Software Protection Research

ISSISP 2017 — Program Analysis

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What is Program Analysis?

Control Flow Analysis

Discussion

What is Program Analysis?

Program Analysis

```
int foo() {
  int x;
  int* y;
  printf(x+*y);
}
```

- Who calls foo?
- Who does foo call?
- Is x ever initialized?
- Can y ever be null?
- What will foo print?

- ***Defenders**: need to analyze their program to protect it!*

- Who calls foo?
- Who does foo call?
- Is x ever initialized?
- Can y ever be null?
- What will foo print?

Tigress

```
int foo() {
  … … … …
}
```

Obfuscate

```
int foo'() {
  … … … …
}
```

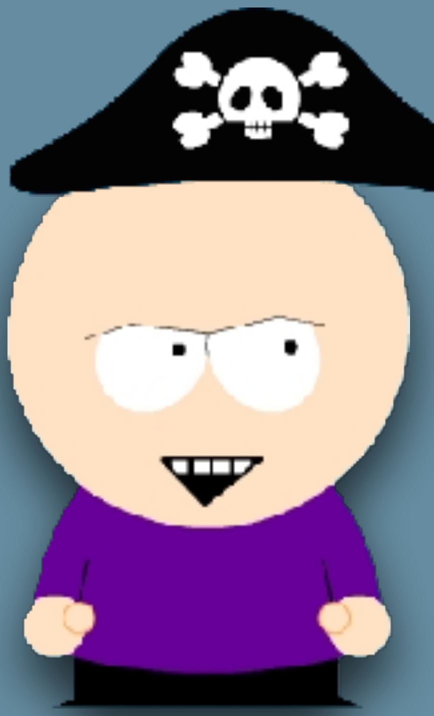
- ***Attackers**: need to analyze our program to modify it!*

- Who calls foo?
- Who does foo call?
- Is x ever initialized?
- Can y ever be null?
- What will foo print?

```
int foo'() {
  … … … …
}
```

De-obfuscate

- Extract Code!
- Discover Algorithms!
- Find Design!
- Find Keys!
- Modify Code!



Two kinds of analyses:

- **static analysis:** collect information about a program by studying its code;
- **dynamic analysis:** collect information from *executing* the program.

- **static analysis:** collect information about a program by studying its code

```
int foo() {
  … … … …
}
```

Static Analysis

I.e. we analyze the source or binary code of the program itself.

- Who calls foo?
- Who does foo call?
- Is x ever initialized?
- Can y ever be null?
- What will foo print?

- **dynamic analysis:** collect information from *executing* the program.

```
int foo() {
  … … … …
}
```

Program inputs

Dynamic Analysis

I.e. we analyze a *trace* of the program as it is running on some *particular input*

- Who calls foo?
- Who does foo call?
- Is x ever initialized?
- Can y ever be null?
- What will foo print?

Static Analyses

- **control-flow graphs**: representation of (possible) control-flow in functions.
- **call graphs**: representation of (possible) function calls.
- **disassembly**: turn raw executables into assembly code.
- **decompilation**: turn raw assembly code into source code.

Dynamic Analyses

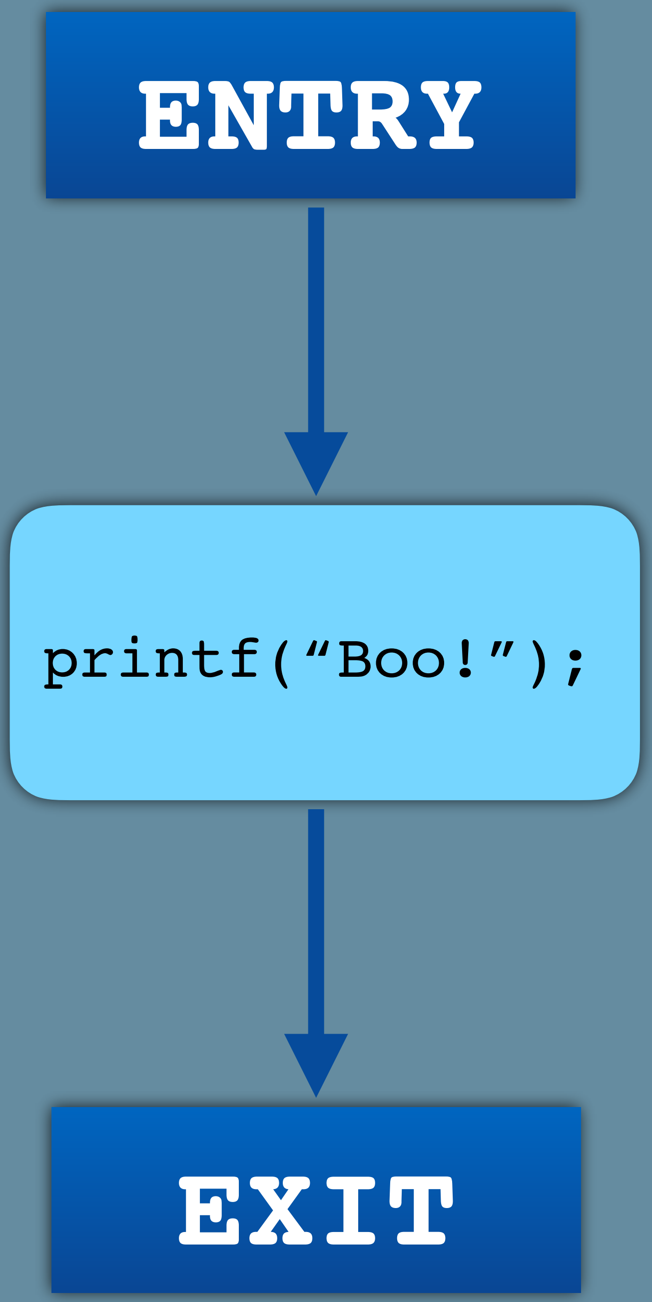
- **debugging:** what path does the program take?
- **tracing:** which functions/system calls get executed?
- **profiling:** what gets executed the most?

Control Flow Analysis

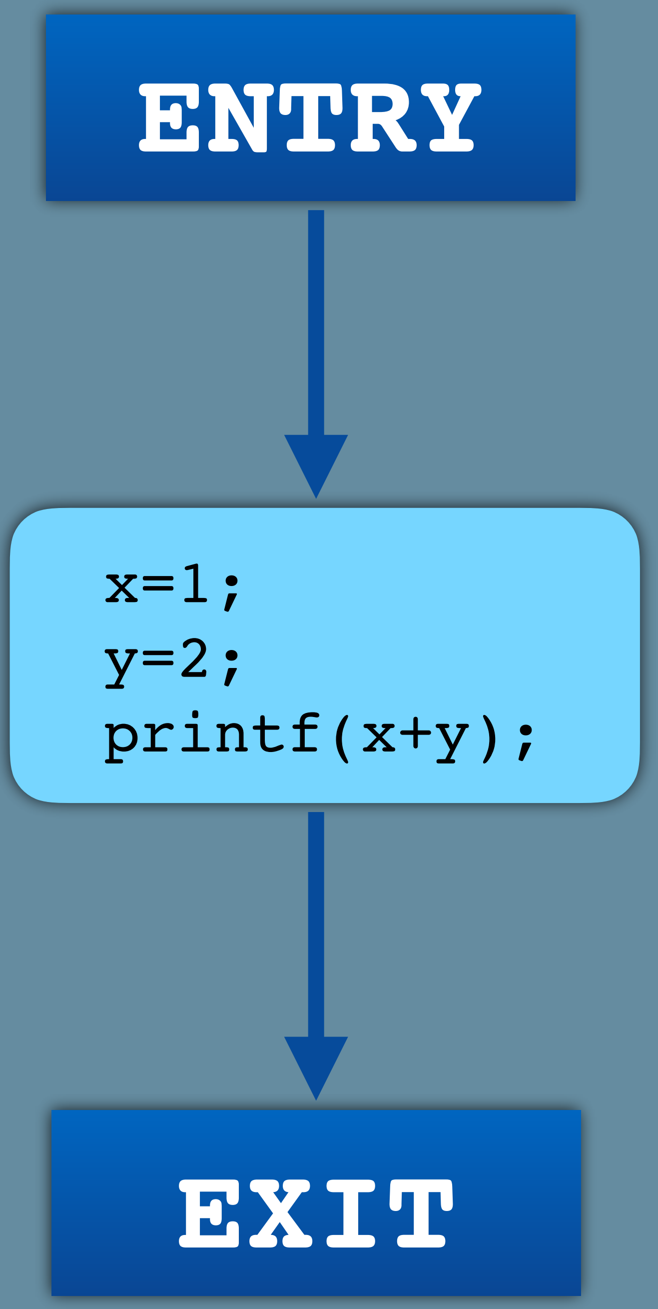
Control-Flow Graph (CFG)

- A way to represent the possible flow of control inside a function.
- **Nodes**: called **basic blocks.** Each block consists of straight-line code ending (possibly) in a branch.
- **Edges**: An edge A → B means that control could flow from A to B.
- There is one unique **entry node** and one unique **exit node**.

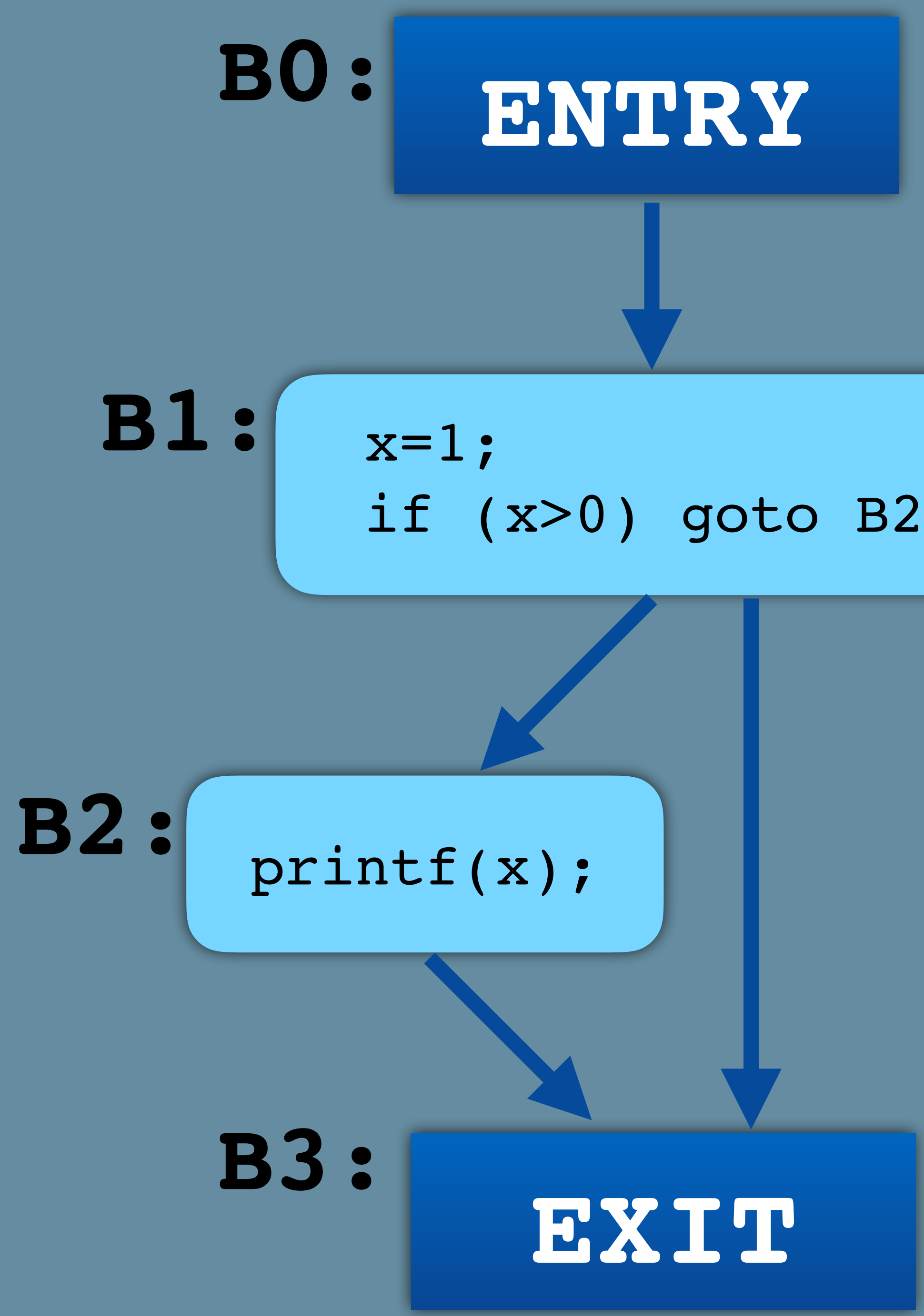
```
int foo() {
   printf("Boo!");
}
```



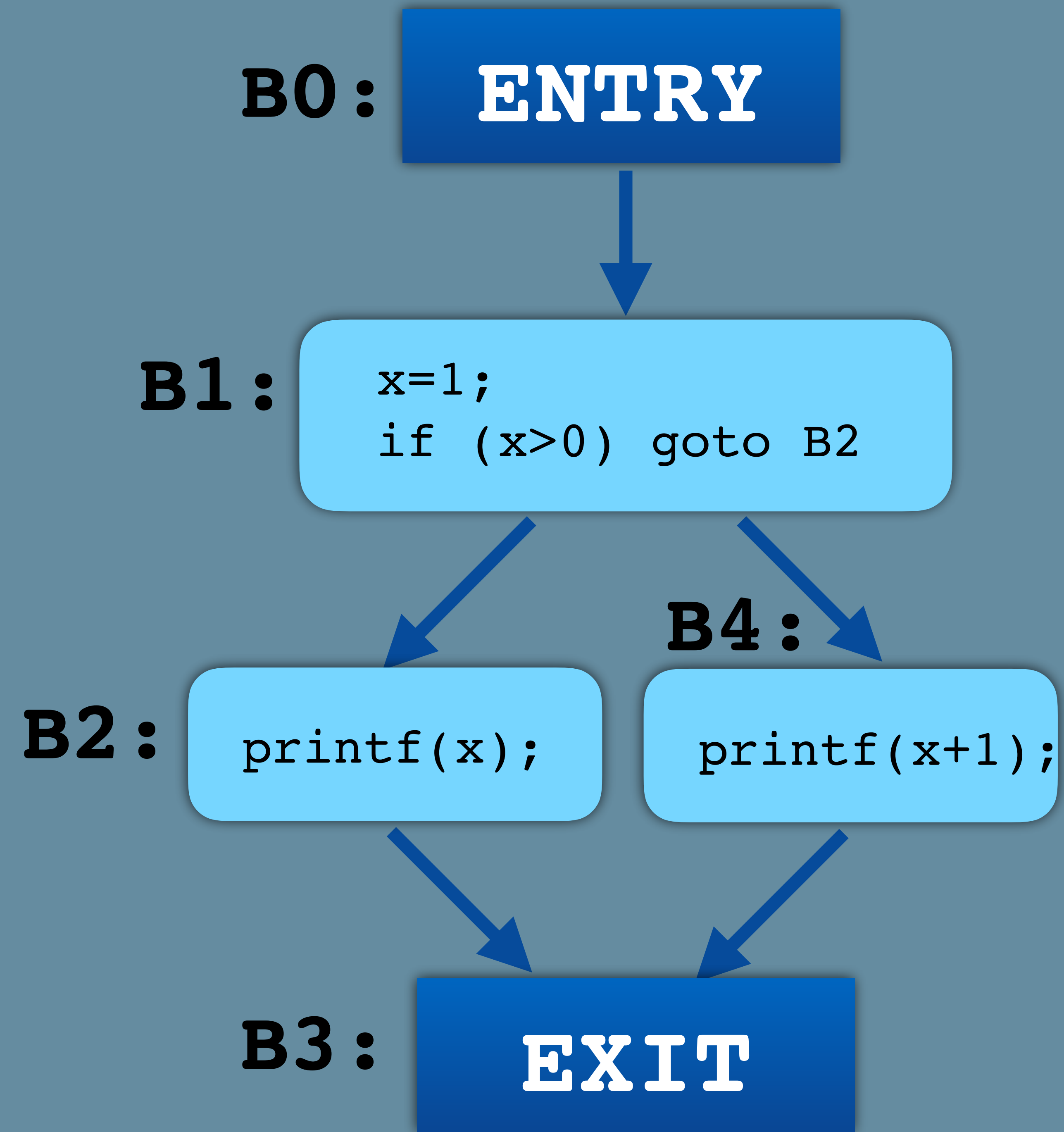
```c
int foo() {
    x=1;
    y=2;
    printf(x+y);
}
```



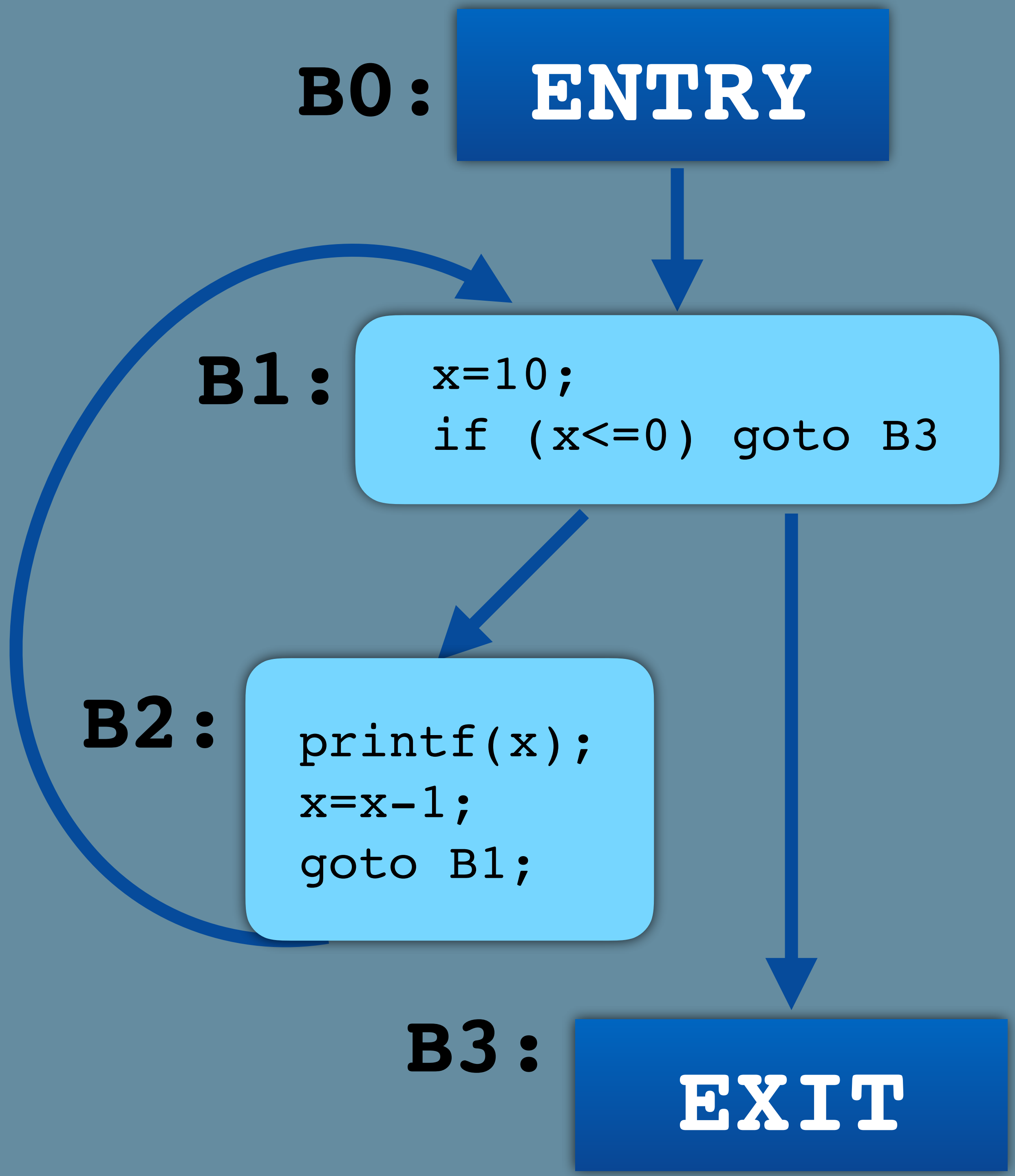
```
int foo() {
  read(x);
  if (x>0)
      printf(x);
}
```



```c
int foo() {
  read(x);
  if (x>0)
    printf(x);
  else
    printf(x+1);
}
```



```
int foo() {
  x=10;
  while (x>0){
    printf(x);
    x=x-1;
  }
}
```



1. Mark every instruction which can start a basic block as a **leader**:
    1. the **first instruction**
    2. a **target of a branch**
    3. any **instruction following a conditional branch**
2. **A basic block**: the instructions from a leader up to, but not including, the next leader.
3. Add an edge A→B if A ends with a branch to B or can fall through to B.

Exercise!

```
X ← 20;
while (X<10){
    X←X-1;
    A[X]←10;
    if (X=4)
        X←X-2;
};
Y←X+5;
```

←

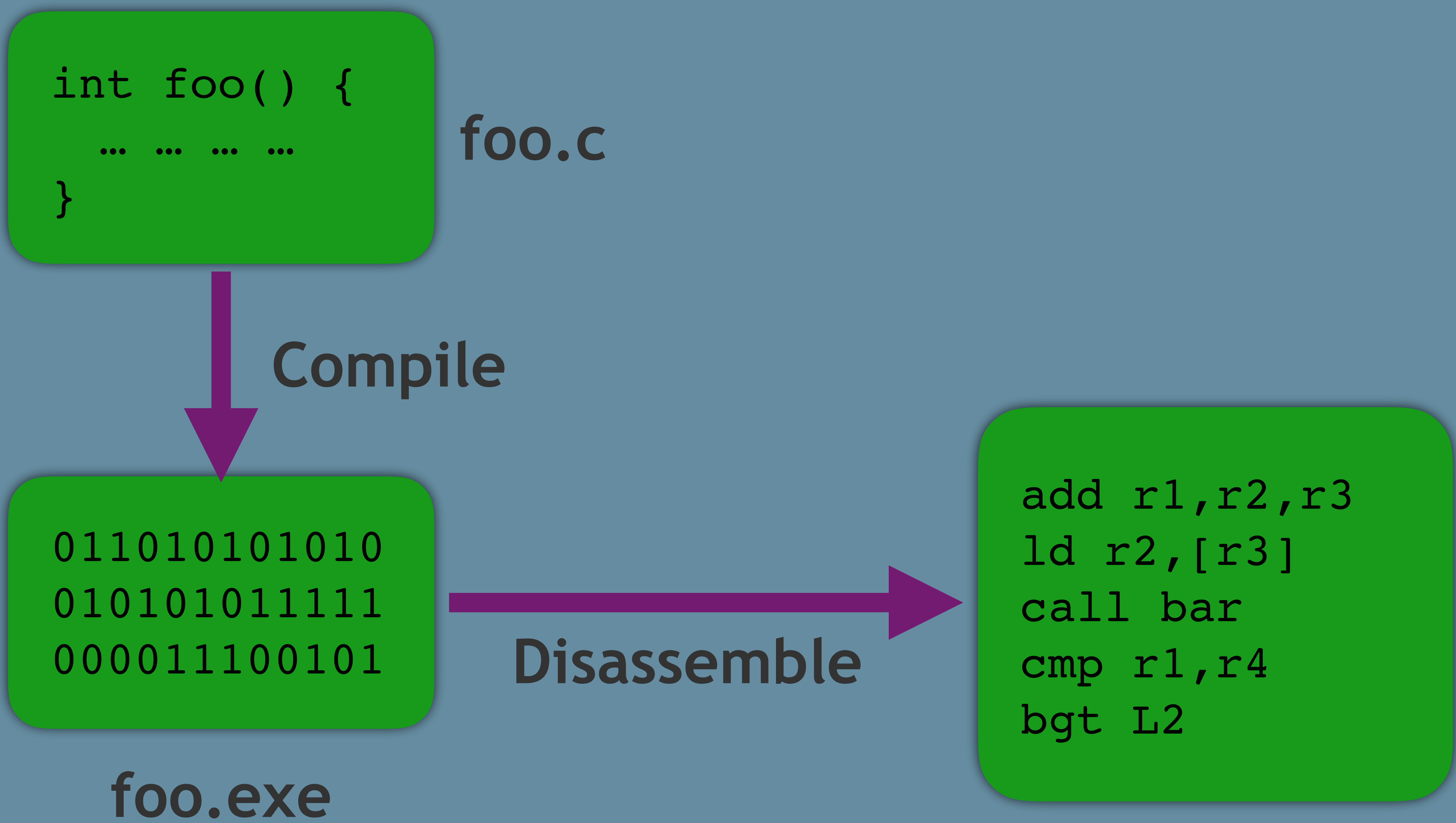
```
1: X←20
2: if X>=10 goto (8)
3: X←X-1
4: A[X]←10
5: if X!=4 goto (7)
6: X←X-2
7: goto (2)
8: Y←X+5
```

Convert to CFG! First simplify!

Work with your friends!!!

Disassembly

- ***Attackers**: prefer looking at assembly code than machine code*

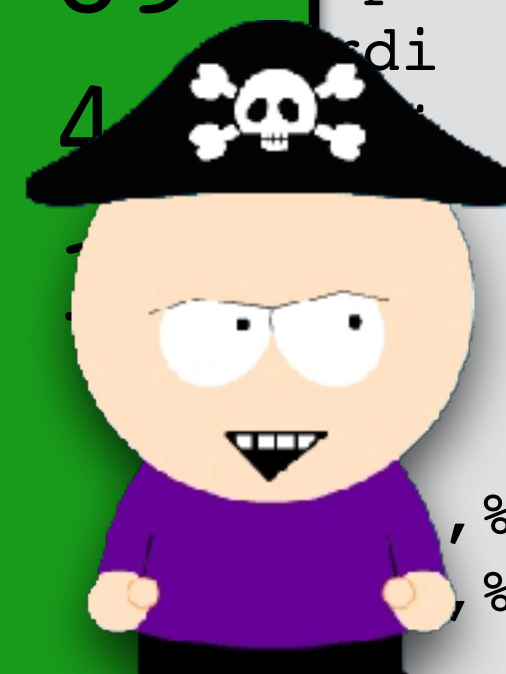


Static Disassembly

```
objdump -d i/bin/ls | less
```

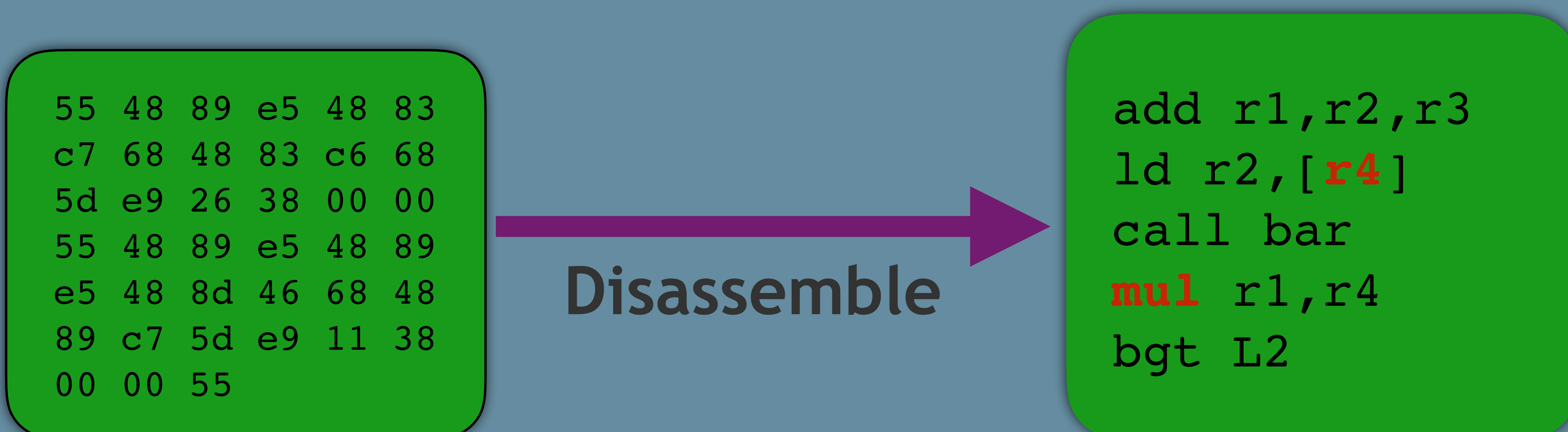
Address Code bytes Assembly

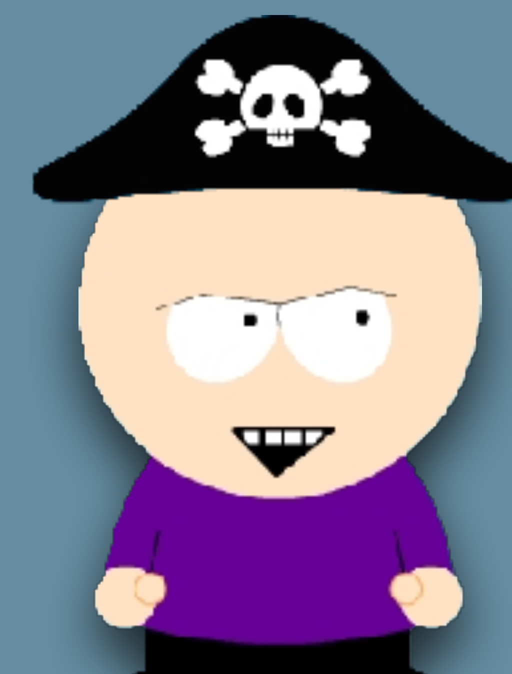
```
55 48 89 e5 48 83 c7
68 48 83 c6 68 5d e9
26 38 00 00 55 48 89
e5 48 89 e5 48 8d 4
68 48 89 c7 5d e9 1
38 00 00 55
```



```
13.  0xd9a:  e9 11 38 00 00   jmpq   1000045b0
14.  0xd9f:  55               push   %rbp
```

- *Disassembly is hard! And sometimes disassemblers get it wrong!*





  - *In general, this is always the case: program analysis is more or less precise.*

- *There are two general algorithm ideas for disassembly:*
    1. *Linear Sweep Traversal*
    2. *Recursive Traversal*
- *At times, both with fail.*
- *We typically add heuristics to improve precision.*

```
55 48 89 e5 48 83 c7 68
48 83 c6 68 5d e9 26 38
00 00 55
```

1. push   %rbp
2. mov   %rsp,%rbp
3. add $0x68,%rdi
4. add $0x68,%rsi
5. pop   %rbp
6. jmpq   1000045b0
7. push   %rbp

Linear sweep disassembly

```
55 48 89 e5 48 83 c7 68
48 83 c6 68 5d e9 26 38
00 00 55
```

```
1. 0xd78   push %rbp
2. 0xd79:  mov  %rsp,%rbp
3. 0xd7c:  add  $0x68,%rdi
4. 0xd80:  add  $0x68,%rsi
5. 0xd84:  pop  %rbp
6. 0xd85:  jmpq 0x45b0
7. 0xd8a   push %rbp
```

Recursive traversal disassembly

Stack

0xd8a

Exercise!

```
0xd78: push %rbp
0xd79: mov  %rsp,%rbp
0xd7c: add  $0x68,%rdi
0xd80: add  $0x68,%rsi
0xd84: pop  %rbp
0xd85: jmpq 0x45b0
0xd8a: .byte 0x55
0xd8b: mov  %rdi,%rbp
```

`0x55 ≡ push %rbp!!!`

- How would a **linear sweep** disassembly handle this code?

Exercise!

```
1. 0xd78: push %rbp
2. 0xd79: mov  %rsp,%rbp
3. 0xd7c: add  $0x68,%rdi
4. 0xd80: add  $0x68,%rsi
5. 0xd84: pop  %rbp
6. 0xd85: jmpr %rdi
7.0xd8b: mov  %rdi,%rbp
```

Indirect jump!

- How would a **recursive traversal** disassembly handle this code?



Questions?