SymLM: Predicting Function Names in Stripped Binaries via Context-Sensitive Execution-Aware Code Embeddings

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Predicting binary function names is extremely useful

- Function names: summary of function behavior and semantics.

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```
void FUN_001092f3(byte *param_1) {
    byte *local_48;
    ulong local_40;
    ...
    if (*local_48 == 10) {
        local_48 = local_48 + 1;
    }
    else if (*local_48 == 0x3a) {
        DAT_00119470 = '\0';
        bVar3 = *local_48;
    }
    ...
}
```

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        bVar3 = *local_48;
    }
    ...
}
```

Function Name Prediction →

```c
void DNS_flood(byte *param_1) {
    byte *local_48;
    ulong local_40;
    ...
    if (*local_48 == 10) {
        local_48 = local_48 + 1;
    }
    else if (*local_48 == 0x3a) {
        DAT_00119470 = '\0';
        bVar3 = *local_48;
    }
    ...
}
```

Predicting binary function names is very challenging

Challenges

1. **Missing Semantics**. Very limited semantic information.

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Missing Semantics

Names of **identifiers** and **function parameters** use the same words as function names [LWN21].

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openssl-1.0.1 libcrypto.a

```
<CMS_add0_cert>:
...
mov  eax, dword ptr  [rbp-0x2c]
add  eax, 1
mov  dword  ptr  [rbp-0x2c], eax
....
```

Add Obfuscation

openssl-1.0.1 libcrypto.a (obfuscated)

```
<CMS_add0_cert>:
...
xor  ecx, ecx
mov  eax, dword ptr  [rbp-0x2c]
sub  ecx, 1
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....
```
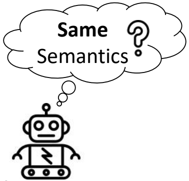

eax + 1

eax - (-1)



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Reasons

- Synonyms and abbreviations are ubiquitous in function names.
- Even single letters can be meaningful when probably used [BGOF17].
- Probability (two developers select same names for the same function) = **6.9%** [FMN+20].

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4. **OOV Issues**. Out-of-vocabulary words widely used.

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OOV Words

	Category	**Ratio**	**Examples**
1	Abbreviation concatenation	29.9%	statinfo, streq
2	Clean word concatenation	22.3%	sharefile, startpoints
3	Misspelling	14.6%	anewer, tac, sb
4	Clean word	12.1%	dependent, specifer
5	Abbreviation	7.0%	utils, pred
6	Inflection	9.6%	addresses, using
7	Digits in word	4.5%	add32, merge2

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5. **Comprehensive semantic modeling**. Semantics preserved in calling context.

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```
YY_BUFFER_STATE yy_scan_string (char *yystr) {
  size_t _yybytes_len;
  YY_BUFFER_STATE pyVar1;
  _yybytes_len = strlen(yystr);
  pyVar1 = yy_scan_bytes (yystr,_yybytes_len);
  return pyVar1;
}
```

Prior Works and Limitations

- Limited features, e.g.,
  1. **handcrafted features**: Debin [HIT+18] and Punstrip [PECK20].
  2. **partial function semantics**: NERO [DAY20] and NFRE [GCXZ21].

Prior Works and Limitations

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```
1   xor   ecx, ecx
2   mov   eax, dword ptr [rbp-0x2c]
3   sub   eax, ecx
4   mov   dword ptr [rbp-0x2c], eax
```

Normalization $\Longrightarrow$

```
1   INST_1534
2   INST_5741
3   INST_7745
4   INST_2573
```

Preprocessing Step of NFRE

Key Observations and Insights

Predicting function names

- Program semantics is manifested in execution behavior.

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```

Same Semantics
Different Instructions

openssl-1.0.1 libcrypto.a (obfuscated)

```
<CMS_add0_cert>:
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xor    ecx, ecx
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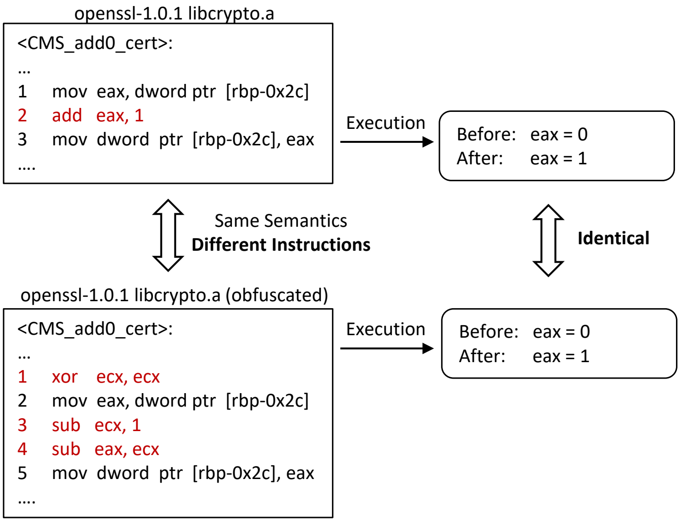
Key Observations and Insights



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Predicting function names

- Program semantics is manifested in execution behavior. $\Rightarrow$ C1 and C2
- Learning semantics requires understanding both function instructions and calling context. $\Rightarrow$ C5
- Function name semantic similarity needs to be measured. $\Rightarrow$ C3 and C4

System Workflow: Step 1

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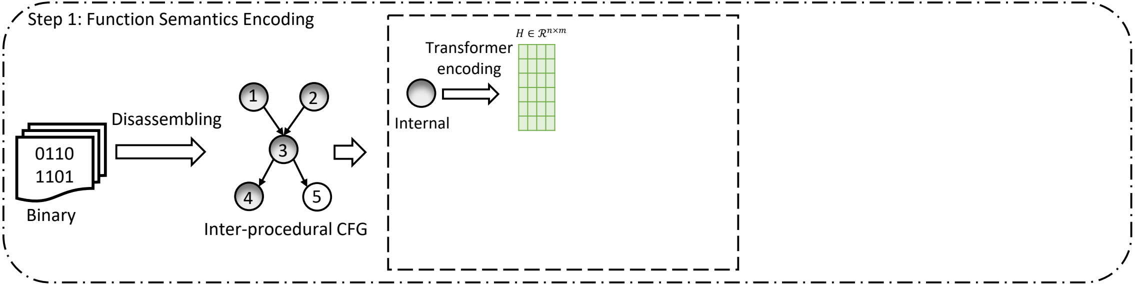

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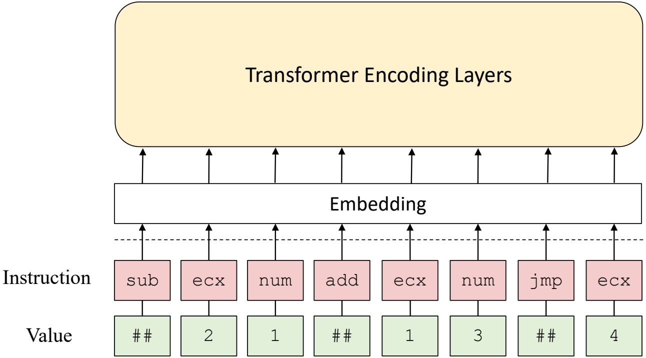

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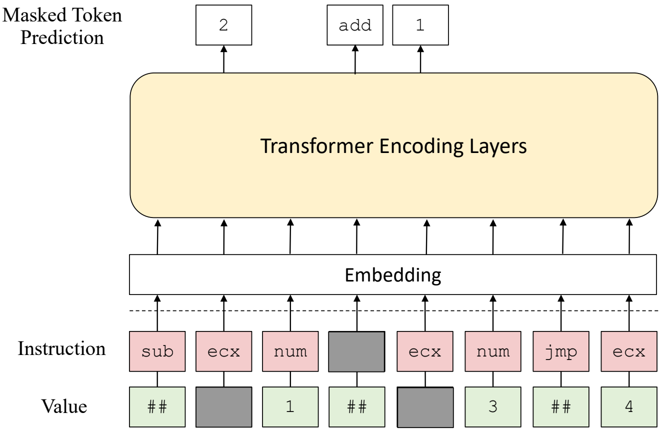

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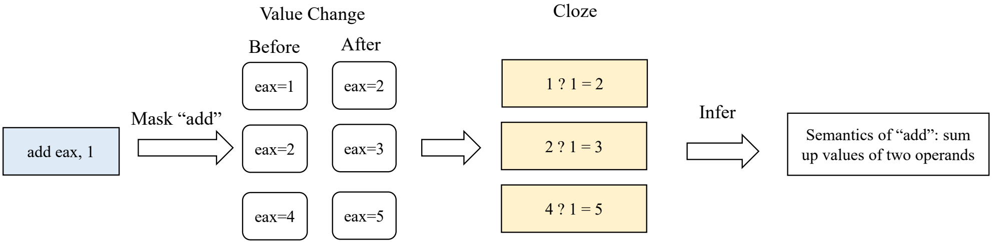

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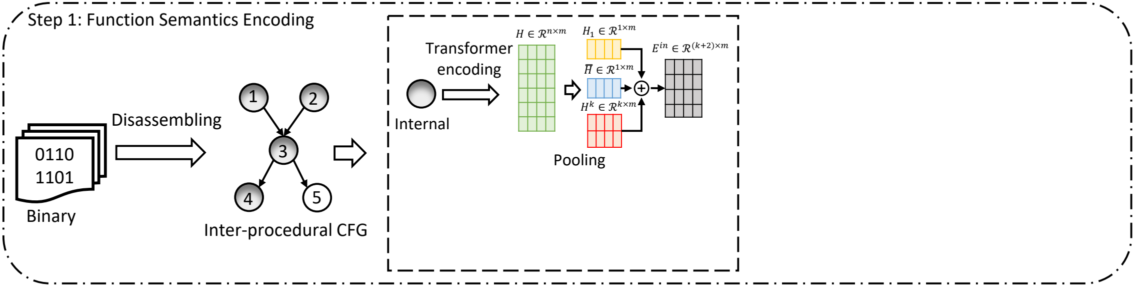

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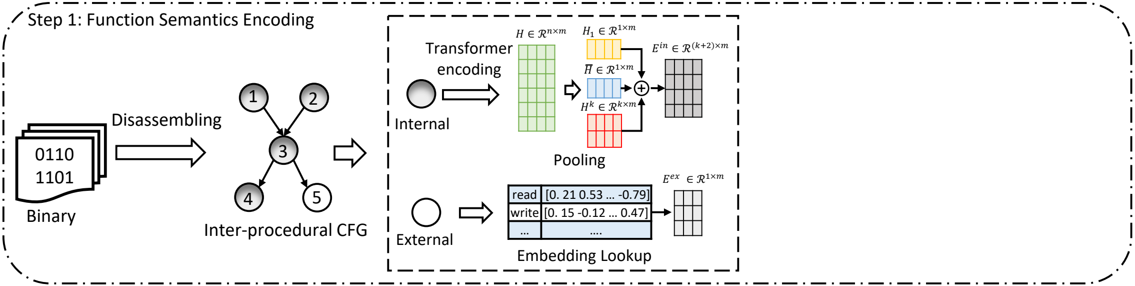

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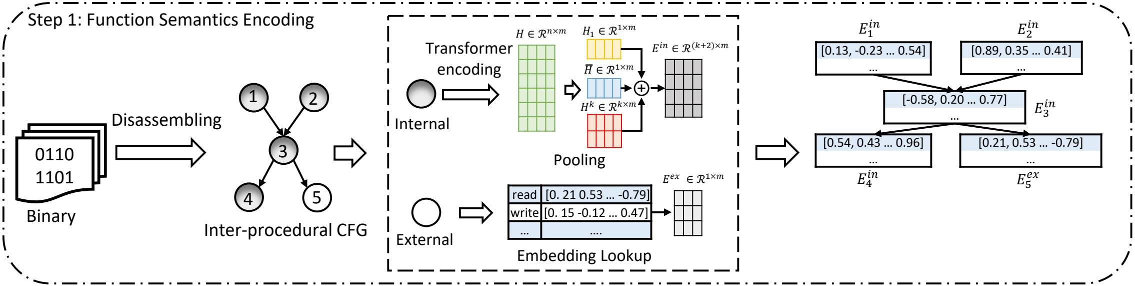

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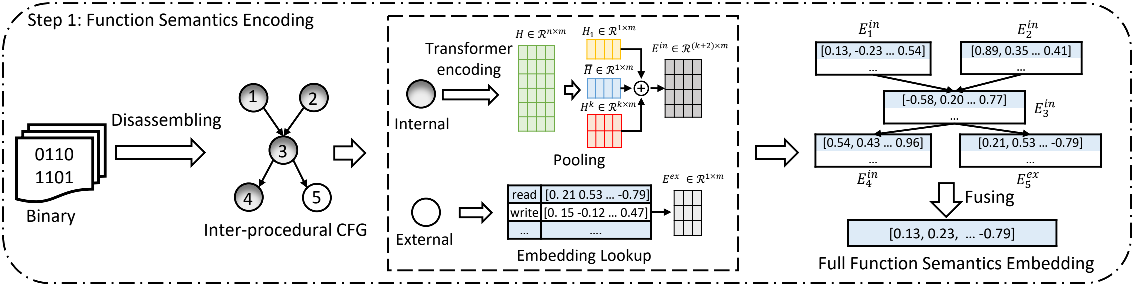
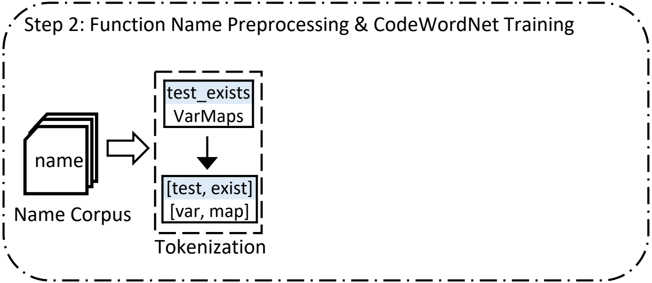


System Workflow: Step 2



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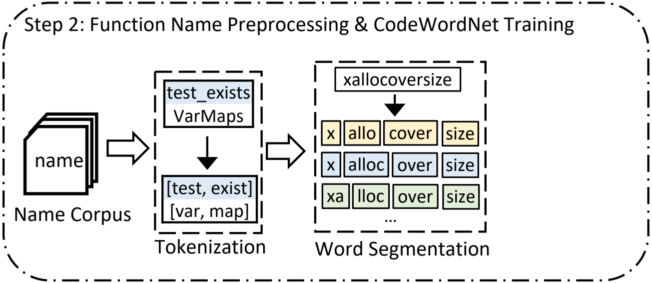

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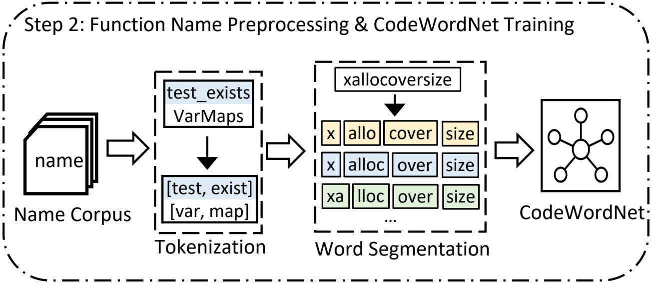

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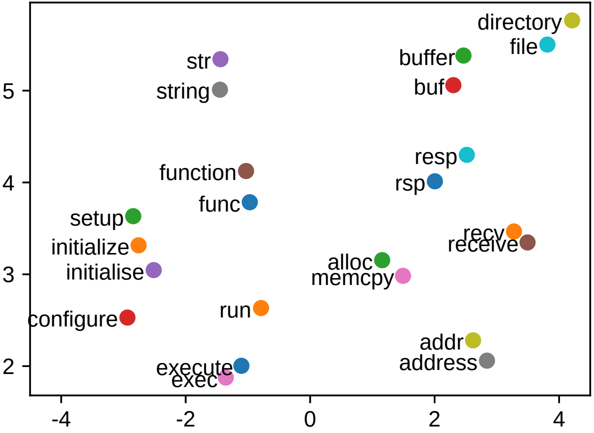
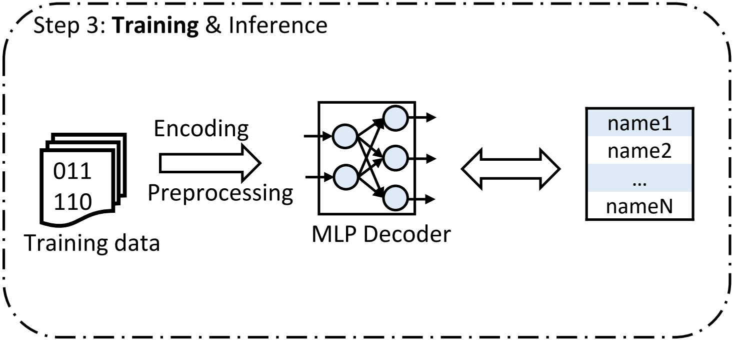


System Workflow: Step 3



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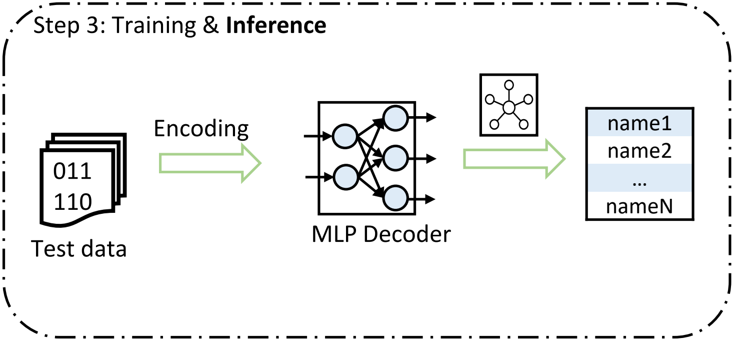

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   - 27 open-source projects.
   - 4 architectures: x86, x64, ARM, and MIPS.
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   - 4 obfuscation options: bcf, cff, sub, and split (LLVM obfuscator).

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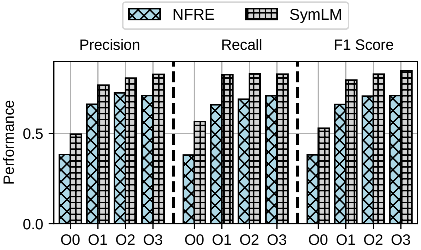
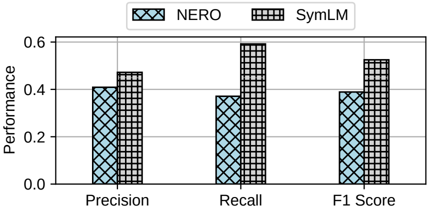
2. Baselines: NERO [DAY20] and NFRE [GCXZ21].
3. Metrics: precision, recall, and F1-score.

Baseline Comparison

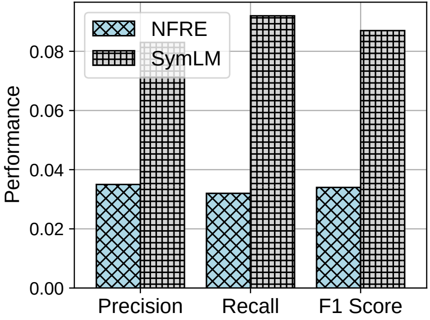
- SymLM outperforms the state-of-the-art works (up to 35% improvement on F1 score).

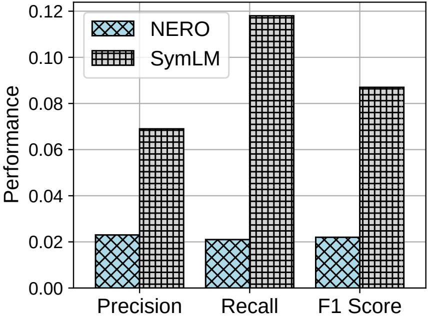




Generalizability

- SymLM is more generalizable to unseen binary functions (295.5% better F1 score).





Use Case

- SymLM successfully infers function semantics of IoT firmware image [Gat].

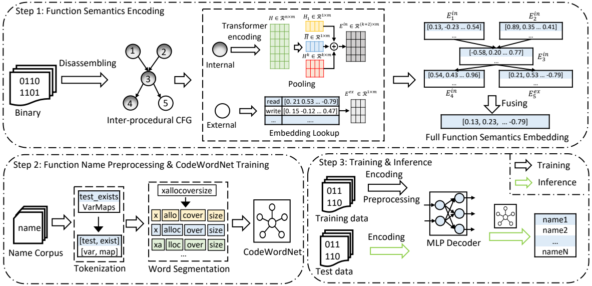
```c
uint32_t analogRead(uint32_t ulPin){
  ...
  if (pin == NC) uVar3 = 0;
  else {
    uVar2 = adc_read_value(pin);
    uVar3 = (uint32_t)uVar2;
    if (uVar4 != 0xc) {
      if ((uint) uVar4 < 0xc)
        return (uint)(uVar2 >> (0xcU - uVar4 & 0xff));
      return uVar3 << (uVar4 - 0xcU & 0xff);
    }
  }
  return uVar3;
}
```

Ground Truth

```c
uint32_t read(uint32_t ulPin){
  ...
  if (pin == NC) uVar3 = 0;
  else {
    uVar2 = read_value(pin);
    uVar3 = (uint32_t)uVar2;
    if (uVar4 != 0xc) {
      if ((uint) uVar4 < 0xc)
        return (uint)(uVar2 >> (0xcU - uVar4 & 0xff));
      return uVar3 << (uVar4 - 0xcU & 0xff);
    }
  }
  return uVar3;
}
```

Prediction

Takeaway



SymLM

- A novel neural architecture that generates execution-aware context-sensitive code embeddings.
- Effective modules, function name preprocessing and CodeWordNet, to calculate function name similarity.
- Advancing the state-of-the-art and practical use cases.

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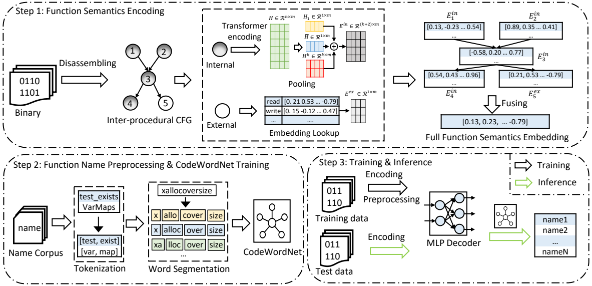

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- A novel neural architecture that generates execution-aware context-sensitive code embeddings.
- Effective modules, function name preprocessing and CodeWordNet, to calculate function name similarity.
- Advancing the state-of-the-art and practical use cases.

The source code is available at `https://github.com/OSUSecLab/SymLM`.

References I

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