TMVA SOFIE

Developing the Machine Learning Inference Engine

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ROOT TMVA

- Toolkit for Multivariate Analysis
- Provides a Machine Learning environment for training, testing and evaluation of multivariate methods.

SOFIE

SOFIE

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System for

SOFIE

System for Optimized

SOFIE

System for Optimized Fast

SOFIE

System for Optimized Fast Inference

SOFIE

System for Optimized Fast Inference code Emit

SOFIE

System for **O**ptimized **F**ast **I**nference code **E**mit

inference code, fast to operate, with least dependencies

TMVA SOFIE

- Intermediate representation following ONNX standards.
- Inference code generation with least latency and minimal dependency

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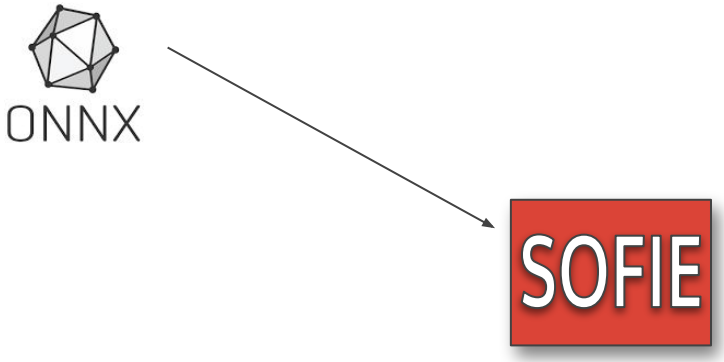

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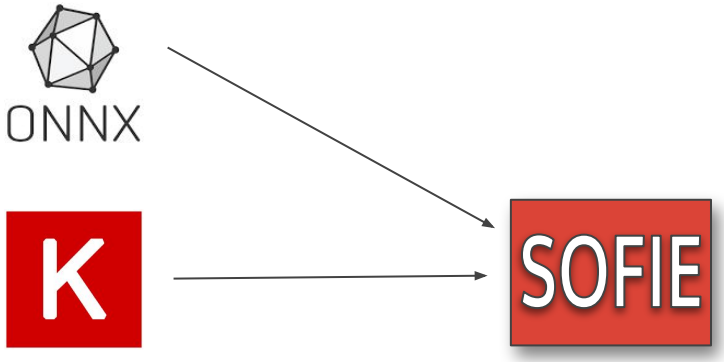

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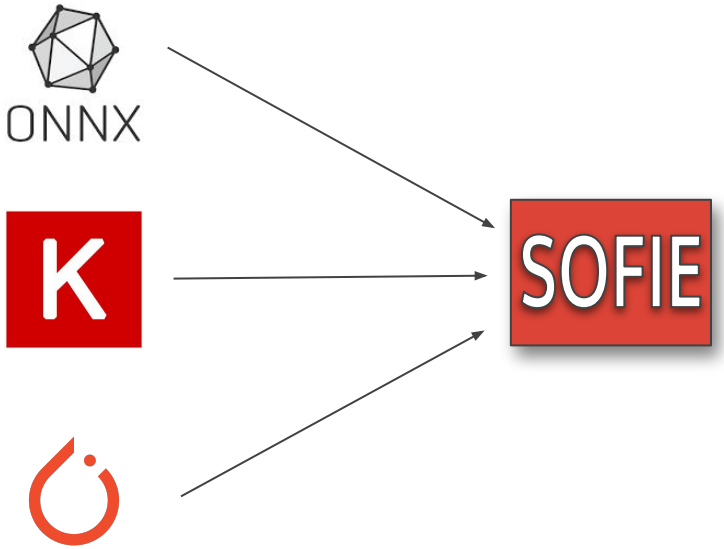

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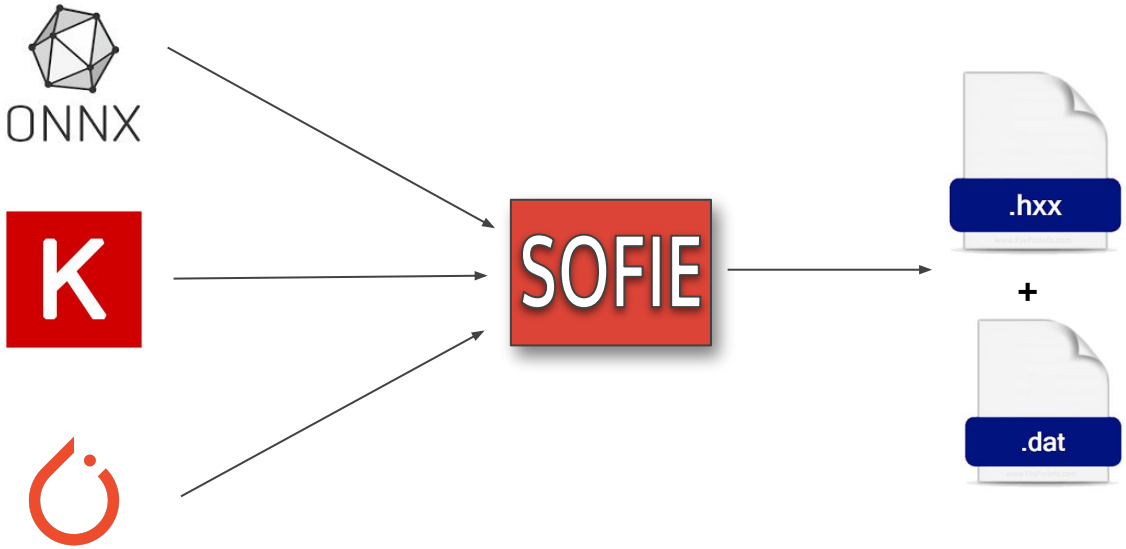

TMVA SOFIE

Parser for translating an ONNX model to SOFIE's IR

```
using namespace TMVA::Experimental::SOFIE;
RModelParser_ONNX parser;
RModel model = parser.Parse("model.onnx");
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Parser for translating PyTorch (`.pt`) and Keras (`.h5`) models

```
SOFIE::RModel model = SOFIE::PyTorch::Parse("PyTorchModel.pt");
SOFIE::RModel model = SOFIE::PyKeras::Parse("KerasModel.h5");
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Inference code generation

```
// generate text code internally (with some options)
model.Generate();
// write output header file and data weight file
model.OutputGenerated();
```

TMVA SOFIE

```
namespace TMVA_SOFIE_Linear_event{

struct Session {

Session(std::string filename ="") {
   if (filename.empty()) filename = "Linear_event.dat";
   std::ifstream f;
   f.open(filename);
   // read weight data file
   ……————————..
}
std::vector<float> infer(float* tensor_input1){
————————————.
//——— Gemm
    BLAS::sgemm_(&op_0_transB, &op_0_transA, &op_0_n, &op_0_m, &op_0_k, &op_0_alpha,
tensor_0weight, &op_0_ldb, tensor_input1, &op_0_lda, &op_0_beta, tensor_21, &op_0_n);

//------ RELU
   for (int id = 0; id < 50 ; id++){
      tensor_22[id] = ((tensor_21[id] > 0 )? tensor_21[id] : 0);
   }
————————————..
   BLAS::sgemm_(&op_18_transB, &op_18_transA, &op_18_n, &op_18_m, &op_18_k, &op_18_alpha,
tensor_18weight, &op_18_ldb, tensor_38, &op_18_lda, &op_18_beta, tensor_39, &op_18_n);

// return output
   std::vector<float> ret (tensor_39, tensor_39 + 10);
   return ret;
}
};
}
```

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- Implement support for parsing Graph Neural Networks in SOFIE

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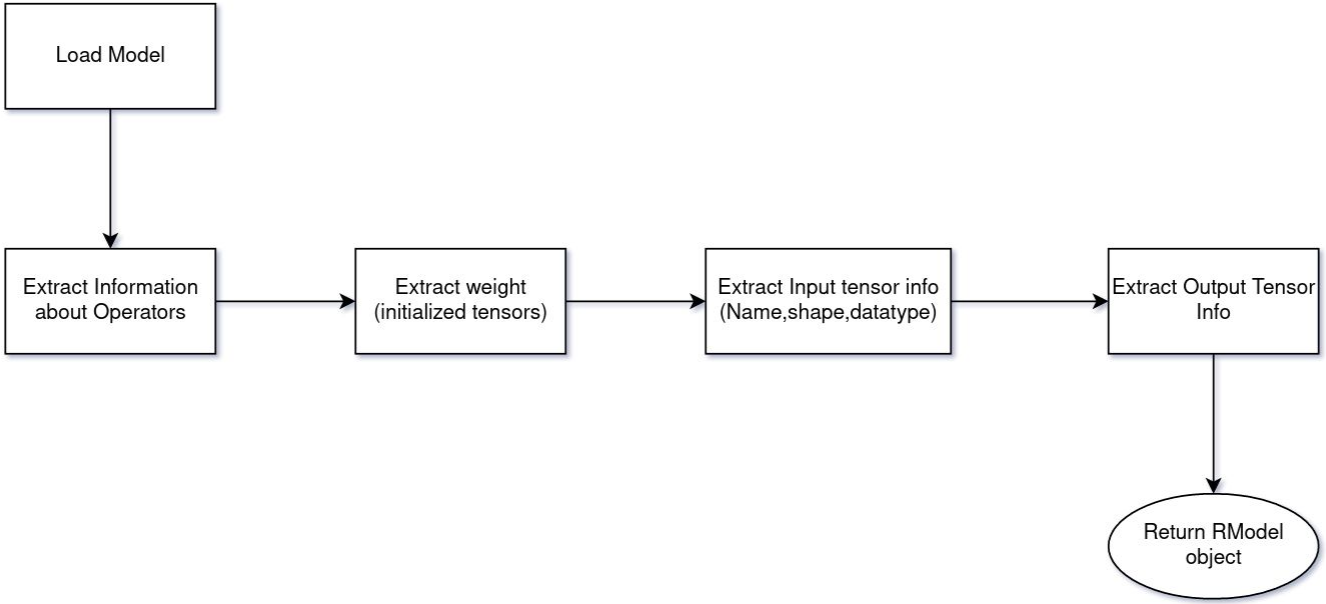
```
auto model = TMVA::Experimental::SOFIE::PyKeras::Parse("trained_model_dense.h5");
```

SOFIE Keras Parser

Algorithm for Parser



SOFIE Keras Parser

Current Support

Keras Layer	Status
Dense	Implemented & Integrated
Permute	Implemented & Integrated
ReLU, Selu, Sigmoid	Implemented & Integrated
Batch Normalization	PR Merged
Convolution (2D)	PR Merged
Basic Binary Operators: Add, Subtract, Multiply	PR Under Review
Reshape	PR Under Review
Activations: Softmax, LeakyRelu, Tanh	PR Drafted
Concat	PR Drafted

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- Need a custom user operator specification
  - simple to define
  - easy to test, debug, and evaluate
  - few overheads and dependencies

SOFIE Custom Operator

Definition

- Define custom operator with the required attributes
  - Operator name
  - Input tensor names
  - Output tensor names
  - Output tensor shapes
  - Header file name

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Interface

```
std::unique_ptr<SOFIE::ROperator> op;
op.reset(new SOFIE::ROperator_Custom<float>("Exp", {"denseBiasAdd0"}, {"exp_out"}, {{1,4}},
"exp_compute.hxx"));
```

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  - uses Particlenet; graph neural network supporting graph convolution, i.e. edge convolution and dynamic graph CNN methods
  - applications in heavy flavour jet tagging, jet mass regression, etc.
- LHCb
  - uses DeepMind's Graph Nets library; builds GNN on top of Tensorflow & Sonnet

Future Plan

- Finishing implementation & integration of Graph Neural Network support in SOFIE

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- Integrating support for inference of BDT models in TMVA
    - Parser & Inference engine already built; requires a translation bridge.
- Implementing support for new operators in TMVA SOFIE

Conclusion

- Link to Forked Repository
  github.com/sanjibansg/root
- Link to SOFIE in current ROOT master
  github.com/root-project/root/tree/master/tmva/sofie
- Link to TMVA/SOFIE tutorials
  root.cern.ch/doc/master/group__tutorial__tmva.html
- Link to SOFIE notebooks
  github.com/lmoneta/tmva-tutorial/tree/master/sofie