Neural Reverse Engineering of Stripped Binaries using Augmented Control Flow Graphs



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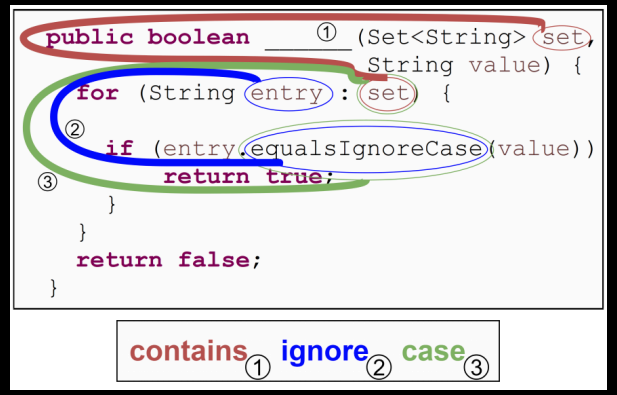
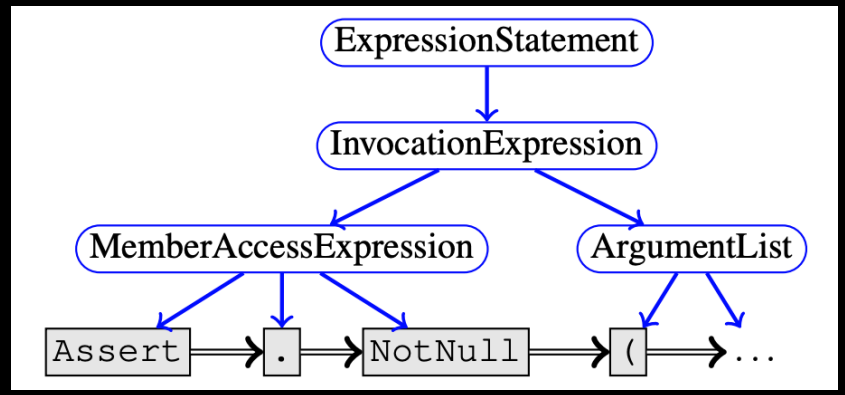
Great Progress Using ML on Source Code



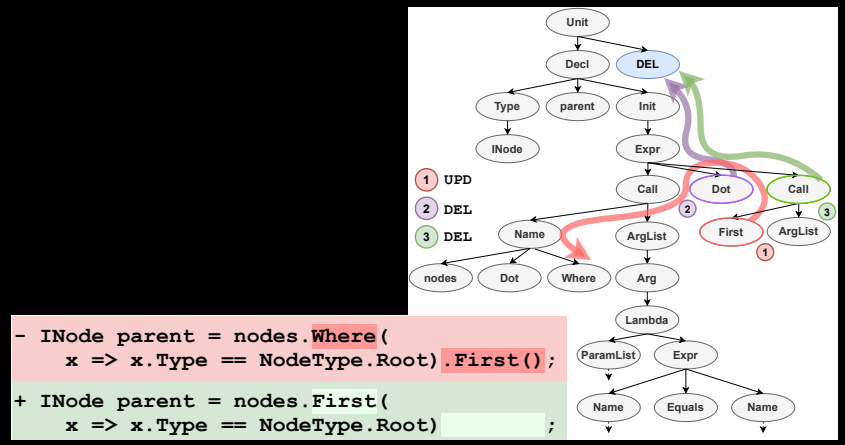
["code2seq", Alon et al., ICLR'2019]



[Program graphs, Allamanis et al., ICLR'2018]

```
void updateView() {
  // ...
  View v = ViewUtil.findView(name);
  if (v == null) {
    return;
  }
  data.send(((UpdatableView) v)
      .getContentMgt(), "UPDATE");
  // ...
}
```

["Getafix", Bader et al., OOPSLA'2019]



[Edit Completion, Brody et al., OOPSLA'2020]

Not a Lot of Progress for Binaries

- Why?

Source code in a high-level language

- Programmers follow common **patterns** (sort, merge, …)
- These patterns employ sequences of the language's **syntactic structures**
- Many **global** anchors: types, class structures, frameworks

```
void f(int[] a) {
    boolean s = true;
    for (int i = 0; i < a.length && s; i++) {
        s = false;
        for (int j = 0; j < a.length - 1 - i; j++) {
            if (a[j] > a[j+1]) {
                int temp = a[j];
                a[j] = a[j+1];
                a[j+1]= temp;
                s = true;
            }
        }
    }
}
```

Rich, structured, expressive & filled with hints

Disassembled Binary Code

```
...
mov rsi, rdi
mov rdx, 16
mov rax, [rbp-58h]
mov rdi, rax
mov edx, eax
mov rax, [rbp-4h]
mov rax, [rbp-58h]
mov rdi, rax
mov r8, 4
mov rdx, 10
mov esi, 0
lea rcx, [rbp-88h]
mov rdi, rax
...
```

- Machine generated, adhering to hardware specifications & limitations
- Few simple control flow instructions:
  - jump & call (+interrupt)
- Optimization causes: entangled computation flows, context dependent

Long unstructured seqeunce of low-level operations

Disassembled Binary Code

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mov rsi, rdi
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- Machine generated, adhering to hardware specifications & limitations
- Optimiz… uses: entangled computat… ows, context dependent

These put a lot of pressure on the model

Long unstructured seqeunce of low-level operations

Key Idea: Use Binary Program Analysis to Create a Compact & Rich Representation

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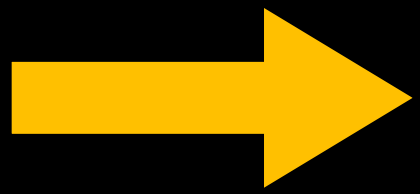
mov rdi, rax
...
```



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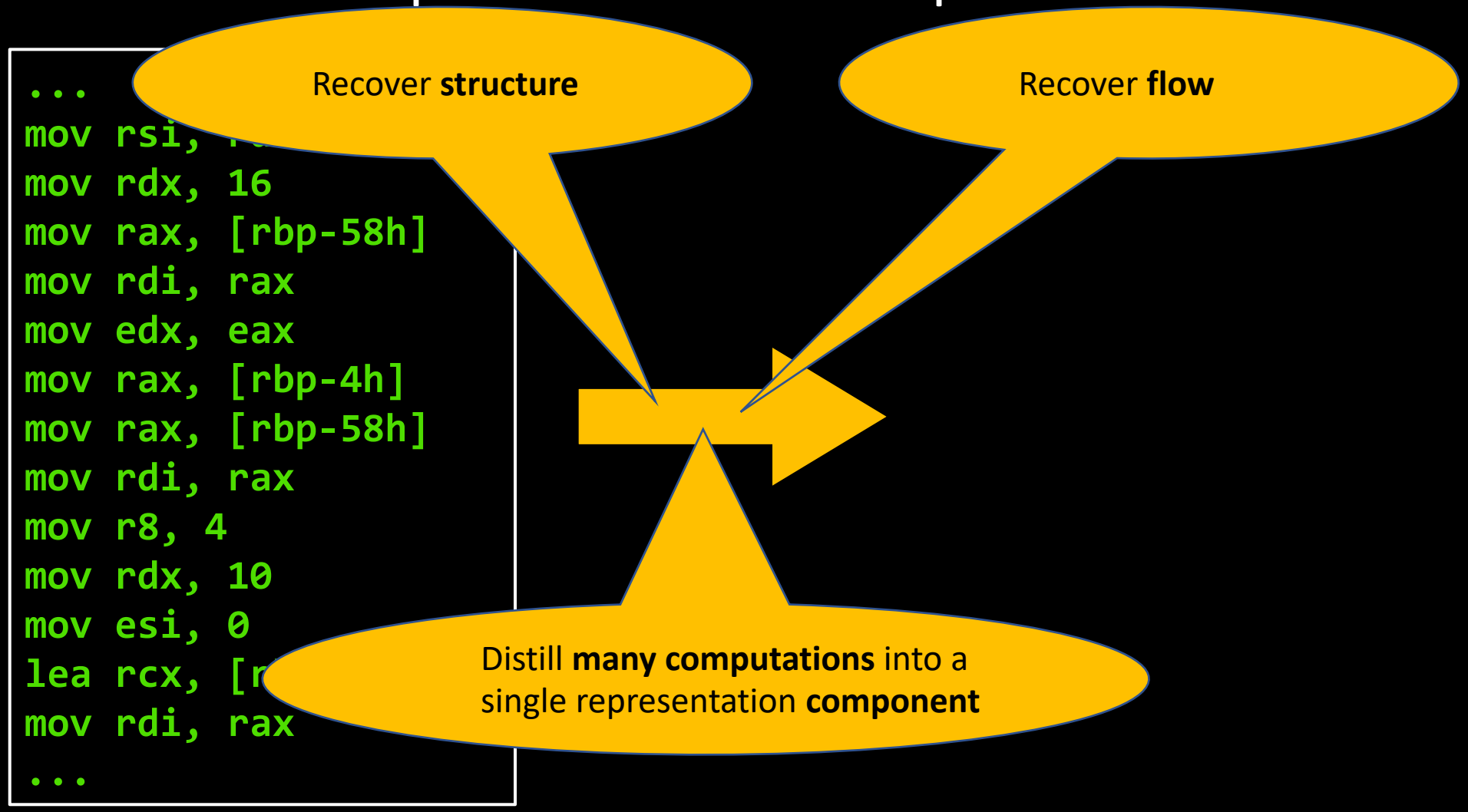

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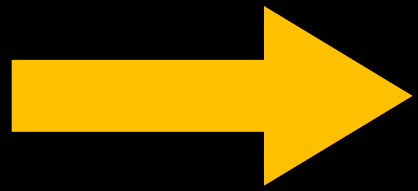

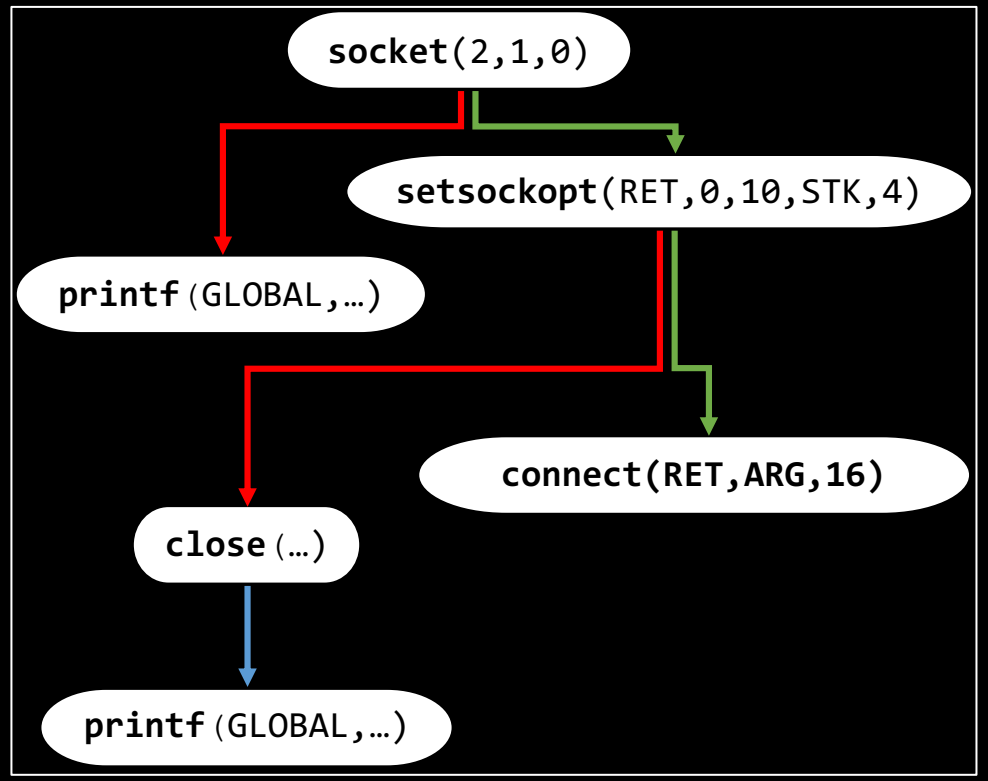

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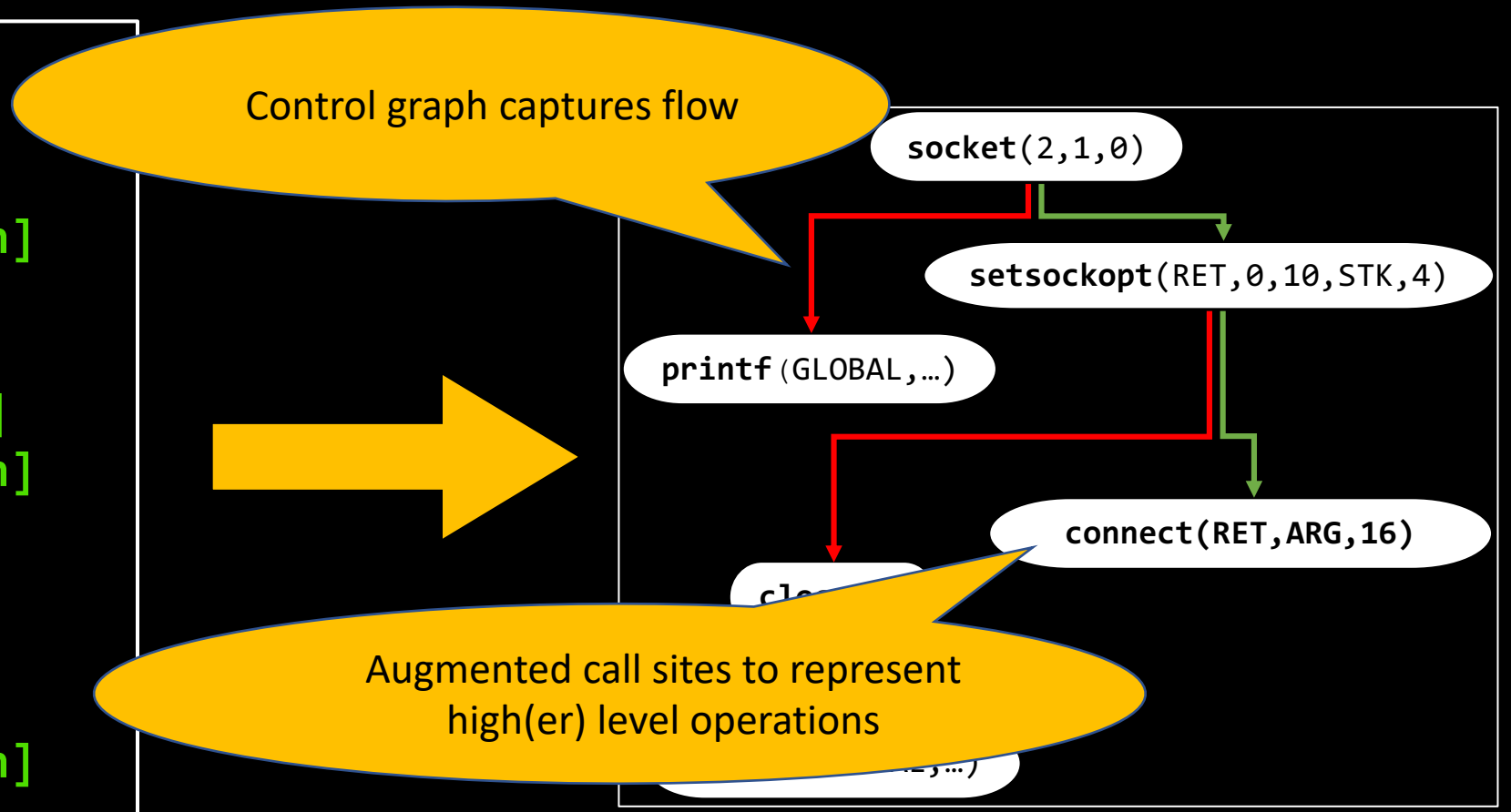


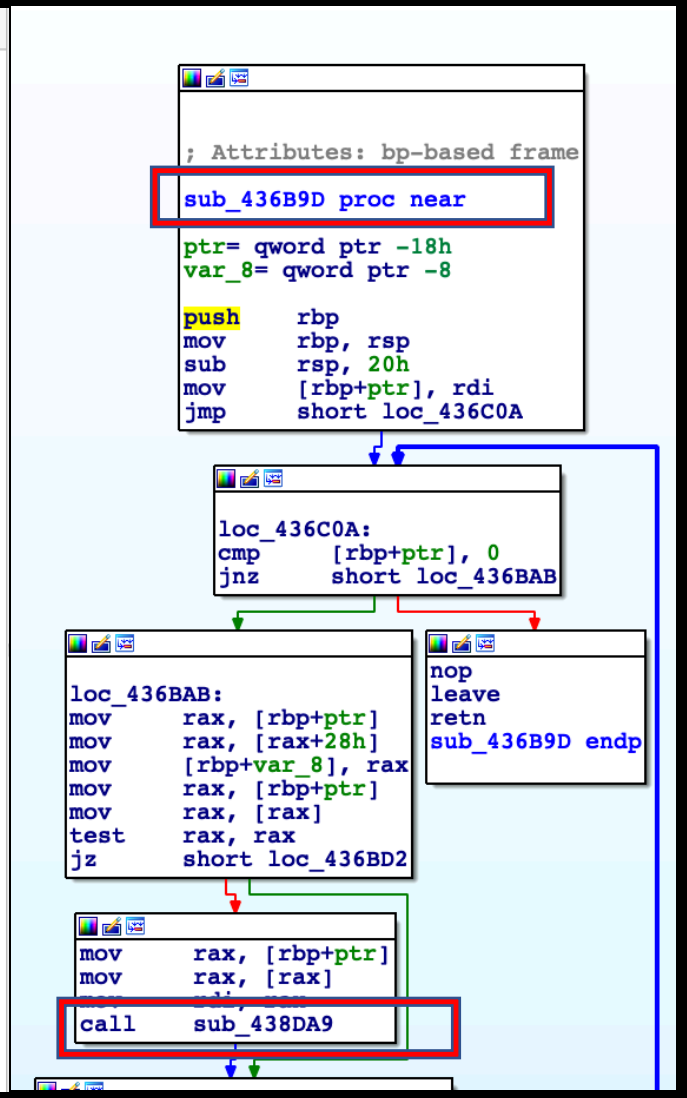
Motivating Task

Naming Procedures in Binaries

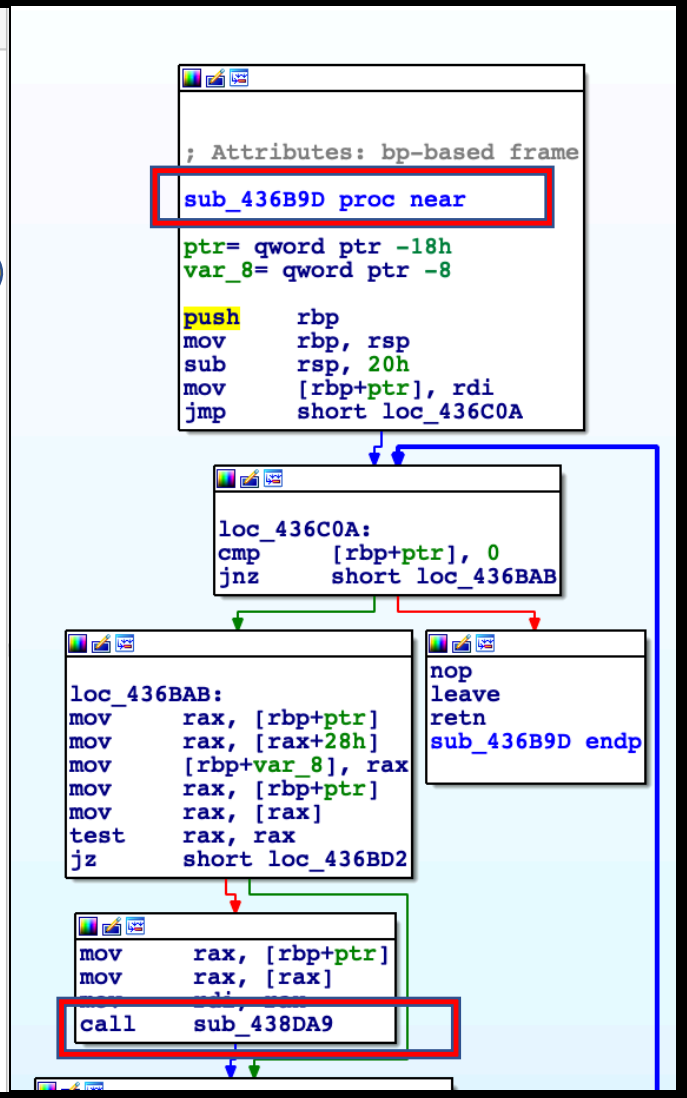
Helping Reverse Engineers

Function name

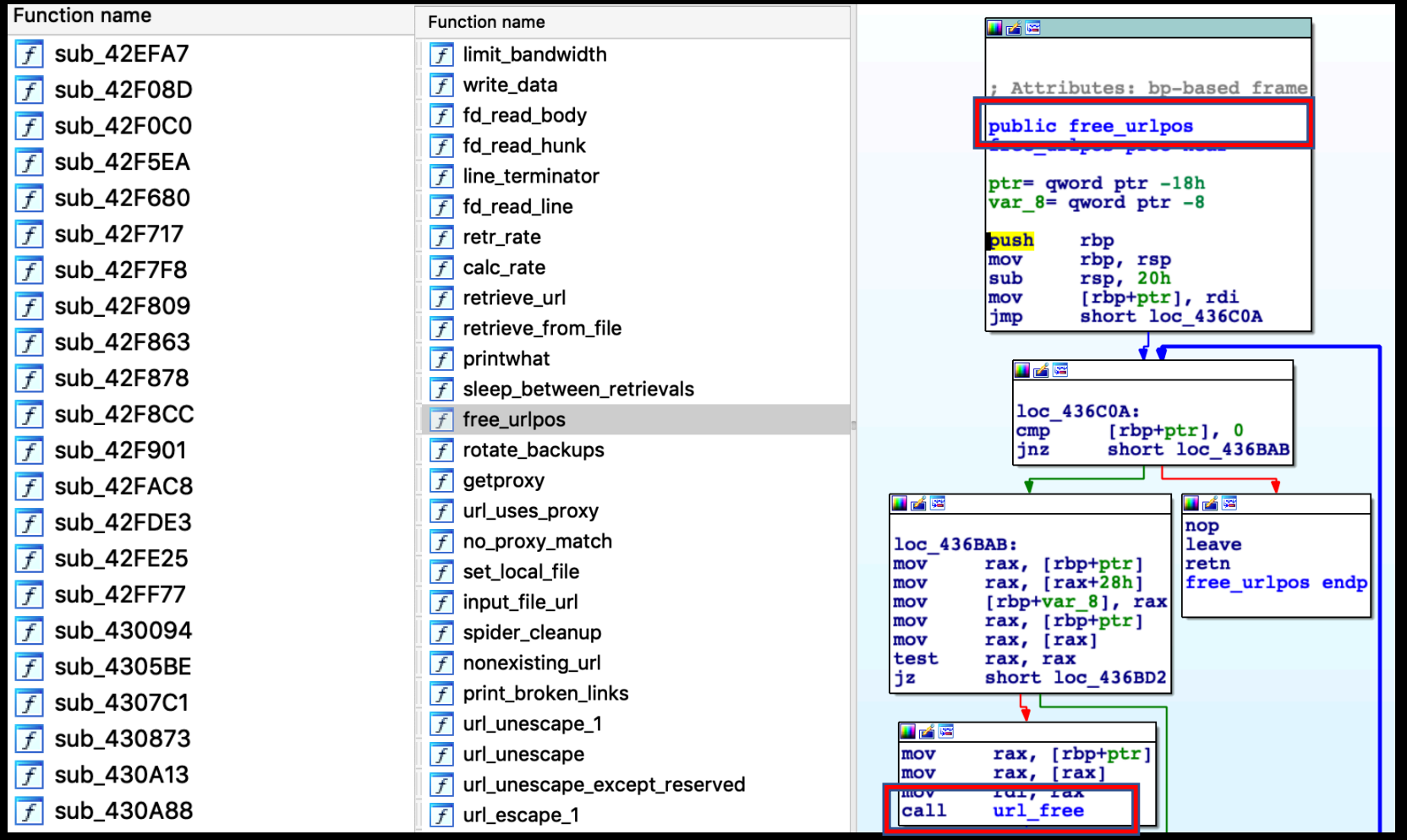
- sub_42EFA7
- sub_42F08D
- sub_42F0C0
- sub_42F5EA
- sub_42F680
- sub_42F717
- sub_42F7F8
- sub_42F809
- sub_42F863
- sub_42F878
- sub_42F8CC
- sub_42F901
- sub_42FAC8
- sub_42FDE3
- sub_42FE25
- sub_42FF77
- sub_430094
- sub_4305BE
- sub_4307C1
- sub_430873
- sub_430A13
- sub_430A88



Helping Reverse Engineers



Un-Stripping Procedure Names



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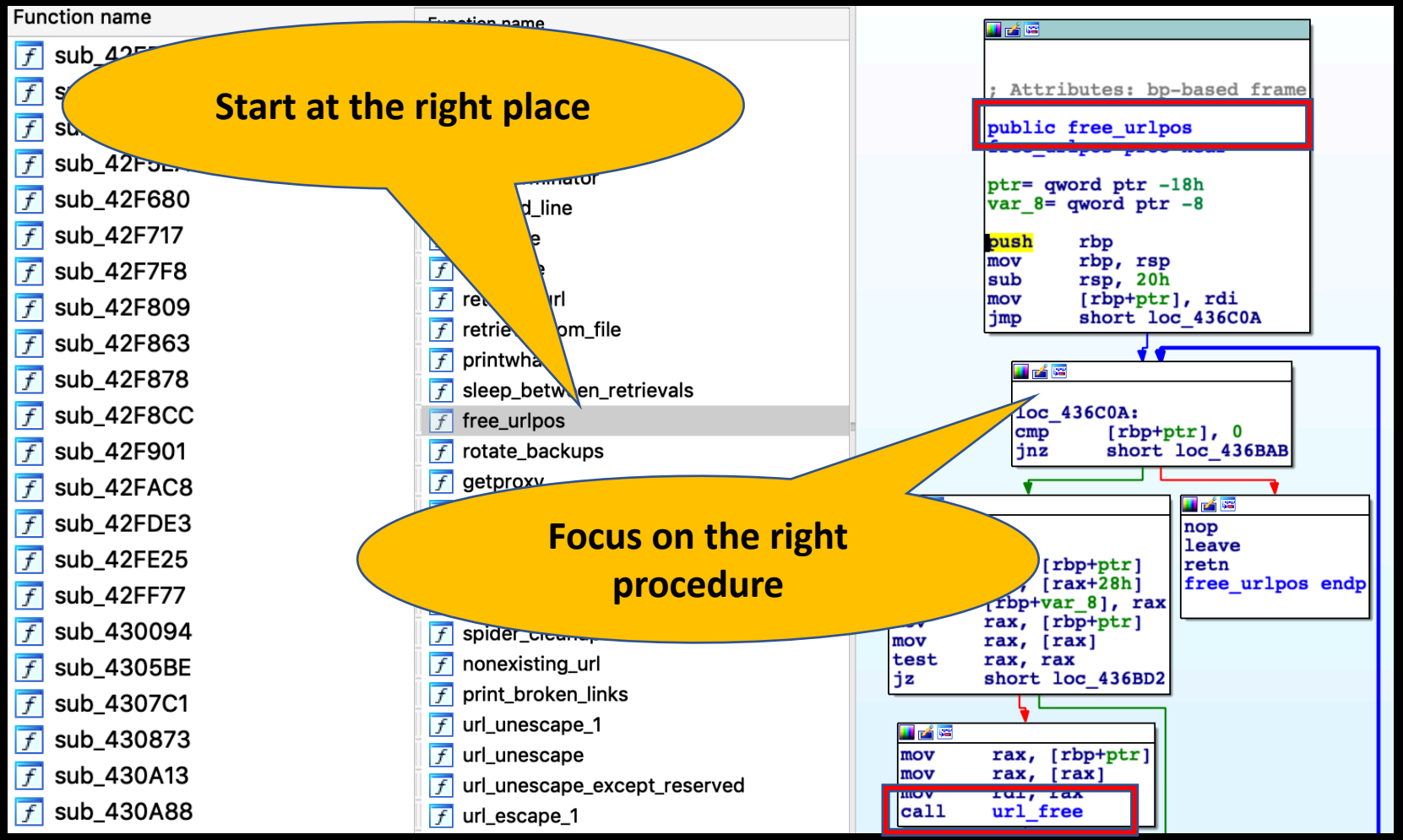
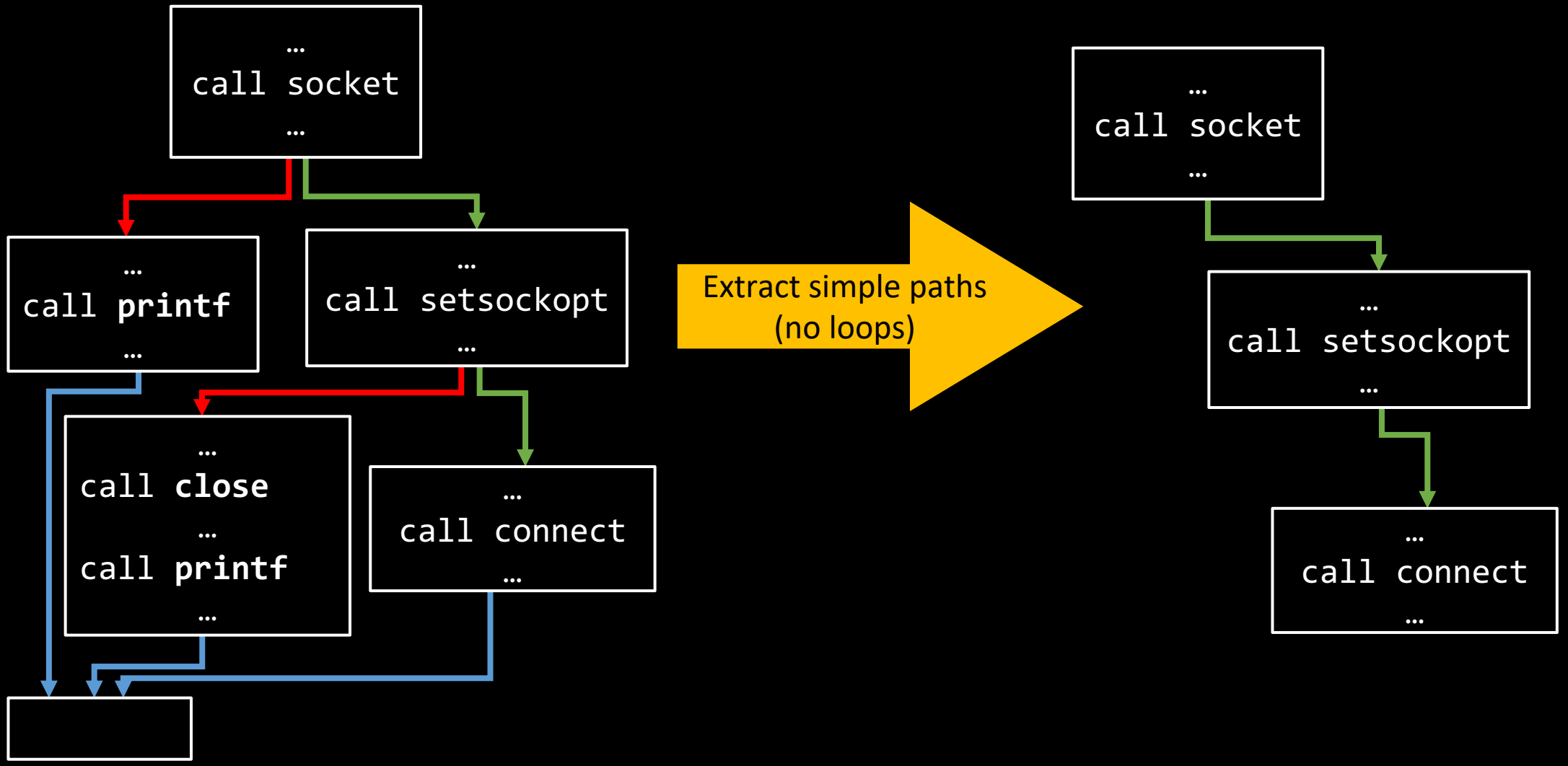
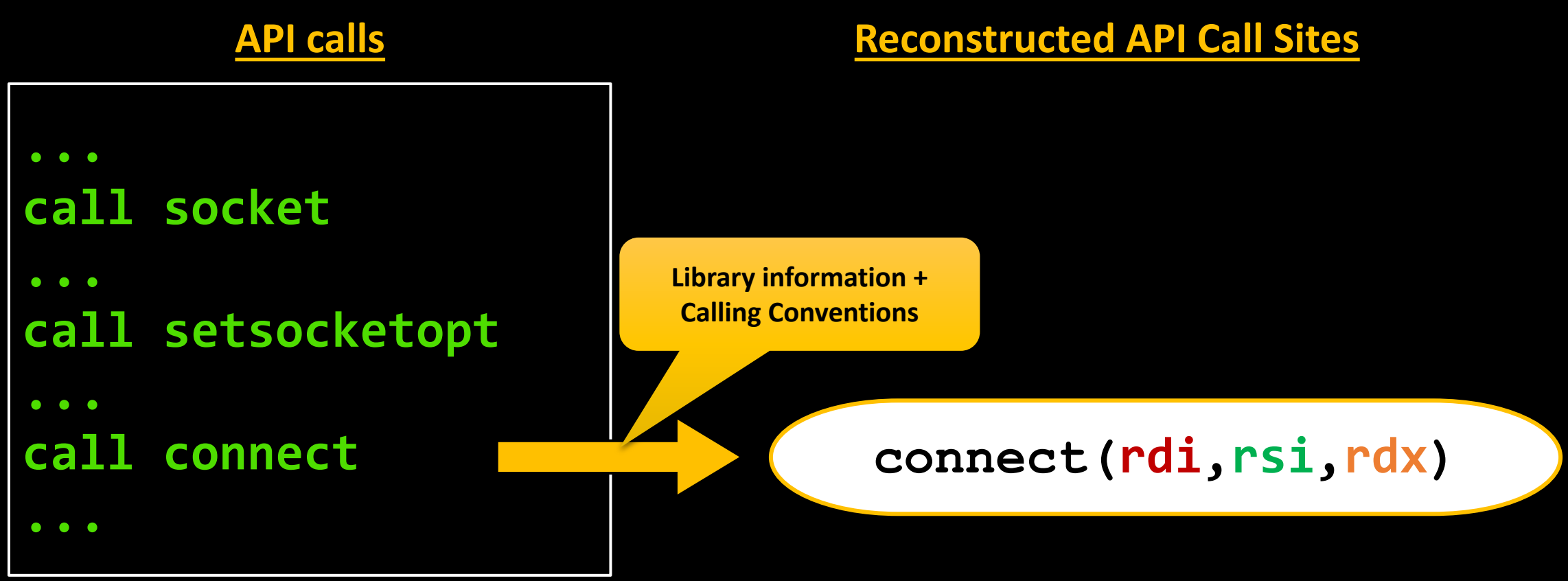


Our Approach

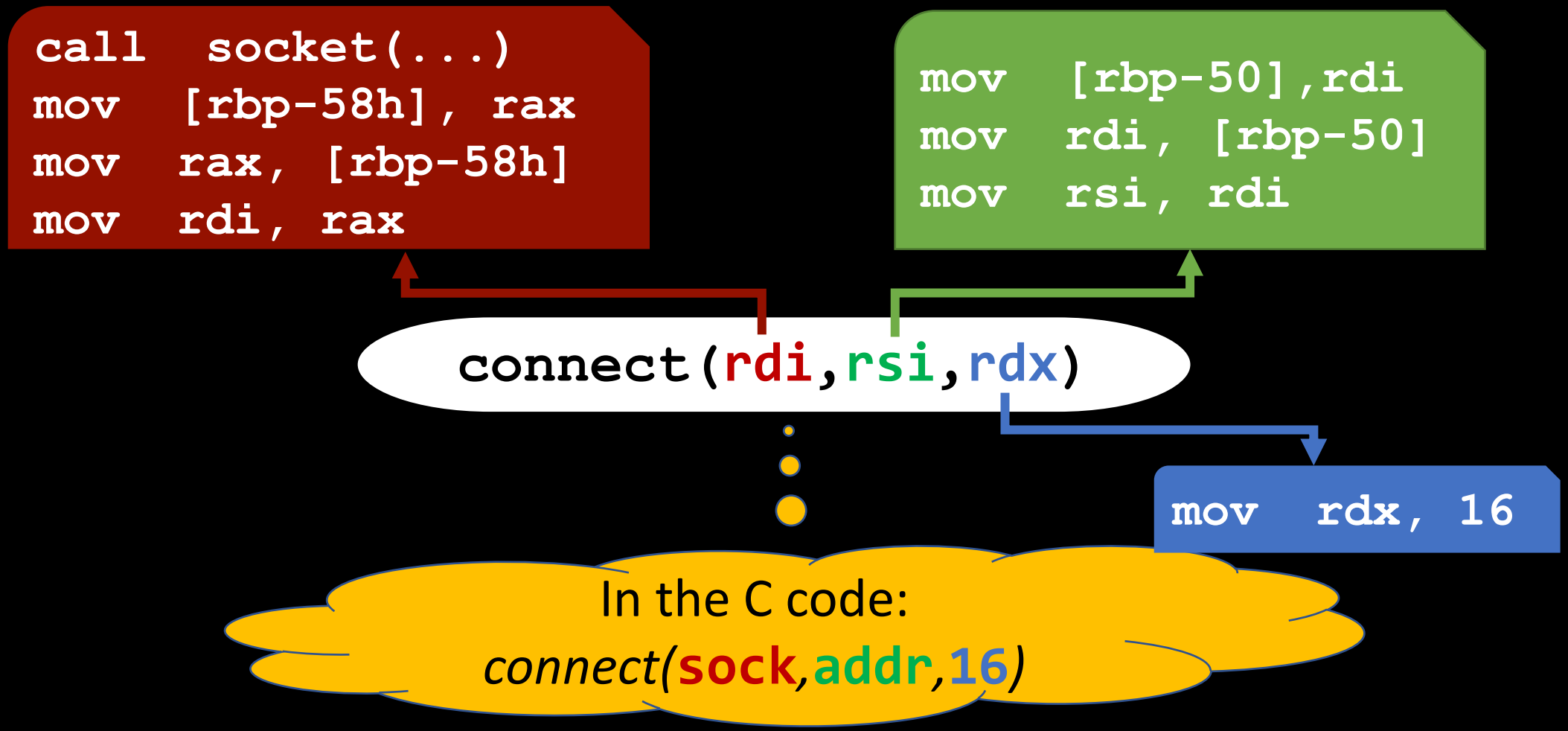
Extract Paths From the CFG



Using API Calls

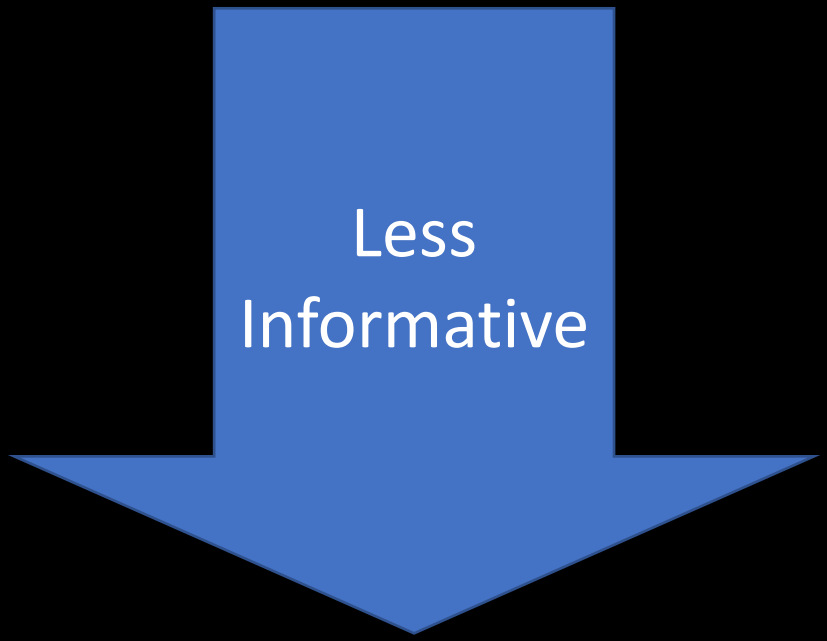


Augmenting Call Sites

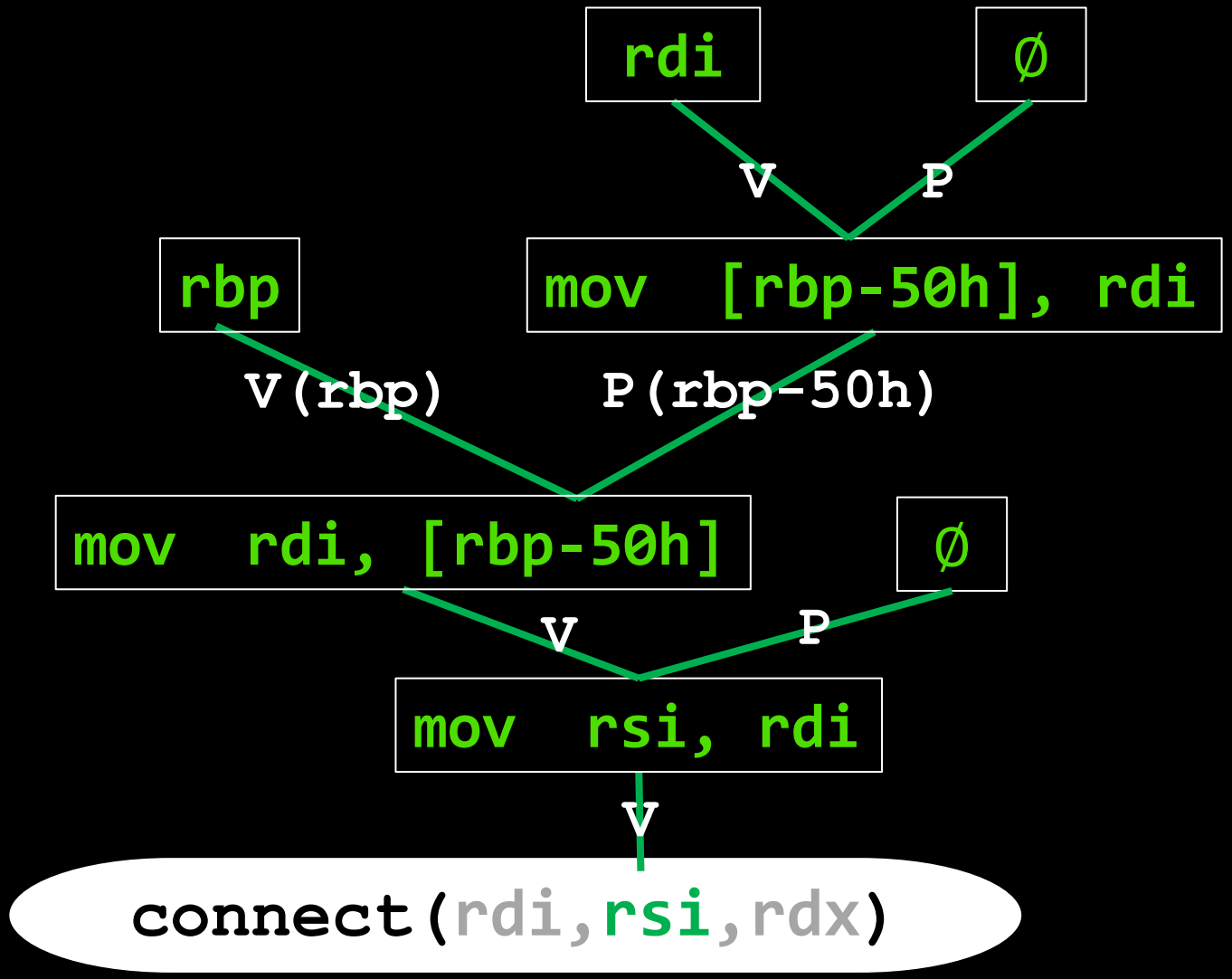


Using Concrete or Abstracted Values

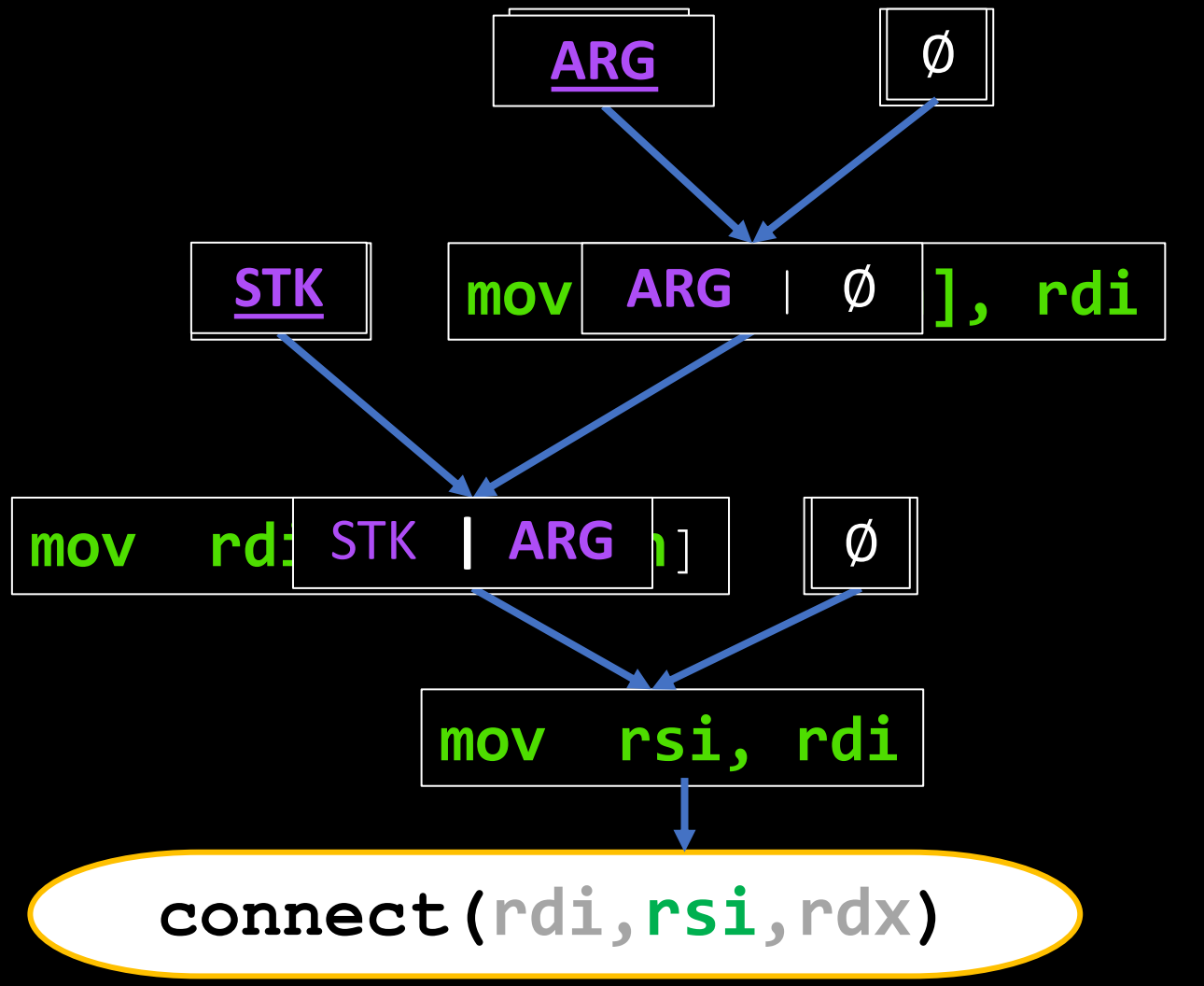
1. Concrete value (Integer, Enum, String)
2. ARG – procedure argument
3. GLOBAL - pointer to a global variable
4. RET – a return value from a call
5. STACK – pointer to stack memory
6. Ø – no information



Pointer-Aware Slicing of Call Site Arguments



Augmenting Call Site Arguments



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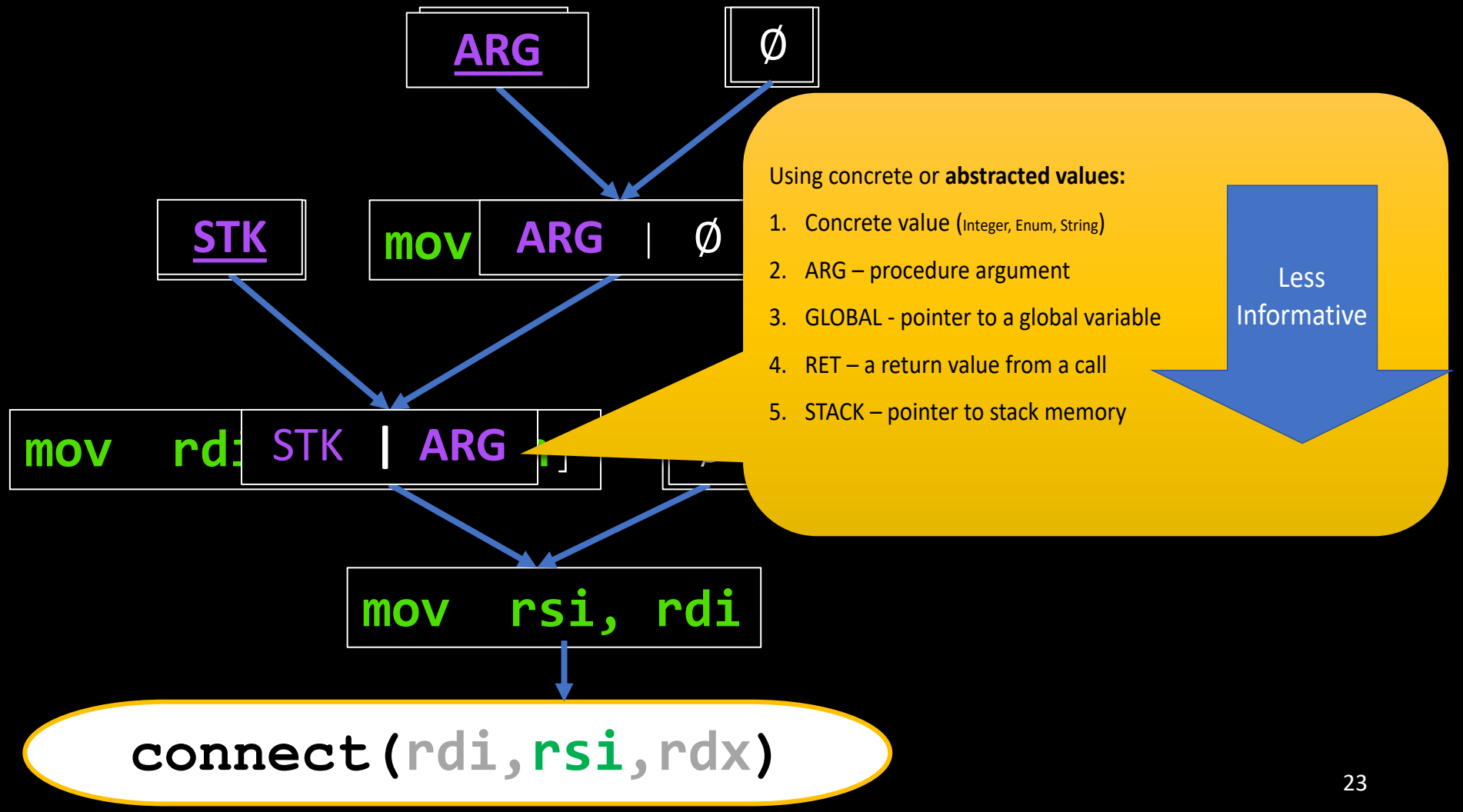

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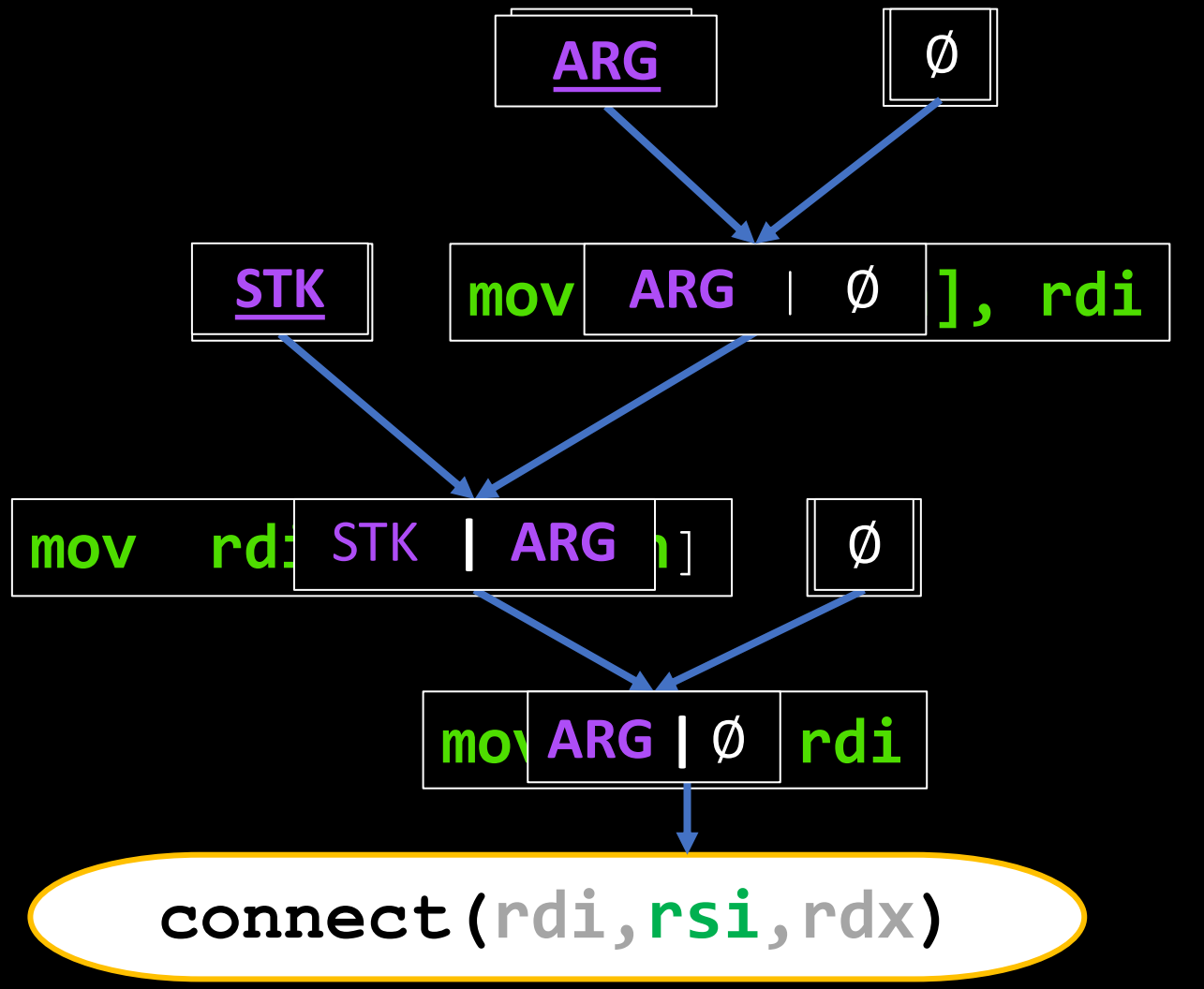

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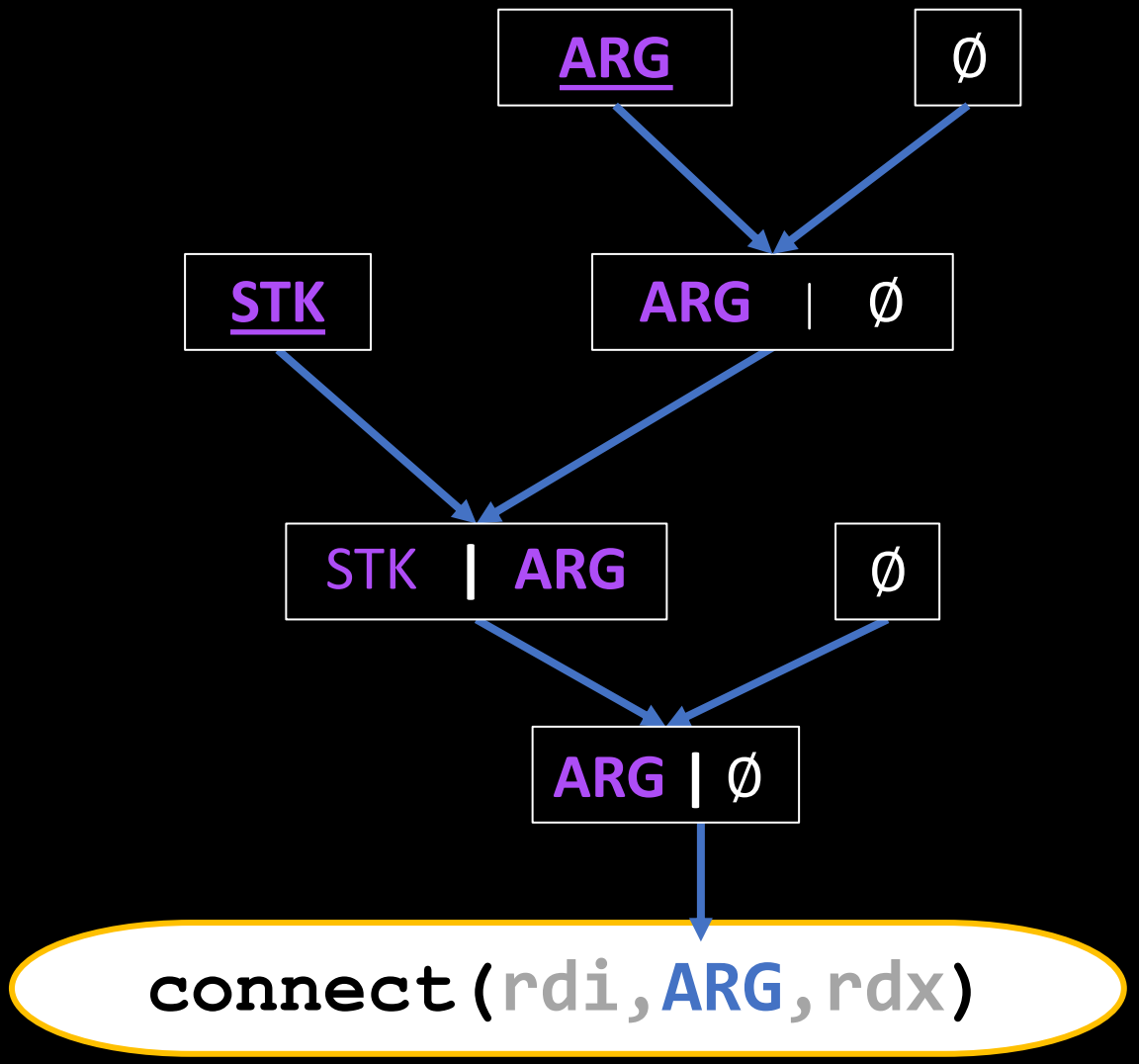
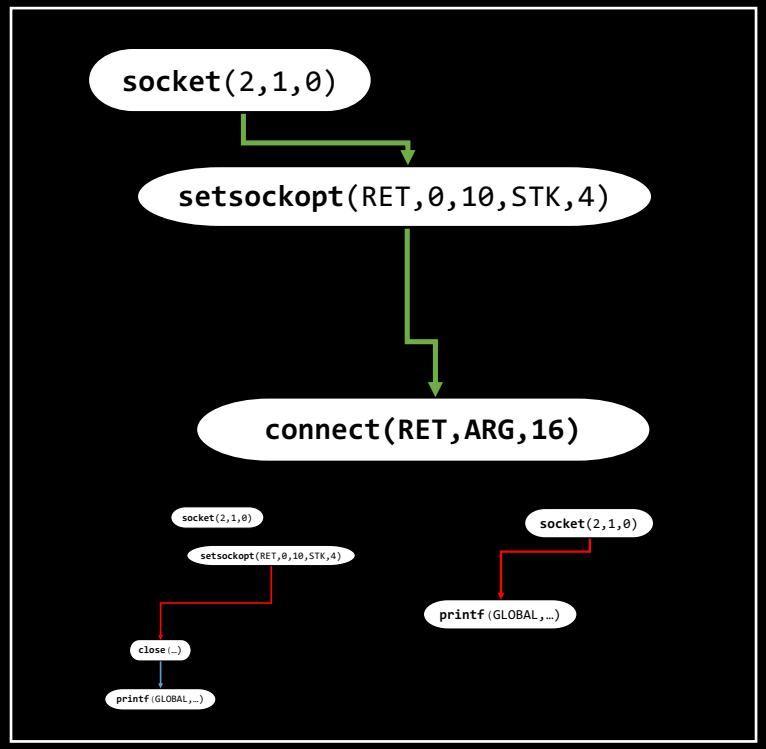
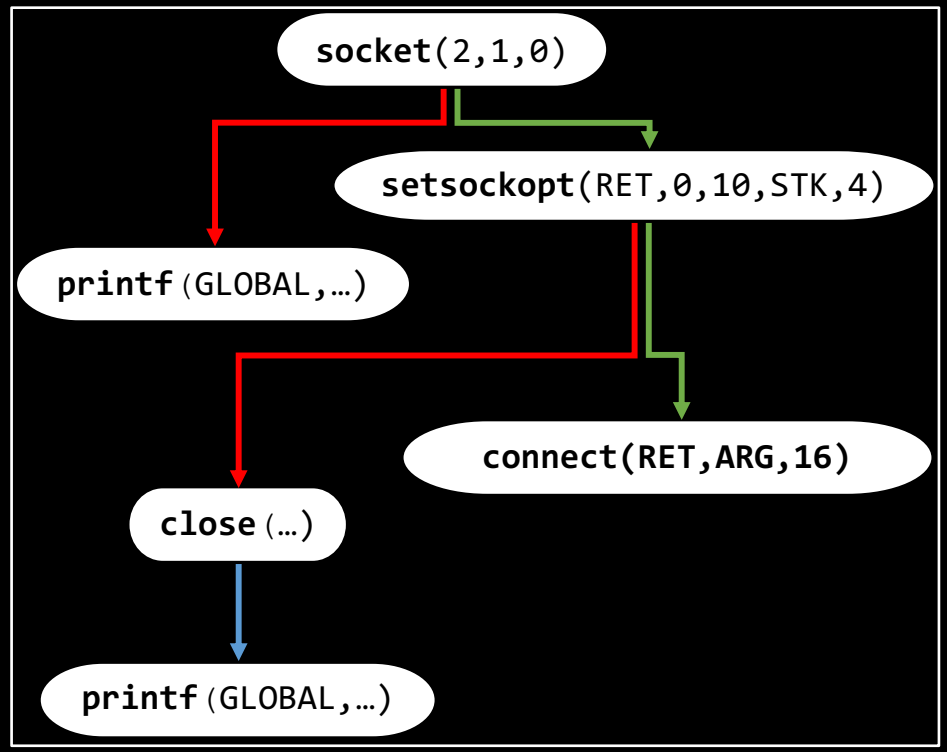


Augmented Control Flow Graph



Place augmented call sites back in the CFG



LSTM & Transformer

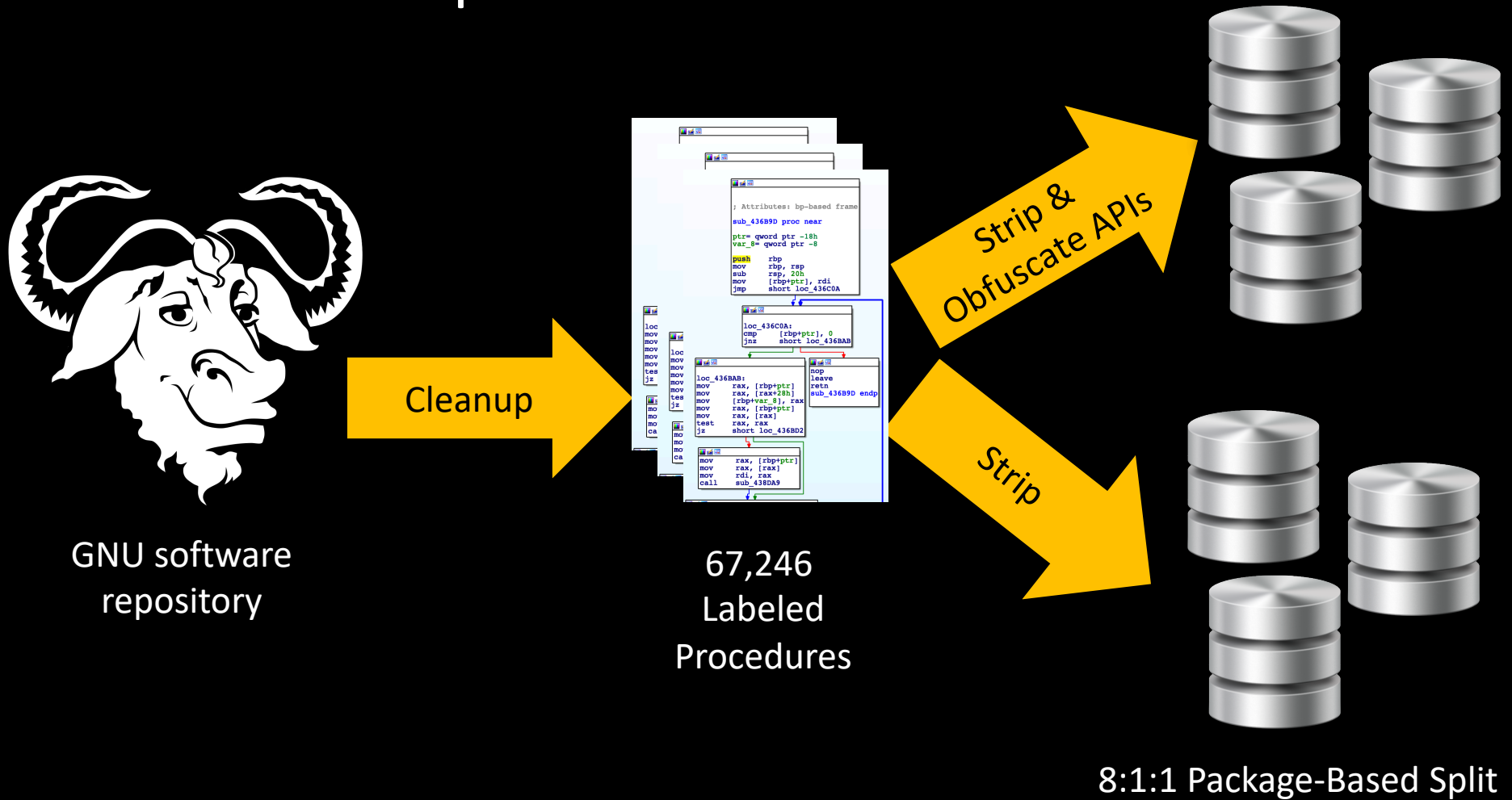
GNN

Evaluation

Implementation: Nero

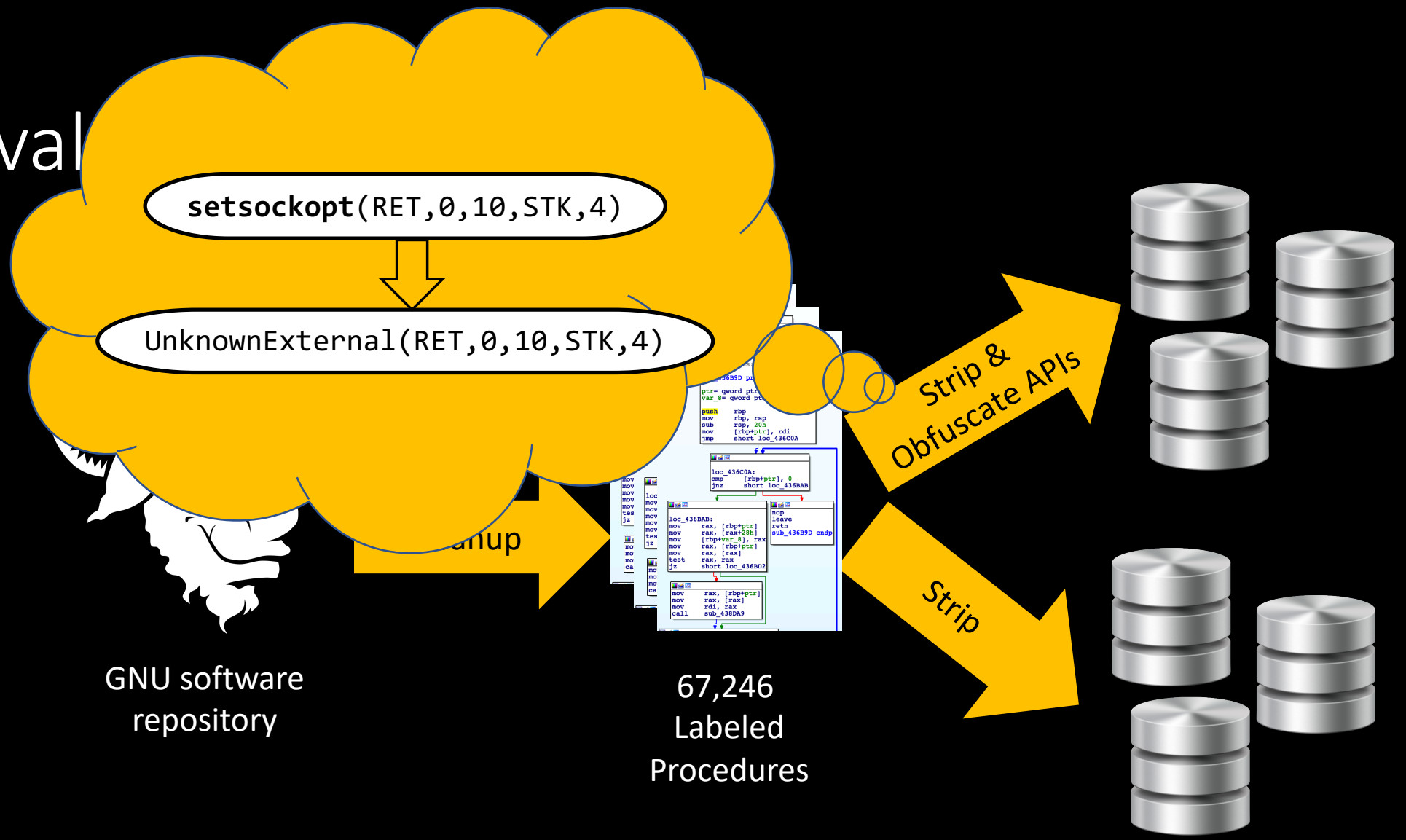
https://github.com/tech-srl/Nero

Evaluation Corpus



zenodo https://doi.org/10.5281/zenodo.4081641

Eval



GNU software repository

67,246 Labeled Procedures

8:1:1 Package-Based Split

zenodo https://doi.org/10.5281/zenodo.4081641

Evaluation Results

Nero-GNN

Nero-Transformer

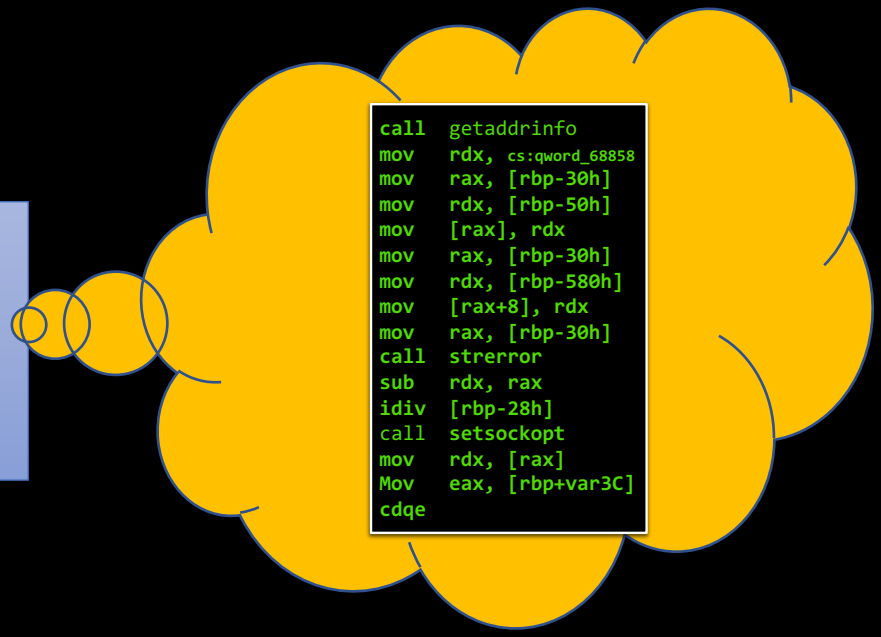
Nero-LSTM

DIRE [Lacomis et al. 2019]

Debin [He et al. 2018]

LSTM-text

Transformer-text



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”Debin: Predicting Debug Information in Stripped Binaries”, CCS’ 18

”DIRE: A Neural Approach to Decompiled Identifier Naming”, ASE ’19

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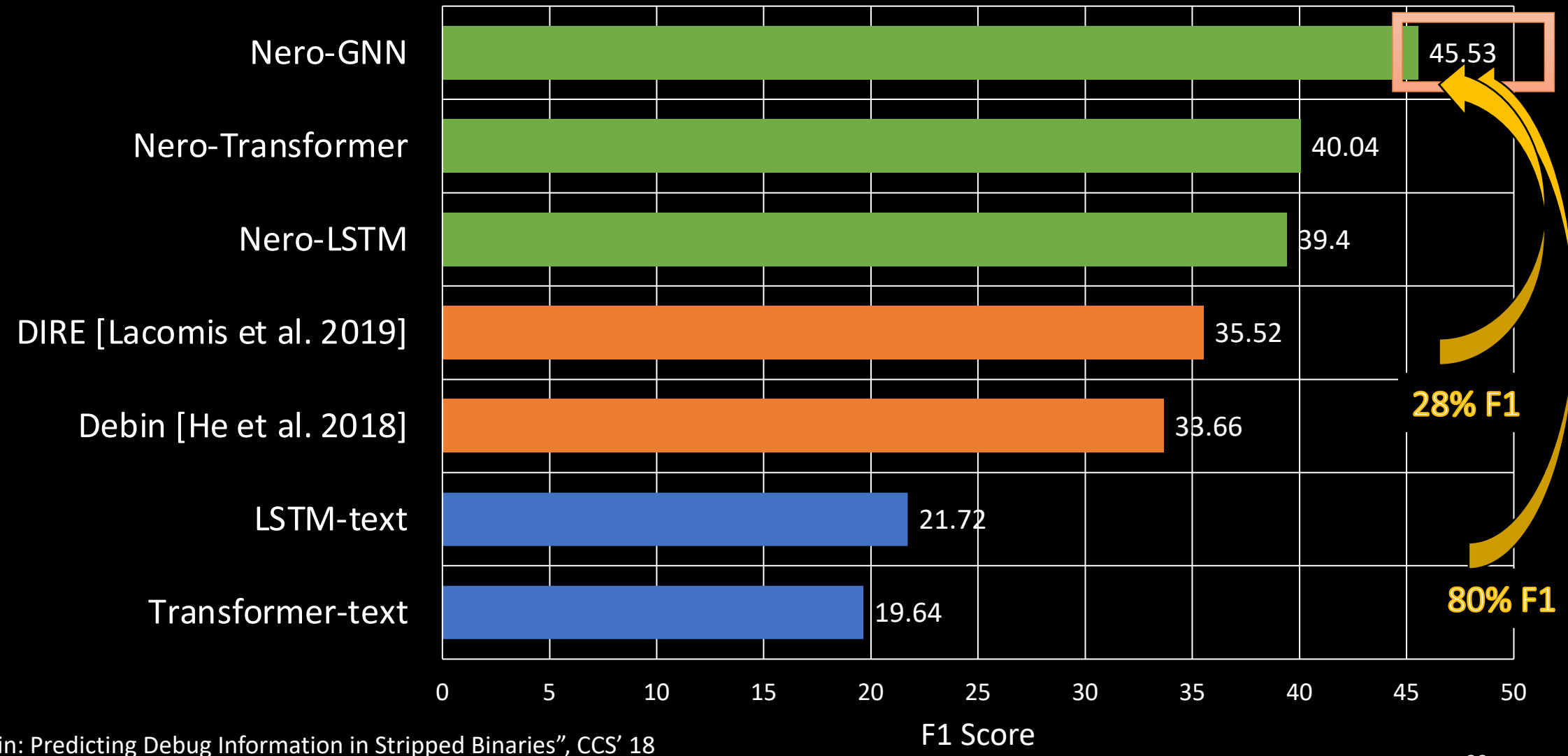

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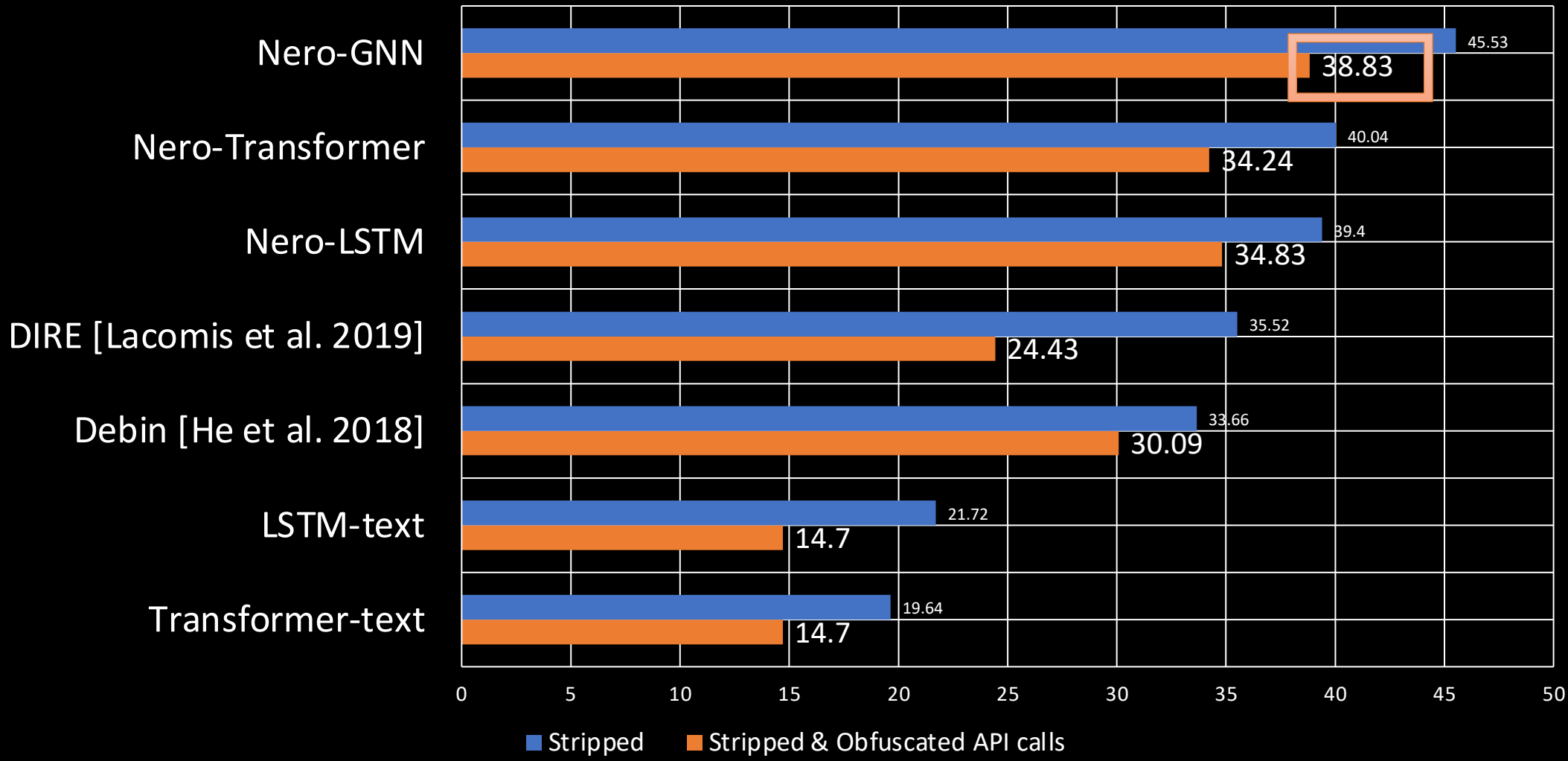

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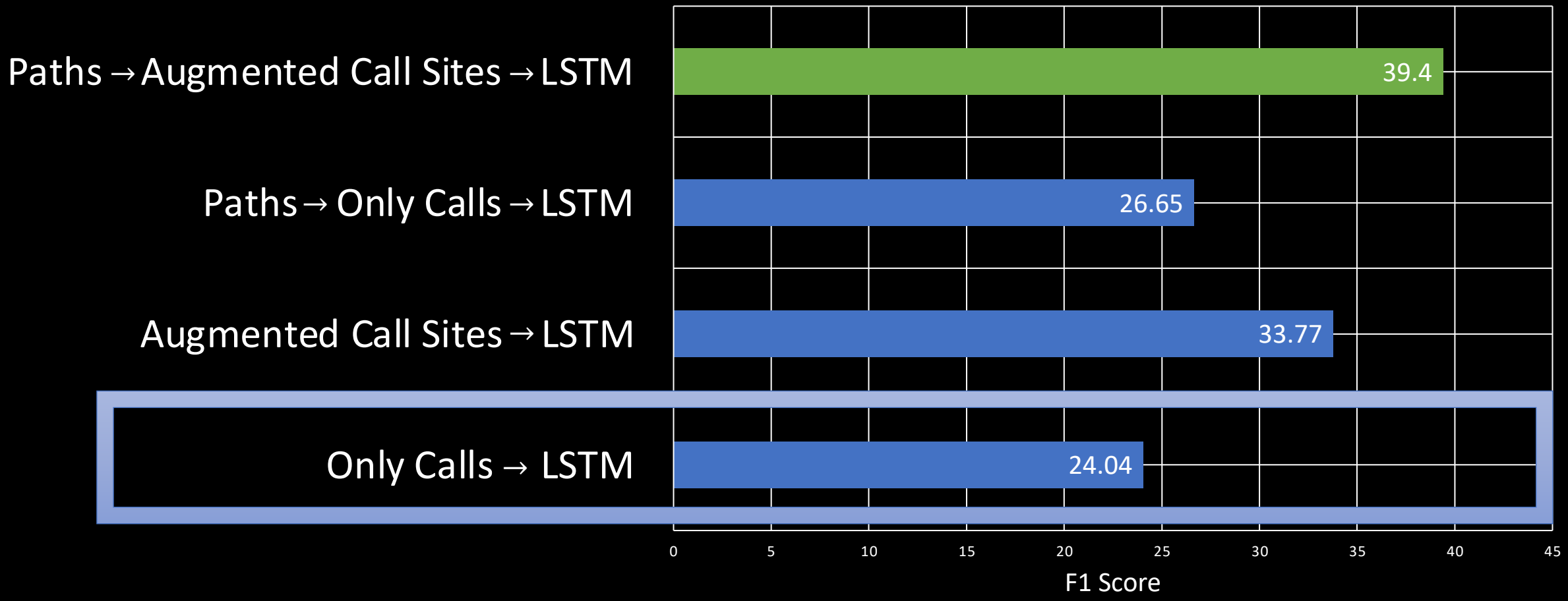
Ablation Study



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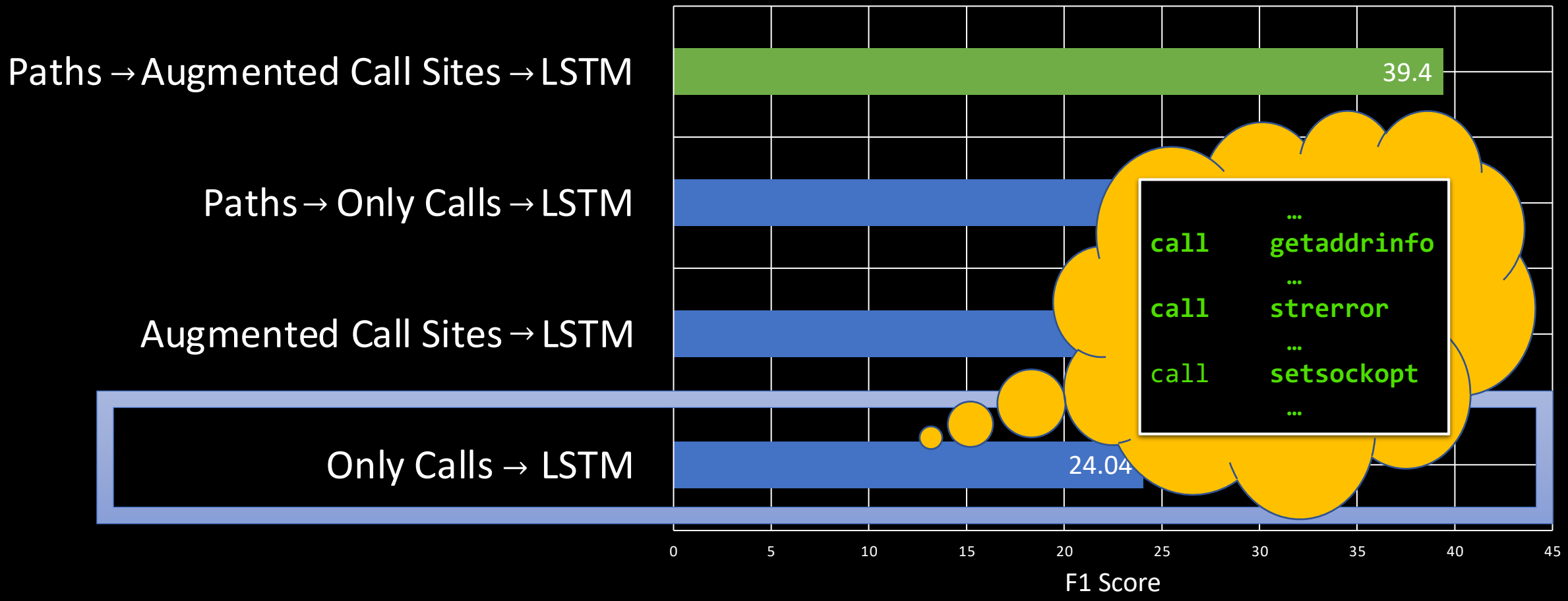

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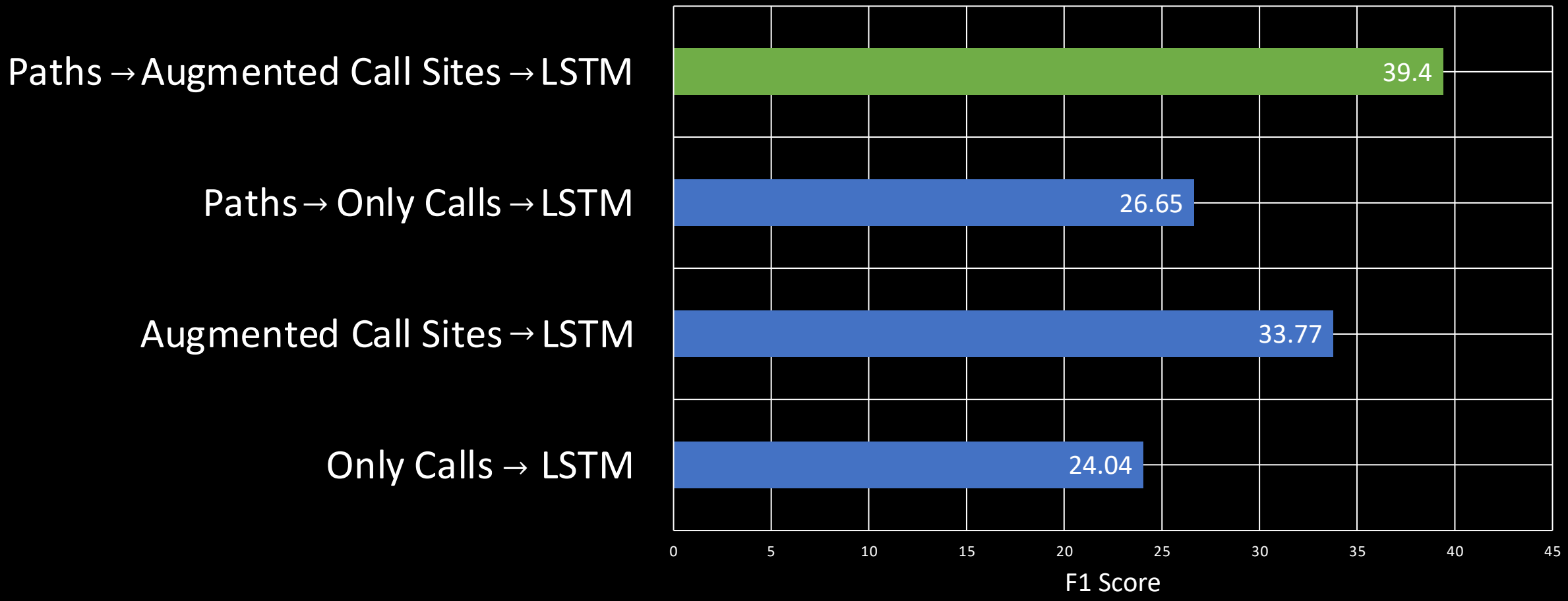

Qualitive Evaluation

Error Type	Ground Truth	Predicted Name
Programmers Vs English Language	i18n_**initialize**	i18n_**init**
	split_**cfg**_path	split_**config**_path
	add_env_**opt**	add_**option**
Date Structure Name Missing	get_**best_speed**	get_**list_item**
	ftp_parse_**winnt_ls**	parse_**tree**
	abort_**gzip**_signal	fatal_signal_handler
Verb Replaced	**read**_units	**parse**
	retrieve_from_file	**get**_from_file
	display_help	**show**_help

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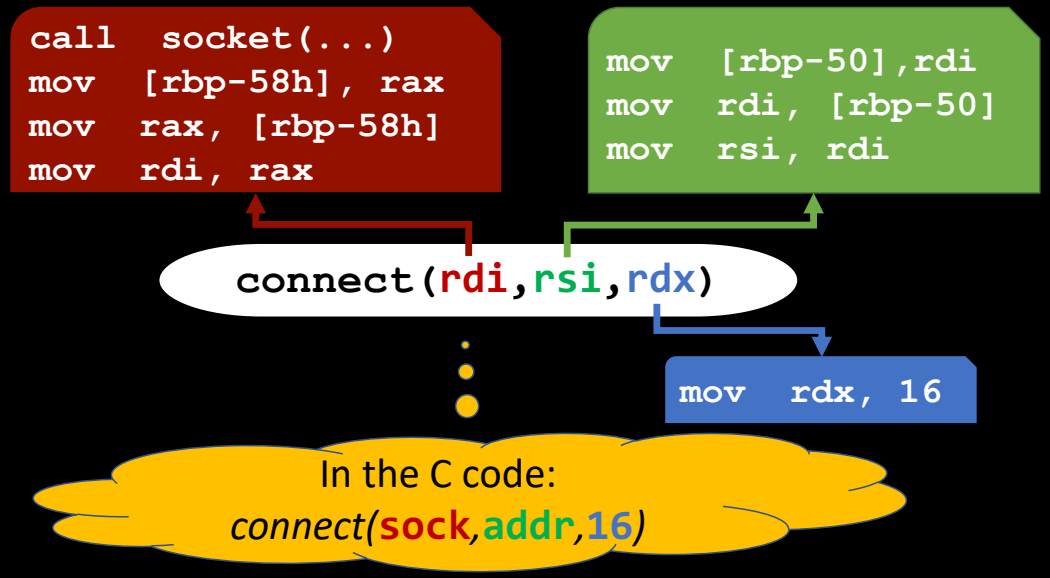
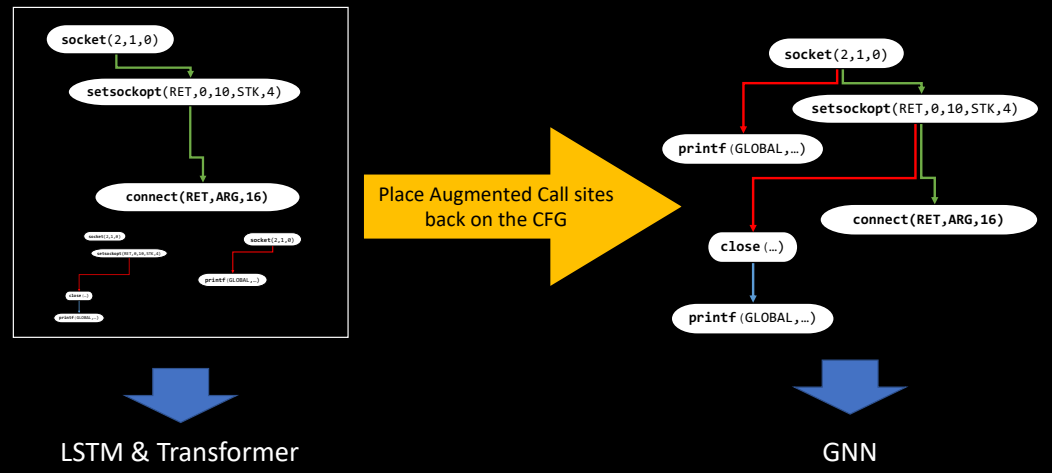
Measured F1 is actually a lower-bound

Takeaway Messages

Augmented call sites serve as a strong basis for procedure representations



Reconstructing the CFG enables the use of seq2seq and GNN models



https://github.com/tech-srl/Nero