('pname', 'Temp', 1);
param.setIndex('plistarr', '300 320', 1);
time = std.feature.create('time', 'Transient');
time.set('tlist', 'range(0,1,25)');
```

Set the sweep type to generate all possible combinations of the parameters `power` and `tf` and compute the study:

```matlab
param.set('sweeptype', 'filled');
std.run;
```

Once the solution is computed (it takes about 90 seconds), you can retrieve the solution information in the model:

```matlab
info = mphsolutioninfo(model)
```

The output `info` is a structure containing nine fields. By navigating in the `info` structure you can retrieve how the solutions are stored in the model.

- `info.sol1` contains the solution information related to the solver sequence `sol1`. The associated data set is `dset1`.
- `info.sol2` contains the solution information for the parametric sequence. This regroups the solution vectors computed for all outer parameters.

The other substructures contain the solution information for all possible outer solution combinations.

Get the relation between the parameter values and the inner and outer solution numbers:
map = info.sol2.map

Retrieve the solution information related to the parameters power = 60 W:

info = mphsolutioninfo(model, ‘parameters’, {'power',60,0})

Retrieve the solution information related to the parameters power = 60 W, Temp = 300 K and t = 10.4 seconds, for the time use a tolerance of 0.5 seconds to find the appropriate inner solution number:

info = mphsolutioninfo(model, ‘parameters’, {{'power',60,0},...
{'Temp',300,0},{'t',10.4,0.5}})

To get the list of the solutions that contain the given parameters enter:

solnum = info.solutions

Code for use with MATLAB®

model = mphopen(‘model_tutorial_llmatlab’);
std = model.study.create(‘std’);
param = std.feature.create(‘param’, ‘Parametric’);
param.setIndex(‘pname’, ‘power’, 0);
param.setIndex(‘plistarr’, ‘30 60 90’,0);
param.setIndex(‘pname’, ‘Temp’, 1);
param.setIndex(‘plistarr’, ‘300 320’, 1);
time = std.feature.create(‘time’, ‘Transient’);
time.set(‘tlist’, ‘range(0,1,25)’);
param.set(‘sweeptype’, ‘filled’);
std.run;
info = mphsolutioninfo(model)
map = info.sol2.map
info = mphsolutioninfo(model, ‘parameters’, {'power',60,0})
info = mphsolutioninfo(model, ‘parameters’, {'power',60,0},...
{'Temp',300,0},{'t',10.4,0.5})
solnum = info.solutions

Extracting Solution Vector

To extract the solution vector with the function mphgetu, enter:

U = mphgetu(model)

where U is an Nx1 double array, where N is the number of degrees of freedom of the COMSOL Multiphysics model.
This section includes information about Specifying the Solution and the Output Format.

### Specifying the Solution
Change the solver node to extract the solution vector with the property `solname`:

\[
U = \text{mphgetu}(\text{model}, 'soltag', <\text{soltag}>)
\]

where `<soltag>` is the tag of the solver node.

For solver settings that compute for several inner solutions, select the inner solution to use with the `solnum` property:

\[
U = \text{mphgetu}(\text{model}, 'solnum', <\text{solnum}>)
\]

where `<solnum>` a positive integer vector that corresponds to the solution number to use to extract the solution vector. For time-dependent and continuation analyses, the default value for the `solnum` property is the last solution number. For an eigenvalue analysis, it is the first solution number.

A model can contain different types of solution vectors—the solution of the problem, the reaction forces vector, the adjoint solution vector, the functional sensitivity vector, or the forward sensitivity. In `mphgetu`, you can specify the type of solution vector to extract with the `type` property:

\[
U = \text{mphgetu}(\text{model}, 'type', type)
\]

where `type` is one of these strings 'sol', 'reacf', 'adj', or 'sens' used to extract the solution vector, the reaction forces, the functional sensitivity, or the forward sensitivity, respectively.

### Output Format
`mphgetu` returns the default the solution vector. Get the time derivative of the solution vector `Udot` by adding a second output variable:

\[
[U, Udot] = \text{mphgetu}(\text{model})
\]

In case the property `solnum` is set as a 1x M array and the solver node only uses one mesh to create the solution, the default output is an NxM array, where N is the number of degrees of freedom of the model. Otherwise, the output U is a cell array that contains you can refer to the function `mphxmeshinfo` to receive the DOF name or the node coordinates in the solution vector, see Retrieving Xmesh Information.
each solution vector. If you prefer to have the output in a cell array format, set the property `matrix` to `off`:

```matlab
U = mphgetu(model, 'solnum', <solnum>, 'matrix', 'off')
```
Retrieving Xmesh Information

Use LiveLink™ for MATLAB® to retrieve low level information of the COMSOL Multiphysics finite element model.

In this section:
- The Extended Mesh (Xmesh)
- Extracting Xmesh Information

The Extended Mesh (Xmesh)

The extended mesh (xmesh) is the finite element mesh used to compute the solution. This contains the information about elements, nodes, and degrees of freedom such as DOF names, position of the nodes in the assembled matrix system, or how elements and nodes are connected.

Extracting Xmesh Information

The function `mphxmeshinfo` returns the extended mesh information. To get the xmesh information of the current solver and mesh node, enter the command:

```
info = mphxmeshinfo(model)
```

where `info` is a MATLAB structure that contains the fields in the table:

<table>
<thead>
<tr>
<th>Fields</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>soltag</code></td>
<td>Tag of the solver node</td>
</tr>
<tr>
<td><code>ndofs</code></td>
<td>Number of degrees of freedom</td>
</tr>
<tr>
<td><code>fieldnames</code></td>
<td>List of field variables names</td>
</tr>
<tr>
<td><code>fieldndofs</code></td>
<td>Number of degrees of freedom for each field variable</td>
</tr>
<tr>
<td><code>meshtypes</code></td>
<td>List of the mesh type</td>
</tr>
<tr>
<td><code>geoms</code></td>
<td>Tag of the geometry node used in the model</td>
</tr>
<tr>
<td><code>dofs</code></td>
<td>Structure containing the dofs information</td>
</tr>
<tr>
<td><code>nodes</code></td>
<td>Structure containing the nodes information</td>
</tr>
<tr>
<td><code>elements</code></td>
<td>Structure containing the elements information</td>
</tr>
</tbody>
</table>
The `dofs` substructure contains the fields listed in the table:

<table>
<thead>
<tr>
<th>FIELDS</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>geomnums</td>
<td>1-based geometry numbers for all DOFs</td>
</tr>
<tr>
<td>coords</td>
<td>Global coordinates for all DOFs in the model length unit. The ( k )th column of this matrix contains the coordinates of DOF number ( k )</td>
</tr>
<tr>
<td>nodes</td>
<td>0-based node numbers for all DOFs</td>
</tr>
<tr>
<td>dofnames</td>
<td>DOF names</td>
</tr>
<tr>
<td>nameinds</td>
<td>0-based indices into <code>dofNames()</code> for all DOFs</td>
</tr>
<tr>
<td>solvectorinds</td>
<td>0-based indices into solution vector for all DOFs</td>
</tr>
</tbody>
</table>

The `nodes` substructure contains the fields listed in the table:

<table>
<thead>
<tr>
<th>FIELDS</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>coords</td>
<td>Global coordinates for all nodes. The ( n )th column contains the coordinates of node point number ( n )</td>
</tr>
<tr>
<td>dofnames</td>
<td>DOF names</td>
</tr>
<tr>
<td>dofs</td>
<td>0-based DOF numbers for all nodes in this geometry.</td>
</tr>
<tr>
<td>dofs()[]</td>
<td>( k )[( n )] is the DOF number for DOF name <code>dofNames()</code> at node point ( n ). A value of -1 means that there is no DOF with this name at the node. Note: If there is a slit, only one of the DOFs is given for each node point</td>
</tr>
</tbody>
</table>

The `elements` substructure contains the fields listed in the table:

<table>
<thead>
<tr>
<th>FIELDS</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>meshtypes</td>
<td>List of the type of mesh available</td>
</tr>
<tr>
<td>type</td>
<td>Substructure containing the information of element of type <code>type</code></td>
</tr>
</tbody>
</table>

The `type` substructure lists the information for each element. The possible mesh types are `vtx`, `edg`, `quad`, `tri`, `quad`, `tet`, `hex`, `prism`, and `pyr`. The substructure `type` contains the fields listed in the table:

<table>
<thead>
<tr>
<th>FIELDS</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>localcoords</td>
<td>Local coordinates of nodes. The ( k )th column contains the coordinates of local node point number ( k )</td>
</tr>
<tr>
<td>localdofcoords</td>
<td>The local coordinates for each local DOF (one column for each local DOF)</td>
</tr>
<tr>
<td>localdofnames</td>
<td>The name for each local DOF</td>
</tr>
</tbody>
</table>
To specify the solver node to retrieve the xmesh information, set the property `soltag` as in this command:

```matlab
info = mphxmeshinfo(model, 'soltag', <soltag>)
```

where `<soltag>` is the tag of the solver used to extract the xmesh information.

To retrieve the xmesh information for a specific study step node, specify it with the property `studysteptag`:

```matlab
info = mphxmeshinfo(model, 'studysteptag', <studysteptag>)
```

where `<studysteptag>` is the tag of either a compiled equation node or a variable node.

In case several mesh cases have been used by a specific solver, for example, with an automatic remeshing procedure, you can specify which mesh case to use to get the discretization information:

```matlab
info = mphxmeshinfo(model, 'meshcase', <meshcase>)
```

where `<meshcase>` is the mesh case number or the tag of the mesh case.

### FIELDS DESCRIPTION

<table>
<thead>
<tr>
<th>FIELDS</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>nodes</td>
<td>0-based node point indices for all mesh elements of type <code>type</code>. A value -1 means that there is no node point at this location</td>
</tr>
<tr>
<td>dofs</td>
<td>0-based DOF numbers for all mesh elements of type <code>type</code>. A value -1 means that there is no DOF at this location</td>
</tr>
</tbody>
</table>
Navigating the Model

The model object contains all the finite element model settings. To retrieve the model information you can navigate in the model object using a graphical user interface or directly at the MATLAB® prompt. Learn how to get the list of predefined expressions available for a given model and how to extract the value of these expressions and also the properties of the method used in the model.

In this section:

- Navigating the Model Object Using a GUI
- Navigating The Model Object At The Command Line
- Finding Model Expressions
- Evaluating the Model Parameters
- Getting Feature Model Properties
- Getting Parameter and Variable Definitions
- Getting Selection Information

Navigating the Model Object Using a GUI

The usual approach to navigate through the model object in a graphical user interface (GUI) is to load the model object at the COMSOL Desktop. Then transfer the model object from the COMSOL Multiphysics Server to the COMSOL Desktop as in Sharing the Model Between the COMSOL Desktop® and the MATLAB® Prompt.

An alternative approach is to call the function `mphnavigator` that displays the model object information in a MATLAB® GUI. To run the function at the MATLAB prompt enter the command:

```
mpnavigator
```
This command pops-up a MATLAB GUI as in this figure:

![MATLAB GUI](image)

If you have installed the COMSOL apps in the MATLAB Apps ribbon, click the COMSOL Model Navigator icon ( ).

If the COMSOL model objected is not stored in the MATLAB variable `model` enter the command:

```
mpnavigator(<modelvar>)
```

where `<modelvar>` is the variable name in MATLAB that contains the model.

If a new model object is created with the same MATLAB object name, restart `mpnavigator` in order to have the updated model information.
The menu bar items

The `mphnavigator` GUI menu bar has the following options:

- The **File** menu, where the current model object can be saved in the MPH-format, a new model object can be opened, and the `mphnavigator` window can be closed.
- The **Tools** menu lists the navigation tools available for the model object. **Search** is a shortcut to the command `mphsearch` that starts a GUI to search expressions or tags in the model object (see Finding Model Expressions). **Solutions** starts a GUI to display the solution object available in the COMSOL Multiphysics model object. **Show Errors** lists the error or warning nodes available in the model object (see Handling Errors and Warnings).
- The **Settings** menu only contains the **Advanced** options. Select or deselect the advanced model object methods that are displayed in the **Model Viewer** tree.
- The **Help** menu.

The shortcut icon

Just under the menu bar are several shortcut buttons.

These buttons are unavailable if no method has been selected in the **Model Tree** section.

- The **Open plot window** button ( ) generate the plot in COMSOL of the selected node and transfer the image in a MATLAB figure. This supports other plot than geometry, mesh or plot group such as functions.
- The **Plot** button ( ) displays the geometry, the mesh, or a plot group in a MATLAB figure.
- The **Help** button ( ) shows context sensitive help for the currently selected node in the model tree.
• The **Help for COMSOL API** button ( ) open the COMSOL API Documentation corresponding to the selected node.

• The **Report** button ( ) generate report node in the model, you can choose between brief, intermediate or complete report.

• The **Write report** button ( ), write the report in a document.

**THE MODEL TREE SECTION**

The **Model Tree** section has the list of the nodes of the model object. Use the scroll bar to the right to scroll down the list and click the + icon to expand the model object feature nodes.

When a feature node is selected, its associated command is listed just beneath the model tree. Click **Copy** to copy syntax to the clipboard and then paste it in your script.

---

The **Model Tree** list is slightly different to the **Model Builder** list available in the COMSOL Desktop. This is because `mphnavigator` displays all feature nodes and does not use the same filter as in the COMSOL Desktop to order the available feature nodes.
**THE PROPERTIES SECTION**

The **Properties** and the **Value** sections list the properties of a selected feature node and the associated values respectively. The **Allowed Value** section list the allowed value for the corresponding property.

Not all feature node returns a list of allowed value for the properties.

Click **Copy set** to copy to the clipboard the command that sets the selected property to its current value.

Click **Copy get** to copy to the clipboard the command to get the value of the currently selected property.

Click **Copy Table** to copy the entire properties table to the clipboard, then paste into a text or spreadsheet editor.

Click **Copy** to copy a selected cell in the properties table.
The Methods section lists all the methods associated to the feature node selected in the Model Tree section.

Click Filter to filter the reduce the methods list to the one that returns simple information that is easy and fast to evaluate.

Select a method in the list to get its associated syntax at the button of the Methods section. Use the Copy button to copy the syntax to the clipboard. Click Copy call to copy the method syntax associated to the selected feature node, the syntax is ready to use at the MATLAB prompt.

Navigating The Model Object At The Command Line

Use the command `mphmodel` at the MATLAB® prompt to retrieve model object information, such as tags for nodes and subnodes of a COMSOL Multiphysics model object.

To get the list of the main feature nodes and the tags of the model object `model`, enter the command:

```matlab
mphmodel(model)
```

To list the subfeature of the node type `model.feature` enter the command:

```matlab
mphmodel(model.feature)
```

To list the subfeature node of the feature node `model.feature(<ftag>)`, enter:

```matlab
mphmodel(model.feature(<ftag>))
```

Use the flag `-struct` to return the model object information to MATLAB structure:
\( str = \text{mphmodel}(\text{model}, '-struct') \)

\( str \) is a MATLAB structure and the fields consist of each feature node associated to the root node.

**Finding Model Expressions**

Each model object contains predefined expressions that depend on the physics interface used in the model.

The function `mphsearch` starts a MATLAB® GUI that displays the list of all the expressions, constants, solution variables, or parameters available in the model object. To run the function type at the MATLAB prompt:

\[ \text{mphsearch} \]

This command pops-up a MATLAB GUI as in this figure:

![MATLAB GUI](image)

If you have installed the COMSOL apps in the MATLAB Apps ribbon, click the COMSOL Search icon ( )

Using the COMSOL Model Search apps( ) only model object with name `model` are supported.

If the COMSOL model object is linked with a MATLAB object with a different name than `model`, enter the command:

\[ \text{mphsearch}(\text{modelname}) \]
where `modelname` is the name of the MATLAB object.

The table has the following for each entry, the:

- **Name** of the expression,
- **Expression** as it is set in the property value,
- **Description** if there is one set for the expression,
- **Type** of the expression, and the
- **Path** in the model object.

The **Search** section has a search tool to filter the list. Enter any string in the text field and select where to search the string—in the name, the expression, or the description of the table entry. You can also select the type you want to list. The expression type can be Equation, Field, Function, Geom, Mesh, Tag, VarNames, or Weak. You can select **Starts with** to search for any expression that start with the string enter in the text field.

- Click **Go** to display the result of the search. Click **Clear** to clear the search settings.
- Click **Model info** to get the model description in a separate window.
- Click **Copy** to copy any entry of the table to the clipboard.
- Click **Close** to close the `mphsearch` window.

### Evaluating the Model Parameters

Use the command `mphevaluate` to evaluate the expression defined in the Parameters node as in the command below:

```
value = mphevaluate(model, <expr>)
```

The evaluation does not require an existing solution data set in the model, which means you can evaluate the expression even if there is no solution computed in the model.

To evaluate multiple expressions at once, define `<expr>` as a cell array of expressions as in the command below:

```
str = mphevaluate(model, {<expr1>, <expr2>, ...})
```

The output `str` is an array of structs with the same size as for the cell array of expressions. For multiple parameters evaluation only a single output is permitted. The struct contains the following fields: `name`, the parameter name; `value`, its value in the unit specified in the field `unit`; `def`, the string for the definition of the parameter; and `descr` the string description of the parameter.
To evaluate all the parameters defined in the table enter:

```matlab
str = mphevaluate(model)
```

The output `str` is an array of structs with the same size as for the parameters table.

Get the full information of a model parameter expression with the command:

```matlab
[value, unit, def, descr] = mphevaluate(model, <expr>)
```

where `value`, `unit`, `def` and `descr` are the parameter value, the parameter unit, the parameter definition and the parameter description respectively.

You can specify the unit of the expression to evaluate with the command:

```matlab
value = mphevaluate(model, <expr>, <unit>)
```

where `<unit>` is the unit to evaluate the expression `<expr>` in.

To evaluate and return only the value of the expression use the command:

```matlab
value = mphevaluate(model, <expr>, <unit>, 'value')
```

To evaluate and return only the unit of the expression use the command:

```matlab
value = mphevaluate(model, <expr>, <unit>, 'unit')
```

To evaluate and return the definition string of the expression use the command:

```matlab
value = mphevaluate(model, <expr>, <unit>, 'valueunit')
```

The above command can be used to set a new parameter using an existing one.

### Getting Feature Model Properties

Use the command `mphgetproperties` to extract at the MATLAB® prompt the properties of a specified node of the model object. Not all nodes contains properties. Use the command:

```matlab
str = mphgetproperties(model.<feature>)
```

where `str` is a MATLAB structure that lists all the properties and the value of the feature node `<feature>`.

Some model node provides also a list of allowed value for their properties, to get such a list enter the command:

```matlab
[str, allowed] = mphgetproperties(model.<feature>)
```

this also returns the MATLAB structure `allowed` containing the list of the allowed values for the properties of the feature node `<feature>`.
**Getting Parameter and Variable Definitions**

Use the command `mphgetexpressions` to get the expressions and the descriptions of parameters and variables. Use the command:

```matlab
e = mphgetexpressions(<node>)
```

where `<node>` is the node to get the expressions from. Nodes that can be used are `model.param`, `model.variable(<tag>)`, and `model.result.param`.

`expr` is an Nx3 cell array where N is the number of expressions for this node.

**Getting Selection Information**

Use the function `mphgetselection` to retrieve the model selection information:

```matlab
str = mphgetselection(model.selection(<seltag>))
```

where `<seltag>` is the tag a selection node defined in the model object. The output `str` is a MATLAB® structure with the following fields:

- **dimension**, the space dimension of the geometry entity selected,
- **geom**, the tag of the geometry node used in the selection,
- **entities**, the list of the entity indexes listed in the selection, and
- **isGlobal**, Boolean value to indicate if the selection is global or not.
Handling Errors and Warnings

In this section:

- Errors and Warnings
- Using MATLAB® Tools to Handle COMSOL® Exceptions
- Displaying Warnings and Errors in the Model

Errors and Warnings

COMSOL Multiphysics reports these types of problems:

- Errors, which prevents the program from completing a task, and
- Warnings, which are problems that do not prevent the completion of a task but that might affect the accuracy or other aspects of the model.

For both errors and warnings a message is stored in a separate node located just below the problematic model feature node.

In case of errors, a Java® Exception is thrown to MATLAB®, which also breaks the execution of the script.

Using MATLAB® Tools to Handle COMSOL® Exceptions

When running a model that returns an error in MATLAB®, the execution of the script is automatically stopped. You can use MATLAB tools to handle exceptions and prevent the script from breaking. Use the try and catch MATLAB statements to offer alternatives to a failed model.

In a loop, for example, use the try and catch statements to continue to the next iteration. For automatic geometry or mesh generation you can use it to set the model properties with alternative values that circumvent the problem.

Displaying Warnings and Errors in the Model

Use the command mphshowerrors to search in a given model object for warning or error nodes. To display the error and warning messages and their location in the model object enter the command:

mphshowerrors(model)
Alternatively `mphshowerrors` can also return the error and warning information in a MATLAB® variable:

```matlab
str = mphshowerrors(model)
```

where `str` is an \( N \times 2 \) cell array, with \( N \) the number of error and warning nodes that contain the model object. \( str\{1,1\} \), which contains the location in the model of the \( i \)th error/warning message, \( str\{1,2\} \) contains the message of the \( i \)th error/warning message, \( str\{1,3\} \) contains a cell arrays of the model tree nodes that contain the error information. This last information make it easier to extract error information for automated processing of error and warning conditions.
Improving Performance for Large Models

Memory management is key to successful modeling. In COMSOL Multiphysics the finite element model can store a large amount of data depending on the complexity of the model. Exchanging such a large amount of data between MATLAB® and the COMSOL server can be problematic in terms of memory management or execution time. This section discusses the model settings if you are experiencing memory problems or slowness of command execution.

- Allocating Memory
- Disabling Model Feature Update
- Disabling The Model History

Allocating Memory

COMSOL Multiphysics stores the data in Java®. If you are experiencing memory problems during meshing, postprocessing operations, or when exchanging data between the COMSOL server and MATLAB®, this can mean that the Java heap size is set with too low a value.

Either set The COMSOL Multiphysics Server Java Heap Size or Setting Manually the Memory in MATLAB.

THE COMSOL MULTIPHYSICS SERVER JAVA HEAP SIZE

The Java heap size settings for the COMSOL Multiphysics Server process are stored in the `comsolmphserver.ini` file. You can find this file in the `COMSOL53a/Multiphysics/bin/<arch>` directory. `<arch>` correspond to the architecture of the machine where the COMSOL Multiphysics Server is running (win64, maci64, or glnxa64).

Edit the file with a text editor, the Java heap settings are defined as in the following lines:

Increasing the memory allocated for the Java process necessarily decreases the memory available for the solver.
-Xss4m
-Xms40m
-Xmx1024m
-XX:MaxPermSize=256m

The values are given in Mb, modify these value to satisfy the model requirements.

**SETTING MANUALLY THE MEMORY IN MATLAB**

To modify the Java heap size you need to edit the java.opts file available under the COMSOL with MATLAB start-up directory. The java.opts file is stored by default with the following settings:

- Xss4m
- Xmx768m
- XX:MaxPermSize=256m

The values are given in Mb, modify these value to satisfy the model requirements.

To modify the MATLAB Java Heap size the `java.opts` file has to be stored at the MATLAB start-up directory. This is the case when starting COMSOL with MATLAB.

---

If you are manually connecting MATLAB with a COMSOL Multiphysics Server, make sure you have the `java.opts` at the MATLAB start-up directory.

---

**Disabling Model Feature Update**

Every time a setting in changed in a model COMSOL Multiphysics automatically checks the settings for that particular feature and updates any other feature that may depend on the new setting. This ensures you that the features are built with updated expressions and that any error messages appear as soon as possible after a COMSOL command has been executed.

For models that contain a large amount of physics feature nodes this update operation can take some time. For small models this is not an issue, but for larger models the checks can be time consuming. It can help to deactivate the model feature update.

To disable the feature model update enter the command:

```java
model.disableUpdates(true)
```

You have to enable the feature update again prior to computing the solution in order to make sure that COMSOL works on an updated model definition. Enabling the
feature update is also necessary before building the geometry or the mesh in case these
are defined using expressions.

To enable the feature model update, enter the command:

```matlab
model.disableUpdates(false)
```

**Disabling The Model History**

If you run a model in a loop you can experience a slowdown when the number of
iterations increases. This happens only with a large amount of iterations. The
increasing memory requirements for storing the model history explains this slowdown.
You can see all the operations performed on the model when saving it as an M-file. If
you run a model in a loop you do not need to store the model history because it
contains the same operations as many times as you have iterations in the loop. The
solution is to disable the history recording. To do this, enter the command:

```matlab
model.hist.disable
```

When the model history is disabled you no longer see the commands used to set up
the model when saving it as an M-file.

The functions `mphload` and `mphopen` automatically disables the model
history when loading a model.

To activate the model history, enter the command:

```matlab
model.hist.enable```
Creating a Custom GUI

You can use the MATLAB® Guide or App Designer functionality to create a GUI and connect the interface to a COMSOL Multiphysics model object. Each operation in the GUI sets the value of a MATLAB variable or calls a MATLAB command. You can call commands at the MATLAB prompt to set up a COMSOL model object or set MATLAB variables in the COMSOL model object.

The figure below illustrates a GUI made in MATLAB and linked to a COMSOL model object.

The simplified GUI only allows the user to compute a heat transfer problem on a given geometry. The user can only change the radius and the position of the bottom circle geometry. The heat source applied to the bottom circle is also defined by the user.

The button executes the building operation of the geometry and mesh. Another button executes the computation of the solution.
Calling External Functions

This section introduces you to the MATLAB® function callback from the COMSOL Desktop® and COMSOL Multiphysics® model object.

In this chapter:

- Running External Function
- The MATLAB® Function Feature Node
Running External Function

When running the model containing a MATLAB function feature node, COMSOL Multiphysics automatically starts a MATLAB process that evaluates the function and returns the value to the COMSOL model.

You do not need to start COMSOL with MATLAB to call a MATLAB function from within the model; starting the COMSOL Desktop is sufficient. The MATLAB process starts automatically to evaluate the function.

On Linux operating systems, specify the MATLAB root directory path MLROOT and load the gcc library when starting the COMSOL Desktop: comsol -mlroot MLROOT -forcegcc.

Allowing External MATLAB functions

To run MATLAB functions you need to allow external processes in the security preferences.

In the COMSOL Desktop go to the Preferences and select Security, in the General section select Allow external MATLAB® functions. Then click OK.

In the COMSOL Server, you need to connect as administrator then go to Administration>Preferences, in the Security section set Allow external MATLAB® functions to On. Then click OK.

ALLOWING EXTERNAL PROCESSES IN THE COMMAND LINE

Add the flag -allowexternalmatlab on to the COMSOL start-up command to enable external processes.

Disabling MATLAB® Splash Screen at Start-up

To disable the MATLAB splash screen that pops-up when the MATLAB engine is started you need to create the environment variable COMSOL_MATLAB_INIT before starting COMSOL and set this variable with the value "matlab -nosplash".
Running a MATLAB® Function in Applications

To run an application from the COMSOL Server™ that uses an external MATLAB function, it is recommended to embed the function M-file in the application. The Application Builder offers the possibility to upload file that can then be accessible on the server. Under the Libraries node, select Files, and in the Files node’s Settings window, click the Add File to Library button ( ) to add the M-file to the library.

Applications that use external MATLAB function are not supported using the COMSOL Client. It is only possible to use such applications using a browser.

After embedding an M-file used by an existing MATLAB function, the embedded M-file will only be used for new solutions. So it is recommended to update any solutions that are saved in the application, if they depend on the embedded M-file.
The MATLAB® Function Feature Node

MATLAB® functions are global in scope and you can use them in a model to define model settings such as

- Parameters
- Geometry settings
- Mesh settings
- Material properties
- Physics settings (domain conditions, boundary conditions, etc.)

Material properties and physics settings are evaluated while the model is solved whereas the features can be used while the model is constructed.

- Defining a MATLAB® Function in the COMSOL® Model
- Setting the Function Directory Path in MATLAB®
- Adding a MATLAB® Function with the COMSOL® API Syntax
- Function Input/Output Considerations
- Updating Functions
- Defining Function Derivatives

Defining a MATLAB® Function in the COMSOL® Model

These topics are described for the MATLAB® function:

- Adding the MATLAB Function Node
- Defining the MATLAB Function
- Plotting the Function
- Example: Define the Hankel Function

Adding the MATLAB Function Node

To evaluate a MATLAB function from in the COMSOL Multiphysics model you need to add a MATLAB node in the model object where the function name, the list of the arguments, and, if required, the function derivatives, are defined.
To add a MATLAB function node, on the Home toolbar, click Functions and select Global>MATLAB.

The Settings window of the MATLAB node has these sections:

- **Functions**, where you declare the name of the MATLAB functions and their arguments.
- **Derivatives**, where you define the derivative of the MATLAB functions with respect to all function arguments.
- **Plot Parameters**, where you can define the limit of the arguments value in order to display the function in the COMSOL Desktop Graphics window.
DEFINING THE MATLAB FUNCTION

This figure illustrates the Settings window for MATLAB:

Under Functions, you define the function name and the list of the function arguments.

In the table columns and rows, enter the Function name and the associated function Arguments. The table supports multiple function definitions. You can define several functions in the same table or add several MATLAB nodes, as you prefer.

About Requirements for Functions and How to Test Them

Any function that you want to call using a MATLAB node must fulfill the following requirements:

- It can take any number of inputs as vectors and must return a single output vector.
- The input vectors can be of arbitrary size, but in a single call the inputs vectors will all have the same length. The returned vector must have exactly the same length as the input vectors.

For example, functions such as + and - (plus and minus) work well on vector inputs, but matrix multiplication (*, mtimes) and matrix power (^, mpower) do not. Instead, use the elementwise array operators .* and .^ See also Function Input/Output Considerations.
It is good practice to test your own functions and any MATLAB functions that you want to call from COMSOL Multiphysics by running them on the MATLAB command line using vectors with suitable values as inputs. For example, using `besselj`, a Bessel function of the first kind:

```matlab
input = (1:10)';
size(input)
out = besselj(input, input)
size(out)
```

Here there are no errors, and the size of the input and output is the same.

As another example, test the `corrcoef` function for computing correlation coefficients:

```matlab
input = (1:10)';
size(input)
out = corrcoef(input, input)
size(out)
```

There are no errors when calling `corrcoef` using vector inputs, but the result does not have the same size as the input and hence a call to `corrcoef` in this way will not work.

PLOTTING THE FUNCTION

Click the Plot button ( ) to display a plot of the function.

Click the Create Plot button ( ) to create a plot group under the Results node.

To plot the function you first need to define limits for the arguments. Expand the Plot Parameters section and enter the desired value in the Lower limit and Upper limit columns. In the Plot Parameters table the number of rows correspond to the number of input arguments of the function. The first input argument corresponds to the top row.

In case there are several functions declared in the Functions table, only the function that has the same number of input arguments as the number of filled in rows in the Plot Parameters table is plotted.

If several functions have the same number of input arguments, the first function in the table (from top to bottom) is plotted. Use the Move up (↑) and Move down (↓) buttons to change the order of functions in the table.
EXAMPLE: DEFINE THE HANKEL FUNCTION

Assume that you want to use MATLAB's Bessel function of the third kind (Hankel function) in a COMSOL model. Add a MATLAB function node, then define the following settings:

<table>
<thead>
<tr>
<th>FUNCTION NAME</th>
<th>ARGUMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>besselh</td>
<td>nu, x</td>
</tr>
</tbody>
</table>

To plot the function you need first to define the lower and upper limits for both \( \nu \) and \( x \). In the Plot Parameters table set the first row (which corresponds to the first argument \( \nu \)) of the Lower limit column to 0 and the Upper limit column to 5 and set the second row (corresponding of \( x \)) of the Lower limit column to 0 and the Upper limit column to 10:
Click the Plot button ( ) to get this plot:

![Plot](image)

**Setting the Function Directory Path in MATLAB®**

To be able to run a model that use an external MATLAB® function, the path directory of the function has to be set in MATLAB before it is called by COMSOL Multiphysics to evaluate the function.

To proceed you have these options to set the directory path in MATLAB:

- the model MPH-file in the same directory as for the M-functions;
- Set the system environment variable COMSOL_MATLAB_PATH with the M-functions directory path; or
- Use the Set Path window to specify the MATLAB search path. To open the window type `pathtool` at the MATLAB prompt or in the MATLAB desktop go the **Home** toolbar, **Environment** group.
Adding a MATLAB® Function with the COMSOL® API Syntax

To add a MATLAB® feature node to the COMSOL Multiphysics model using the COMSOL API, enter the command:

```python
model.func.create(<ftag>, 'MATLAB')
```

Define the function name and function arguments with the command:

```python
model.func(<ftag>).setIndex('funcs', <function_name>, 0, 0)
model.func(<ftag>).setIndex('funcs', <arglist>, 0, 1)
```

where `<function_name>` is a string set with the function name and `<arglist>` is a string that defines the list of the input arguments.

Function Input/Output Considerations

The functions called from COMSOL Multiphysics must support vector arguments of any length. COMSOL calls a MATLAB® function using vector arguments to reduce the number of expensive calls from COMSOL to MATLAB. All common MATLAB functions such as `sin`, `abs`, and other mathematical functions support vector arguments.

When you write your own functions, remember that the input arguments are vectors. The output must have the same size as the input. All arguments and results must be double-precision vectors real or complex valued.

Consider the following example function where the coefficient `$c$` depends on the `$x$` coordinate:

```matlab
function c = func1(x)
    if x > 0.6
        c = x/1.6;
    else
        c = x^2+0.3;
    end
```
This function looks good at first but it does not work in COMSOL Multiphysics because the input \( x \) is a vector:

- Element-by-element multiplication, division, and power must be used—that is, the operators .*, ./, and .^ . Replace expressions such as \( x/1.6 \) and \( x^2+0.3 \) with \( x ./1.6 \) and \( x .^ 2+0.3 \), respectively.
- The comparison \( x > 0.6 \) returns a matrix with ones (true) for the entries where the expression holds true and zeros (false) where it is false. The function evaluates the conditional statement if, and only if, all the entries are true (1).

You can replace the `if` statement with a single assignment to the indices retrieved from the \( x > 0.6 \) operation and another assignment to the indices where \( x \leq 0.6 \). The function could then look like this:

```matlab
function c = func2(x)
c = (x./1.6).*(x>0.6) + (x.^2+0.3).*(x<=0.6);
```

### Updating Functions

If the function M-file is modified using a text editor, click **Clear Functions** to ensure that the functions’ modifications are updated in the COMSOL Multiphysics model.

An alternative is to select the **Clear functions automatically before solving** check box.

### Defining Function Derivatives

Automatic differentiation is not supported with MATLAB® functions. In case the MATLAB function has Jacobian contributions, its derivatives with respect to the function input arguments need to be defined. By default COMSOL Multiphysics assumes the derivatives to be null.

Expand the **Derivatives** section to define the derivatives of the function with respect to the function arguments. In the table define the derivative for each function argument. In the **Function** column enter the function name, in the **Argument** column enter the
argument. Finally in the **Function derivative** column enter the expression for the corresponding derivative.

The function derivatives can also be defined by additional MATLAB functions.

The section, **Example: Define the Hankel Function**, defined the function derivative by entering the following settings in the table:

<table>
<thead>
<tr>
<th>FUNCTION</th>
<th>ARGUMENT</th>
<th>FUNCTION DERIVATIVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>besselh</td>
<td>nu</td>
<td>(besselh(nu-1,x) - besselh(nu+1,x))/2</td>
</tr>
<tr>
<td>besselh</td>
<td>x</td>
<td>(besselh(0,x) - besselh(2,x))/2</td>
</tr>
</tbody>
</table>

The table shows:

- **Function name**: besselh
- **Argument**: nu
- **Partial derivative**: (besselh(nu-1,x) - besselh(nu+1,x))/2

- **Function name**: besselh
- **Argument**: x
- **Partial derivative**: (besselh(0,x) - besselh(2,x))/2
The main reference for the syntax of the commands available with LiveLink™ for MATLAB® is the COMSOL Multiphysics Programming Reference Manual. This section documents additional interface functions that come with the product.

In this chapter:

- Summary of Commands
- Commands Grouped by Function
Summary of Commands

colortable  mphmeshstats
mphapplicationlibraries  mphmin
mphcd  mphmodel
mphdoc  mphnavigator
mpheval  mphopen
mphevalglobalmatrix  mphparticle
mphevalpoint  mphplot
mphevalpointmatrix  mphquad2tri
mphevaluate  mphray
mphgeom  mphreadstl
mphgetadj  mphreduction
mphgetcoords  mphsave
mphgetexpressions  mphsearch
mphgetproperties  mphselectbox
mphgetselection  mphselectcoords
mphgetu  mphshowerrors
mphglobal  mphsolinfo
mphimage2geom  mphsolutioninfo
mphinputmatrix  mphstart
mphint2  mphstate
mphinterp  mphparticle
mphinterpolationfile  mphparticle
mphlaunch  mphparticle
mphload  mphהלך
mphmatrix  mphverbatim
mphmax  mphversion
mphmean  mphviewselection
mphmesh  mphwritestl
mphmeshstats  mphxmeshinfo
# Commands Grouped by Function

## Interface Functions

<table>
<thead>
<tr>
<th>Function</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>mphcd</td>
<td>Change the directory to the directory of the model.</td>
</tr>
<tr>
<td>mphlaunch</td>
<td>Launch a COMSOL Multiphysics Client, connect it to the server and load a model.</td>
</tr>
<tr>
<td>mphload</td>
<td>Load a COMSOL model MPH-file.</td>
</tr>
<tr>
<td>mphopen</td>
<td>GUI for opening recent model files.</td>
</tr>
<tr>
<td>mphpsave</td>
<td>Save a COMSOL model.</td>
</tr>
<tr>
<td>mphstart</td>
<td>Connect MATLAB to a COMSOL server.</td>
</tr>
<tr>
<td>mphphtags</td>
<td>Get tags and names for nodes in a COMSOL model.</td>
</tr>
<tr>
<td>mphpthumbnail</td>
<td>Set or get model thumbnail.</td>
</tr>
<tr>
<td>mphversion</td>
<td>Return the version number of COMSOL Multiphysics</td>
</tr>
</tbody>
</table>

## Geometry Functions

<table>
<thead>
<tr>
<th>Function</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>mphgeom</td>
<td>Plot a geometry in a MATLAB figure.</td>
</tr>
<tr>
<td>mphimage2geom</td>
<td>Convert image data to geometry.</td>
</tr>
<tr>
<td>mphviewselection</td>
<td>Display a geometric entity selection in a MATLAB figure.</td>
</tr>
</tbody>
</table>

## Mesh Functions

<table>
<thead>
<tr>
<th>Function</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>mphmesh</td>
<td>Plot a mesh in a MATLAB figure.</td>
</tr>
<tr>
<td>mphmeshstats</td>
<td>Return mesh statistics and mesh data information.</td>
</tr>
</tbody>
</table>

## Utility Functions

<table>
<thead>
<tr>
<th>Function</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>mphevaluate</td>
<td>Evaluate Parameters expressions in model.</td>
</tr>
<tr>
<td>mphgetadj</td>
<td>Return geometric entity indices adjacent to each other.</td>
</tr>
<tr>
<td>mphgetcoords</td>
<td>Return point coordinates of geometry entities.</td>
</tr>
<tr>
<td>mphgetu</td>
<td>Return solution vectors.</td>
</tr>
<tr>
<td>FUNCTION</td>
<td>PURPOSE</td>
</tr>
<tr>
<td>---------------------</td>
<td>-------------------------------------------------------------------------</td>
</tr>
<tr>
<td>mphinputmatrix</td>
<td>Add matrix system for a linear solver.</td>
</tr>
<tr>
<td>mphinterpolationfile</td>
<td>Save data in file readable by the Interpolation feature.</td>
</tr>
<tr>
<td>mphmatrix</td>
<td>Get model matrices.</td>
</tr>
<tr>
<td>mphquad2tri</td>
<td>Convert plot data quad mesh into simplex mesh.</td>
</tr>
<tr>
<td>mphreadstl</td>
<td>Read an STL file and returns the data as a struct.</td>
</tr>
<tr>
<td>mphreduction</td>
<td>Return reduced order state space matrices for a model.</td>
</tr>
<tr>
<td>mphselectbox</td>
<td>Select a geometric entity using a rubber band/box.</td>
</tr>
<tr>
<td>mphselectcoords</td>
<td>Select a geometric entity using point coordinates.</td>
</tr>
<tr>
<td>mphsolinfo</td>
<td>Get information about a solution object.</td>
</tr>
<tr>
<td>mphsolutioninfo</td>
<td>Get information about solution objects and data sets containing given parameters.</td>
</tr>
<tr>
<td>mphstate</td>
<td>Get state space matrices for dynamic systems.</td>
</tr>
<tr>
<td>mphsurf</td>
<td>Create plot data structure from surf data.</td>
</tr>
<tr>
<td>mphwritestl</td>
<td>Export plot data as an STL file.</td>
</tr>
<tr>
<td>mphxmeshinfo</td>
<td>Extract information about the extended mesh.</td>
</tr>
</tbody>
</table>
### POSTPROCESSING FUNCTIONS

<table>
<thead>
<tr>
<th>FUNCTION</th>
<th>PURPOSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>mpheval</td>
<td>Evaluate expressions on node points.</td>
</tr>
<tr>
<td>mphevalglobalmatrix</td>
<td>Evaluate global matrix variables.</td>
</tr>
<tr>
<td>mphevalpoint</td>
<td>Evaluate expressions at geometry vertices.</td>
</tr>
<tr>
<td>mphevalpointmatrix</td>
<td>Evaluate matrix quantities at points in the geometry</td>
</tr>
<tr>
<td>mphglobal</td>
<td>Evaluate global quantities.</td>
</tr>
<tr>
<td>mphint2</td>
<td>Perform integration of expressions.</td>
</tr>
<tr>
<td>mphinterp</td>
<td>Evaluate expressions in arbitrary points or data sets.</td>
</tr>
<tr>
<td>mphmax</td>
<td>Perform maximum of expressions.</td>
</tr>
<tr>
<td>mphmean</td>
<td>Perform mean of expressions.</td>
</tr>
<tr>
<td>mphmin</td>
<td>Perform minimum of expressions.</td>
</tr>
<tr>
<td>mphparticle</td>
<td>Evaluate expressions on particle trajectories.</td>
</tr>
<tr>
<td>mphplot</td>
<td>Render a plot group in a figure window.</td>
</tr>
<tr>
<td>mphray</td>
<td>Evaluate expressions on particle and ray trajectories.</td>
</tr>
<tr>
<td>mphetable</td>
<td>Get table data.</td>
</tr>
</tbody>
</table>

### MODEL INFORMATION AND NAVIGATION

<table>
<thead>
<tr>
<th>FUNCTION</th>
<th>PURPOSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>mphapplicationlibraries</td>
<td>GUI for viewing the product Application Libraries.</td>
</tr>
<tr>
<td>mphdoc</td>
<td>Open help window for a certain topic</td>
</tr>
<tr>
<td>mphgetproperties</td>
<td>Get properties from a model node.</td>
</tr>
<tr>
<td>mphgetexpressions</td>
<td>Get the model variables and parameters.</td>
</tr>
<tr>
<td>mphgetselection</td>
<td>Get information about a selection node.</td>
</tr>
<tr>
<td>mphmodel</td>
<td>Return tags for the nodes and subnodes in the COMSOL model object.</td>
</tr>
<tr>
<td>mphnavigator</td>
<td>GUI for viewing the COMSOL model object.</td>
</tr>
<tr>
<td>mphsearch</td>
<td>GUI for searching expressions in the COMSOL model object.</td>
</tr>
<tr>
<td>mphshowerrors</td>
<td>Show messages in error and warning nodes in the COMSOL model object.</td>
</tr>
</tbody>
</table>
**colortable**

Return a MATLAB® colormap for a COMSOL Multiphysics color table.

**SYNTAX**

```matlab
map = colortable(name)
```

**DESCRIPTION**

`map = colortable(name)` returns the color table (of 1024 colors) for `name`, where `name` can be one of the following strings:

- **AuroraAustralis**: A color table that spans from white through green and indigo to blue as for the colors in the aurora australis (southern light).

- **AuroraBorealis**: This color table resembles the colors in the aurora borealis (northern light). The color table spans from white through green and indigo to blue but with a larger indigo portion.

- **Cividis**: Uses yellow and blue colors in a color table that is suited for normal vision, a deuteranomaly, or red-green colorblindness.

- **Cyclic**: A color table that varies the hue component of the hue-saturation-value color model, keeping the saturation and value constant (equal to 1). The colors begin with red, pass through yellow, green, cyan, blue, magenta, and return to red. This table is useful to display periodic functions and has a sharp color gradient.

- **Disco**: This color table spans from red through magenta and cyan to blue.

- **Discolight**: Similar to Disco but uses lighter colors.

- **Grayscale**: A color table that uses no color, only the gray scale varying linearly from black to white.

- **Grayprint**: Varies linearly from dark gray (0.95, 0.95, 0.95) to light gray (0.05, 0.05, 0.05). This color table overcomes two disadvantages that the GrayScale color table has when used for printouts on paper—it gives the impression of being dominated by dark colors and that white cannot be distinguished from the background.

- **HeatCamera**: The colors range from black through blue, magenta, red, and yellow to white, corresponding to the colors in an image from a heat camera.

- **HeatCameraLight**: Similar to HeatCamera but with slightly lighter colors.

- **JupiterAuroraBorealis**: The color table spans from black through blue to white as for the Jupiter’s aurora.
Rainbow - The color ordering in this table corresponds to the wavelengths of the visible part of the electromagnetic spectrum: beginning at the small-wavelength end with dark blue, the colors range through shades of blue, cyan, green, yellow, and red.

Rainbowlight - Similar to Rainbow, this color table uses lighter colors.

Thermal - Ranges from black through red and yellow to white, which corresponds to the colors iron takes as it heats up.

Thermalquidistant - Similar to Thermal but uses equal distances from black to red, yellow, and white, which means that the black and red regions become larger.

Traffic - Spans from green through yellow to red.

Trafficlight - Similar to Traffic but uses lighter colors.

Twilight - The color table uses colors associated with twilight (the illumination of the Earth’s lower atmosphere when the Sun is not directly visible), spanning colors from pink through white to blue.

Wave - Ranges linearly from blue to light gray, and then linearly from white to red. When the range of the visualized quantity is symmetric around zero, the color red or blue indicates whether the value is positive or negative, and the saturation indicates the magnitude.

Wavelight - Similar to Wave and ranges linearly from a lighter blue to white (instead of light gray) and then linearly from white to a lighter red.

Calling colortable is equivalent to calling the corresponding colormap function directly.

EXAMPLE

Create a rainbow color map

```matlab
map = colortable('Rainbow');
map = rainbow;
```

mphapplicationlibraries

Graphical user interface (GUI) for viewing the Application Libraries.

SYNTAX

mphapplicationlibraries
**DESCRIPTION**

mphapplicationlibraries starts a GUI to visualize and access the example model available in the COMSOL Application Libraries. The model MPH-file can be loaded in MATLAB®, and the model documentation PDF-file is accessible directly. Models that are specific to LiveLink™ for MATLAB® also contains the script M-file.

![GUI screenshot](image)

**SYNTAX**

mphcd(model)

**DESCRIPTION**

mphcd(model) changes the current directory in MATLAB® to the directory where the model was last saved.

**mphcd**

Change directory to the directory of the model.
**SEE ALSO**

*mphload, mphsave*

**mphdoc**

Open help window for a certain topic.

**SYNTAX**

mphdoc  
mphdoc(node)  
mphdoc(node,fname)  
mphdoc api

**DESCRIPTION**

mphdoc opens the COMSOL documentation Help Desk.

mphdoc(node) opens the help window for the entry on *node*.

mphdoc(node,fname) opens the help window for the entry on *node* with the feature *fname*.

mphdoc api opens a window with the JavaDoc help for the COMSOL API.

**EXAMPLE**

Create a model a model object:

```java
    model = ModelUtil.create('Model');
```

Get the documentation for the mesh node;

```java
    mphdoc(model.mesh)
```

Get the documentation of the geometry feature Rectangle:

```java
    mphdoc(model.geom,'Rectangle')
```

**SEE ALSO**

*mphapplicationlibraries*

**mpheval**

Evaluate expressions on node points.

**SYNTAX**

```java
    pd = mpheval(model,{e1,...,en},...)
```
**DESCRIPTION**

```
pd = mpheval(model,{e1,...,en},...) returns the post data pd for the expressions e1,...,en.
```

The output value pd is a structure with fields `expr`, `p`, `t`, `ve`, `unit` and fields for data values.

- The field `expr` contains the expression name evaluated.
- For each expression `e1,...,en` a field with the name `d1,... dn` is added with the numerical values. The columns in the data value fields correspond to node point coordinates in columns in `p`. The data contains only the real part of complex-valued expressions.
- The field `p` contains node point coordinate information. The number of rows in `p` is the number of space dimensions.
- The field `t` contains the indices to columns in `p` of a simplex mesh, each column in `t` representing a simplex.
- The field `ve` contains indices to mesh elements for each node point.
- The field `unit` contains the list of the unit for each expression.

The function `mpheval` accepts the following property/value pairs:

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>PROPERTY VALUE</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>complexfun</td>
<td>off</td>
<td>on</td>
<td>on</td>
</tr>
<tr>
<td>complexout</td>
<td>off</td>
<td>on</td>
<td>on</td>
</tr>
<tr>
<td>dataonly</td>
<td>off</td>
<td>on</td>
<td>off</td>
</tr>
<tr>
<td>dataset</td>
<td>String</td>
<td></td>
<td>Data set tag</td>
</tr>
<tr>
<td>edim</td>
<td>point</td>
<td>edge</td>
<td>boundary</td>
</tr>
<tr>
<td>matherr</td>
<td>off</td>
<td>on</td>
<td>off</td>
</tr>
<tr>
<td>outersolnum</td>
<td>Positive integer</td>
<td>all</td>
<td>end</td>
</tr>
<tr>
<td>pattern</td>
<td>lagrange</td>
<td>gauss</td>
<td>lagrange</td>
</tr>
</tbody>
</table>
The property `Dataset` controls which data set is used for the evaluation. Data Sets contain or refer to the source of data for postprocessing purposes. Evaluation is supported only on Solution Data Sets.

The property `Edim` decides which elements to evaluate on. Evaluation takes place only on elements with space dimension `Edim`. If not specified, `Edim` equal to the space dimension of the geometry is used. The setting is specified as one of the following strings ‘point’, ‘edge’, ‘boundary’ or ‘domain’. In previous versions it was only possible to specify `Edim` as a number. For example, in a 3D model, if evaluation is done on edges (1D elements), `Edim` is 1. Similarly, for boundary evaluation (2D elements), `Edim` is 2, and for domain evaluation (3D elements), `Edim` is 3 (default in 3D).

Use `Recover` to recover fields using polynomial-preserving recovery. This techniques recover fields with derivatives such as stresses or fluxes with a higher theoretical convergence than smoothing. Recovery is expensive so it is turned off by default. The value `pprint` means that recovery is performed inside domains. The value `ppr` means that recovery is also applied on all domain boundaries.

The property `Refine` constructs evaluation points by making a regular refinements of each element. Each mesh edge is divided into `Refine` equal parts.
The property Smooth controls if the post data is forced to be continuous on element edges. When Smooth is set to internal, only elements not on interior boundaries are made continuous.

The property Solnum is used to select the solution to plot when a parametric, eigenvalue or time-dependent solver has been used to solve the problem.

The property Outersolnum is used to select the solution to plot when a parametric sweep has been used in the study.

When the property Phase is used, the solution vector is multiplied with \( \exp(i\cdot\text{phase}) \) before evaluating the expression.

The expressions \( e_1, \ldots, e_n \) are evaluated for one or several solutions. Each solution generates an additional row in the data fields of the post data output structure. The property Solnum and \( t \) control which solutions are used for the evaluations. The Solnum property is available when the data set has multiple solutions, for example in the case of parametric, eigenfrequency, or time-dependent solutions. The \( t \) property is available only for time-dependent problems. If Solnum is provided, the solutions indicated by the indices provided with the Solnum property are used. If \( t \) is provided solutions are interpolated. If neither Solnum nor \( t \) is provided, all solutions are evaluated.

For time-dependent problems, the variable \( t \) can be used in the expressions \( e_i \). The value of \( t \) is the interpolation time when the property \( t \) is provided, and the time for the solution, when Solnum is used. Similarly, \( \lambda \) and the parameter are available as eigenvalues for eigenvalue problems and as parameter values for parametric problems, respectively.

**EXAMPLE**

Evaluate the temperature at node points:

```matlab
model = mphopen('model_tutorial_llmatlab');
std = model.study.create('std');
std.feature.create('stat','Stationary');
std.run;
dat = mpheval(model,'T');
```

Evaluate both the total heat flux magnitude and the temperature:

```matlab
data = mpheval(model,{'ht.tfluxMag', 'T'});
```

Evaluate the temperature and return the data only:

```matlab
data = mpheval(model,'T','dataonly','on');
```
Evaluate the temperature at the node points in domain 2:
   data = mpheval(model,'T','selection',2);
Evaluate the temperature at the node points on boundary 7:
   data = mpheval(model,'T','selection',7,'edim','boundary');
Evaluate the temperature at second order Lagrange points:
   data = mpheval(model,'T','refine',2);
Evaluate the temperature at the Gauss points:
   data = mpheval(model,'T','pattern','gauss');
Evaluate the temperature at every time step computed with power set to 30:
   model = mphopen('model_tutorial_llmatlab');
   std = model.study.create('std');
   param = std.feature.create('param','Parametric');
   time = std.feature.create('time','Transient');
   time.set('tlist', 'range(0,1,25)');
   param.setIndex('pname','power',0);
   param.setIndex('plistarr','30 60 90',0);
   std.run;
   data = mpheval(model,'T','dataset','dset2');
Evaluate the temperature at the fifth time step:
   data = mpheval(model,'T','dataset','dset2','solnum',5);
Evaluate the temperature at 10.5 sec and 15.2 sec:
   data = mpheval(model,'T','dataset','dset2','t',[10.5,15.2]);
Evaluate the temperature at every time step computed with power set to 90:
   data = mpheval(model,'T','dataset','dset2','outersolnum',3);

SEE ALSO
mphevalglobalmatrix, mphevalpoint, mphevalpointmatrix, mphglobal,
mphint2, mphinterp, mphparticle, mphray

mphevalglobalmatrix
Evaluate global matrix variables.

SYNTAX
M = mphevalglobalmatrix(model,expr,...)
**DESCRIPTION**

\[ M = \text{mphevalglobalmatrix}(\text{model}, \text{expr}, \ldots) \]

evaluates the global matrix of the variable \text{expr} and returns the full matrix \( M \).

The function \text{mphevalglobalmatrix} accepts the following property/value pairs:

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>PROPERTY VALUE</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>dataset</td>
<td>String</td>
<td></td>
<td>Data set tag</td>
</tr>
<tr>
<td>dataseries</td>
<td>none</td>
<td>average</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>sum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>outerdataseries</td>
<td>none</td>
<td>average</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>sum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>outerolsolnum</td>
<td>Positive integer</td>
<td>end</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>all</td>
<td></td>
<td></td>
</tr>
<tr>
<td>solnum</td>
<td>Integer vector</td>
<td>end</td>
<td>all</td>
</tr>
<tr>
<td></td>
<td>all</td>
<td></td>
<td></td>
</tr>
<tr>
<td>t</td>
<td>Double array</td>
<td></td>
<td>Time for evaluation</td>
</tr>
<tr>
<td>trans</td>
<td>none</td>
<td>inverse</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>maxwellmutual</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>mutualmaxwell</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>sy</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>sz</td>
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<tr>
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<td>ys</td>
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<td></td>
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</tr>
<tr>
<td></td>
<td>zs</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>zy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>y0</td>
<td>Double array</td>
<td>Taken from the physics interfaces</td>
<td>If \text{trans} is sy or ys: The characteristic admittance</td>
</tr>
<tr>
<td>z0</td>
<td>Double array</td>
<td>Taken from the physics interfaces</td>
<td>If \text{trans} is sz or zs: The characteristic impedance</td>
</tr>
</tbody>
</table>

**Note:** S-parameters evaluation requires the RF module.

**EXAMPLE**

Load \text{lossy_circulator}_3d.mph from the RF Module’s Applications Libraries:

\[ \text{model} = \text{mphopen}('\text{lossy_circulator}_3d.mph'); \]

Evaluate the S-parameters matrix using the solution data set \text{dset4}:
M = mphevalglobalmatrix(model,'emw.SdB','dataset','dset4');

SEE ALSO
mpheval, mphevalpoint, mphevalpointmatrix, mphglobal, mphint2, mphinterp, mphparticle, mphray

**mphevalpoint**
Evaluate expressions at geometry vertices.

**SYNTAX**
\[
[v1,...,vn] = \text{mphevalpoint}(\text{model},\{e1,...,en\},...)
\]
\[
[v1,...,vn,\text{unit}] = \text{mphevalpoint}(\text{model},\{e1,...,en\},...)
\]

**DESCRIPTION**
\[
[v1,...,vn] = \text{mphevalpoint}(\text{model},\{e1,...,en\},...) \text{ returns the results from evaluating the expressions } e1,...,en \text{ at the geometry vertices. The values } v1,...,vn \text{ can either be a cell array or a matrix depending on the options.}
\]
\[
[v1,...,vn,\text{unit}] = \text{mphevalpoint}(\text{model},\{e1,...,en\},...) \text{ also returns the unit of all expressions } e1,...,en \text{ in the 1xN cell array } \text{unit}.
\]

The function **mphevalpoint** accepts the following property/value pairs:

**TABLE 6-3: PROPERTY/VALUE PAIRS For the MPHEVALPOINT COMMAND.**

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>PROPERTY VALUE</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>dataset</td>
<td>String</td>
<td>none</td>
<td>Data set tag</td>
</tr>
<tr>
<td>dataseries</td>
<td>none</td>
<td>mean</td>
<td>int</td>
</tr>
<tr>
<td>matrix</td>
<td>off</td>
<td>on</td>
<td>on</td>
</tr>
<tr>
<td>minmaxobj</td>
<td>Real</td>
<td>abs</td>
<td>real</td>
</tr>
<tr>
<td>outersolnum</td>
<td>Positive integer</td>
<td>1</td>
<td>Solution number for parametric sweep</td>
</tr>
<tr>
<td>selection</td>
<td>Integer vector</td>
<td>all domains</td>
<td>Set selection tag or entity number</td>
</tr>
</tbody>
</table>

COMMANDS GROUPED BY FUNCTION | 263
The property `Dataset` controls which data set is used for the evaluation. Data Sets contain or refer to the source of data for postprocessing purposes. Evaluation is supported only on Solution Data Sets.

The `Dataseries` property is used to control any filtering of the data series. The supported operations are: average (`mean`), integral (`int`), maximum (`max`), minimum (`min`), root mean square (`rms`), standard deviation (`std`) and variance (`var`).

Set the property `Matrix` to `off` to get the results in a cell array format.

In case the property `Dataseries` is either `min` or `max`, you can specify the how the value are treated using the property `Minmaxobj`. Use either the real data or the absolute data.

The property `Solnum` is used to select the solution to plot when a parametric, eigenvalue or time-dependent solver has been used to solve the problem.

The expressions $e_1, \ldots, e_n$ are evaluated for one or several solutions. Each solution generates an additional row in the data fields of the post data output structure. The property `Solnum` and $t$ control which solutions are used for the evaluations. The `Solnum` property is available when the data set has multiple solutions, for example in the case of parametric, eigenfrequency, or time-dependent solutions. The $t$ property is available only for time-dependent problems. If `Solnum` is provided, the solutions indicated by the indices provided with the `Solnum` property are used. If `t` is provided solutions are interpolated. If neither `Solnum` nor `t` is provided, all solutions are evaluated.

For time-dependent problems, the variable $t$ can be used in the expressions $e_i$. The value of $t$ is the interpolation time when the property $t$ is provided, and the time for the solution, when `Solnum` is used. Similarly, `lambda` and the parameter are available as eigenvalues for eigenvalue problems and as parameter values for parametric problems, respectively.
EXAMPLE
Evaluate the temperature on all geometry points:

```matlab
model = mphopen('model_tutorial_llmatlab');
std = model.study.create('std');
std.feature.create('stat','Stationary'); std.run;
T = mphevalpoint(model,'T');
```

Evaluate the temperature on point 5:

```matlab
T = mphevalpoint(model,'T','selection',5);
```

Evaluate the temperature and the magnitude of the total heat flux on point 5:

```matlab
[T, heatflux, unit] = mphevalpoint(model,{ 'T','ht.tfluxMag' },... 
' selection',5);
```

Evaluate the temperature at every time step computed with power set to 30:

```matlab
model = mphopen('model_tutorial_llmatlab');
std = model.study.create('std');
param = std.feature.create('param','Parametric');
time = std.feature.create('time','Transient');
time.set('tlist', 'range(0,1,25)');
param.setIndex('pname','power',0)
param.setIndex('plistarr','30 60 90',0);
std.run;
T = mphevalpoint(model,'T','selection',5,'dataset','dset2');
```

Evaluate the temperature at the seventh time step:

```matlab
T = mphevalpoint(model,'T','selection',5,'dataset','dset2',... 
'solnum',7);
```

Evaluate the temperature at 10.5 sec:

```matlab
T = mphevalpoint(model,'T','selection',5,'dataset','dset2',... 
't',10.5);
```

Evaluate the temperature on point 5 computed with power set to 90:

```matlab
T = mphevalpoint(model,'T','selection',5,'dataset','dset2',... 
'outersolnum',3)
```

Evaluate the temperature average over all time steps:

```matlab
T_avg = mphevalpoint(model,'T','selection',5,... 
'dataset','dset2','dataseries','average');
```
**SEE ALSO**
mpheval, mphevalglobalmatrix, mphevalpointmatrix, mphglobal, mphint2, mphinterp, mphparticle, mphray

---

**mphevalpointmatrix**

Evaluate matrix quantities at points in the geometry.

**SYNTAX**

\[
M = \text{mphevalpointmatrix}(\text{model}, \text{expr}, \ldots)
\]

**DESCRIPTION**

\( M = \text{mphevalpointmatrix}(\text{model}, \text{expr}, \ldots) \) evaluates the point matrix of the variable \( \text{expr} \) and returns the full matrix \( M \).

The function \( \text{mphevalpointmatrix} \) accepts the following property/value pairs:

**TABLE 6-4: PROPERTY/VALUE PAIRS FOR THE MPHEVAL COMMAND.**

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>PROPERTY VALUE</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>dataset</td>
<td>String</td>
<td></td>
<td>Data set tag</td>
</tr>
<tr>
<td>dataseries</td>
<td>none</td>
<td>average</td>
<td>sum</td>
</tr>
<tr>
<td>outersolnum</td>
<td>Positive integer</td>
<td>1</td>
<td>Solution number for parametric sweep</td>
</tr>
<tr>
<td>selection</td>
<td>String</td>
<td>positive integer</td>
<td>array</td>
</tr>
<tr>
<td>solnum</td>
<td>Integer</td>
<td>vector</td>
<td>end</td>
</tr>
<tr>
<td>t</td>
<td>Double</td>
<td>array</td>
<td>Time for evaluation</td>
</tr>
</tbody>
</table>

**SEE ALSO**
mpheval, mphevalglobalmatrix, mphevalpoint, mphglobal, mphint2, mphinterp, mphparticle, mphray
mphevaluate

Evaluate parameter expressions in models.

**SYNTAX**

mphevaluate(model, expr)
str = mphevaluate(model)
[value, unit, def, descr] = mphevaluate(model, expr,...)
[value,...] = mphevaluate(model, expr, unit)
[value,...] = mphevaluate(model, expr, asvalue)

**DESCRIPTION**

mphevaluate(model, expr) evaluates the expression expr defined in the Parameters node.

str = mphevaluate(model) returns all the expressions defined in the Parameters node as a structs arrays.

str = mphevaluate(model,{e1,...}) returns all the expressions defined in the cell array {e1,...} as a structs arrays. When multiple expressions are evaluated only one output is supported.

[value,unit,def,descr] = mphevaluate(model,expr,...) evaluates the expression expr and return the unit (unit), the definition in the model (def) and the description (descr).

[value,...] = mphevaluate(model,expr,unit) evaluates the expression expr in the unit defined by unit.

value = mphevaluate(model,expr,unit,'value') returns only the value of the expression expr.

unit = mphevaluate(model,expr,unit,'unit') returns only the unit of the expression expr.

def = mphevaluate(model,expr,unit,'valueunit') returns as a string the value and the unit of the expression expr. This is useful to set a new parameter based on an existing one.

The evaluation does not require an existing solution data set in the model.

**EXAMPLE**

Evaluate the parameter power defined in the model:

```matlab
model = mphopen('model_tutorial_llmatlab');
```
power = mphevaluate(model,'power');

Evaluate Temp in degrees Celsius and its definition in the model:

[Temp,unit,def] = mphevaluate(model,'Temp','degC');

Evaluate an expression of parameters:

Temp = mphevaluate(model,'Temp+20[degC]','degF');

SEE ALSO
mpheval, mphglobal, mphinterp, mphparticle, mphray

mphgeom

Plot a geometry in a MATLAB® figure.

SYNTAX
mphgeom(model)

mphgeom(model, geomtag, ...)

DESCRIPTION
mphgeom(model) plots the model geometry in a MATLAB figure.

mphgeom(model, geomtag, ...) plots the model geometry with the tag geomtag in a MATLAB figure. If the model only contains one geometry then the geomtag can be empty.

The function mphgeom accepts the following property/value pairs:

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>VALUE</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>build</td>
<td>on</td>
<td>off</td>
<td>current</td>
</tr>
<tr>
<td>domainlabels</td>
<td>on</td>
<td>off</td>
<td>off</td>
</tr>
<tr>
<td>domainlabelscolor</td>
<td>Char</td>
<td>k</td>
<td></td>
</tr>
<tr>
<td>edgecolor</td>
<td>Char</td>
<td>k</td>
<td></td>
</tr>
<tr>
<td>edgelabels</td>
<td>on</td>
<td>off</td>
<td>off</td>
</tr>
<tr>
<td>edgelabelscolor</td>
<td>Char</td>
<td>k</td>
<td></td>
</tr>
<tr>
<td>edgemode</td>
<td>on</td>
<td>off</td>
<td>on</td>
</tr>
</tbody>
</table>
The `Build` property determines if `mphgeom` build the geometry prior to display it. If the `Build` property is set with a geometric object tag, the geometry is built up to that object. `mphgeom` only displays built geometry objects.

**Example**

Plot the model geometry:

```matlab
model = mphopen('model_tutorial_llmatlab.mph');
mphgeom(model)
```

Plot the model geometry with face labels:

```matlab
mphgeom(model,'geom1','facelabels','on','facelabelscolor','r');
```

Plot boundaries 7, 8, 9 and 11:

```matlab
mphgeom(model,'geom1','entity','boundary',... 'selection',[7:9,11]);
```
The geometry can be plotted with view settings applied. This results in a geometry plot with grid, axes labels, lights, hiding etc. applied to the plot. Usually it is sufficient to use the auto setting, but any valid view can be applied:

```matlab
mphmesh(model, 'mesh1', 'view', 'auto')
```

Plot the model geometry on an existing axis:

```matlab
figure(2);
mphgeom(model, 'geom1','parent',(gca);
```

SEE ALSO

`mphmesh`, `mphviewselection`

**mphgetadj**

Return geometry entity indices that are adjacent to each other.

**SYNTAX**

```matlab
n = mphgetadj(model,geomtag,returntype,adjtype,adjnumber)
```

**DESCRIPTION**

`n = mphgetadj(model,geomtag,returntype,adjtype,adjnumber)` returns the indices of the adjacent geometry entities.

- `returntype` is the type of the geometry entities whose index are returned.
- `adjtype` is the type of the input geometry entity.

The entity type can be one of 'point', 'edge', 'boundary' or 'domain' following the entity space dimension defined below:

- 'domain': maximum geometry space dimension
- 'boundary': maximum geometry space dimension -1
- 'edges': 1 (only for 3D geometry)
- 'point': 0

**EXAMPLE**

Return the indices of the boundaries adjacent to point 2:

```matlab
model = mphopen('model_tutorial_llmatlab');
bnd_idx = mphgetadj(model, 'geom1', 'boundary', 'point', 2);
```

Return the indices of the points adjacent to domain 2:

```matlab
...
pt_idx = mphgetadj(model, 'geom1', 'point', 'domain', 2);

SEE ALSO
mphgetcoords, mphselectbox, mphselectcoords

mphgetcoords
Return point coordinates of geometry entities.

SYNTAX
\[ c = \text{mphgetcoords}(\text{model}, \text{geomtag}, \text{entitytype}, \text{entitynumber}) \]

DESCRIPTION
\( c = \text{mphgetcoords}(\text{model}, \text{geomtag}, \text{entitytype}, \text{entitynumber}) \) returns the coordinates of the points that belong to the entity object with the type \text{entitytype} and the index \text{entitynumber}.

The \text{entitytype} property can be one of 'point', 'edge', 'boundary' or 'domain' following the entity space dimension defined below:

- 'domain': maximum geometry space dimension
- 'boundary': maximum geometry space dimension -1
- 'edge': 1 (only for 3D geometry)
- 'point': 0

EXAMPLE
Return the coordinates of points that belong to domain 2:
\[
\begin{align*}
\text{model} &= \text{mphopen('model_tutorial_llmatlab')}; \\
\text{c0} &= \text{mphgetcoords}\text{(model, 'geom1', 'domain', 2)};
\end{align*}
\]

Return the coordinates of points that belong to boundary 5:
\[
\begin{align*}
\text{c1} &= \text{mphgetcoords}\text{(model, 'geom1', 'boundary', 5)};
\end{align*}
\]

Return the coordinates of point number 10:
\[
\begin{align*}
\text{c2} &= \text{mphgetcoords}\text{(model, 'geom1', 'point', 10)};
\end{align*}
\]

SEE ALSO
mphgetadj, mphselectbox, mphselectcoords
**mphgetexpressions**

Get the model variables and model parameters expressions.

**SYNTAX**

```matlab
expr = mphgetexpressions(modelnode)
```

**DESCRIPTION**

`expr = mphgetexpressions(modelnode)` returns expressions from the node `modelnode` as a cell array. `expr` contains the list of the variable names, the variable expressions and the variable descriptions.

Note that not all nodes have expressions defined.

**EXAMPLE**

Get the expressions defined in the parameters node

```matlab
model = mphopen('model_tutorial_llmatlab');
expr = mphgetexpressions(model.param)
```

**SEE ALSO**

`mphgetproperties`, `mphgetselection`, `mphmodel`, `mphnavigator`, `mphsearch`

**mphgetproperties**

Get the properties from a model node.

**SYNTAX**

```matlab
str = mphgetproperties(modelnode)
[str,allowed] = mphgetproperties(modelnode)
```

**DESCRIPTION**

`str = mphgetproperties(modelnode)` returns the structure `str` containing the properties that are defined for the node `modelnode`.

`[str,allowed] = mphgetproperties(modelnode)` also returns the structure `allowed` containing the allowed values for the corresponding properties.

**EXAMPLE**

Build the mesh in the model `model_tutorial_llmatlab.mph` and get the mesh size properties and their allowed values:

```matlab
model = mphopen('model_tutorial_llmatlab');
```
mesh1 = model.component('comp1').mesh('mesh1');
mesh1.run;
msize = mesh1.feature('size');
[prop, allowed] = mphgetproperties(msize)

SEE ALSO
mphgetexpressions, mphgetselection, mphmodel, mphnavigator, mphsearch

mphgetselection
Get information about a selection node.

SYNTAX
info = mphgetselection(selnode)

DESCRIPTION
info = mphgetselection(selnode) returns the selection data of the selection node selnode.

The output info is a MATLAB® structure defined with the following fields:
- dimension, the space dimension of the geometry entity selected.
- geom, the geometry tag.
- entities, the indexes of the selected entities.
- isGlobal, a Boolean expression that indicates if the selection is global.

EXAMPLE
Add a selection node to the model busbar.mph and retrieve its information:

    model = mphopen('model_tutorial_llmatlab.mph');
    ball = model.selection.create('ball','Ball');
    ball.set('entitydim',2);
    ball.set('posz',11e-3);
    ball.set('r',1e-5);
    info = mphgetselection(model.selection('ball'))

SEE ALSO
mphgetexpressions, mphgetproperties, mphmodel, mphnavigator, mphsearch

mphgetu
Return a solution vector.
**SYNTAX**

\[ U = \text{mphgetu}(\text{model},...) \]

\[ [U, Udot] = \text{mphgetu}(\text{model},...) \]

**DESCRIPTION**

\( U = \text{mphgetu}(\text{model}) \) returns the solution vector \( U \) for the default solution data set.

\( [U, Udot] = \text{mphgetu}(\text{model},...) \) returns in addition \( Udot \), which is the time derivative of the solution vector. This syntax is available for a time-dependent solution only.

For a time-dependent and parametric analysis type, the last solution is returned by default. For an eigenvalue analysis type the first solution number is returned by default.

The function \( \text{mphgetu} \) accepts the following property/value pairs:

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>VALUE</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>soltag</td>
<td>String</td>
<td></td>
<td>Solver node tag</td>
</tr>
<tr>
<td>solnum</td>
<td>Positive integer vector</td>
<td></td>
<td>Solution for evaluation</td>
</tr>
<tr>
<td>type</td>
<td>String</td>
<td>Sol</td>
<td>Solution type</td>
</tr>
<tr>
<td>matrix</td>
<td>off</td>
<td>on</td>
<td>on</td>
</tr>
</tbody>
</table>

The \text{solname} property sets the solution data set to use associated with the defined solver node.

Type is used to select the solution type. This is 'Sol' by default. The valid types are: 'Sol' (main solution), 'Reacf' (reaction force), 'Adj' (adjoint solution), 'Fsens' (functional sensitivity) and 'Sens' (forward sensitivity).

If \text{solnum} is a vector and the result has been obtained with the same mesh then the solution is stored in a matrix if the \text{Matrix} option is set to 'on'.

**EXAMPLE**

Extract the solution vector:

```matlab
model = mphopen('model_tutorial_llmatlab');
std = model.study.create('std');
std.feature.create('stat','Stationary');
std.run;
U = mphgetu(model);
```

Extract the reaction force vector:
reacf = mphgetu(model,'type','reacf');

Extract the solution vectors for the first and the last time step:

model = mphopen('model_tutorial_llmatlab');
std = model.study.create('std');
param = std.feature.create('param','Parametric');
time = std.feature.create('time','Transient');
time.set('tlist', 'range(0,1,25)');
param.setIndex('pname','power',0);
param.setIndex('plistarr','30 60 90',0);
std.run;
U = mphgetu(model,'solnum',[1,26]);

Extract the solution vector computed with power set to 30:
U = mphgetu(model,'soltag','sol13');

SEE ALSO
mphsolinfo

mphglobal

Evaluate global quantities.

SYNTAX
[d1,...,dn] = mphglobal(model,{e1,...,en},...)
[d1,...,dn,unit] = mphglobal(model,{e1,...,en},...)

DESCRIPTION
[d1,...,dn] = mphglobal(model,{e1,...,en},...), returns the results from evaluating the global quantities specified in the string expression e1,..., en.

[d1,...,dn,unit] = mphglobal(model,{e1,...,en},...), also returns the unit of the expressions e1,..., en. unit is a nx1 cell array.

The function mphglobal accepts the following property/value pairs:

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>PROPERTY VALUE</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>complexfun</td>
<td>off</td>
<td>on</td>
<td>on</td>
</tr>
<tr>
<td>complexout</td>
<td>off</td>
<td>on</td>
<td>on</td>
</tr>
<tr>
<td>dataset</td>
<td>String</td>
<td>Active solution data set</td>
<td>Data set tag</td>
</tr>
</tbody>
</table>
The property `Dataset` controls which data set is used for the evaluation. Data Sets contain or refer to the source of data for postprocessing purposes. Evaluation is supported only on solution data sets.

When the property `Phase` is used, the solution vector is multiplied with \( \exp(i \cdot \text{phase}) \) before evaluating the expression.

The expressions \( \theta_i \) are evaluated for one or several solutions. Each solution generates an additional row in the output data array \( d_i \). The property `solnum` and `t` control which solutions are used for the evaluations. The `solnum` property is available when the data set has multiple solutions, for example in the case of parametric, eigenfrequency, or time-dependent solutions. The `t` property is available only for time-dependent problems. If `solnum` is provided, the solutions indicated by the indices provided with the `solnum` property are used. If `t` is provided solutions are interpolated. If neither `solnum` nor `t` is provided, all solutions are evaluated.

For time-dependent problems, the variable `t` can be used in the expressions \( \theta_i \). The value of `t` is the interpolation time when the property `t` is provided, and the time for the solution, when `solnum` is used. Similarly, `lambda` and the parameter are available as eigenvalues for eigenvalue problems and as parameter values for parametric problems, respectively.

In case of multiple expression if the `unit` property is defined with a string, the same unit is used for both expressions. To use different units, set the property with a cell array. In case of inconsistent unit definition, the default unit is used instead.

Solnum is used to select the solution number when a parametric, eigenvalue or time-dependent solver has been used.

---

### TABLE 6-7: PROPERTY/VALUE PAIRS FOR THE MPHGLOBAL COMMAND.

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>PROPERTY VALUE</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>materrr</td>
<td>off</td>
<td>on</td>
<td>off</td>
</tr>
<tr>
<td>outsolnum</td>
<td>Positive integer</td>
<td>all</td>
<td>end</td>
</tr>
<tr>
<td>phase</td>
<td>Scalar</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>solnum</td>
<td>Integer vector</td>
<td>all</td>
<td>end</td>
</tr>
<tr>
<td>t</td>
<td>Double array</td>
<td></td>
<td></td>
</tr>
<tr>
<td>unit</td>
<td>String</td>
<td>cell array</td>
<td></td>
</tr>
</tbody>
</table>

The property `Dataset` controls which data set is used for the evaluation. Data Sets contain or refer to the source of data for postprocessing purposes. Evaluation is supported only on solution data sets.

When the property `Phase` is used, the solution vector is multiplied with \( \exp(i \cdot \text{phase}) \) before evaluating the expression.

The expressions \( \theta_i \) are evaluated for one or several solutions. Each solution generates an additional row in the output data array \( d_i \). The property `solnum` and `t` control which solutions are used for the evaluations. The `solnum` property is available when the data set has multiple solutions, for example in the case of parametric, eigenfrequency, or time-dependent solutions. The `t` property is available only for time-dependent problems. If `solnum` is provided, the solutions indicated by the indices provided with the `solnum` property are used. If `t` is provided solutions are interpolated. If neither `solnum` nor `t` is provided, all solutions are evaluated.

For time-dependent problems, the variable `t` can be used in the expressions \( \theta_i \). The value of `t` is the interpolation time when the property `t` is provided, and the time for the solution, when `solnum` is used. Similarly, `lambda` and the parameter are available as eigenvalues for eigenvalue problems and as parameter values for parametric problems, respectively.

In case of multiple expression if the `unit` property is defined with a string, the same unit is used for both expressions. To use different units, set the property with a cell array. In case of inconsistent unit definition, the default unit is used instead.

Solnum is used to select the solution number when a parametric, eigenvalue or time-dependent solver has been used.
Outersolnum is used to select the outer solution number when a parametric sweep has been used in the study step node.

**EXAMPLE**

Evaluate the maximum temperature in the model

```matlab
model = mphopen('model_tutorial_llmatlab');
model.cpl.create('maxop', 'Maximum', 'geom1').selection.all;
std = model.study.create('std');
std.feature.create('stat', 'Stationary');
std.run;
maxT = mphglobal(model, 'maxop(T)')
```

Evaluate the maximum temperature in the model in degrees Celsius

```matlab
maxT = mphglobal(model, 'maxop(T)', 'unit', 'degC')
```

Evaluate a global expression at every time step computed with power set to 30:

```matlab
model = mphopen('model_tutorial_llmatlab');
model.cpl.create('maxop', 'Maximum', 'geom1').selection.all;
std = model.study.create('std');
param = std.feature.create('param', 'Parametric');
time = std.feature.create('time', 'Transient');
time.set('tlist', 'range(0,1,25)');
param.setIndex('pname', 'power', 0);
param.setIndex('plistarr', '30 60 90', 0);
std.run;
maxT = mphglobal(model, 'maxop(T)', 'dataset', 'dset2');
```

Evaluate maxop(T) for the first and fifth time step:

```matlab
maxT = mphglobal(model, 'maxop(T)', 'dataset', 'dset2', ...
'solnum', [1,5]);
```

Evaluate maxop(T) at 20.512 sec:

```matlab
maxT = mphglobal(model, 'maxop(T)', 'dataset', 'dset2', ...
't', 20.512);
```

Evaluate maxop(T) at every time step computed with power set to 90:

```matlab
maxT = mphglobal(model, 'maxop(T)', 'dataset', 'dset2', ...
'outersolnum', 3);
```

**SEE ALSO**

mpheval, mphevalglobalmatrix, mphevalpoint, mphevalpointmatrix, mphint2, mphinterp
**mphimage2geom**

Convert image data to a geometry.

**SYNTAX**

```matlab
model = mphimage2geom(imagedata, level,...)
```

**DESCRIPTION**

`model = mphimage2geom(imagedata, level,...)` converts the image contained in `imagedata` into a geometry which is returned in the model object `model`.

The contour of the image is defined by the value `level`. `imagedata` must be a 2D matrix.

The function `mphimage2geom` accepts the following property/value pairs:

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>PROPERTY VALUE</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>compose</td>
<td>on</td>
<td>off</td>
<td>on</td>
</tr>
<tr>
<td>curvetype</td>
<td>auto</td>
<td>polygon</td>
<td>auto</td>
</tr>
<tr>
<td>geom</td>
<td>Geometry node</td>
<td>geom1</td>
<td>Geometry creation</td>
</tr>
<tr>
<td>minarea</td>
<td>Value</td>
<td>1</td>
<td>Minimum area for interior curves (in square pixels)</td>
</tr>
<tr>
<td>mindist</td>
<td>Value</td>
<td>1</td>
<td>Minimum distance between coordinates in curves (in pixels)</td>
</tr>
<tr>
<td>modeltag</td>
<td>String</td>
<td>Model</td>
<td>Model tag in the COMSOL server</td>
</tr>
<tr>
<td>rectangle</td>
<td>on</td>
<td>off</td>
<td>off</td>
</tr>
<tr>
<td>rtol</td>
<td>Value</td>
<td>1e-3</td>
<td>Relative tolerance for interpolation curves</td>
</tr>
<tr>
<td>scale</td>
<td>Value</td>
<td>1</td>
<td>Scale factor from pixels to geometry scale</td>
</tr>
<tr>
<td>type</td>
<td>solid</td>
<td>closed</td>
<td>solid</td>
</tr>
</tbody>
</table>
The default curve types creates a geometry with the best suited geometrical primitives. For interior curves this is Interpolation Curves and for curves that are touching the perimeter of the image, Polygons is used.

To add the geometry created with mphimage2geom, specify the geometry node with property Geom.

**EXAMPLE**
Create a set of point coordinates:

```matlab
p = (peaks+7)*5;
```

Display contour plot of the point data:

```matlab
figure(1); [c,h] = contourf(p); clabel(c, h); colorbar
```

Create a geometry object following the contour made with point of value 50:

```matlab
model = mphimage2geom(p, 50);
figure(2); mphgeom(model)
```

Create the same geometry object with a scale factor of 1e-3 and add it into an existing 3D model:

```matlab
model = mphopen('model_tutorial_llmatlab');
wp1 = model.component('comp1').geom('geom1').feature.create('wp1', 'WorkPlane');
wp1.set('quickz', 1e-2);
mphimage2geom(p, 50, 'scale', 1e-3, wp1.geom);
mphgeom(model)
```

Create a geometry using MRI data. The geometry object is created following the contour made with point of value 30 and disregard objects with an area (in pixel) lower than 2:

```matlab
mri = load('mri');
im = mri.D(:,:,1,1);
figure(1); image(im);
mphimage2geom(im, 30, 'minarea', 2);
```

**mphinputmatrix**

Add a matrix system for linear solvers.

**SYNTAX**

```matlab
mphinputmatrix(model, str, soltag, soltypetag)
```
mphinputmatrix(model, str, soltag, soltypetag) adds the system matrices and vectors stored in the MATLAB® structure str to the model. The system matrices is associated to the linear solver configuration defined with the tag soltag and solved with the solver defined with the tag soltypetag.

soltypetag can only be one of the following solver type: Stationary, Eigenvalue, Time.

A valid structure for a stationary solver includes the following fields:

<table>
<thead>
<tr>
<th>FIELD NAME</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>Stiffness matrix</td>
</tr>
<tr>
<td>L</td>
<td>Load vector</td>
</tr>
<tr>
<td>M</td>
<td>Constraint vector</td>
</tr>
<tr>
<td>N</td>
<td>Constraint Jacobian</td>
</tr>
</tbody>
</table>

A valid structure for a time-dependent/ eigenvalue solver includes the following fields:

<table>
<thead>
<tr>
<th>FIELD NAME</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>Stiffness matrix</td>
</tr>
<tr>
<td>L</td>
<td>Load vector</td>
</tr>
<tr>
<td>M</td>
<td>Constraint vector</td>
</tr>
<tr>
<td>N</td>
<td>Constraint Jacobian</td>
</tr>
<tr>
<td>D</td>
<td>Damping matrix</td>
</tr>
<tr>
<td>E</td>
<td>Mass matrix</td>
</tr>
</tbody>
</table>

There is also the possibility to include the constraint force Jacobian vector NF.

Once the matrix system is loaded in the model, the solver configuration is set ready to run.

**Note:** The system matrices are not stored in the model when it is saved as an MPH-file or loaded into the COMSOL Desktop.

**Example**
Create a model with a square geometry
model = ModelUtil.create('Model');
comp = model.component.create('comp1', true);
geom = comp.geom.create('geom1', 2);
geom.create('sq1', 'Square');
geom.run;

Add an Equation General Form physics interface

g = comp.physics.create('g', 'GeneralFormPDE', 'geom1');
g.prop('ShapeProperty').set('order', 1)
g.prop('ShapeProperty').set('boundaryFlux', false);
cons = g.create('cons1', 'Constraint', 1).set('R', 'u');
cons.selection.set([1 2]);

Create a mapped mesh

map = comp.mesh.create('mesh1').create('map1', 'Map');
map.create('dis1', 'Distribution').set('numelem', 2);
map.feature('dis1').selection.set([1 2]);

Set-up the study and the solver configuration for a stationary problem:

std = model.study.create('std1');
std.create('stat', 'Stationary');
sol = model.sol.create('sol1');
sol.study('std1');
sol.feature.create('st1', 'StudyStep').set('studystep', 'stat');
sol.feature.create('v1', 'Variables');
sol.feature.create('s1', 'Stationary');

Extract the linear stationary matrix system in MATLAB:

str = mphmatrix(model,'sol1','out',{'K','L','M','N'},'
initmethod','sol','initsol','zero');

Change the linear system by scaling the stiffness matrix:

str.K = str.K*0.5;

Insert the system matrix back to the model:

mphinputmatrix(model,str,'sol1','s1')

Run the solver configuration:

model.sol('sol1').runAll;

SEE ALSO
mphmatrix, mphxmeshinfo
**mphint2**

Perform integration of expressions.

**SYNTAX**

\[
[v1,...,v2] = \text{mphint2}(\text{model},\{e1,...,en\},\text{edim},...)
\]

\[
[v1,...,v2,\text{unit}] = \text{mphint2}(\text{model},\{e1,...,en\},\text{edim},...)
\]

**DESCRIPTION**

\[
[v1,...,vn] = \text{mphint2}(\text{model},\{e1,...,en\},...)
\]

evaluates the integrals of the string expressions \(e1,...,en\) and returns the result in \(N\) matrices \(v1,...,vn\) with \(M\) rows and \(P\) columns. \(M\) is the number of inner solution and \(P\) the number of outer solution used for the evaluation. \(\text{edim}\) defines the element dimension, as a string: \text{line}, \text{surface}, \text{volume} or as an integer value.

\[
[v1,...,vn] = \text{mphint2}(\text{model},\{e1,...,en\},...)
\]

also returns the units of the integral in a \(1\times N\) cell array.

The function mphint2 accepts the following property/value pairs:

**TABLE 6-11: PROPERTY/VALUE PAIRS FOR THE MPHINT2 COMMAND.**

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>PROPERTY VALUE</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>dataseriest</td>
<td>none</td>
<td>average</td>
<td>integral</td>
</tr>
<tr>
<td>dataset</td>
<td>String</td>
<td>active solution data set</td>
<td></td>
</tr>
<tr>
<td>intorder</td>
<td>Positive integer</td>
<td>4</td>
<td>Integration order</td>
</tr>
<tr>
<td>intsurface</td>
<td>on</td>
<td>off</td>
<td>on</td>
</tr>
<tr>
<td>intvolume</td>
<td>on</td>
<td>off</td>
<td>off</td>
</tr>
<tr>
<td>matrix</td>
<td>on</td>
<td>off</td>
<td>on</td>
</tr>
<tr>
<td>method</td>
<td>auto</td>
<td>integration</td>
<td>summation</td>
</tr>
<tr>
<td>outer solnum</td>
<td>Positive integer</td>
<td>1</td>
<td>Solution number for parametric sweep</td>
</tr>
<tr>
<td>selection</td>
<td>Integer vector</td>
<td>string</td>
<td>all</td>
</tr>
</tbody>
</table>
The property `dataset` controls which data set is used for the evaluation. Data Sets contain or refer to the source of data for postprocessing purposes. Evaluation is supported only on Solution Data Sets.

The expressions $e_1, \ldots, e_n$ are integrated for one or several solutions. Each solution generates an additional column in the returned matrix. The property `solnum` and $t$ control which solutions are used for the integrations. The `solnum` property is available when the data set has multiple solutions, for example in the case of parametric, eigenfrequency, or time-dependent solutions. The $t$ property is available only for time-dependent problems. If `solnum` is provided, the solutions indicated by the indices provided with the `solnum` property are used. If $t$ is provided solutions are interpolated. If neither `solnum` nor $t$ is provided, all solutions are evaluated.

For time-dependent problems, the variable $t$ can be used in the expressions $e_i$. The value of $t$ is the interpolation time when the property $t$ is provided, and the time for the solution, when `solnum` is used. Similarly, `lambda` and the parameter are available as eigenvalues for eigenvalue problems and as parameter values for parametric problems, respectively.

The `unit` property defines the unit of the integral, if a inconsistent unit is entered, the default unit is used. In case of multiple expression, if the `unit` property is defined with a string, the same unit is used for both expressions. To use different units, set the property with a cell array. In case of inconsistent unit definition, the default unit is used instead.

`Solnum` is used to select the solution number when a parametric, eigenvalue or time-dependent solver has been used.

`Outersolnum` is used to select the outer solution number when a parametric sweep has been used in the study step node.

**EXAMPLE**

Integrate the normal heat flux across all boundaries:

```matlab
model = mphopen('model_tutorial_lammatlab');
```
std = model.study.create('std');
std.feature.create('stat','Stationary');
std.run;

[Q, unit] = mphint2(model,'ht.ntflux','surface');

Integrate the normal heat flux across all exterior boundaries

[Q, unit] = mphint2(model,'ht.ntflux','surface',...
'selection',[1:5,7:12]);

**SEE ALSO**
mpheval, mphevalglobalmatrix, mphevalpoint, mphevalpointmatrix, mphint2,
mphinterp, mphparticle, mphray

**mphinterp**
Evaluate expressions in arbitrary points or data sets.

**SYNTAX**

\[
[v_1, \ldots, v_n] = \text{mphinterp}(\text{model}, \{e_1, \ldots, e_n\}, \text{'coord'}, \text{coord}, \ldots)
\]
\[
[v_1, \ldots, v_n] = \text{mphinterp}(\text{model}, \{e_1, \ldots, e_n\}, \text{'dataset'}, \text{dsettag}, \ldots)
\]
\[
[v_1, \ldots, v_n, \text{unit}] = \text{mphinterp}(\text{model}, \{e_1, \ldots, e_n\}, \ldots)
\]

**DESCRIPTION**

\[v_1, \ldots, v_n = \text{mphinterp}(\text{model}, \{e_1, \ldots, e_n\}, \text{'coord'}, \text{coord}, \ldots)\]
evaluates expressions \(e_1, \ldots e_n\) at the coordinates specified in the double matrix \text{coord}.

Evaluation is supported only on Solution Data Sets.

\[v_1, \ldots, v_n = \text{mphinterp}(\text{model}, \{e_1, \ldots, e_n\}, \text{'dataset'}, \text{dsettag}, \ldots)\]
evaluates expressions \(e_1, \ldots e_n\) on the specified data set \text{dsettag}. In this case the data set needs to be of a type that defines an interpolation in itself, such as cut planes, revolve, and so forth.

\[v_1, \ldots, v_n, \text{unit} = \text{mphinterp}(\text{model}, \{e_1, \ldots, e_n\}, \ldots)\]
returns in addition the unit of the expressions.

The function mphinterp accepts the following property/value pairs:

**TABLE 6-12: PROPERTY/VALUE PAIRS FOR THE MPHINTERP COMMAND.**

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>PROPERTY VALUE</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>complexfun</td>
<td>off</td>
<td>on</td>
<td>on</td>
</tr>
<tr>
<td>complexout</td>
<td>off</td>
<td>on</td>
<td>on</td>
</tr>
<tr>
<td>PROPERTY</td>
<td>PROPERTY VALUE</td>
<td>DEFAULT</td>
<td>DESCRIPTION</td>
</tr>
<tr>
<td>-----------------</td>
<td>----------------</td>
<td>---------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>coord</td>
<td>Double array</td>
<td></td>
<td>Coordinates for evaluation</td>
</tr>
<tr>
<td>coorderr</td>
<td>off</td>
<td>on</td>
<td>off</td>
</tr>
<tr>
<td>dataset</td>
<td>String</td>
<td>Auto</td>
<td>Data set tag</td>
</tr>
<tr>
<td>differential</td>
<td>off</td>
<td>on</td>
<td>on</td>
</tr>
<tr>
<td>edim</td>
<td>point</td>
<td>edge</td>
<td>0.1</td>
</tr>
<tr>
<td>evalmethod</td>
<td>linpoint</td>
<td>harmonic</td>
<td>Applicable only for solutions with a stored linearization point. Controls if the linearization point, the perturbation, or a combination should be used when evaluating the expression.</td>
</tr>
<tr>
<td>ext</td>
<td>Double between 0 and 1</td>
<td>0.1</td>
<td>Extrapolation distance: How much outside the mesh that the interpolation searches. The scale is in terms of the local element size.</td>
</tr>
<tr>
<td>matherr</td>
<td>off</td>
<td>on</td>
<td>off</td>
</tr>
<tr>
<td>outersolnum</td>
<td>Positive integer</td>
<td>1</td>
<td>Solution number for parametric sweep</td>
</tr>
<tr>
<td>phase</td>
<td>Scalar</td>
<td>0</td>
<td>Phase angle in degrees</td>
</tr>
<tr>
<td>recover</td>
<td>off</td>
<td>ppr</td>
<td>off</td>
</tr>
<tr>
<td>selection</td>
<td>Positive Integer array</td>
<td>all</td>
<td>Selection list</td>
</tr>
<tr>
<td>solnum</td>
<td>Positive integer array</td>
<td>all</td>
<td>Inner solutions for evaluation</td>
</tr>
</tbody>
</table>
The columns of the matrix \( \text{coord} \) are the coordinates for the evaluation points. If the number of rows in \( \text{coord} \) equals the space dimension, then \( \text{coord} \) are global coordinates, and the property \( \text{edim} \) determines the dimension in which the expressions are evaluated. For instance, \( \text{edim} = \text{boundary} \) means that the expressions are evaluated on boundaries in a 3D model. If \( \text{edim} \) is less than the space dimension, then the points in \( \text{coord} \) are projected onto the closest point on a domain of dimension \( \text{edim} \). If, in addition, the property \( \text{selection} \) is given, then the closest point on domain number \( \text{selection} \) in dimension \( \text{edim} \) is used.

If the number of rows in \( \text{coord} \) is less than the space dimension, then these coordinates are parameter values on a geometry face or edge. In that case, the domain number for that face or edge must be specified with the property \( \text{selection} \).

The expressions that are evaluated can be expressions involving variables, in particular physics interface variables.

The matrices \( v_1, \ldots, v_n \) are of the size \( k \times \text{size(\text{coord},2)} \), where \( k \) is the number of solutions for which the evaluation is carried out, see below. The value of expression \( e_i \) for solution number \( j \) in evaluation point \( \text{coord}(:,m) \) is \( v_i(j,m) \).

The vector \( \text{pe} \) contains the indices \( m \) for the evaluation points \( \text{code}(:,m) \) that are outside the mesh, or, if a domain is specified, are outside that domain.

The property \( \text{Data} \) controls which data set is used for the evaluation. Data Sets contain or refer to the source of data for postprocessing purposes. Evaluation is supported only on Solution Data Sets. The active solution data set is used by default.

The property \( \text{edim} \) decides which elements to evaluate on. Evaluation takes place only on elements with space dimension \( \text{edim} \). If not specified, \( \text{edim} \) equal to the space dimension of the geometry is used. The setting is specified as one of the following strings ‘point’, ‘edge’, ‘boundary’ or ‘domain’. In previous versions it was only possible to specify \( \text{edim} \) as a number. For example, in a 3D model, if evaluation is done on edges (1D elements), \( \text{edim} \) is 1. Similarly, for boundary evaluation (2D elements), \( \text{edim} \) is 2, and for domain evaluation (3D elements), \( \text{edim} \) is 3 (default in 3D).

The property \( \text{evalmethod} \) decides which solution to use in presence of linearization point. Set the property value to harmonic to harmonic perturbation analysis,

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>PROPERTY VALUE</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>t</td>
<td>Double array</td>
<td>Time for evaluation</td>
<td></td>
</tr>
<tr>
<td>unit</td>
<td>String</td>
<td>Unit to use for the evaluation</td>
<td></td>
</tr>
</tbody>
</table>

**TABLE 6-12: PROPERTY/VALUE PAIRS FOR THE MPHINTERP COMMAND.**
*linpoint* evaluates the expression by taking the values of any dependent variables from the linearization point of the solution, *lintotal* evaluates the expression by adding the linearization point and the harmonic perturbation and taking the real part of this sum. *lintotalavg* (*lintotalrms* and *lintotalpeak*) do the same as with *lintotal* and then averaging (taking the RMS and taking the maximum respectively) over all phases of the harmonic perturbation. When *harmonic* is selected, the property differential specify to evaluate the differential of the expression with respect to the perturbation at the linearization point (*on*) or to evaluates the expression by taking the values of any dependent variables from the harmonic perturbation part of the solution (*off*).

Use *Recover* to recover fields using polynomial-preserving recovery. This techniques recover fields with derivatives such as stresses or fluxes with a higher theoretical convergence than smoothing. Recovery is expensive so it is turned off by default. The value *pprint* means that recovery is performed inside domains. The value *ppr* means that recovery is also applied on all domain boundaries.

The property *Refine* constructs evaluation points by making a regular refinements of each element. Each mesh edge is divided into *Refine* equal parts.

The property *smooth* controls if the post data is forced to be continuous on element edges. When *smooth* is set to internal, only elements not on interior boundaries are made continuous.

When the property *phase* is used, the solution vector is multiplied with \( \exp(i \cdot \text{phase}) \) before evaluating the expression.

The expressions \( e_1, \ldots, e_n \) are evaluated for one or several solutions. Each solution generates an additional row in the data fields of the post data output structure. The property *solnum* and *t* control which solutions are used for the evaluations. The *solnum* property is available when the data set has multiple solutions, for example, in the case of parametric, eigenfrequency, or time-dependent solutions. The *t* property is available only for time-dependent problems. If *solnum* is provided, the solutions indicated by the indices provided with the *solnum* property are used. If *t* is provided solutions are interpolated. If neither *solnum* nor *t* is provided, all solutions are evaluated.

For time-dependent problems, the variable *t* can be used in the expressions \( e_i \). The value of *t* is the interpolation time when the property *t* is provided, and the time for the solution, when *solnum* is used. Similarly, *lambda* and the parameter are available as eigenvalues for eigenvalue problems and as parameter values for parametric problems, respectively.
In case of multiple expression, if the unit property is defined with a string, the same unit is used for both expressions. To use different units, set the property with a cell array. In case of inconsistent unit definition, the default unit is used instead.

The property `solnum` is used to select the solution number when a parametric, eigenvalue or time-dependent solver has been used.

The property `outersolnum` is used to select the outer solution number when a parametric sweep has been used in the study step node.

**EXAMPLE**

Evaluate the temperature at given coordinates:

```matlab
model = mphopen('model_tutorial_llmatlab');
std = model.study.create('std');
std.feature.create('stat','Stationary');
std.run;
coord = [0,0,1e-2;0,0,1e-2;0,1e-2,1e-2];
T = mphinterp(model,'T','coord',coord);
```

Evaluate both the temperature and the heat flux magnitude:

```matlab
[T,tfluxMag] = mphinterp(model,{'T','ht.tfluxMag'},'coord',coord);
```

Evaluate the temperature field on a structure grid:

```matlab
x0 = [0,1e-2,2.5e-2,5e-2]; y0 = x0; z0 = [5e-3,1e-2,1.1e-2];
[x,y,z] = meshgrid(x0,y0,z0); xx = [x(:),y(:),z(:)]';
T = mphinterp(model,'T','coord',xx);
```

Evaluate the temperature on boundary 7 using global coordinates:

```matlab
x0 = [0,5e-3,1e-2]; y0 = x0; z0 = [1.1e-2];
[x,y,z] = meshgrid(x0,y0,z0); xx = [x(:),y(:),z(:)]';
T = mphinterp(model,'T','coord',xx,'edim','boundary','selection',7);
```

Evaluate the temperature and evaluation point global coordinates on boundary 7 using local coordinates:

```matlab
s10 = [0,0.25,0.5]; s20 = [0,0.25,0.5];
[s1,s2] = meshgrid(s10,s20); ss = [s1(:),s2(:)]';
[x,y,z,T] = mphinterp(model,{'x','y','z','T'},'coord',ss,'edim','boundary','selection',7);
```

Modify the extrapolation distance for point coordinates outside of the geometry:

```matlab
coord = [5e-2;5e-2;1.1e-2];
T = mphinterp(model,'T','coord',coord)
```
T = mphinterp(model, 'T', 'coord', coord, 'ext', 0.5);

Extract data using a cut line data set. First create the cutline data set, then evaluate the
temperature field along the line:

    cln = model.result.dataset.create('cln', 'CutLine3D');
    cln.setIndex('genpoints', '1e-2', 1, 0);
    cln.setIndex('genpoints', '1e-2', 0, 2);
    cln.setIndex('genpoints', '5e-2', 1, 0);
    T = mphinterp(model, 'T', 'dataset', 'cln');

Evaluation including several solution

    model = mphopen('model_tutorial_llmatlab');
    std = model.study.create('std');
    param = std.feature.create('param', 'Parametric');
    time = std.feature.create('time', 'Transient');
    time.set('tlist', 'range(0,1,25)');
    param.setIndex('pname', 'power', 0);
    param.setIndex('plistarr', '30 60 90', 0);
    std.run;

Evaluate the temperature at every time step computed with power set to 30:

    coord = [0 0 1e-2; 0 0 1e-2; 0 1e-2 1e-2];
    T = mphinterp(model, 'T', 'coord', coord, 'dataset', 'dset2');

Evaluate the temperature at the fifth time step:

    T = mphinterp(model, 'T', 'coord', coord, 'dataset', 'dset2', ...
                 'solnum', 5);

Evaluate the temperature at 10.5 sec:

    T = mphinterp(model, 'T', 'coord', coord, 'dataset', 'dset2', ...
                 't', 10.5);

Evaluate the temperature at every time step computed with power set to 90:

    T = mphinterp(model, 'T', 'coord', coord, 'dataset', 'dset2', ...
                 'outersolnum', 3)

See Also

mpheval, mphevalglobalmatrix, mphevalpoint, mphevalpointmatrix, mphint2,
mphint2, mphparticle, mphray

mphinterpolationsfile

Save data in files readable by the Interpolation feature.
SYNTAX

mphinterpolationfile(filename,type,data)
mphinterpolationfile(filename,type,data,xdata)
mphinterpolationfile(filename,type,data,xdata,ydata)

DESCRIPTION

mphinterpolationfile(filename,type,data) saves the NxM matrix data into the text file filename with the format type. The interpolation coordinates are vectors with values from 1 to N and 1 to M.

mphinterpolationfile(filename,type,data,xdata) saves the vector data and the interpolation coordinate xdata into the text file filename with the format type.

mphinterpolationfile(filename,type,data,xdata,ydata) saves the matrix data and the interpolation coordinate vectors xdata and ydata into the text file filename with the format type.

type can be either 'grid', 'sectionwise' or 'spreadsheet'.

EXAMPLE

Create random 10x10 interpolation data to file using grid format:

```matlab
data = cumsum(0.1*randn(size(10))); mphinterpolationfile('datagrid.txt','grid',data);
```

1D interpolation data to file using spreadsheet format:

```matlab
t = 0:0.05:2*pi;
z = sin(cos(t)*4)+sin(51*t)*0.05; mphinterpolationfile('dataspread.txt','spreadsheet',z,t);
```

2D interpolation data to file using sectionwise format:

```matlab
z = magic(9); x = 1:9; y = 0:8; mphinterpolationfile('datasection.txt','sectionwise',z,x,y);
```

SEE ALSO

mphquad2tri, mphreadstl, mphsurf, mphwritestl

**mpblaunch**

Launch COMSOL Desktop, connect it to the running server and import an application.
**SYNTAX**

mphlaunch
mphlaunch(model)
mphlaunch ModelTag
mphlaunch(..., timeout)

**DESCRIPTION**

mphlaunch launches a COMSOL Multiphysics Client and connect it to the same server as MATLAB® is connected to. Then it imports the model on the server into the COMSOL Multiphysics Client.

mphlaunch(model) does the same as above, but uses the model argument to select which model is imported.

mphlaunch ModelTag uses the model with the tag 'ModelTag' in the server to be imported. This can also be done using the syntax: mphlaunch('ModelTag')

mphlaunch(..., tms) uses the timeout tms (in milliseconds) to force MATLAB to wait until the COMSOL server is free again. The default timeout value is 500. A negative value results in no timeout.

**EXAMPLE**

Load the file model_tutorial_llmatlab.mph:

    model = mphopen('model_tutorial_llmatlab');

Launch a COMSOL Multiphysics Client, connect it with the running server, import the model defined as model,; and set a timeout of 1s.:

    mphlaunch(model,1000);

mphload

Load a COMSOL Multiphysics model MPH-file.

**SYNTAX**

model = mphload(filename)
model = mphload(filename, mtag)
model = mphload(filename, mtag, '-history')
model = mphload(filename, mtag, pwd)
[model, filename] = mphload(filename, ...)

**DESCRIPTION**

model = mphload(filename) loads a COMSOL model object saved with the name filename and assigns the default tag Model in the COMSOL server. If a model with
tag Model already exists and is also open in a COMSOL Multiphysics client, the loaded model an index number is appended to the tag, for instance Model1.

`model = mphload(filename, mtag)` loads a COMSOL model object and assigns the tag `mtag` in the COMSOL server.

`model = mphload(filename, mtag, '-history')` turns on model history recording.

`model = mphload(filename, mtag, pwd)` loads the COMSOL model object saved with the name `filename` protected with the password `pwd`.

`[model, filenameloaded] = mphload(filename, ...)` also returns the full file name `filenameloaded` of the file that was loaded.

The model tag `mtag` and the password `pwd` are defined as string.

If the model tag is the same as a model that is currently in the COMSOL server the loaded model overwrites the existing one.

Note that MATLAB® searches for the model on the MATLAB path if an absolute path is not supplied.

`mphload` turns off the model history recording by default, unless the property `-history` is used.

The extension `.mph` can be omitted.

`mphload` does not look for lock file when opening a model in the COMSOL server.

**EXAMPLE**

Load the file `model_tutorial_llmatlab.mph`:

```matlab
model = mphload('model_tutorial_llmatlab');
```

Load the file `model_tutorial_llmatlab.mph` and set the model name in the COMSOL server to `Model2`:

```matlab
model = mphload('model_tutorial_llmatlab', 'Model2');
```

Load `model_tutorial_llmatlab.mph` and return the filename:

```matlab
[model, filename] = mphload('model_tutorial_llmatlab');
```

**SEE ALSO**

`mphopen, mphsave`
mphmatrix

Get model matrices.

**SYNTAX**

\[ \text{str} = \text{mphmatrix}(\text{model}, \text{soltag}, 'Out', ...) \]

**DESCRIPTION**

\[ \text{str} = \text{mphmatrix}(\text{model}, \text{soltag}, 'Out', \{'A'\}, ...) \] returns a MATLAB® structure str containing the matrix \( A \) assembled using the solver node soltag and accessible as str.A. \( A \) being taken from the Out property list.

\[ \text{str} = \text{mphmatrix}(\text{model}, \text{soltag}, \text{fname}, 'Out', \{'A','B',...\}) \] returns a MATLAB structure str containing the matrices \( A, B, ... \) assembled using the solver node solname and accessible as str.A and str.B. \( A \) and \( B \) being taken from the Out property list.

The function mphmatrix accepts the following property/value pairs:

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>EXPRESSION</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>complexfun</td>
<td>on</td>
<td>off</td>
<td>off</td>
</tr>
<tr>
<td>eigname</td>
<td>String</td>
<td>lambda</td>
<td>Eigenvalue name</td>
</tr>
<tr>
<td>eigref</td>
<td>Double</td>
<td>0</td>
<td>Value of eigenvalue linearization point</td>
</tr>
<tr>
<td>extractafter</td>
<td>Solution feature tag</td>
<td>First dependent variable node</td>
<td>Specify at which point to extract the matrices</td>
</tr>
<tr>
<td>initmethod</td>
<td>init</td>
<td>sol</td>
<td>init</td>
</tr>
<tr>
<td>initsol</td>
<td>string</td>
<td>zero</td>
<td>Active solver tag</td>
</tr>
<tr>
<td>matherr</td>
<td>on</td>
<td>off</td>
<td>on</td>
</tr>
<tr>
<td>nullfun</td>
<td>flnullorth</td>
<td>flspnull</td>
<td>flexplicit</td>
</tr>
<tr>
<td>out</td>
<td>Cell array of strings</td>
<td></td>
<td>List of matrices to assemble</td>
</tr>
<tr>
<td>rowscale</td>
<td>on</td>
<td>off</td>
<td>on</td>
</tr>
</tbody>
</table>
The following values are valid for the `out` property:

Property/Value Pairs for the property `out`.

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>EXPRESSION</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>out</td>
<td>K</td>
<td></td>
<td>Stiffness matrix</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td></td>
<td>Load vector</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td></td>
<td>Constraint vector</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td></td>
<td>Constraint Jacobian</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td></td>
<td>Damping matrix</td>
</tr>
<tr>
<td></td>
<td>E</td>
<td></td>
<td>Mass matrix</td>
</tr>
<tr>
<td></td>
<td>NF</td>
<td></td>
<td>Constraint force Jacobian</td>
</tr>
<tr>
<td></td>
<td>NP</td>
<td></td>
<td>Optimization constraint Jacobian (*)</td>
</tr>
<tr>
<td></td>
<td>MP</td>
<td></td>
<td>Optimization constraint vector (*)</td>
</tr>
<tr>
<td></td>
<td>MLB</td>
<td></td>
<td>Lower bound constraint vector (*)</td>
</tr>
<tr>
<td></td>
<td>MUB</td>
<td></td>
<td>Upper bound constraint vector (*)</td>
</tr>
<tr>
<td></td>
<td>Kc</td>
<td></td>
<td>Eliminated stiffness matrix</td>
</tr>
<tr>
<td></td>
<td>Lc</td>
<td></td>
<td>Eliminated load vector</td>
</tr>
<tr>
<td></td>
<td>Dc</td>
<td></td>
<td>Eliminated damping matrix</td>
</tr>
<tr>
<td></td>
<td>Ec</td>
<td></td>
<td>Eliminated mass matrix</td>
</tr>
<tr>
<td></td>
<td>Null</td>
<td></td>
<td>Constraint null-space basis</td>
</tr>
<tr>
<td></td>
<td>Nullf</td>
<td></td>
<td>Constraint force null-space matrix</td>
</tr>
<tr>
<td></td>
<td>ud</td>
<td></td>
<td>Particular solution ud</td>
</tr>
<tr>
<td></td>
<td>uscale</td>
<td></td>
<td>Scale vector</td>
</tr>
</tbody>
</table>

(*) Requires the Optimization Module.
Note that the assembly of the eliminated matrices uses the current solution vector as scaling method. To get the unscaled eliminated system matrices, it is required to set the scaling method to ‘none’ in the variables step of the solver configuration node.

The load vector is assembled using the current solution available as linearization point unless the initmethod property is provided. In case of the presence of a solver step node in the solver sequence, the load vector correspond then to the residual of the problem.

The function `mphmatrix` does not solve the problem as the assembly is performed before the solver node in the solution sequence. You can specify the solution feature node after which to assemble the system matrices with the property `extractafter`. This is useful if you need to compute the solution before extracting the matrices or if you have a solution sequence using different solver sequences and you want to extract the matrices for a specific one.

The Advanced section in the COMSOL Multiphysics Reference Manual, describes the functionality corresponding to the properties `complexfun`, `nullfun`, and `rowscale`.

Use the property `symmetric` to assemble the model matrix system as symmetric/hermitian or you can use the automatic feature to find out (see Advanced in the COMSOL Multiphysics Reference Manual).

**EXAMPLE**

Evaluate the system matrices of a stationary problem

```matlab
model = mphopen('model_tutorial_llmatlab');
std = model.study.create('std1');
std.feature.create('stat', 'Stationary');
std.run;
```

Get the stationary matrix system, use the initial solution as linearization point:

```matlab
str = mphmatrix(model,'sol1','out',{'K','L','M','N'},
    'initmethod','init');
```

Display the sparsity of the stiffness matrix and the constraint Jacobian and compute the total load applied in the matrix system:

```matlab
subplot(2,1,1); spy(str.K);subplot(2,1,2);spy(str.N)
Q = sum(str.L)
```

Get the eliminated matrix system, use the initial solution as linearization point:

```matlab
str = mphmatrix(model,'sol1','out',{'Kc'},'initmethod','init');
```

Compare the sparsity between the eliminated and non-eliminated stiffness matrix:
Evaluate the eliminated load vector using the current solution as linearization point:

```matlab
str = mphmatrix(model,'sol1','out', {'Lc'}, 'initmethod','sol');
```

Evaluate the system matrices of a dynamic problem:

```matlab
model = mphopen('model_tutorial_llmatlab');
std = model.study.create('std1');
time = std.feature.create('time', 'Transient');
time.set('tlist', 'range(0,1,25)');
std.run;
```

Get the dynamic matrix system:

```matlab
str = mphmatrix(model,'sol1','out', {'E','D','K','L','M','N'});
```

Display the sparsity of the mass and stiffness matrices:

```matlab
subplot(1,2,1); spy(str.D); subplot(1,2,2); spy(str.K);
```

Get the eliminated dynamic matrix system:

```matlab
str = mphmatrix(model,'sol1','out', {'Ec','Dc','Kc','Lc','M','N'});
```

Assemble the Jacobian using solution number 15 as linearization point:

```matlab
str = mphmatrix(model,'sol1','out', {'K'}, ...
    'initmethod','sol','initsol','sol1','solnum',15);
```

Assemble the Jacobian using the zero vector as linearization point:

```matlab
str = mphmatrix(model,'sol1','out', {'K'}, ...
    'initmethod','sol','initsol','zero');
```

### SEE ALSO

mphstate, mphxmeshinfo, mphinputmatrix

---

**mphmax**

Perform a maximum of expressions.

**SYNTAX**

```matlab
[v1,...,vn] = mphmax(model,{e1,...,en},edim,...)
[v1,...,vn,unit] = mphmax(model,{e1,...,en},edim,...)
```

**DESCRIPTION**

```matlab
[v1,...,vn] = mphmax(model,{e1,...,en},edim,...) evaluates the maximum of the string expressions e1,...,en and returns the result in N matrices v1,...,vn
```
with M rows and P columns. M is the number of inner solution and P the number of outer solution used for the evaluation. \texttt{edim} defines the element dimension: \texttt{line}, \texttt{surface}, \texttt{volume} or as an integer value.

\[ [v_1, \ldots, v_n] = \texttt{mphmax}(	exttt{model}, \{e_1, \ldots, e_n\}, \texttt{edim}, \ldots) \] also returns the units of the maximum in a 1xN cell array.

The function \texttt{mphmax} accepts the following property/value pairs:

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>PROPERTY VALUE</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>dataseries</td>
<td>none</td>
<td>average</td>
<td>integral</td>
</tr>
<tr>
<td>dataset</td>
<td>String</td>
<td>active solution data set</td>
<td></td>
</tr>
<tr>
<td>matrix</td>
<td>on</td>
<td>off</td>
<td>on</td>
</tr>
<tr>
<td>outersolnum</td>
<td>Positive integer array</td>
<td>all</td>
<td>end</td>
</tr>
<tr>
<td>selection</td>
<td>Integer vector</td>
<td>string</td>
<td>all</td>
</tr>
<tr>
<td>solnum</td>
<td>Integer vector</td>
<td>end</td>
<td>all</td>
</tr>
<tr>
<td>squeeze</td>
<td>on</td>
<td>off</td>
<td>on</td>
</tr>
<tr>
<td>t</td>
<td>Double array</td>
<td>Time for evaluation</td>
<td></td>
</tr>
</tbody>
</table>

The property \texttt{dataset} controls which data set is used for the evaluation. Data Sets contain or refer to the source of data for postprocessing purposes. Evaluation is supported only on Solution Data Sets.

The maximum expressions \(e_1, \ldots, e_n\) is evaluated for one or several solutions. Each solution generates an additional column in the returned matrix. The property \texttt{solnum} and \texttt{t} control which solutions are used for the evaluation. The \texttt{solnum} property is available when the data set has multiple solutions, for example in the case of parametric, eigenfrequency, or time-dependent solutions. The \texttt{t} property is available only for time-dependent problems. If \texttt{solnum} is provided, the solutions indicated by the indices provided with the \texttt{solnum} property are used. If \texttt{t} is provided solutions are interpolated. If neither \texttt{solnum} nor \texttt{t} is provided, all solutions are evaluated.
The property `solnum` is used to select the solution number when a parametric, eigenvalue or time-dependent solver has been used.

The property `outersolnum` is used to select the outer solution number when a parametric sweep has been used in the study step node.

If the matrix property is set to off the output is cell arrays of length P containing cell arrays of length M.

**EXAMPLE**

Evaluate the maximum temperature in the model domain:

```matlab
model = mphopen('model_tutorial_llmatlab');
std = model.study.create('std');
std.feature.create('stat','Stationary');
std.run;
maxT = mphmax(model,'T','volume');
```

Evaluate the maximum temperature on boundary 9:

```matlab
maxT = mphmax(model,'T','surface','selection',9);
```

Evaluate maximum of expression using several solution:

```matlab
model = mphopen('model_tutorial_llmatlab');
std = model.study.create('std');
param = std.feature.create('param','Parametric');
time = std.feature.create('time','Transient');
time.set('tlist', 'range(0,1,25)');
param.setIndex('pname','power',0);
param.setIndex('plistarr','30 60 90',0);
std.run;
```

Evaluate the maximum of the temperature at every time step computed with power set to 30:

```matlab
maxT = mphmax(model,'T','volume','dataset','dset2');
```

Evaluate the maximum of the temperature at the fifth time step:

```matlab
maxT = mphmax(model,'T','volume','dataset','dset2',... 'solnum',5));
```

Evaluate the maximum of the temperature at 10.5 sec and 15.2 sec:

```matlab
maxT = mphmax(model,'T','volume','dataset','dset2',... 't',[10.5,15.2]);
```

Evaluate the maximum of the temperature at every time step computed with power set to 90:
\texttt{maxT = mphmax(model,'T','volume','dataset','dset2',... 'outersolnum',3)};

\textbf{SEE ALSO}\n
\textit{mphmean, mphmin}

\textit{mphmean}

Perform a mean of expressions.

\textbf{SYNTAX}

\[
[v1,\ldots,vn] = \text{mphmean}(\text{model},\{e1,\ldots,en\},\text{edim},\ldots)
\]

\[
[v1,\ldots,vn,\text{unit}] = \text{mphmean}(\text{model},\{e1,\ldots,en\},\text{edim},\ldots)
\]

\textbf{DESCRIPTION}

\[
[v1,\ldots,vn] = \text{mphmean}(\text{model},\{e1,\ldots,en\},\text{edim},\ldots)
\]

evaluates the means of the string expressions \(e1,\ldots,en\) and returns the result in \(N\) matrices \(v1,\ldots,vn\) with \(M\) rows and \(P\) columns. \(M\) is the number of inner solution and \(P\) the number of outer solution used for the evaluation. \textit{edim} defines the element dimension: \textit{line, surface, volume} or as an integer value.

\[
[v1,\ldots,vn] = \text{mphmean}(\text{model},\{e1,\ldots,en\},\text{edim},\ldots)
\]

also returns the units of the maximum in a 1x\(N\) cell array.

The function \textit{mphmean} accepts the following property/value pairs:

\begin{table}
\centering
\begin{tabular}{|l|l|l|l|}
\hline
\textbf{PROPERTY} & \textbf{PROPERTY VALUE} & \textbf{DEFAULT} & \textbf{DESCRIPTION} \\
\hline
dataseries & none | average | integral | maximum | minimum | rms | stddev | variance & none & Data series operation \\
\hline
dataset & String & active solution data set & Data set tag \\
\hline
intorder & Positive integer & 4 & Integration order \\
\hline
matrix & off | on & on & Returns data as a matrix or as a cell \\
\hline
method & auto | integration | summation & auto & Integration method \\
\hline
outersolnum & Positive integer array | all | end & 1 & Solution number for parametric sweep \\
\hline
\end{tabular}
\end{table}

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The property `dataset` controls which data set is used for the evaluation. Data Sets contain or refer to the source of data for postprocessing purposes. Evaluation is supported only on Solution Data Sets.

The mean of expressions $e_1, \ldots, e_n$ is evaluated for one or several solutions. Each solution generates an additional column in the returned matrix. The property `solnum` and `$t$` control which solutions are used for the evaluation. The `solnum` property is available when the data set has multiple solutions, for example in the case of parametric, eigenfrequency, or time-dependent solutions. The `$t$` property is available only for time-dependent problems. If `solnum` is provided, the solutions indicated by the indices provided with the `solnum` property are used. If `$t$` is provided solutions are interpolated. If neither `solnum` nor `$t$` is provided, all solutions are evaluated.

The property `solnum` is used to select the solution number when a parametric, eigenvalue or time-dependent solver has been used.

The property `outersolnum` is used to select the outer solution number when a parametric sweep has been used in the study step node.

If the `matrix` property is set to `off` the output is cell arrays of length $P$ containing cell arrays of length $M$.

### Example

Evaluate the mean temperature in the model domain:

```matlab
model = mphopen('model_tutorial_llmatlab');
std = model.study.create('std');
std.feature.create('stat', 'Stationary');
std.run;
maxT = mphmean(model,'T','volume');
```

Evaluate the mean temperature on boundary 9:

```matlab
maxT = mphmean(model,'T','surface','selection',9);
```
Evaluate mean of expression using several solutions:

```matlab
model = mphopen('model_tutorial_llmatlab');
std = model.study.create('std');
param = std.feature.create('param','Parametric');
time = std.feature.create('time','Transient');
time.set('tlist', 'range(0,1,25)');
param nIndex('pname', 'power', 0);
param nIndex('plistarr', '30 60 90', 0);
std.run;
```

Evaluate the mean of the temperature at every time step computed with power set to 30:

```matlab
maxT = mphmean(model,'T','volume','dataset','dset2');
```

Evaluate the mean of the temperature at the fifth time step:

```matlab
maxT = mphmean(model,'T','volume','dataset','dset2',
    'solnum', 5);
```

Evaluate the mean of the temperature at 10.5 sec and 15.2 sec:

```matlab
maxT = mphmean(model,'T','volume','dataset','dset2',
    't', [10.5, 15.2]);
```

Evaluate the mean of the temperature at every time step computed with power set to 90:

```matlab
maxT = mphmean(model,'T','volume','dataset','dset2',
    'outersolnum', 3);
```

**SEE ALSO**

mphmax, mphmin

mphmesh

Plot a mesh in a MATLAB® figure window.

**SYNTAX**

```
mphmesh(model)
mphmesh(model, meshtag, ...)
pd = mphmesh(model, meshtag, ...)
```

**DESCRIPTION**

mphmesh(model) plots the mesh case in a MATLAB figure.
mphmesh(model,meshtag,...) plots the mesh case meshtag in a MATLAB figure. If there is only one mesh in the model the meshtag can be left empty.

The function mphmesh accepts the following property/value pairs:

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>VALUE</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parent</td>
<td>Double</td>
<td></td>
<td>Parent axis</td>
</tr>
<tr>
<td>Edgecolor</td>
<td>Char</td>
<td>k</td>
<td>Edge color</td>
</tr>
<tr>
<td>Edgelabels</td>
<td>on</td>
<td>off</td>
<td>off</td>
</tr>
<tr>
<td>Edgelabelscolor</td>
<td>Char</td>
<td>k</td>
<td>Color for edge labels</td>
</tr>
<tr>
<td>Edgemode</td>
<td>on</td>
<td>off</td>
<td>on</td>
</tr>
<tr>
<td>Facealpha</td>
<td>Double</td>
<td>1</td>
<td>Set transparency value</td>
</tr>
<tr>
<td>Facelabels</td>
<td>on</td>
<td>off</td>
<td>off</td>
</tr>
<tr>
<td>Facelabelscolor</td>
<td>Char</td>
<td>k</td>
<td>Color for face labels</td>
</tr>
<tr>
<td>Facemode</td>
<td>on</td>
<td>off</td>
<td>on</td>
</tr>
<tr>
<td>Meshcolor</td>
<td>Char</td>
<td>vector</td>
<td>gray</td>
</tr>
<tr>
<td>Vertexcolor</td>
<td>Char</td>
<td>vector</td>
<td>k</td>
</tr>
<tr>
<td>Vertexlabels</td>
<td>on</td>
<td>off</td>
<td>off</td>
</tr>
<tr>
<td>Vertexlabelscolor</td>
<td>Char</td>
<td>vector</td>
<td>k</td>
</tr>
<tr>
<td>Vertexmode</td>
<td>on</td>
<td>off</td>
<td>off</td>
</tr>
<tr>
<td>View</td>
<td>String</td>
<td></td>
<td>View settings</td>
</tr>
</tbody>
</table>

**EXAMPLE**

Plot the mesh case

```matlab
model = mphopen('model_tutorial_llmatlab');
model.component('comp1').mesh.run;
mphmesh(model)
```

Create a second mesh case with an “extra fine” default mesh settings and plot it:

```matlab
mesh = model.component('comp1').create('mesh2');
mesh.autoMeshSize(2);
mesh.run;
mphmesh(model,'mesh2','meshcolor','r');
```
The mesh can be plotted with view settings applied. This results in a mesh with grid, axes labels, lights, hiding etc. applied to the plot. Usually it is sufficient to use the auto setting, but any valid view can be applied:

```matlab
mphmesh(model, 'mesh1', 'view', 'auto')
```

Plot data can be returned from `mphmesh`. This can be used to create the plot later or to extract information used to create the plot for further analysis

```matlab
pd = mphmesh(model, 'mesh1');
mphplot(pd)
```

**SEE ALSO**

`mphgeom`, `mphmeshstats`, `mphplot`

### `mphmeshstats`

Return mesh statistics and mesh data information.

**SYNTAX**

```matlab
stats = mphmeshstats(model)
stats = mphmeshstats(model, meshtag, ...)
[stats, data] = mphmeshstats(model, meshtag, ...)
```

**DESCRIPTION**

- `stats = mphmeshstats(model)` returns mesh statistics of the model mesh case in the structure `str`.
- `stats = mphmeshstats(model, meshtag, ...)` returns mesh statistics of a mesh case `meshtag` in the structure `str`.
- `[stats, data] = mphmeshstats(model, meshtag, ...)` returns in addition the mesh data information such as vertex coordinates and definitions of elements in the structure `data`.

The function `mphmeshstats` accepts the following property/value pairs:

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>VALUE</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>entity</td>
<td>domain</td>
<td></td>
<td>Selected entity type</td>
</tr>
<tr>
<td></td>
<td>boundary</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>edge</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>point</td>
<td></td>
<td></td>
</tr>
<tr>
<td>qualityhistogram</td>
<td>Int</td>
<td>20</td>
<td>Number of bins in the quality distribution histogram</td>
</tr>
</tbody>
</table>

| PROPERTY | VALUE | DEFAULT | DESCRIPTION |
|----------|-------|---------|-------------|-------------|
| entity   | domain|         | Selected entity type |             |
|          | boundary|        |                        |             |
|          | edge    |         |                        |             |
|          | point   |         |                        |             |
| qualityhistogram | Int  | 20     | Number of bins in the quality distribution histogram |
Selection and/or Entity properties cannot be set if the data structure is returned. The output structure stats contains the following fields:

**TABLE 6-18: FIELDS IN THE STATS STRUCTURE**

<table>
<thead>
<tr>
<th>FIELD</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>meshtag</td>
<td>Mesh case tag</td>
</tr>
<tr>
<td>geomtag</td>
<td>Associated geometry tag</td>
</tr>
<tr>
<td>isactive</td>
<td>Is the mesh node active</td>
</tr>
<tr>
<td>hasproblems</td>
<td>Does the mesh have problems?</td>
</tr>
<tr>
<td>iscomplete</td>
<td>Is the mesh built to completion?</td>
</tr>
<tr>
<td>sdim</td>
<td>Space dimension</td>
</tr>
<tr>
<td>secondderelements</td>
<td>Does the mesh have second-order elements?</td>
</tr>
<tr>
<td>contributing</td>
<td>Contributing physics and multiphysics</td>
</tr>
<tr>
<td>types</td>
<td>Cell array with type names</td>
</tr>
<tr>
<td>numelem</td>
<td>Vector with the number of elements for each type</td>
</tr>
<tr>
<td>qualitymeasure</td>
<td>Quality measure</td>
</tr>
<tr>
<td>minquality</td>
<td>Minimum quality</td>
</tr>
<tr>
<td>meanquality</td>
<td>Mean quality</td>
</tr>
<tr>
<td>qualitydistr</td>
<td>Quality distribution (vector)</td>
</tr>
<tr>
<td>minvolume</td>
<td>Volume/area of the smallest element</td>
</tr>
<tr>
<td>maxvolume</td>
<td>Volume/area of the largest element</td>
</tr>
</tbody>
</table>

* Selection and/or Entity properties cannot be set if the data structure is returned.
Provides statistics for the entire selection regardless of the element type property.

The output structure data contains the following fields:

**TABLE 6-18: FIELDS IN THE STATS STRUCTURE**

<table>
<thead>
<tr>
<th>FIELD</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>volume</td>
<td>Volume/area of the mesh</td>
</tr>
<tr>
<td>maxgrowthrate</td>
<td>Maximum growth rate*</td>
</tr>
<tr>
<td>meangrowthrate</td>
<td>Mean growth rate*</td>
</tr>
</tbody>
</table>

* Provides statistics for the entire selection regardless of the element type property.

**TABLE 6-19: FIELDS IN THE DATA STRUCTURE**

<table>
<thead>
<tr>
<th>FIELD</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>vertex</td>
<td>Coordinates of mesh vertices</td>
</tr>
<tr>
<td>elem</td>
<td>Cell array of definition of each element type</td>
</tr>
<tr>
<td>elementity</td>
<td>Entity information for each element type</td>
</tr>
</tbody>
</table>

**EXAMPLE**

Get the mesh statistics:

```matlab
model = mphopen('model_tutorial_llmatlab');
model.component('comp1').mesh.run;
stats = mphmeshstats(model);
```

Show the mesh quality distribution in a figure:

```matlab
bar(linspace(0,1,20),stats.qualitydistr)
```

Get the mesh statistics and the mesh data:

```matlab
[stats,data] = mphmeshstats(model);
```

Show the element vertices in a plot:

```matlab
plot3(data.vertex(1,:), data.vertex(2,:), data.vertex(3,:), '.');
axis equal
```

Get the number of edge element:

```matlab
numedgeelem = stats.numelem(strcmp(stats.types,'edg'))
```

**SEE ALSO**

* mphmesh
  * mphmin

Perform a minimum of expressions.
SYNTAX

[v1,...,vn] = mphmin(model,{e1,...,en},edim,...)
[v1,...,vn,unit] = mphmin(model,{e1,...,en},edim,...)

DESCRIPTION

[v1,...,vn] = mphmin(model,{e1,...,en},edim,...) evaluates the minimum of the string expressions e1,...,en and returns the result in N matrices v1,...,vn with M rows and P columns. M is the number of inner solution and P the number of outer solution used for the evaluation. edim defines the element dimension: line, surface, volume or as an integer value.

[v1,...,vn] = mphmin(model,{e1,...,en},edim,...) also returns the units in a 1xN cell array.

The function mphmin accepts the following property/value pairs:

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>PROPERTY VALUE</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>dataseries</td>
<td>none</td>
<td>average</td>
<td>integral</td>
</tr>
<tr>
<td>dataset</td>
<td>String</td>
<td>active</td>
<td>solution</td>
</tr>
<tr>
<td>matrix</td>
<td>off</td>
<td>on</td>
<td>on</td>
</tr>
<tr>
<td>outersolnum</td>
<td>Positive integer array</td>
<td>all</td>
<td>end</td>
</tr>
<tr>
<td>selection</td>
<td>Integer vector</td>
<td>string</td>
<td>all</td>
</tr>
<tr>
<td>solnum</td>
<td>Integer vector</td>
<td>end</td>
<td>all</td>
</tr>
<tr>
<td>squeeze</td>
<td>on</td>
<td>off</td>
<td>on</td>
</tr>
<tr>
<td>t</td>
<td>Double array</td>
<td>Time for evaluation</td>
<td></td>
</tr>
</tbody>
</table>

The property dataset controls which data set is used for the evaluation. Data Sets contain or refer to the source of data for postprocessing purposes. Evaluation is supported only on Solution Data Sets.

The mean of expressions e1,...,en is evaluated for one or several solutions. Each solution generates an additional column in the returned matrix. The property solnum
and \( t \) control which solutions are used for the evaluation. The `solnum` property is available when the data set has multiple solutions, for example in the case of parametric, eigenfrequency, or time-dependent solutions. The `t` property is available only for time-dependent problems. If `solnum` is provided, the solutions indicated by the indices provided with the `solnum` property are used. If `t` is provided solutions are interpolated. If neither `solnum` nor `t` is provided, all solutions are evaluated.

The property `solnum` is used to select the solution number when a parametric, eigenvalue or time-dependent solver has been used.

The property `outersolnum` is used to select the outer solution number when a parametric sweep has been used in the study step node.

If the `matrix` property is set to `off` the output is cell arrays of length \( P \) containing cell arrays of length \( M \).

**EXAMPLE**

Evaluate the minimum temperature in the model domain:

```matlab
model = mphopen('model_tutorial_llmatlab');
std = model.study.create('std');
std.feature.create('stat','Stationary');
std.run;
maxT = mphmin(model,'T','volume');
```

Evaluate the minimum temperature on boundary 9:

```matlab
maxT = mphmin(model,'T','surface','selection',9);
```

Evaluate minimum of expression using several solution:

```matlab
model = mphopen('model_tutorial_llmatlab');
std = model.study.create('std');
param = std.feature.create('param','Parametric');
time = std.feature.create('time','Transient');
time.set('tlist', 'range(0,1,25)');
param.setIndex('pname','power',0);
param.setIndex('plistarr','30 60 90',0);
std.run;
```

Evaluate the minimum of the temperature at every time step computed with power set to 30:

```matlab
maxT = mphmin(model,'T','volume','dataset','dset2');
```

Evaluate the minimum of the temperature at the fifth time step:

```matlab
maxT = mphmin(model,'T','volume','dataset','dset2',...
Evaluate the minimum of the temperature at 10.5 sec and 15.2 sec:

\[
\text{maxT} = \text{mphmin}(\text{model}, 'T', 'volume', 'dataset', 'dset2', 't', [10.5, 15.2]);
\]

Evaluate the minimum of the temperature at every time step computed with power set to 90:

\[
\text{maxT} = \text{mphmin}(\text{model}, 'T', 'volume', 'dataset', 'dset2', 'outersolnum', 3);
\]

SEE ALSO
mphmax, mphmean

mphmodel

Return tags for the nodes and subnodes in the COMSOL model object.

SYNTAX
mphmodel(model)
str = mphmodel(model, '-struct')

DESCRIPTION
mphmodel(model) returns the tags for the nodes and subnodes of the object model. str = mphmodel(model, '-struct') returns the tags for the nodes and subnodes of the object model as a MATLAB® structure str.

The function mphmodel can be used when navigating the model object and learning about its structure. The mphmodel function is mainly designed for usage when working on the command line and one needs to learn what nodes are placed under a particular node.

EXAMPLE
Load the model busbar.mph and get the list of the nodes available under the root node:

\[
\text{model} = \text{mphopen('busbar')}
\text{mphmodel(model)}
\]

Get the model information as a structure:

\[
\text{res} = \text{mphmodel(model, '-struct')}
\]
The GUI requires that the COMSOL object is stored in a variable in the base workspace (at the MATLAB® command prompt) with the name `model`.

`mphnavigator(model)` opens the model object defined with the name `model` in Model Object Navigator.
EXAMPLE
Load busbar.mph from the Model Library:

    mphopen busbar

Navigate the model object that is accessible with the variable model

    mphnavigator

Load effective_diffusivity.mph from the Applications Libraries and set the model object with the variable eff_diff:

    eff_diff = mphopen('effective_diffusivity');

Navigate the model object that is accessible with the variable eff_diff

    mphnavigator(eff_diff)

SEE ALSO
mphgetexpressions, mphgetproperties, mphgetselection, mphmodel, mphsearch, mphshowerrors

mphopen
Graphical user interface (GUI) to open recent model files.

SYNTAX
mphopen
mphopen -dir dirpath
mphopen -clear
model = mphopen(filename)
model = mphopen(filename, mtag)
model = mphopen(filename, mtag, '-nostore')
model = mphopen(filename, mtag, '-history')
model = mphopen(filename, mtag, pwd)
[model, filenameloaded] = mphopen(filename,...)

DESCRIPTION
mphopen starts a GUI with the recent opened files list.

mphopen -dir dirpath starts a GUI with a list of the files in the specified directory dirpath. If dirpath is not specified the working directory is taken by default.

mphopen -clear resets the recent opened files list.

model = mphopen(filename) loads a COMSOL model object saved with the name filename and assigns the default tag Model in the COMSOL server. If a model with
tag Model already exists and is also open in a COMSOL Multiphysics client, the loaded model an index number is appended to the tag, for instance Model1.

model = mphopen(filename, mtag) loads a COMSOL model object and assigns the tag mtag in the COMSOL server.

model = mphopen(filename, mtag, '-nostore') does not update the recent opened model list.

model = mphopen(filename, mtag, '-history') turns on history recording.

model = mphopen(filename, mtag, pwd) loads the COMSOL model in the file protected with the password pwd.

[model, filenameloaded] = mphopen(filename, ...) also returns the full file name filenameloaded of the file that was loaded.

The model tag mtag and the password pwd are defined as string.

If the model tag is the same as a model that is currently in the COMSOL server the loaded model overwrites the existing one.

Note that MATLAB® searches for the model on the MATLAB path if an absolute path is not supplied.

mphopen turns off the model history recording by default, unless the property '-history' is used.

The extension mph can be omitted.

mphopen does not look for lock file when opening a model in the COMSOL server.
**SEE ALSO**

*mphload*, *mphsave*

**mphparticle**

Evaluate expressions on particle and ray trajectories.

**SYNTAX**

\[
pd = \text{mphparticle}(\text{model})
\]

\[
pd = \text{mphparticle}(\text{model},'expr',{e1,...,en},...)
\]

**DESCRIPTION**

\(\text{mphparticle}(\text{model})\) returns particle position and particle velocity at all time steps stored in the first particle data set.

\(\text{mphparticle}(\text{model},'expr',{e1,...,en},...\) returns particle position, particle velocity and expressions \(e1,...,\) \(en\) evaluated on particle trajectories.

The function \(\text{mphparticle}\) accepts the following property/value pairs:

**TABLE 6-21: PROPERTY/VALUE PAIRS FOR THE MPHPARTICLE COMMAND**

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>VALUE</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>expr</td>
<td>String</td>
<td>Cell array</td>
<td>Expressions to evaluate</td>
</tr>
<tr>
<td>dataonly</td>
<td>on</td>
<td>off</td>
<td>Return only expression values</td>
</tr>
</tbody>
</table>
The returned value `pd` is a structure with the following content:

**Table 6-21: Property/Value Pairs for the `mphparticle` Command**

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>VALUE</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>dataset</td>
<td>String</td>
<td>First particle data set</td>
<td>Data set tag</td>
</tr>
<tr>
<td>t</td>
<td>Double array</td>
<td>Time for evaluation</td>
<td></td>
</tr>
</tbody>
</table>

**Table 6-22: Fields in the Info Structure**

<table>
<thead>
<tr>
<th>FIELD</th>
<th>CONTENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>v</td>
<td>Velocity of the particles</td>
</tr>
<tr>
<td>p</td>
<td>Position of the particles</td>
</tr>
<tr>
<td>d#</td>
<td>Result of evaluation #</td>
</tr>
<tr>
<td>t</td>
<td>Time for evaluation</td>
</tr>
<tr>
<td>expr</td>
<td>Evaluated expressions</td>
</tr>
<tr>
<td>unit</td>
<td>Unit of evaluations</td>
</tr>
</tbody>
</table>

**Note:** `mphparticle` only evaluates expressions using particle and ray data sets.

**Example**

Load the model `trapped_protons` from the Applications Libraries:

```matlab
model = mphopen('trapped_protons');
```

Extract the particle positions and particle velocities along the computed trajectories at every time steps stored in the model:

```matlab
pd = mphparticle(model)
```

Evaluate the mirror point latitude (`Lm`) and the particle equatorial pitch angle (`Ea`) at `t = 0.7` sec., extract only the data:

```matlab
pd = mphparticle(model,'dataset','dset2',... 'expr',{'Lm','Ea*180/pi'},'t',0.7,'dataonly','on')
```

**See Also**

`mpheval`, `mphevalpoint`, `mphint2`, `mphinterp`, `mphray`
**mphplot**

Render a plot group in a figure window.

**SYNTAX**

```matlab
mphplot(model)
mphplot(model,pgtag,...)
pd = mphplot(model,pgtag,...)
mphplot(pd,...)
```

**DESCRIPTION**

`mphplot(model)` opens a figure window and adds a menu where it is possible to switch between all the different result plots in a model as well as any geometry and mesh plots. A toolbar is added to the figure that allows the user to control the use of views, lights, and camera settings.

`mphplot(model,pgtag,...)` renders the plot group tagged `pgtag` from the model object `model` in a figure window in MATLAB®.

`pd = mphplot(model,pgtag,...)` also returns the plot data used in the MATLAB figure in a cell array `pd`. `pd` contains ordinary MATLAB data and can later be used to recreate the plot using `mphplot`. It is also possible to investigate and extract data from the plot this way in order to create plots in other ways or to further analyze the data. Set `createplot` to `off` if a plot should be not be created. Note that `pd` contains data in single precision even though all calculations in COMSOL Multiphysics are carried out in double precision.

`mphplot(pd,...)` makes a plot using the post data structure `pd` that is generated using the function `mpheval`. Plots involving points, lines and surfaces are supported.

The function `mphplot` accepts the following property/value pairs:

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>VALUE</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>colortable</td>
<td>Char</td>
<td>rainbow</td>
<td>Color table used for plotting post data structure</td>
</tr>
<tr>
<td>createplot</td>
<td>on</td>
<td>off</td>
<td>on</td>
</tr>
<tr>
<td>index</td>
<td>Positive integer</td>
<td>1</td>
<td>Index of variable to use for plotting post data structure</td>
</tr>
<tr>
<td>mesh</td>
<td>on</td>
<td>off</td>
<td>on</td>
</tr>
<tr>
<td>parent</td>
<td>Double</td>
<td></td>
<td>Set the parent axes</td>
</tr>
</tbody>
</table>
Note: The plot on server option requires that you start COMSOL with MATLAB in graphics mode.

Only one color range bar and one legend bar is supported in a MATLAB figure. When the option plot on server is active, all active color range bar are displayed.

The property `createplot` is useful when extracting plot data structure on machines without a graphics display.

The data fields returned by `mphplot` are subject to change. The most important fields are:

- \( p \), the coordinates for each point that are used for creating lines or triangles.
- \( n \), the normals in each point for the surfaces. These are not always available.
- \( t \), contains the indices to columns in \( p \) of a simplex mesh, each column in \( t \) representing a simplex.
- \( d \), the data values for each point.
- \( rgb \), the color values (red, green and blue) entities at each point.

**Example**

Display the plot settings `pg` using a MATLAB figure

```matlab
model = mphopen('model_tutorial_llmatlab');
std = model.study.create('std');
std.feature.create('stat','Stationary');
std.run;
model.result.dataset.create('mir', 'Mirror3D');
pg = model.result.create('pg', 'PlotGroup3D');
pg.set('data', 'mir');
surf1 = pg.feature.create('surf1', 'Surface');
surf1.set('colortable', 'Thermal');

mphplot(model,'pg')
```

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>VALUE</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>rangenum</td>
<td>Positive Integer</td>
<td>none</td>
<td>Color range bar (or legend) to display</td>
</tr>
<tr>
<td>server</td>
<td>on</td>
<td>off</td>
<td>Plot on server</td>
</tr>
<tr>
<td>view</td>
<td>Char</td>
<td>'auto'</td>
<td>View settings tag</td>
</tr>
</tbody>
</table>
Combine plot types on the same plot group:

```matlab
surf2 = pg.feature.create('surf2', 'Surface');
surf2.set('data', 'dset1');
surf2.set('expr', 'ht.tfluxMag');
```

Display the plot group and the color range bar of the second plot type:

```matlab
mphplot(model,'pg','rangenum',2)
```

Display the plot group on the server:

```matlab
mphplot(model,'pg','server','on')
```

Display expression value evaluated using `mpheval`:

```matlab
model = mphopen('model_tutorial_llmatlab');
std = model.study.create('std');
std.feature.create('stat','Stationary');
std.run;
```

Extract temperature and total heat flux magnitude in domain 2:

```matlab
pd = mpheval(model,{'T','ht.tfluxMag'},'selection',2);
```

Plot the temperature data using thermal color table:

```matlab
mphplot(pd,'index',1,'colortable','Thermal','rangenum',1)
```

**SEE ALSO**

`colortable`, `mpheval`

`mphquad2tri`

Convert plot data quad mesh into simplex mesh.

**SYNTAX**

```matlab
pdout = mphquad2tri(pdin)
```

**DESCRIPTION**

`pdout = mphquad2tri(pdin)` converts the plot data stored in the structure `pdin` into the structure `pdout` using a simplex mesh.

The input and output structures, respectively `pdin` and `pdout`, are structures with fields `p`, `d`, `t`, `rgb` and `expr`.

- The field `p` is a 2xN array containing the vertex coordinates.
- The field saved is a Nx1 array containing the data value at the vertices.
The field \textit{t} is an array containing the indices to columns in \textit{p} of a quad mesh for \textit{pdin} and of a simplex mesh for \textit{pdout}, each column in \textit{t} representing respectively a quad and a simplex.

The field \textit{rgb} is a Nx3 array containing the color model data. This field is optional.

The field \textit{expr} is a string containing the description of the data. This field is optional.

\textbf{EXAMPLE}

Generate 3D surf data

\begin{verbatim}
[x,y] = meshgrid(-0.1:0.2:1.1,-0.4:0.2:0.4);
z = cumsum(0.1*randn(size(x)));\end{verbatim}

Create plotdata in a quad mesh:

\begin{verbatim}
pd = mphsurf(x,y,z);\end{verbatim}

Convert the plot data into triangle mesh:

\begin{verbatim}
pd = mphquad2tri(pd);
mpplot(pd)\end{verbatim}

\textbf{SEE ALSO}
mphsurf, mphreadstl, mphwritestl

\textit{mphray}

Evaluate expressions on particle and ray trajectories.

\textbf{SYNTAX}

\begin{verbatim}
pd = mphray(model)
pd = mphray(model,'expr',{e1,...,en},...)
\end{verbatim}

\textbf{DESCRIPTION}

\begin{verbatim}
pd = mphray(model)\end{verbatim} returns particle position and particle velocity at all time steps stored in the first particle data set.

\begin{verbatim}
pd = mphray(model,'expr',{e1,...,en},...)\end{verbatim} returns particle position, particle velocity and expressions \texttt{e1},...,\texttt{en} evaluated on particle or ray trajectories.

\textit{pd} is a structure with fields \texttt{p}, \texttt{v}, \texttt{d#}, \texttt{t}, \texttt{expr}, and \texttt{unit}.

- The field \texttt{p} contains the position of the particles.
- The field \texttt{v} contains the velocity of the particles.
- The field $d^#$ contains the result of evaluation $#$.
- The field $t$ contains the time for evaluation.
- The field $expr$ contains the evaluated expressions.
- The field $unit$ contains the unit of evaluations.

The function `mphray` accepts the following property/value pairs:

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>VALUE</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>dataonly</td>
<td>on</td>
<td>off</td>
<td>off</td>
</tr>
<tr>
<td>dataset</td>
<td>String</td>
<td>Data set tag</td>
<td></td>
</tr>
<tr>
<td>expr</td>
<td>String</td>
<td>Cell array</td>
<td>Expressions to evaluate</td>
</tr>
<tr>
<td>outersolnum</td>
<td>Positive integer</td>
<td>1</td>
<td>Outer solution for evaluation</td>
</tr>
<tr>
<td>solnum</td>
<td>Positive integer array</td>
<td>all</td>
<td>Inner solution for evaluation</td>
</tr>
<tr>
<td>t</td>
<td>Double array</td>
<td>Time for evaluation</td>
<td></td>
</tr>
<tr>
<td>times</td>
<td>on</td>
<td>off</td>
<td>on</td>
</tr>
<tr>
<td>velocities</td>
<td>on</td>
<td>off</td>
<td>on</td>
</tr>
</tbody>
</table>

**Note:** `mphray` only evaluates expressions using particle and ray data sets.

**SEE ALSO**
- `mpheval`, `mphevalpoint`, `mphevalpoint`, `mphint2`, `mphinterp`, `mphparticle`

`mphreadstl`

Read an STL file and return the data into a plot data structure.

**SYNTAX**

```plaintext```
pd = mphreadstl(filename)
```

**DESCRIPTION**

`pd = mphreadstl(filename)` reads the STL file `filename` and returns the data into the plot data structure `pd`. 

---

**TABLE 6-24: PROPERTY/VALUE PAIRS FOR THE MPHRAY COMMAND**

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>VALUE</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>dataonly</td>
<td>on</td>
<td>off</td>
<td>off</td>
</tr>
<tr>
<td>dataset</td>
<td>String</td>
<td>Data set tag</td>
<td></td>
</tr>
<tr>
<td>expr</td>
<td>String</td>
<td>Cell array</td>
<td>Expressions to evaluate</td>
</tr>
<tr>
<td>outersolnum</td>
<td>Positive integer</td>
<td>1</td>
<td>Outer solution for evaluation</td>
</tr>
<tr>
<td>solnum</td>
<td>Positive integer array</td>
<td>all</td>
<td>Inner solution for evaluation</td>
</tr>
<tr>
<td>t</td>
<td>Double array</td>
<td>Time for evaluation</td>
<td></td>
</tr>
<tr>
<td>times</td>
<td>on</td>
<td>off</td>
<td>on</td>
</tr>
<tr>
<td>velocities</td>
<td>on</td>
<td>off</td>
<td>on</td>
</tr>
</tbody>
</table>
pd is a structure with fields \( n \), \( p \), \( t \), \texttt{name} , \texttt{ref} , \texttt{rgb} , \texttt{expr} , and \( d1 \).

- The field \( n \) contains the normal vector for the triangle.
- The field \( p \) contains node point coordinate information.
- The field \( t \) contains the indices to columns in \( p \) of a simplex mesh, each column in \( t \) representing a simplex.
- The field \texttt{name} contains the name of the file the data come from.
- The field \texttt{ref} contains the header of the file.
- The field \texttt{rgb} contains the color model data at each vertices. The columns correspond to node point coordinates in columns in \( p \).
- The field \texttt{expr} contains the data description.
- The field \( d1 \) contains the data value at each vertices. The columns correspond to node point coordinates in columns in \( p \).

Both binary and ASCII STL files are supported.

\textbf{SEE ALSO}

mphquad2tri, mphsurf, mphwritestl

\texttt{mphreduction}

Return reduced order state space matrices for a model.

\textbf{SYNTAX}

\texttt{data = mphreduction(model, ...)}

\textbf{DESCRIPTION}

\texttt{data = mphreduction(model, ...)} calculates reduced order state-space matrices for a model based on a time dependent model and a training study. These studies may already exist in the model or new studies may be added by \texttt{mphreduction}.

\texttt{mphreduction} will by default delete all added studies upon completion. The property \texttt{keepfeature} may be used to change that, which makes it possible to work further on already added studies since \texttt{mphreduction} does not support all settings that are possible for model reduction.
The function `mphreduction` accepts the following property/value pairs:

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>VALUE</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>out</td>
<td>char</td>
<td>'all'</td>
<td>Names of output matrices</td>
</tr>
<tr>
<td>unreducedstudy</td>
<td>char</td>
<td></td>
<td>Unreduced study tag</td>
</tr>
<tr>
<td>unreducedstudystep</td>
<td>char</td>
<td></td>
<td>Unreduced study step tag</td>
</tr>
<tr>
<td>unreducedsteps</td>
<td>1</td>
<td></td>
<td>Unreduced time or frequency steps</td>
</tr>
<tr>
<td>trainingstudy</td>
<td>char</td>
<td></td>
<td>Training study tag</td>
</tr>
<tr>
<td>trainingstudystep</td>
<td>char</td>
<td></td>
<td>Training study step tag</td>
</tr>
<tr>
<td>trainingstudyneigs</td>
<td>integer</td>
<td>6</td>
<td>Number of eigenvalues in training study</td>
</tr>
<tr>
<td>trainingstudyeigsnear</td>
<td>char</td>
<td>'1[Hz]'</td>
<td>Search for eigenvalues near</td>
</tr>
<tr>
<td>reductionstudy</td>
<td>char</td>
<td></td>
<td>Model reduction study tag</td>
</tr>
<tr>
<td>reductionsol</td>
<td>char</td>
<td></td>
<td>Model reduction solution tag</td>
</tr>
<tr>
<td>reductionmodalsol</td>
<td>char</td>
<td></td>
<td>Modal solver tag</td>
</tr>
<tr>
<td>eigmethod</td>
<td>default</td>
<td>default</td>
<td>Method for finding eigenvalues</td>
</tr>
<tr>
<td>appneigs</td>
<td>integer</td>
<td></td>
<td>Approximate number of eigenvalues</td>
</tr>
<tr>
<td>maxneigs</td>
<td>integer</td>
<td></td>
<td>Maximum number of eigenvalues</td>
</tr>
<tr>
<td>eigsrange</td>
<td>integer</td>
<td></td>
<td>Eigenvalues in range</td>
</tr>
<tr>
<td>controls</td>
<td>cell array</td>
<td></td>
<td>Model control inputs parameters (u)</td>
</tr>
<tr>
<td>controlvals</td>
<td>vector</td>
<td></td>
<td>Control input values</td>
</tr>
<tr>
<td>output</td>
<td>cell array</td>
<td></td>
<td>Outputs (y)</td>
</tr>
<tr>
<td>return</td>
<td>struct</td>
<td>ss</td>
<td>Return type</td>
</tr>
<tr>
<td>keepfeature</td>
<td>on</td>
<td>off</td>
<td>Keep the added features in the model</td>
</tr>
<tr>
<td>clean</td>
<td>on</td>
<td>off</td>
<td>Clean previously added features from the model</td>
</tr>
</tbody>
</table>
EXAMPLE

Calculate a reduced order state space system using the existing unreduced study std1 and existing eigenvalue study std2. Use the control variable (parameter) Qin and the output (probe) comp1.intop1(T).

```matlab
MR = mphreduction(model, ... 'out', {'MA' 'MB' 'A' 'B' 'C' 'D'}, ... 'controls', {'Qin'}, ... 'controlvals', [1], ... 'output', 'comp1.intop1(T)', ... 'unreducedstudy', 'std1', ... 'trainingstudy', 'std2')
```

SEE ALSO

mphstate

mphsave

Save a COMSOL Multiphysics model.

SYNTAX

mphsave(model)

mphsave(model,filename,...)

DESCRIPTION

mphsave(model) saves the COMSOL model object model.

mphsave(model,filename,...) saves the COMSOL model object model to the file named filename.

The function mphsave accepts the following property/value pairs:

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>VALUE</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>component</td>
<td>on</td>
<td>off</td>
<td>Save M-file using the component syntax</td>
</tr>
<tr>
<td>optimize</td>
<td>size</td>
<td>speed</td>
<td>Optimize for speed or file size</td>
</tr>
</tbody>
</table>

If the file name is not provided, the model has to be saved previously on disk.

If the file name does not provide a path, the file is saved relatively to the current path in MATLAB®.

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The model can be saved as an MPH-file, Java file, or M-file. The file extension determines which format that is saved.

**Note:** Model created with older version than COMSOL 5.3 cannot be saved using the component syntax.

**SEE ALSO**

`mphopen`, `mphload`  

`mphsearch`  

Graphical user interface (GUI) for searching expressions in the COMSOL model object.

**SYNTAX**

`mphsearch(model)`

**DESCRIPTION**

`mphsearch(model)` opens a graphical user interface that can be used to search expressions in the model object `model`. Search using a text available in the name, expression or description of the variable.
SEE ALSO
mphgetexpressions, mphgetproperties, mphgetselection, mphmodel, mphnavigator

mphselectbox

Select geometric entity using a rubberband/box.

SYNTAX
n = mphselectbox(model, geomtag, boxcoord, entity, ...)

DESCRIPTION
n = mphselectbox(model, geomtag, boxcoord, entity, ...) returns the indices of the geometry entities that are inside the rubberband domain (rectangle or box). This method looks only on the vertex coordinates and does not observe all points on curves and surfaces.

boxcoord set the coordinates of the selection domain, specified as a Nx2 array, where N is the geometry space dimension.

entity can be one of point, edge, boundary or domain following the entity space dimension defined below:

• domain: maximum geometry space dimension
• boundary: maximum geometry space dimension -1
• edges: 1 (only for 3D geometry)

The function mphselectbox accepts the following property/value pairs:

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>VALUE</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>adjnumber</td>
<td>Scalar</td>
<td>none</td>
<td>Adjacent entity number</td>
</tr>
</tbody>
</table>

When a model uses form an assembly more than one vertex can have the same coordinate if the coordinate is shared by separate geometric objects. In that case one can use the adjnumber property in order to identify the domain that the vertices should be adjacent to.

EXAMPLE
Find the domains using a box selection:

model = mphpopen('model_tutorial_llmatlab');
coordBox = [-1e-3,11e-3;-1e-3,11e-3;9e-3,11e-3];

Find the boundaries inside the selection box:

n = mphselectbox(model,'geom1',coordBox,'boundary');

Find the boundaries inside the selection box that are adjacent to domain number 1:

n = mphselectbox(model,'geom1',coordBox,'boundary','adjnumber',1);

Find geometry entity number in an assembly

model = mphopen('model_tutorial_llmatlab');
geom = model.component('comp1').geom('geom1');
geom.feature('fin').set('action','assembly');
geom.run('fin');

Find the boundaries within a box:

coordBox = [-1e-3,51e-3;-1e-3,51e-3;9e-3,11e-3];

n = mphselectbox(model,'geom1',coordBox,'boundary');

Find the boundary adjacent to domain 2:

n = mphselectbox(model,'geom1',coordBox,'boundary','adjnumber',2);

SEE ALSO
mphgetadj, mphgetcoords, mphselectcoords, mphviewselection

mphselectcoords

Select a geometric entity using point coordinates.

SYNTAX

n = mphselectcoords(model,geomtag,coord,entity,...)

DESCRIPTION

n = mphselectcoords(model,geomtag,coord,entity,...) finds geometry entity numbers based on their vertex coordinates.

One or more coordinates can be provided. The function searches for vertices near these coordinates using a tolerance radius. The list of the entities that are adjacent to such vertices is returned.
coord is a NxM array where N correspond of the number of point to use and M the space dimension of the geometry.

entity can be one of point, edge, boundary or domain following the entity space dimension defined below:

- domain: maximum geometry space dimension
- boundary: maximum geometry space dimension -1
- edges: 1 (only for 3D geometry)

The function mphpselectcoords accepts the following property/value pairs:

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>VALUE</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>adjnumber</td>
<td>Scalar</td>
<td></td>
<td>Adjacent entity number</td>
</tr>
<tr>
<td>radius</td>
<td>Scalar</td>
<td>auto</td>
<td>Search radius</td>
</tr>
<tr>
<td>include</td>
<td>all</td>
<td>any</td>
<td>all</td>
</tr>
</tbody>
</table>

When a model uses form an assembly more than one vertex can have the same coordinate if the coordinate is shared by separate geometric objects. In that case one can use the adjnumber property in order to identify the domain that the vertices should be adjacent to.

The radius property is used to specify the radius of the sphere/circle that the search should be within. A small positive radius (based on the geometry size) is used by default in order to compensate for rounding errors.

Use the property include when two point coordinates are used. Set it to all to select objects within the search radius of all points. any returns objects within the search radius of any points.

**EXAMPLE**

Find geometry entity number

```matlab
model = mphpopen('model_tutorial_llmatlab');
coord = [10e-3 0 10e-3; 0 10e-3 10e-3];
n = mphpselectcoords(model,'geom1',coord,'point')
```

Return the indices of the point at coordinates within a search radius of 0.011:

```matlab
n = mphpselectcoords(model,'geom1',coord,'point',...
radius',0.011)
```

Return the indices of the boundaries that have a vertex within the search radius:
n = mphselectcoords(model,'geom1',coord','boundary','...
'radius',11e-3)

Return the indices of the edges that have a vertex within the search radius from all
points:

coord = [5e-3 0 10e-3;0 5e-3 10e-3];
n = mphselectcoords(model,'geom1',coord','edge','...
'radius',6e-3);

Return the indices of the edges that have a vertex within the search radius from at least
one point:

n = mphselectcoords(model,'geom1',coord','edge','...
'radius',6e-3,'include','any'));

Find geometry entity index in an assembly

model = mphopen('model_tutorial_llmatlab');
geom = model.component('comp1').geom('geom1');
geom.feature('fin').set('action', 'assembly');
geom.run('fin');

Return the indices of the boundaries that have any vertices within the search range of
a point:

coord = [0,0,10e-3];
n0 = mphselectcoords(model,'geom1',coord,'boundary')

Return the indices of the boundaries that also are adjacent to domain 1:

n1 = mphselectcoords(model,'geom1',coord,'boundary','...
'adjnumber',1);

Return the indices of the boundaries that also are adjacent to domain 2:

n1 = mphselectcoords(model,'geom1',coord,'boundary','...
'adjnumber',2);

SEE ALSO
mphgetadj, mphgetcoords, mphselectbox, mphviewselection

mphshowerrors

Show the messages in error nodes in the COMSOL Multiphysics model.

SYNTAX
mphshowerrors(model)
list = mphshowerrors(model)
**DESCRIPTION**

*mphshowerrors(model)* shows the error and warning messages stored in the model and where they are located. The output is displayed in the command window.

`list = mphshowerrors(model)` returns the error and warning messages stored in the model and where they are located in the Nx3 cell array list. `N` corresponding to the number of errors or warning found in the model object. The first column contains the node of the error, the second column contain the error message and the third column contains a cell arrays of the model tree nodes that contain the error information, which can help for automated processing of error and warning conditions.

*mphsolinfo*

Get information about a solution object.

**SYNTAX**

```matlab
info = mphsolinfo(model,...)
info = mphsolinfo(model,'solname',soltag,...)
```

**DESCRIPTION**

`info = mphsolinfo(model,...)` returns information about the solution object. The function `mphsolinfo` accepts the following property/value pairs:

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>VALUE</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>soltag</td>
<td>String</td>
<td>Active solution object</td>
<td>Solution object tag</td>
</tr>
<tr>
<td>dataset</td>
<td>String</td>
<td>Active solution data set</td>
<td>Data set tag</td>
</tr>
<tr>
<td>NU</td>
<td>on</td>
<td>off</td>
<td>off</td>
</tr>
</tbody>
</table>

The returned value `info` is a structure with the following content

<table>
<thead>
<tr>
<th>FIELD</th>
<th>CONTENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>soltag</td>
<td>Solution node tag</td>
</tr>
<tr>
<td>study</td>
<td>Study node tag</td>
</tr>
<tr>
<td>size</td>
<td>Size of the solution vector</td>
</tr>
</tbody>
</table>
You can use the function `mphgetu` to obtain the actual values of the solution vector. Note that these functions are low level functions and you most often would use functions such as `mphinterp` and `mpheval` to extract numerical data from a model.

**Example**

Get the information about the default solution object:

```python
model = mphopen('model_tutorial_llmatlab');
std = model.study.create('std');
std.feature.create('stat', 'Stationary');
std.run;
solinfo = mphsolinfo(model)
```

Get information of multiple solver solution:

```python
model = mphopen('model_tutorial_llmatlab');
std = model.study.create('std');
param = std.feature.create('param', 'Parametric');
time = std.feature.create('time', 'Transient');
```
time.set('tlist', 'range(0,1,25)');
param.setIndex('pname','power',0);
param.setIndex('plistarr','30 60 90',0);
std.run;

Get the information about the 1st outer solution (power = 30):
solinfo = mphsolinfo(model,'soltag','sol3');
Get the solution vector for 2nd outer solution (power = 60):
solinfo = mphsolinfo(model,'soltag','sol4');

SEE ALSO
mphgetu, mphxmeshinfo, mphsolutioninfo

mphsolutioninfo
Get information about solution objects and data sets containing given parameters.

SYNTAX
info = mphsolutioninfo(model)
info = mphsolutioninfo(model,'parameters',{{ei,vi,toli},...},...)

DESCRIPTION
info = mphsolutioninfo(model) returns information about all solution object and
solution data set combinations in model.

info = mphsolutioninfo(model,'parameters',{{ei,vi,toli}, ...}, ...) returns information about solution object and solution data set containing the given
inner/outer solution parameters ei with the value equal to vi within the tolerance
toli.

The function mphsolutioninfo accepts the following property/value pairs:

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>VALUE</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>cellmap</td>
<td>off</td>
<td>on</td>
<td>off</td>
</tr>
<tr>
<td>dataset</td>
<td>String</td>
<td>Active solution data set</td>
<td>Data set tag</td>
</tr>
<tr>
<td>parameters</td>
<td>Cell</td>
<td>Cell array</td>
<td>Filter parameters, values and tolerances</td>
</tr>
</tbody>
</table>
The returned value info is a structure with the following content.

**TABLE 6-31: PROPERTY VALUE PAIRS FOR THE MPH SOLUTIONINFO COMMAND**

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>VALUE</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>soltag</td>
<td>String</td>
<td>String</td>
<td>Solution object tag</td>
</tr>
<tr>
<td></td>
<td>cell array</td>
<td></td>
<td></td>
</tr>
<tr>
<td>sort</td>
<td>String</td>
<td>auto</td>
<td>Sort the map by column number</td>
</tr>
<tr>
<td></td>
<td>Scalar</td>
<td>auto</td>
<td>or header tag</td>
</tr>
</tbody>
</table>

The returned value info is a structure with the following content.

**TABLE 6-32: FIELDS IN THE INFO STRUCTURE**

<table>
<thead>
<tr>
<th>FIELD</th>
<th>CONTENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>solutions</td>
<td>List of matched solution tags</td>
</tr>
<tr>
<td>sol#</td>
<td>Substructure containing information related to solution number #</td>
</tr>
</tbody>
</table>

The substructure info.sol# has the following content.

**TABLE 6-33: FIELDS IN THE INFO.SOL# SUBSTRUCTURE**

<table>
<thead>
<tr>
<th>FIELD</th>
<th>CONTENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>dataset</td>
<td>Tag of the solution data set</td>
</tr>
<tr>
<td>study</td>
<td>Tag of the study associated to the solution</td>
</tr>
<tr>
<td>sequencetype</td>
<td>Type of solution object</td>
</tr>
<tr>
<td>cellmap</td>
<td>Cellmap describing the connections between parameters and inner/outer solution numbers</td>
</tr>
<tr>
<td>values</td>
<td>Parameters values used in the solution</td>
</tr>
<tr>
<td>parameters</td>
<td>Parameters names used in the solution</td>
</tr>
<tr>
<td>mapheaders</td>
<td>Headers for the map</td>
</tr>
<tr>
<td>map</td>
<td>Map describing the connections between parameters and inner/outer solution numbers</td>
</tr>
</tbody>
</table>

**EXAMPLE**

Load model_tutorial_llmatlab.mph:

```plaintext
model = mphopen('model_tutorial_llmatlab');
```

Create a study combining a parametric sweep and a transient study step:

```plaintext
std = model.study.create('std');
param = std.feature.create('param','Parametric');
time = std.feature.create('time','Transient');
```

Set the time stepping and the parametric sweep parameters:
time.set('tlist', 'range(0,1,25)');
param.setIndex('pname','power',0);
param.setIndex('plistarr','30 60 90', 0);

Run the study:
std.run;

Retrieve the solution information corresponding to power = 30 W:
info = mphsolutioninfo(model,'parameters',{"power',30,0})

Retrieve the solution information corresponding to power = 90 W and around t = 10.4 sec. and its associated solution data set:
info = mphsolutioninfo(model,'parameters',{{'power',90,0},
{'t',10.4,0.5}})

Get the solution solution data set associated:
dset = info.sol2.dataset

Get the inner and outer solution number:
solnum = info.sol2.map(end-1)
outersolnum = info.sol2.map(end)

SEE ALSO
mphgetu, mphxmeshinfo, mphsolinfo

mphstart

Connect MATLAB® to a COMSOL server.

SYNTAX
mphstart
mphstart(port)
mphstart(ipaddress, port)
mphstart(ipaddress, port, username, password)
mphstart(ipaddress, port, comsolpath)
 mphstart(ipaddress, port, comsolpath, username, password)

DESCRIPTION
mphstart creates a connection with a COMSOL server using the default port number (which is 2036).

mphstart(port) creates a connection with a COMSOL server using the specified port number port.
mphstart(ipaddress, port) creates a connection with a COMSOL server using the specified IP address ipaddress and the port number port. This command assumes that the client and the server machine share the same login properties.

mphstart(ipaddress, port, username, password) creates a connection with a COMSOL server using the specified IP address ipaddress and the port number port, the username username and password password.

mphstart(ipaddress, port, comsolpath) creates a connection with a COMSOL server using the specified IP address and port number using the comsolpath that is specified. This is useful if mphstart cannot find the location of the COMSOL Multiphysics installation.

mphstart(ipaddress, port, comsolpath, username, password) creates a connection with a COMSOL server using the specified IP address, the port number, the username and password using the comsolpath that is specified. This is useful if mphstart cannot find the location of the COMSOL Multiphysics installation.

mphstart can be used to create a connection from within MATLAB when this is started without using the COMSOL with MATLAB option. mphstart then sets up the necessary environment and connect to COMSOL.

Prior to calling mphstart it is necessary to set the path of mphstart.m in the MATLAB path or to change the current directory in MATLAB (for example, using the cd command) to the location of the mphstart.m file.

A COMSOL server must be started prior to running mphstart.

mphstart connect to either a COMSOL Multiphysics server (started with the command: comsol mphserver) or the COMSOL Server. To connect to the COMSOL Server from a computer that has just MATLAB installed it is necessary to run the COMSOL Server Client installer.

Once MATLAB is connected to the server, import the COMSOL class in order to use the ModelUtil commands. To import the COMSOL class enter:

```plaintext
import com.comsol.model.*
import com.comsol.model.util.*
```

**EXAMPLE**

Connect manually MATLAB to a COMSOL Multiphysics Server and create a model:

```plaintext
mphstart
import com.comsol.model.*
import com.comsol.model.util.*
```
model = ModelUtil.create('Model');

Connect manually MATLAB to a COMSOL Multiphysics Server running on the computer with the IP address 192.168.0.1 using port 2037:

mphstart('192.168.0.1',2037)

mphstate

Get state space matrices for a dynamic system.

**SYNTAX**

\[
\text{str} = \text{mphstate}(\text{model}, \text{soltag}, \text{'Out'}, \{'\text{SP}'\}) \\
\text{str} = \text{mphstate}(\text{model}, \text{soltag}, \text{'Out'}, \{'\text{SP1}', '\text{SP2}', ...\})
\]

**DESCRIPTION**

\[
\text{str} = \text{mphstate}(\text{model}, \text{soltag}, \text{'out'}, \{'\text{SP}'\}) \text{ returns a MATLAB® structure } \text{str} \text{ containing the state space matrix SP assembled using the solver node soltag and accessible as \text{str.SP}. SP being taken from the \text{Out} property list.}
\]

\[
\text{str} = \text{mphstate}(\text{model}, \text{soltag}, \text{'out'}, \{'\text{SP1}', '\text{SP2}', ...\}) \text{ returns a MATLAB structure } \text{str} \text{ containing the state space matrices SP1, SP2,... assembled using the solver node soltag and accessible as \text{str.SP1} and \text{str.SP2}. SP1 and SP2 being taken from the \text{out} property list.}
\]

The function `mphstate` accepts the following property/value pairs:

**TABLE 6-34: PROPERTY VALUE FOR THE MPHSTATE COMMAND**

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>VALUE</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>out</td>
<td>MA</td>
<td>MB</td>
<td>A</td>
</tr>
<tr>
<td>keepfeature</td>
<td>off</td>
<td>on</td>
<td>off</td>
</tr>
<tr>
<td>input</td>
<td>String</td>
<td>Input variables</td>
<td></td>
</tr>
<tr>
<td>output</td>
<td>String</td>
<td>Output variables</td>
<td></td>
</tr>
<tr>
<td>sparse</td>
<td>off</td>
<td>on</td>
<td>off</td>
</tr>
<tr>
<td>initmethod</td>
<td>init</td>
<td>sol</td>
<td>init</td>
</tr>
<tr>
<td>initSol</td>
<td>soltag</td>
<td>zero</td>
<td>soltag</td>
</tr>
<tr>
<td>solnum</td>
<td>Positive integer</td>
<td>auto</td>
<td>Solution number</td>
</tr>
</tbody>
</table>
The property **Sparse** controls whether the matrices $A$, $B$, $C$, $D$, $M$, $MA$, $MB$, and $Null$ are stored in the sparse format.

The equations correspond to the system below:

$$
\begin{align*}
M_C \dot{x} &= M_C A x + M_C B u \\
y &= C x + D u
\end{align*}
$$

where $x$ are the state variables, $u$ are the input variables, and $y$ are the output variables.

A static linearized model of the system can be described by:

$$
y = (D - C(M_C A)^{-1} M_C B) u
$$

The full solution vector $U$ can be then obtained from

$$
U = Null x + ud + u_0
$$

where $Null$ is the null space matrix, $ud$ the constraint contribution, and $u_0$ is the linearization point, which is the solution stored in the sequence once the state space export feature is run.

The matrices $M_C$ and $M_C A$ are produced by the same algorithms that do the finite-element assembly and constraint elimination in COMSOL Multiphysics. $M_C$ and $M_C A$ are the same as the matrices $D_C$ (eliminated mass matrix) and $-K_C$ ($K_C$ is the eliminated stiffness matrix). The matrices are produced from an exact residual vector Jacobian calculation (that is, differentiation of the residual vector with respect to the degrees of freedoms $x$) plus an algebraic elimination of the constraints. The matrix $C$ is produced in a similar way (that is, the exact output vector Jacobian matrix plus constraint elimination).

The matrices $M_C B$ and $D$ are produced by a numerical differentiation of the residual and output vectors, respectively, with respect to the input parameters (the algorithm systematically perturbs the input parameters by multiplying them by a factor $1+10^{-8}$).

The input cannot be a variable constraint in the model.

**Example**

Load `model_tutorial_llmatlab.mph`:

```matlab
model = mphopen('model_tutorial_llmatlab');
comp1 = model.component('comp1');
comp1.mesh('mesh1').autoMeshSize(9);
std = model.study.create('std');
```
```matlab
% Create time feature
time = std.feature.create('time','Transient');
time.set('tlist','range(0,1,50)');
std.run;

% Add a domain point probe plot
pdom = comp1.probe.create('pdom', 'DomainPoint');
pdom.model('comp1');
pdom.setIndex('coords3','1e-2',0,0);
pdom.setIndex('coords3','1e-2',0,1);
pdom.setIndex('coords3','0.5e-2',0,2);

% Extract matrices of the state-space system
M = mphstate(model,'sol1','out',{'A','B','C','D'},
              'input','power','output','comp1.ppb1');

% Plot the sparsity of the matrix A
subplot(1,2,1); spy(M.A); subplot(1,2,2); spy(abs(M.A)>1e-2)

% Set input power parameter and reference temperature
power = 30; T0 = 300;

% Compute system solution
func = @(t,x) M.A*x + M.B*power;
[t,x] = ode45(func,0:1:50,zeros(size(M.A,1),1));
y = M.C*x';
y = y+T0;

% Plot result
figure, plot(t,y), grid

% Evaluate steady-state temperature value
G = M.D-M.C*(inv(M.A))*M.B;
y = full(G*power);
y = y + T0

mphsurf

Create plot data structure from surf data.

SYNTAX

```
**DESCRIPTION**

pd = mphsurf(x, y, z) creates the plot data structure pd from surf data x, y and z.

pd = mphsurf(z) creates the plot data structure pd from surf data z. A unit scale is assumed for the x and y coordinates.

**EXAMPLE**

Create random height data

```matlab
[x,y] = meshgrid(-0.1:0.2:1.1,-0.4:0.2:0.4);
z = cumsum(0.1*randn(size(x)));```

Create 3D surface plot data structure

```matlab
pd = mphsurf(x,y,z);
mpplot(pd)
```

**SEE ALSO**

mphquad2tri, mphreadstl, mphwritestl

---

**mphtable**

Get table data.

**SYNTAX**

```matlab
info = mphtable(model,tabletag)
```

**DESCRIPTION**

info = mphtable(model,tabletag) returns the structure info containing the data with the tabletag tag and its headers.

The returned value info is a structure with the following content

**TABLE 6-35: FIELDS IN THE INFO STRUCT**

<table>
<thead>
<tr>
<th>FIELD</th>
<th>CONTENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>headers</td>
<td>Headers of the table</td>
</tr>
<tr>
<td>tag</td>
<td>Tag of the table</td>
</tr>
<tr>
<td>data</td>
<td>Data of the extracted table</td>
</tr>
<tr>
<td>filename</td>
<td>Filename when table exported to file</td>
</tr>
</tbody>
</table>

**EXAMPLE**

Load model_tutorial_llmatlab.mph, add a stationary study and compute the solution for different power values:
```matlab
model = mphopen('model_tutorial_llmatlab');
std = model.study.create('std');
stat = std.feature.create('stat','Stationary')
stat.setIndex('pname','power',0);
stat.setIndex('plistarr','30 60 90',0);
std.run;

Evaluate the maximum temperature in the model and set the results in a table:

max = model.result.numerical.create('max','MaxVolume');
max.selection.all;
tbl = model.result.table.create('tbl','Table');
tbl.comments('Volume Maximum (T)');
max.set('table','tbl');
max.setResult;

Extract the table data:

str = mphtable(model,'tbl');
tbl_data = str.data
```

**SEE ALSO**

mpheval, mphevalpoint, mphglobal, mphint2, mphinterp, mphmax, mphmean, mphmin

`mphtags`

Get tags and names for nodes in a COMSOL Multiphysics model.

**SYNTAX**

`mphtags(model)`

`mphtags(node)`

`mphtags(model, type)`

`[tags,labels,displaystrings] = mphtags(...)`

`mphtags -show`

`[tags,filename,fullfilename] = mphtags`

**DESCRIPTION**

`mphtags` is used to retrieve tags from nodes in a COMSOL Multiphysics model or tags from models that are loaded on the server.

When `mphtags` is called with a model or node variable the tags are returned form the model. `mphtags` also be called using a model variable and a type, where type can be one of these strings: `result`, `dataset`, `table`, `numerical`, and `export` to give
easy access to the nodes under the result node. It is sufficient to use the first letter of
the types.

If `mphtags` is called with output arguments it is possible to get both the tags as well as
labels and display names used for the nodes. For example,

```matlab
[tags,labels,displaystrings] = mphtags(model.geom)
```

If `mphtags` is called with the root model node as argument, the filename of the model
can be returned:

```matlab
[tag,filename,displaystring] = mphtags(model)
```

`mphtags` can be used to return a list of files currently loaded on the server. For
example,

```matlab
[tags,filename,fullfilename] = mphtags
```

In order to see this information quickly it is possible to call `mphtags` like this:

```matlab
mphtags -show
```

that just produces output that is useful viewing on screen.

---

*mphthumbnail*

Set or get model thumbnail.

**SYNTAX**

```matlab
mphthumbnail(model,filename)
mphthumbnail(model,image)
mphthumbnail(model,fig)
mphthumbnail(model,'')
```

**DESCRIPTION**

`mphthumbnail` sets or gets the model thumbnail for model loaded on the server. In
order to update the model thumbnail on disk the model must be saved.

`mphthumbnail(model,filename)` sets the thumbnail for the model to the image
contained in `filename`. The file must be a PNG- or JPG-file.

`mphthumbnail(model,image)` sets the thumbnail using the image data `image`. `image`
is either a NxM or a NxMx3 matrix. The preferred size of the image is 280 by 210
pixels.
mphthumbnail(model, fig) sets the thumbnail using the image in the figure with handle fig.

mphthumbnail(model, '') clears the thumbnail from the model.

[image, imagefilename] = mphthumbnail(model) gets the image data image and the image filename imagefilename for the thumbnail stored in the model model.

EXAMPLE
Load model_tutorial_llmatlab.mph:

    model = mphopen('model_tutorial_llmatlab');

Get the thumbnail image:

    im = mphthumbnail(model);

Show the thumbnail in a MATLAB figure:

    imshow(im)

Save the current figure image as an image file:

    filename = fullfile(tempdir,'imagefile.png');
    print(filename,'-dpng','-r48')

Set the thumbnail for the model:

    mphthumbnail(model, filename)

SEE ALSO
mphload, mphsave

mphversion

Return the version number for COMSOL Multiphysics.

SYNTAX
v = mphversion
[v,vm] = mphversion(model)

DESCRIPTION
v = mphversion returns the COMSOL Multiphysics version number that MATLAB is connected to as a string.
[v,vm] = mphversion(model) returns the COMSOL Multiphysics version number that MATLAB is connected to as a string in the variable v and the version number of the model in the variable vm.

**EXAMPLE**

Load model_tutorial_llmatlab.mph:
```
model = mphopen('model_tutorial_llmatlab');
```
Get the version numbers:
```
[version, model_version] = mphversion(model)
```

**SEE ALSO**

mphload, mphsave

`mphviewselection`

Display a geometric entity selection in a MATLAB® figure.

**SYNTAX**

`mphviewselection(model,geomtag,number,entity,...)`

`mphviewselection(model,seltag,...)`

**DESCRIPTION**

`mphviewselection(model,geomtag,number,entity,...)` displays the geometric entity number of type `entity` in MATLAB figure including the representation of the geometry `geomtag`.

`mphviewselection(model,seltag,...)` displays the geometric entity selection `seltag` in a MATLAB figure including the representation of the geometry.

The function `mphviewselection` accepts the following property/value pairs:

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>VALUE</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>edgecolor</td>
<td>Char</td>
<td>RGB array</td>
<td>k</td>
</tr>
<tr>
<td>edgecolorselected</td>
<td>RGB array</td>
<td>[1,0,0]</td>
<td>Color for selected edges</td>
</tr>
<tr>
<td>edgelabels</td>
<td>on</td>
<td>off</td>
<td>off</td>
</tr>
<tr>
<td>edgelabelscolor</td>
<td>Char</td>
<td>RGB array</td>
<td>g</td>
</tr>
<tr>
<td>edgemode</td>
<td>on</td>
<td>off</td>
<td>on</td>
</tr>
</tbody>
</table>
TABLE 6.36 PROPERTY VALUE PAIRS FOR THE MPHVIEWSELECTION FUNCTION

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>VALUE</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>entity</td>
<td>Domain</td>
<td>boundary</td>
<td>edge</td>
</tr>
<tr>
<td>facealpha</td>
<td>Double</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>facecolor</td>
<td>RGB array</td>
<td>[0.6,0.6,0.6]</td>
<td></td>
</tr>
<tr>
<td>facecolorselected</td>
<td>RGB array</td>
<td>[1,0,0]</td>
<td></td>
</tr>
<tr>
<td>facelabels</td>
<td>on</td>
<td>off</td>
<td>off</td>
</tr>
<tr>
<td>facelabelscolor</td>
<td>Char</td>
<td>RGB array</td>
<td>b</td>
</tr>
<tr>
<td>facemode</td>
<td>on</td>
<td>off</td>
<td>on</td>
</tr>
<tr>
<td>geommode</td>
<td>on</td>
<td>off</td>
<td>on</td>
</tr>
<tr>
<td>marker</td>
<td>.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>markerselection</td>
<td>Char</td>
<td>RGB array</td>
<td>r</td>
</tr>
<tr>
<td>markersize</td>
<td>Int</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>parent</td>
<td>Double</td>
<td></td>
<td></td>
</tr>
<tr>
<td>renderer</td>
<td>Opengl</td>
<td>zbuffer</td>
<td>opengl</td>
</tr>
<tr>
<td>selection</td>
<td>String</td>
<td>Positive integer array</td>
<td></td>
</tr>
<tr>
<td>selectoralpha</td>
<td>Double</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>selectorcolor</td>
<td>RGB array</td>
<td>[0,0,1]</td>
<td></td>
</tr>
<tr>
<td>showselector</td>
<td>on</td>
<td>off</td>
<td>on</td>
</tr>
<tr>
<td>vertexlabels</td>
<td>on</td>
<td>off</td>
<td>off</td>
</tr>
<tr>
<td>vertexlabelscolor</td>
<td>Char</td>
<td>RGB array</td>
<td>r</td>
</tr>
<tr>
<td>vertexmode</td>
<td>on</td>
<td>off</td>
<td>off</td>
</tr>
</tbody>
</table>

**EXAMPLE**

Plot boundary 6 using yellow color:

```cpp
model = mphopen('model_tutorial_llmatlab');
mphviewselection(model,'geom1',6,'boundary',...
  'facecolorselected',[1 1 0],'facealpha',0.5)
```
Plot edges 1 to 8 using green color:

```matlab
mphviewselection(model,'geom1',1:8,'edge', ... 
'edgecolorselected',[0 1 0])
```

Add an explicit selection for boundaries 7 to 12 and plot the selection in a figure:

```matlab
model.selection.create('sel1', 'Explicit').geom(2).set(7:12);
```

```matlab
mphviewselection(model,'sel1');
```

Add a selection to get the vertex indices with the box delimited with the coordinates 

```matlab
[-1e-3 11e-3-1e-3 11e-3;9e-3 11e-3] 
```

and plot both the selected entities and the selector:

```matlab
box = model.selection.create('box1', 'Box'); 
box.set('entitydim', '0'); 
box.set('xmin', '-1e-3').set('xmax', '11e-3'); 
box.set('ymin', '-1e-3').set('ymax', '11e-3'); 
box.set('zmin', '9e-3').set('zmax', '11e-3'); 
```

```matlab
mphviewselection(model,'box1','facemode','off');
```

SEE ALSO

mphgeom, mphselectbox, mphselectcoords

`mphwritestl`

Export plot data as an STL file.

SYNTAX

```matlab
mphwritestl(filename, pd) 
```

```matlab
mphwritestl(filename, pd, '-binary')
```

DESCRIPTION

`mphwritestl(filename, pd)` exports data in the plot data structure `pd` as the STL file `filename`.

`mphwritestl(filename, pd, '-binary')` exports data in the plot data structure `pd` as the STL file `filename` using the binary file format.

`pd` is a structure with fields `pd` and `t`.

- The field `p` contains node point coordinate information.
- The field `t` contains the indices to columns in `p` of a simplex mesh, each column in `t` representing a simplex.

Other fields in the plot data structure are not considered to generate the surface mesh.
EXAMPLE

Generate a surface mesh from solution plot:

```matlab
model = mphopen('vacuum_flask_llmatlab')
pd = mphplot(model, 'pg1')
pd2stl = pd{2}{1};
mphwritestl('vacuum_flask.stl', pd2stl)
```

Generate a surface mesh from a volume mesh

```matlab
model = mphopen('model_tutorial_llmatlab');
model.component('comp1').mesh('mesh1').run;
{s,d} = mphmeshstats(model, 'mesh1');
idx = strcmp(s.types, 'tri');
pdmesh.p = d.vertex;
pdmesh.t = d.elem(idx);
mphwritestl('mesh2geom.stl', pdmesh);
```

SEE ALSO

mphquad2tri, mphreadstl, mphsurf

mphxmeshinfo

Extract information about the extended mesh.

SYNTAX

```matlab
info = mphxmeshinfo(model, ...)
```

DESCRIPTION

info = mphxmeshinfo(model,...) extracts extended mesh information from the active solution object.

The function mphxmeshinfo accepts the following property/value pairs:

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>VALUE</th>
<th>DEFAULT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>soltag</td>
<td>String</td>
<td>Active solution object</td>
<td>Solution object tag</td>
</tr>
<tr>
<td>studysteptag</td>
<td>String</td>
<td></td>
<td>Study step node tag</td>
</tr>
<tr>
<td>meshcase</td>
<td>Positive integer</td>
<td>1</td>
<td>Mesh case tag</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The function `xmeshinfo` returns a structure with the fields shown in the table below:

<table>
<thead>
<tr>
<th>FIELD</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>soltag</td>
<td>Tag of the solution object</td>
</tr>
<tr>
<td>ndofs</td>
<td>Number of DOFs</td>
</tr>
<tr>
<td>fieldnames</td>
<td>Names of the field variables</td>
</tr>
<tr>
<td>fieldndofs</td>
<td>Number of DOFs per field name</td>
</tr>
<tr>
<td>meshtypes</td>
<td>Types of mesh element</td>
</tr>
<tr>
<td>dofs</td>
<td>Structure with information about the degrees of freedom</td>
</tr>
<tr>
<td>nodes</td>
<td>Structure with information about the nodes</td>
</tr>
<tr>
<td>elements</td>
<td>Structure with information about each element type</td>
</tr>
</tbody>
</table>

The extended mesh information provide information about the numbering of elements, nodes, and degrees of freedom (DOFs) in the extended mesh and in the matrices returned by `mphmatrix` and `mphgetu`.

**EXAMPLE**

Extract xmesh information:

```matlab
model = mphopen('model_tutorial_llmatlab.mph');
std = model.study.create('std');
std.feature.create('stat', 'Stationary');
std.run;
info = mphxmeshinfo(model)
```

Get the number of degrees of freedom and the nodes coordinates:

```matlab
dofs = info.ndofs
coops = info.dofs.coords;
```

Get the DOFs indices connected to the tetrahedron:

```matlab
idx = info.elements.tet.dofs
```

Retrieve the xmesh information with several physics

```matlab
model = mphopen('model_tutorial_llmatlab.mph');
comp1 = model.component('comp1');
ce = comp1.physics.create('ec','ConductiveMedia','geom1');
ce.feature.create('gnd1','Ground',2).selection.set(3);
pot = ec.feature.create('pot','ElectricPotential',2);
pot.selection.set(7);
pot.set('V0',1,'50[mV]');
hs = comp1.physics('ht').feature('hs1');
```
hs.set('heatSourceType',1,'generalSource');
hs.set('Q_src',1,'root.comp1.ec.Qh');
std = model.study.create('std');
std.feature.create('stat', 'Stationary');
std.run;
info = mphxmeshinfo(model)

Get the index of the nodes for element with the index 100:

    idx_nodes = info.elements.tet.nodes(:,100)

Get the index of the DOFs for element with the index 100:

    idx_dofs = info.elements.tet.dofs(:,100)

Get the index of the variables names corresponding to the DOFs with the index idx_dofs:

    idx_names = info.dofsinds(idx_dofs);

Find the dofname index corresponding to the variable V:

    idx_dofnames = find(strcmp(info.dofs.dofnames,'comp1.V'))-1;

Get the list of DOFs that correspond to the variable V:

    idx = find(idx_names==idx_dofnames)

Get the coordinates of the DOFs corresponding to the dependent variable V that belong to element 100:

    info.dofs.coords(:,idx_dofs(idx))

SEE ALSO:

mphgetu, mphmatrix, mphsolinfo, mphsolutioninfo
Index

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