

# NonLinearSystemNeuralNetworkFMU.jl

August 17, 2023

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**Part I**

**Home**

## Chapter 1

# NonLinearSystemNeuralNetworkFMU.jl

Generate Neural Networks to replace non-linear systems inside OpenModelica 2.0 FMUs.

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### 1.2 Overview

The package generates an FMU from a modelica file in 3 steps (+ 1 user step):

1. Find non-linear equation systems to replace.
  - Simulate and profile Modelica model with OpenModelica using [OMJulia.jl](#).
  - Find slowest equations below given threshold.
  - Find depending variables specifying input and output for every non-linear equation system.
  - Find min-max ranges for input variables by analyzing the simulation results.
2. Generate training data.

- Generate 2.0 Model Exchange FMU with OpenModelica.
  - Add C interface to evaluate single non-linear equation system without evaluating anything else.
  - Re-compile FMU.
  - Initialize FMU using `FMI.jl`.
  - Generate training data for each equation system by calling new interface.
3. Train neural network.
- Step performed by user.
4. Integrate neural network into FMU
- Replace equations with neural network in generated C code.
  - Re-compile FMU.

### 1.3 Installation

Clone this repository to your machine and use the package manager Pkg to develop this package.

```
| (@v1.7) pkg> dev /path/to/NonLinearSystemNeuralNetworkFMU  
| julia> using NonLinearSystemNeuralNetworkFMU
```

**Part II**

**Main**

## Chapter 2

# Main Data Generation Routine

To perform all needed steps for data generation the following functions have to be executed:

1. `profiling`
2. `generateFMU`
3. `addEqInterface2FMU`
4. `generateTrainingData`

These functionalities are bundled in `main`.

### 2.1 Functions

`NonLinearSystemNeuralNetworkFMU.main` - Function.

```
main(modelName, moFiles; options=OMOptions(workingDir=joinpath(pwd(), modelName)),  
↳ dataGenOptions=DataGenOptions(method = RandomMethod(), n=1000, nBatches=Threads.nthreads()),  
↳ reuseArtifacts=false)
```

Main routine to generate training data from Modelica file(s). Generate BSON artifacts and FMUs for each step. Artifacts can be re-used when restarting main routine to skip already performed steps.

Will perform profiling, min-max value compilation, FMU generation and data generation for all non-linear equation systems of `modelName`.

#### Arguments

- `modelName::String`: Name of Modelica model to simulate.
- `moFiles::Array{String}`: Path to .mo file(s).

#### Keywords

- `omOptions::OMOptions`: Settings for OpenModelica compiler.
- `dataGenOptions::DataGenOptions`: Settings for data generation.
- `reuseArtifacts=false`: Use artifacts to skip already performed steps if true.

#### Returns

- `csvFiles::Array{String}`: Array of generate CSV files with training data.
- `fmu::String`: Path to unmodified 2.0 ME FMU.
- `profilingInfo::Array{ProfilingInfo}`: Array of profiling information for each non-linear equation system.

See also [profiling](#), [minMaxValuesReSim](#), [generateFMU](#), [addEqInterface2FMU](#), [generateTrainingData](#).

[source](#)



## **Part III**

# **Profiling**

## Chapter 3

# Profiling Modelica Models

### 3.1 Functions

NonLinearSystemNeuralNetworkFMU.profiling - Function.

```
| profiling(modelName, moFiles; pathToOmc, workingDir, threshold = 0.03)
```

Find equations of Modelica model that are slower than threshold.

#### Arguments

- modelName::String: Name of the Modelica model.
- moFiles::Array{String}: Path to the \*.mo file(s) containing the model.

#### Keywords

- options::OMOptions: Options for OpenModelica compiler.
- threshold=0.01: Slowest equations that need more than threshold of total simulation time.
- ignoreInit::Bool=true: Ignore equations from initialization system if true.

#### Returns

- profilingInfo::Vector{ProfilingInfo}: Profiling information with non-linear equation systems slower than threshold.

[source](#)

NonLinearSystemNeuralNetworkFMU.minMaxValuesReSim - Function.

```
| minMaxValuesReSim(vars, modelName, moFiles; pathToOmc="" workingDir=pwd())
```

(Re-)simulate Modelica model and find minimum and maximum value each variable has during simulation.

#### Arguments

- vars::Array{String}: Array of variables to get min-max values for.
- modelName::String: Name of Modelica model to simulate.
- moFiles::Array{String}: Path to .mo file(s).

**Keywords**

- `options::OMOptions`: Options for OpenModelica compiler.

**Returns**

- `min::Array{Float64}`: Minimum values for each variable listed in `vars`, minus some small epsilon.
- `max::Array{Float64}`: Maximum values for each variable listed in `vars`, plus some small epsilon.

See also [profiling](#).

[source](#)

**3.2 Structures**

`NonLinearSystemNeuralNetworkFMU.ProfilingInfo` – Type.

| `ProfilingInfo` <: **Any**

Profiling information for single non-linear equation.

- `eqInfo::EqInfo`: Non-linear equation
- `iterationVariables::Array{String}`: Iteration (output) variables of non-linear system
- `innerEquations::Array{Int64}`: Inner (torn) equations of non-linear system.
- `usingVars::Array{String}`: Used (input) variables of non-linear system.
- `boundary::NonLinearSystemNeuralNetworkFMU.MinMaxBoundaryValues{Float64}`: Minimum and maximum boundary values of `usingVars`.

[source](#)

`NonLinearSystemNeuralNetworkFMU.EqInfo` – Type.

| `EqInfo` <: **Any**

Equation info struct.

- `id::Int64`: Unique equation id
- `ncall::Int64`: Number of calls during simulation
- `time::Float64`: Total time [s] spend on evaluating this equation.
- `maxTime::Float64`: Maximum time [s] needed for single evaluation of equation.
- `fraction::Float64`: Fraction of total simulation time spend on evaluating this equation.

[source](#)

### 3.3 Examples

#### Find Slowest Non-linear Equation Systems

We have a Modelica model SimpleLoop, see [test/simpleLoop.mo](#) with some non-linear equation system

$$r^2 = x^2 + y^2$$

$$rs = x + y$$

We want to see how much simulation time is spend solving this equation. So let's start [profiling](#):

```
julia> using NonLinearSystemNeuralNetworkFMU

julia> modelName = "simpleLoop";

julia> moFiles = [joinpath("test", "simpleLoop.mo")];

julia> profilingInfo = profiling(modelName, moFiles, omc; threshold=0)
ERROR: MethodError: no method matching profiling(::String, ::Vector{String}, ::String;
↳ threshold::Int64)

Closest candidates are:
  profiling(::String, ::Array{String}; options, threshold, ignoreInit)
    @ NonLinearSystemNeuralNetworkFMU
↳ ~/work/NonLinearSystemNeuralNetworkFMU.jl/NonLinearSystemNeuralNetworkFMU.jl/src/profiling.jl:333
```

We can see that non-linear equation system 14 is using variables s and r as input and has iteration variable y. x will be computed in the inner equation.

```
julia> profilingInfo[1].usingVars
ERROR: UndefVarError: `profilingInfo` not defined

julia> profilingInfo[1].iterationVariables
ERROR: UndefVarError: `profilingInfo` not defined
```

So we can see, that equations 14 is the slowest non-linear equation system. It is called 2512 times and needs around 15% of the total simulation time, in this case that is around 592  $\mu s$ .

During [profiling](#) function [minMaxValuesReSim](#) is called to re-simulate the Modelica model and read the simulation results to find the smallest and largest values for each given variable.

We can check them by looking into

```
julia> profilingInfo[1].boundary.min
ERROR: UndefVarError: `profilingInfo` not defined

julia> profilingInfo[1].boundary.min
ERROR: UndefVarError: `profilingInfo` not defined
```

## **Part IV**

# **Data Generation**

## Chapter 4

# Training Data Generation

To generate training data for the slowest non-linear equations found during [Profiling Modelica Models](#) we now simulate the equations multiple time and save in- and outputs.

We will use the [Functional Mock-up Interface \(FMI\)](#) standard to generate FMU that we extend with some function to evaluate single equations without the need to simulate the rest of the model.

### 4.1 Functions

`NonLinearSystemNeuralNetworkFMU.generateFMU` – Function.

```
| generateFMU(modelName, moFiles; [pathToOmc], workingDir=pwd(), clean=false)
```

Generate 2.0 Model Exchange FMU for Modelica model using OMJulia.

#### Arguments

- `modelName::String`: Name of the Modelica model.
- `moFiles::Array{String}`: Path to the \*.mo file(s) containing the model.

#### Keywords

- `options::OMOptions`: Options for OpenModelica compiler.

#### Returns

- Path to generated FMU `workingDir/<modelName>.fmu`.

See also [addEqInterface2FMU](#), [generateTrainingData](#).

[source](#)

`NonLinearSystemNeuralNetworkFMU.addEqInterface2FMU` – Function.

```
| addEqInterface2FMU(modelName, pathToFmu, eqIndices; workingDir=pwd())
```

Create extendedFMU with `special_interface` to evaluate single equations.

#### Arguments

- `modelName::String`: Name of Modelica model to export as FMU.

- `pathToFmu::String`: Path to FMU to extend.
- `eqIndices::Array{Int64}`: Array with equation indices to add equation interface for.

**Keywords**

- `workingDir::String=pwd()`: Working directory. Defaults to current working directory.

**Returns**

- Path to generated FMU `workingDir/<modelName>.interface.fmu`.

See also [profiling](#), [generateFMU](#), [generateTrainingData](#).

[source](#)

`NonLinearSystemNeuralNetworkFMU.generateTrainingData` – Function.

```
generateTrainingData(fmuPath, workDir, fname, eqId, inputVars, min, max, outputVars;
                    options=DataGenOptions())
```

Generate training data for given equation of FMU.

Generate random inputs between min and max, evaluate equation and compute output. All input-output pairs are saved in CSV file `fname`.

**Arguments**

- `fmuPath::String`: Path to FMU.
- `workDir::String`: Working directory for `generateTrainingData`.
- `fname::String`: File name to save training data to.
- `eqId::Int64`: Index of equation to generate training data for.
- `inputVars::Array{String}`: Array with names of input variables.
- `minBound::AbstractVector{T}`: Array with minimum value for each input variable.
- `maxBound::AbstractVector{T}`: Array with maximum value for each input variable.
- `outputVars::Array{String}`: Array with names of output variables.

**Keywords**

- `options::DataGenOptions`: Settings for data generation.

See also [generateFMU](#).

[source](#)

## 4.2 Examples

First we need to create a Model-Exchange 2.0 FMU with OpenModelica.

This can be done directly from OpenModelica or with [generateFMU](#):

```
using NonLinearSystemNeuralNetworkFMU #hide
omc = string(strip(read(`which omc`, String))) #hide

fmu = generateFMU("simpleLoop",
                  ["test/simpleLoop.mo"];
                  pathToOmc = omc,
                  workingDir = "tempDir")
rm("tempDir", recursive=true, force=true) #hide
```

Next we need to add non-standard C function

```
fmi2Status myfmi2EvaluateEq(fmi2Component c, const size_t eqNumber)
```

that will call `<modelName>_eqFunction_<eqIndex>(DATA* data, threadData_t *threadData)` for all non-linear equations we want to generate data for.

Using [addEqInterface2FMU](#) this C code will be generated and added to the FMU.

```
interfaceFmu = addEqInterface2FMU("simpleLoop",
                                  fmu,
                                  [14],
                                  workingDir = "tempDir")
rm("tempDir", recursive=true, force=true) #hide
```

Now we can create evaluate equation 14 for random values and save the outputs to generate training data.

```
using CSV
using DataFrames
generateTrainingData(interfaceFmu,
                     "simpleLoop_data.csv",
                     14,
                     ["s", "r"],
                     [0.0, 0.95],
                     [1.5, 3.15],
                     ["y"];
                     N = 10)
df = CSV.File("simpleLoop_data.csv")
rm("simpleLoop_data.csv", force=true) #hide
```