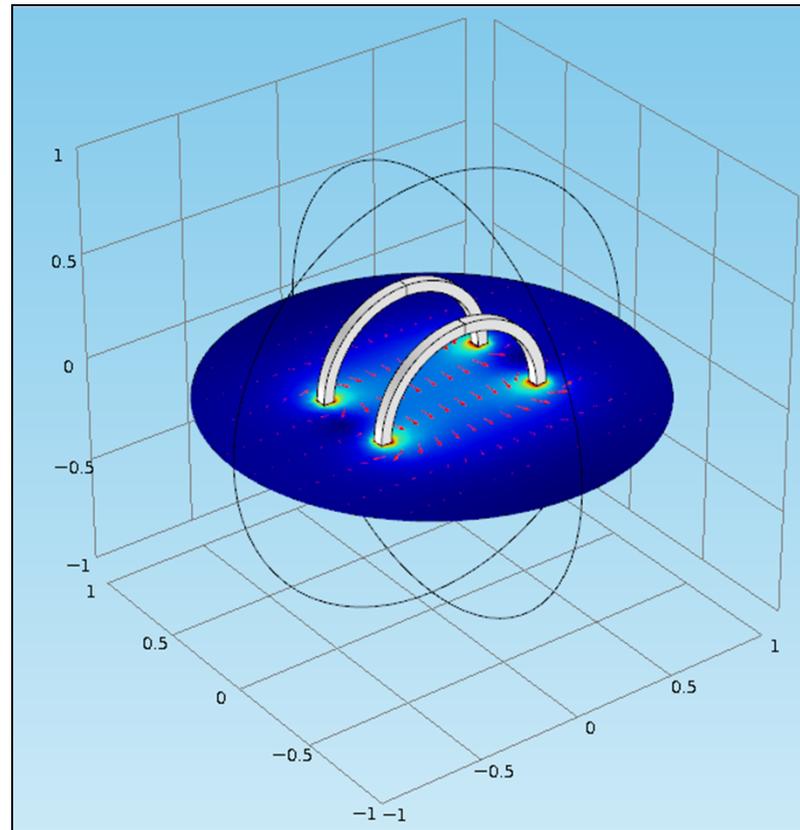


How to plot the gradients of magnetic field



Background

- 3D magnetic problems are solved in COMSOL using vector (curl) elements.
- The solution to these problems is the magnetic vector potential (**A**).
- The magnetic flux density (**B**) involves the 1st derivative of **A** and is given by the following equation.

$$\mathbf{B} = \nabla \times \mathbf{A}$$

- The second derivative is not defined on vector elements and hence we cannot visualize spatial gradients of **B** directly in COMSOL.

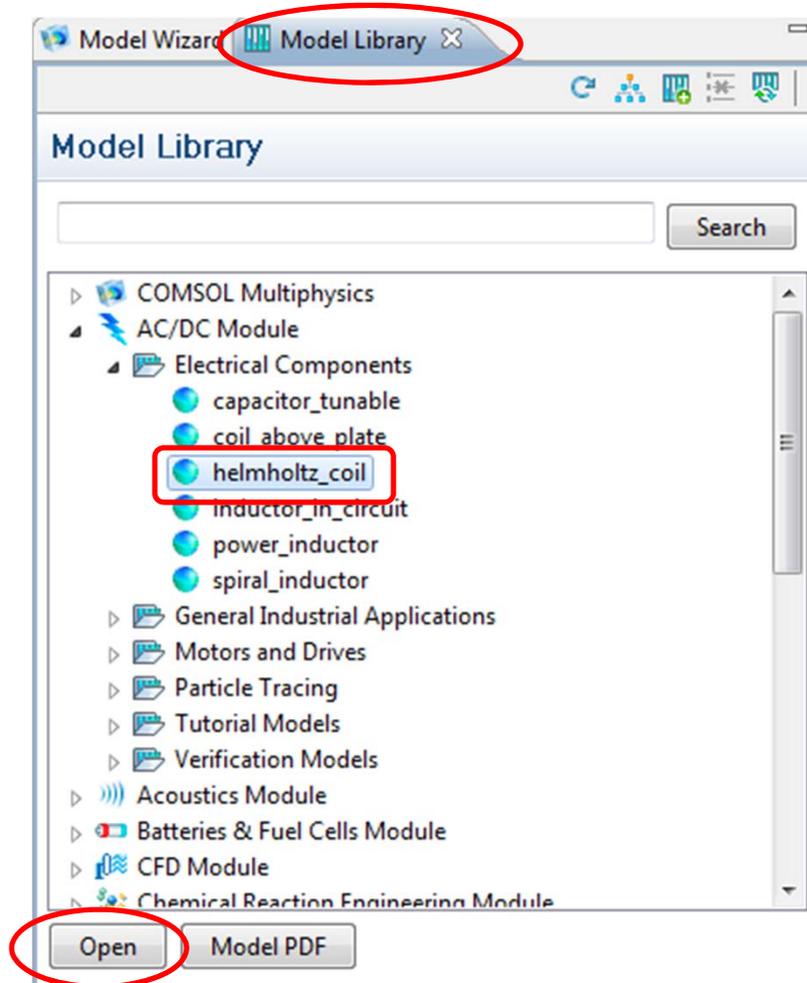
Objective

- This tutorial shows how to visualize the spatial derivatives of \mathbf{B} .
- The technique demonstrated here shows how each component of $\mathbf{B} = [B_x, B_y, B_z]$ can be mapped to a separate variable say u, u_2, u_3 respectively.
- These new variables would be defined on Lagrange elements.
- Since both 1st and 2nd order derivatives are defined on Lagrange elements, we would be able to obtain spatial derivatives of each component of \mathbf{B} .
- The mapping on Lagrange elements will also allow the use of polynomial patch recovery to get smooth values of derivatives.

Modeling steps

- The next few slides illustrate the steps involved in mapping the solution from an existing 3D magnetic model.
- The detailed steps are available in the file:
helmholtz_coil_field_gradient_42a

Open the Helmholtz Coil example



- Click on the **Model Library** tab
- AC/DC Module > Electrical Components > helmholtz_coil
- Click on the **Open** button

Add three PDEs

The image shows a screenshot of the COMSOL software interface. On the left is the 'Model Builder' window, and on the right is the 'Model Wizard' window. The 'Model Wizard' window is titled 'Add Physics' and shows a tree view of physics categories. The 'Mathematics' category is expanded, and 'PDE Interfaces' is selected. Under 'PDE Interfaces', 'Coefficient Form PDE (c)' is highlighted. Below the tree view, there is a section for 'Selected physics' which lists three items: 'Δu PDE (c)', 'Δu PDE (c2)', and 'Δu PDE (c3)'. At the bottom of the 'Model Wizard' window, there are fields for 'Dependent variables', including 'Field name' (u3), 'Number of dependent variables' (1), and 'Dependent variables' (u3). Four numbered callout boxes with arrows point to specific elements: 1. Points to 'Model 1 (mod1)' in the Model Builder tree. 2. Points to 'Coefficient Form PDE (c)' in the Model Wizard tree. 3. Points to the 'Add Selected' icon (a plus sign in a circle) at the bottom of the Model Wizard. 4. Points to the 'Next' icon (a right-pointing arrow in a circle) at the top right of the Model Wizard. A text box on the right explains that three PDEs are added to solve for variables u, u2, and u3.

1. Right-click on **Model 1** and select **Add Physics**
2. Select **Coefficient Form PDE**
3. Click the **Add Selected** icon three times
4. Click on the **Next** icon

In this way, we add three PDEs which will solve for the variables u , u_2 and u_3 respectively

Choose a stationary study

Select Study Type

← → [Finish icon]

– Studies

- Presets for Selected Physics
 - Small-Signal Analysis, Frequency Domain
 - Stationary**
 - Time Dependent
- Custom Studies

1. Select **Stationary**

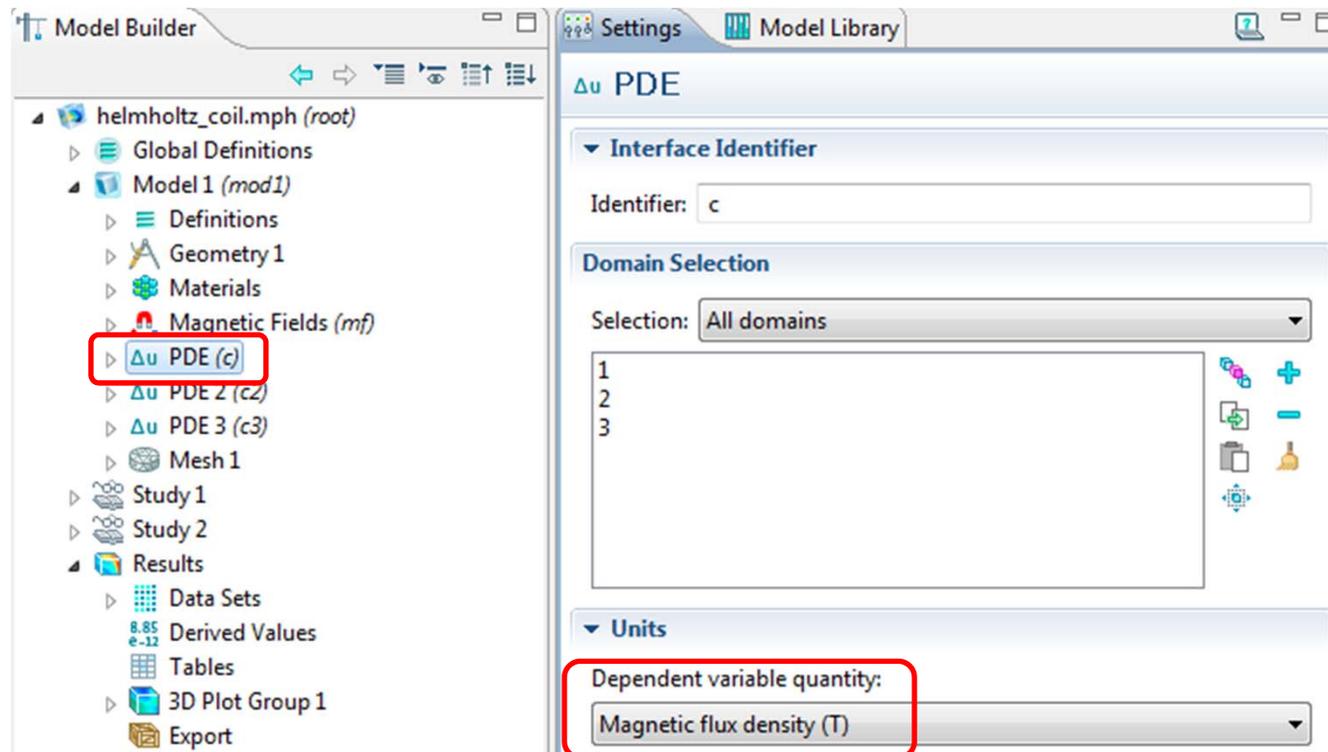
2. Click the **Finish** icon

Add study

– Selected physics

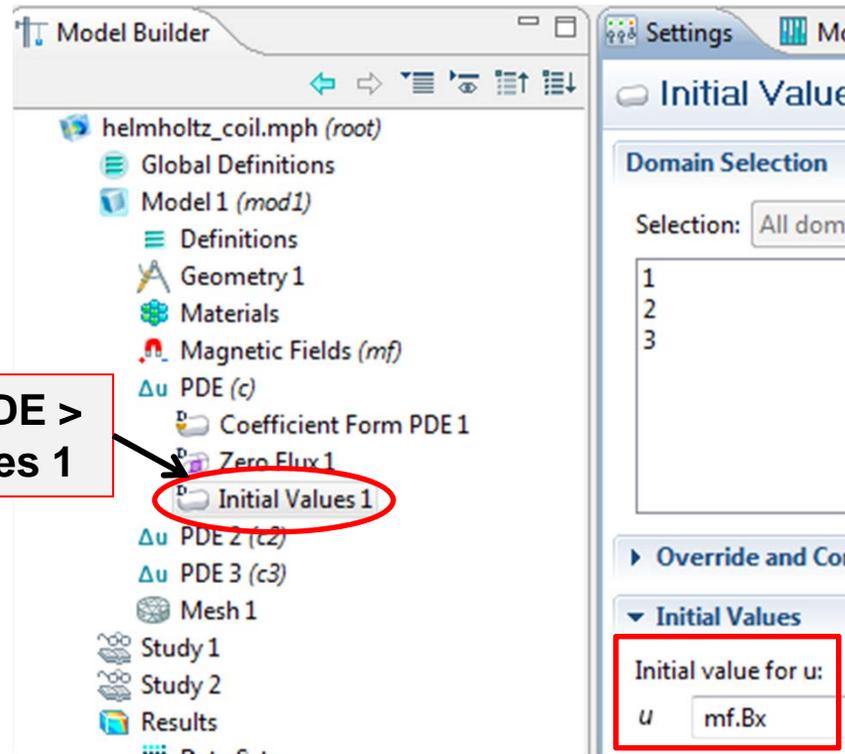
- Δu PDE (c)
- Δu PDE (c2)
- Δu PDE (c3)
- \mathbf{A} Magnetic Fields (mf)

Specify the unit



- This imparts the unit of magnetic flux density to the dependent variable u for this PDE interface.
- Repeat the same for the other two PDE interfaces as well.

Map the solution

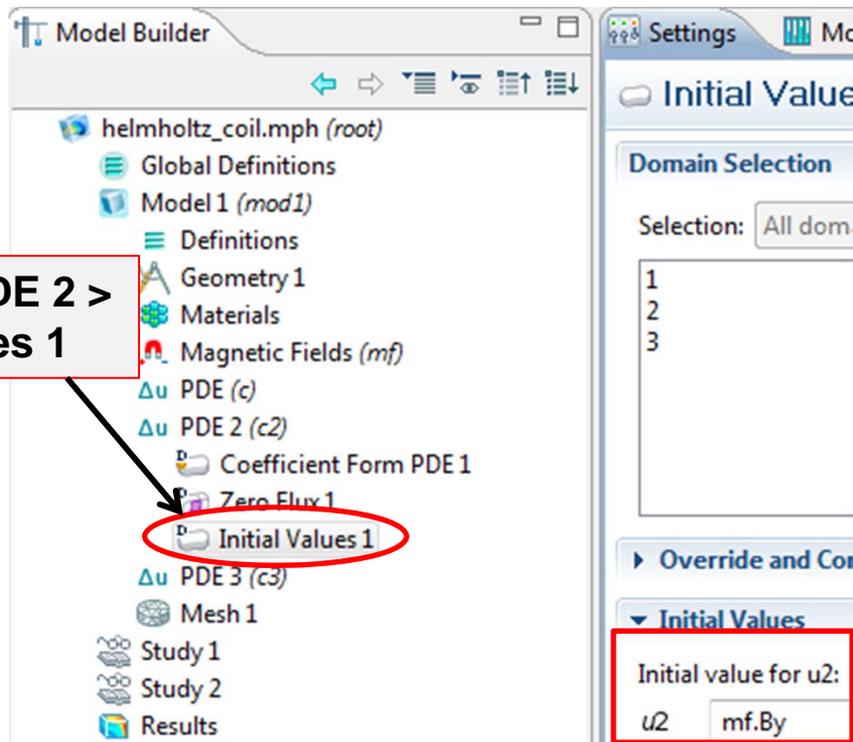


1. Select PDE > Initial Values 1

2. Set the value of u to be **mf.Bx**.
This is the value of the x-component of the B-field which was solved in the **Magnetic Fields** problem

Repeat the step to map $mf.By$ onto $u2$

1. Select **PDE 2 > Initial Values 1**



2. Set the value of $u2$ to be $mf.By$.
This is the value of the y-component of the B-field which was solved in the **Magnetic Fields** problem

Repeat the step to map $mf.Bz$ onto $u3$

1. Select **PDE 3 > Initial Values 1**

2. Set the value of **$u3$** to be **$mf.Bz$** .
This is the value of the z-component of the B-field which was solved in the **Magnetic Fields** problem

The screenshot shows the Model Builder interface for a model named 'helmholtz_coil.mph'. The tree view on the left shows the hierarchy: Global Definitions, Model 1 (mod1), Definitions, Geometry 1, Materials, Magnetic Fields (mf), PDE (c), PDE 2 (c2), PDE 3 (c3), Coefficient Form PDE 1, Zero Flux 1, Initial Values 1, Mesh 1, Study 1, Study 2, and Results. The 'Initial Values 1' node is circled in red. The right-hand pane shows the 'Initial Value' settings for the selected node. Under 'Domain Selection', the selection is 'All domains'. Under 'Initial Values', the 'Initial value for $u3$ ' is set to 'mf.Bz'.

Deselect Magnetic Fields from Study 2

1. Select **Study 2** >
Step 1: Stationary

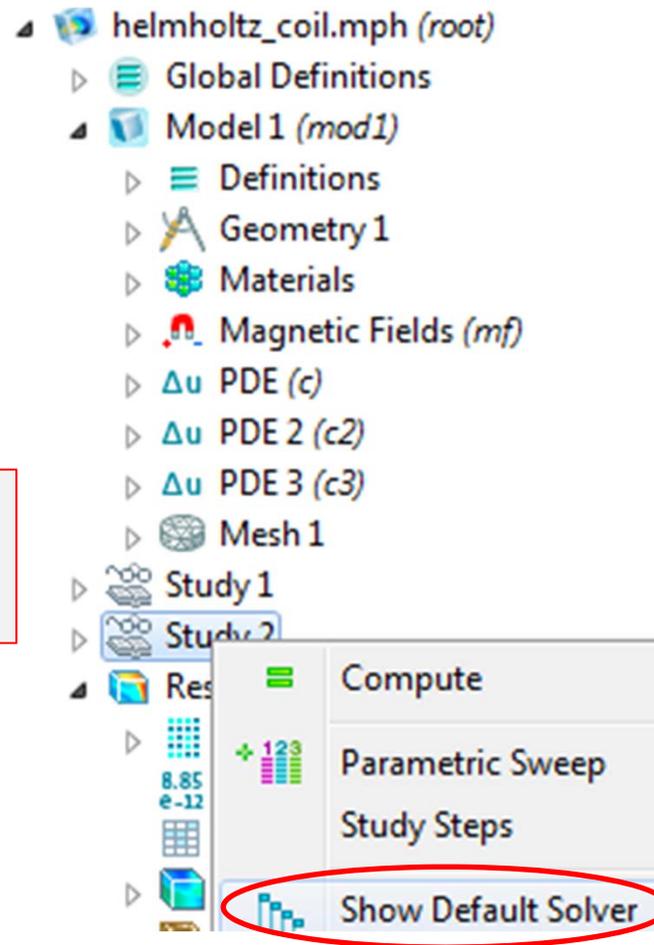
The screenshot displays the COMSOL Multiphysics interface. On the left, the Model Builder tree shows the hierarchy: helmholtz_coil.mph (root) > Global Definitions > Model 1 (mod1) > Definitions > Geometry 1 > Materials > Magnetic Fields (mf) > PDE (c). Under 'Study 1', 'Study 2' is selected, and its 'Step 1: Stationary' is highlighted. On the right, the Settings window is open to the 'Stationary' study settings. The 'Mesh Selection' section shows 'Geometry 1' selected. The 'Physics Selection' section contains a table with the following data:

Physics interface	Use	Discretization
Magnetic Fields (mf)	✗	Physics settings
PDE (c)	✓	Physics settings
PDE 2 (c2)	✓	Physics settings
PDE 3 (c3)	✓	Physics settings

2. In the **Physics interface** list check the green checkmark next to **Magnetic fields**. You should now see an orange cross.

Find the default solver settings for Study 2

Right-click **Study 2**
and select **Show
Default Solver**



Get the initial values of the PDE variables

The screenshot shows the COMSOL Model Builder interface. On the left, the 'Model Builder' tree is visible, with 'u,v,w Dependent Variables 1' selected and highlighted in a red box. The main window displays the settings for this component. The 'General' section shows 'Defined by study step: Step 1: Stationary'. The 'Initial Values of Variables Solved For' section has 'Method: Initial expression' and 'Solution: Solver 1', with the latter circled in red. The 'Values of Variables Not Solved For' section has 'Method: Initial expression' and 'Solution: Zero'. A red box highlights the 'Compute to Selected' icon in the top right corner of the settings window, with an arrow pointing to it. Three numbered instructions are overlaid on the image: 1. Select Study 2 > Solver Configurations > Solver 2 > Dependent Variables 1; 2. Change the Initial Values of Variables Solver For to Solver 1; 3. Click on the Compute to Selected icon.

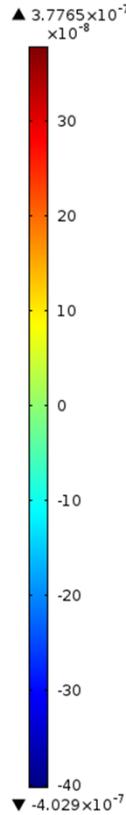
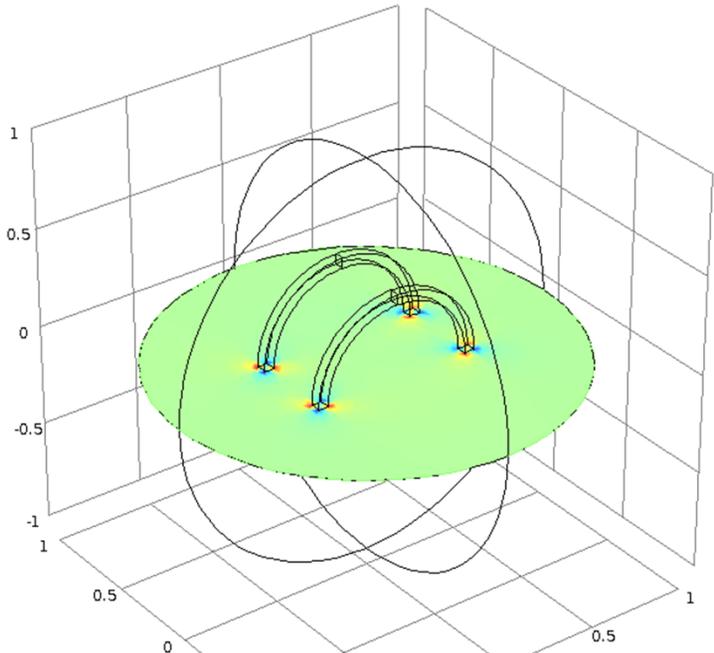
1. Select **Study 2 > Solver Configurations > Solver 2 > Dependent Variables 1**

2. Change the **Initial Values of Variables Solver For to Solver 1**

3. Click on the **Compute to Selected** icon

Results > 3D Plot Group 2

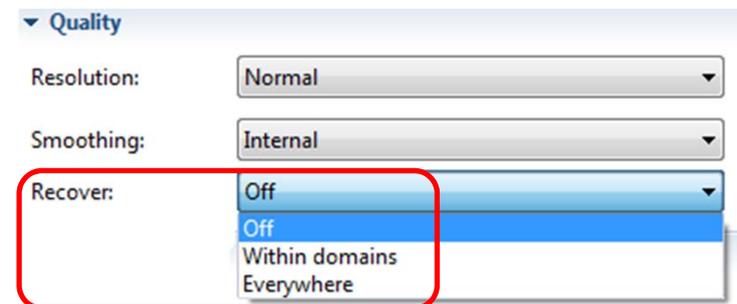
Time=0 Slice: Gradient of u, x component (kg/(m*s²+A))



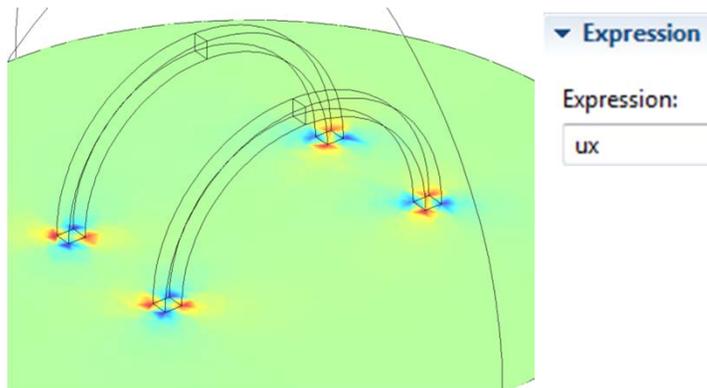
Plot u_x which is equivalent of plotting $\partial B_x / \partial x$

Note on polynomial patch recovery (ppr)

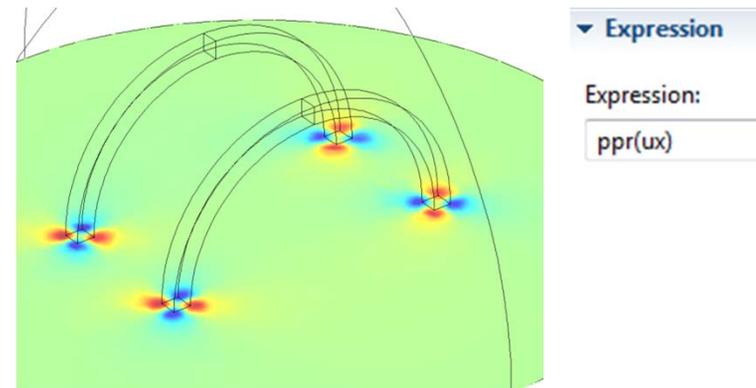
- The *polynomial patch recovery* feature allows you to obtain smoother derivatives.
- How to use this feature?
 - You can either use the *ppr* or *pprint* function OR...
 - Expand the **Quality** section of the plot settings and see the **Recover** list
- Refer to the COMSOL Multiphysics User's Guide for details.



Apply ppr to derivatives of B-field

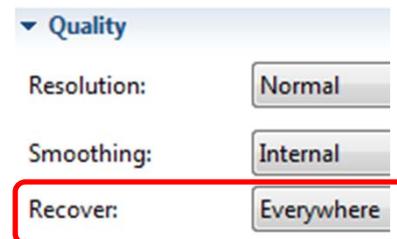


Plot of u_x (notice the rough edges in the color pattern)



Plot of $ppr(u_x)$ (notice the smoothed color pattern)

You will get the same smoothing if you set the expression as u_x and choose **Everywhere** for **Recover**.



Summary

- This tutorial showed how to visualize the spatial gradient of magnetic field.
- The magnetic field solution was mapped from vector elements to Lagrange elements.
- The derivative operations could be performed on the solution on the Lagrange elements.
- Mapping the solution onto Lagrange elements also give us the advantage to get smooth derivatives by using the polynomial patch recovery feature.