

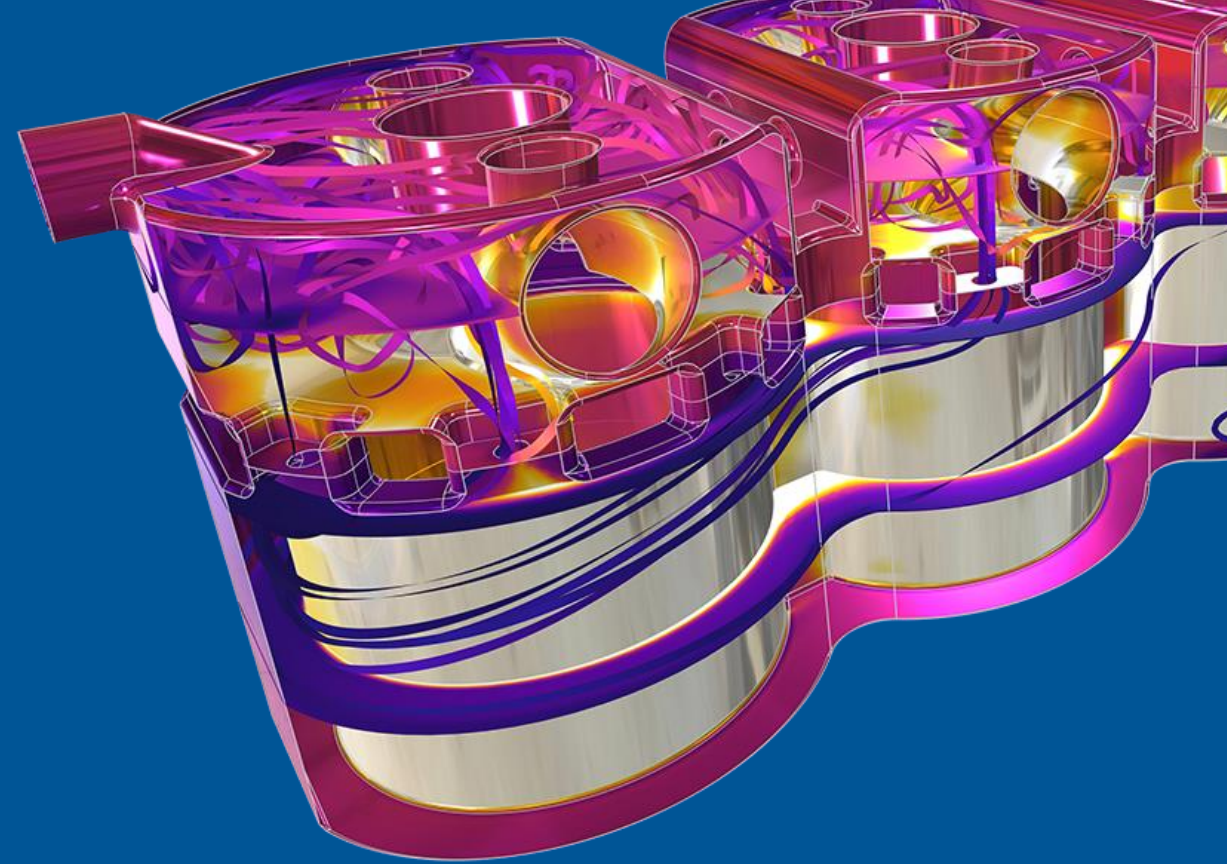
Setting up a Deep Neural Network for Structural-Thermal-Optical Model



Tomáš Vrbata
vrbata@humusoft.cz

Schedule

1. Deep Neural Networks (DNN)
2. STOP Analysis
3. Demo – Model Description
4. Demo – How to Create Surrogate model for STOP Analysis
5. Conclusions



Deep Neural Networks (DNN) in COMSOL Multiphysics

Tomáš Vrbata

New Powerful Functionality

- DNN is a new type of function
- General multidimensional function interpolation and approximation
- Requires a training data table

The screenshot displays the COMSOL Multiphysics software interface for a tubular reactor surrogate model. The main window is titled "tubular_reactor_surrogate.mph - COMSOL". The interface is divided into several sections:

- Model Builder:** Shows the project hierarchy for "tubular_reactor_surrogate.mph (root)". Key components include:
 - Global Definitions: Parameters 1, Deep Neural Network 1 (dnn_1, dnn_2), Default Model Inputs.
 - Component 1 (comp_1): Definitions, Geometry 1, Materials, Transport of Diluted Species (tds), Heat Transfer in Fluids (ht), Coefficient Form Boundary PDE (cb), Mesh 1.
 - Study 1: Surrogate Model Training, Step 1: Stationary, Step 2: Stationary 2, Solver Configurations, Results.
- Settings Panel:** Configures the "Deep Neural Network 1".
 - Layers:** A table defining the network structure:

Type	Settings
Dense	Input, Input features=5, Output features=50, Activation=tanh
Dense	Hidden, Output features=40, Activation=tanh
Dense	Hidden, Output features=30, Activation=tanh
Dense	Hidden, Output features=20, Activation=tanh
Dense	Output, Output features=2, Activation=tanh
 - Data:** Data source is "Result table", Result table is "Design Data", and "Ignore NaN/Inf data points" is checked.
 - Data Column Settings:** A table defining input and output columns:

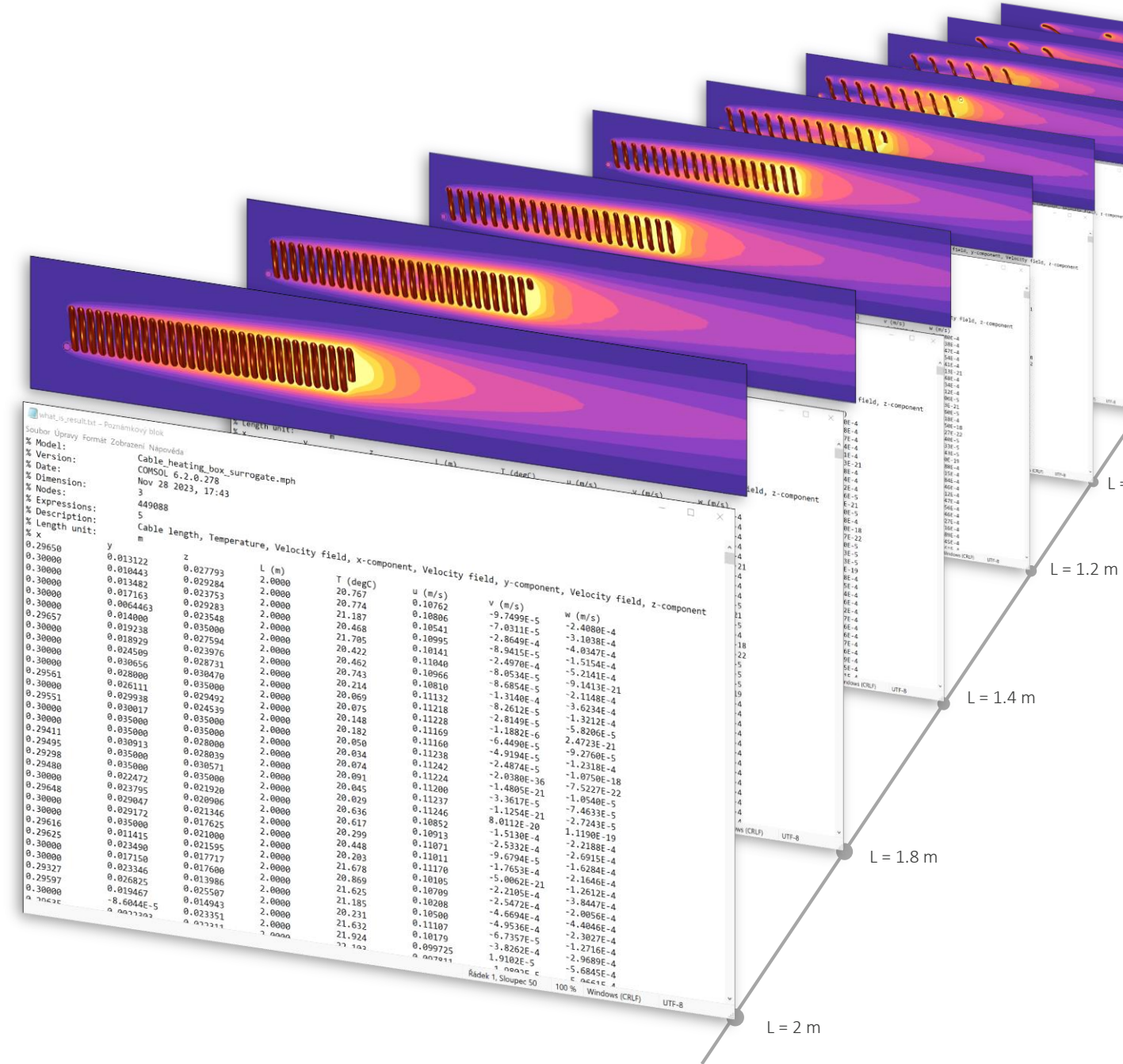
Columns	Type	Settings
r0	Argument	Name=x1, Scaling=to01
z0	Argument	Name=x2, Scaling=to01
E	Argument	Name=x3, Scaling=to01
ke	Argument	Name=x4, Scaling=to01
dHrx	Argument	Name=x5, Scaling=to01
comp1.pp1	Function values	Name=dnn_1, Scaling=to01
comp1.pp2	Function values	Name=dnn_2, Scaling=to01
 - Training and Validation:** Method is "Adam", Learning rate is "1e-3", and Weight decay is "0".
- Graphics:** Displays a 3D visualization of the reactor geometry with a color-coded temperature distribution. A coordinate system (x, y, z) is shown at the bottom left of the graphics area.
- Messages/Progress/Log/Design Data:** A table showing the results of the training process:

r0	z0	E	ke	dHrx	comp1.pp1	cor
0.032140	0.33178	72563	2.6236	-87001	331.64	0.50
0.055063	0.83791	75719	4.5499	-82537	314.94	0.31
0.025539	0.60275	75944	3.3028	-88487	319.27	0.18
0.021129	0.98724	74405	1.4382	-76038	337.06	0.71
0.076463	0.56690	74356	2.0612	-93668	321.90	0.62

New Powerful Functionality

- The original parametrized 3D FEM model can be viewed as a set of large tables:

x, y, z, parameters, computed quantities

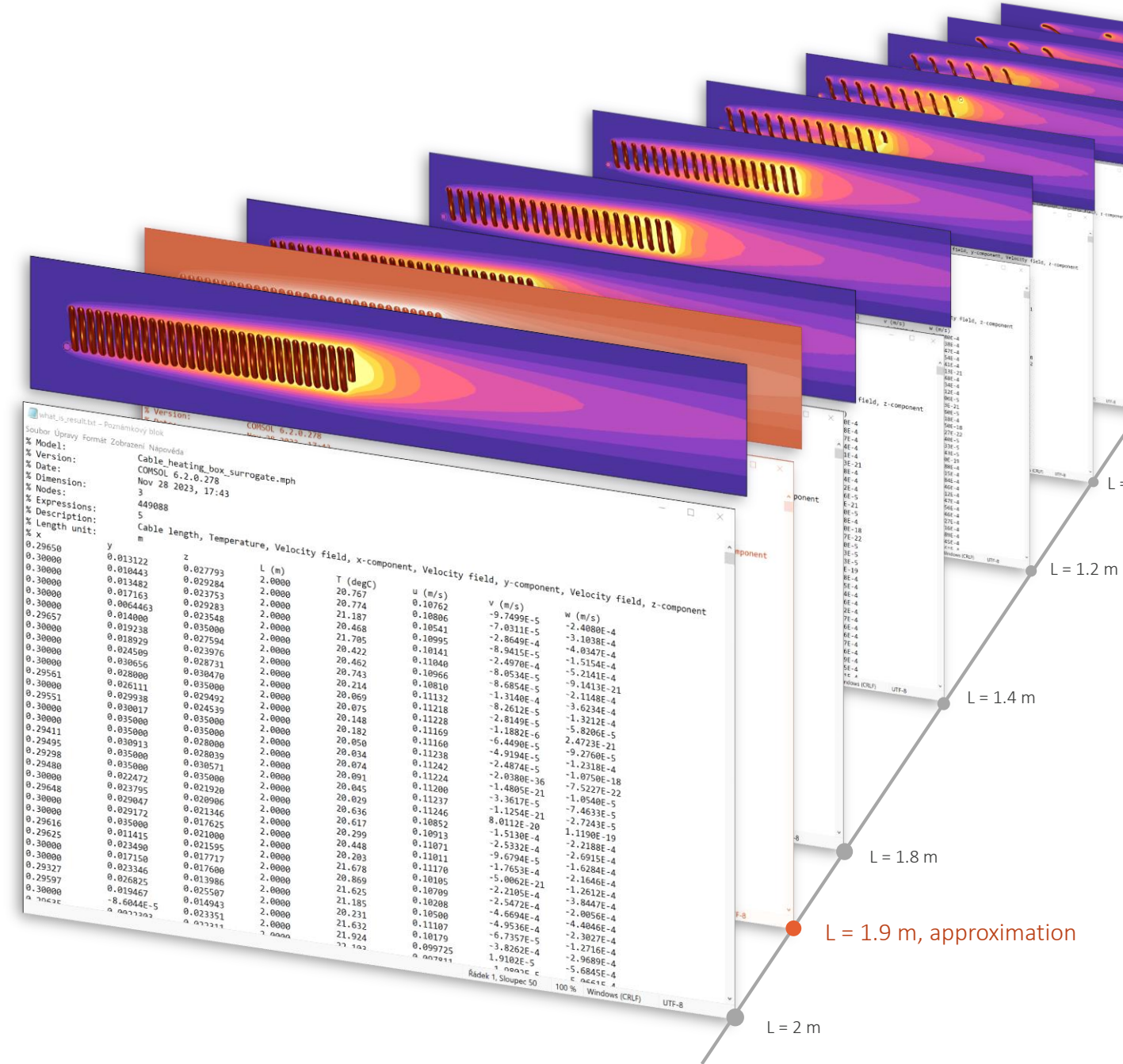


New Powerful Functionality

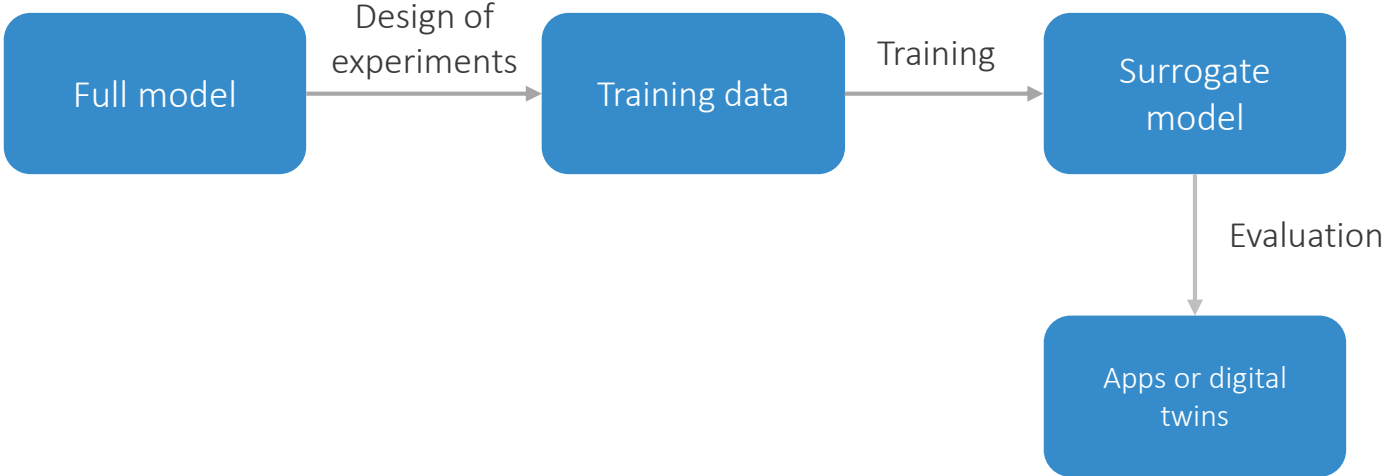
- The original parametrized 3D FEM model can be viewed as a set of large tables:

x, y, z, parameters, computed quantities

- The surrogate model replaces the original model with new DNN function that approximate the model in the whole space of parameters

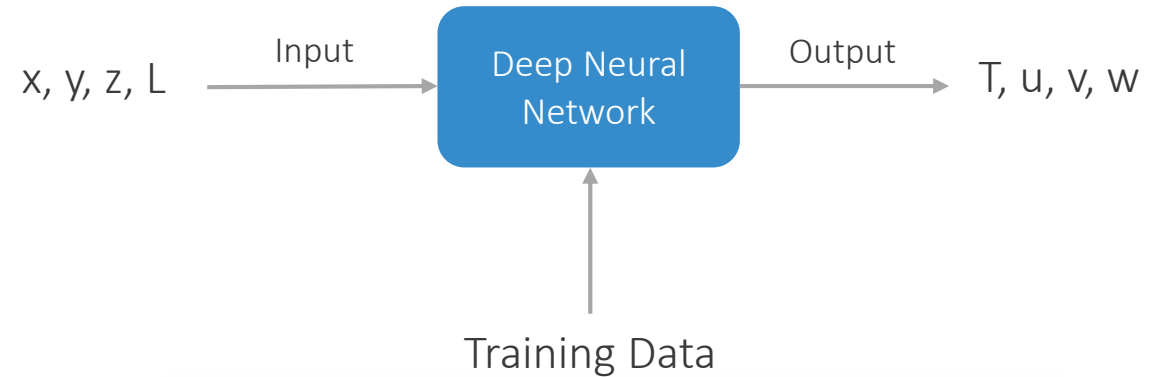


Surrogate Model Workflow



How Training Data look like?

- Inputs and Outputs together
- Data file (*.csv, *.txt, *.dat) or result table



what_is_result.txt - Poznámkový blok

Soubor Úpravy Formát Zobrazení Nápověda

% Model: Cable_heating_box_surrogate.mph
 % Version: COMSOL 6.2.0.178
 % Date: Nov 28 2023, 17:43
 % Dimension: 3
 % Nodes: 449088
 % Expressions: 5
 % Description: Cable length, Temperature, Velocity field, x-component, Velocity field, y-component, Velocity field, z-component
 % Length unit: m

% x	y	z	L (m)	T (degC)	u (m/s)	v (m/s)	w (m/s)
0.29650	0.013122	0.027793	2.0000	20.767	0.10762	-9.7499E-5	-2.4080E-4
0.30000	0.010443	0.029284	2.0000	20.774	0.10806	-7.0311E-5	-3.1038E-4
0.30000	0.013482	0.023753	2.0000	21.187	0.10541	-2.8649E-4	-4.0347E-4
0.30000	0.017163	0.029283	2.0000	20.468	0.10995	-8.9415E-5	-1.5154E-4
0.30000	0.0064463	0.023548	2.0000	21.705	0.10141	-2.4970E-4	-5.2141E-4
0.30000	0.014000	0.035000	2.0000	20.422	0.11040	-8.0534E-5	-9.1413E-21
0.29557	0.015238	0.027594	2.0000	20.462	0.10966	-8.6854E-5	-2.1148E-4
0.30000	0.018929	0.023976	2.0000	20.743	0.10810	-1.3140E-4	-3.6234E-4
0.30000	0.024509	0.028731	2.0000	20.214	0.11132	-8.2612E-5	-1.3212E-4
0.30000	0.030656	0.030470	2.0000	20.069	0.11218	-2.8149E-5	-5.8206E-5
0.30000	0.028000	0.035000	2.0000	20.075	0.11228	-1.1882E-6	2.4723E-21
0.29561	0.026111	0.029492	2.0000	20.148	0.11169	-6.4490E-5	-9.2760E-5
0.30000	0.029938	0.024539	2.0000	20.182	0.11160	-4.9194E-5	-1.2318E-4
0.29551	0.030917	0.035000	2.0000	20.050	0.11238	-2.4874E-5	-1.0750E-18
0.30000	0.035000	0.035000	2.0000	20.034	0.11242	-2.6390E-36	-7.5227E-22
0.30000	0.035000	0.028000	2.0000	20.074	0.11224	-1.4805E-21	-1.0540E-5
0.29411	0.030913	0.028039	2.0000	20.091	0.11200	-3.3617E-5	-7.4633E-5
0.29495	0.035000	0.030571	2.0000	20.045	0.11237	-1.1254E-21	-2.7243E-5
0.29298	0.035000	0.035000	2.0000	20.029	0.11246	8.0112E-20	1.1190E-19
0.29480	0.022472	0.021920	2.0000	20.636	0.10852	-1.5130E-4	-2.2188E-4
0.30000	0.023795	0.020906	2.0000	20.617	0.10913	-2.5332E-4	-2.6915E-4
0.29648	0.029847	0.021346	2.0000	20.299	0.11071	-9.6794E-5	-1.6284E-4
0.30000	0.029172	0.017625	2.0000	20.448	0.11011	-1.7653E-4	-2.1646E-4
0.30000	0.035000	0.021000	2.0000	20.203	0.11170	-5.0062E-21	-1.2612E-4
0.29616	0.011415	0.021595	2.0000	21.678	0.10105	-2.2105E-4	-3.8447E-4
0.29625	0.023490	0.017717	2.0000	20.869	0.10709	-2.5472E-4	-2.0056E-4
0.30000	0.017150	0.017600	2.0000	21.625	0.10208	-4.6694E-4	-4.4046E-4
0.30000	0.023346	0.013986	2.0000	21.185	0.10500	-4.9536E-4	-2.3027E-4
0.29327	0.025825	2.0000	20.231	20.231	0.11107	-6.7357E-5	-1.2716E-4
0.29597	0.019467	0.014943	2.0000	21.632	0.10179	-3.8262E-4	-2.9689E-4
0.30000	-8.6044E-5	0.023351	2.0000	21.924	0.099725	1.9102E-5	-5.6845E-4
0.29625	0.007702	0.027211	2.0000	22.102	0.097011	1.0661E-5	-6.6611E-4

Rádek 1, Sloupec 50 100% Windows (CRLF) UTF-8

How to Generate Training Data?

- Third-party data
 - External data file
- Parametric study results
 - Manual setting of sampling (range)
 - Time-consuming for larger number of parameters
- Surrogate Model Training study
 - Design Of Experiments method generates dataset automatically
 - Default option is Latin Hypercube Sampling (LHS)
 - More strategic approach for larger number of parameters

The screenshot displays the COMSOL Multiphysics interface for a model named 'tubular_reactor_surrogate.mph'. The 'Model Builder' tree on the left shows the hierarchy: Global Definitions (Parameters 1, Deep Neural Network 1), Component 1 (Definitions, Geometry 1, Materials, Transport of Diluted Species, Heat Transfer in Fluids, Coefficient Form Boundary PDE, Mesh 1), and Study 1 (Surrogate Model Training, Step 1: Stationary, Step 2: Stationary 2, Solver Configurations, Results).

The 'Settings' pane for 'Surrogate Model Training' is active, showing the following configuration:

- Label: Surrogate Model Training
- Compute action: Compute and build surrogate model
- Solution to use: Automatic
- Surrogate model: Design of experiments (No surrogate model)
- Output table group: Design of Experiments

Quantities of interest (Outputs) table:

Expression	Description	Individual solution to use
comp1.ppb1	Temperature	From "Solution to use"
comp1.ppb2	Conversion	From "Solution to use"

Input Parameters table:

Parameter	Source type	Parameter description
r0 (Radial position)	Analytic	Uniform from [0, 0.1]
z0 (Axial position)	Analytic	Uniform from [0, 1]
E (Activation energy)	Analytic	Uniform from [71518, 79205]
ke (Thermal conductivity)	Analytic	Uniform from [0.0559, 5.6]
dHrx (Heat of reaction)	Analytic	Uniform from [-101600, -67733]

Correlation groups: Correlation matrix (Active)

Input parameters sampling settings:

- Number of input points type: Manual
- Number of input points: 4000
- Random seed type: Automatic
- Initial random seed: 1014

Advanced Settings: (Expanded)

The 'Graphics' pane on the right shows a 3D visualization of the reactor's cross-section with a color-coded temperature distribution, ranging from blue (cooler) to red (warmer). The 'Messages' pane at the bottom right displays a table of generated data points:

r0	z0	E	ke	dHrx	comp1.ppb1	comp1.ppb2
0.032140	0.33178	72563	2.6236	-87001	331.64	0.50
0.055063	0.83791	75719	4.5499	-82537	314.94	0.31
0.025539	0.60275	75944	3.3028	-88487	319.27	0.18
0.021129	0.98724	74405	1.4382	-76038	337.06	0.71
0.076463	0.56690	74356	2.0612	-93668	321.90	0.62

Deep Neural Network Settings

1. Training data source
 - Inputs: arguments
 - Outputs: function value
2. Data source column settings
 - Number of layers
 - Output features (neurons) per layer
 - Activation function
3. Deep Neural Network settings
 - Number of layers
 - Output features (neurons) per layer
 - Activation function
4. Training and Validation settings
 - Method
 - Learning rate
 - Weight decay
 - Batch size
 - Loss function
 - Random seed type
 - Random seed
 - Stop condition
 - Number of epochs
 - Validation data
 - Validation data fraction
 - Random seed type
 - Random seed
5. Training / Continue training

5. Start of training, Continue training

3. Deep Neural Network

1. Training data source

2. Inputs and Outputs

4. Training and Validation

Settings

Deep Neural Network

Plot Create Plot Train Model Continue Training

Layers

Type	Settings
Dense	Input, Input features=1, Output features=1, Activation=tanh
Dense	Hidden, Output features=15, Activation=tanh
Dense	Hidden, Output features=15, Activation=tanh
Dense	Hidden, Output features=15, Activation=tanh
Dense	Output, Output features=1, Activation=Linear (none)

Output features: 1

Activation: tanh

Data

Data source: Result table

Result table: Probe Table 2 - imported surface maximum L vs. maxT with CFD

Ignore NaN/Inf data points

Data Column Settings

Columns	Type	Settings
L (m)	Argument	Name=x1, Scaling=to01, Unit=m
Wire surface temperature...	Function values	Name=dnn1, Scaling=to01, Unit=K

Training and Validation

Method: Adam

Learning rate: 1e-3

Weight decay: 0

Batch size: 512

Loss function: Root-mean-square error

Random seed type: Fixed

Random seed: 0

– Stop condition

Number of epochs: 10000

– Validation data

Validation data: Random sample of data values

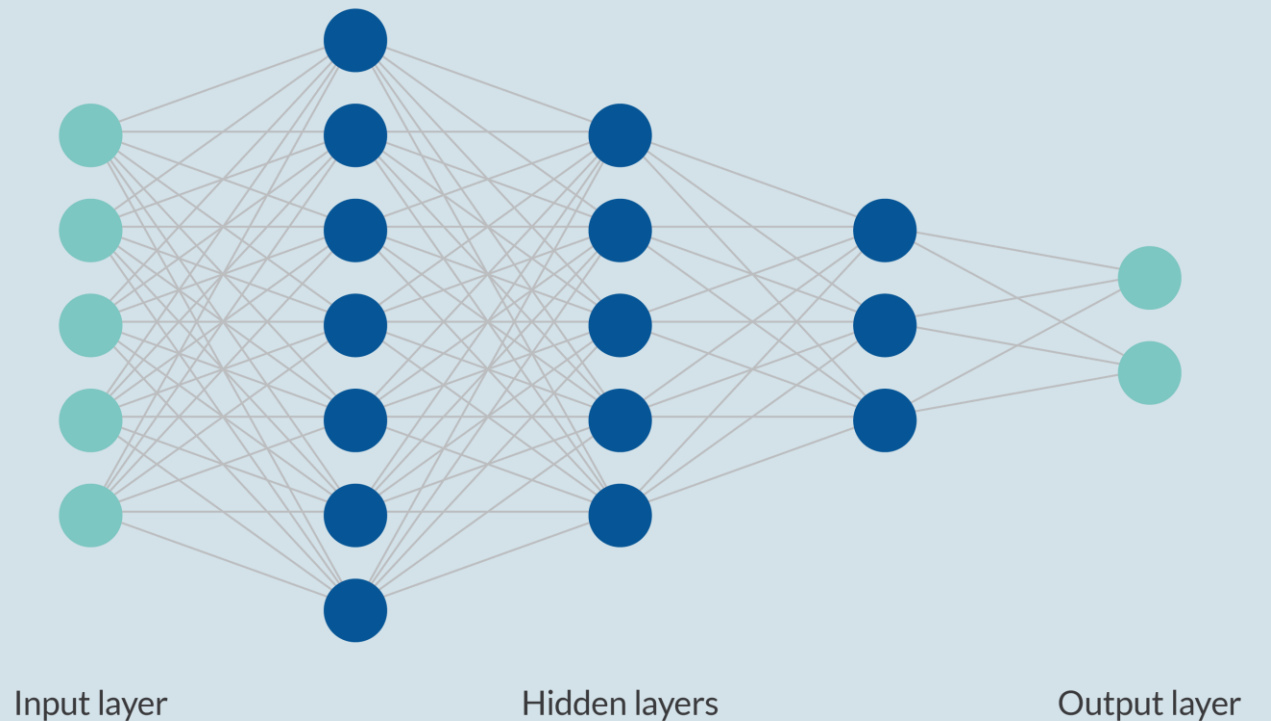
Validation data fraction: 0.2

Random seed type: Fixed

Random seed: 0

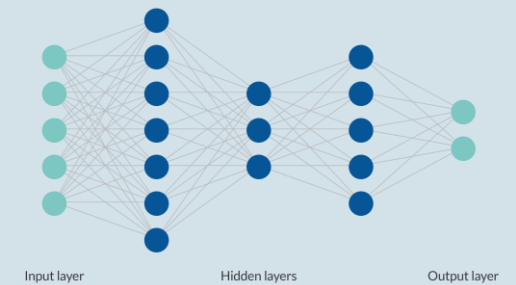
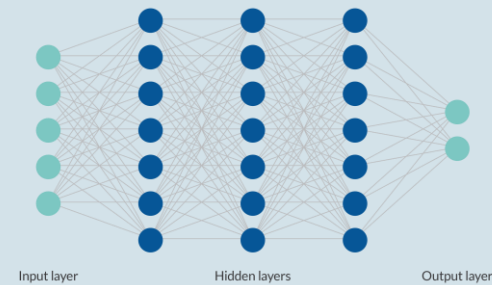
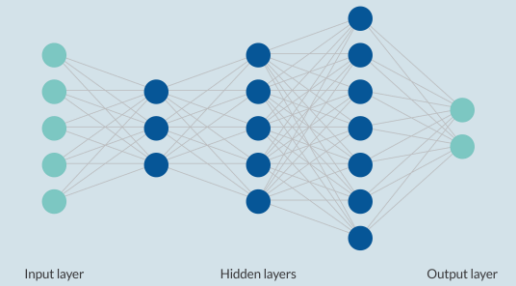
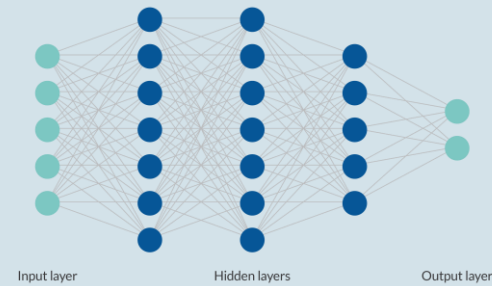
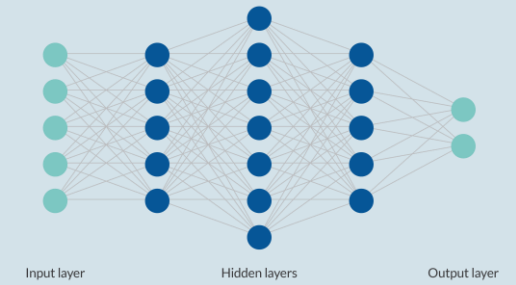
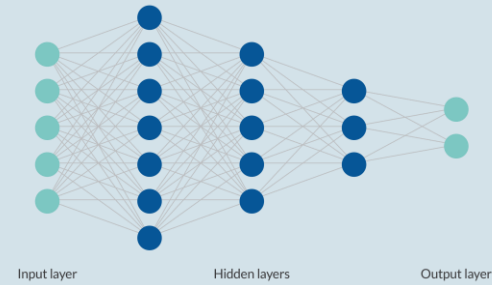
Deep Neural Network

- A DNN model consists of an input layer, a series of hidden layers, and an output layer.
- Each layer consists of a number of nodes, or neurons, or output features. The figure shows a graph for a network with three hidden layers, 5 input nodes, and 2 output nodes.
- You can define any number of layers and nodes for a DNN surrogate model.



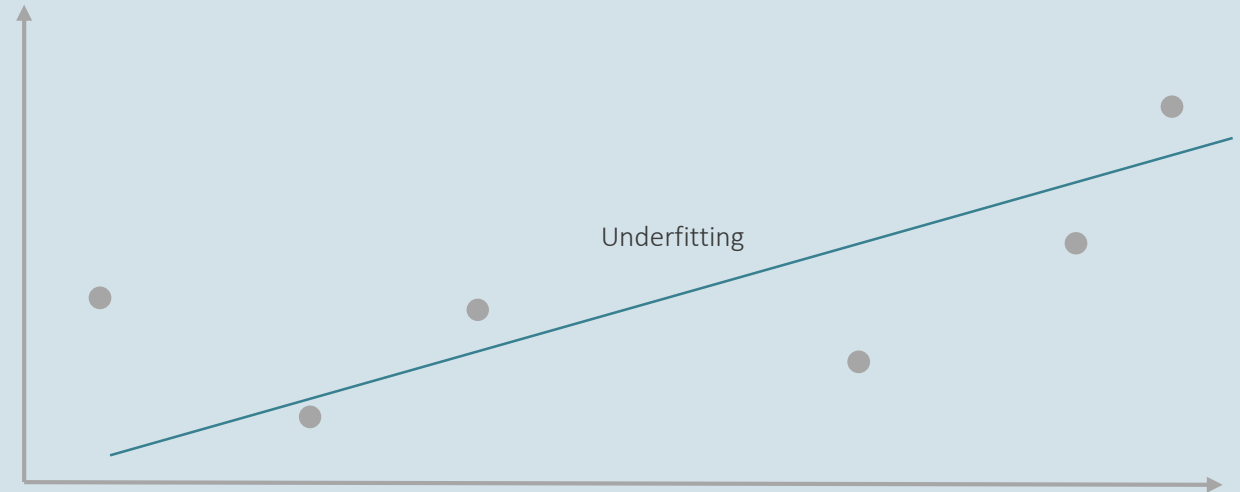
Optimizing Neural Network Architecture

- Selection of layers and nodes is iterative and based on:
 - Problem-specific knowledge
 - Empirical testing



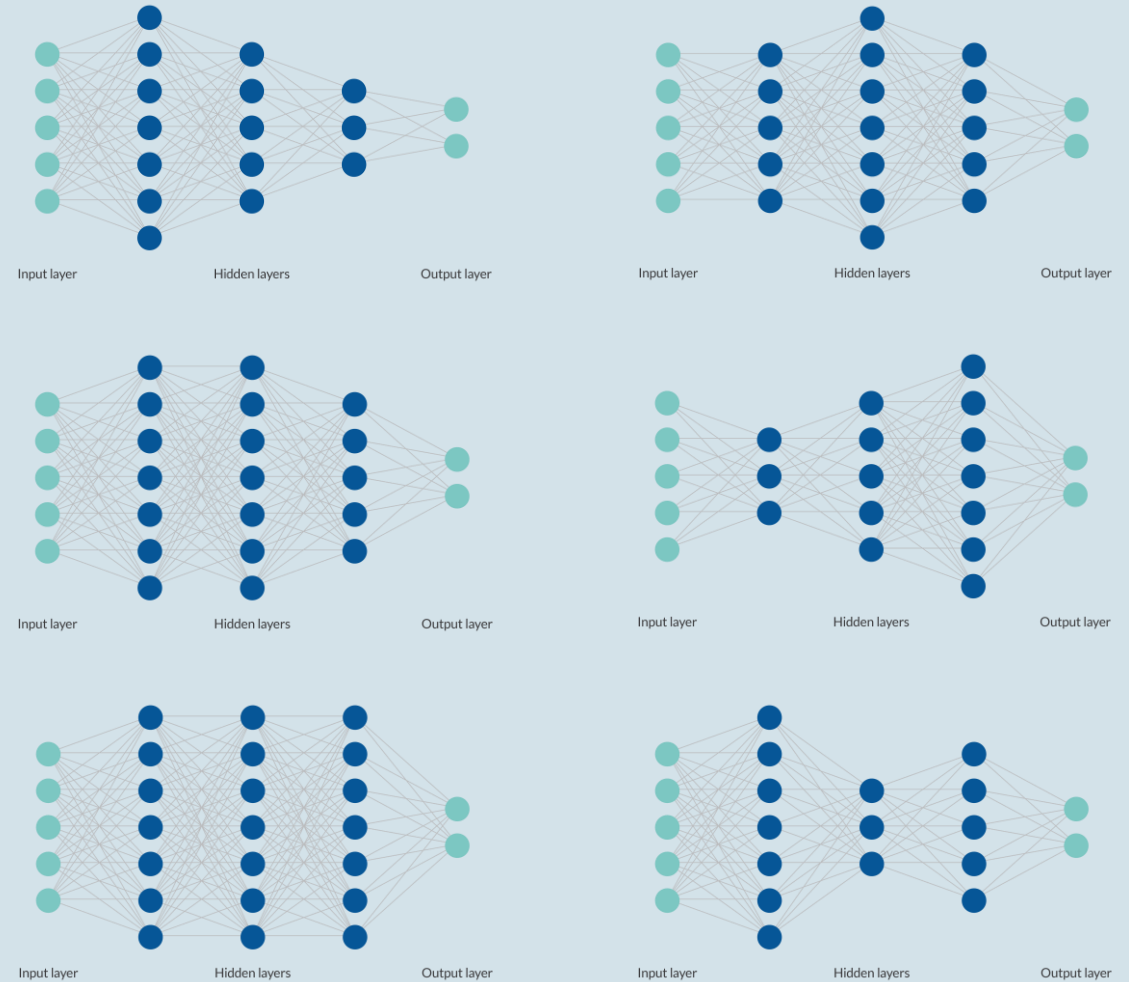
Optimizing Neural Network Architecture

- Selection of layers and nodes is iterative and based on:
 - Problem-specific knowledge
 - Empirical testing
- Balance is key:
 - Too few layers/nodes may lead to underfitting and be inadequate for complex surrogate modeling.
 - Excess layers/nodes can cause overfitting, yielding high accuracy on training data but poor generalization.



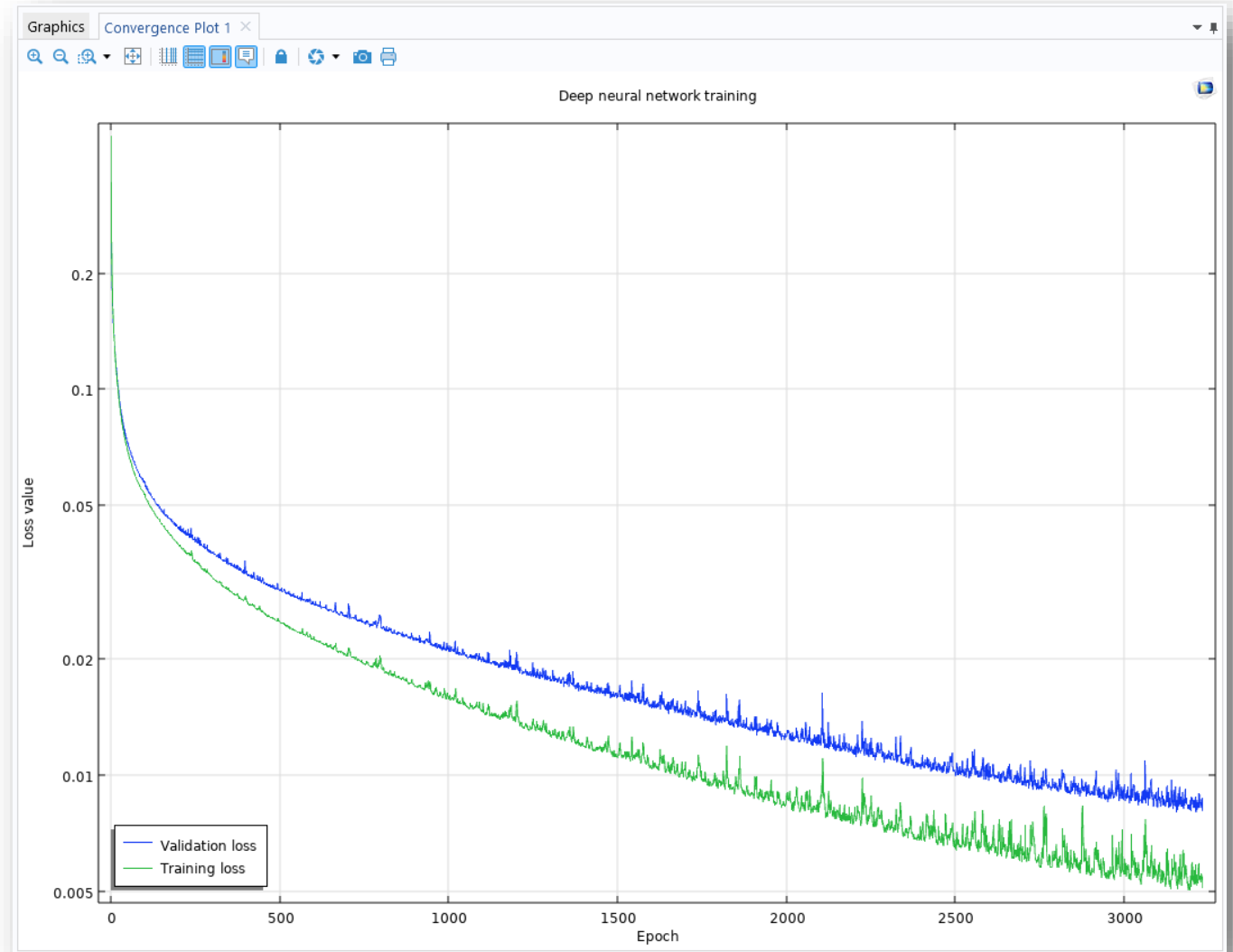
Optimizing Neural Network Architecture

- Selection of layers and nodes is iterative and based on:
 - Problem-specific knowledge
 - Empirical testing
- Balance is key:
 - Too few layers/nodes may lead to underfitting and be inadequate for complex surrogate modeling.
 - Excess layers/nodes can cause overfitting, yielding high accuracy on training data but poor generalization.
- Consider computational costs:
 - More layers/nodes increase model evaluation time.
 - Rule-of-thumb starting point: 3 hidden layers with 64, 32, and 16 nodes



Training a DNN

- The internal parameters of the neural network are called weights and biases
- Training involves optimizing weights and biases to minimize error
- Objective of training: Align surrogate model closely with the finite element model
- Error measurement is done via the loss function
- Default loss function is root mean squared error (RMSE)

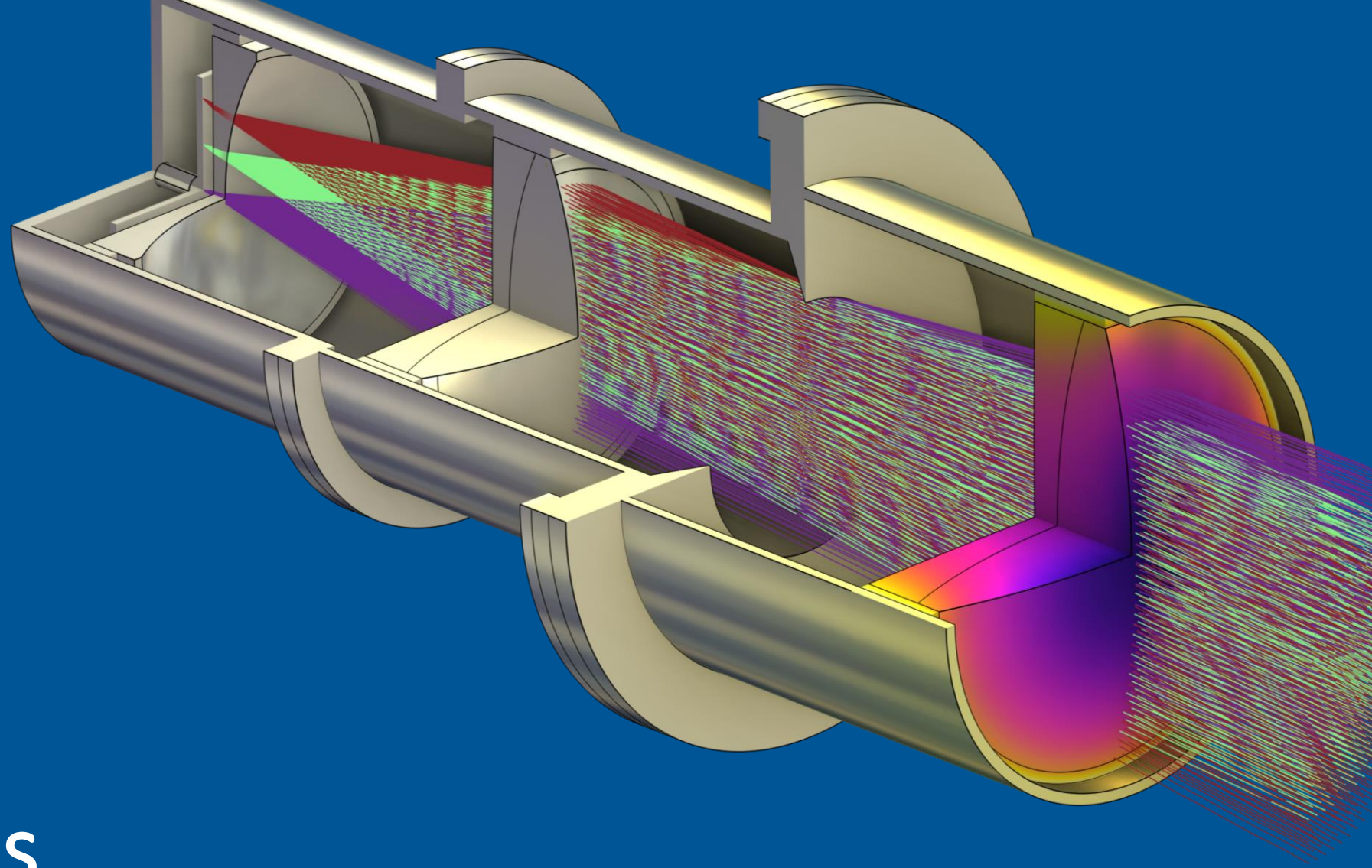


Training and Validation Settings

- The DNN is trained using a specialized optimization solver.
- The solver settings are called *hyperparameters*. Some of the most important are:
 - *Learning rate*:
 - Controls optimization step size
 - Analogous to numerical damping in nonlinear solvers
 - *Batch size*:
 - Determines subdivision of training data into subsets
 - *Number of epochs*:
 - Indicates total passes through the full dataset

The screenshot shows the 'Training and Validation' settings panel in COMSOL. The panel is titled 'Training and Validation' and contains the following settings:

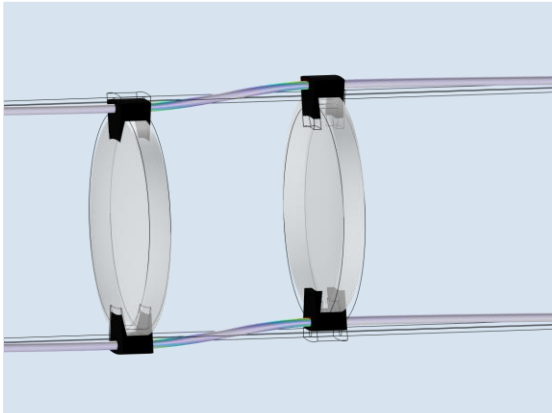
Method:	Adam
Learning rate:	1e-3
Weight decay:	0
Batch size:	512
Loss function:	Root-mean-square error
Random seed type:	Fixed
Random seed:	0
— Stop condition	
Number of epochs:	10000
— Validation data	
Validation data:	Random sample of data values
Validation data fraction:	0.2
Random seed type:	Fixed
Random seed:	0



STOP Analysis

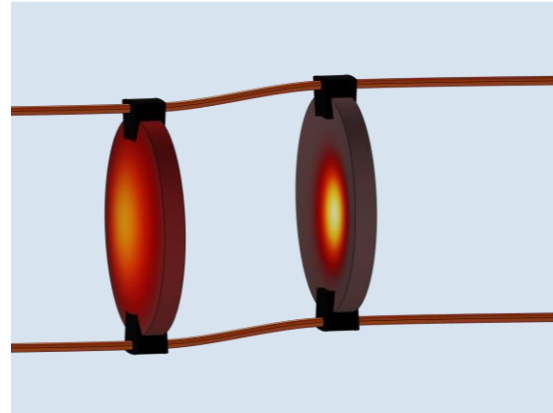
Tomáš Vrbata

STOP Analysis in COMSOL[®]



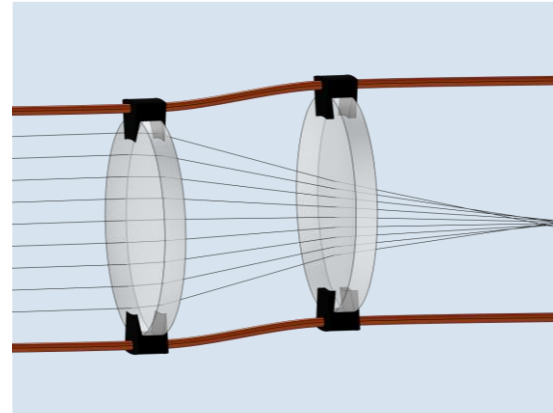
Structural

Model the structural displacements in an optical system.



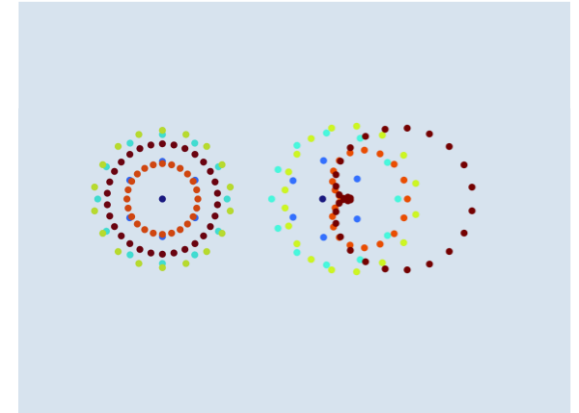
Thermal

Apply a fixed operating temperature or simulate the temperature distribution. Heat sources may include absorption from the beam itself.



Optical

With the local temperature and displacement considered, model how light will propagate through the system.



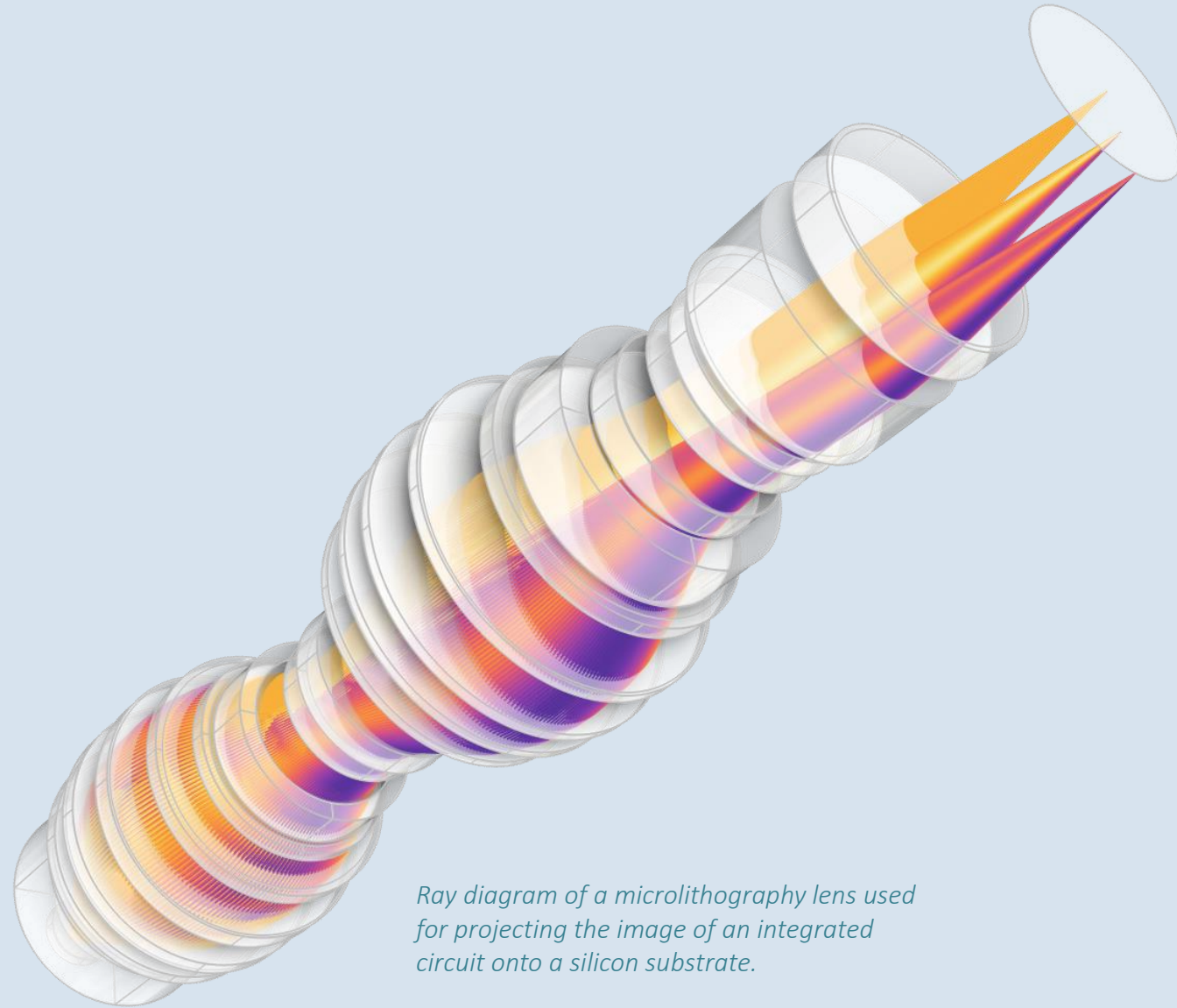
Performance

Evaluate the optical performance under the influence of thermal and structural loads.

OVERVIEW

Geometrical Optics

- Ray tracing in homogeneous and graded media
- Detailed analysis of ray intensity and polarization
- Variety of features for releasing rays and controlling interaction with boundaries
- Functionality for multiscale electromagnetics modeling
- Multiphysics couplings for STOP analysis



Ray diagram of a microlithography lens used for projecting the image of an integrated circuit onto a silicon substrate.

Ray Optics Module Part Library

The Ray Optics Module Part Library contains parameterized geometry parts for optical systems:

- Apertures and obstructions
- Aspheric, cylindrical, doublet, triplet, and spherical lenses
- Beam splitters and prisms
- Mirrors and reflectors

The parts include predefined selections for convenient set up of boundary conditions

The screenshot shows the COMSOL Multiphysics software interface. The top menu bar includes File, Home, Definitions, Geometry, Materials, Physics, Mesh, Study, Results, and Developer. The toolbar contains various icons for building, adding materials, and defining geometry. The Model Builder tree on the left shows a project named 'double_gauss_lens.mph' with a hierarchy of definitions, components, and results. The Settings panel on the right shows the 'Part Instance' settings for 'Spherical Lens 3D', including a table of input parameters and options for position and orientation of output. The Graphics window on the right displays a 3D model of a doublet lens system, showing two lenses with a central stop and a coordinate system (x, y, z) at the bottom.

Model Builder

- double_gauss_lens.mph (root)
 - Global Definitions
 - Parameters 1: Lens Prescription
 - Parameters 2: General
 - Geometry Parts
 - Default Model Inputs
 - Materials
 - Component 1 (comp 1)
 - Definitions
 - Boundary System 1 (sys1)
 - View 1
 - Camera
 - Directional Light 1
 - Directional Light 2
 - Directional Light 3
 - Headlight 4
 - Clip Plane 1
 - Double Gauss Lens
 - Lens 1 (pi1)
 - Lens 2 (pi2)
 - Lens 3 (pi3)
 - Stop (pi4)
 - Lens 4 (pi5)
 - Lens 5 (pi6)
 - Lens 6 (pi7)
 - Image (pi8)
 - Form Union (fin)
 - Cumulative Selections
 - Materials
 - Geometrical Optics (gop)
 - Mesh 1
 - Study 1
 - Results
 - Datasets
 - Views
 - Derived Values
 - Tables
 - Ray Diagram 1
 - Ray Diagram 2
 - Spot Diagram
 - Optical Aberration Diagram
 - Optical Aberration 1
 - Optical Aberration 2
 - Export
 - Reports

Settings

Part Instance

Build Selected Build All Objects

Part: Spherical Lens 3D

Choose from Library...

Input Parameters

Name	Expression	Value	Description
R1	R1_3	0 m	Radius of cu
R2	R2_3	25.65 mm	Radius of cu
Tc	Tc_3	2 mm	Center thick
d0	d0_3	51 mm	Lens full dia
d1	d1_3	0 m	Diameter, su
d2	d2_3	40 mm	Diameter, su
d1_clear	d1_clear_3	49 mm	Clear apertu
d2_clear	d2_clear_3	39 mm	Clear apertu
nix	0	0	Local optica
niy	0	0	Local optica
niz	1	1	Local optica
n_extra_r	0	0	Number of
n_extra_a	0	0	Number of

Position and Orientation of Output

Coordinate system in part

Work plane in part: xy-plane

Coordinate system to match

Take work plane from: Lens 2 (pi2)

Work plane: Surface 2 vertex intersec

Displacement

xw: 0 mm

yw: 0 mm

zw: T_2 mm

Rotation

Specify: Axis of rotation

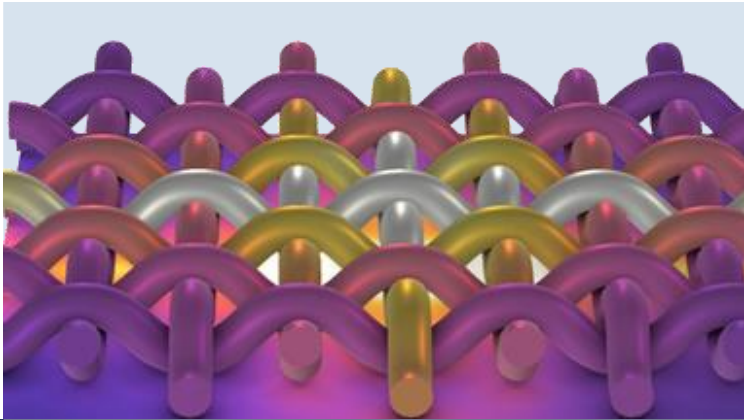
Axis type: zw-axis

Graphics

Messages Progress Log

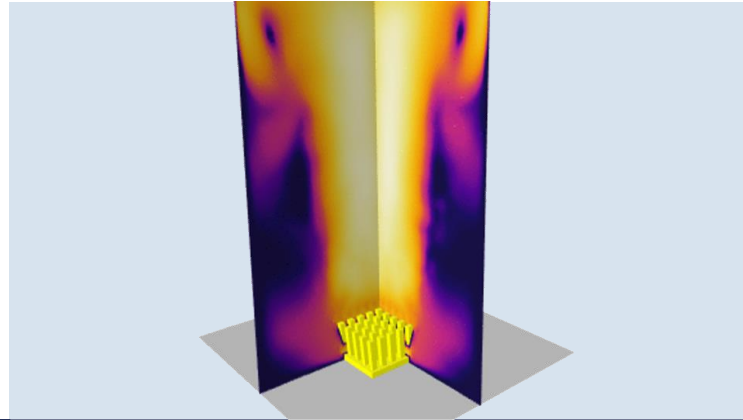
OVERVIEW

Heat Transfer Functionality



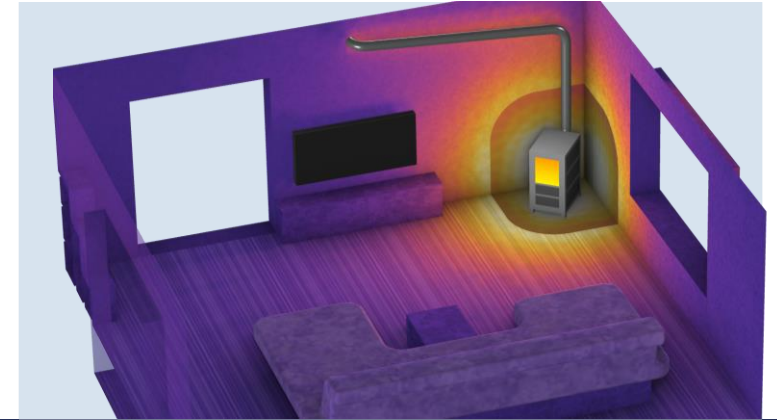
Conduction

- Isotropic, anisotropic, linear, and nonlinear thermal conductivity
- Thermal contact
- Thin layers



Convection

- Free and forced convection
- Laminar and turbulent flow
- Effective material properties

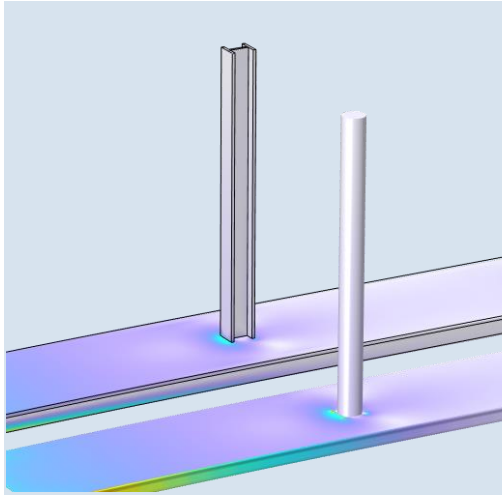


Radiation

- Surface-to-ambient and surface-to-surface radiation
- External radiation sources
- Radiation in participating media

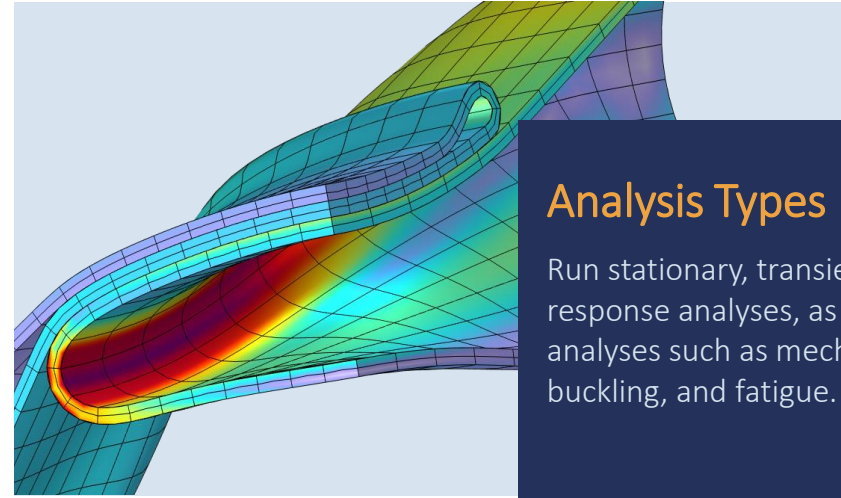
OVERVIEW

Structural Mechanics Functionality



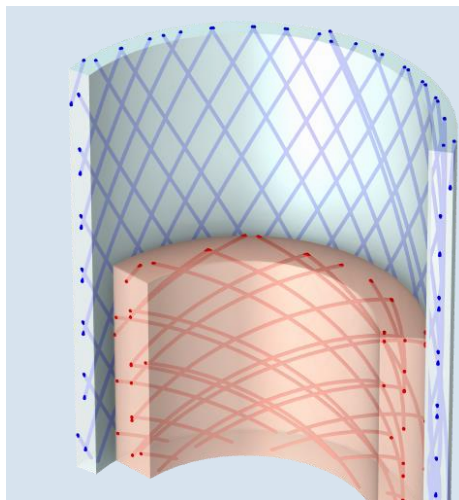
Formulations

Combine solids, single and layered shells, plates, membranes, beams, pipes, trusses, and wires.



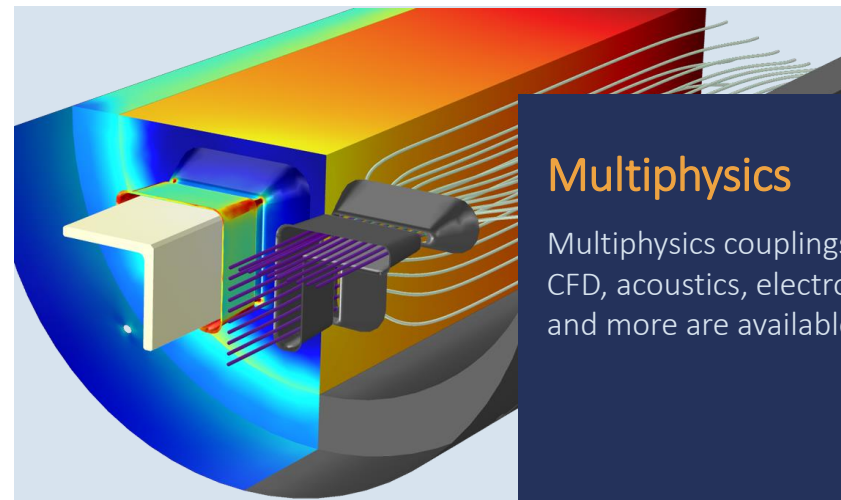
Analysis Types

Run stationary, transient, and frequency response analyses, as well as specialized analyses such as mechanical contact, buckling, and fatigue.



Material Models

Choose from a wide variety of elastic, viscoelastic, hyperelastic, elastoplastic, and composite material models. Materials can be spatially varying, anisotropic, and dependent on other variables.



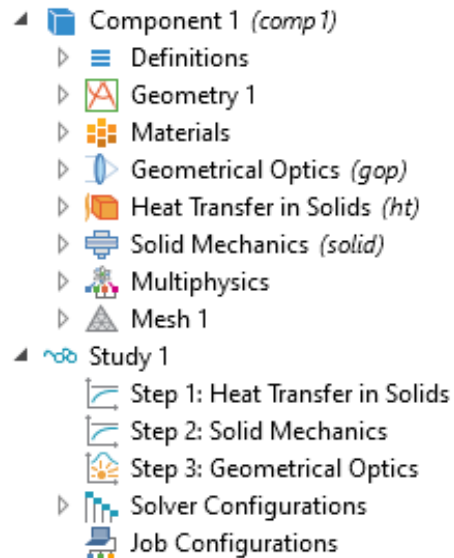
Multiphysics

Multiphysics couplings with heat transfer, CFD, acoustics, electromagnetics, optics, and more are available.

Study Setup

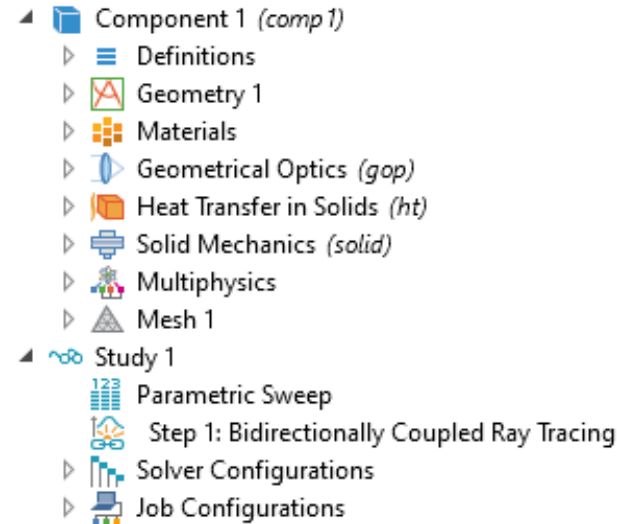
One-Way Coupled STOP Analysis

- With the temperatures affecting the deformations, and both temperatures and deformations influencing the ray paths, you can solve for the different physics interfaces one at a time.



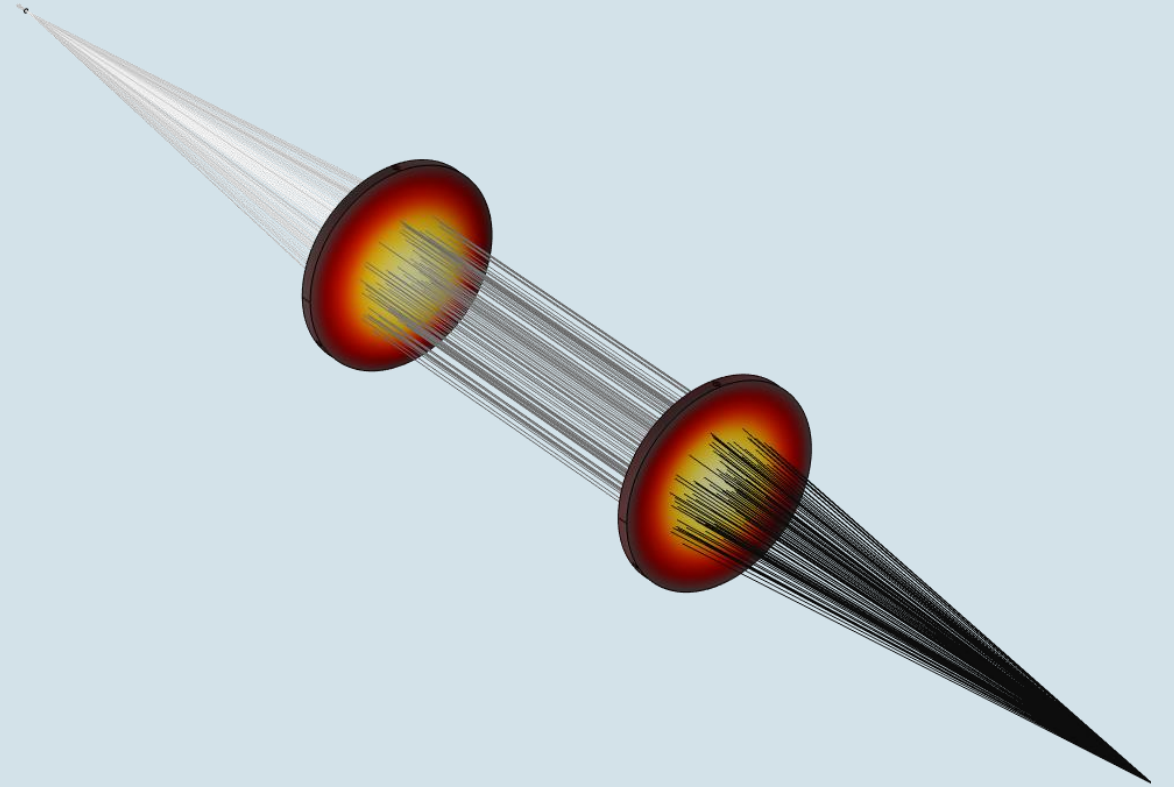
STOP Analysis with Ray Heating

- The dedicated *Bidirectionally Coupled Ray Tracing* study type, along with the *Ray Heat Source* feature, will automatically follow the iteration scheme in the previous slide.



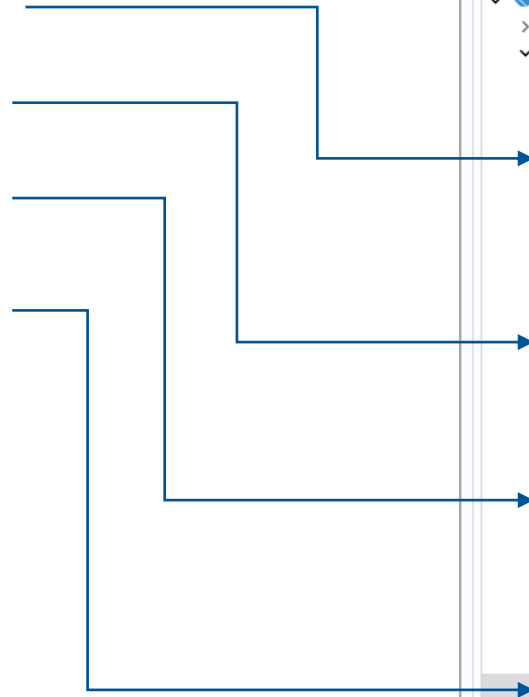
DEMO: Surrogate model for STOP Analysis

- Creation of a digital twin of Laser Focusing System to obtain instantaneous values of temperature, stress and lens deformation.



COMSOL Multiphysics

- Geometrical Optics
- Heat Transfer
- Solid Mechanics
- Ray Heat Source
- Thermal Expansion



The screenshot displays the COMSOL Multiphysics software interface. The top menu bar includes File, Home, Definitions, Geometry, Materials, Physics, Mesh, Study, Results, and Developer. The toolbar contains icons for Application Builder, Model Manager, Component 1, Add Component, Parameters, Variable Utilities, Build All, Add Physics, Add Mathematics, Solid Mechanics, Build Mesh, and Mesh 1. The Model Builder tree on the left shows the project structure for 'STOP_Surrogate.mph', including Global Definitions, Component 1 (comp1), and various physics nodes. The Settings panel on the right is configured for a 'Ray Heat Source' (rhs1), showing domain selection, equation settings, and coupled interfaces. The Graphics window on the right displays a 3D model of a cylindrical component with a coordinate system (x, y, z) and a scale of 20 mm. The status bar at the bottom right indicates a file size of 2.16 GB and a total size of 2.72 GB.

Our Neural Networks for STOP Model

- 6 DNNs in total (3 for each lens)
- 6 input parameters: x , y , z , I_{rms} , T_0 , λ_{lam}^*
- Output parameters: temperature, stress, displacement
- Training data for 300 parameter combinations (I_{rms} , T_0 , λ_{lam})
- 4 hidden layers, number of neurons: 100, 50, 30, 10
- Activations:
 - Output layers activation: linear
 - Other layers activation: tanh

* I_{rms} = laser power, T_0 = room temperature, λ_{lam} = laser wavelength

Settings
Deep Neural Network

Plot Create Plot Train Model Continue Training

Label: DNN_T1

Layers

Type	Settings
Dense	Input, Input features=6, Output features=100, Activation=tanh
Dense	Hidden, Output features=100, Activation=tanh
Dense	Hidden, Output features=50, Activation=tanh
Dense	Hidden, Output features=30, Activation=tanh
Dense	Hidden, Output features=10, Activation=tanh
Dense	Output, Output features=1, Activation=Linear (none)

Data

Data Column Settings

Columns	Type	Settings
Column 1	Argument	Name=x1, Scaling=to01, Unit=mm
Column 2	Argument	Name=x2, Scaling=to01, Unit=mm
Column 3	Argument	Name=x3, Scaling=to01, Unit=mm
Column 4	Argument	Name=x4, Scaling=to01, Unit=W
Column 5	Argument	Name=x5, Scaling=to01, Unit=K
Column 6	Argument	Name=x6, Scaling=to01, Unit=mm
Column 7	Function	Name=dnn_T1, Scaling=to01, Unit=K
Column 8	Ignored c	
Column 9	Ignored c	

Training and Validation

Method: Adam

Learning rate: 0.5e-3

Weight decay: 0

Batch size: 1024

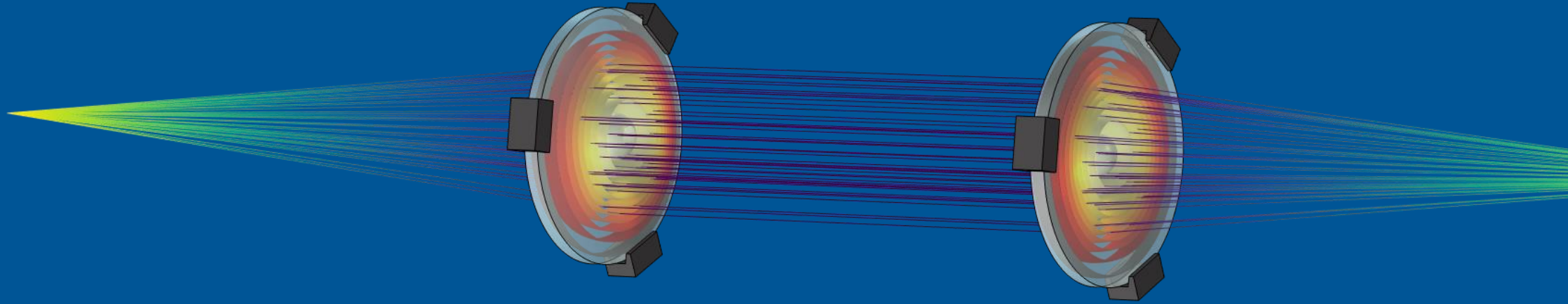
Loss function: Root-mean-square error

Random seed type: Fixed

Random seed: 0

Graphics

Messages Progress Log Evaluation 3D



How to Create Surrogate Model from STOP Simulation

Tomáš Vrbata

Setting up Surrogate Model Training

File Home Definitions Geometry Materials Physics Mesh Study Results Developer

Application Builder Model Manager Component 1 Add Component Parameters Variables Variable Utilities Build All Import Add Material Geometrical Optics Add Physics Add Mathematics Build Mesh Mesh 1 Compute Study 1 Add Study Ray Trajectories (gop) Add Plot Group Add Predefined Plot Windows Reset Desktop

Workspace Model Definitions Geometry Materials Physics Mesh Study Results Layout

Model Builder

Type filter text

- thermally_induced_focal_shift.mph (root)
 - Global Definitions
 - Parameters 1 (default)
 - Geometry Parts
 - Default Model Inputs (cmimpt)
 - Materials
 - Component 1 (comp1) (comp1)
 - Definitions
 - Geometry 1 (geom1)
 - Materials
 - Geometrical Optics (gop) (gop)
 - Medium Properties 1 (mp1)
 - Material Discontinuity 1 (matd1)
 - Ray Properties 1 (op1)
 - Release from Grid 1 (relg1)
 - Wall 1 (wall1)
 - Equation View (info)
 - Heat Transfer in Solids (ht) (ht)
 - Solid 1 (solid1)
 - Initial Values 1 (init1)
 - Thermal Insulation 1 (ins1)
 - Heat Flux 1 (hf1)
 - Equation View (info)
 - Solid Mechanics (solid) (solid)
 - Linear Elastic Material 1 (lemm1)
 - Free 1 (free1)
 - Initial Values 1 (init1)
 - Fixed Constraint 1 (fix1)
 - Equation View (info)
 - Multiphysics
 - Ray Heat Source 1 (rhs1) (rhs1)
 - Thermal Expansion 1 (te1) (te1)
 - Mesh 1 (mesh1)
 - Study 1 (std1)
 - Parametric Sweep (param)
 - Step 1: Bidirectionally Coupled Ray Tracing (bcrt)
 - Solver Configurations
 - Job Configurations
 - Results
 - Datasets
 - Views
 - Derived Values
 - Tables
 - Color Tables
 - Ray Trajectories (gop) (pg1)
 - Temperature (ht) (pg2)
 - Stress (solid) (pg3)
 - Deposited Ray Power (lenses) (pg4)
 - Deposited Ray Power (target) (pg5)

Settings

Study

Compute Update Solution

Label: Study 1

Study Settings

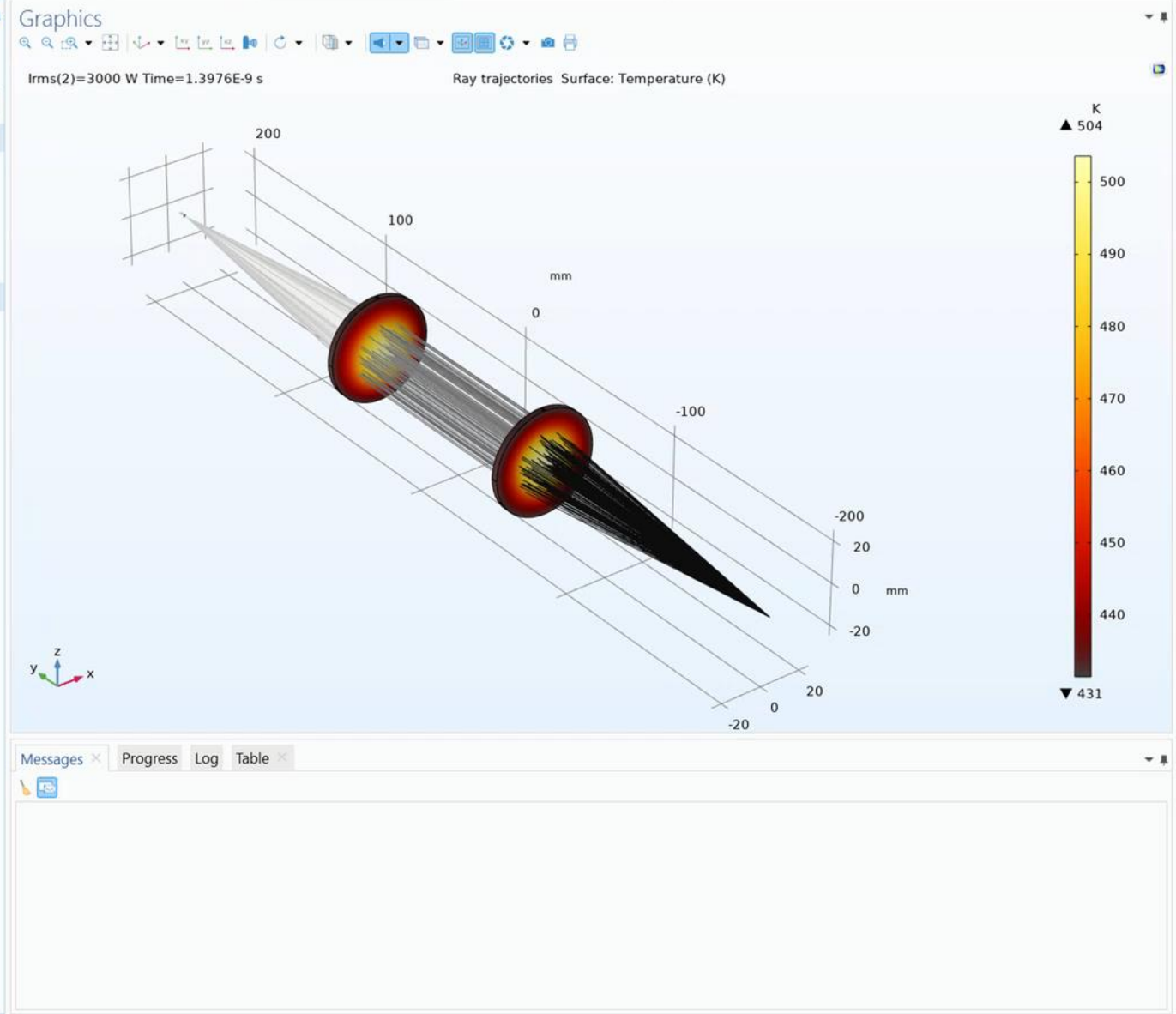
- Generate default plots
- Generate convergence plots
- Store solution for all intermediate study steps
- Generate default plots for intermediately stored solutions
- Plot the location of undefined values

Information

Last computation time: 2 min 43 s

Last computation date: Sep 30, 2023, 2:48:12 AM

Computed in version: COMSOL 6.2.0.259



Generation of training data

File Home Definitions Geometry Materials Physics Mesh Study Results Developer

Application Builder Model Manager Component 1 Add Component Parameters Variables Variable Utilities Build All Import Add Material Solid Mechanics Add Physics Add Mathematics Build Mesh Mesh 1 Compute Study 2 Add Study Ray Trajectories (gop) Add Plot Add Predefined Plot Windows Reset Desktop

Workspace Model Definitions Geometry Materials Physics Mesh Study Results Layout

Model Builder

Type filter text

- Geometry Parts
 - Default Model Inputs (cminpt)
- Materials
- Component 1 (comp1) (comp1)
 - Definitions
 - Geometry 1 (geom1)
 - Materials
 - Geometrical Optics (gop) (gop)
 - Medium Properties 1 (mp1)
 - Material Discontinuity 1 (matd1)
 - Ray Properties 1 (op1)
 - Release from Grid 1 (relg1)
 - Wall 1 (wall1)
 - Equation View (info)
 - Heat Transfer in Solids (ht) (ht)
 - Solid 1 (solid1)
 - Initial Values 1 (init1)
 - Thermal Insulation 1 (ins1)
 - Heat Flux 1 (hfl)
 - Equation View (info)
 - Solid Mechanics (solid) (solid)
 - Linear Elastic Material 1 (lemm1)
 - Free 1 (free1)
 - Initial Values 1 (init1)
 - Fixed Constraint 1 (fix1)
 - Equation View (info)
 - Multiphysics
 - Ray Heat Source 1 (rhs1) (rhs1)
 - Thermal Expansion 1 (te1) (te1)
 - Mesh 1 (mesh1)
- Study 2 (std2)
 - Surrogate Model Training (sm)
 - Step 1: Bidirectionally Coupled Ray Tracing (bcrt)
 - Solver Configurations
 - Job Configurations
- Results
 - Datasets
 - Study 2/Solution 1 (sol1) (dset1)
 - Ray 1 (ray1)
 - Views
 - Derived Values
 - Tables
 - Color Tables
 - Ray Trajectories (gop) (pg1)
 - Temperature (ht) (pg2)
 - Stress (solid) (pg3)
 - Export
 - Reports

Settings

Datasets

Graphics

Time=0

200

100 mm

0

20

0 mm

-20

20

0

-20 mm

x y z

Messages Progress Log Table

Setting up a Deep Neural Network

File Home Definitions Geometry Materials Physics Mesh Study Results Developer

Application Builder Model Manager Component 1 Add Component Parameters Variables Variable Utilities Build All Import Add Material Geometrical Optics Add Physics Add Mathematics Build Mesh Mesh 1 Compute Study 2 Add Study Ray Trajectories (gop) Add Plot Group Add Predefined Plot Windows Reset Desktop

Workspace Model Definitions Geometry Materials Physics Mesh Study Results Layout

Model Builder

Type filter text

- Geometry 1 (geom1)
- Materials
- Geometrical Optics (gop) (gop)
 - Medium Properties 1 (mp1)
 - Material Discontinuity 1 (matd1)
 - Ray Properties 1 (op1)
 - Release from Grid 1 (relg1)
 - Wall 1 (wall1)
 - Equation View (info)
- Heat Transfer in Solids (ht) (ht)
 - Solid 1 (solid1)
 - Initial Values 1 (init1)
 - Thermal Insulation 1 (ins1)
 - Heat Flux 1 (hf1)
 - Equation View (info)
- Solid Mechanics (solid) (solid)
 - Linear Elastic Material 1 (lemm1)
 - Free 1 (free1)
 - Initial Values 1 (init1)
 - Fixed Constraint 1 (fix1)
 - Equation View (info)
- Multiphysics
 - Ray Heat Source 1 (rhs1) (rhs1)
 - Thermal Expansion 1 (te1) (te1)
- Mesh 1 (mesh1)
- Study 2 (std2)
 - Surrogate Model Training (sm)
 - Step 1: Bidirectionally Coupled Ray Tracing (bcrt1)
 - Solver Configurations
 - Job Configurations
 - Results
 - Datasets
 - Views
 - Derived Values
 - Tables
 - Color Tables
 - Ray Trajectories (gop) (pg1)
 - Temperature (ht) (pg2)
 - Stress (solid) (pg3)
 - Displacement (solid) (pg4)
 - Ray Trajectories (gop) 1 (pg5)
 - Temperature (ht) 1 (pg6)
 - Stress (solid) 1 (pg7)
 - Ray Trajectories (gop) 2 (pg8)
 - Temperature (ht) 2 (pg9)
 - Stress (solid) 2 (pg10)
 - Export
 - Reports

Settings

Surrogate Model Training

Compute Update Solution

Label: Surrogate Model Training

Study Settings

Compute action: Compute and build surrogate model

Solution to use: Automatic

Surrogate model: Design of experiments (No surrogate model)

Output table group: Design of Experiments (de1)

Quantities of interest (Outputs)

Expression	Description	Individual solution to use
1		From "Solution to use"

Input Parameters

Parameter	Source type	Parameter description
Irms (Roo)	Analytic	Uniform from [1000, 4000]
T0 (Room)	Analytic	Uniform from [-20, 50]
lam (Fiber)	Analytic	Uniform from [800, 2000]

Correlation groups

Correlation groups	Correlation matrix	Active
		Active

Input parameters sampling settings

Number of input points type: Manual

Number of input points: 300

Random seed type: Automatic

Initial random seed: 1014

Advanced Settings

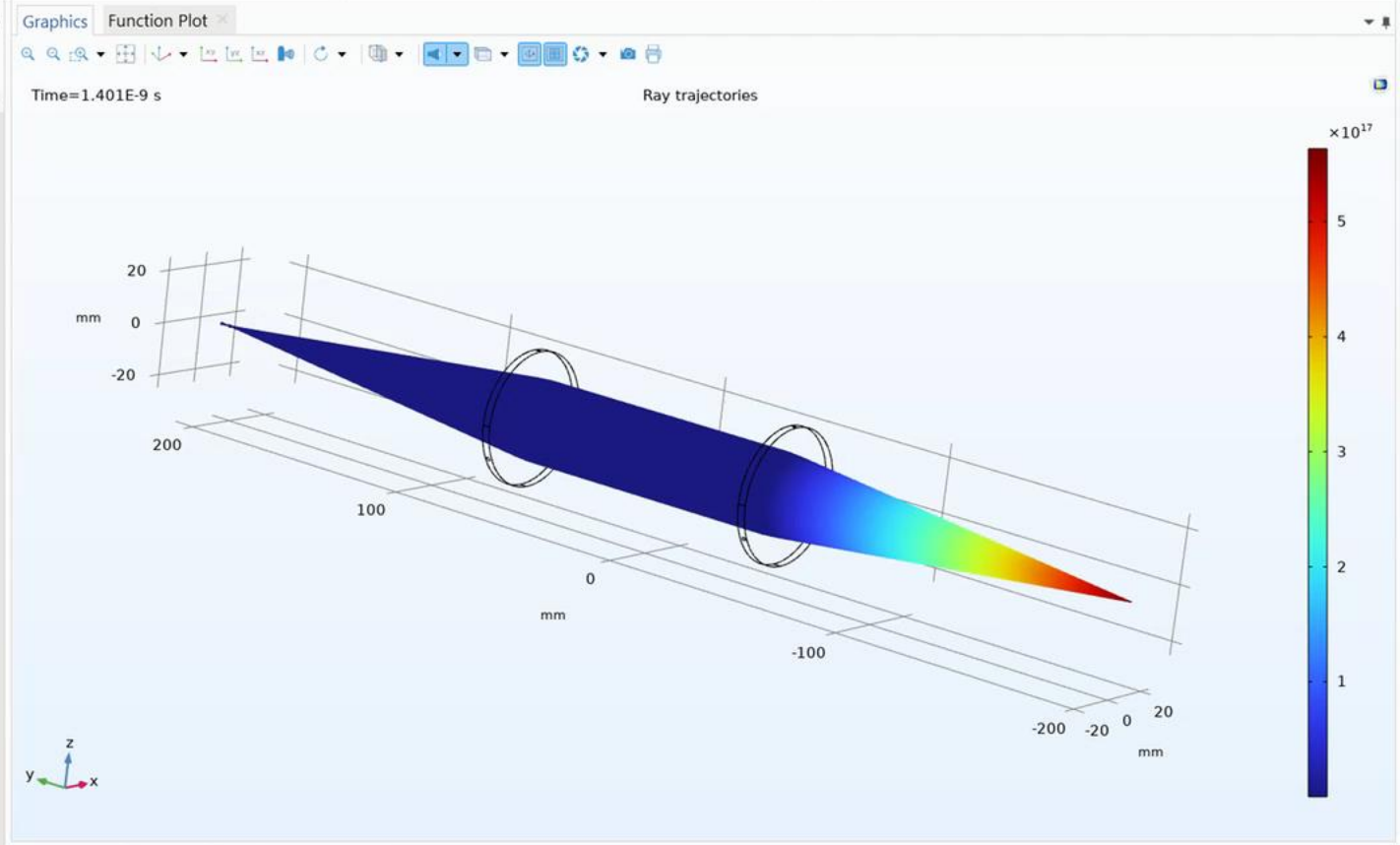
Accumulated probe table

Output table: New

Use all probes

Error handling: Skip problematic parameters

Keep model evaluations in memory: Only last



Messages X Progress Log Design Data X

DNN visualization and postprocessing

File Home Definitions Geometry Materials Physics Mesh Study Results Developer

Application Builder Model Manager Component 1 Add Component Parameters Variables Variable Utilities Build All Import Add Material Geometrical Optics Add Physics Add Mathematics Build Mesh Mesh 1 Compute Study 2 Add Study Ray Trajectories (gop) Add Plot Group Add Predefined Plot Windows Reset Desktop

Workspace Model Definitions Geometry Materials Physics Mesh Study Results Layout

Model Builder

Type filter text

- thermally_induced_focal_shift1.mph (root)
 - Global Definitions
 - Parameters 1 (default)
 - DNN_T1 (dnn_T1) (dnn1)
 - DNN_T2 (dnn_T2) (dnn2)
 - DNN_S1 (dnn_S1) (dnn3)
 - DNN_S2 (dnn_S2) (dnn4)
 - DNN_D1 (dnn_D1) (dnn5)
 - DNN_D2 (dnn_D2) (dnn6)
 - Geometry Parts
 - Default Model Inputs (cmnpt)
 - Materials
 - Component 1 (comp1) (comp1)
 - Definitions
 - Geometry 1 (geom1)
 - Materials
 - Geometrical Optics (gop) (gop)
 - Medium Properties 1 (mp1)
 - Material Discontinuity 1 (matd1)
 - Ray Properties 1 (op1)
 - Release from Grid 1 (relg1)
 - Wall 1 (wall1)
 - Equation View (info)
 - Heat Transfer in Solids (ht) (ht)
 - Solid 1 (solid1)
 - Initial Values 1 (init1)
 - Thermal Insulation 1 (ins1)
 - Heat Flux 1 (hf1)
 - Equation View (info)
 - Solid Mechanics (solid) (solid)
 - Linear Elastic Material 1 (lemm1)
 - Free 1 (free1)
 - Initial Values 1 (init1)
 - Fixed Constraint 1 (fix1)
 - Equation View (info)
 - Multiphysics
 - Ray Heat Source 1 (rhs1) (rhs1)
 - Thermal Expansion 1 (te1) (te1)
 - Mesh 1 (mesh1)
 - Study 2 (std2)
 - Surrogate Model Training (sm)
 - Step 1: Bidirectionally Coupled Ray Tracing (bcrt1)
 - Solver Configurations
 - Job Configurations
 - Results
 - Datasets
 - Views
 - Derived Values
 - Tables

Settings

Deep Neural Network

Plot Create Plot Train Model Continue Training

Column 7	Function v	Name=dnn_T1, Scaling=to01, Unit=K
Column 8	Ignored c	
Column 9	Ignored c	

Name: dnn_T1
 Description:
 Scaling: Scale to [0,1]
 Unit: K

Training and Validation

Method: Adam
 Learning rate: 0.5e-3
 Weight decay: 0
 Batch size: 1024
 Loss function: Root-mean-square error
 Random seed type: Fixed
 Random seed: 0
 Stop condition
 Number of epochs: 1000
 Validation data
 Validation data fraction: 0.1
 Random seed type: Fixed
 Random seed: 0

Plot Parameters

Function name: dnn_T1

Plot	Argument	Lower limit	Upper limit	Fixed value	Unit
<input checked="" type="checkbox"/>	x1	-25[mm]	25[mm]	0[mm]	m
<input checked="" type="checkbox"/>	x2	-59.3029[mm]	-51.603[mm]	-55.453[mm]	m
<input checked="" type="checkbox"/>	x3	-25[mm]	25[mm]	0[mm]	m
<input type="checkbox"/>	x4	1001.18	3993.15	2497.16	W
<input type="checkbox"/>	x5	253.281	323.061	288.171	K
<input type="checkbox"/>	x6	8.01119E-4[mm]	0.0019995[mm]	0.00140031[m...	m

Information

Trained functions: dnn_T1 [K]

Graphics

Convergence Plot 1 Function Plot X

dnn_T1(x1,x2,x3,2497.2,288.17,0.0014003) (K)

Messages x Progress Log Design Data x

Application running

Making an application skipped

vrbata administrator

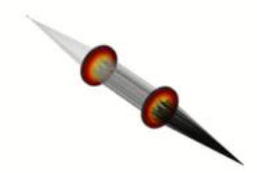
- Application Library
- Upload
- Administration
- Licensed and Used Products
- Your Settings

COMSOL Server / Application Library

Library

Search Filter: Public Sort By: Date Uploaded ↓ 53/69


STOP Analysis - Surrogate Model



Date uploaded: 2024-05-20 15:39:22

Run in browser


Air-Cooled BESS



Date uploaded: 2024-04-12 15:30:30

Run in browser

Thermal Actuator Surrogate Model Application



Date uploaded: 2023-11-15 08:33:52

Run in browser

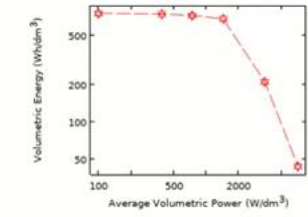
Tubular Reactor Surrogate Model Application



Date uploaded: 2023-11-10 16:06:40

Run in browser


Surrogate Model Training of a Battery Rate Capability Model



Date uploaded: 2023-11-10 16:06:40

Run in browser

Installation Verification



Date uploaded: 2023-11-10 16:06:40

Run in browser


Homogenized Material Properties of Periodic Microstructures



Date uploaded: 2023-11-10 16:06:40

Run in browser

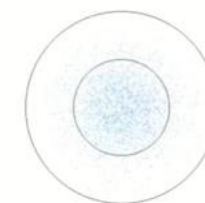
Lungs Ohmic Heating



Date uploaded: 2023-09-11 10:35:51

Run in browser

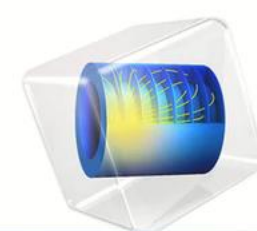
Brownian Motion



Date uploaded: 2023-09-05 10:13:35

Run in browser

MHD 3D



Date uploaded: 2023-09-04 14:49:30

Run in browser

COMSOL CONFERENCE 2024 FLORENCE

October 22-24

Connect with industry leaders at the modeling and simulation event of the year.

