TYGR: Type Inference on Stripped Binaries using Graph Neural Networks

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Compilation

```
int main (int count)
{
  return count++;
}
```

Compilation

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}
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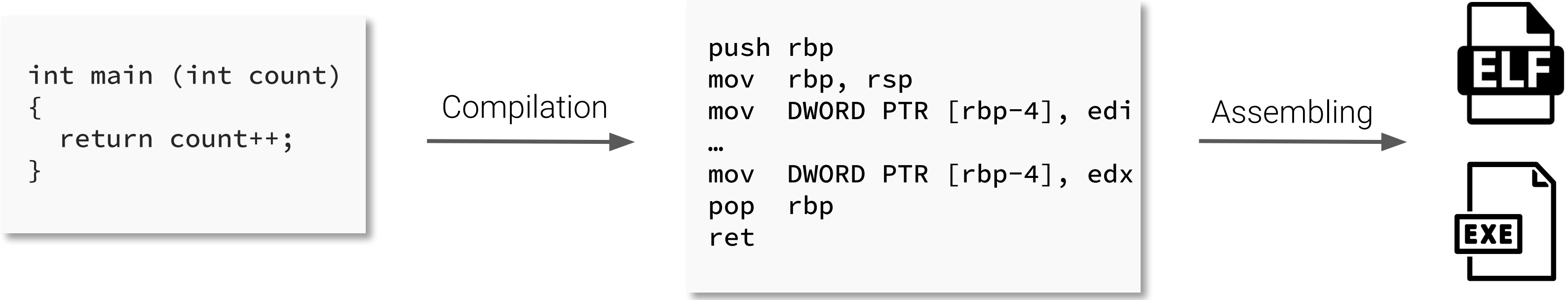
Compilation

```
push rbp
mov  rbp, rsp
mov  DWORD PTR [rbp-4], edi
…
mov  DWORD PTR [rbp-4], edx
pop  rbp
ret
```

Compilation



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int main (int count)
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mov  DWORD PTR [rbp-4], edx
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```

Assembling

Loss of Information

- Variable types
- Variable names
- Control flow structures
- Comments

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int main (int count)
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```

Compilation

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push rbp
mov  rbp, rsp
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…
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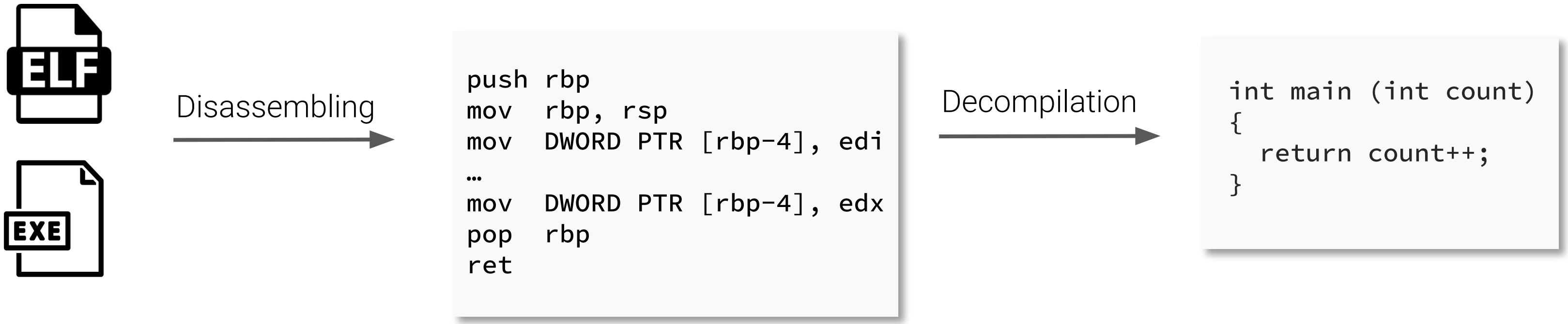
pop  rbp
ret
```

Loss of Information

The information is critical for understanding binaries

- Malware analysis
- Software debugging
- Software maintenance

Reverse Engineering



Disassembling

```
push rbp
mov  rbp, rsp
mov  DWORD PTR [rbp-4], edi
…
mov  DWORD PTR [rbp-4], edx
pop  rbp
ret
```

Decompilation

```
int main (int count)
{
  return count++;
}
```

Reverse Engineering

Loss of information:

- Variable types

The Variable Type Recovery Problem

```c
struct options {
  int flag;
  char name;
};

void func() {
  struct options opt;
  int tmp;
  opt.flag = 1;
  opt.name = 'a';
  tmp = opt.flag + 1;
}
```

```
Func:
     push  rbp
     mov   rbp, rsp
     mov   DWORD PTR [rbp-12], 1
     mov   BYTE PTR [rbp-8], 97
     mov   eax, DWORD PTR [rbp-12]
     add   eax, 1
     mov   DWORD PTR [rbp-4], eax
     pop   rbp
     ret
```

The Variable Type Recovery Problem

```
func:

        opt.flag: ?

        opt.name: ?

        tmp: ?
```

```
func:

        [rbp - 12]

        [rbp - 8]

        [rbp - 4]
```

Variable Type Recovery Attempts

1. Constraint-based methods

- Collect type constraints to encode data flow information:

```
add(x, 5) → x: numeric
```

- Solve constraints: writing rules

Variable Type Recovery Attempts

1. Constraint-based methods

- Collect type constraints to encode data flow information:

```
add(x, 5) → x: numeric
```

- Solve constraints: writing rules

2. ML-based methods

- Implicitly encode data flow information
- No need to write rules

Our Intuition

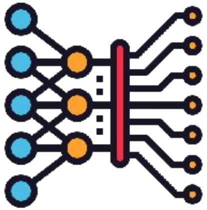
- Explicitly encode data flow information into graph
    - Variable access patterns
    - Variable usage

- No need to manually write rules

TYGR

Model training

- Data flow analysis
- Graph embedding



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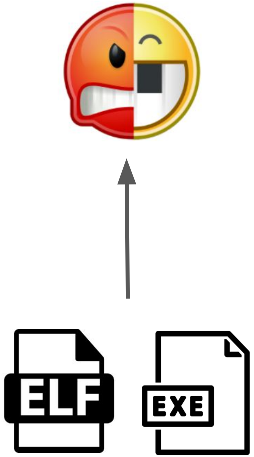
Model training

- Data flow analysis
- Graph embedding

Building a data set

- Software source code
- x64, x86, AArch64, ARM, MIPS

TYGR: Pipeline



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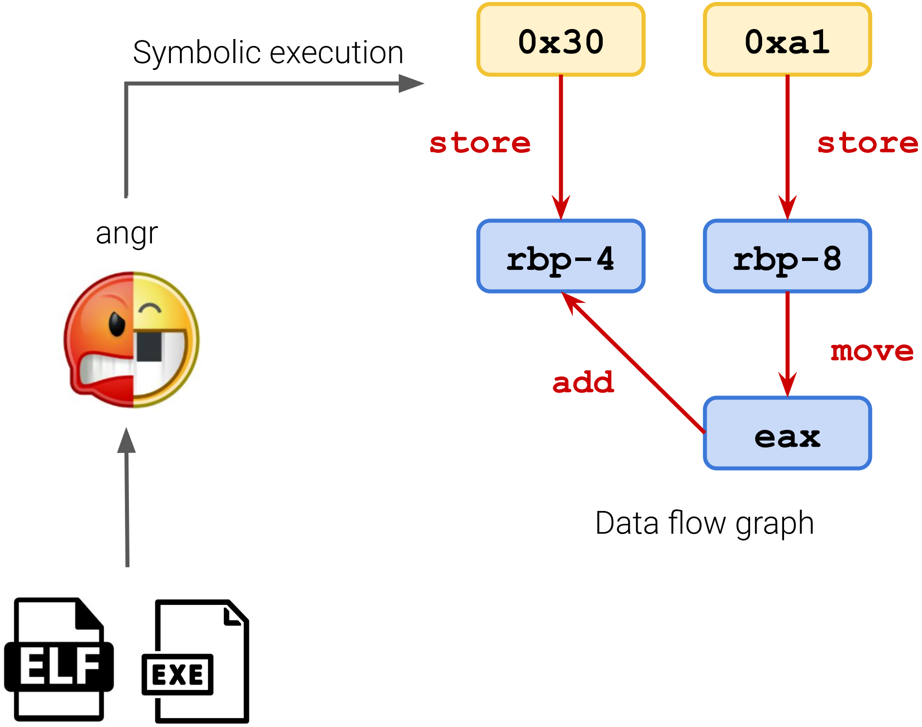
TYGR: Pipeline



Symbolic execution

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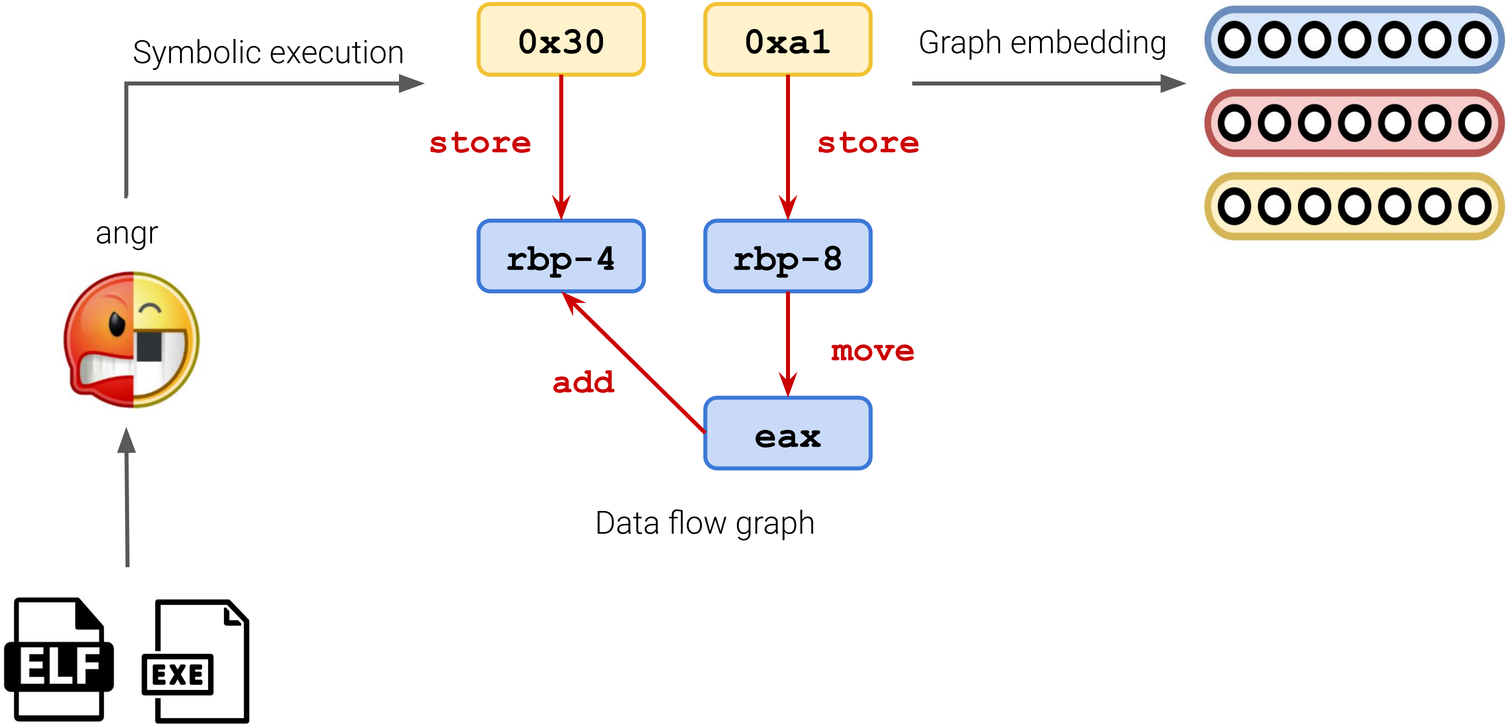
Data flow graph

TYGR: Pipeline



Symbolic execution

angr

`0x30`

`0xa1`

`store`

`store`

`rbp-4`

`rbp-8`

`move`

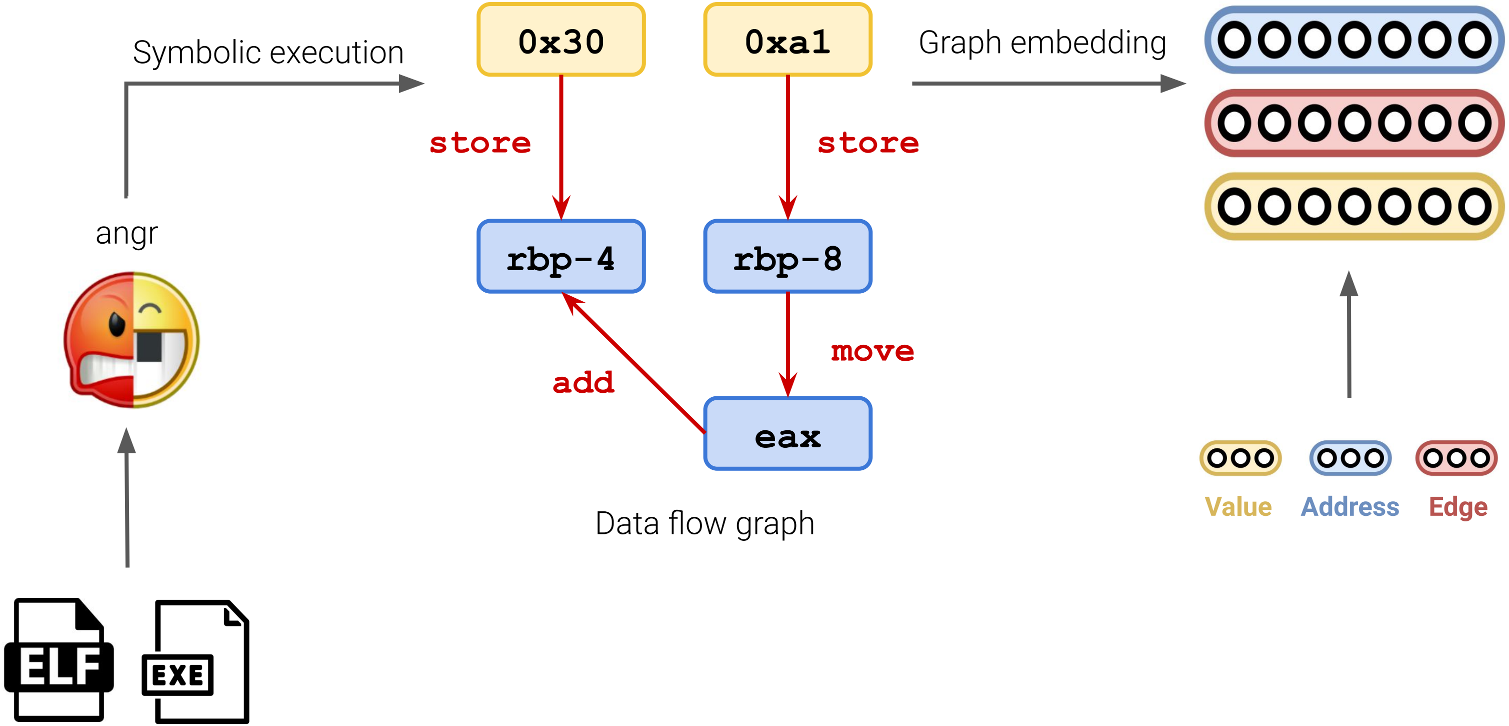
`add`

`eax`

Data flow graph

Graph embedding

TYGR: Pipeline



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Data flow graph

Graph embedding

Value

Address

Edge

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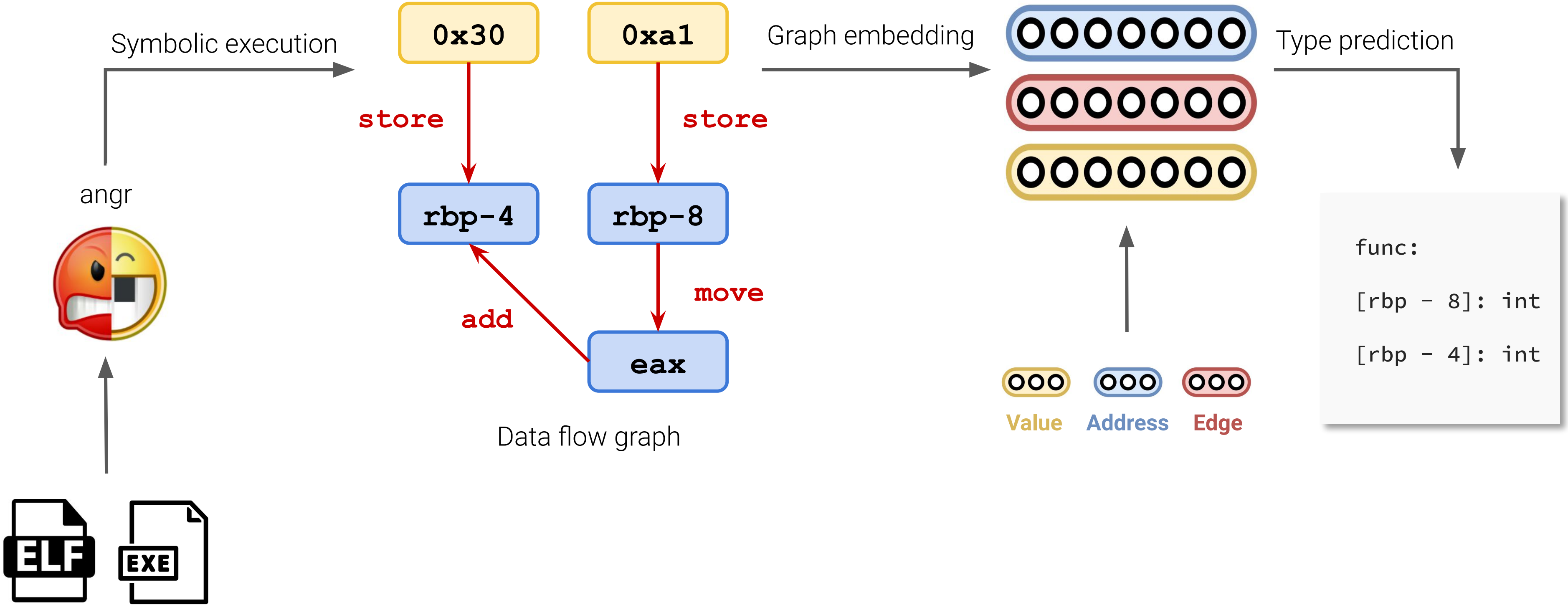

Symbolic execution

angr

Data flow graph

Graph embedding

Value

Address

Edge

Type prediction

```
func:
[rbp - 8]: int
[rbp - 4]: int
```

Challenge: Type Recovery for `struct`

```c
struct options {
  int flag;
  char name;
};

void func() {
  struct options opt;
  int tmp;
  opt.flag = 1;
  opt.name = 'a';
  tmp = opt.flag + 1;
}
```

Challenge: Type Recovery for `struct`

```
func:
    opt.flag: ?
    opt.name: ?
    tmp: ?
```

`struct` Type Recovery by Size

```
func:

    opt.flag: struct<4, 1>

    opt.name: struct<4, 1>

    tmp: Primitive_4
```

Problems:

1. Types with same size
2. Struct with same shape

`struct` Type Recovery using ML

```
func:

    opt.flag: struct<int, char>

    opt.name: struct<int, char>

    tmp: int
```

Problem:

Only if `struct<int, char>` is in the dictionary

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```
func:
    opt.flag: struct
    opt.name: struct
    tmp: int
```

Step 1: Basic type recovery

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```
func:

    opt.flag: int

    opt.name: char
```

Step 2: Member type recovery

TYGR

```
func:
    opt.flag: struct_int
    opt.name: struct_char
    tmp: int
```

Step 1: Basic type recovery

Step 2: Member type recovery

Dataset: TYDA

- Compiled C binary executables from Gentoo and Debian repositories
- Five architectures: x64, x86, AArch64, ARM32, and MIPS
- Four compiler optimizations O0 through O3
- 327K binaries and 130M functions in TYDA

Evaluation: Baselines

	Overall Accuracy	Struct Accuracy
TYGR	**74.5%**	**40.6%**
DIRTY	55.8%	34.1%
OSPREY	71.8%	29.5%

Accuracy results on GNU coreutils `O0` executables

Evaluation: Accuracy per-type (x64 O0)

Type	Occurrence (%)	Accuracy (%)
struct*	25.6	91.1
i32	23.1	90.9
char*	16.3	74.7
bool	1.7	83.9
…	…	…
i16*	0.1	55.0

Case Study: Bool

Type	Occurrence (%)	Accuracy (%)
char*	16.3	74.7
bool	**1.7**	**83.9**

Conclusion

- TYGR is a system that uses a novel graph-based representation of data-flow information for type inference
- We construct a new dataset for x64, x86, AArch64, ARM32, and MIPS architectures

Thank you

https://github.com/sefcom/TYGR

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