Project Report

Project Title: Design Level Trojan Detection For Hardware Security

Project Mentor: Dr Binod Kumar

Group Members: Priyansh (B19CSE067), Praneet Thakur (B19CSE066)

Introduction:
Globalization of hardware design and fabrication processes have raised serious concerns about hardware-based attacks. Hardware has been always assumed to be the guarantee of trustworthiness in cryptographic algorithms and security protocols. However, several backdoors have been reported in the last years, especially in military contexts.

Hardware Trojans (HTs) are malicious changes made to integrated circuits in order to disrupt their functional behaviour. They are made up of two major components: the trigger, which activates the malicious behaviour under certain conditions, and the payload, which performs the malicious tasks.

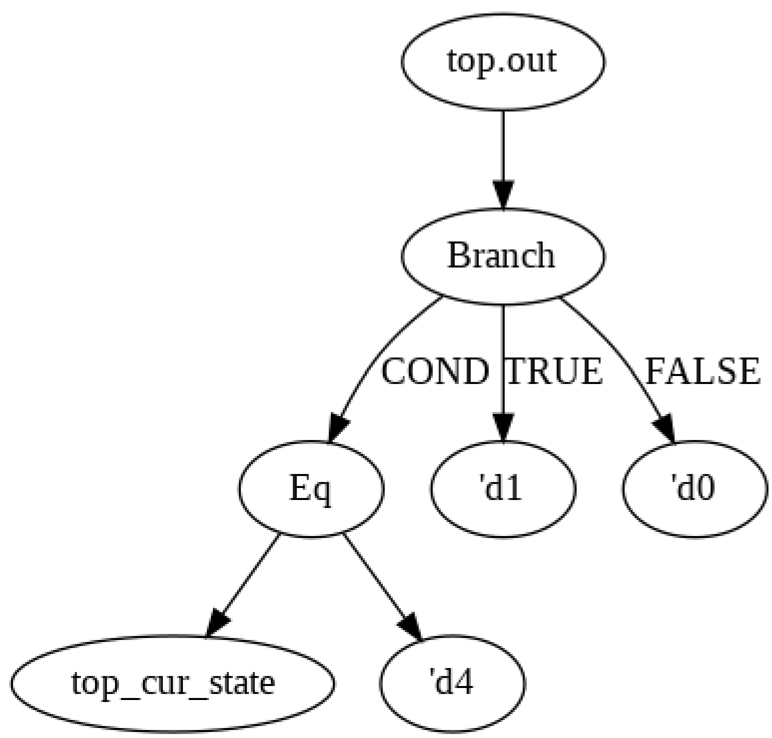
The triggers can include
(i) functional based conditions, e.g., a specific value or a sequence of values, which activates the payload once
it has been observed on a certain register or port,
(ii) physical-based conditions, e.g., reaching a
value of temperature or power,
(iii) time-based conditions, e.g., a certain number of cycles or
operations that must be counted.
Payloads typically exhibit even more diversity, e.g., leakage of
information, data corruptions, performance loss, etc

HTs can be added during every phase of the fabrication process, e.g., design or synthesis, and they are designed to remain silent during the whole verification and testing phase, thus causing the failure of the standard verification approaches. HTs are more and more inserted at RTL because, at this level of abstraction, attackers have high flexibility to implement any malicious function. In this project we have focused on detection of HTs inserted in the RTL phase.

Introduction:

Model the circuit using graph neural networks(GNN) to detect hardware Trojan.
Verilog Code⇒ Data Flow Graph(DFG) and Abstract Systax Tree(AST) => GNN =>Hardware Trojan detection
DFG example: Code and DFG

```
module top ( input clk,
             input rstn,
             input in,
             output out );

  parameter IDLE    = 0,
            S1      = 1,
            S10     = 2,
            S101    = 3,
            S1011   = 4;

  reg [2:0] cur_state, next_state;

  assign out = cur_state == S1011 ? 1 : 0;

  always @ (posedge clk) begin
    if (!rstn)
        cur_state <= IDLE;
     else
        cur_state <= next_state;
  end

  always @ (cur_state or in) begin
    case (cur_state)
      IDLE : begin
        if (in) next_state = S1;
        else next_state = IDLE;
      end

      S1: begin
        if (in) next_state = IDLE;
        else    next_state = S10;
      end

      S10 : begin
        if (in) next_state = S101;
        else    next_state = IDLE;
      end

      S101 : begin
        if (in) next_state = S1011;
        else    next_state = IDLE;
      end

      S1011: begin
        next_state = IDLE;
      end
    endcase
  end
endmodule
```



Steps:

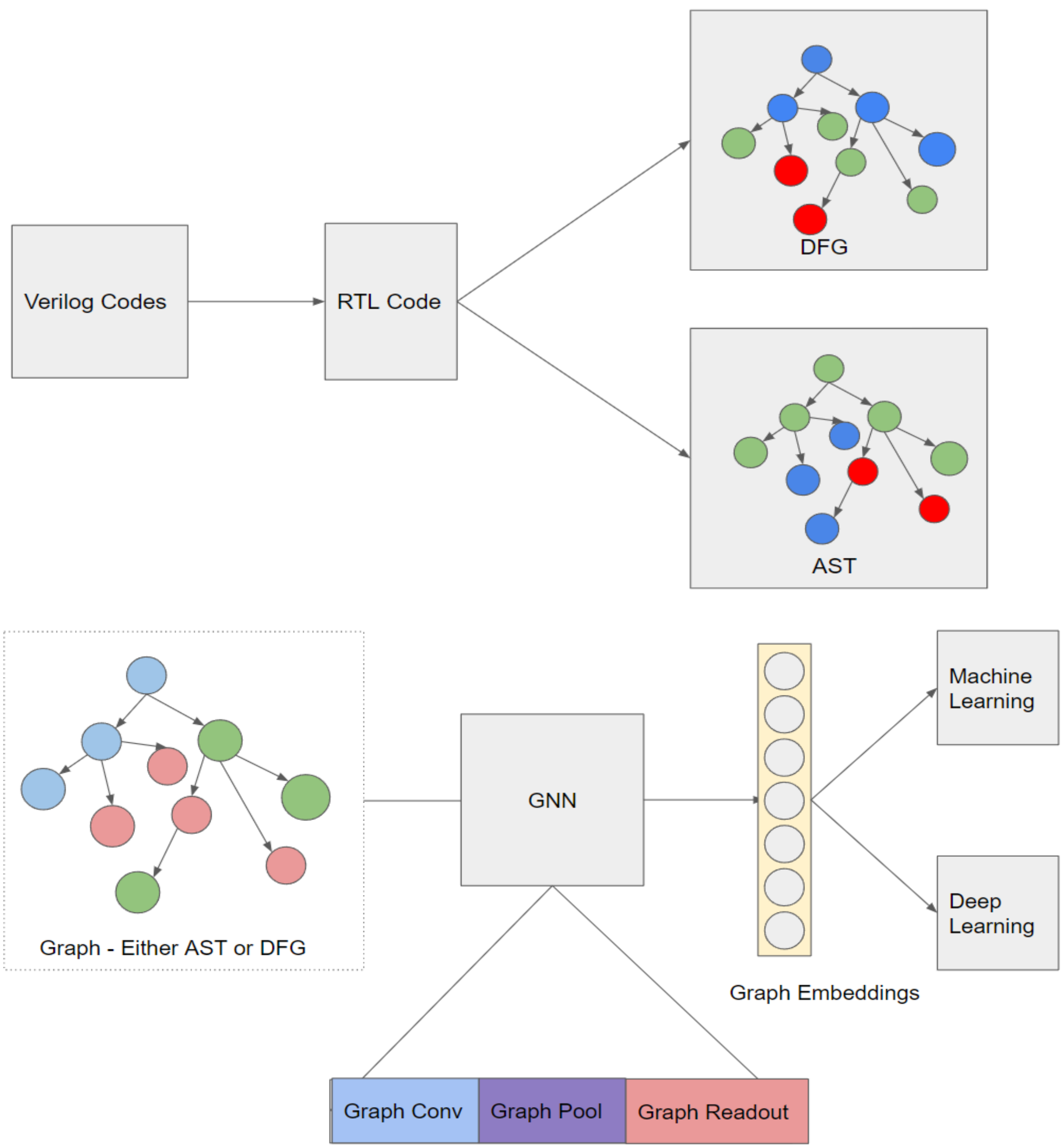
i) Extracting DFG and AST from the hardware designs.

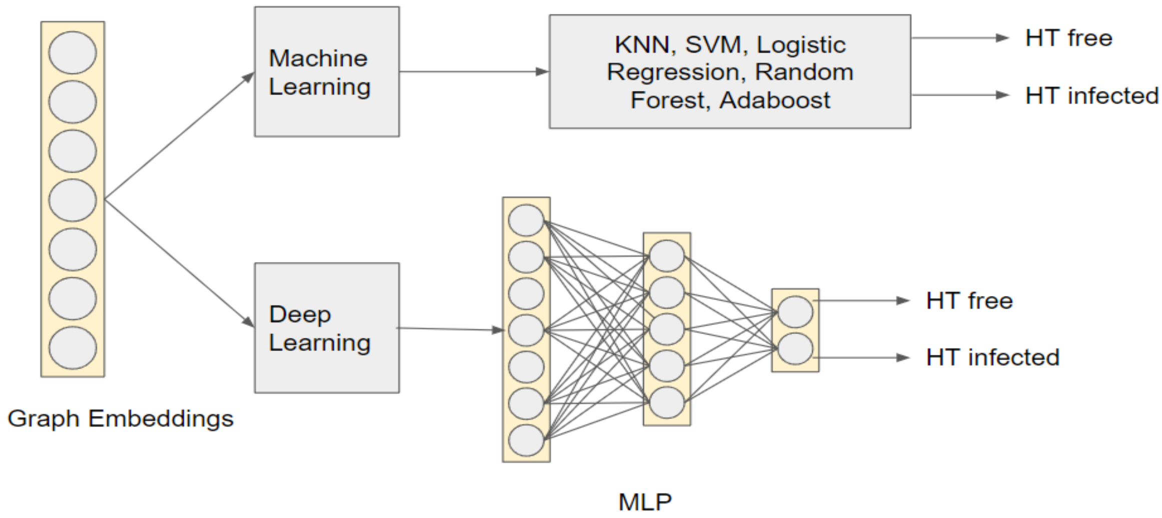
ii) The DFGs and ASTs passed to GNN to generate graph embeddings.

iii) Machine learning models on the generated graph embeddings to detect wheter trojan infected or not.(AST, DFG)

iv) MLP trained on the embeddings to detect whether trojan infected or not.(DFG, AST, AST+DFG)

Workflow Diagram:





Difficulties faced:

We faced a lot of problems in running the code. Tried changing environments multiple times but nothing worked. So, we had to patch some files in pytorch and pytorch-geomertic in order to get embeddings.

The patched portions are:

i)usr/local/lib/torch-geometric/nn/Dense/linear.py

```
    def _lazy_load_hook(self, state_dict, prefix, local_metadata, strict,
                        missing_keys, unexpected_keys, error_msgs):
        temp=state_dict
        d2 = OrderedDict([('layers.0.graph_conv.lin.weight', v) if k == 'layers.0.graph_conv.weight' else (k, v) for k, v in state_dict.items()])
#        print(d2)
        d3 = OrderedDict([('layers.0.graph_conv.lin.bias', v) if k == 'layers.0.graph_conv.bias' else (k, v) for k, v in d2.items()])
#        print(d3)
        d4 = OrderedDict([('layers.1.graph_conv.lin.weight', v) if k == 'layers.1.graph_conv.weight' else (k, v) for k, v in d3.items()])
        #print(d4)
        d5 = OrderedDict([('layers.1.graph_conv.lin.bias', v) if k == 'layers.1.graph_conv.bias' else (k, v) for k, v in d4.items()])
#        print(d5)
        d6 = OrderedDict([('pool1.graph_pool.gnn.lin_rel.weight', v) if k == 'pool1.graph_pool.gnn.lin_l.weight' else (k, v) for k, v in d5.items()]
#        print(d6)
        d7 = OrderedDict([('pool1.graph_pool.gnn.lin_rel.bias', v) if k == 'pool1.graph_pool.gnn.lin_l.bias' else (k, v) for k, v in d6.items()])
        #print(d7)
        d8 = OrderedDict([('pool1.graph_pool.gnn.lin_root.weight', v) if k == 'pool1.graph_pool.gnn.lin_r.weight' else (k, v) for k, v in d7.items()
#        print(d8)
        state_dict=d8
```

ii)usr/local/lib/torch/nn/Module/module.py

```python
def load_state_dict(self, state_dict: 'OrderedDict[str, Tensor]',
                    strict: bool = True):
    r"""Copies parameters and buffers from :attr:`state_dict` into
    this module and its descendants. If :attr:`strict` is ``True``, then
    the keys of :attr:`state_dict` must exactly match the keys returned
    by this module's :meth:`~torch.nn.Module.state_dict` function.

    Args:
        state_dict (dict): a dict containing parameters and
            persistent buffers.
        strict (bool, optional): whether to strictly enforce that the keys
            in :attr:`state_dict` match the keys returned by this module's
            :meth:`~torch.nn.Module.state_dict` function. Default: ``True``

    Returns:
        ``NamedTuple`` with ``missing_keys`` and ``unexpected_keys`` fields:
            * **missing_keys** is a list of str containing the missing keys
            * **unexpected_keys** is a list of str containing the unexpected keys

    Note:
        If a parameter or buffer is registered as ``None`` and its corresponding key
        exists in :attr:`state_dict`, :meth:`load_state_dict` will raise a
        ``RuntimeError``.
    """
    missing_keys: List[str] = []
    unexpected_keys: List[str] = []
    error_msgs: List[str] = []

    # copy state_dict so _load_from_state_dict can modify it
    metadata = getattr(state_dict, '_metadata', None)
    state_dict = state_dict.copy()
    temp=state_dict
    d2 = OrderedDict([('layers.0.graph_conv.lin.weight', v) if k == 'layers.0.graph_conv.weight' else (k, v) for k, v in state_dict.items()])
     print(d2)
#    d3 = OrderedDict([('layers.0.graph_conv.lin.bias', v) if k == 'layers.0.graph_conv.bias' else (k, v) for k, v in d2.items()])
     print(d3)
    d4 = OrderedDict([('layers.1.graph_conv.lin.weight', v) if k == 'layers.1.graph_conv.weight' else (k, v) for k, v in d2.items()])
 #   print(d4)
#    d5 = OrderedDict([('layers.1.graph_conv.lin.bias', v) if k == 'layers.1.graph_conv.bias' else (k, v) for k, v in d4.items()])
#    print(d5)
    d6 = OrderedDict([('pool1.graph_pool.gnn.lin_rel.weight', v) if k == 'pool1.graph_pool.gnn.lin_l.weight' else (k, v) for k, v in d4.items()])
#    print(d6)
    d7 = OrderedDict([('pool1.graph_pool.gnn.lin_rel.bias', v) if k == 'pool1.graph_pool.gnn.lin_l.bias' else (k, v) for k, v in d6.items()])
    #print(d7)
    d8 = OrderedDict([('pool1.graph_pool.gnn.lin_root.weight', v) if k == 'pool1.graph_pool.gnn.lin_r.weight' else (k, v) for k, v in d7.items()])
 #   print(d8)
    state_dict=d8
```

```python
def _load_from_state_dict(self, state_dict, prefix, local_metadata, strict,
                          missing_keys, unexpected_keys, error_msgs):
    r"""Copies parameters and buffers from :attr:`state_dict` into only
    this module, but not its descendants. This is called on every submodule
    in :meth:`~torch.nn.Module.load_state_dict`. Metadata saved for this
    module in input :attr:`state_dict` is provided as :attr:`local_metadata`.
    For state dicts without metadata, :attr:`local_metadata` is empty.
    Subclasses can achieve class-specific backward compatible loading using
    the version number at `local_metadata.get("version", None)`.

    .. note::
        :attr:`state_dict` is not the same object as the input
        :attr:`state_dict` to :meth:`~torch.nn.Module.load_state_dict`. So
        it can be modified.

    Args:
        state_dict (dict): a dict containing parameters and
            persistent buffers.
        prefix (str): the prefix for parameters and buffers used in this
            module
        local_metadata (dict): a dict containing the metadata for this module.
            See
        strict (bool): whether to strictly enforce that the keys in
            :attr:`state_dict` with :attr:`prefix` match the names of
            parameters and buffers in this module
        missing_keys (list of str): if ``strict=True``, add missing keys to
            this list
        unexpected_keys (list of str): if ``strict=True``, add unexpected
            keys to this list
        error_msgs (list of str): error messages should be added to this
            list, and will be reported together in
            :meth:`~torch.nn.Module.load_state_dict`
    """


    for hook in self._load_state_dict_pre_hooks.values():
        hook(state_dict, prefix, local_metadata, strict, missing_keys, unexpected_keys, error_msgs)

    persistent_buffers = {k: v for k, v in self._buffers.items() if k not in self._non_persistent_buffers_set}
    local_name_params = itertools.chain(self._parameters.items(), persistent_buffers.items())
    local_state = {k: v for k, v in local_name_params if v is not None}

    for name, param in local_state.items():
        key = prefix + name
        if key in state_dict:
            input_param = state_dict[key]
            print(key)
            print(input_param.shape)
            if(not key=="pool1.graph_pool.gnn.lin_rel.weight" and not key=="pool1.graph_pool.gnn.lin_root.weight" and not key=="fc.weight" and len(input_param.shape)>1):
              print("Entered")
              input_param=torch.t(input_param)
            print(input_param.shape)
            if not torch.overrides.is_tensor_like(input_param):
                error_msgs.append('While copying the parameter named "{}", '
                                  'expected torch.Tensor or Tensor-like object from checkpoint but '
```

Example Embedding:

Hardware: det_1011

```
module top ( input clk,
             input rstn,
             input in,
             output out );

  parameter IDLE    = 0,
            S1      = 1,
            S10     = 2,
            S101    = 3,
            S1011   = 4;

  reg [2:0] cur_state, next_state;

  assign out = cur_state == S1011 ? 1 : 0;

  always @ (posedge clk) begin
    if (!rstn)
        cur_state <= IDLE;
     else
        cur_state <= next_state;
  end

  always @ (cur_state or in) begin
    case (cur_state)
      IDLE : begin
        if (in) next_state = S1;
        else next_state = IDLE;
      end

      S1: begin
        if (in) next_state = IDLE;
        else    next_state = S10;
      end

      S10 : begin
        if (in) next_state = S101;
        else    next_state = IDLE;
      end

      S101 : begin
        if (in) next_state = S1011;
        else    next_state = IDLE;
      end

      S1011: begin
        next_state = IDLE;
      end
    endcase
  end
endmodule
```

```
tensor([[1.3948e-02, 1.2979e-01, 0.0000e+00, 2.4929e-02, 2.9985e-03, 4.1728e-02,
         2.9751e-02, 1.6098e-01, 4.9910e-02, 6.4285e-02, 1.8172e-02, 1.2490e-01,
         6.1642e-02, 2.5481e-01, 1.3095e-02, 2.7890e-01, 9.4345e-03, 1.9104e-02,
         5.7868e-02, 2.9018e-02, 1.4692e-01, 6.6350e-03, 8.3674e-02, 1.2552e-01,
         1.3926e-01, 0.0000e+00, 6.1905e-02, 1.8589e-01, 1.0695e-02, 8.7878e-02,
         4.8211e-03, 9.0990e-02, 9.4179e-02, 0.0000e+00, 0.0000e+00, 8.1620e-02,
         7.3958e-02, 1.3948e-01, 1.0907e-02, 0.0000e+00, 6.5199e-02, 2.9032e-02,
         5.6405e-03, 5.4433e-02, 4.7946e-02, 9.2855e-02, 3.8569e-02, 2.6426e-02,
         2.4809e-02, 2.2096e-02, 5.5625e-02, 3.2019e-02, 3.3750e-02, 0.0000e+00,
         1.2897e-03, 4.8722e-02, 4.0722e-02, 0.0000e+00, 2.9506e-02, 0.0000e+00,
         1.1650e-02, 6.8441e-02, 1.2338e-01, 4.6509e-03, 4.5510e-02, 7.8622e-02,
         2.4183e-02, 0.0000e+00, 9.9947e-03, 6.6222e-02, 4.9974e-02, 8.7760e-02,
         1.0573e-02, 0.0000e+00, 0.0000e+00, 0.0000e+00, 9.1501e-02, 4.3337e-02,
         9.6938e-02, 0.0000e+00, 0.0000e+00, 0.0000e+00, 4.2152e-02, 5.8777e-03,
         1.3552e-02, 1.5872e-01, 0.0000e+00, 0.0000e+00, 1.9055e-01, 0.0000e+00,
         5.6886e-02, 7.3342e-02, 0.0000e+00, 1.3330e-01, 5.8647e-02, 5.6083e-02,
         3.5284e-02, 0.0000e+00, 0.0000e+00, 0.0000e+00, 1.1944e-02, 0.0000e+00,
         1.7427e-02, 3.8086e-03, 7.6280e-02, 3.7846e-03, 3.4469e-02, 3.9759e-02,
         0.0000e+00, 2.9256e-02, 0.0000e+00, 0.0000e+00, 0.0000e+00, 1.4103e-02,
         6.1886e-02, 1.0444e-01, 7.8638e-02, 4.4072e-02, 2.1238e-01, 2.9323e-02,
         4.9623e-03, 7.0244e-03, 5.0709e-02, 0.0000e+00, 0.0000e+00, 7.9893e-02,
         1.0898e-01, 2.0652e-02, 2.0869e-01, 8.5429e-02, 5.8493e-02, 0.0000e+00,
         6.4630e-02, 6.4834e-02, 2.2735e-01, 1.1476e-01, 7.4748e-03, 9.0293e-03,
         0.0000e+00, 1.3093e-02, 8.2761e-02, 2.9584e-02, 5.2660e-02, 2.2517e-02,
         1.4587e-01, 2.5117e-04, 1.2272e-01, 0.0000e+00, 3.8560e-02, 7.5219e-02,
         3.4223e-02, 9.7445e-02, 3.3781e-02, 1.3148e-01, 0.0000e+00, 2.4623e-01,
         3.8362e-02, 4.0974e-02, 4.8491e-02, 1.6494e-02, 4.6291e-02, 3.5212e-02,
         1.5864e-02, 3.2648e-02, 2.3950e-02, 1.0302e-01, 3.4302e-01, 0.0000e+00,
         2.5280e-02, 1.1299e-01, 0.0000e+00, 1.2514e-01, 3.2592e-02, 1.3427e-01,
         6.6011e-02, 4.2720e-02, 1.0140e-02, 1.5393e-02, 1.0258e-01, 3.8331e-02,
         4.3766e-02, 1.7193e-01, 1.4044e-01, 0.0000e+00, 0.0000e+00, 3.2624e-02,
         1.6002e-02, 2.2024e-04, 1.5550e-01, 1.0395e-01, 2.7653e-02, 0.0000e+00,
         0.0000e+00, 1.5260e-01, 0.0000e+00, 6.2729e-05, 1.1490e-01, 0.0000e+00,
         6.8117e-02, 6.2184e-02]], grad_fn=<CppNode<ScatterMax>>)
```

Results:

KNN

Graph Type	Accuracy
AST	0.70
DFG	0.82

SVM

Graph Type	Accuracy
AST	0.74
DFG	0.86

Random Forest

Graph Type	Accuracy
AST	0.74
DFG	0.90

Adaboost

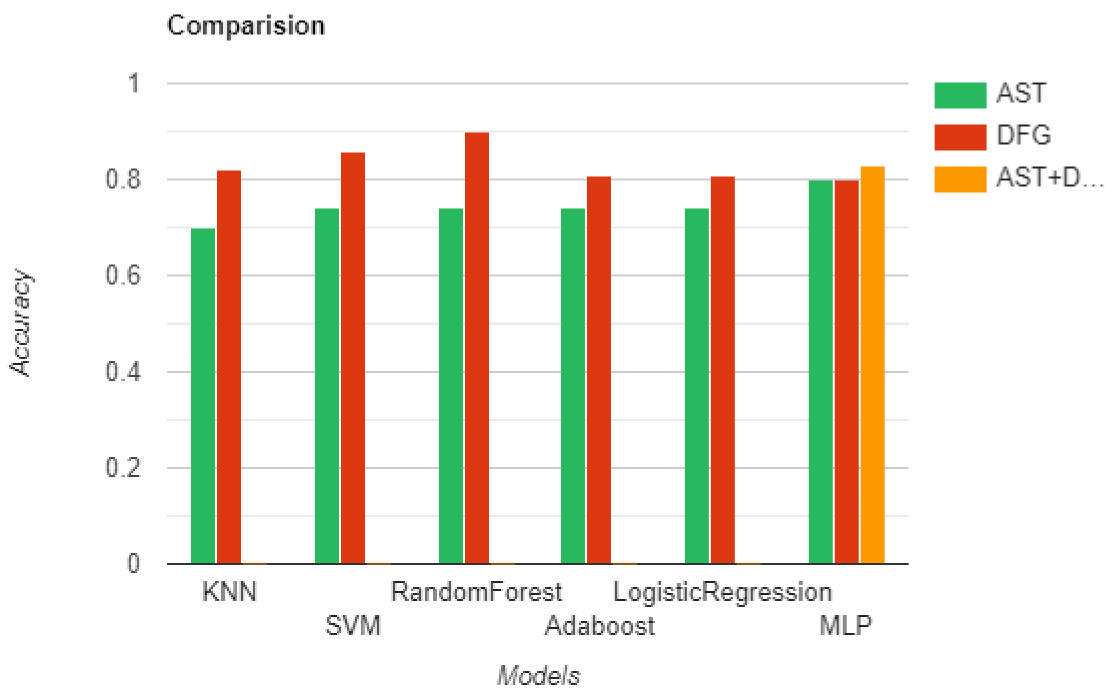
Graph Type	Accuracy
AST	0.74
DFG	0.81

Logistic Regression

Graph Type	Accuracy
AST	0.74
DFG	0.81

MLP

Graph Type	Accuracy
AST	0.80
DFG	0.80
AST+DFG	0.83



Conclusion:
Through this project we have put forward an approach that can be used for the detection of HTs using DFG, GNN and ML/DL models.

Future Works:
One should use the same approach after increasing the dataset size as the dataset we used was very small. We can aslo play around with GNN structure to get a more efficient model. One can use ensemble learning and one can use few shot learning using siamese network. One should also consider using CFG for the task.

Refferences:
https://pypi.org/project/pyverilog/
https://github.com/AICPS/hw2vec