Program Representations

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0101011
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frob.exe

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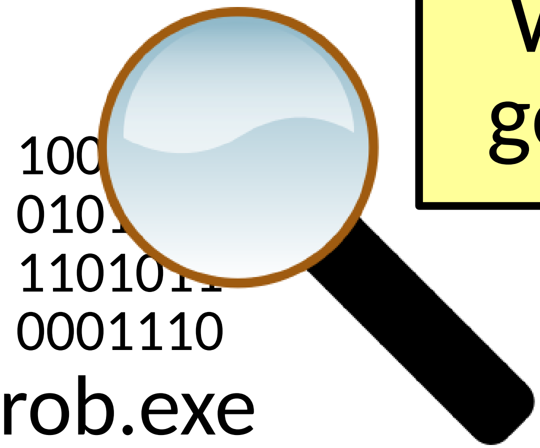
Why might binaries be good for security tasks?



Program Representation

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- Difficult models:
  - Compiled binaries
  - Source code

Foo.c
Bar.c
Baz.c

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  - Compiled binaries
  - Source code
    - Very language specific
    - Relationships can be hard to extract
    - Often used when relating to comments or specs

Program Representation

- Before we can reason about programs, we must have a vocabulary and a *model* to analyze
- Difficult models:
  - Compiled binaries
  - Source code
- A *good* representation should make explicit the relationships you want to analyze

Program Representation

Core graph representations for analysis:

1) Abstract Syntax Trees
2) Control Flow Graphs
3) Program Dependence Graphs
4) Call Graphs
5) Points-to Graphs

1) Abstract Syntax Trees

- Lifts the source into a canonical tree form

```
for i in range(5,10):
    a[i] = i * 5
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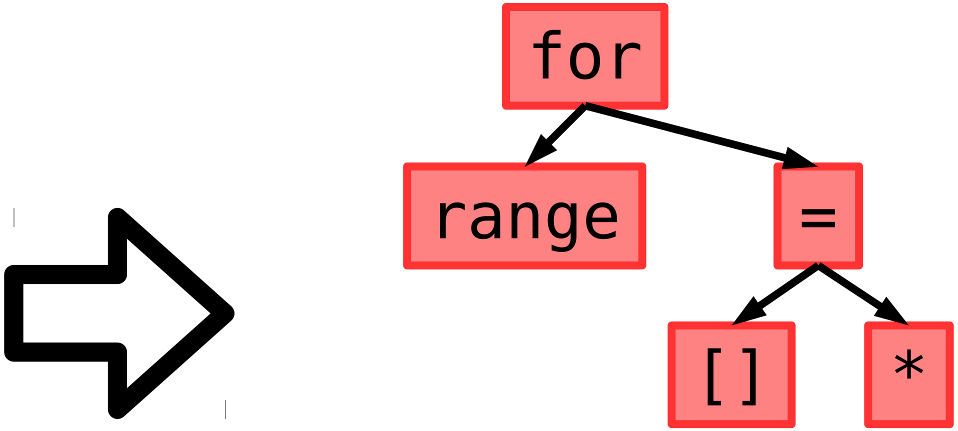

1) Abstract Syntax Trees

- Lifts the source into a canonical tree form
  - Internal nodes are operators, statements, etc.
  - Leaves are values, variables, operands

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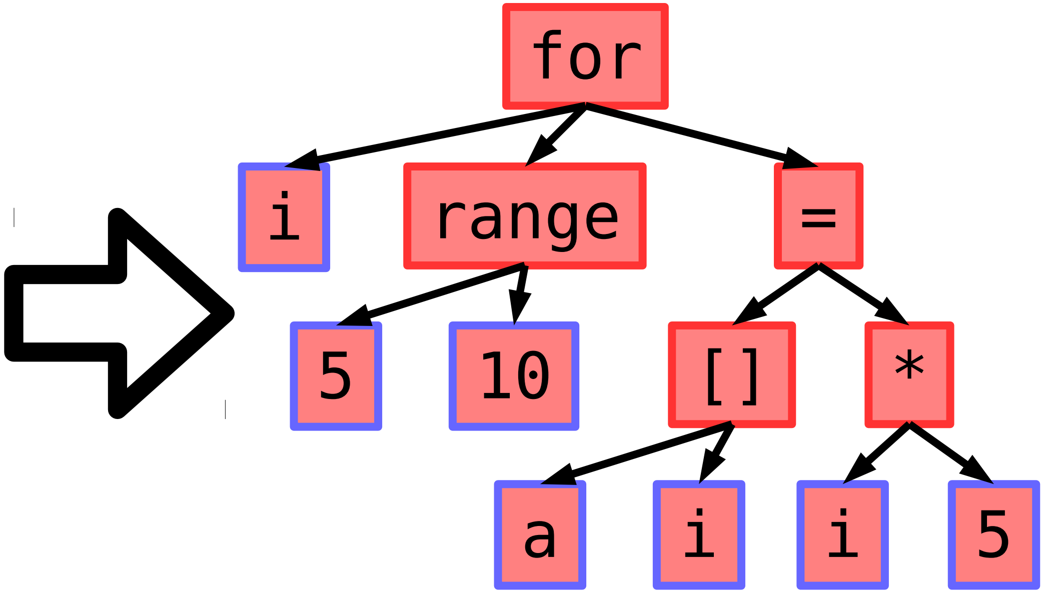
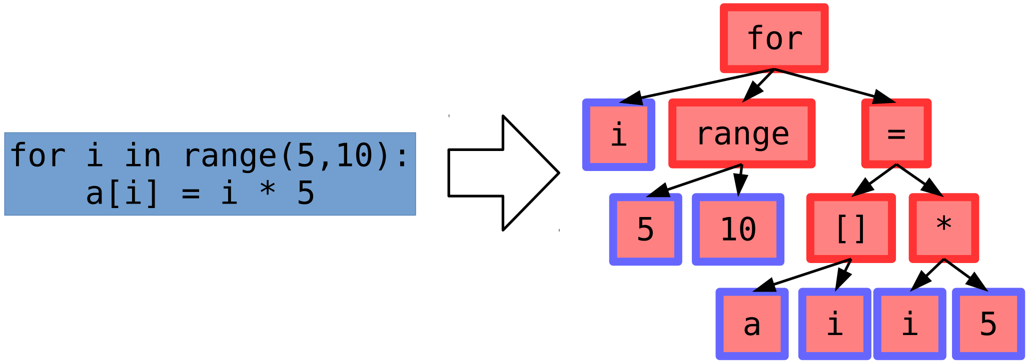

for
i
range
=
5
10
[]
*
a
i
i
5

1) Abstract Syntax Trees

- Lifts the source into a canonical tree form
- Used for syntax analysis & transformation:



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1) Abstract Syntax Trees

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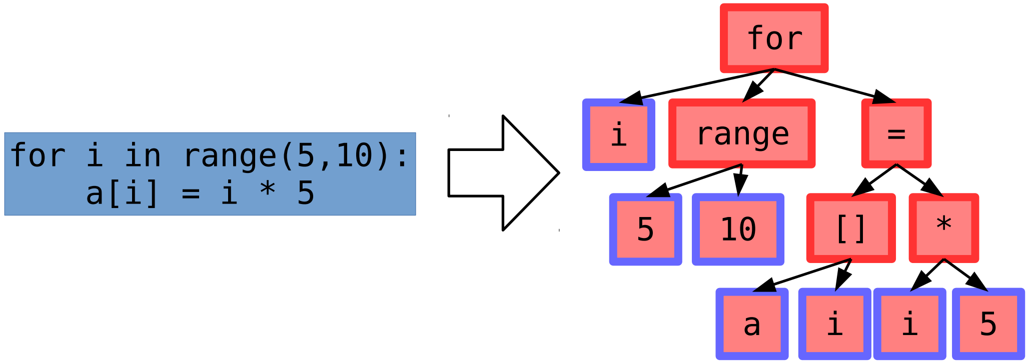
  - Simple bug patterns
  - Style checking
  - Refactoring
  - Training prediction/completion models



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But the same program
may still be spelled many ways.

```
for i in range(5,10):
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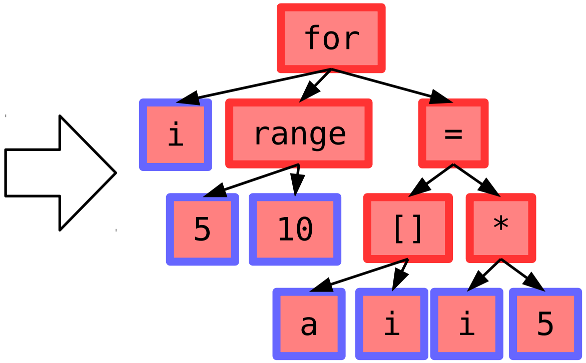

2) Control Flow Graphs

- Express the possible decisions and possible paths through a program

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cond = input()
if cond:
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else:
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print(a)
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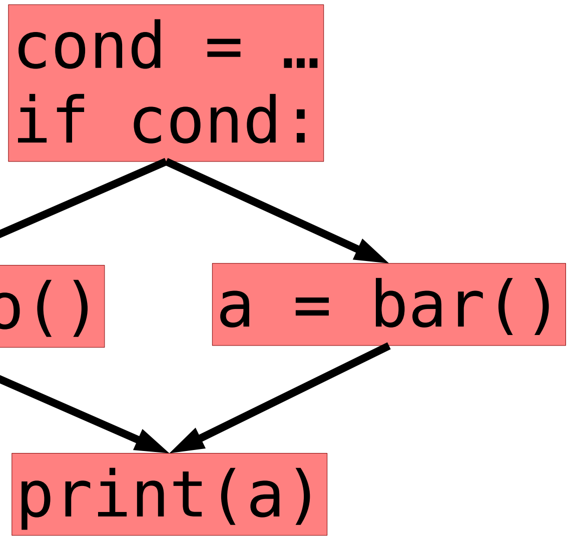

```
cond = …
if cond:
```

```
a = foo()
```

```
a = bar()
```

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print(a)
```

2) Control Flow Graphs

- Express the possible decisions and possible paths through a program
  - ***Basic Blocks*** (Nodes) are straight line code

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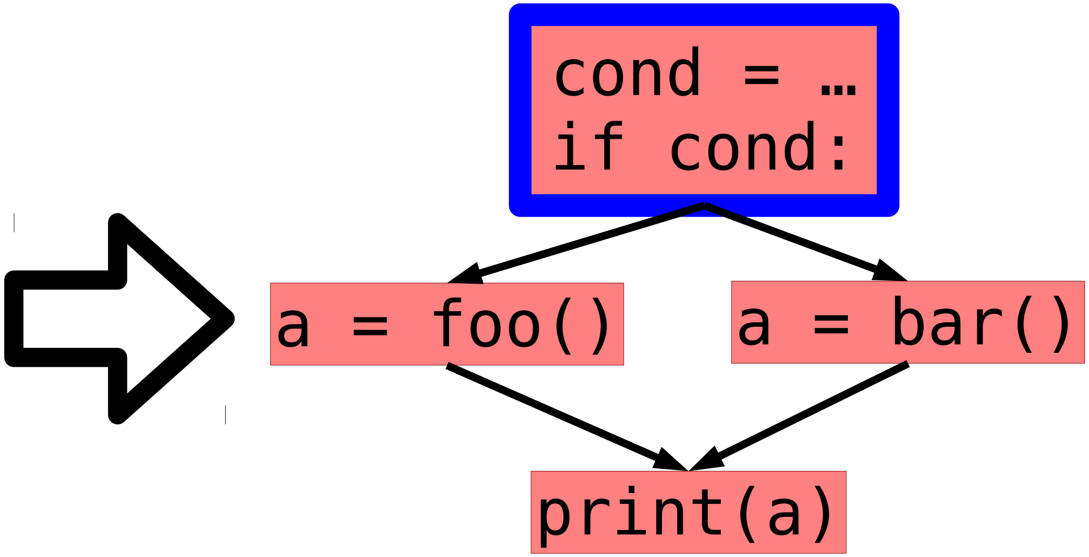

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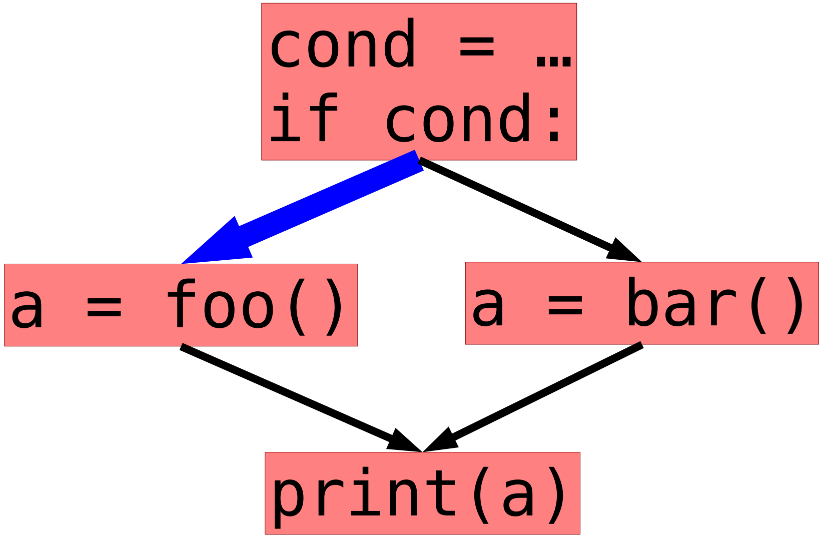

2) Control Flow Graphs

- Express the possible decisions and possible paths through a program
  - *Basic Blocks* (Nodes) are straight line code
  - *Edges* show how decisions can lead to different basic blocks
  - ***Paths*** through the graph are potential paths through the program

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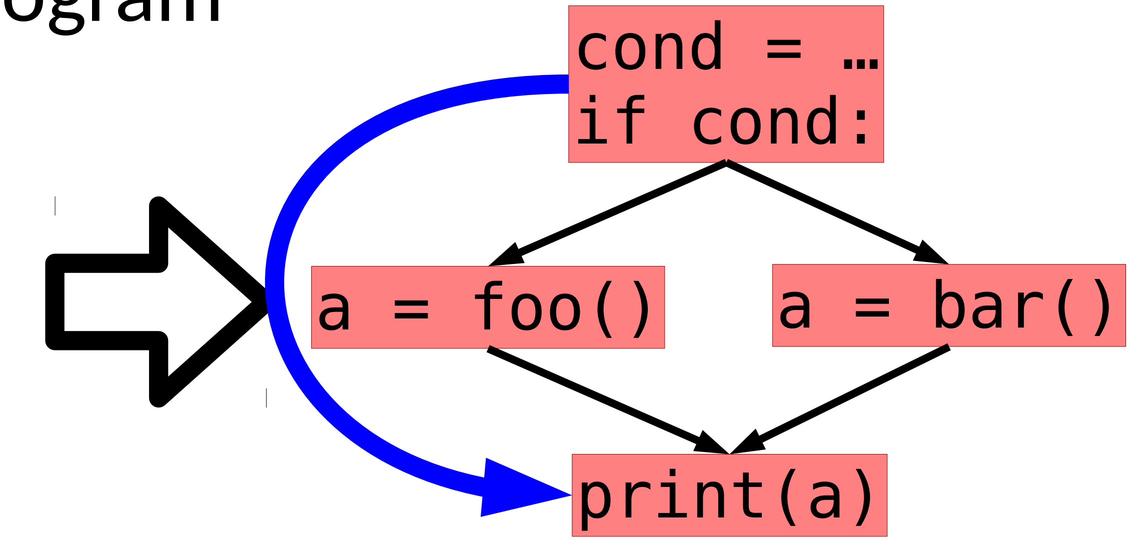

2) Control Flow Graphs (CFGs)

- Language specific features are often abstracted away

```
sum = 0
i = 1
while i < N:
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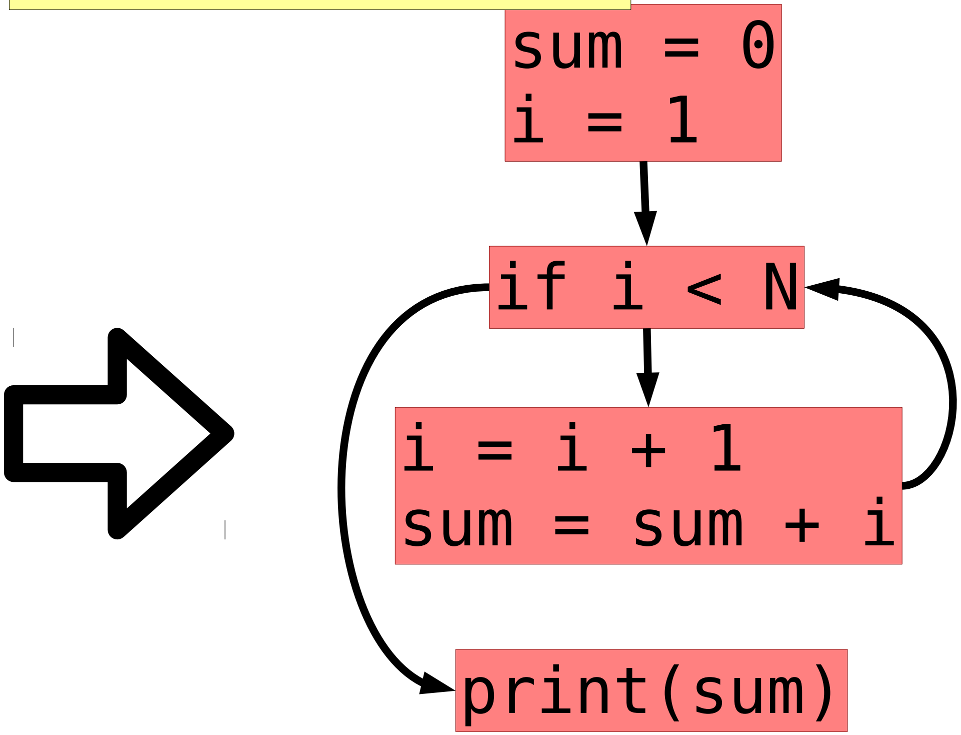
The 'while' is gone



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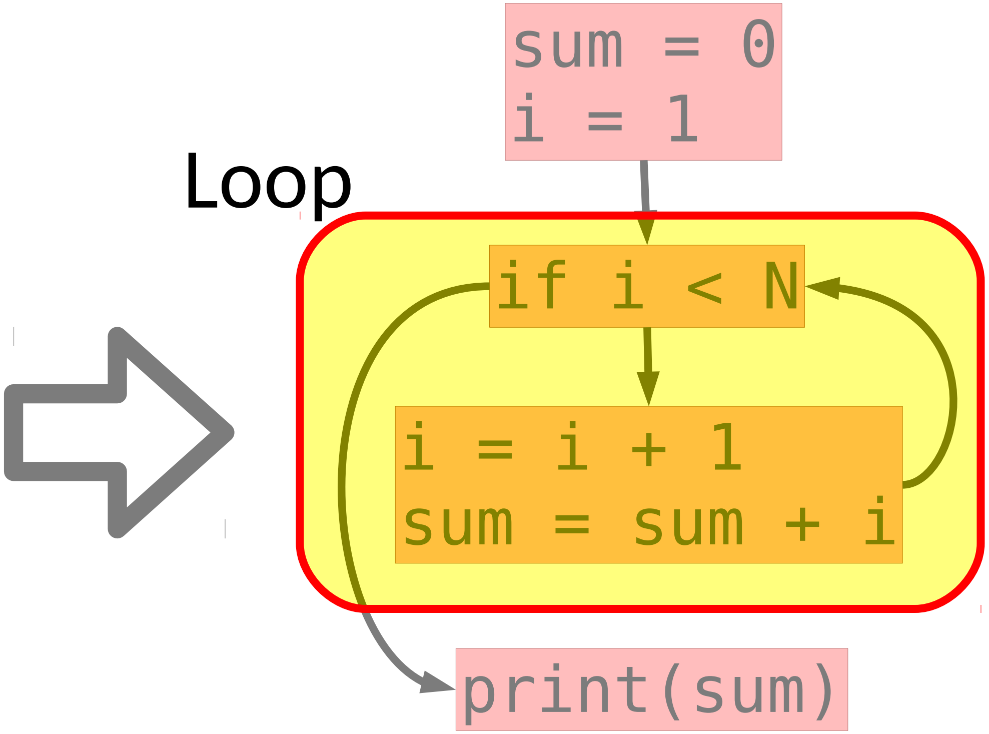

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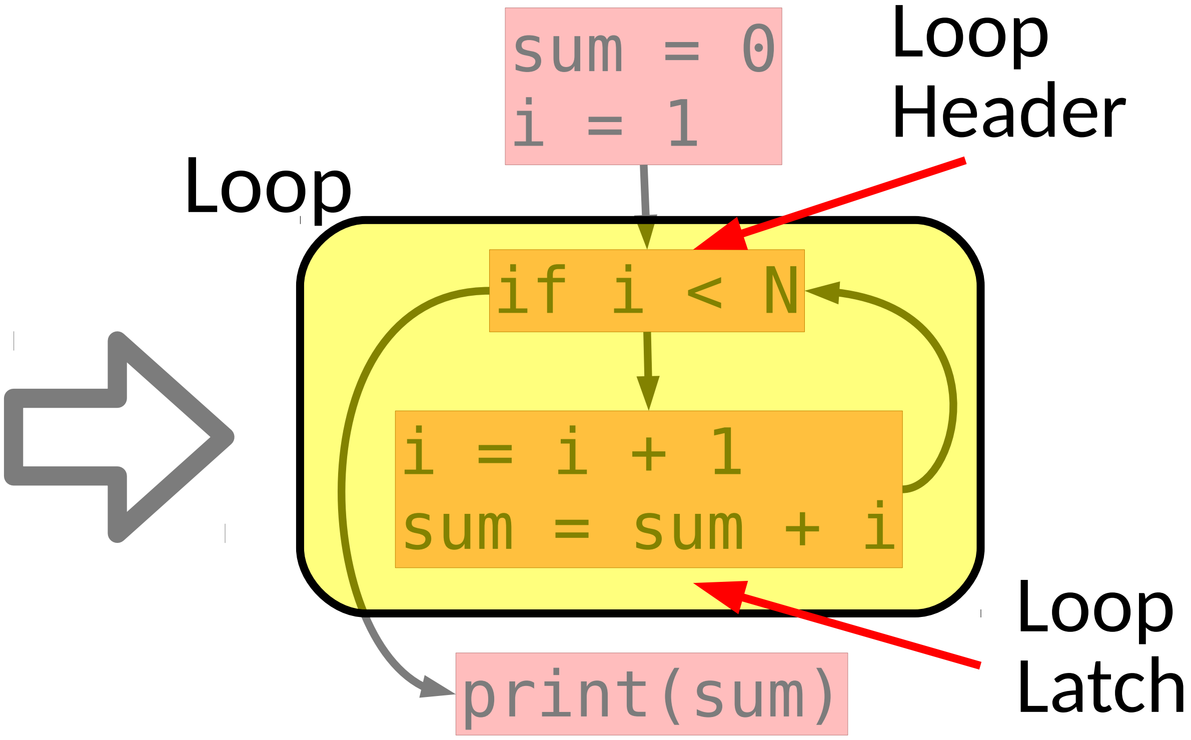

```
sum = 0
i = 1
```

Loop

Loop Header

```
if i < N
```

```
i = i + 1
sum = sum + i
```

Loop Latch

```
print(sum)
```

2) Control Flow Graphs (CFGs)

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Why is the 'if' in a separate block?

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while i < N:
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print(sum)
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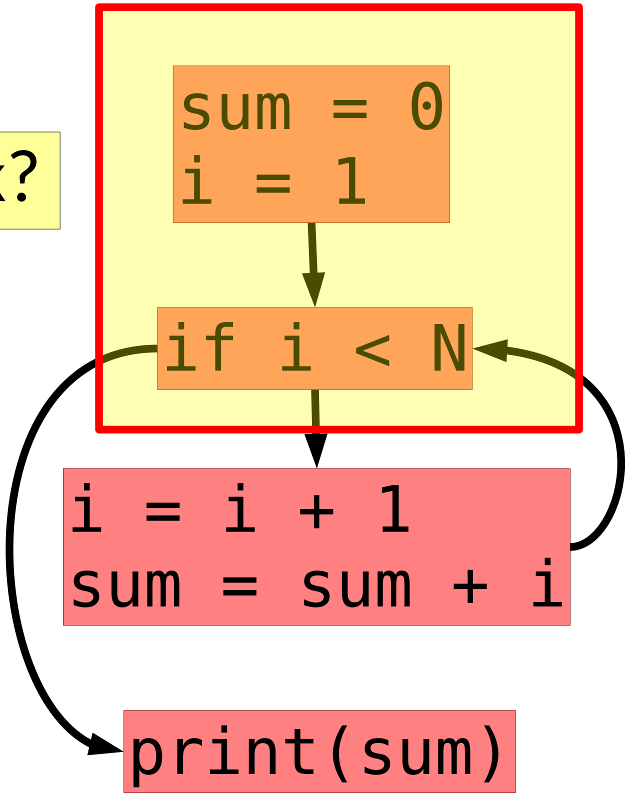

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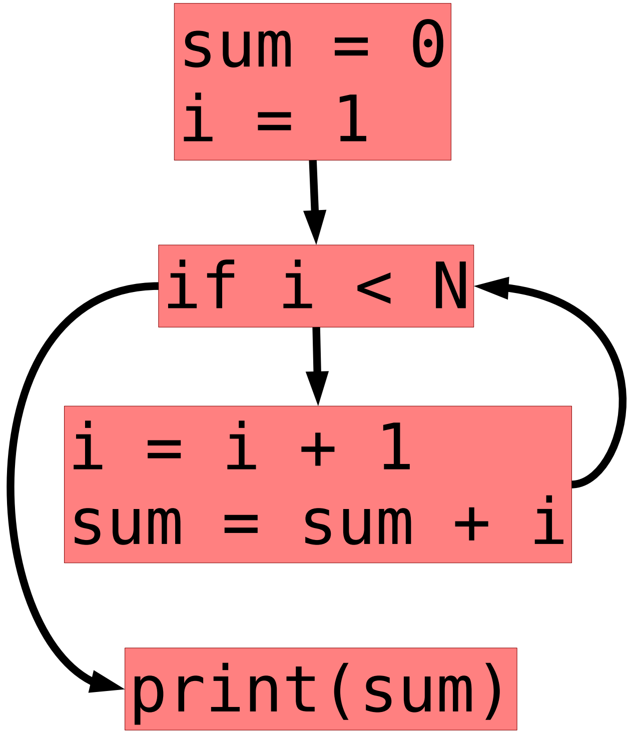

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What would the CFG of the equivalent '`for`' look like?

3)Program Dependence Graph (PDG)

- A ***Program Dependence Graph*** captures how instructions can influence each other

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```
password = input()
...
log(message)
```

e.g. Can my password influence this `log` statement?

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- 2 main types of influence:
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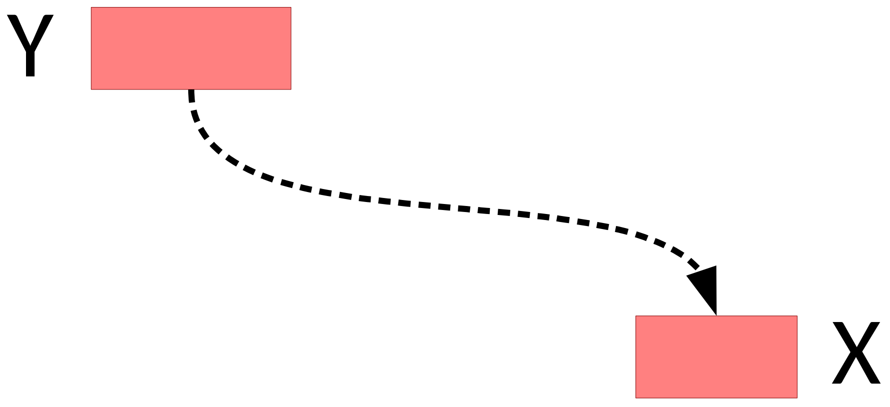
- Instruction X depends on Y if Y *can influence* X
- 2 main types of influence:
  - Data dependence
  - ***Control dependence*** – influence through decisions

Data Dependence

X data depends on Y if

- There exists a path from Y to X in the CFG



Data Dependence

X data depends on Y if

- There exists a path from Y to X in the CFG
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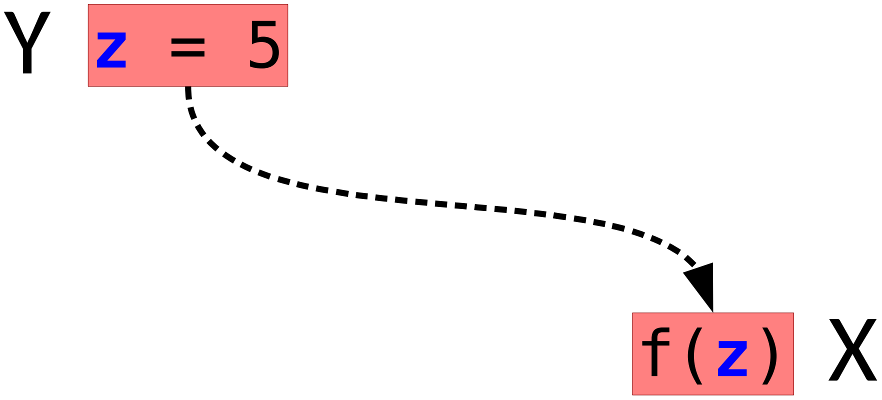

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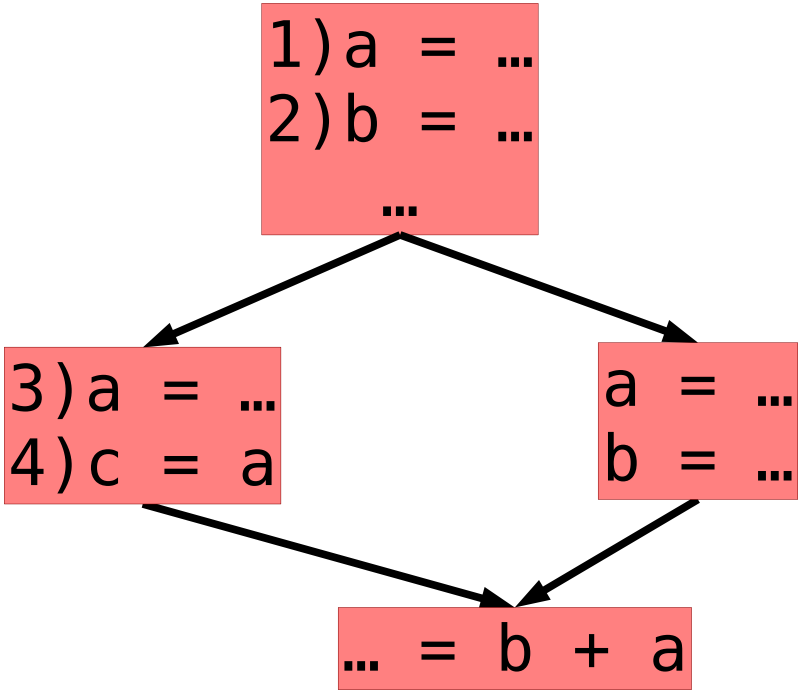

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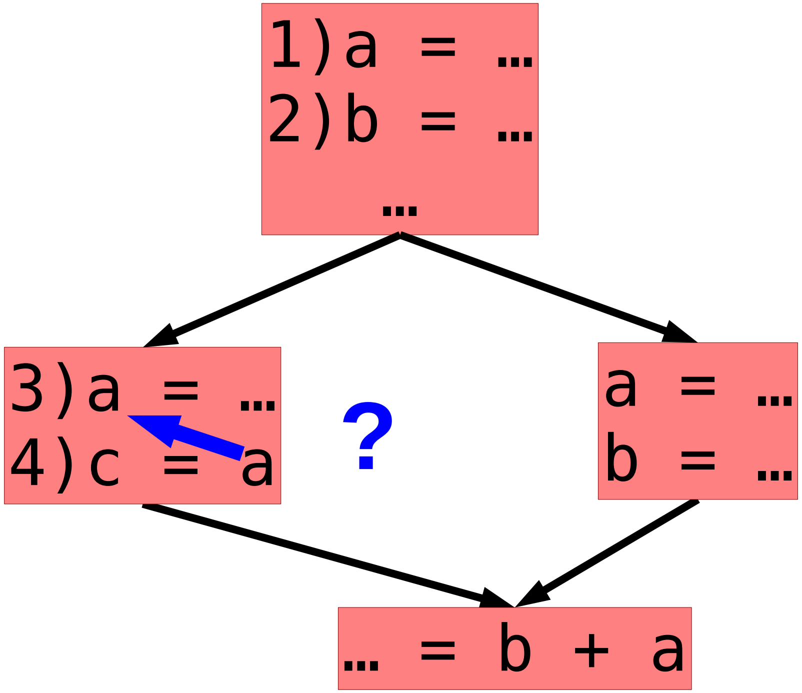

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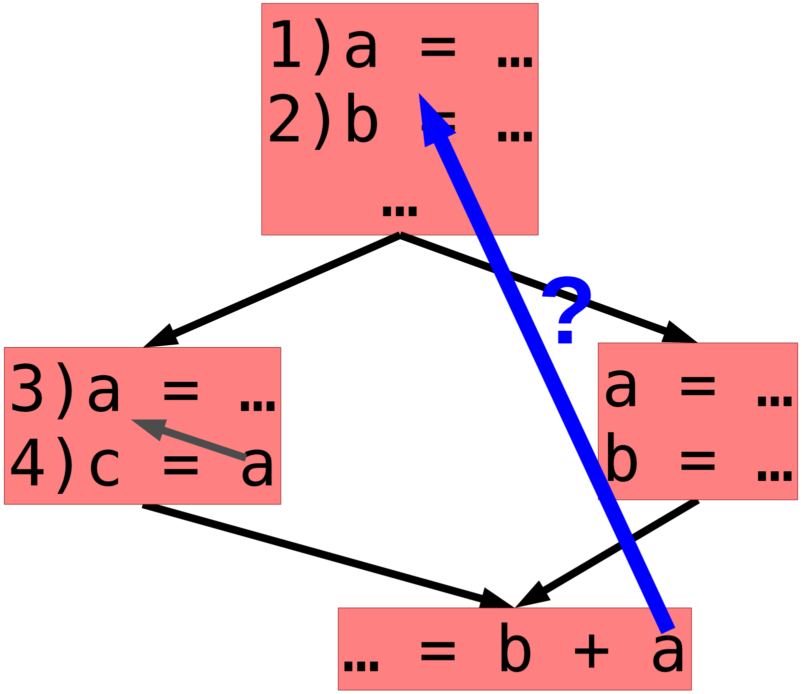

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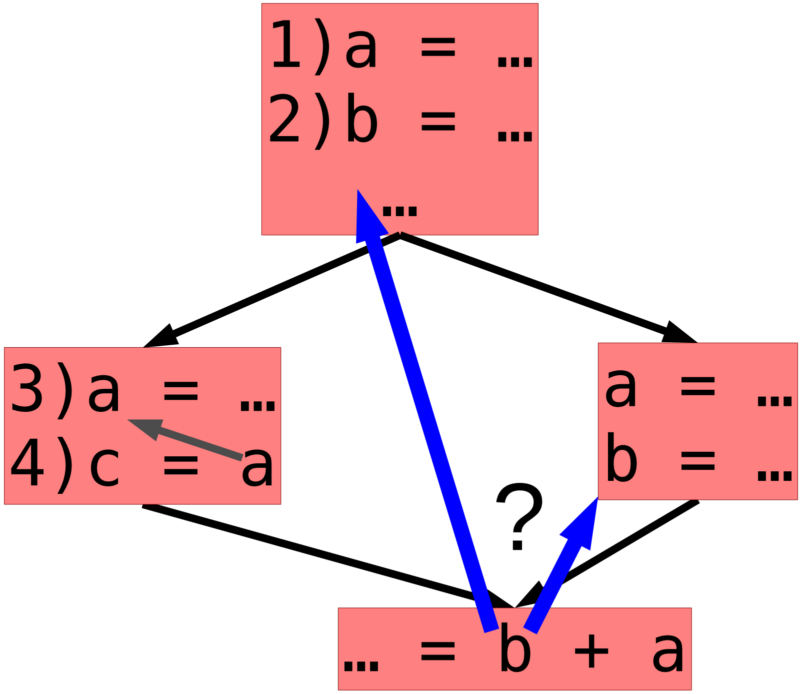

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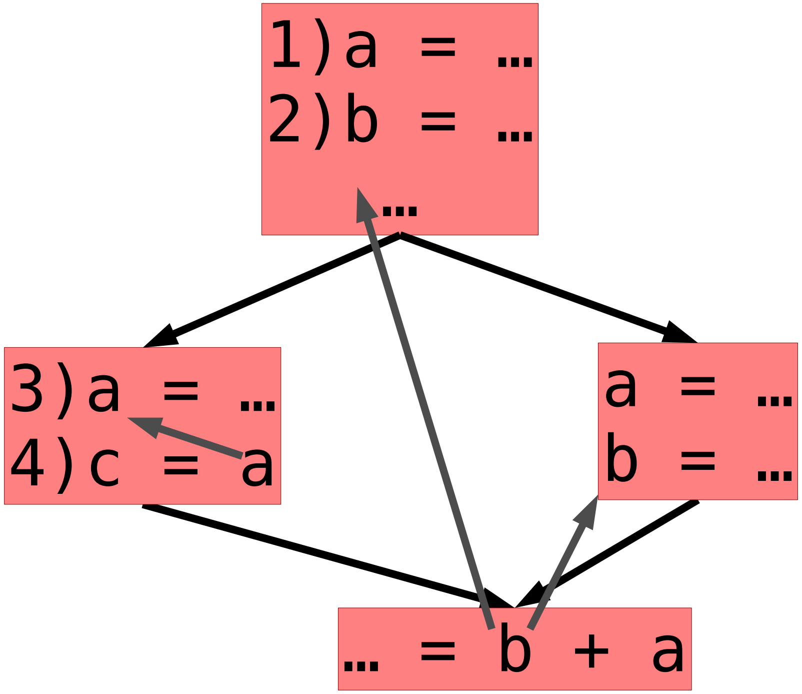

Control Dependence

Recall:
Control dependence captures how decisions influence program behavior.

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We need a way of capturing this via graphs….

Control Dependence

Preliminary: X dominates Y if

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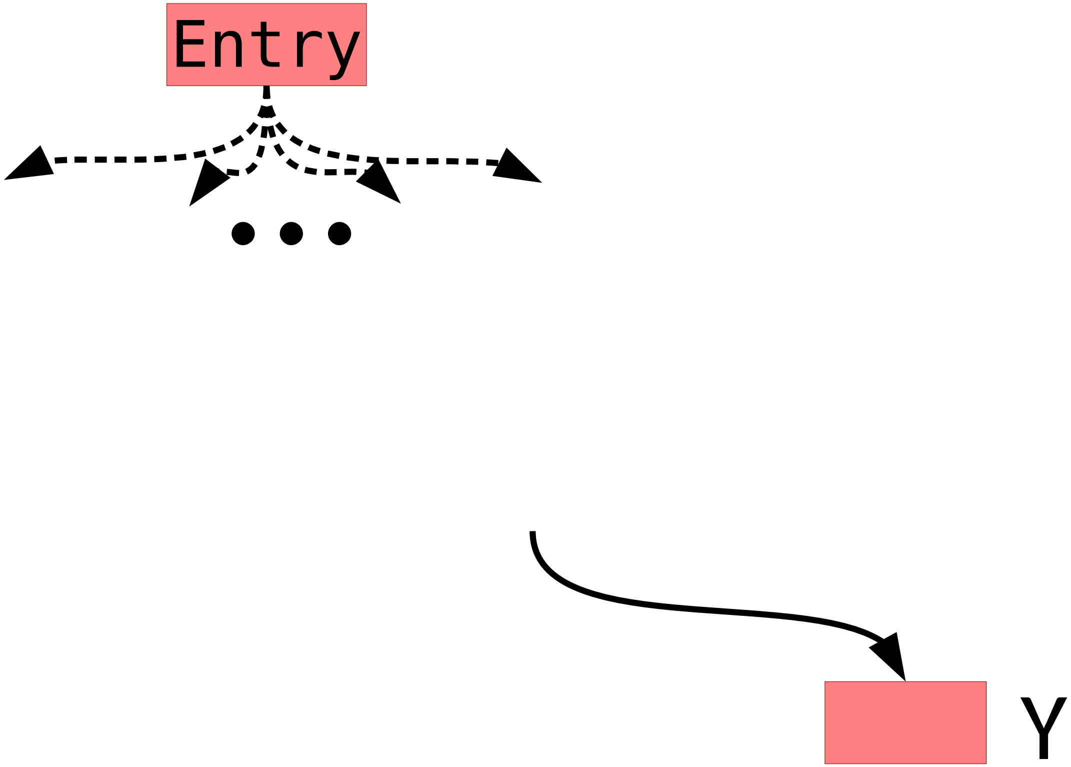

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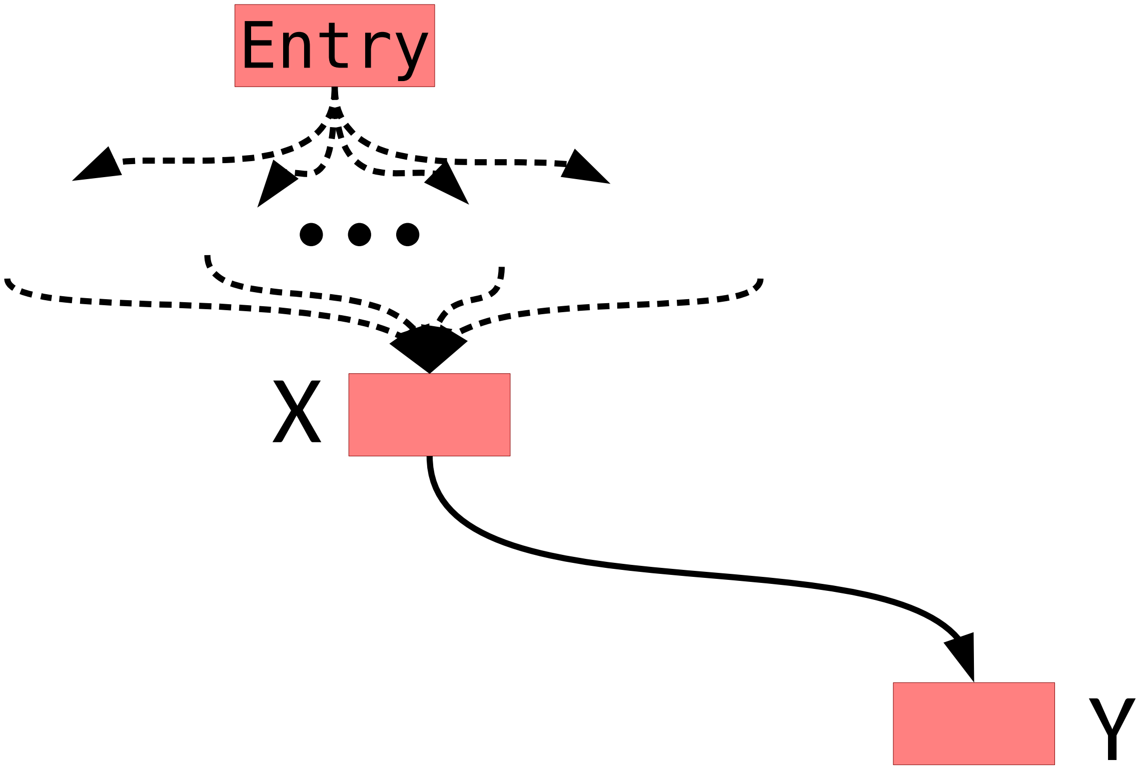

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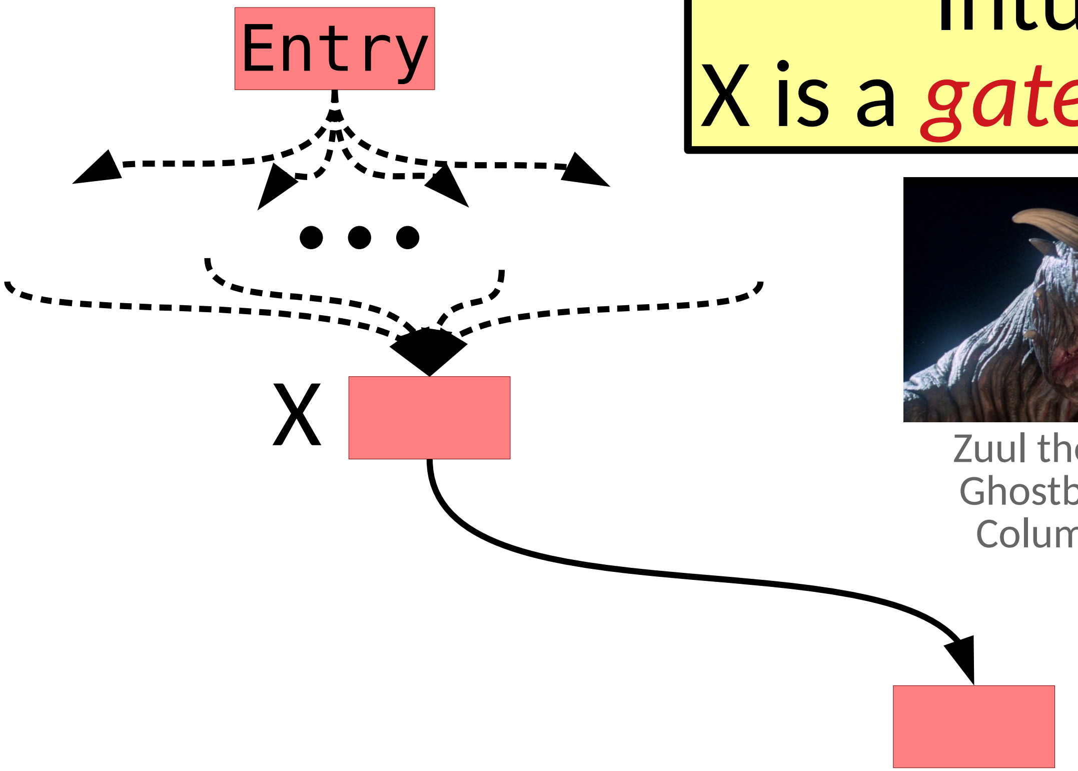

Intuitively,
X is a *gatekeeper* for Y.

Zuul the Gatekeeper.
Ghostbusters, 1982.
Columbia Pictures

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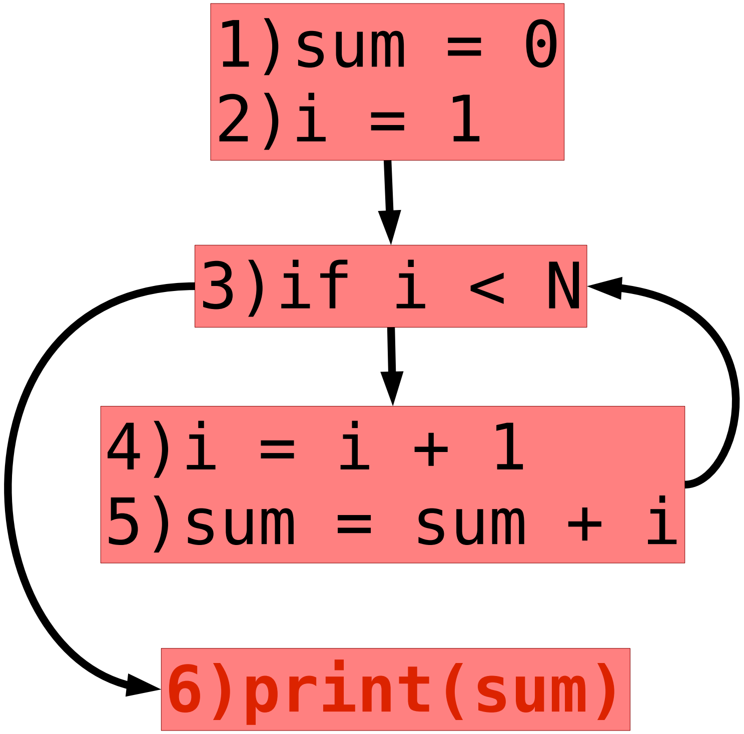
```



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DOM(6)= ?

IDOM(6)= ?

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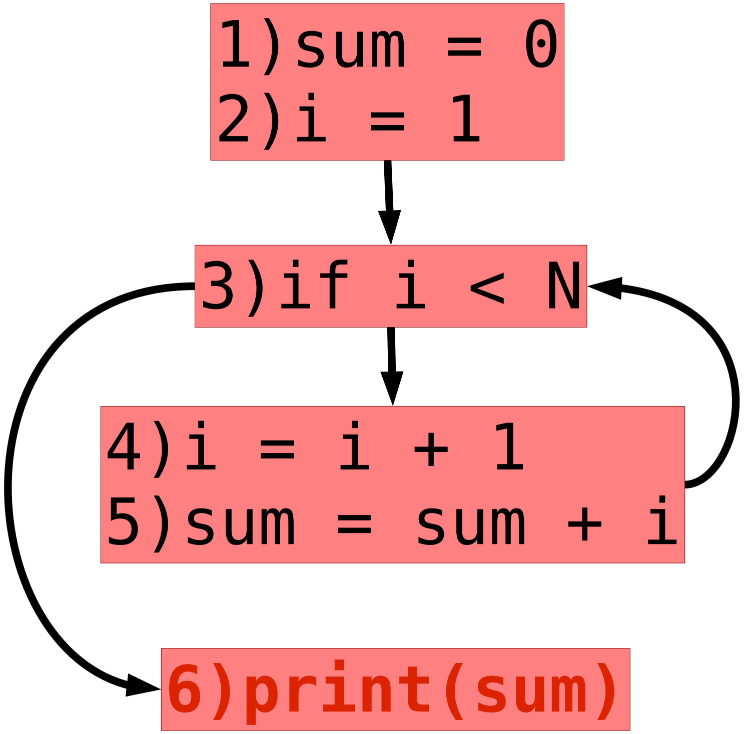
```

DOM(6)={1,2,3,6}   IDOM(6)=3



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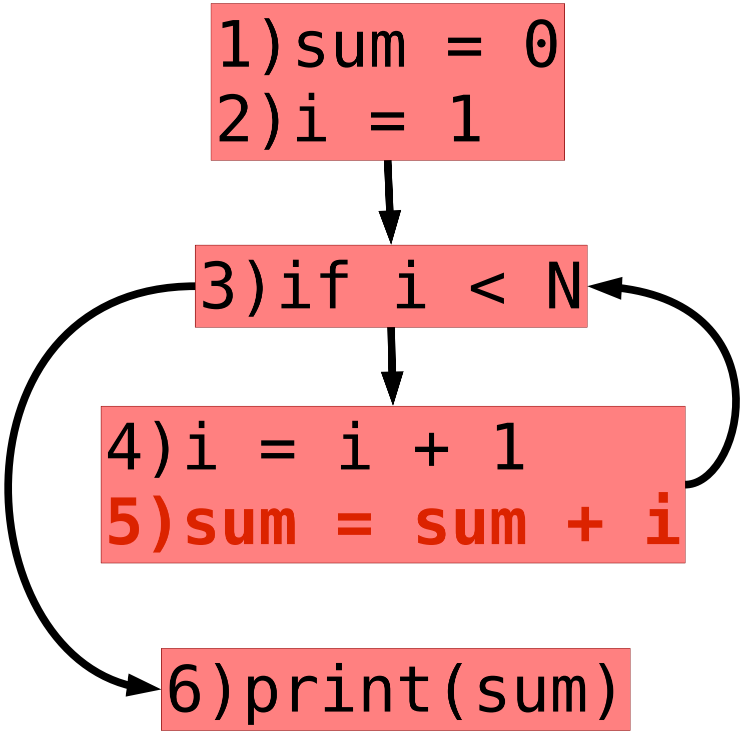

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PDOM(5)= **?**   IPDOM(5)= **?**

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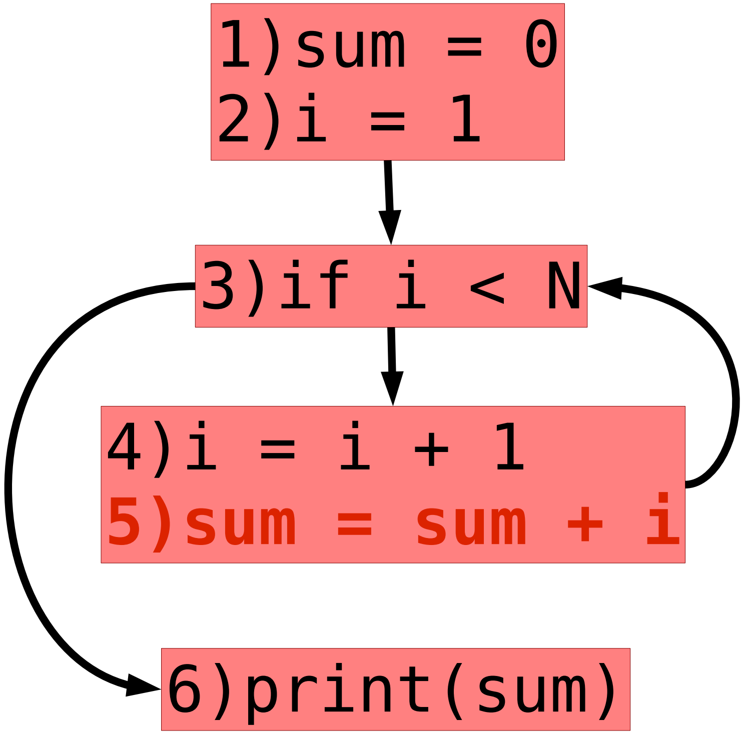

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PDOM(5)={3,5,6}   IPDOM(5)=3

Control Dependence

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- every path from the ***Y to exit*** passes X
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What does this mean intuitively?

```
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2)i = 1
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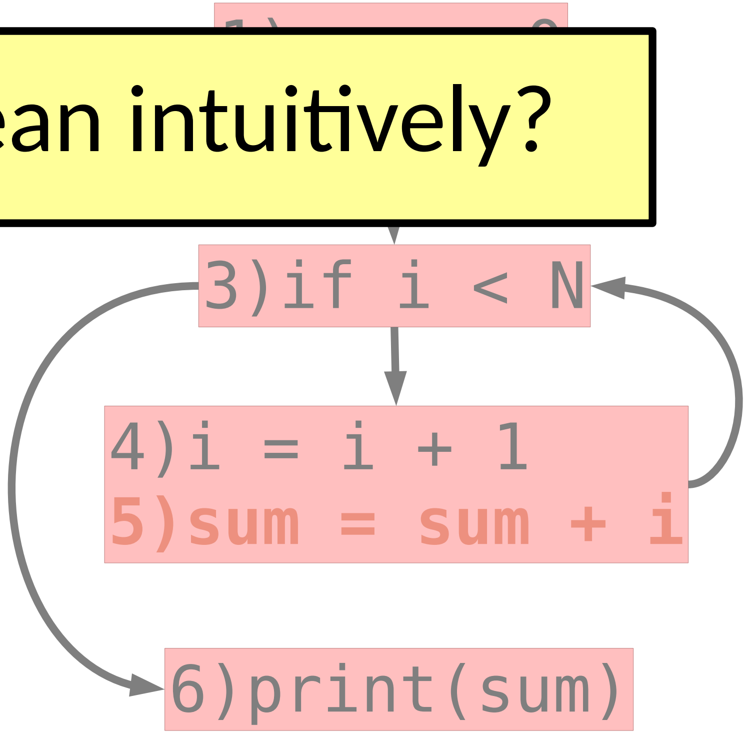

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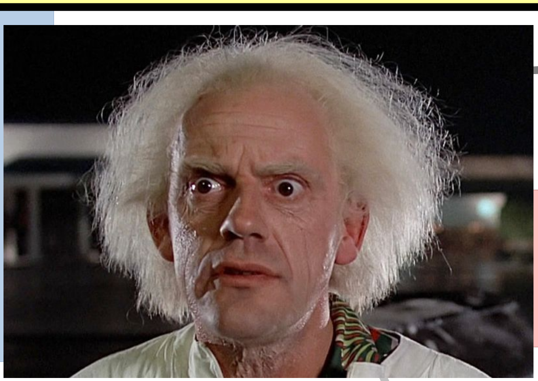
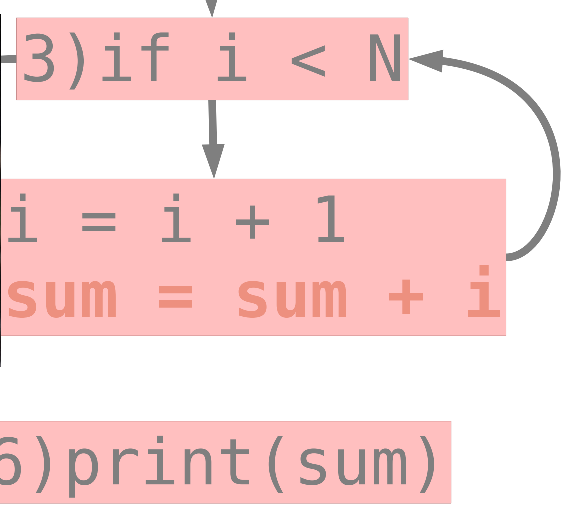


Doc Brown.
Back to the Future, 1985.
Universal Pictures



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Control Dependence (Finally)

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- Definition 2:

  - There exists a path from X to Y s.t. Y post dominates every node between X and Y.
  - Y does not strictly post dominate X

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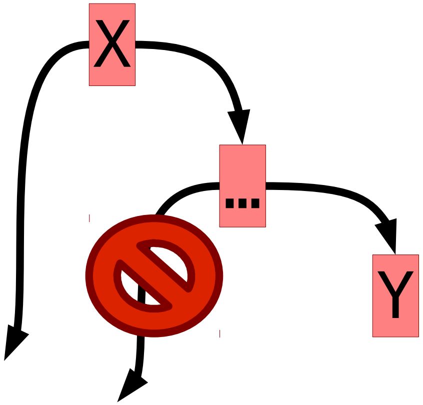

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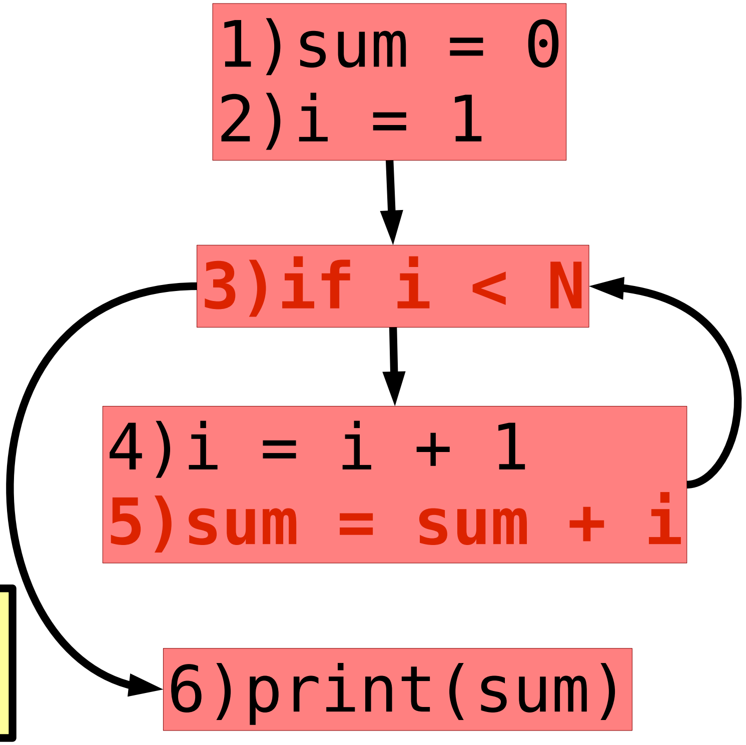

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4)i = i + 1
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5)sum = sum + i

```
6)print(sum)
```

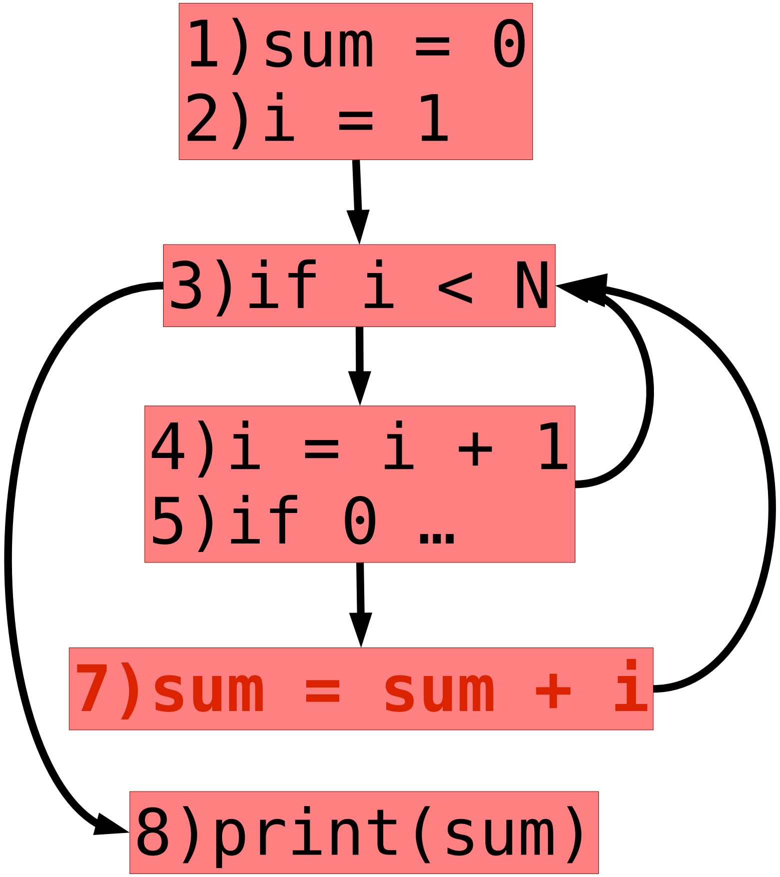
What is CD(5)? CD(3)

Control Dependence

- There exists a path from X to Y s.t. Y post dominates every node between X and Y.
- Y does not strictly post dominate X

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

What is CD(7)?



```
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```
3)if i < N
```

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5)if 0 …
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```
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```
1)if X or Y:
2)   print(X)
3)print(Y)
```

What is CD(2)?

Control Dependence

- There exists a path from X to Y s.t. Y post dominates every node between X and Y.
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```
1)if X or Y:
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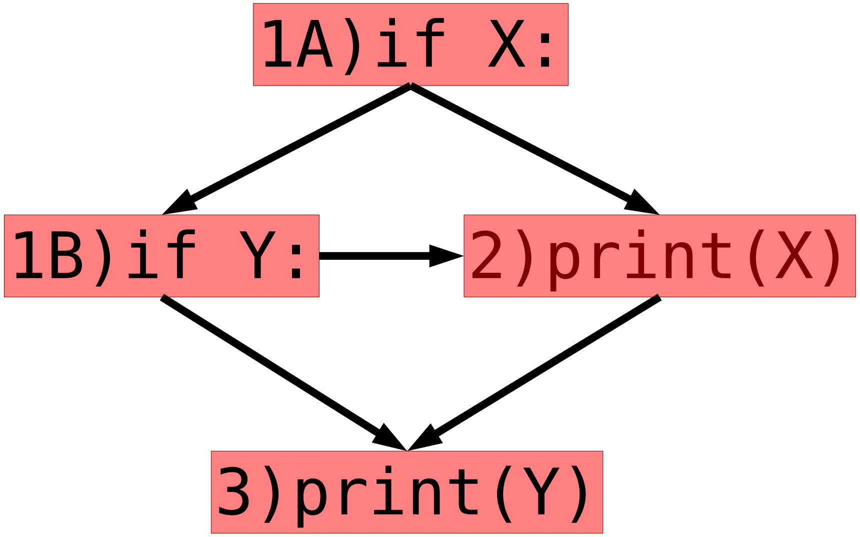
```



What is CD(2)?

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The PDG is the combination of

- The control dependence graph
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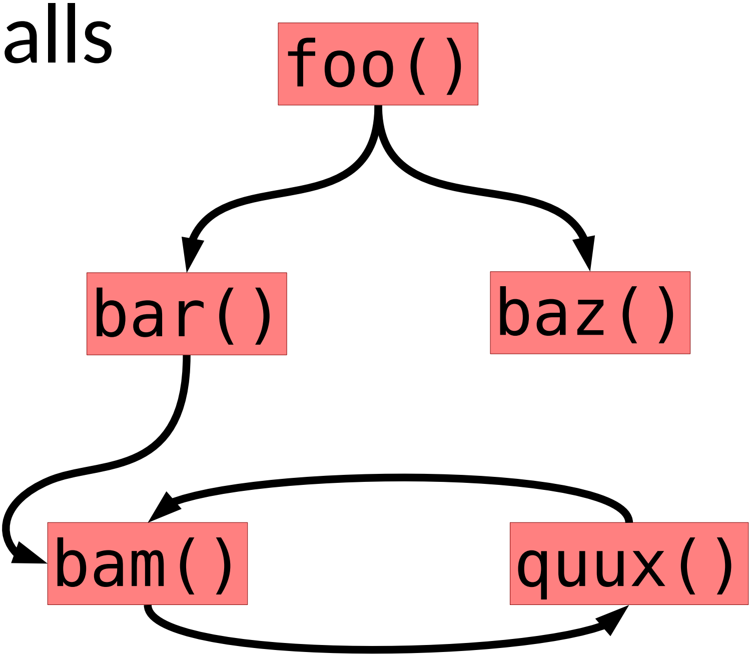
Recall: Edges identify *potential influence*

- **Debugging:** What may have caused a bug?
- **Security:** Can sensitive information leak?
- **Testing:** How can I reach a statement?
- …

4) Call Graph (Multigraph)

- Captures the composition of a program
  - Nodes are functions
  - Edges show possible calls



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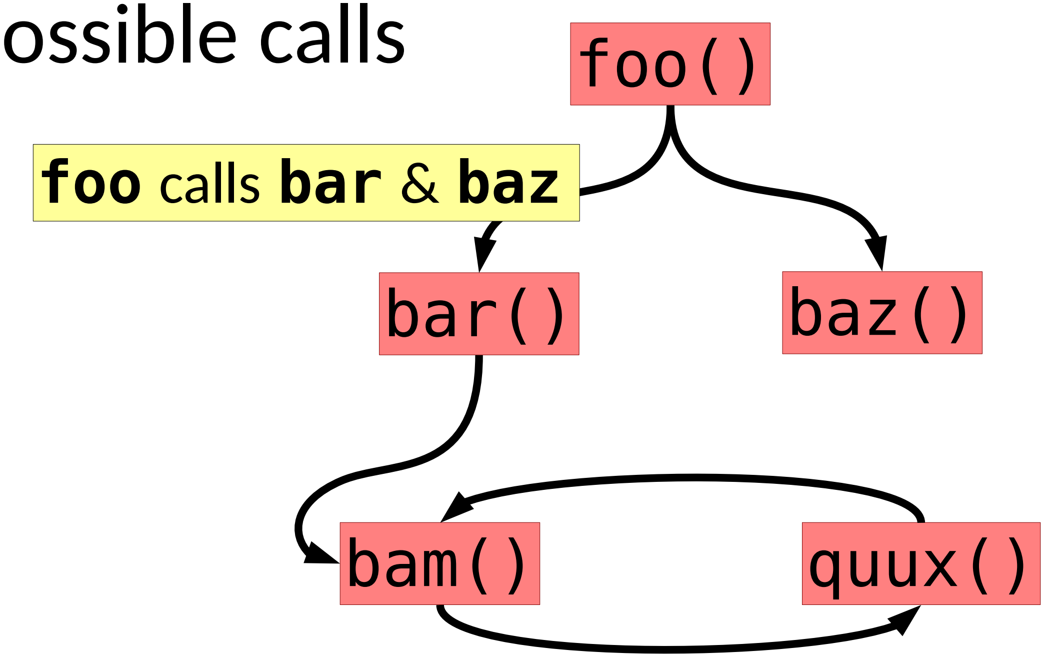

foo calls **bar** & **baz**

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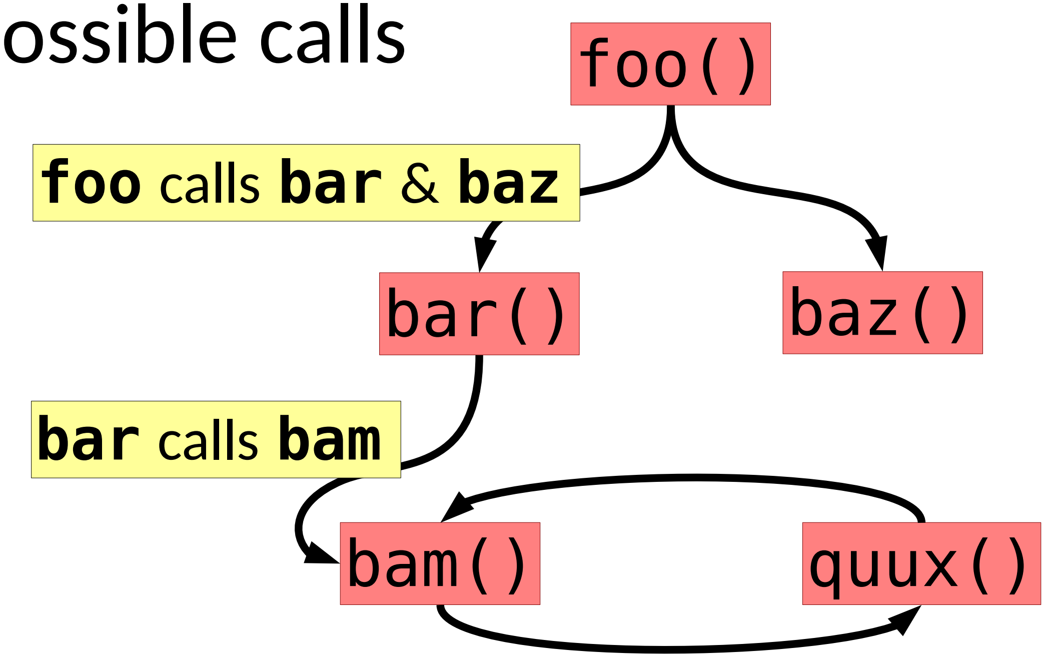

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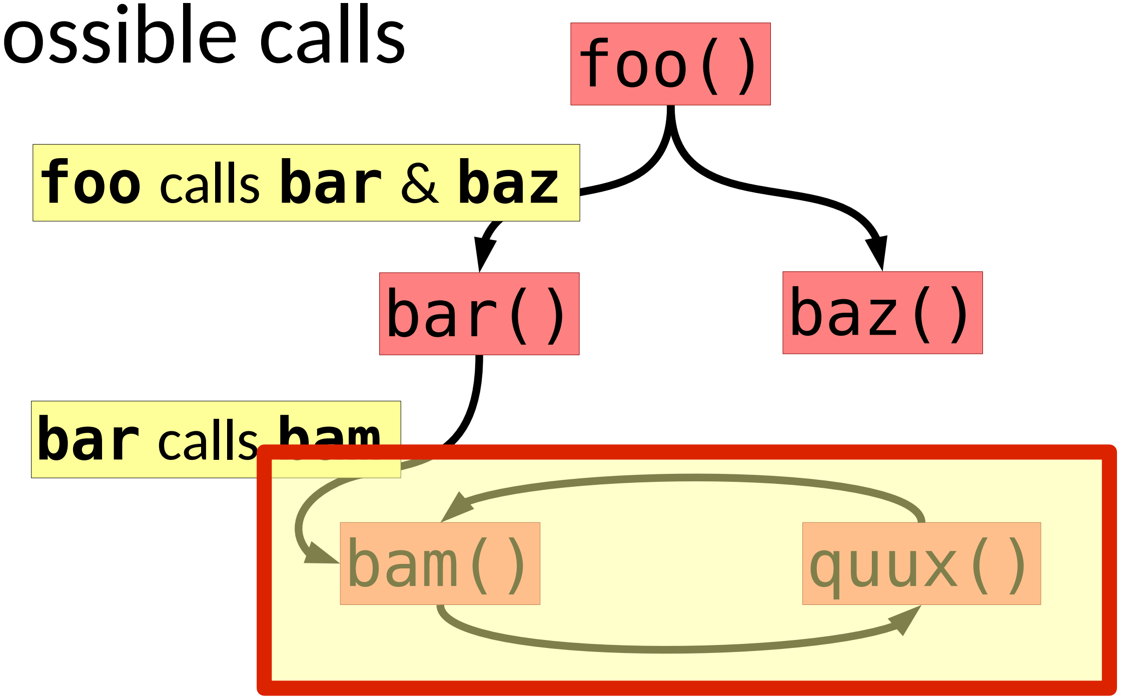

What does this capture?

4) Call Graph (Multigraph)

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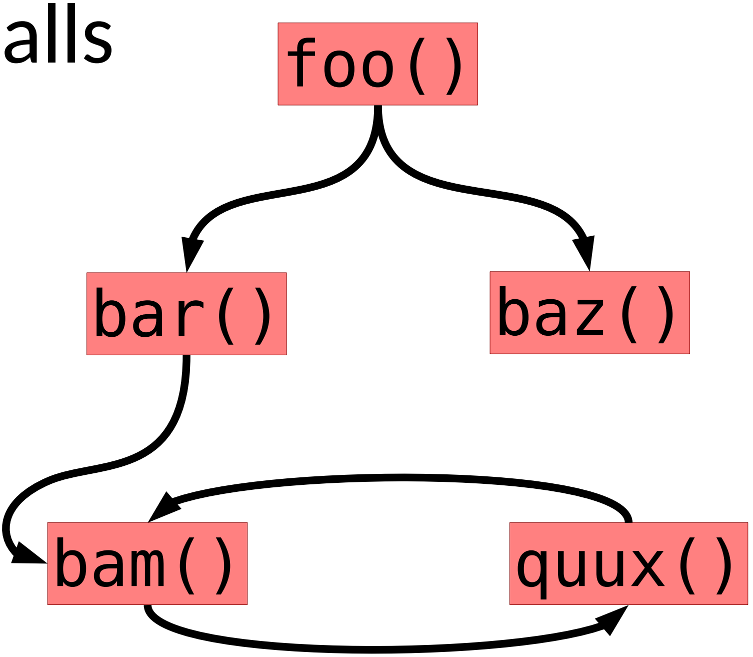
How should we handle function pointers?



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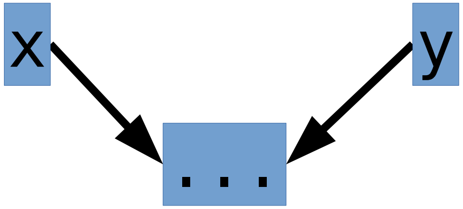

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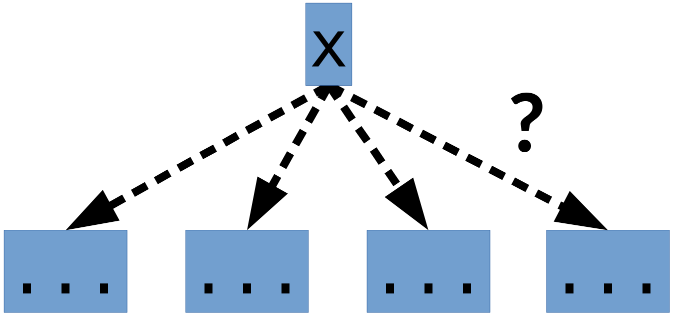

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- Aliasing
  - Multiple variables may denote the same memory location
- Ambiguity
  - One variable may potentially denote several different targets in memory.

```
x.lock()
…
y.unlock()
```

```
x = password
…
broadcast(y)
```

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Points-to graphs capture this points-to relation

- The relation (p,x) where p MAY/MUST point to x
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1) r = C()
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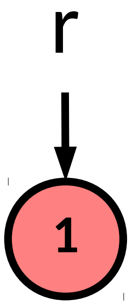

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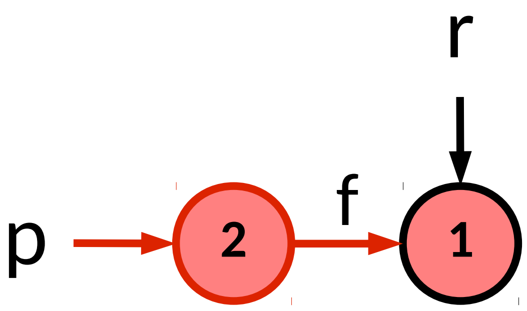

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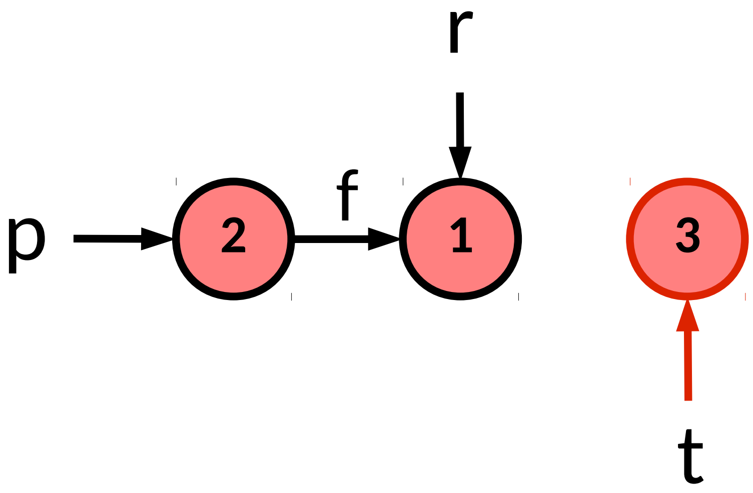

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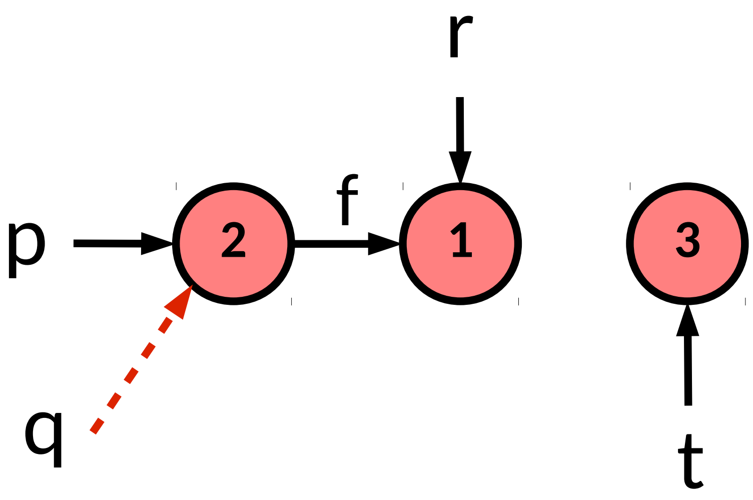

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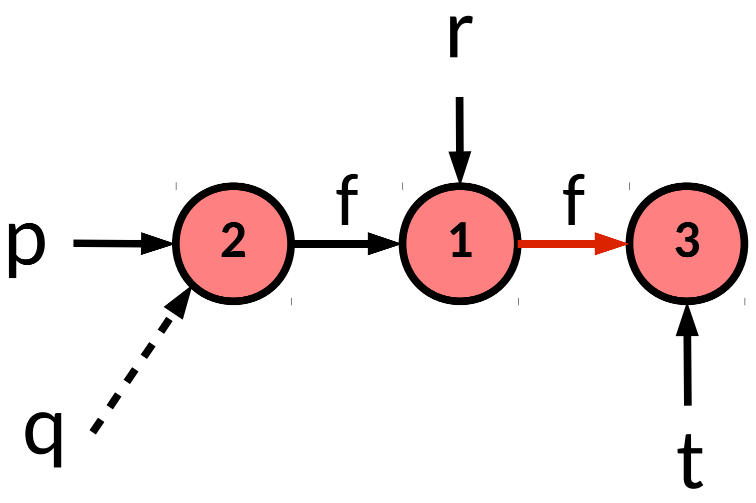

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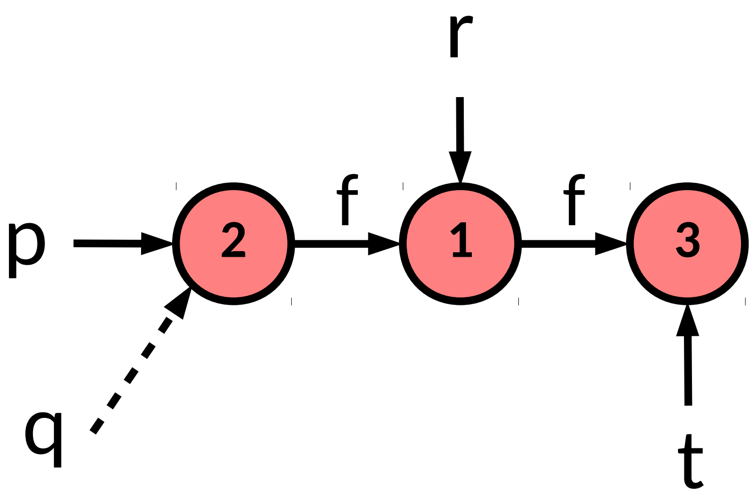

p.f.f MUST ALIAS t
q MAY ALIAS p

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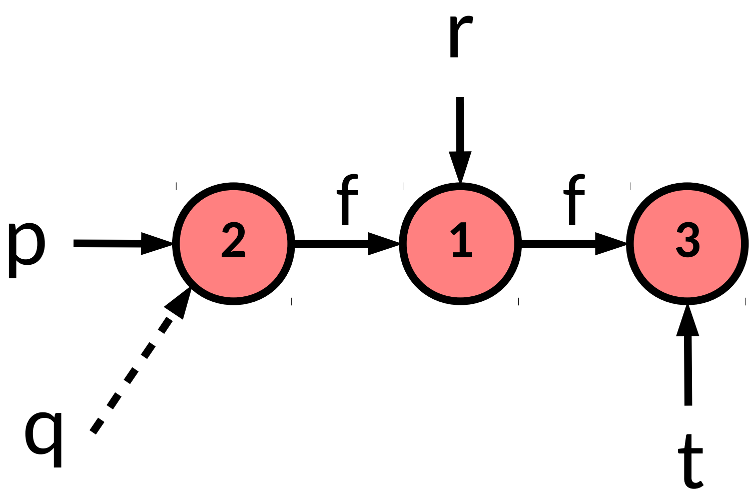

What if we add:
7) q.f = r.f
?

Execution Representations

- ***Program*** representations are *static*
  - All possible program behaviors at once
  - Usually projected onto the CFG

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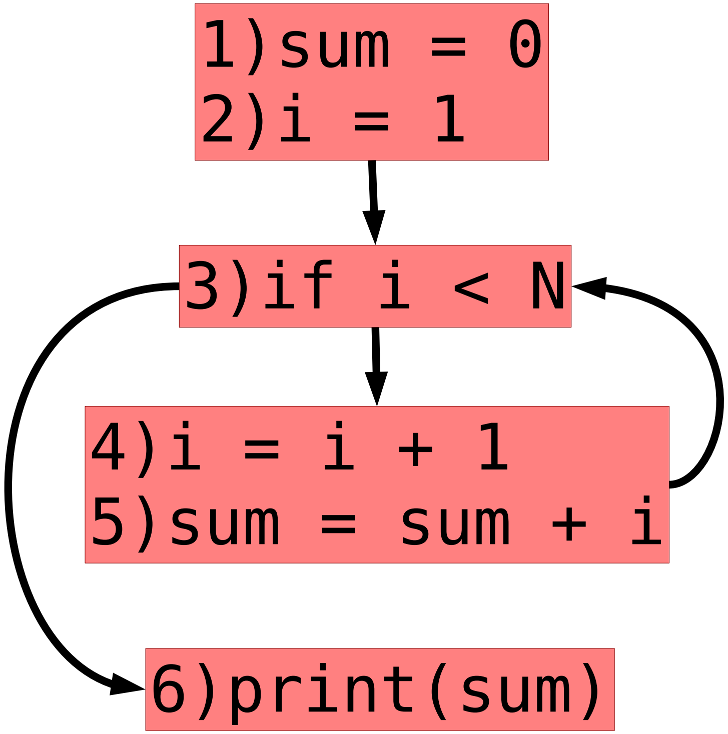
- ***Execution*** representations are *dynamic*
  - Only the behavior of a single real execution
  - Multiple instances of an instruction occur multiple times

Control Flow Trace



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1)sum = 0
2)i = 1
```

```
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```

```
6)print(sum)
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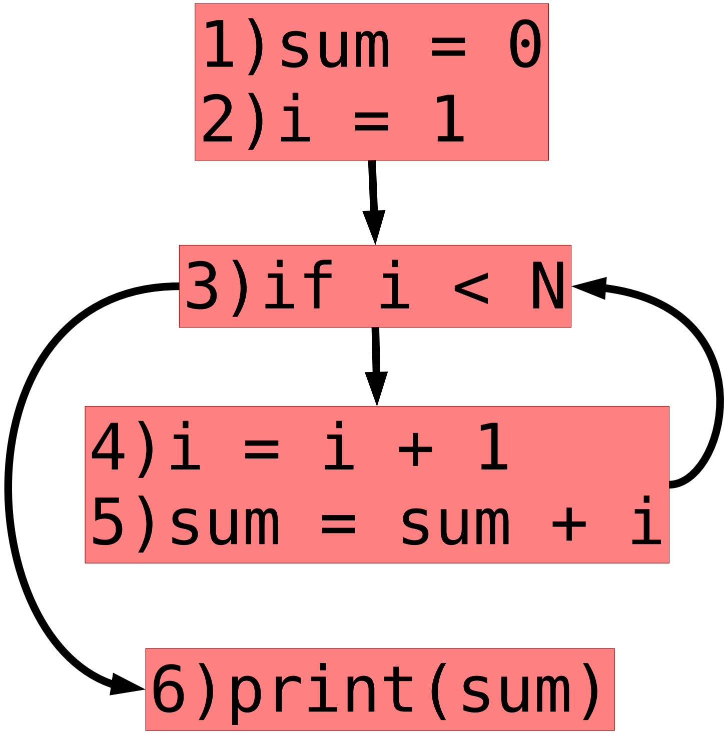

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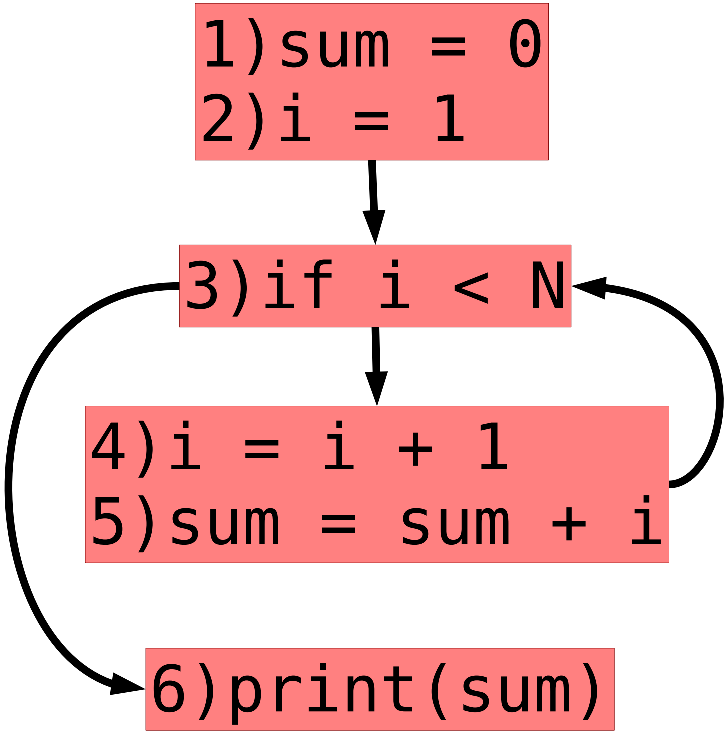

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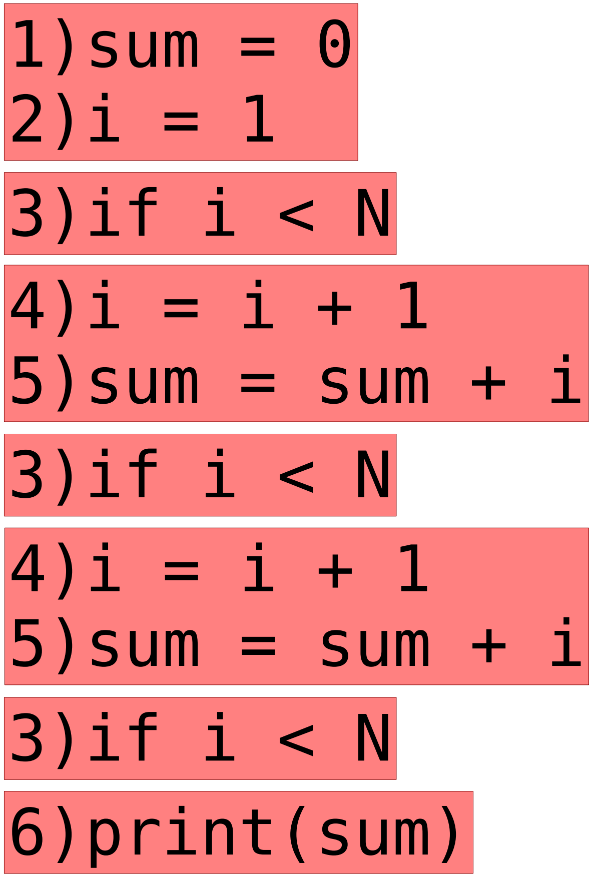

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$1_1\ 2_1\ 3_1\ 4_1\ 5_1\ 3_2\ 4_2\ 5_2\ 3_3\ 6_1$

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TTF

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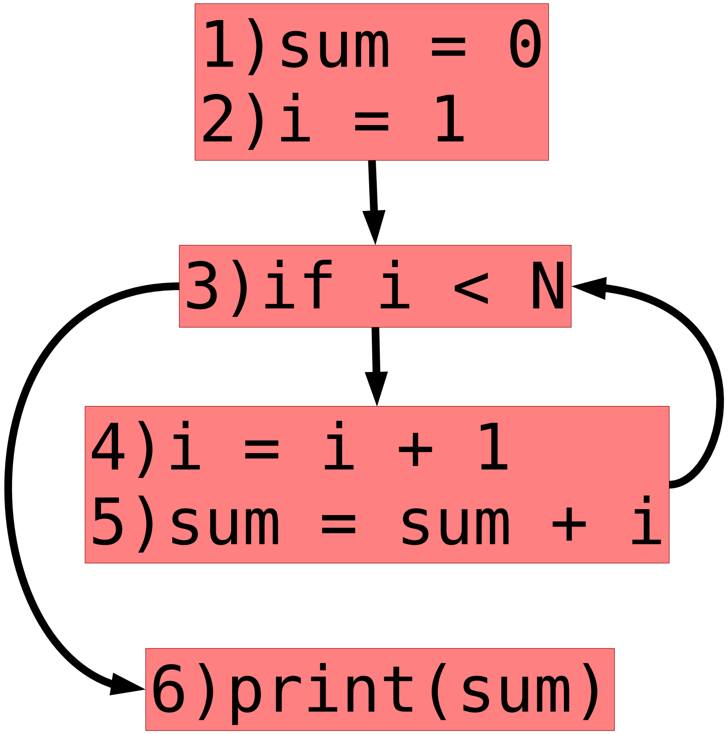

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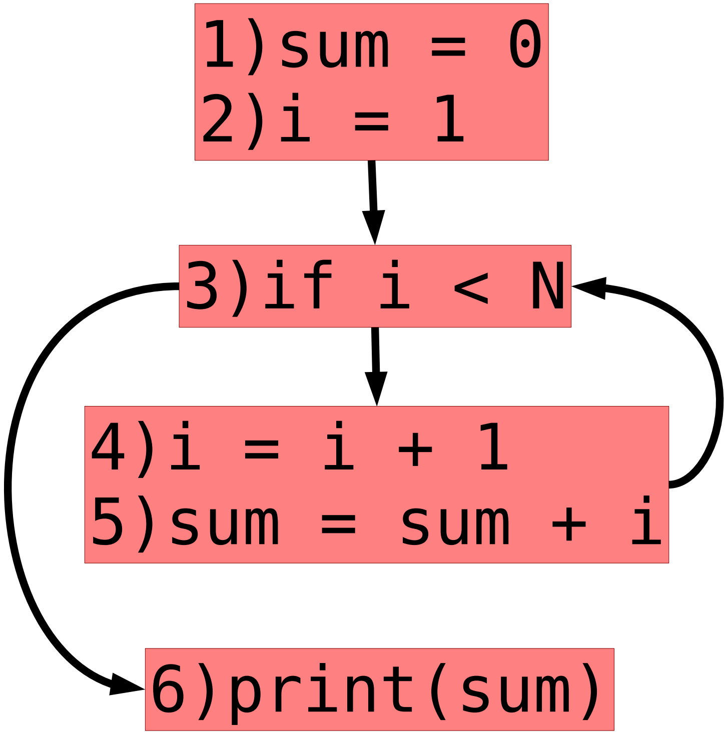
$$\left.\begin{array}{l} 1_1\ 2_1\ 3_1\ 4_1\ 5_1\ 3_2\ 4_2\ 5_2\ 3_3\ 6_1 \\ 1_1\ 3_1\ 4_1\ 3_2\ 4_2\ 3_3\ 6_1 \\ \text{TTF} \end{array}\right\} \text{All Equivalent}$$

Dynamic Dependence Graph



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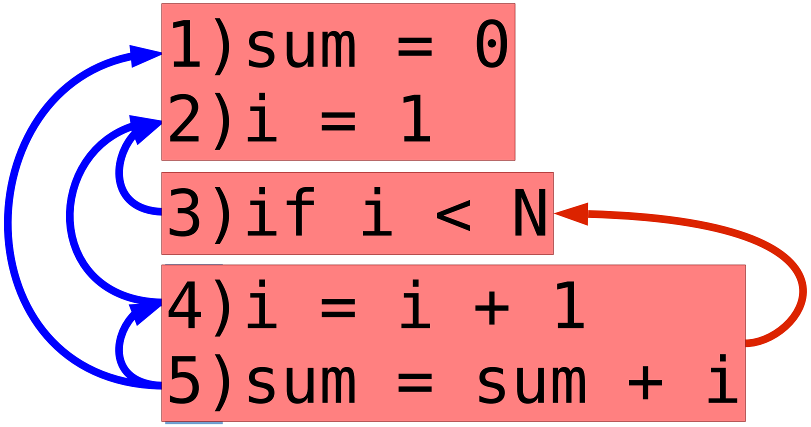

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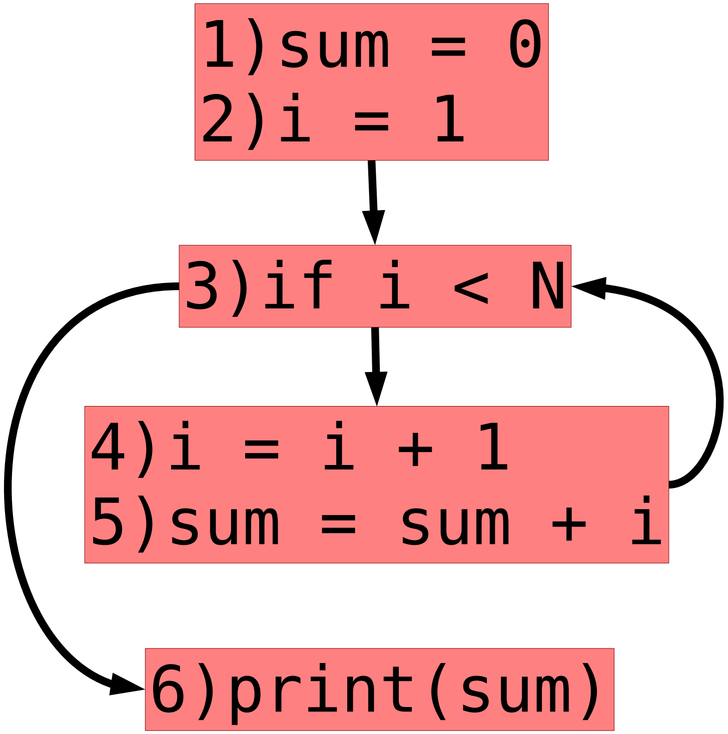

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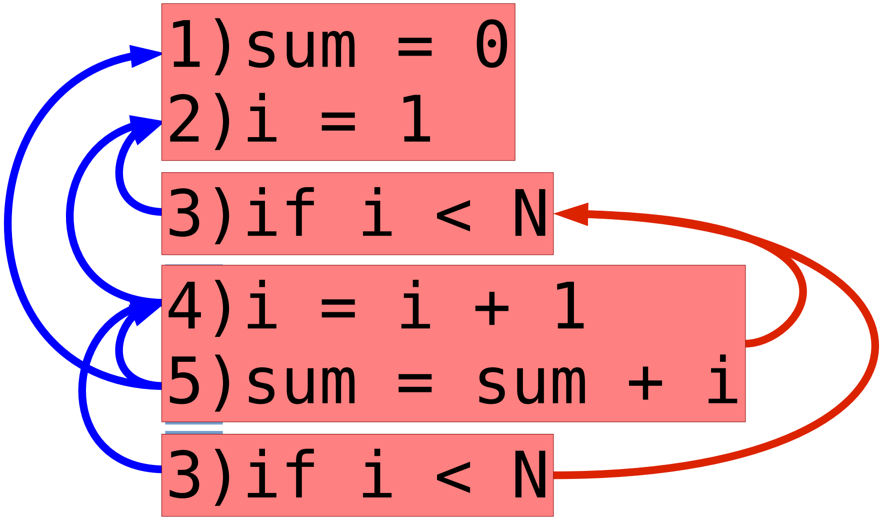

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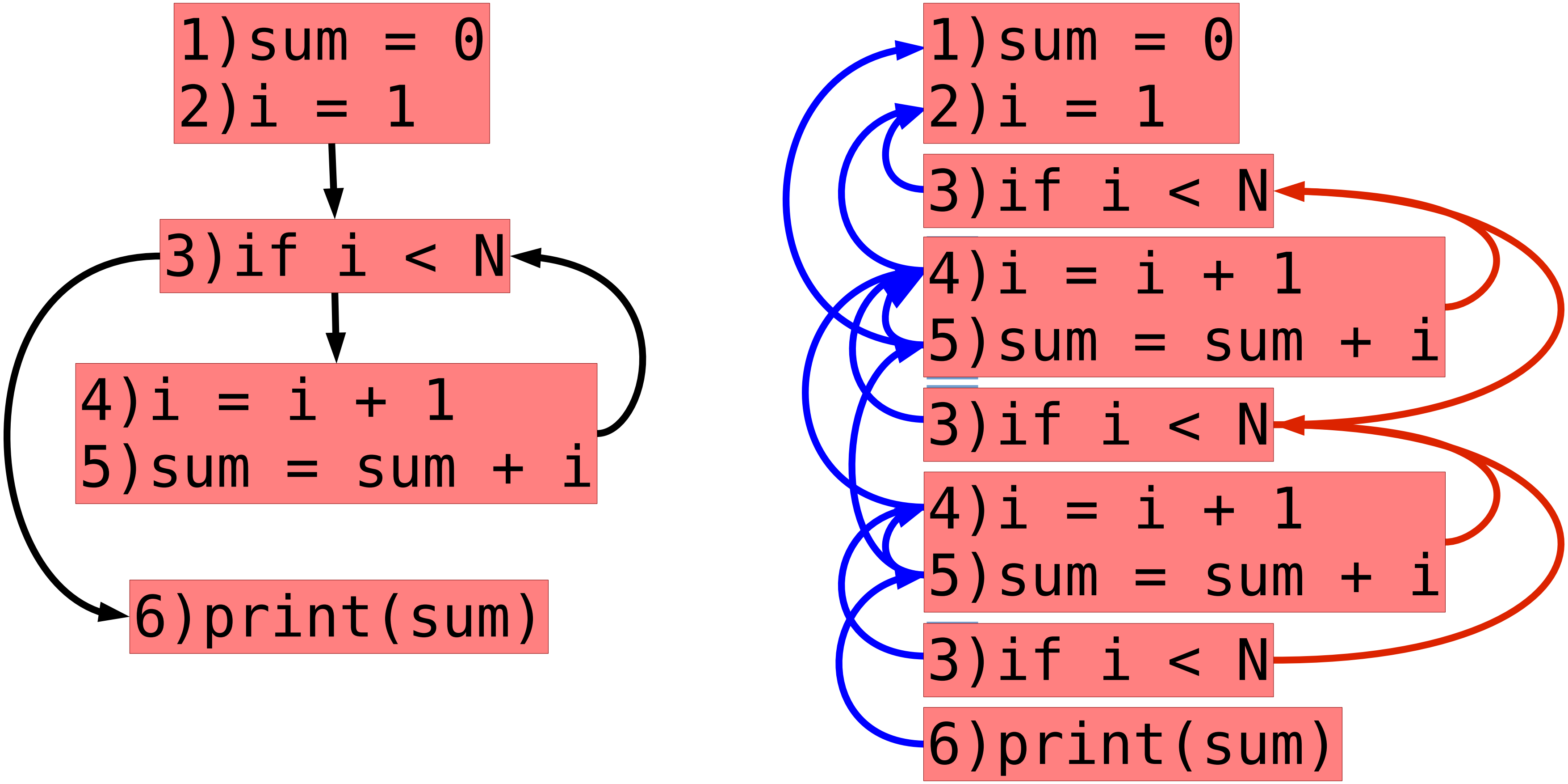

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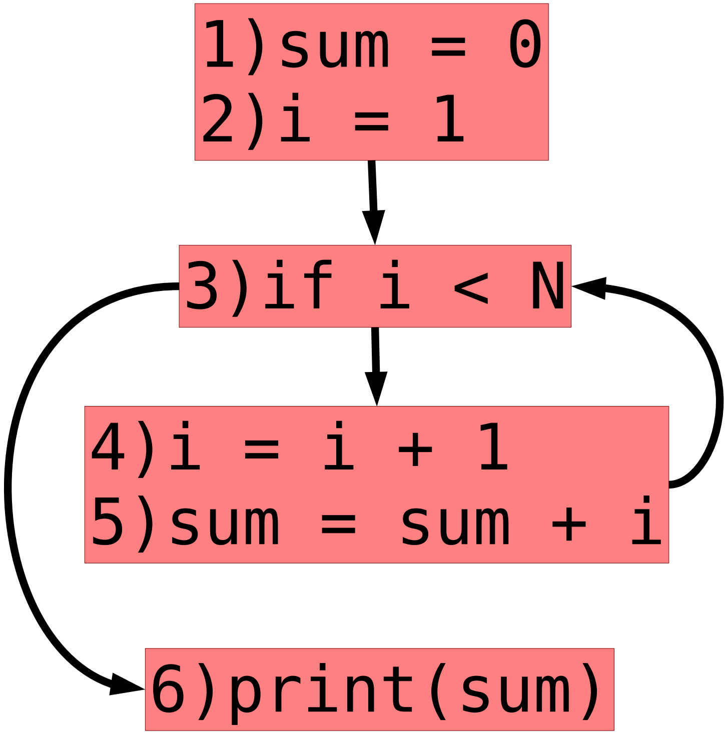

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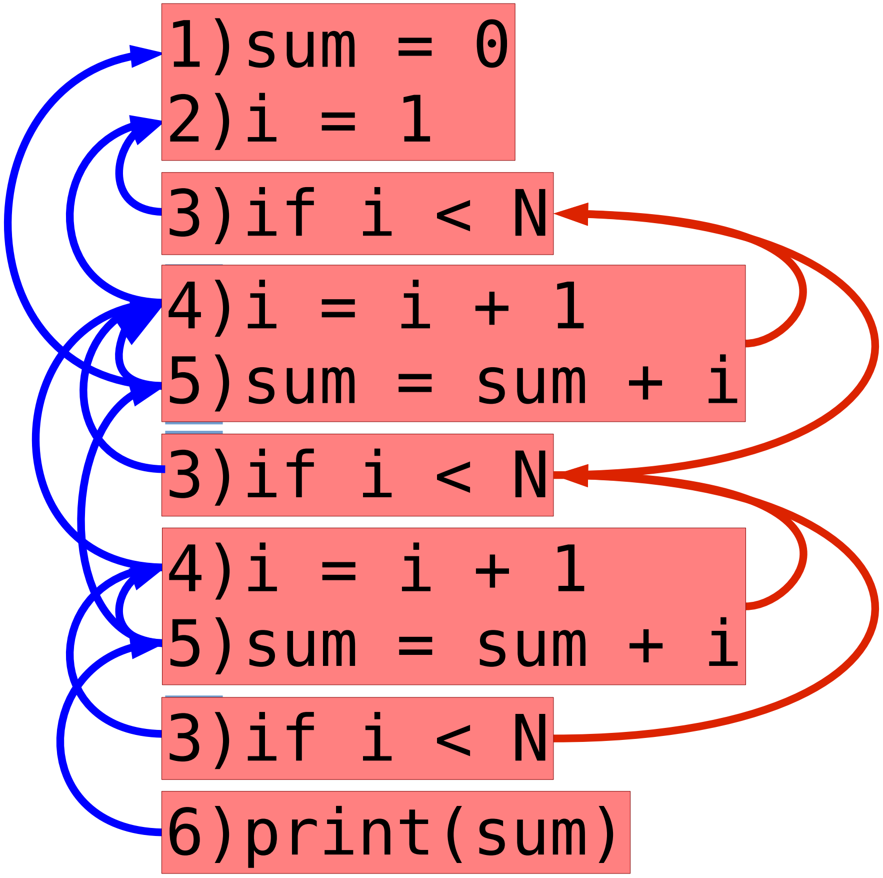

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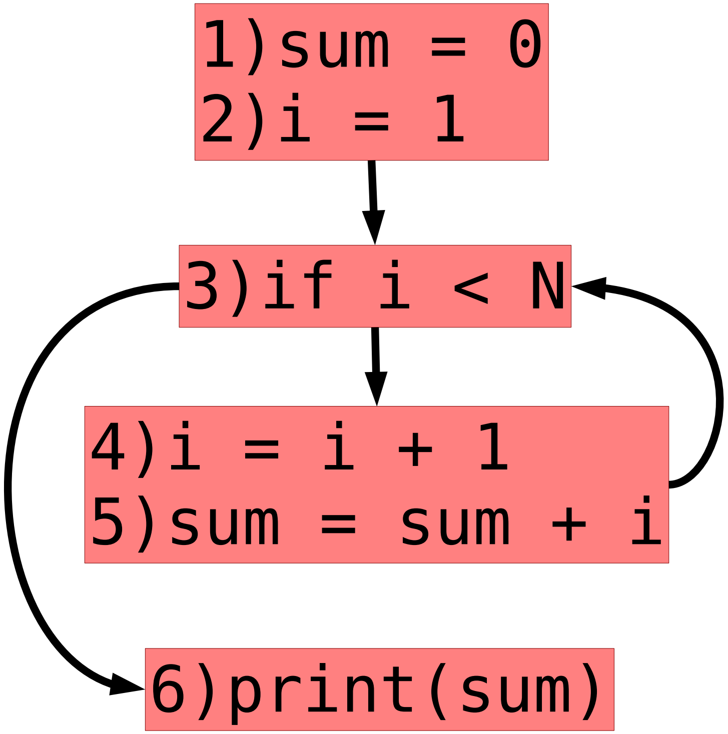

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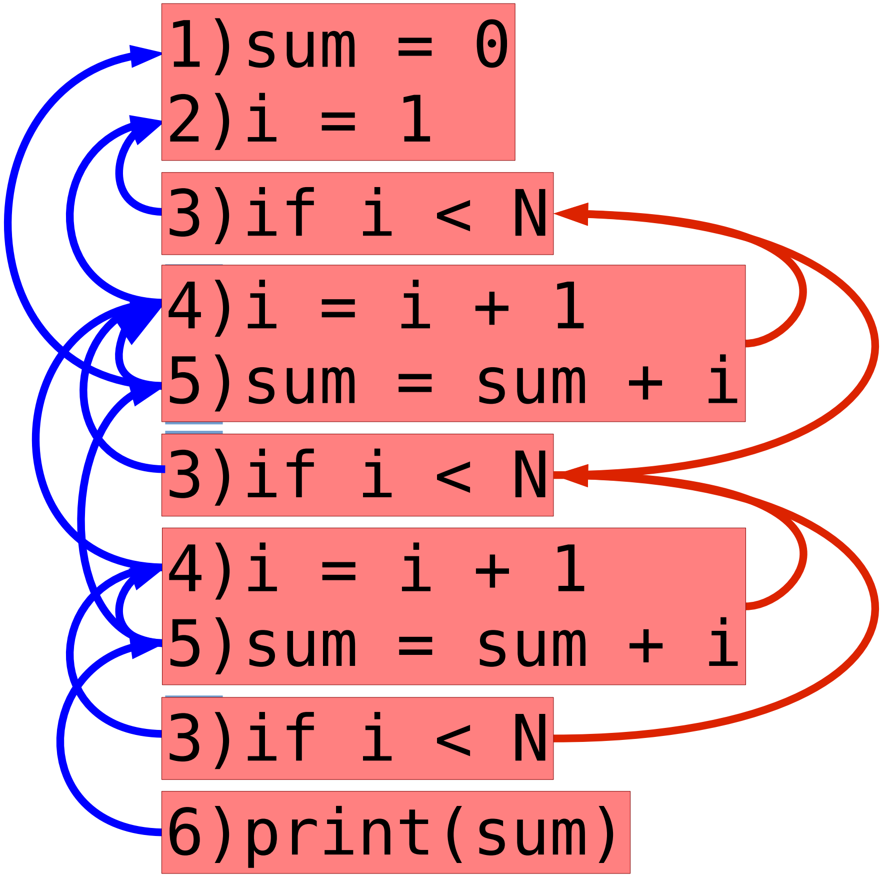

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If only we could focus on the parts that interest us…

Program Representations

Given these models, we can start to discuss interesting transformations and analyses on real programs.

Such as… slicing