MONTANA STATE UNIVERSITY

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Malicious Code Analysis

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Overview

01 Control Flow Graph

02 Program Dependency Graph

03 Call Graph

Part One

01

Control Flow Graph

Control flow graphs

The most commonly used program representation.

Program analysis

Malware analysis

Testing

Program representation: Basic blocks

- A basic block in program P is a sequence of consecutive statements with a single entry and a single exit point. Thus a block has unique entry and exit points.

- Control always enters a basic block at its entry point and exits from its exit point. There is no possibility of exit or a halt at any point inside the basic block except at its exit point. The entry and exit points of a basic block coincide when the block contains only one statement.

Basic blocks: Example

Example: Computing x raised to y

```
begin
    int x, y, power;
    float z;
    scanf("%d %d", &x, &y);
    if (y<0)
      power=-y;
    else
      power=y;
    z=1;
    while (power! = 0) {
      z=z*x;
      power = power-1;
    }
    if (y<0)
      z=1/z;
    printf("%f", z);
end
```

Basic blocks: Example (contd.)

Basic blocks

Block	Lines	Entry point	Exit point
1	2, 3, 4, 5	1	5
2	6	6	6
3	8	8	8
4	9	9	9
5	10	10	10
6	11, 12	11	12
7	14	14	14
8	15	15	15
9	16	16	16

Basic blocks: Example

Example: Computing maximum

```
main:
    call _CRT_INIT
    push    rbp
    mov     rbp, rsp
    sub     rsp, 32
    mov     rcx, 100
    mov     rdx, 200
    call    print_max
    xor     eax, eax
    call ExitProcess
```

Basic blocks: Example (contd.)

Basic blocks

Block	Lines	Entry point	Exit point
1	2	1	2
2	3,4,5,6,7,8	3	8
3	9,10	9	10

Control Flow Graph (CFG)

- A **control flow graph** (or flow graph) G is defined as a finite set N of nodes and a finite set E of edges. An edge (i, j) in E connects two nodes n_i and n_j in N. We often write G= (N, E) to denote a flow graph G with nodes given by N and edges by E.

Control Flow Graph (CFG)

- In a flow graph of a program, each basic block becomes a node and edges are used to indicate the flow of control between blocks.

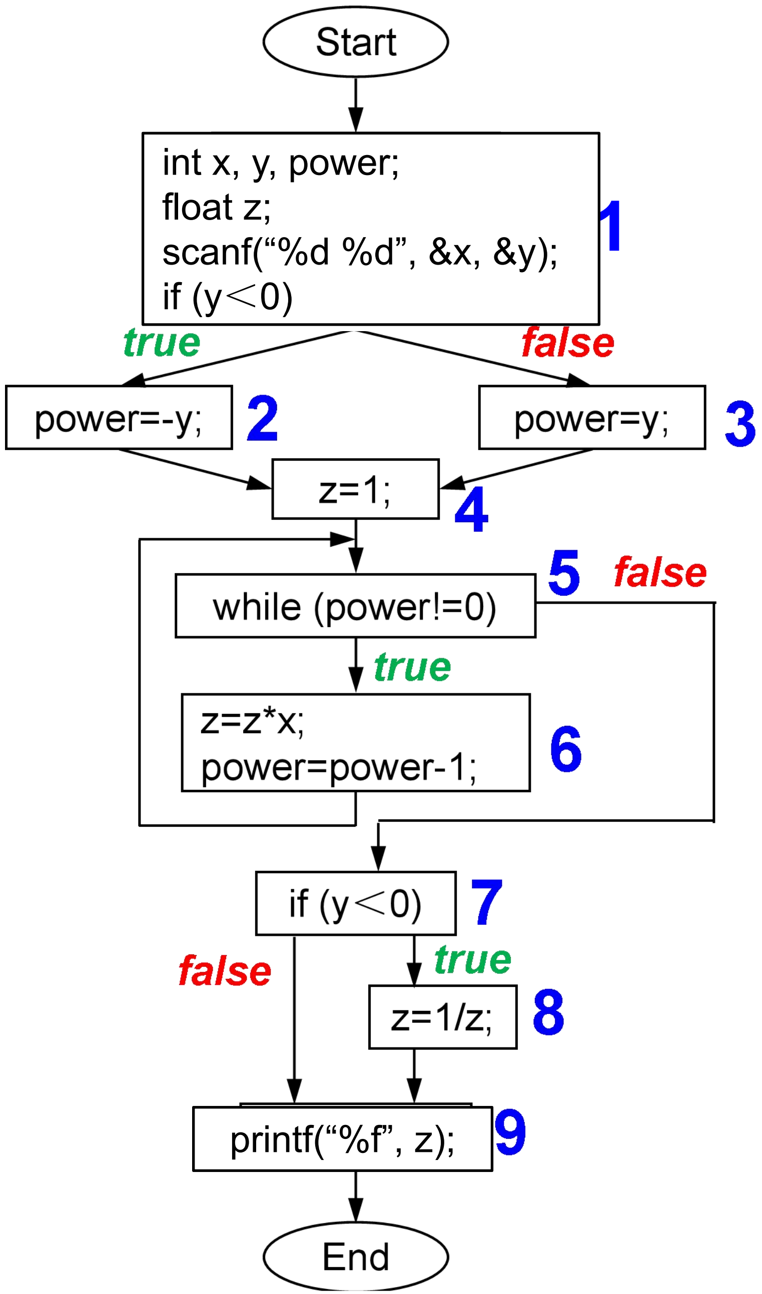
- An edge (i, j) connecting basic blocks b_i and b_j implies that control can go from block b_i to block b_j.

- We also assume that there is a node labeled **Start** in N that has no incoming edge, and another node labeled **End**, also in N, that has no outgoing edge.

CFG Example

- N={Start, 1, 2, 3, 4, 5, 6, 7, 8, 9, End}

- E={(Start,1), (1, 2), (1, 3), (2,4), (3, 4), (4, 5), (5, 6), (6, 5), (5, 7), (7, 8), (7, 9), (9, End)}

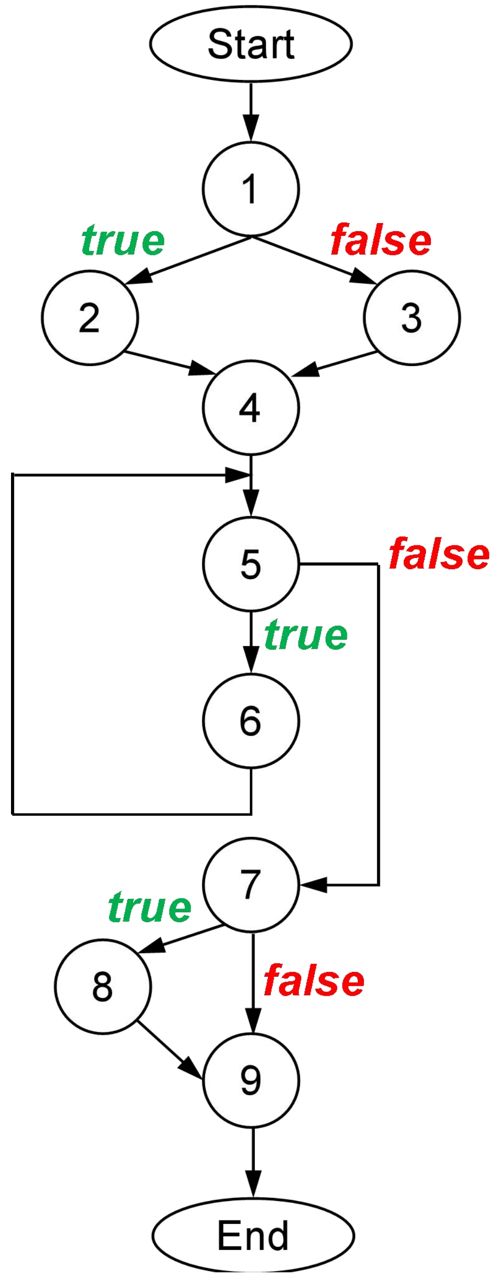


CFG Example

- Same CFG with statements removed.

- N={Start, 1, 2, 3, 4, 5, 6, 7, 8, 9, End}

- E={(Start,1), (1, 2), (1, 3), (2,4), (3, 4), (4, 5), (5, 6), (6, 5), (5, 7), (7, 8), (7, 9), (9, End)}



Paths

- Consider a flow graph G= (N, E). A sequence of k edges, k>0, (e_1, e_2, … e_k) , denotes a path of length k through the flow graph if the following sequence condition holds.

- Given that n_p, n_q, n_r, and n_s are nodes belonging to N, and 0< i<k, if $e_i = (n_p, n_q)$ and $e_{i+1} = (n_r, n_s)$ then $n_q = n_r$. }

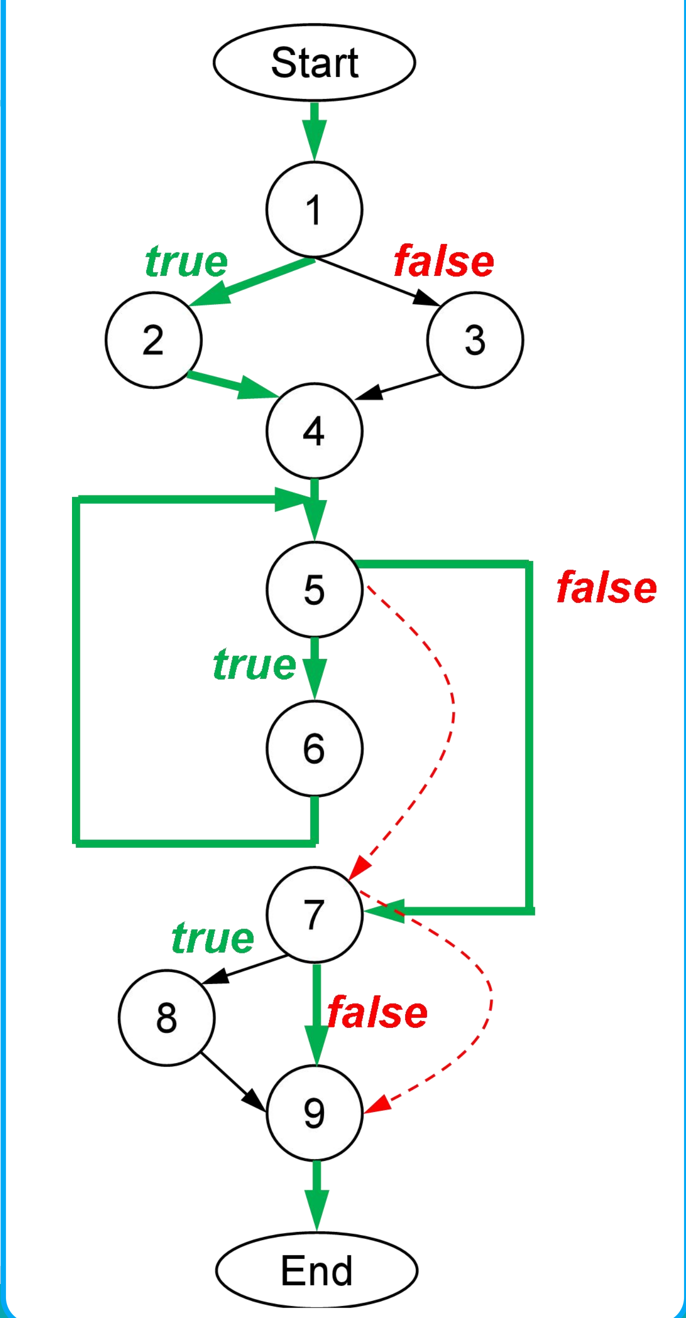
- Complete path: a path from start to end
- Subpath: a subsequence of a complete path

Paths: sample paths through the exponentiation flow graph

- Two feasible and complete paths:
  - p_1= (Start, 1, 2, 4, 5, 6, 5, 7, 9, End)
  - p_2= (Start, 1, 3, 4, 5, 6, 5, 7, 9, End)

- Specified unambiguously using edges:
  - p_1= ((Start, 1), (1, 2), (2, 4), (4, 5), (5, 6), (6, 5), (5, 7), (7, 9), (9, End))

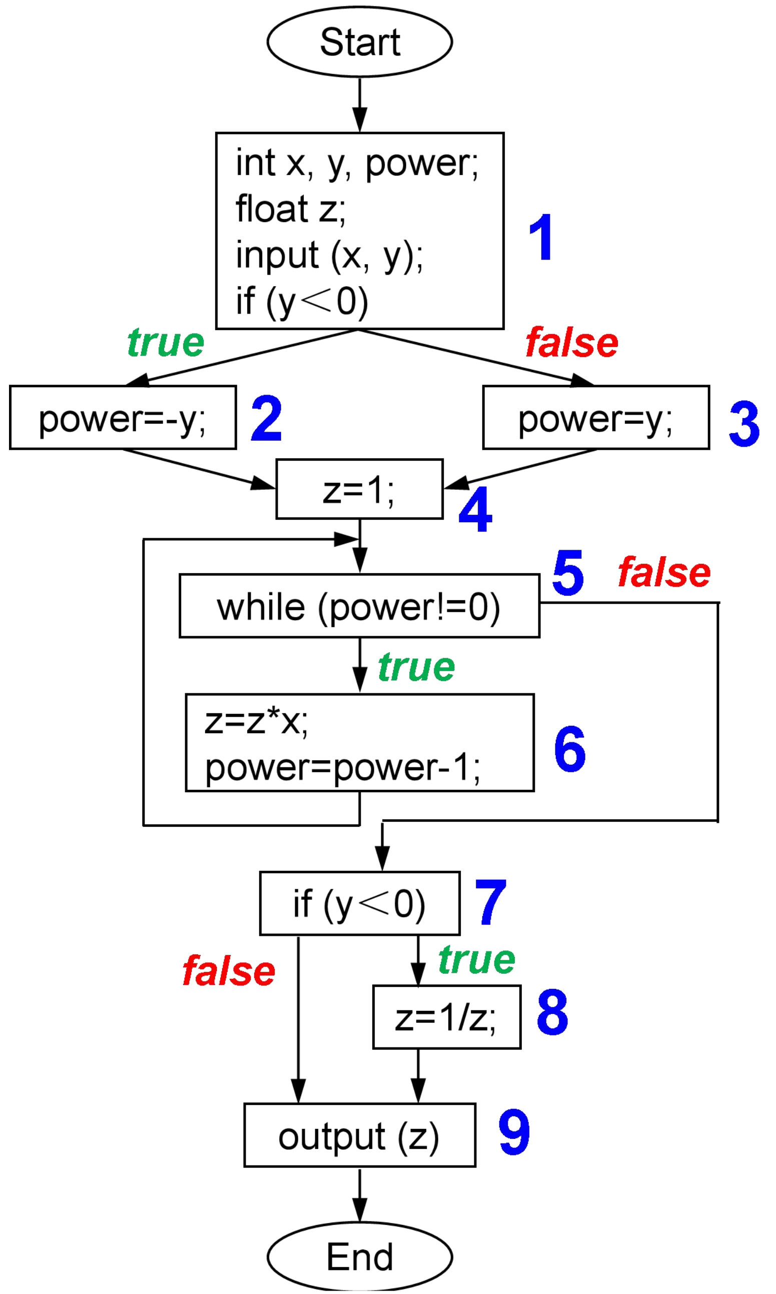
☞ *Green bold edges: complete path.*
☞ *Red dashed edges: subpath.*



Paths: infeasible paths

A path p through a flow graph for program P is considered **feasible** if there exists at least one test case which when input to P causes p to be traversed.

- p1= (Start, 1, 3, 4, 5, 6, 5, 7, 8, 9, End)
- p2= (Start, 1, 2, 4, 5, 7, 9, End)



Number of paths

- There can be many distinct paths through a program. A program with no condition contains exactly one path that begins at node Start and terminates at node End.
- Each additional condition in the program can increase the number of distinct paths by at least one.
- Depending on their location, conditions can have a multiplicative effect on the number of paths.

A Simplified Version of CFG

- Each statement is represented by a node.
  - For readability.
  - Not for efficient implementation.

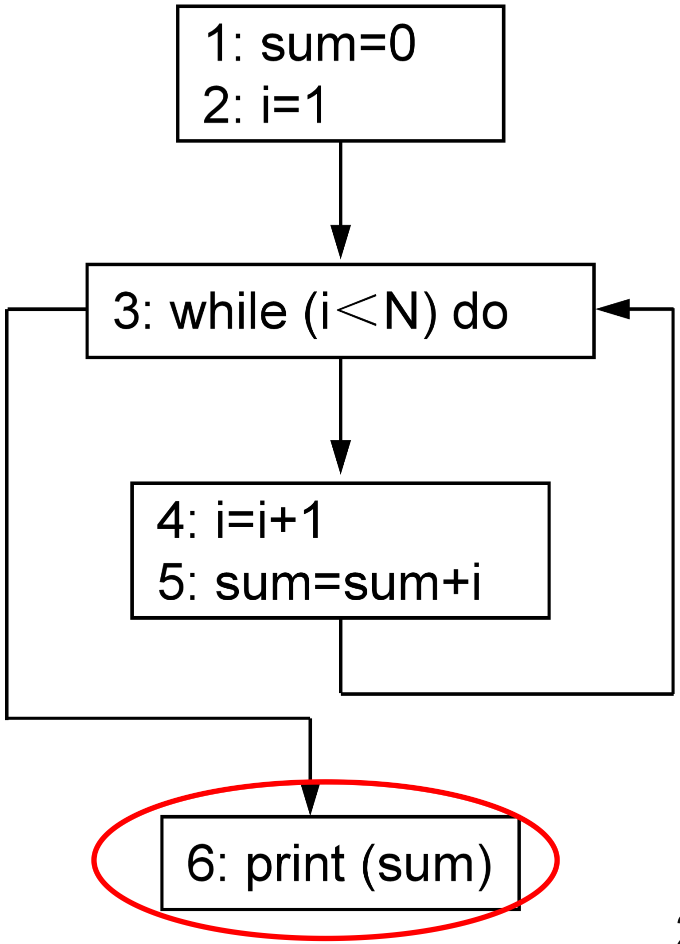
Dominator

X **dominates** Y if all possible program paths from START to Y have to pass X.

Dominator

- X **dominates** Y if all possible program path from START to Y has to pass X.

1	sum=0
2	i=1
3	while (i < N) do
4	i=i+1
5	sum=sum+i endwhile
6	**print (sum)**

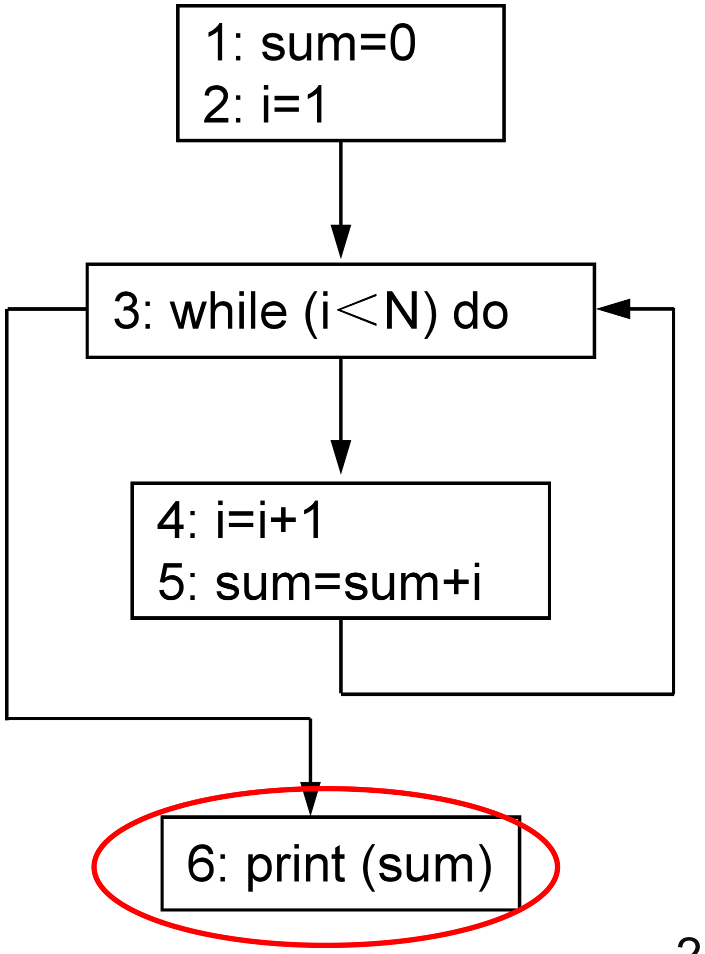


- DOM(6)={1,3,6}

Dominator

- X **strictly dominates** Y if X dominates Y and X!=Y

1	sum=0
2	i=1
3	while (i < N) do
4	i=i+1
5	sum=sum+i endwhile
6	**print (sum)**



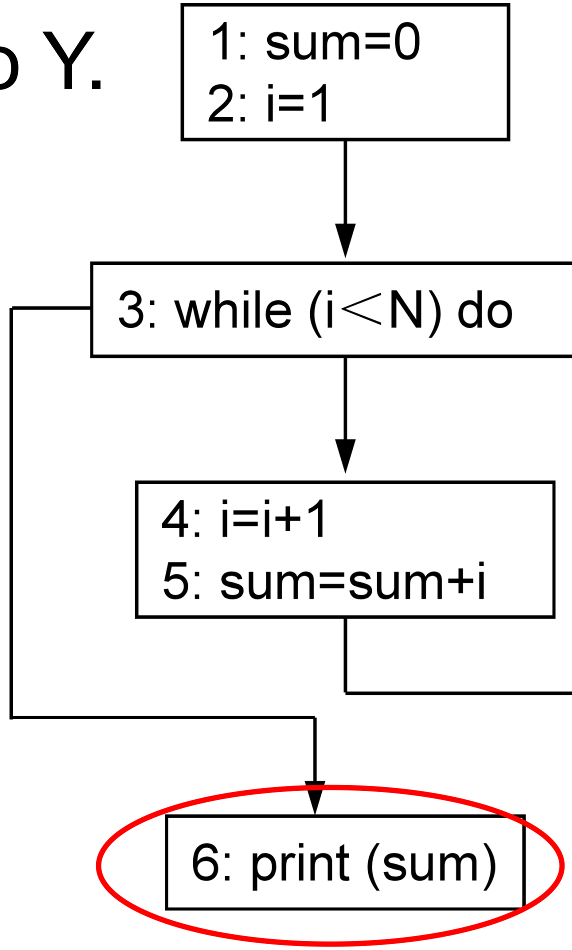
➢ SDOM(6)={1,3}

Dominator

- X is **the immediate dominator** of Y if X is the last dominator of Y along a path from Start to Y.

1	sum=0
2	i=1
3	while (i < N) do
4	i=i+1
5	sum=sum+i endwhile
6	**print (sum)**

- IDOM(6)={3}



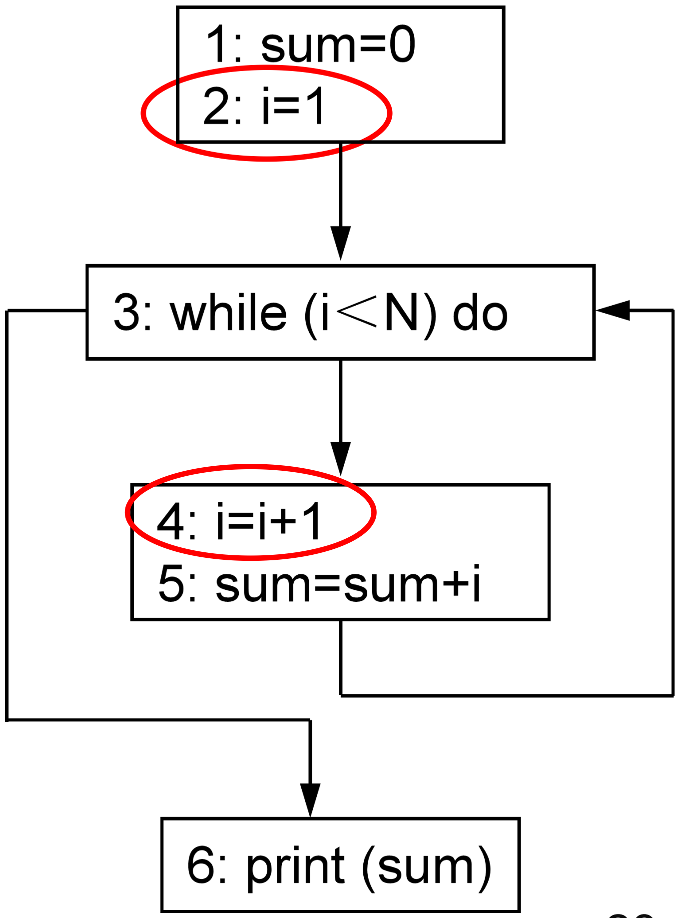
Dominator

X **post-dominates** Y if every possible program path from Y to End has to pass X.

- Strict post-dominator, immediate post-dominance.

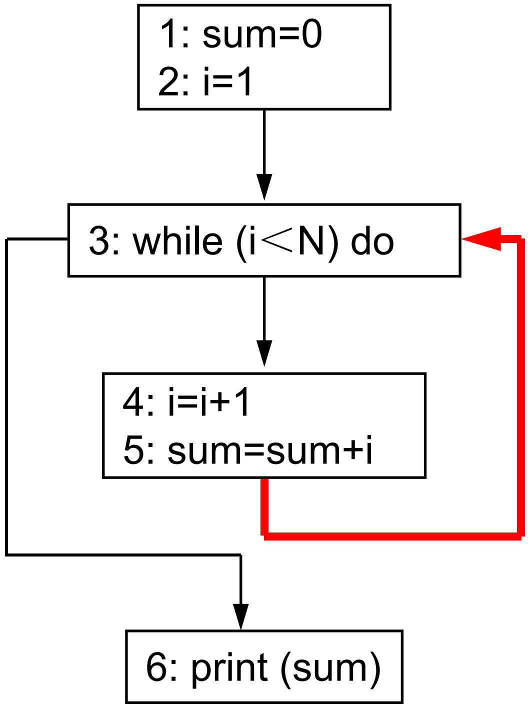
1	sum=0
2	i=1
3	while (i < N) do
4	i=i+1
5	sum=sum+i endwhile
6	**print (sum)**

- SPDOM(4)={3,6}
- IPDOM(4)=3



Back Edges

- A back edge is an edge whose head dominates its tail
  - Back edges often identify loops.



Part Two

02

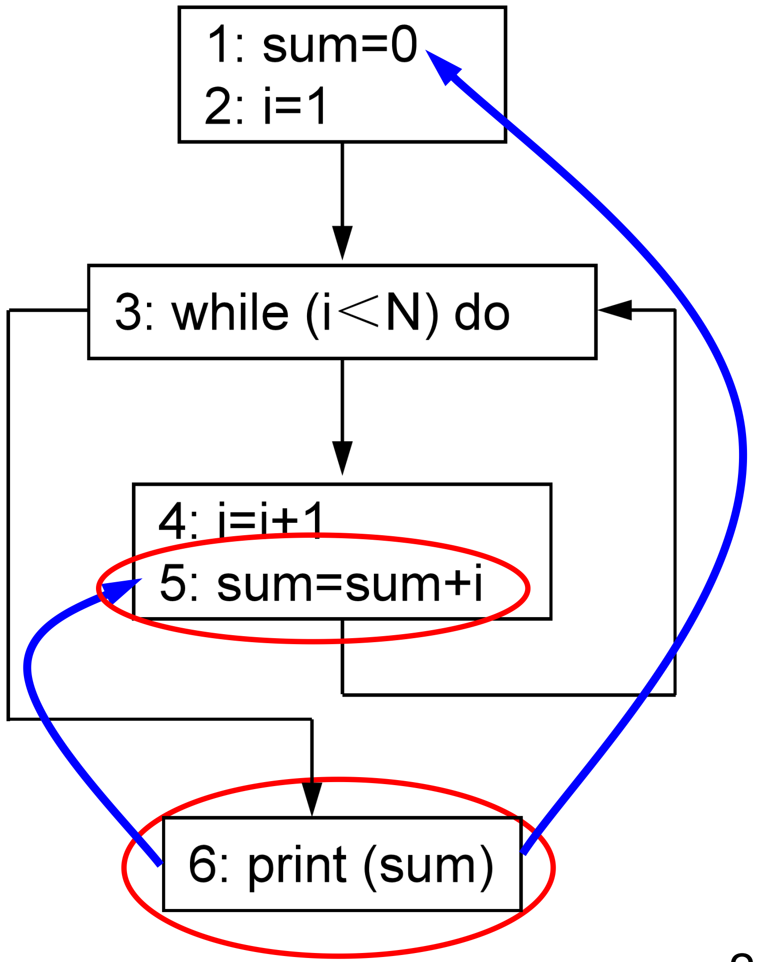
Program Dependency Graph

Program Dependence Graph

- The second widely used program representation.
- Nodes are constituted by statements instead of basic blocks.
- Two types of dependences between statements.
  - Data dependence
  - Control dependence

Data Dependence

- X is data dependent on Y if (1) there is a variable v that is defined at Y and used at X and (2) there exists a path of nonzero length from Y to X along which v is not re-defined.



Computing Data Dependence is Hard in General

- Aliasing
  - A variable can refer to multiple memory locations/objects.

```
int x, y, z, ...;
int * p;
x=...;
y=...;
p=& x;
p=p+z
...=*p;
```

```
foo (ClassX x, ClassY y) {
    x.field=...;
    ...=y.field;
}
```

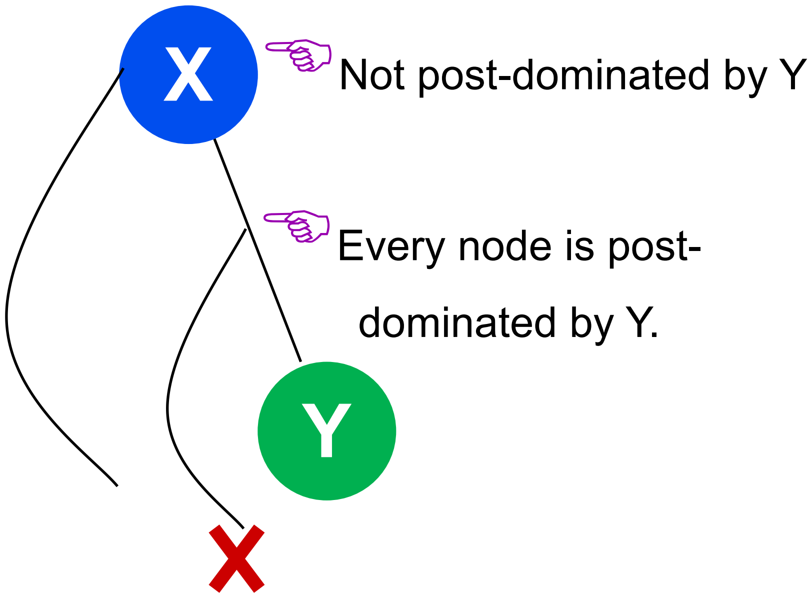
```
foo (o, o);
```

```
o1=new ClassX();
o2=new ClassY();
foo (o1, o2);
```

Control Dependence

- Intuitively, Y is control-dependent on X iff X directly determines whether Y executes (statements inside one branch of a predicate are usually control dependent on the predicate).

- X is not strictly post-dominated by Y.
  - **There is a path from X to End that does not pass Y or X==Y.**
- There exists a path from X to Y s.t. every node in the path other than X and Y is post-dominated by Y.
  - **No such paths for nodes in a path between X and Y.**



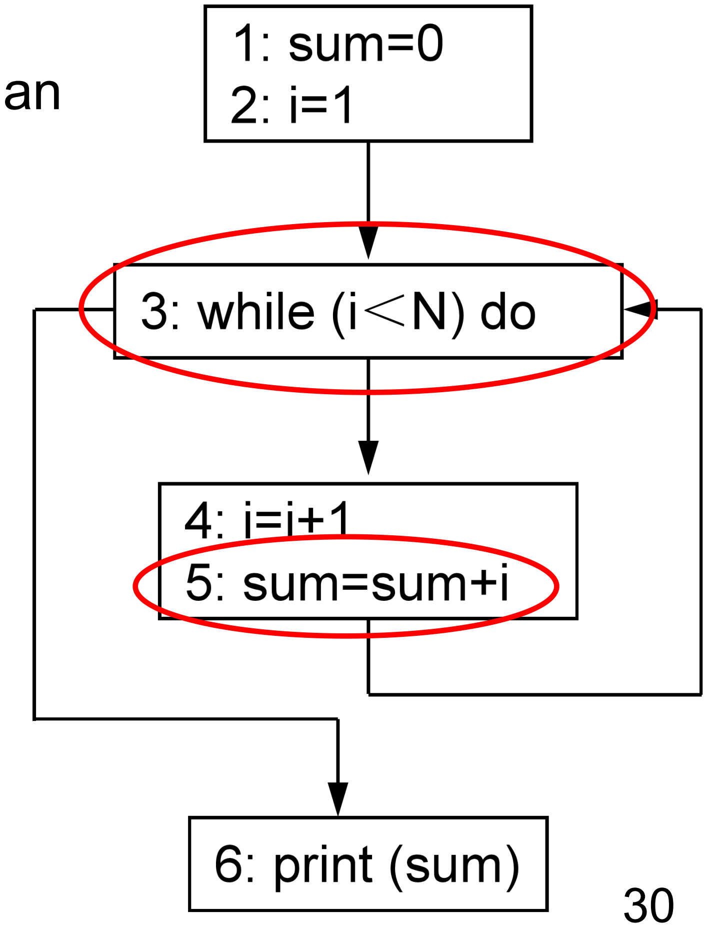
Control Dependence - Example

- Y is control-dependent on X iff X directly determines whether Y executes.
  - X is not strictly post-dominated by Y.
  - There exists a path from X to Y s.t. every node in the path other than X and Y is post-dominated by Y.

1	sum=0
2	i=1
3	while (i < N) do
4	i=i+1
5	sum=sum+i endwhile
6	**print (sum)**

☞ CD(5)=3

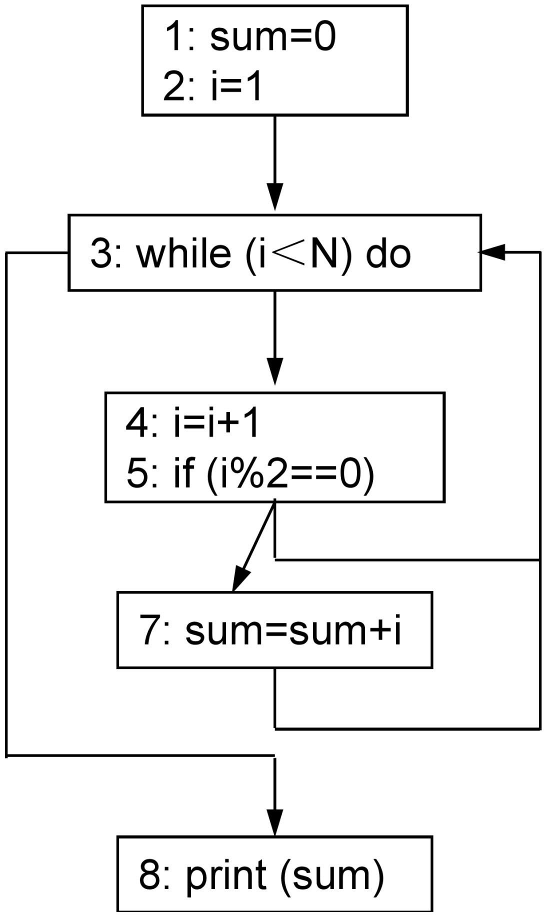
☞ CD(3)=3, **tricky!**



Note: Control Dependence is not Syntactically Explicit

- Y is control-dependent on X iff X directly determines whether Y executes.
  - X is not strictly post-dominated by Y.
  - There exists a path from X to Y s.t. every node in the path other than X and Y is post-dominated by Y.

1	sum=0
2	i=1
3	while (i < N) do
4	i=i+1
5	if (i%2==0)
6	continue
7	sum=sum+i endwhile
8	print (sum)



Control Dependence is Tricky!

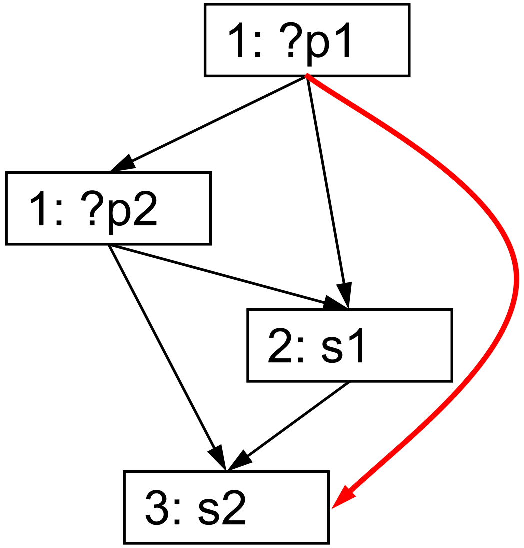
- Y is control-dependent on X iff X directly determines whether Y executes.
  - X is not strictly post-dominated by Y.
  - There exists a path from X to Y s.t. every node in the path other than X and Y is post-dominated by Y.

- Can one statement control depends on two predicates?

1	if (p1 || p2)
2	s1;
3	s2;

What if? →

1	if (p1 && p2)
2	s1;
3	s2;



The Use of PDG

- A program dependence graph consists of control dependence graph and data dependence graph.

- Why it is so important to software reliability?
  - In debugging, what could possibly induce the failure?
  - In security.

```
p=getpassword();
...
send (p);
```

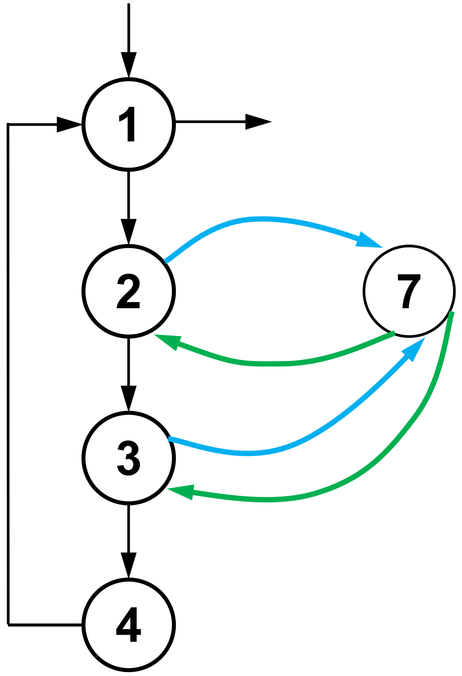
```
p=getpassword();
...
if (p==”zhang”) {
    send (m);
}
```

Super Control Flow Graph (SCFG)

Besides the normal intraprocedural control flow graph, additional edges are added connecting?

- Each call site to the beginning of the procedure it calls.
- The return statement back to the call site.

```
1      for (i=0; i < n, i++) {
2          t1=f(0);
3          t2=f(234);
4          x[i]=t1+t2+t3;
5      }
6   int f (int v) {
7      reture (v+1);
8   }
```



Part Three

03

Call Graph

Call Graph (CG)

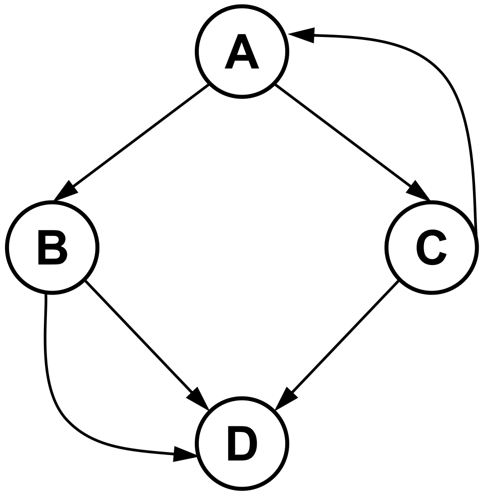
- Y Each node represents a function; each edge represents a function invocation.

```
void A() {
    B();
    C();
}

void C() {
    D();
    A();
}
```

```
viod B() {
L1: D();
L2: D();
}

void D() {
}
```



THE END

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