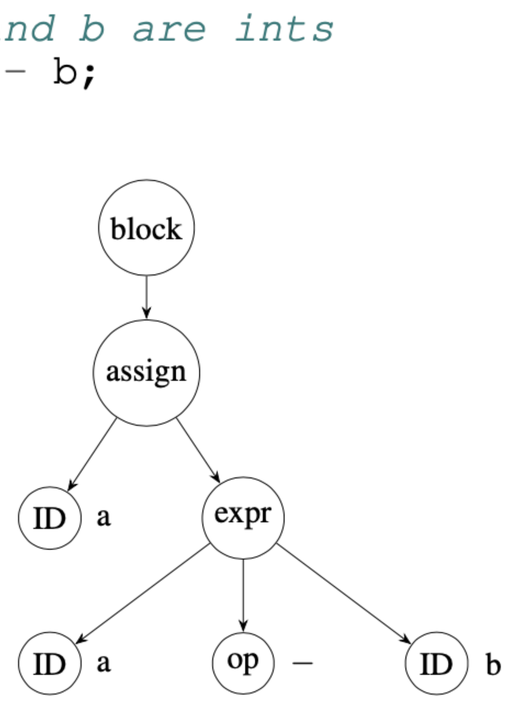
Graph Neural Networks For Mapping Variables Between Programs

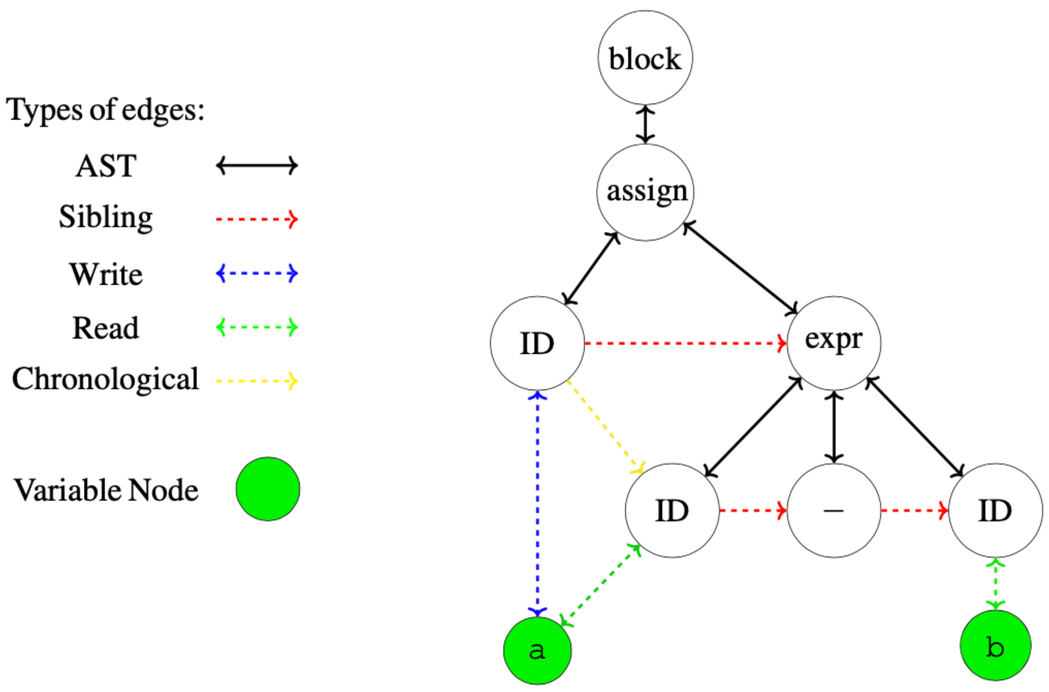
Pedro Orvalho [1], Jelle Piepenbrock [2,3], Mikoláš Janota [3], and Vasco Manquinho [1]

[1] INESC-ID, IST, Universidade de Lisboa, Portugal [2] Radboud University Nijmegen, The Netherlands

[3] Czech Technical University in Prague, Czechia

```
1  { // a and b are ints
2    a = a - b;
3  }
```





1. Motivation

- Comparing two programs is highly challenging;
- A relation between two programs' sets of variables is required;
- Mapping variables between both programs is useful for *program equivalence*, *program repair, etc.*

Listing 1: A semantically correct student's implementation.

```
1  int main(){
2      int n, i;
3      scanf("%d", &n);
4      for(i = 1; i <= n; i++){
5          printf("%d\n", i);
6      }
7      return 0;
8  }
```

Listing 2: A semantically incorrect student's implementation since the variable `j` in the `main` function is not initialized.

```
1  void loop(int j, int l){
2    while (l >= j){
3      printf("%d\n", j);
4      ++j;
5    }
6  }
7  int main(){
8    int j, l;
9    scanf("%d", &l);
10   loop(j, l);
11   return 0;
12 }
```

Figure 1: Two implementations for the IPA of printing all the natural numbers from 1 to a given number n. The program in Listing 2 is semantically incorrect since the variable `j`, which is the variable being used to iterate over all the natural numbers until the number `l`, is not being initialized, i.e., the program has a bug of *missing expression*. The mapping between these programs' sets of variables is {`n : l`; `i : j`}.

2. Contributions

- A program representation that is agnostic to the names of the variables;
- We use GNNs for mapping variables between programs;

3. Program Representation

- We represent programs as *directed graphs* so the information can propagate in both directions in the GNN [1].
- These graphs are based on the programs' *abstract syntax trees* (ASTs).
- *Novelty:* **a unique variable node for each variable in the program** and connect each variable's occurrence to its unique node.
- Prior work on representing programs as graphs [2] **use different nodes for each variable occurrence** and **take into consideration the variable identifier** in the program representation.
- Our GNN is a *relational graph convolutional neural network* (RGCN):

$$\mathbf{x}'_i = \mathbf{\Theta}_{\text{root}} \cdot \mathbf{x}_i + \sum_{r \in \mathcal{R}} \sum_{j \in \mathcal{N}_r(i)} \frac{1}{|\mathcal{N}_r(i)|} \mathbf{\Theta}_r \cdot \mathbf{x}_j,$$

4. Experiments

4.1 Dataset

- We used C-Pack-IPAs [3], a set of students' programs from two academic year, to evaluate our work.
- As training data, **we generated a dataset of pairs of correct/incorrect programs** using MultIPAs [4].
- Incorrect program have one of these types of bugs: *wrong comparison operator* (WCO), *variable misuse* (VM), and *missing expression* (ME).
- *First year* submissions are **divided into a training and validation set**.
- The *second year* was used for the **evaluation set**, consists only of new submissions, simulating a new academic year.

4.2 Training and Evaluation

- *Evaluation metrics:* totally correct mappings and the overlap coefficient

Evaluation Metric	Buggy Programs			
	WCO Bug	VM Bug	ME Bug	All Bugs
# Correct Mappings	87.38%	81.87%	79.95%	82.77%
Avg Overlap Coefficient	96.99%	94.28%	94.51%	95.05%
# Programs	1078	1936	1152	4166

4.3 Program Repair

- We tried to fix each pair of incorrect/correct programs in the evaluation dataset by passing each pair to every repair method: Verifix [5], Clara [6], and our repair approach based on the GNN's variable mappings.
- The baseline is using variables generated based on a uniform distribution.
- The **GNN correctly maps 83% of the evaluation dataset;**
- We leverage the variable mappings to perform automatic program repair;
- While the current state-of-the-art on program repair can only repair about 72% of the evaluation dataset due to structural mismatch errors, **our approach, based on variable mappings, is able to fix 88.5%.**

Repair Method	Buggy Programs				Not Succeeded	
	WCO Bug	VM Bug	ME Bug	All Bugs	% Failed	% Timeouts (60s)
Baseline	618 (57.33%)	1187 (61.31%)	287 (24.91%)	2092 (50.22%)	0 (0.0%)	**2074 (49.78%)**
VERIFIX	555 (51.48%)	1292 (66.74%)	741 (64.32%)	2588 (62.12%)	**1471 (35.31%)**	107 (2.57%)
CLARA	722 (66.98%)	1517 (78.36%)	764 (66.32%)	3003 (72.08%)	1153 (27.68%)	10 (0.24%)
GNN	**992 (92.02%)**	**1714 (88.53%)**	**981 (85.16%)**	**3687 (88.5%)**	0 (0.0%)	479 (11.5%)

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