Program Analysis

- Attackers: need to analyze our program to modify it!
- Defenders: need to analyze our program to protect it!
- Two kinds of analyses:
  1. *static analysis tools* collect information about a program by studying its code;
  2. *dynamic analysis tools* collect information from executing the program.

Static and Dynamic Analyses

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- disassembly: turn raw executables into assembly code.

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- disassembly: turn raw executables into assembly code.
- decompilation: turn raw assembly code into source code.

Outline

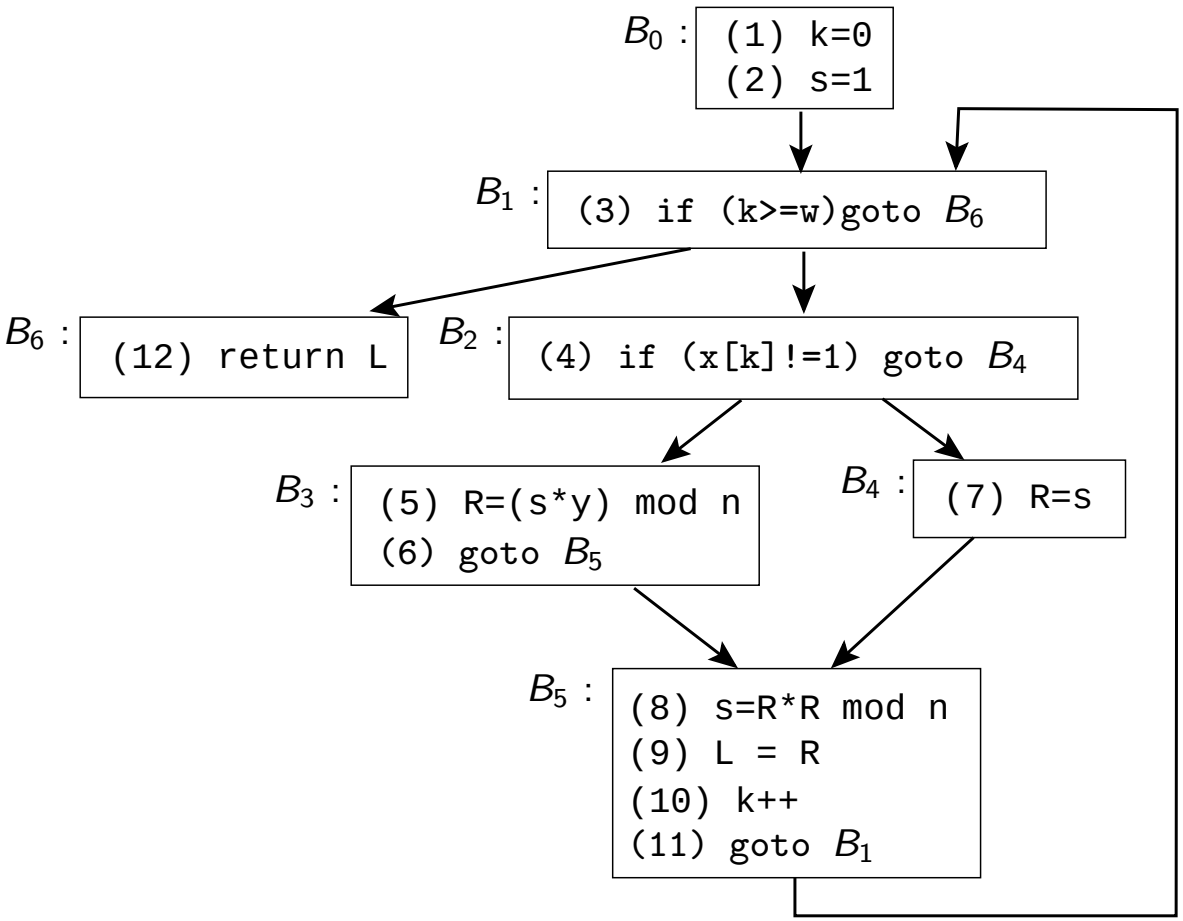
Control-flow Graphs (CFGs)

- A way to represent functions.
- Nodes are called basic blocks.
- Each block consists of straight-line code ending (possibly) in a branch. ¡
- An edge $A \rightarrow B$: control could flow from A to B.

```
int modexp(int y,int x[],
           int w,int n) {
    int R, L;
    int k = 0;
    int s = 1;
    while (k < w) {
        if (x[k] == 1)
            R = (s*y) % n;
        else
            R = s;
        s = R*R % n;
        L = R;
        k++;
    }
    return L;
}
```

```
 (1) k=0
 (2) s=1
 (3) if (k>=w) goto (12)
 (4) if (x[k]!=1) goto (7)
 (5) R=(s*y)%n
 (6) goto (8)
 (7) R=s
 (8) s=R*R%n
 (9) L=R
(10) k++
(11) goto (3)
(12) return L
```

The resulting graph



BuildCFG(F):

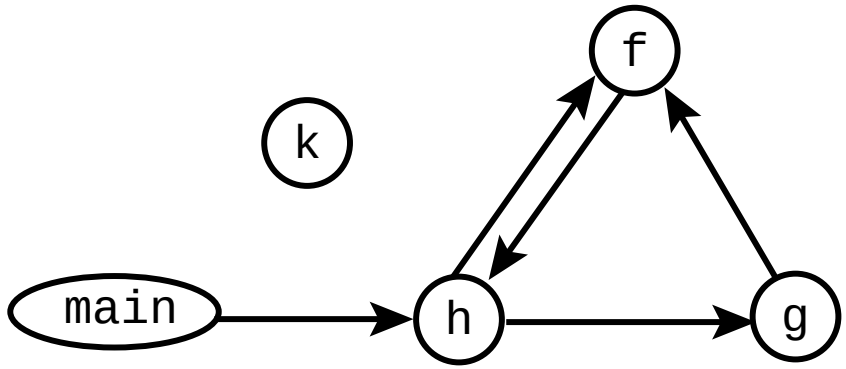
1. Mark every instruction which can start a basic block as a *leader*:
   - the first instruction is a leader;
   - any target of a branch is a leader;
   - the instruction following a conditional branch is a leader.
2. A basic block consists of the instructions from a leader up to, but not including,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

Interprocedural control flow

- *Interprocedural analysis* also considers flow of information between functions.
- Call graphs are a way to represent possible function calls.
- Each node represents a function.
- An edge $A \to B$: A might call B.

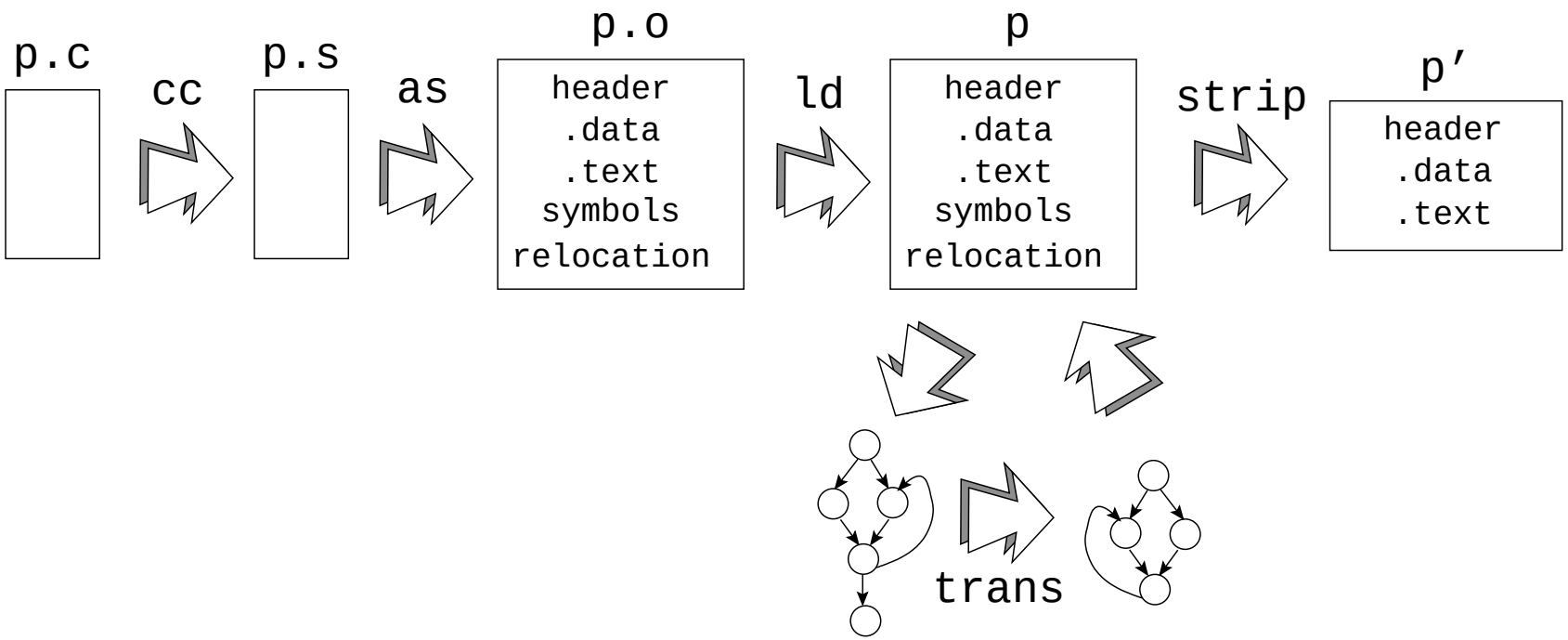
Building call-graphs

```
void h();

void f(){
    h();
}

void g(){
    f();
}

void h() {
   f();
   g();
}

void k() {}

int main() {
    h();
    void (*p)() = &k;
```

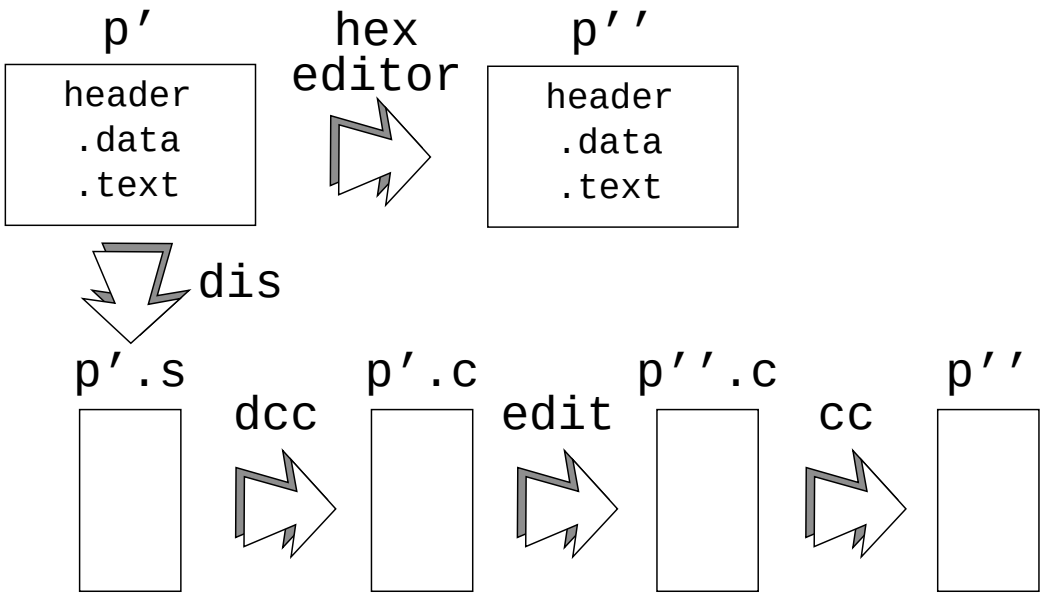


Outline

Reconstituting source



Attacking stripped binary code



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- Finding the end of fuctions — if no dedicated return instruction.
- Handwritten assembly code — won't conform to the standard calling conventions.
- code compression — the code of two functions may overlap.
- Self-modifying code.

Instruction set 1

opcode	mnemonic	operands	semantics
0	`call`	*addr*	function call to *addr*
1	`calli`	*reg*	function call to address in *reg*
2	`brg`	*offset*	branch to $\mathrm{pc} + $ *offset* if flags for $>$ are set
3	`inc`	*reg*	*reg* $\leftarrow$ *reg* $+ 1$
4	`bra`	*offset*	branch to $\mathrm{pc} + $ *offset*
5	`jmpi`	*reg*	jump to address in *reg*
6	`prologue`		beginning of function
7	`ret`		return from function

- Instruction set for a small architecture.
- All operators and operands are one byte long.
- Instructions can be 1-3 bytes long.

Instruction set 2

opcode	mnemonic	operands	semantics
8	`load`	$reg_1, (reg_2)$	$reg_1 \leftarrow [reg_2]$
9	`loadi`	reg, imm	$reg \leftarrow imm$
10	`cmpi`	reg, imm	compare *reg* and *imm* and set flags
11	`add`	reg_1, reg_2	$reg_1 \leftarrow reg_1 + reg_2$
12	`brge`	*offset*	branch to $\mathrm{pc} + offset$ if flags for $\geq$ are set
13	`breq`	*offset*	branch to $\mathrm{pc} + offset$ if flags for $=$ are set
14	`store`	$(reg_1), reg_2$	$[reg_1] \leftarrow reg_2$

Disassembly — example

```
6 0 10 9 0 43 1 0 7 0 6 9 0 1 10 0 1 2 26 9
1 30 11 1 0 8 2 1 5 2 32 37 9 1 3 4 7 9 1 4
4 2 7 6 9 0 3 7 6 9 0 1 7 42 2 4 3 1 7 4
3 4 1
```

- Next few slides show the results of different disassembly algorithms.
- Correctly disassembled regions are in pink.

```
main: # ORIGINAL PROGRAM
0: [6]        prologue
1: [0,10]     call        foo
3: [9,0,43]   loadi       r0,43
6: [1,0]      calli       r0
8: [7]        ret
9: [0]        .align      2
foo:
10:[6]        prologue
11:[9,0,1]    loadi       r0,1
14:[10,0,1    cmpi        r0,1
17:[2,26]     brg         26
19:[9,1,30]   loadi       r1,30
22:[11,1,0]   add         r1,r0
25:[8,2,1]    load  r2,(r1)
28:[5,2]      jmpi        r2
30:[32]       .byte       32
31:[37]       .byte       37
32:[9,1,3]    loadi       r1,3
35:[4,7]      bra         7
37:[9,1,4]    loadi       r1,4
40:[4,2]      bra         2
42:[7]        ret
```

```
bar:
43:[6]        prologue
44:[9,0,3]    loadi       r0,3
47:[7]        ret
baz:
48:[6]        prologue
49:[9,0,1]    loadi       r0,1
52:[7]        ret
life:
53:[42]       .byte       42
fred:
54:[2,4]      brg         4
56:[3,1]      inc         r1
58:[7]        ret
59:[4,3]      bra         3
61:[4,1]      bra         1
```

```
# LINEAR SWEEP DISASSEMBLY
0: [6]          prologue
1: [0,10]       call      10
3: [9,0,43]     loadi     r0,43
6: [1,0]        calli     r0
8: [7]          ret
9: [0,6]        call      6
11:[9,0,1]      loadi     r0,1
14:[10,0,1]     cmpi      r0,1
17:[2,26]       brg       26
19:[9,1,30]     loadi     r1,30
22:[11,1,0]     add       r1,r0
25:[8,2,1]      load   r2,(r1)
28:[5,2]        jmpi      r2
30:[32]         ILLEGAL   32
31:[37]         ILLEGAL   37
32:[9,1,3]      loadi     r1,3
35:[4,7]        bra       7
37:[9,1,4]      loadi     r1,4
40:[4,2]        bra       2
42:[7]          ret
```

```
43:[6]          prologue
44:[9,0,3]      loadi     r0,3
47:[7]          ret
48:[6]          prologue
49:[9,0,1]      loadi     r0,1
52:[7]          ret
53:[42]         ILLEGAL   42
54:[2,4]        brg       4
56:[3,1]        inc       r1
58:[7]          ret
59:[4,3]        bra       3
61:[4,1]        bra       1
```

```
f0: # RECURSIVE TRAVERSAL
0: [6]          prologue
1: [0,10]       call        10
3: [9,0,43]     loadi       r0,43
6: [1,0]        calli       r0
8: [7]          ret

9: [0]          .byte       0

f10:
10:[6]          prologue
11:[9,0,1]      loadi       r0,1
14:[10,0,1]     cmpi        r0,1
17:[2,26]       brg         26
19:[9,1,30]     loadi       r1,30
22:[11,1,0]     add         r1,r0
25:[8,2,1]      load    r2,(r1)
28:[5,2]        jmpi        r2
30:[32]         .byte       32
31:[37]         .byte       37
32:[9,1,3]      loadi       r1,3
35:[4,7]        bra         7
37:[9,1,4]      loadi       r1,4
40:[4,2]        bra         2
42:[7]          ret
43:[6]          prologue
44:[9,0,3]      loadi       r0,3
47:[7]          ret

48:[6]          .byte       6
49:[9]          .byte       9
50:[0]          .byte       0
51:[1]          .byte       1
52:[7]          .byte       7
53:[42]         .byte       42
54:[2]          .byte       2
     ..........
59:[4]          .byte       4
60:[3]          .byte       3
61:[4]          .byte       4
62:[1]          .byte       1
```