CMPT 745
Software Engineering

What are programs?

Nick Sumner
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  - Security!
- We cannot reason about programs in only one way

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Why might binaries be good for security tasks?

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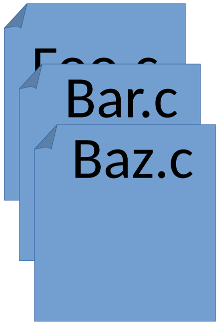
  - Source code



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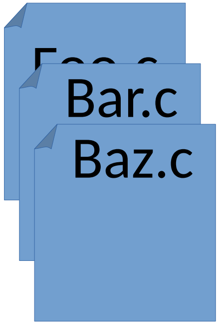

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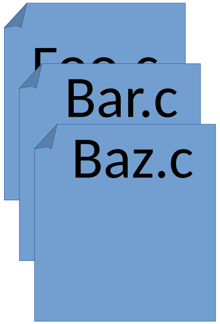

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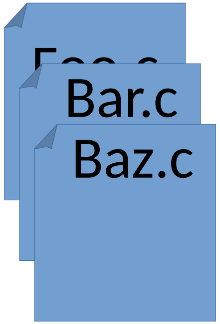
    - Relationships can be hard to extract
    - Often used when relating to comments or specs



Program Representation

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- Difficult models:
  - Compiled binaries
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- 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
6) Emerging Representations for ML

1) Abstract Syntax Trees

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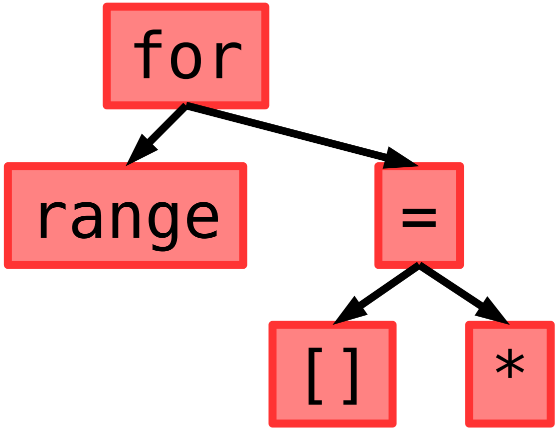

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  - Internal nodes are operators, statements, etc.
  - Leaves are values, variables, operands

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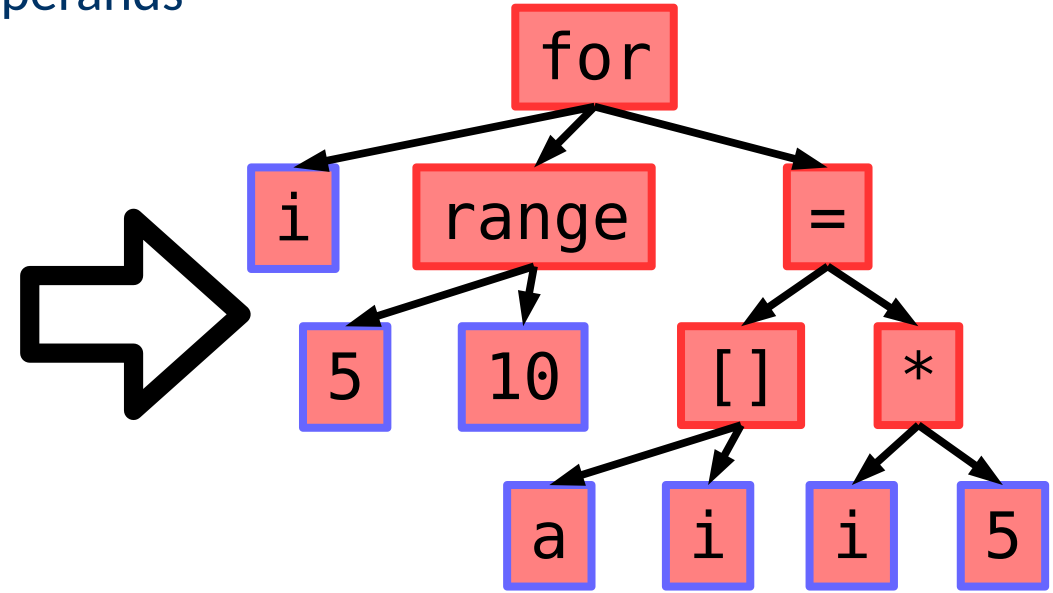

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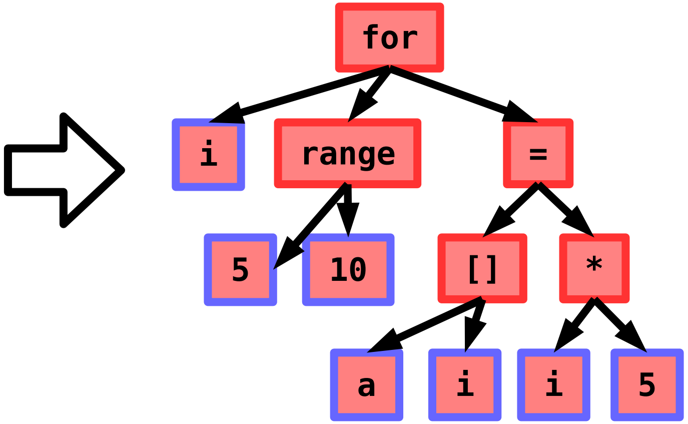

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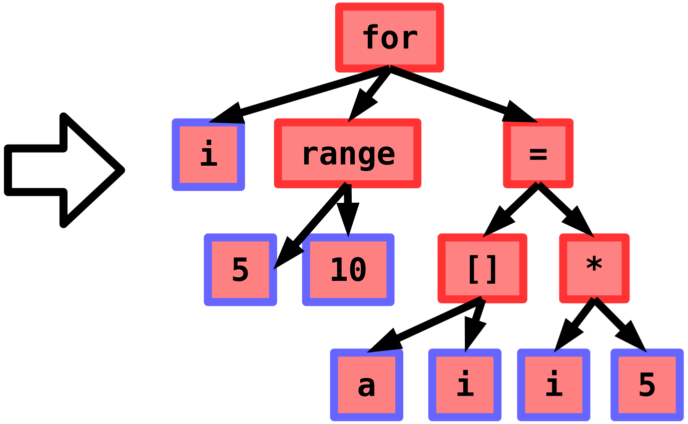

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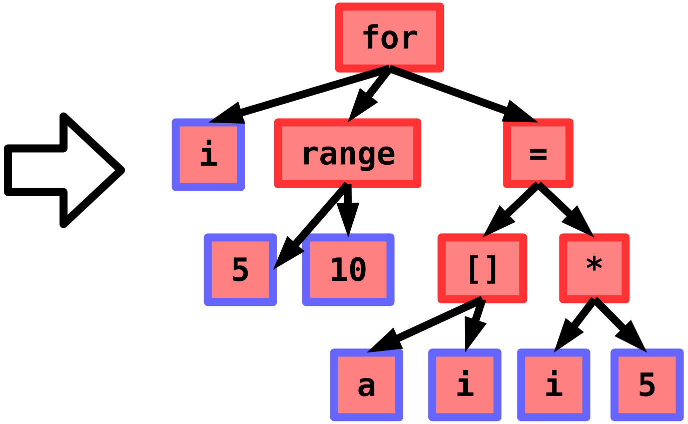

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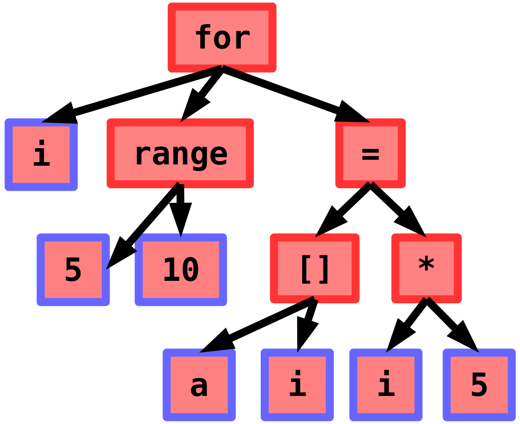

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  - Training prediction/completion models

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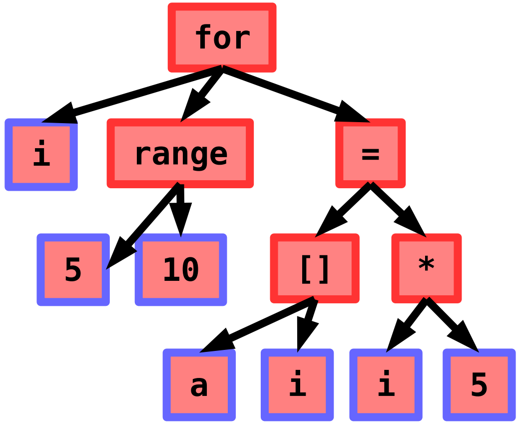

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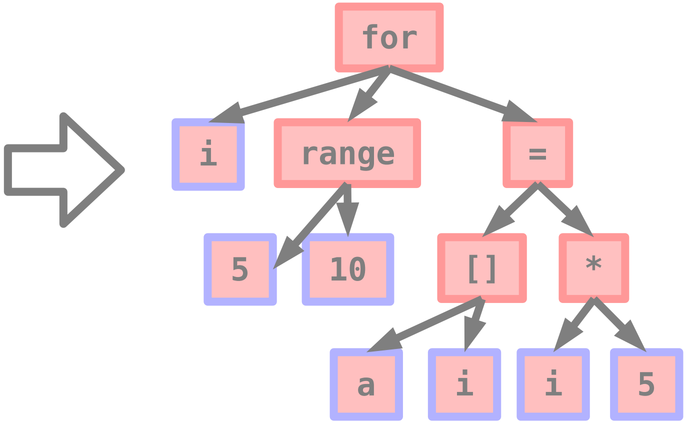

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But:
1) The same program may still be spelled many ways
2) Some information is *implicit* rather than *explicit*

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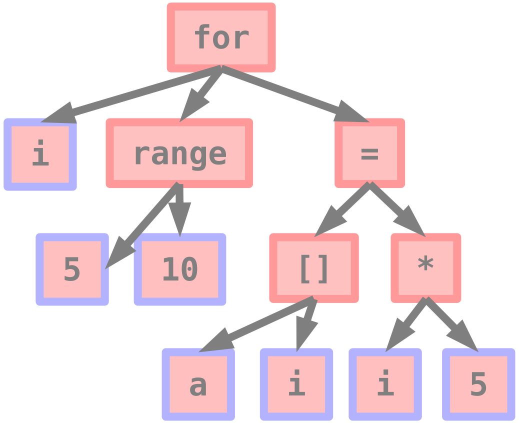

2) Control Flow Graphs

- Express the possible decisions and possible paths through a program

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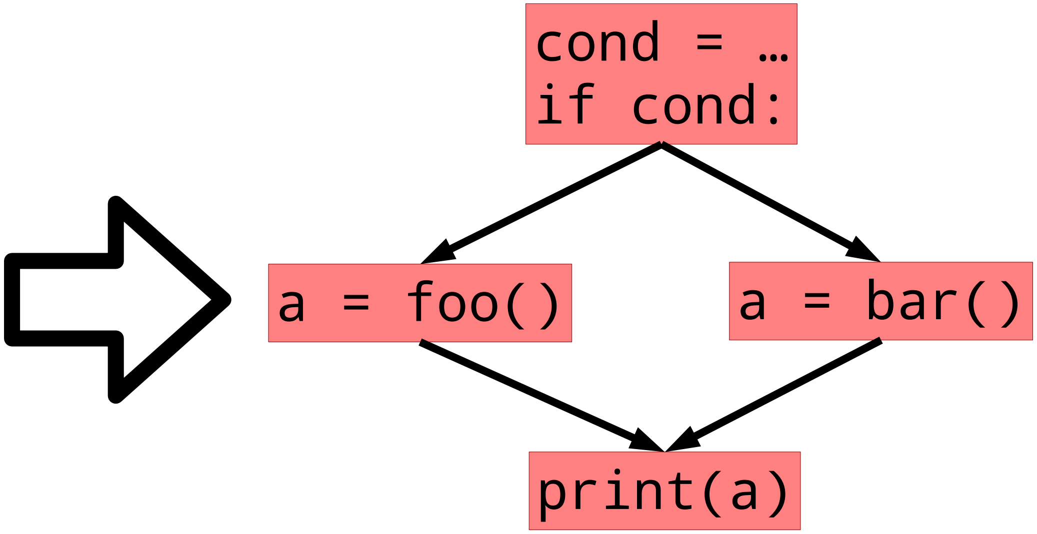

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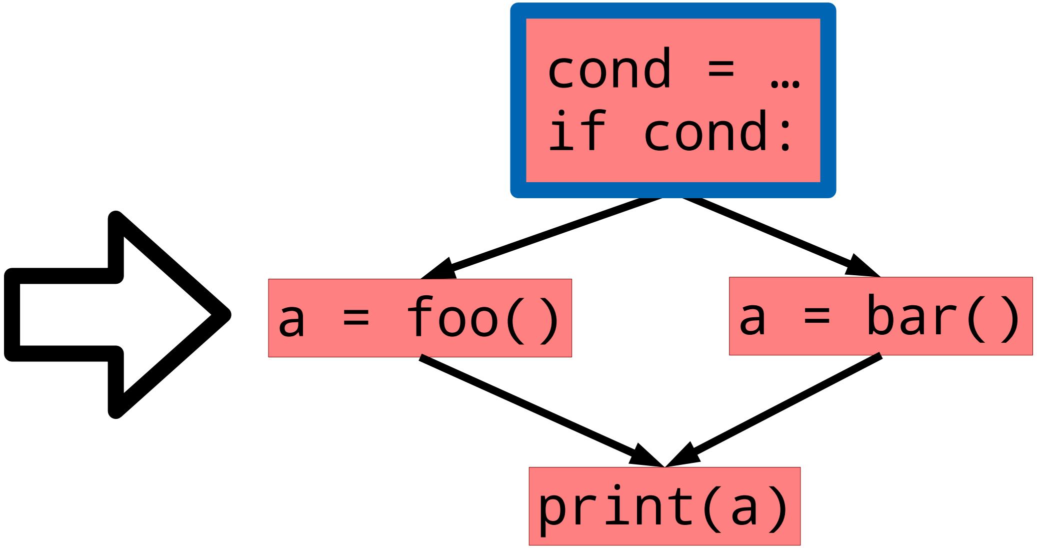

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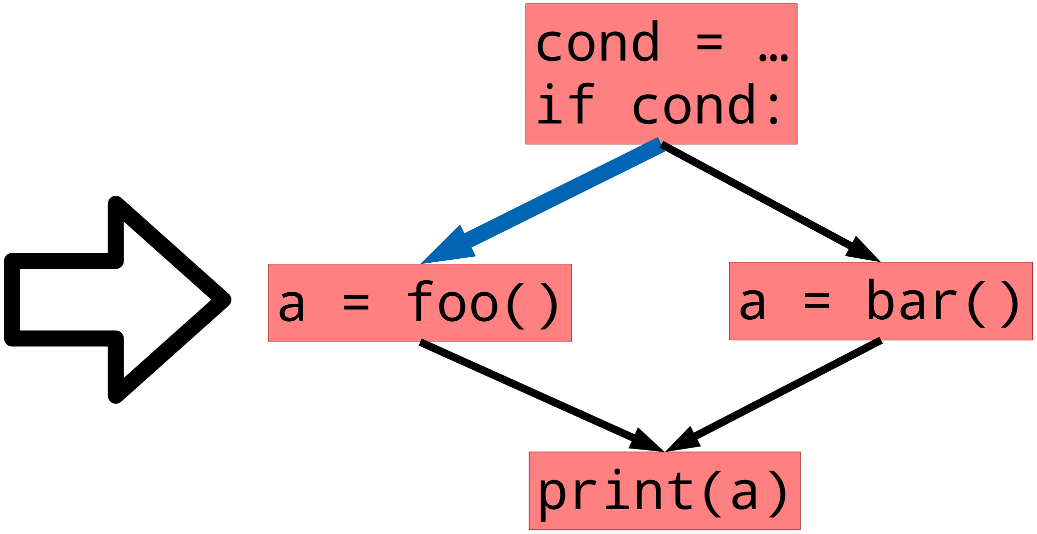

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- Express the possible decisions and possible paths through a program
  - ***Basic Blocks*** (Nodes) are straight line code
  - ***Edges*** show how decisions can lead to different basic blocks
  - ***Paths*** through the graph are potential paths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

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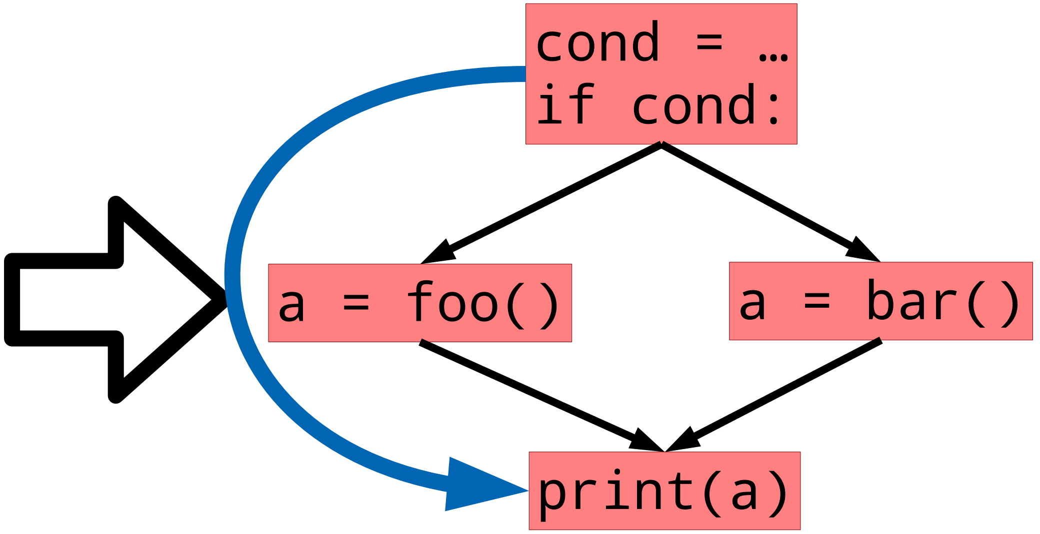

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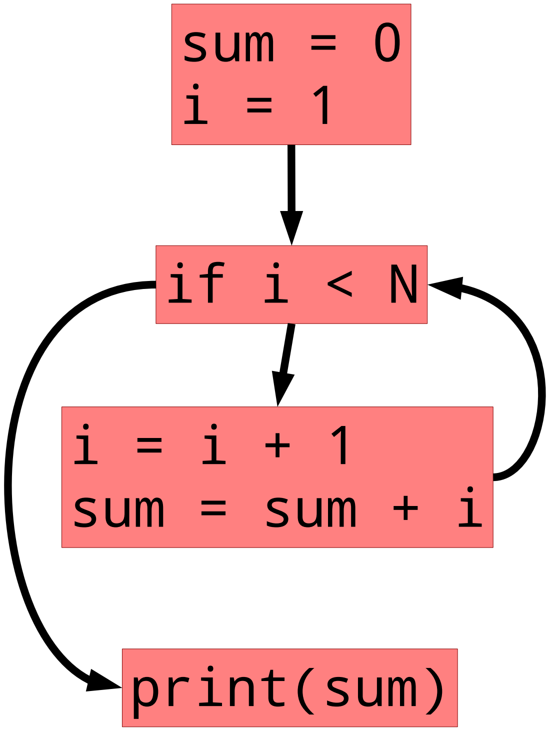

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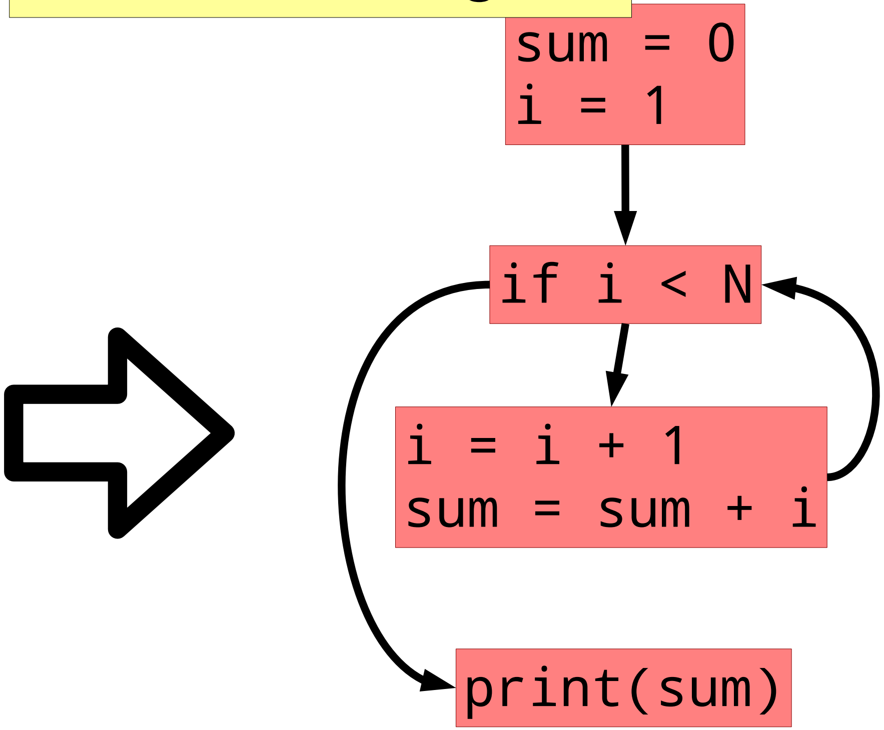

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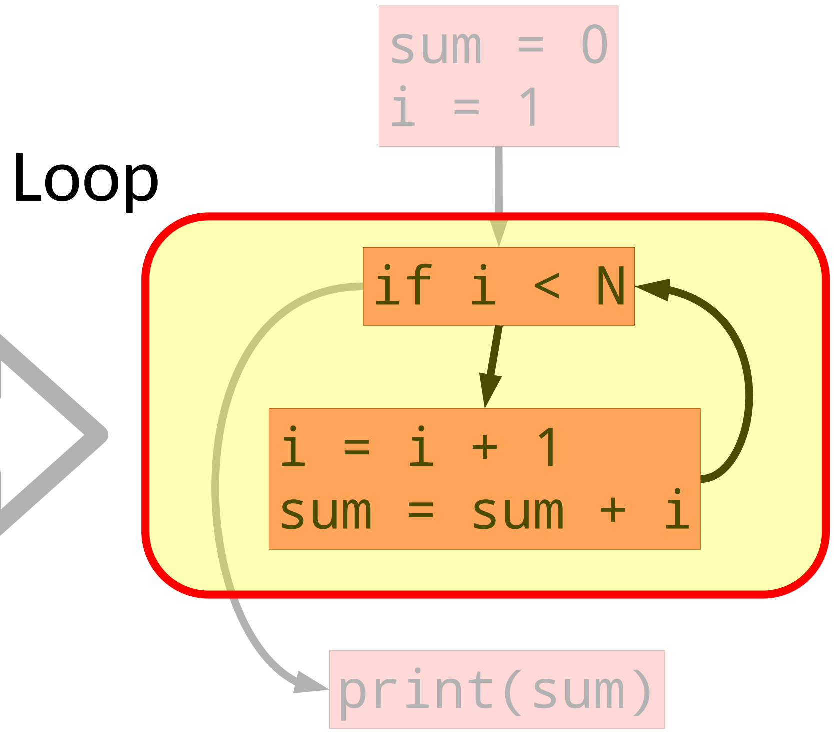

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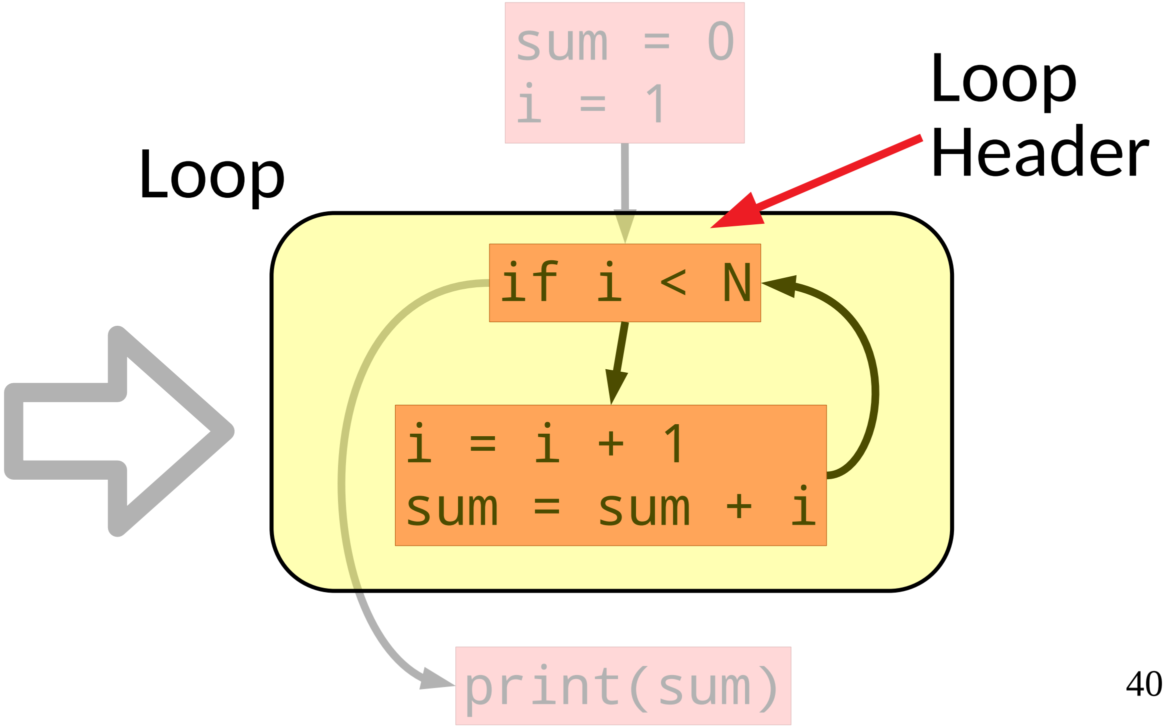

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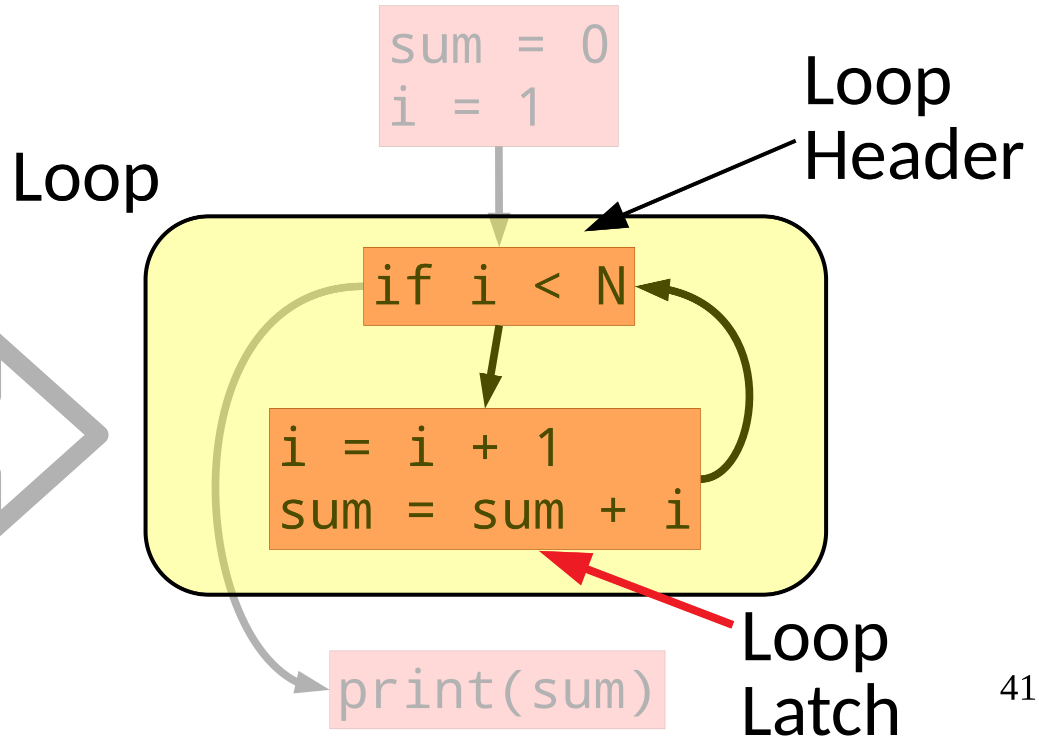

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Why is the 'if' in a separate block?

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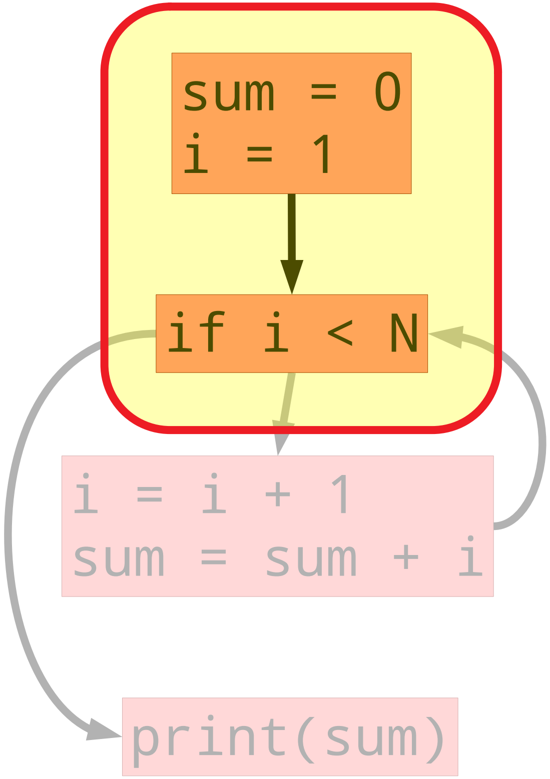

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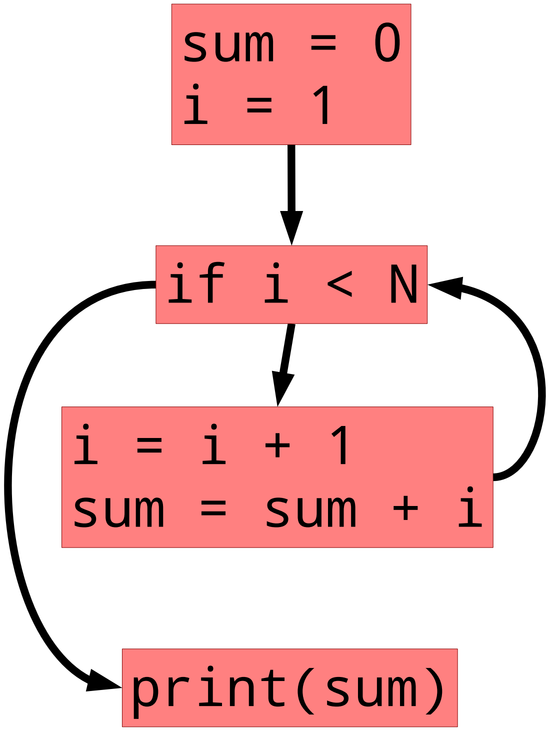
What would the CFG of the equivalent 'for' look like?



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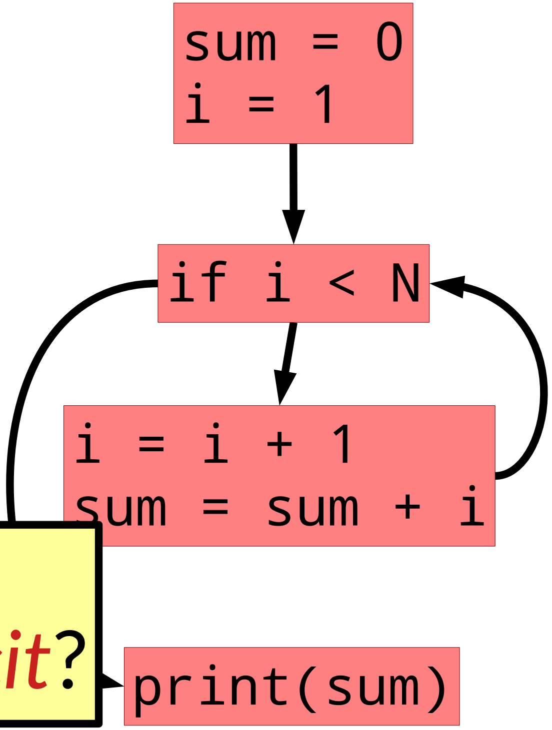

What information is *explicit*?
What information is still *implicit*?

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  - Nodes are instructions
  - An edge Y→X shows that Y influences X

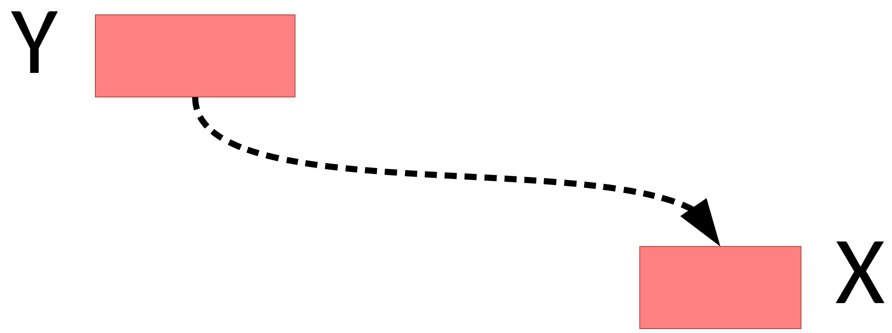
3)Program Dependence Graph (PDG)

- A ***Program Dependence Graph*** captures how instructions can influence each other
- Instruction X depends on Y if Y *can influence* X
- 2 main types of influence:
  - Data dependence
  - Control dependence

Data Dependence

X data depends on Y if

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



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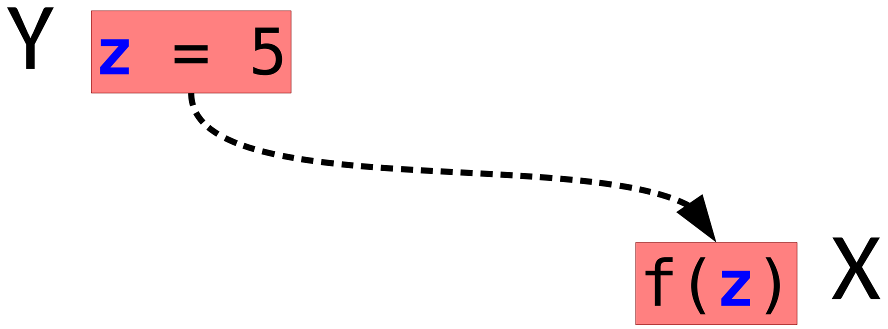

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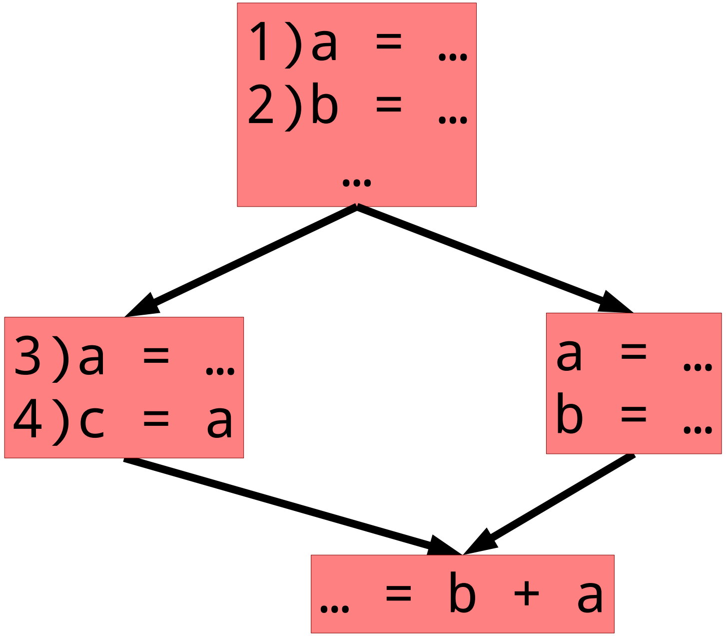

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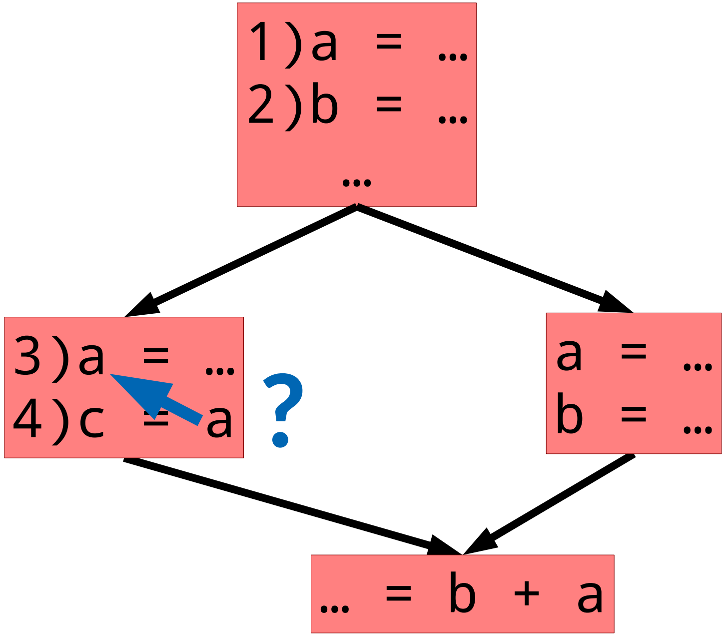

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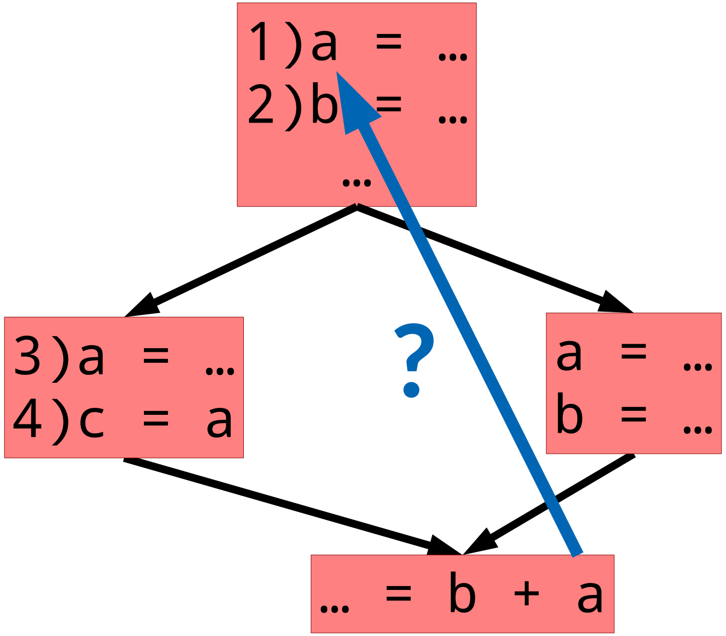

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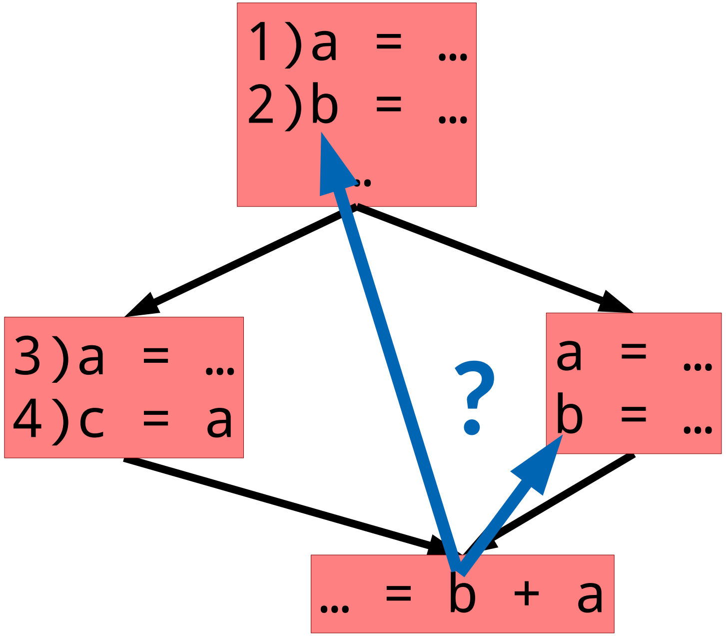

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- every path from the entry node to Y passes X
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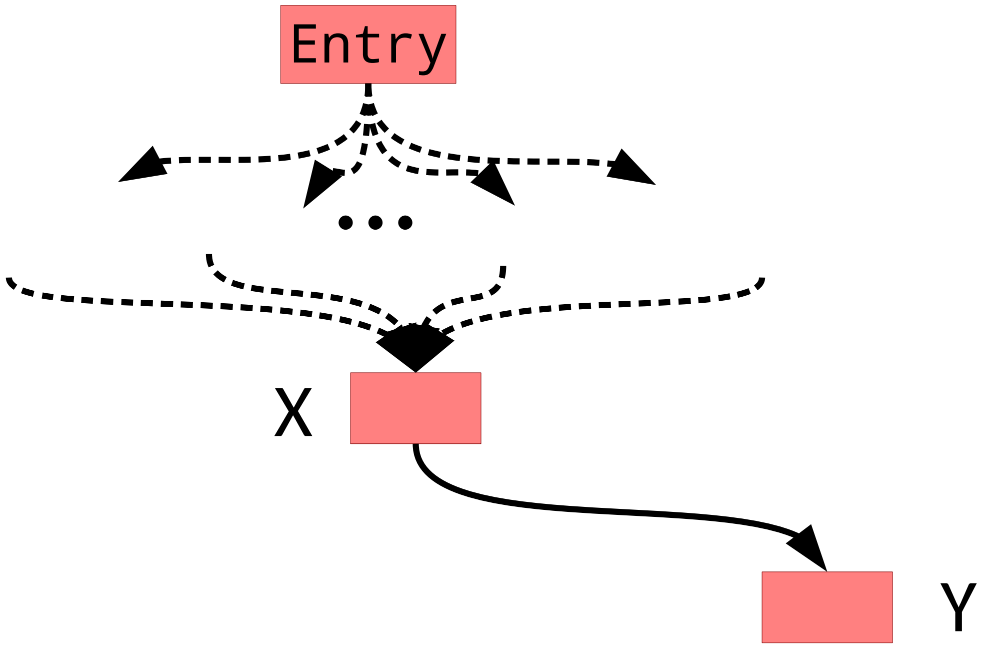

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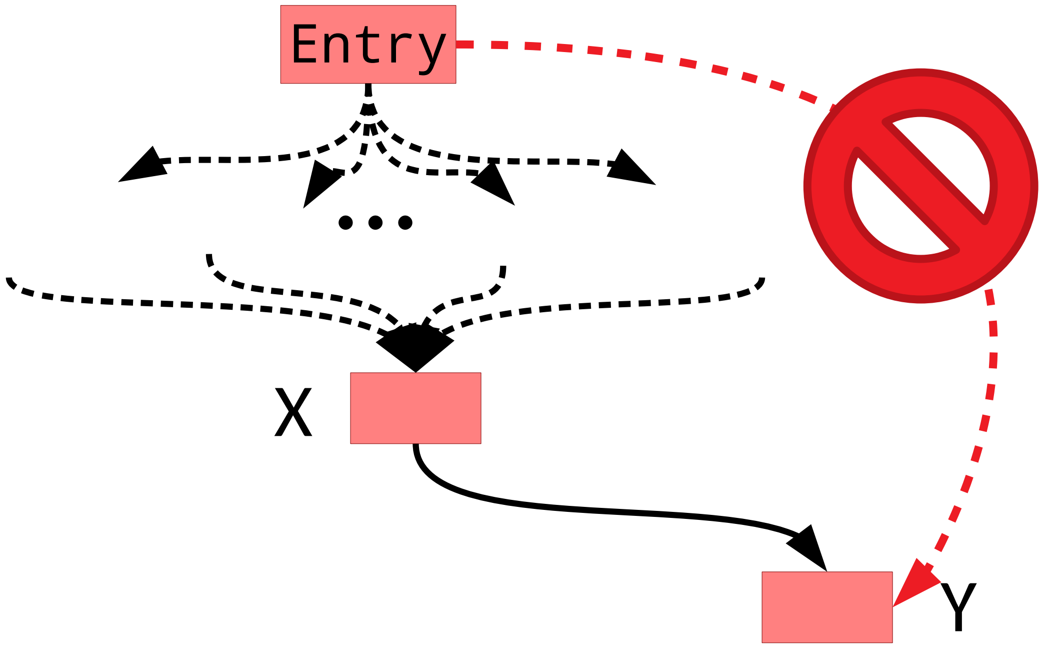

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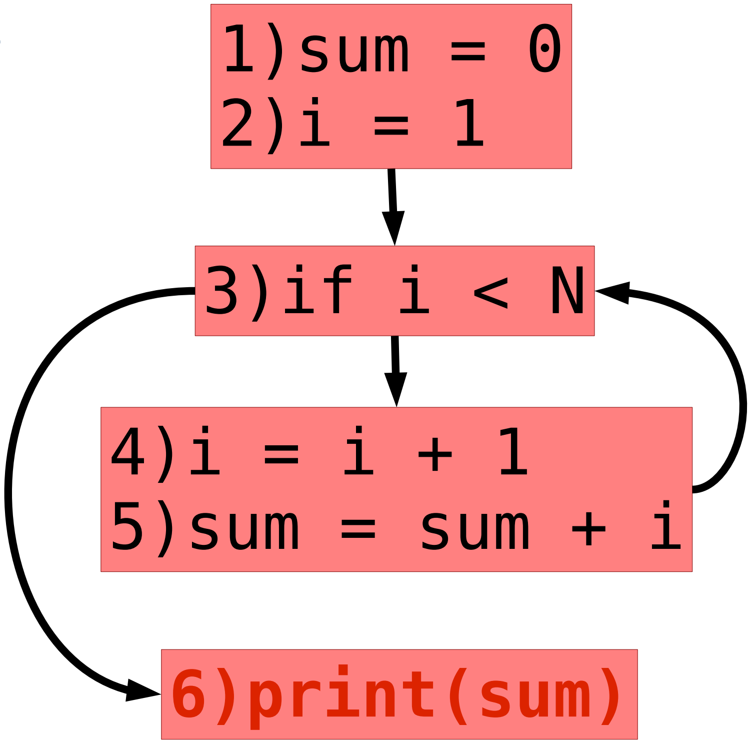

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IDOM(6)= ?

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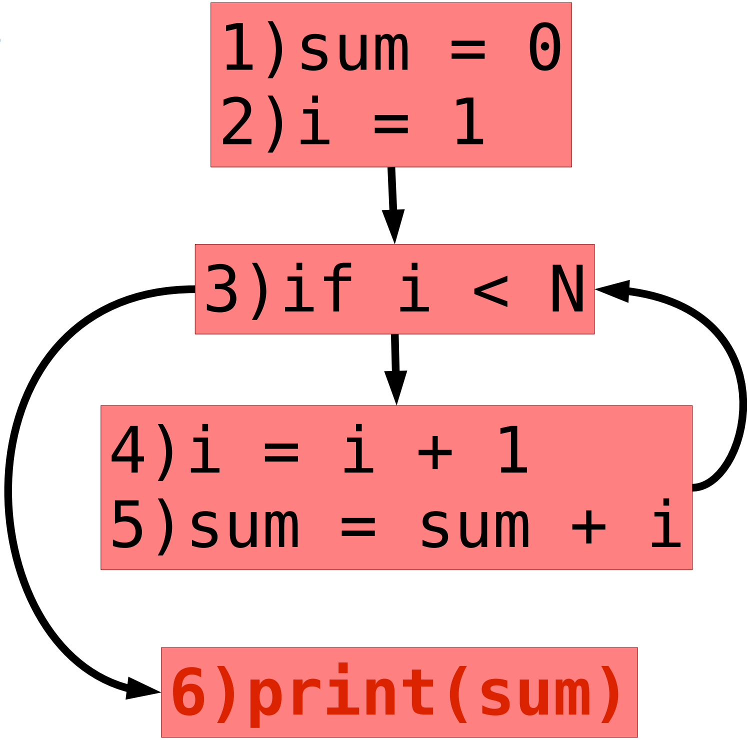

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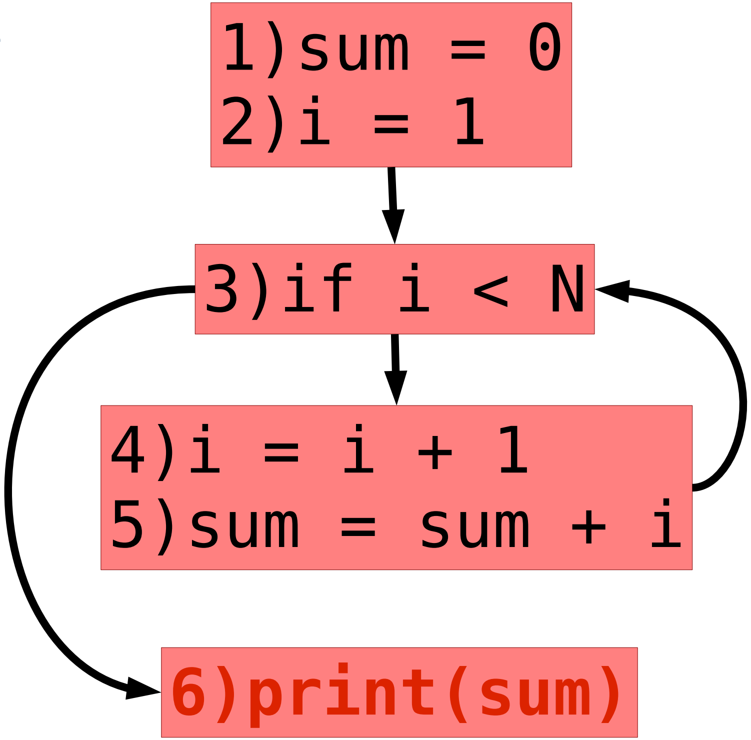

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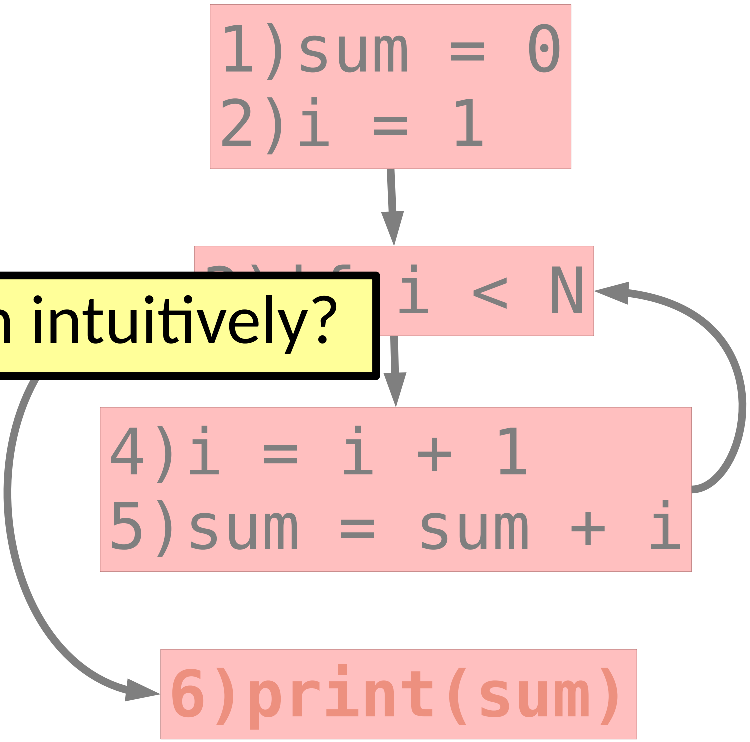
What does this mean intuitively?



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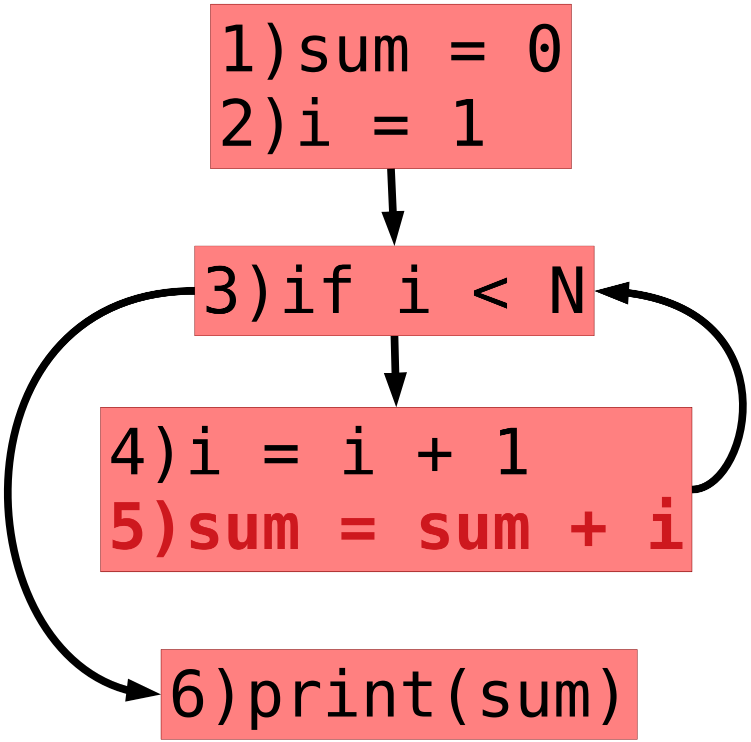

PDOM(5)= **?**   IPDOM(5)= **?**

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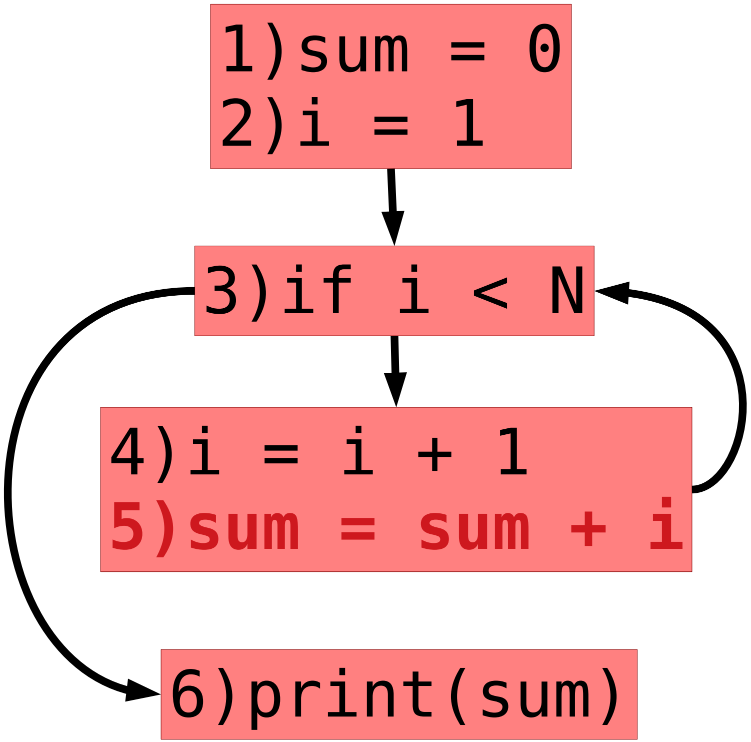

PDOM(5)={3,5,6}   IPDOM(5)= ?

Control Dependence

Preliminary: X ***post*** dominates Y if

- every path from the ***Y to exit*** passes X
  - strict, normal, & immediate dominance

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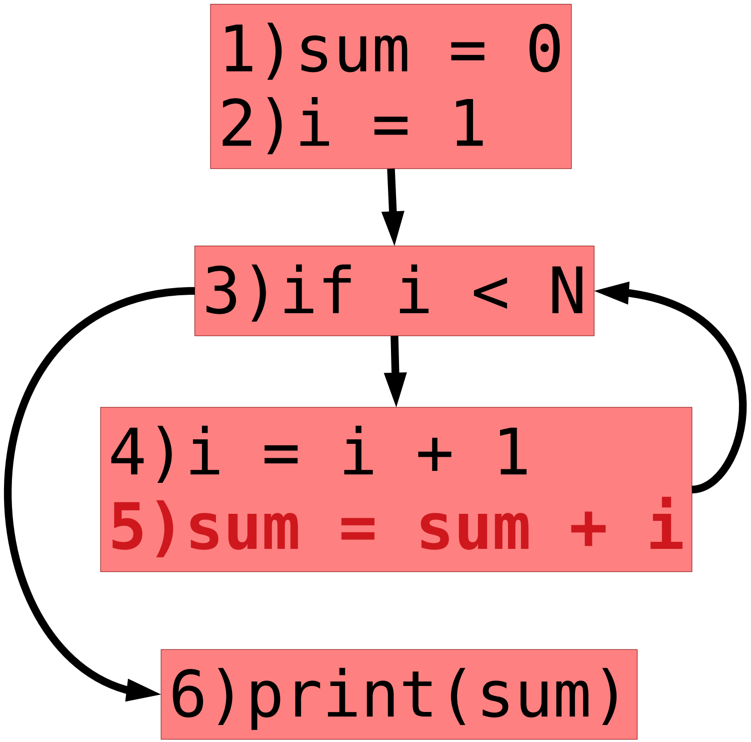

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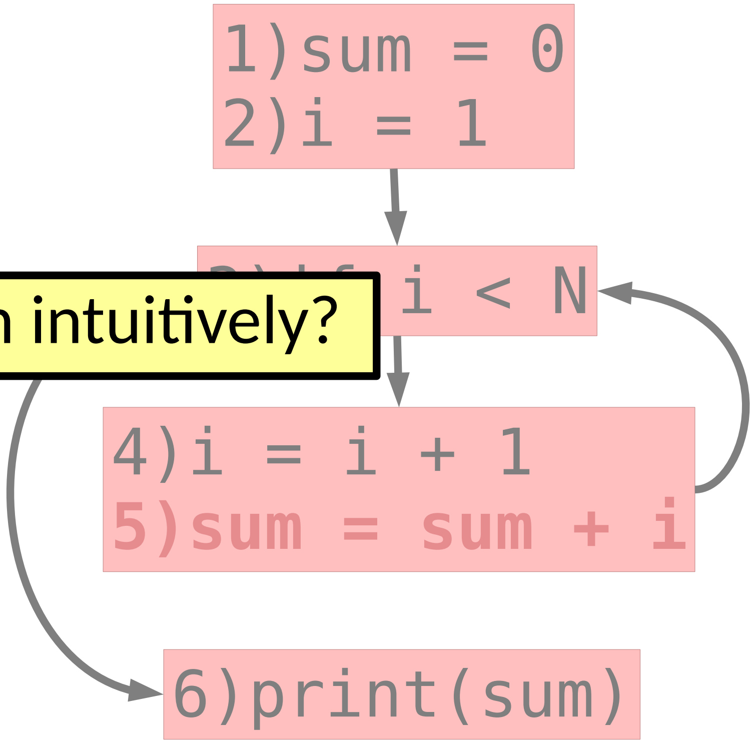
What does this mean intuitively?



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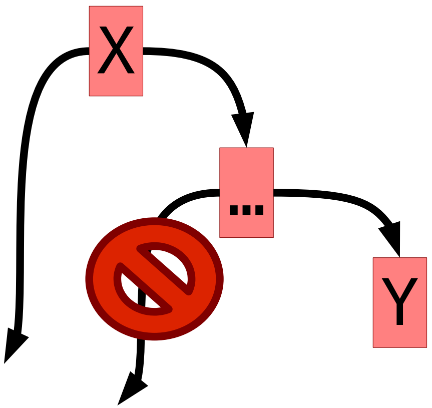

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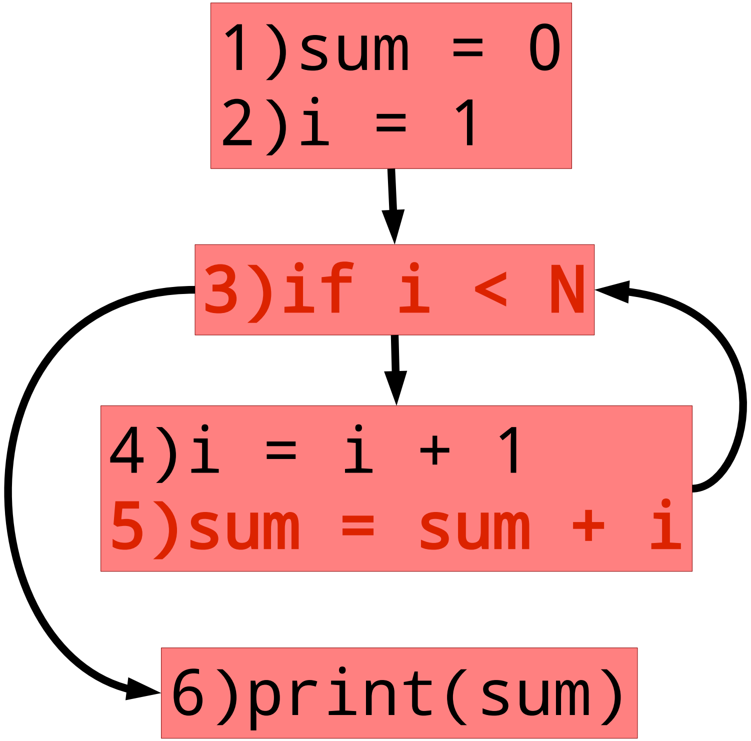

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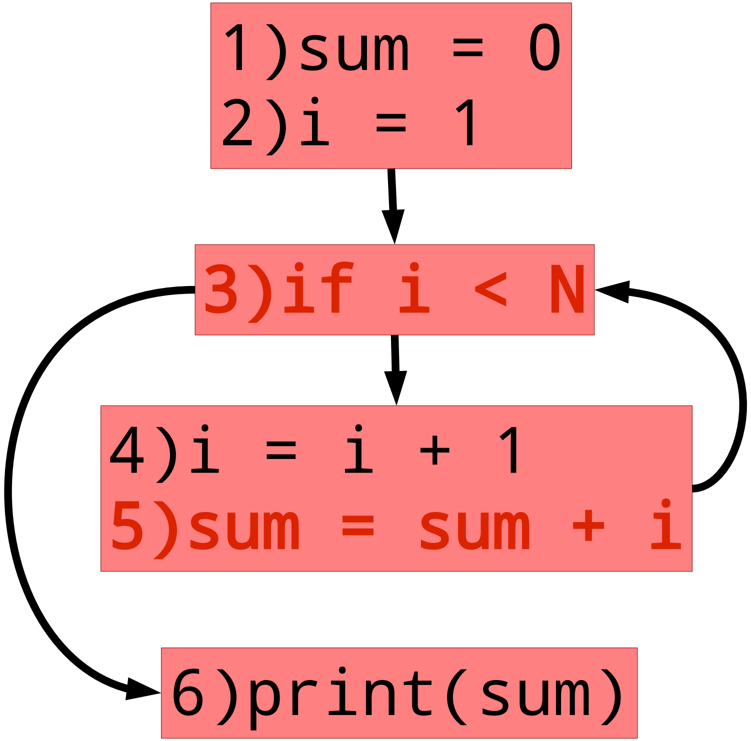

What is CD(5)? CD(3)

Control Dependence

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sum = 0
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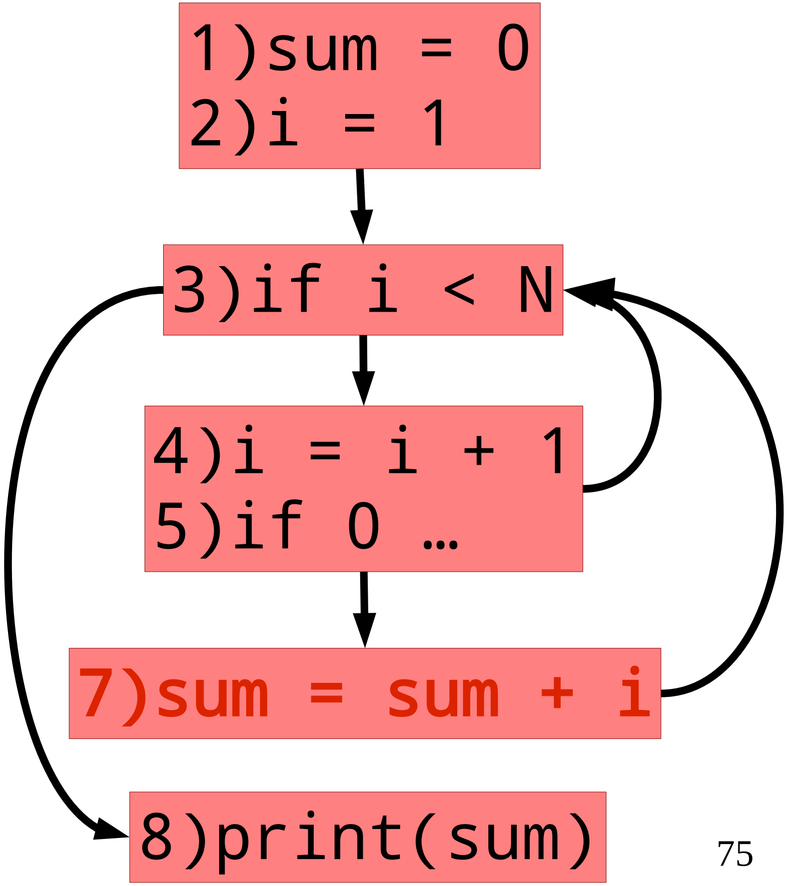

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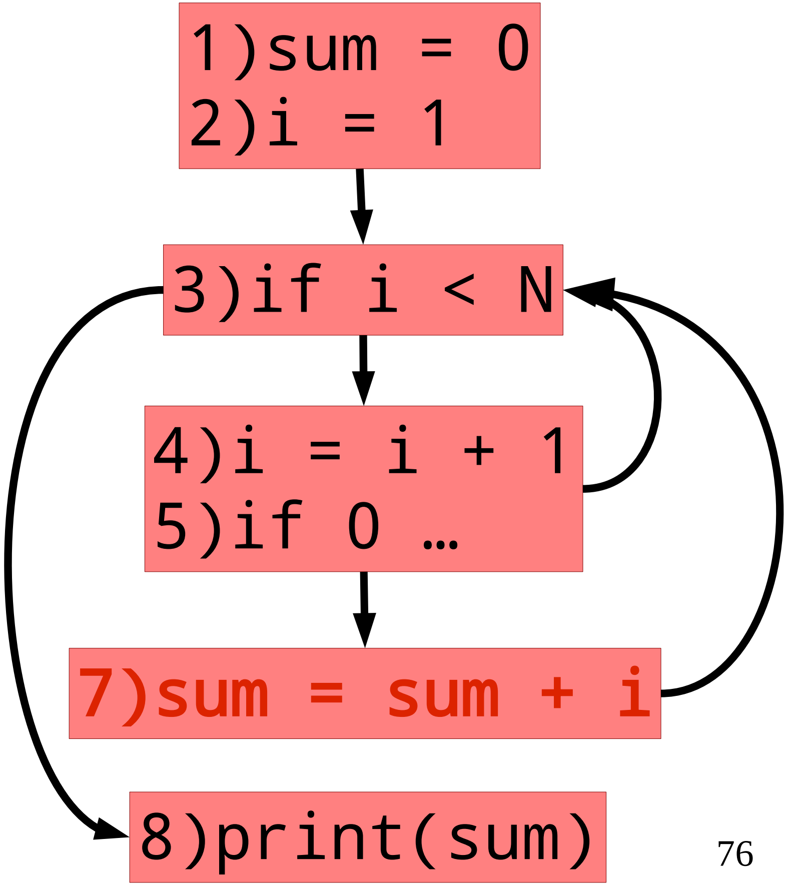

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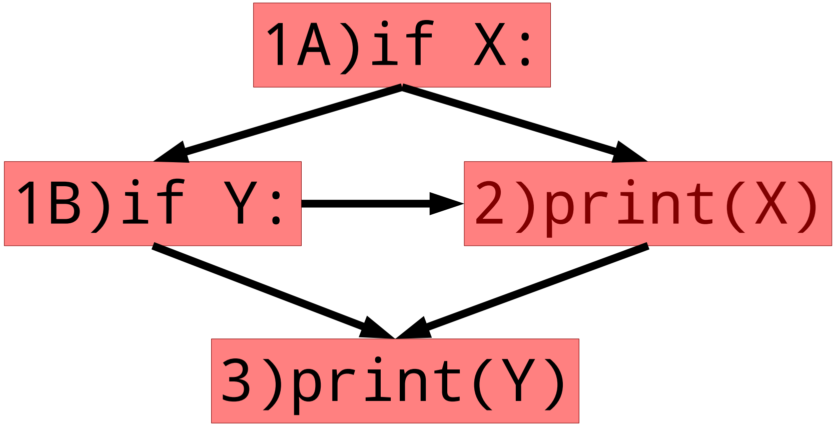

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3)Program Dependence Graph(PDG)

The PDG is the combination of

- The control dependence graph
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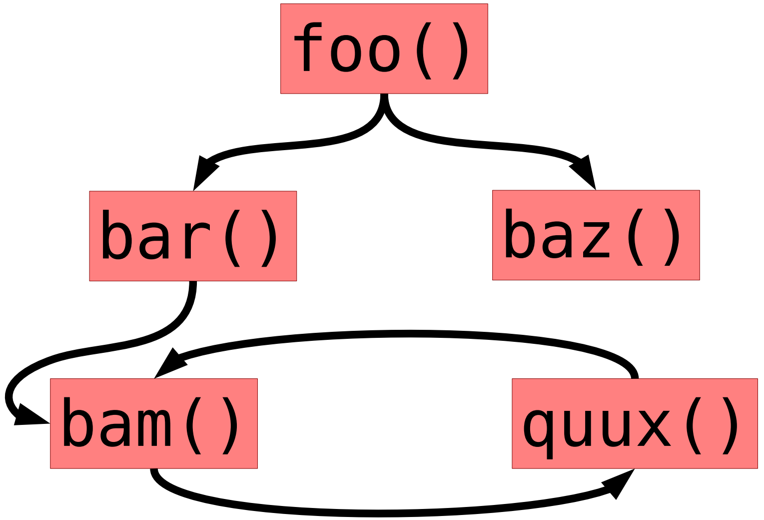
Can you see *challenges* that may arise when using the PDG in practice?

4) Call Graph (Multigraph)

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



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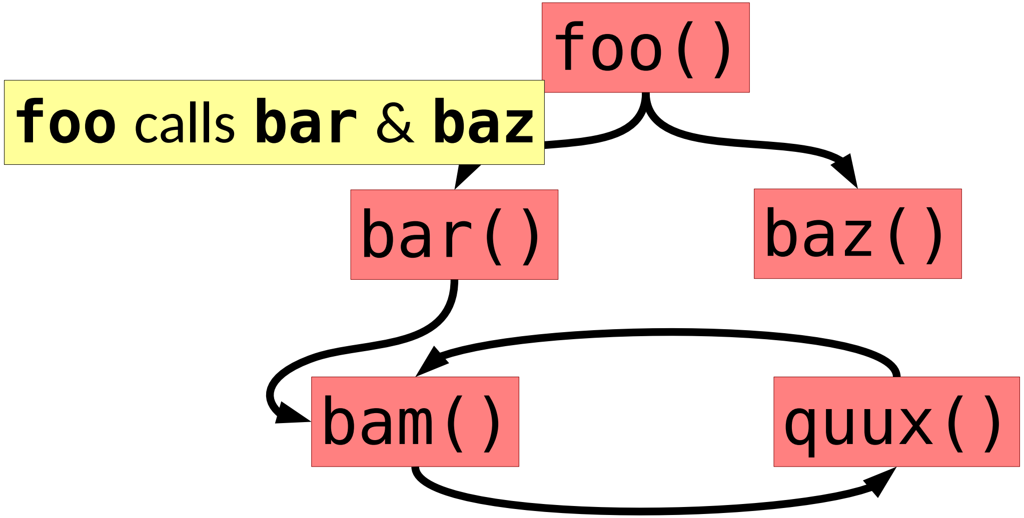

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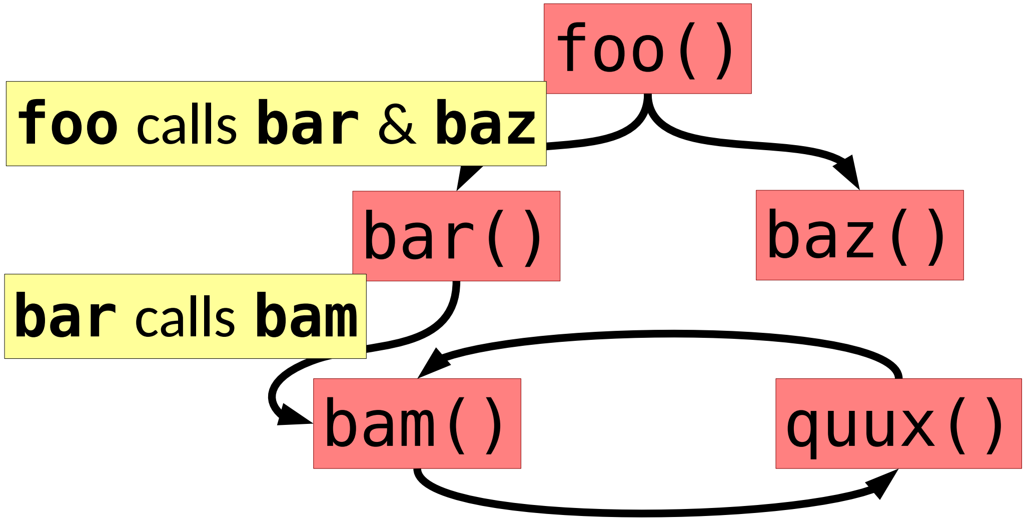

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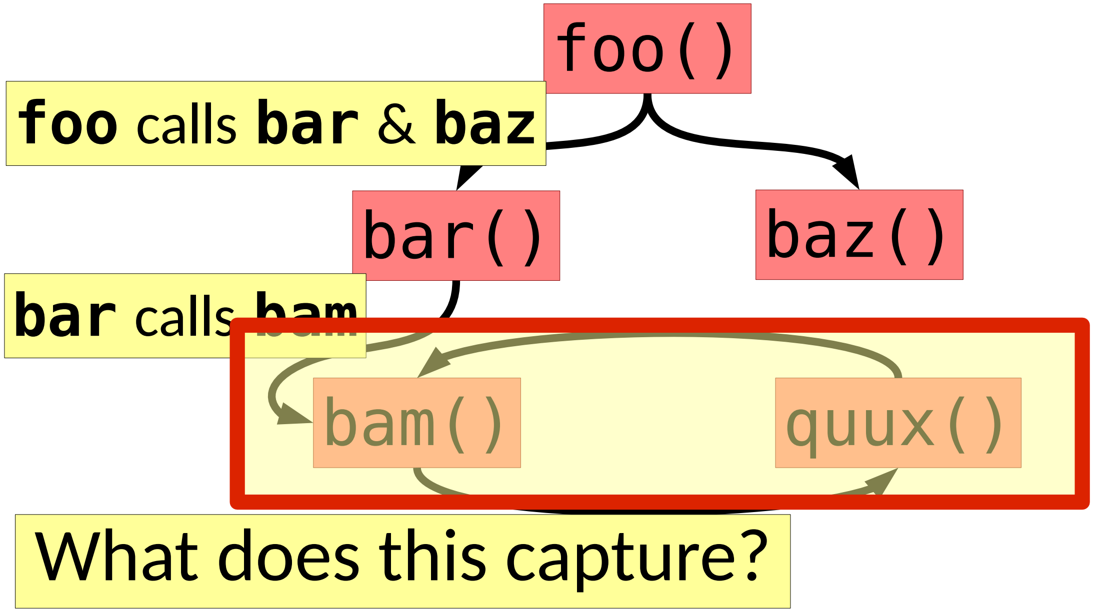

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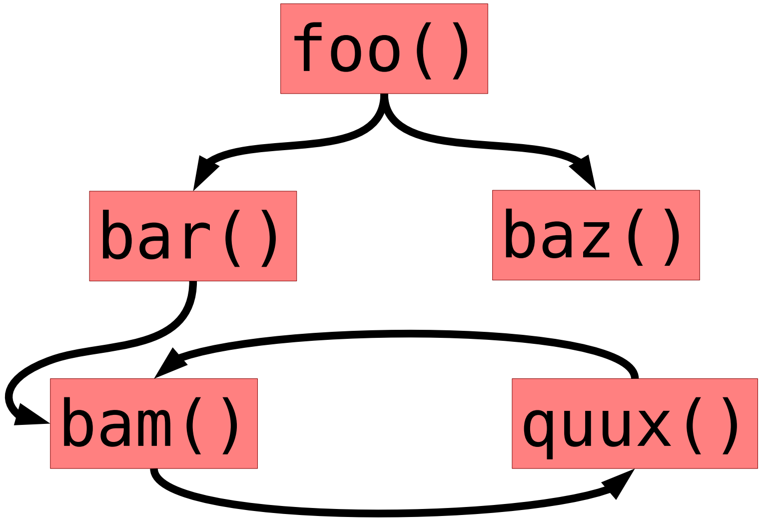
How should we handle function pointers?



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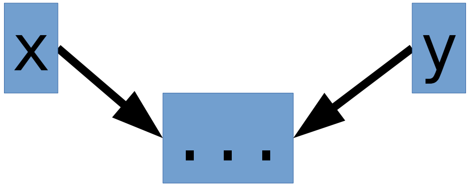

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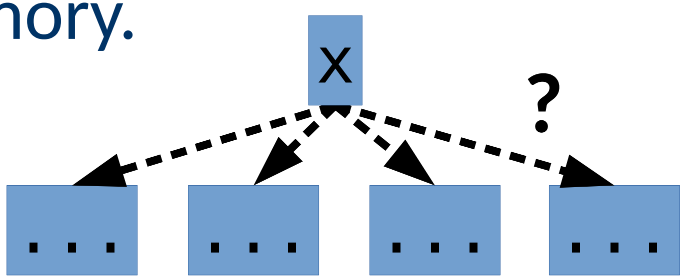

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x.lock()
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```
x = password
…
broadcast(y)
```

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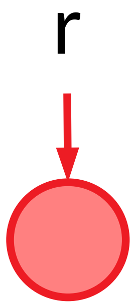

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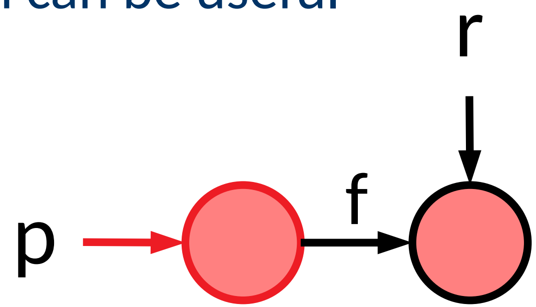

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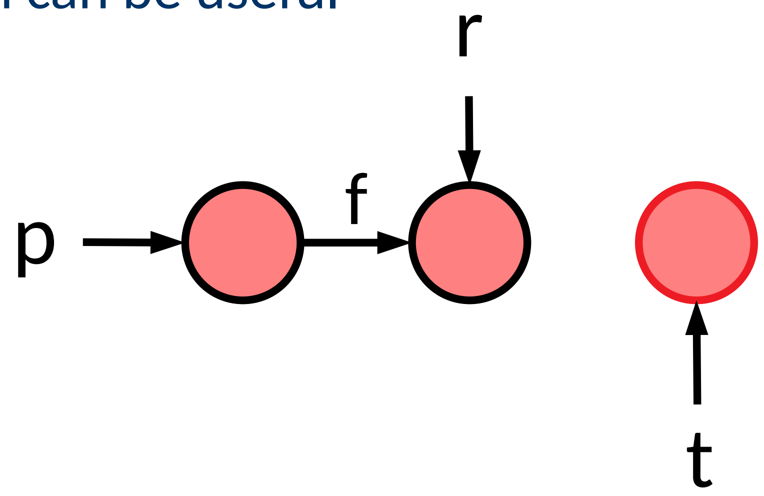

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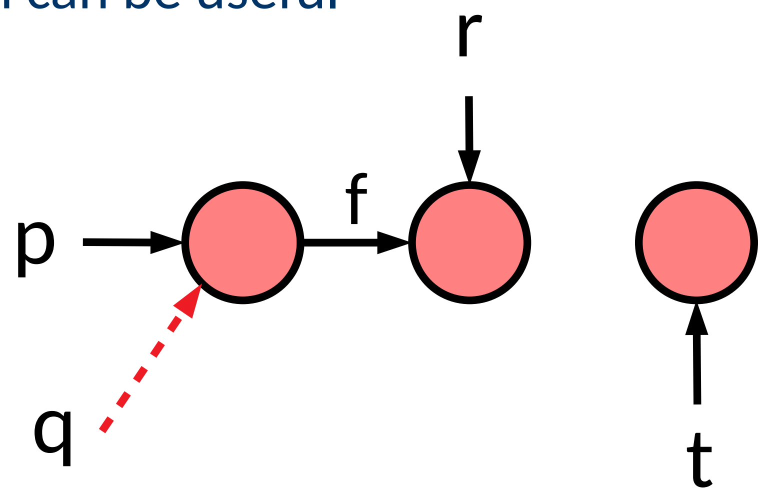

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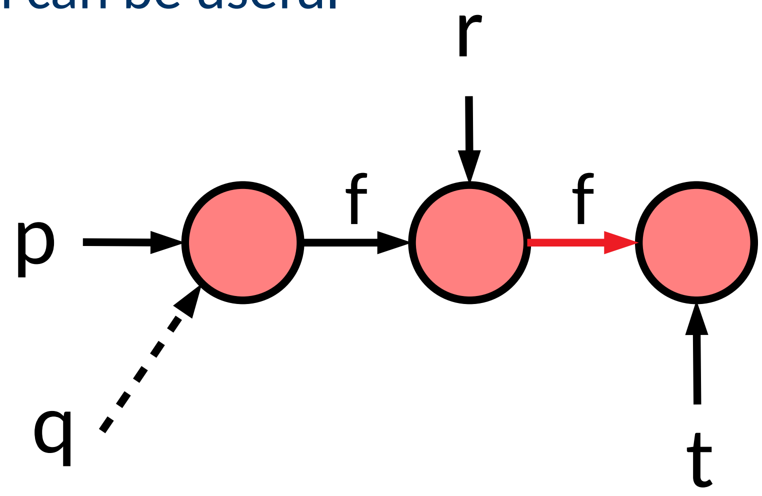

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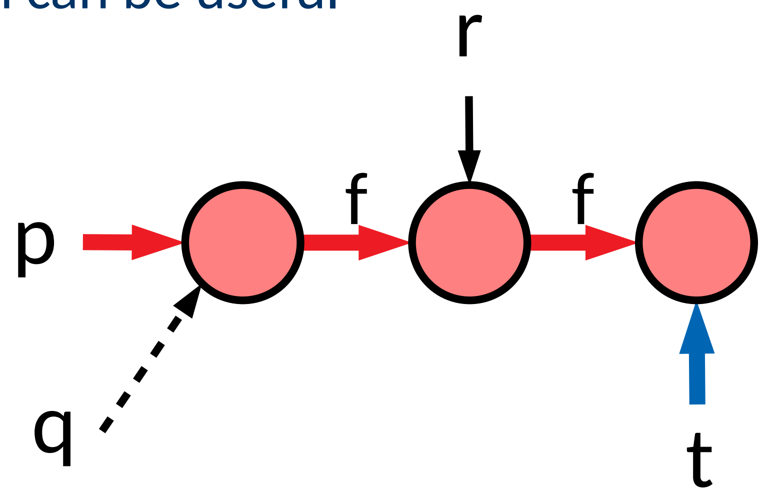

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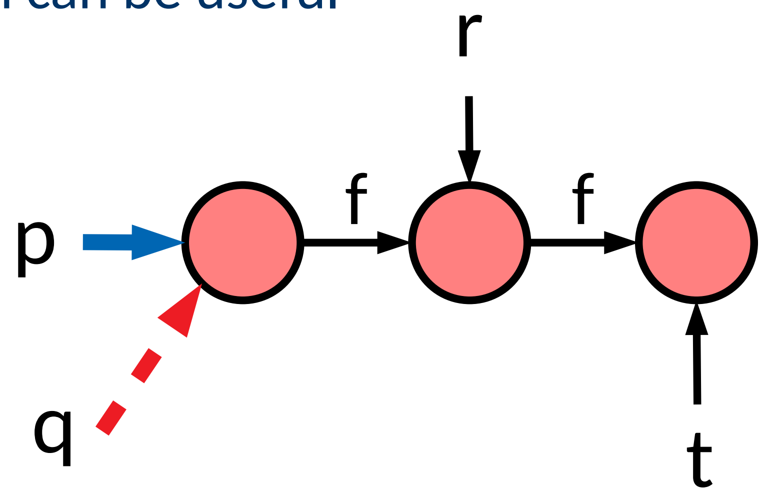

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  - Bug fix & close time estimation [Yedida 2021]
  - Project planning & analytics [Krishna 2020]
  - Recognizing actionable compiler warnings [Yang 2020]

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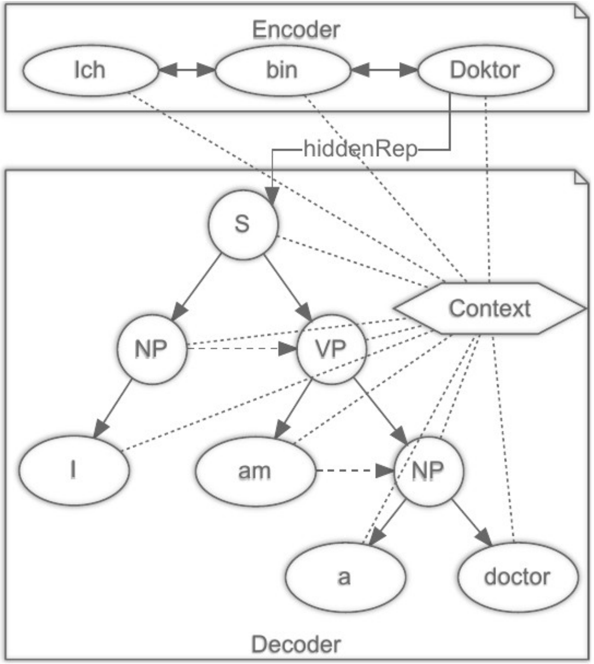
  - Solutions that do not require *a priori* implementation are desirable
- But different models & pipelines arise to aid in
  reasoning about software

6) Emerging Representations for ML

Seq2DRNN
Encoder-Decoders
[Alvarez-Melis 2017, Gu 2019]



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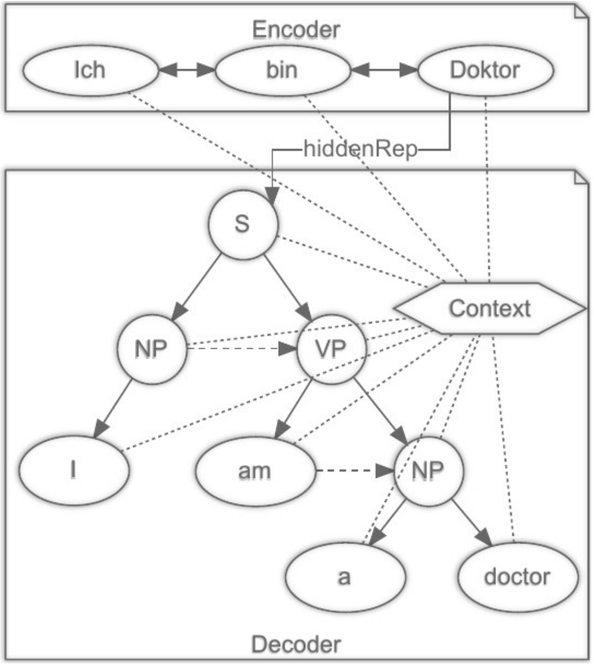
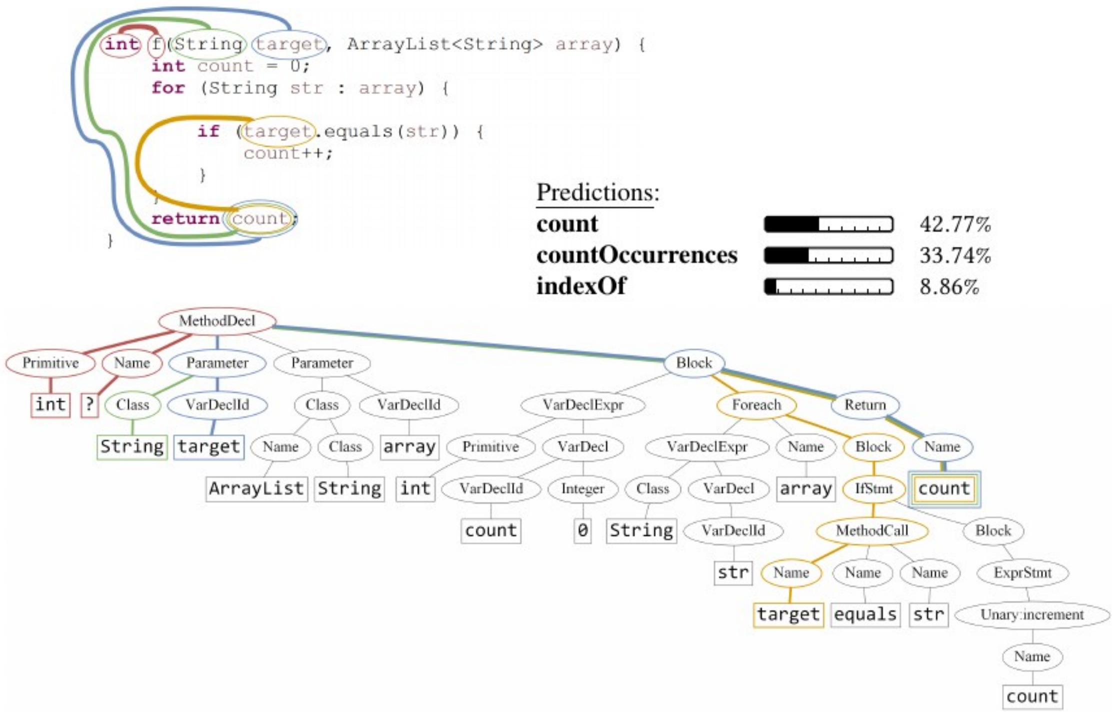


code2vec
[Alon 2018]



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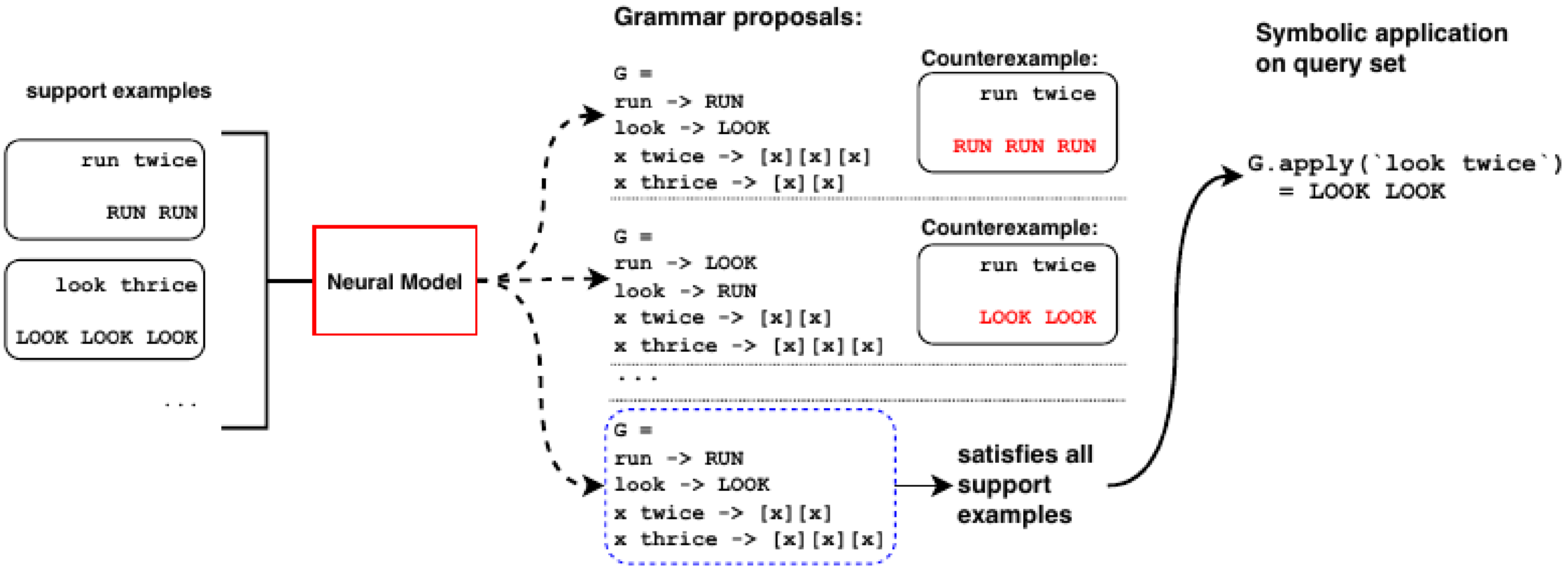

neurosymbolic models for synthesis
[Nye 2020]

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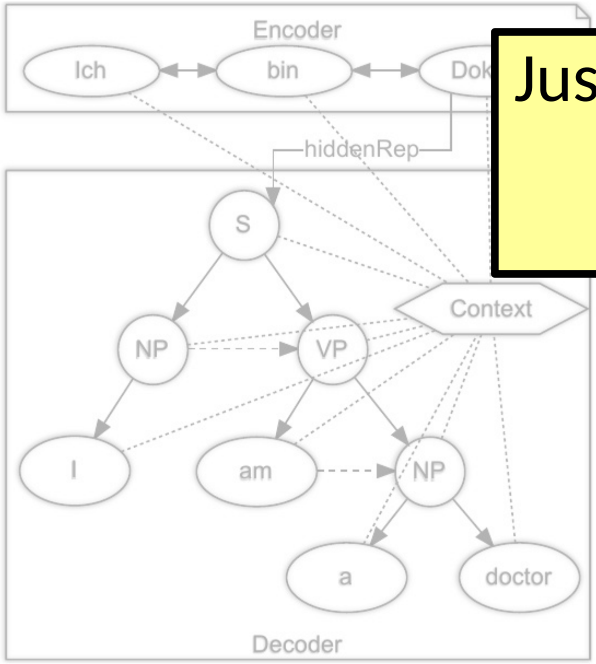

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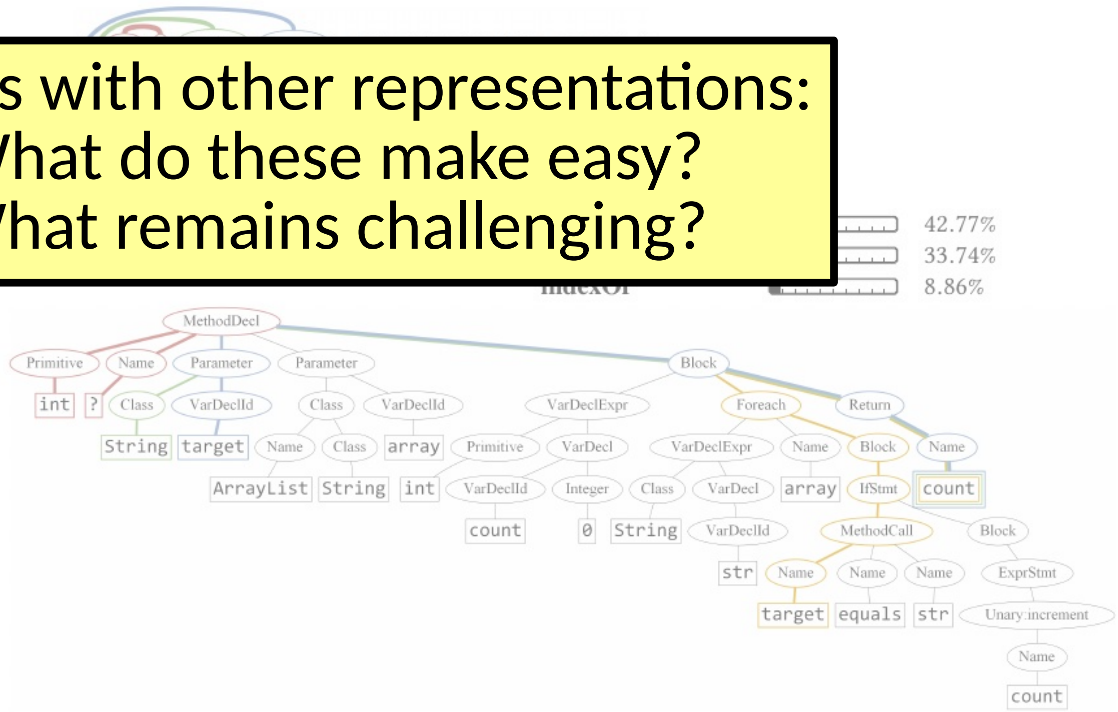

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What do these make easy?
What remains challenging?

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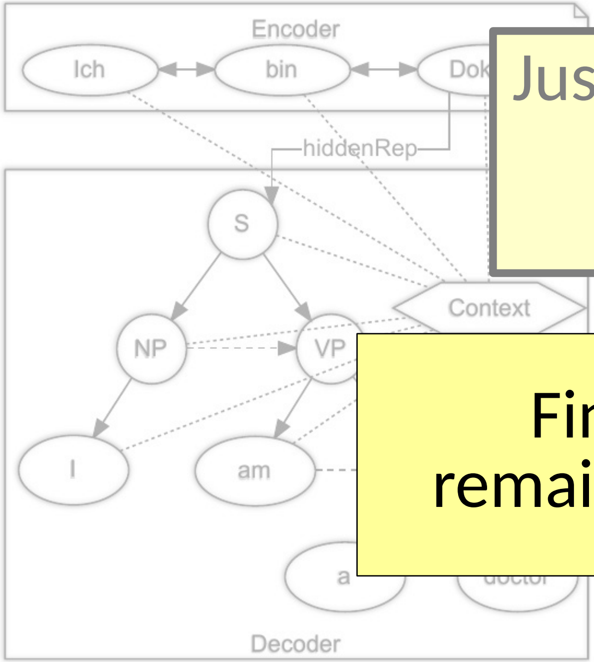

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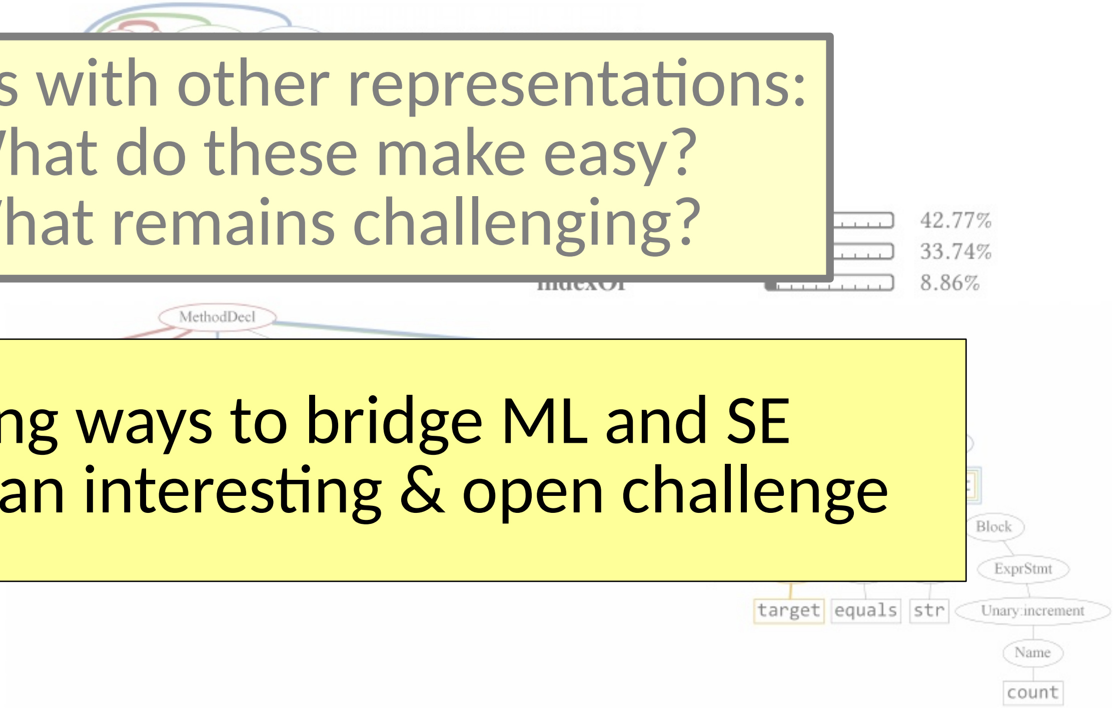

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Finding ways to bridge ML and SE
remains an interesting & open challenge

Representing Program Executions

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- ***Program*** representations are *static*
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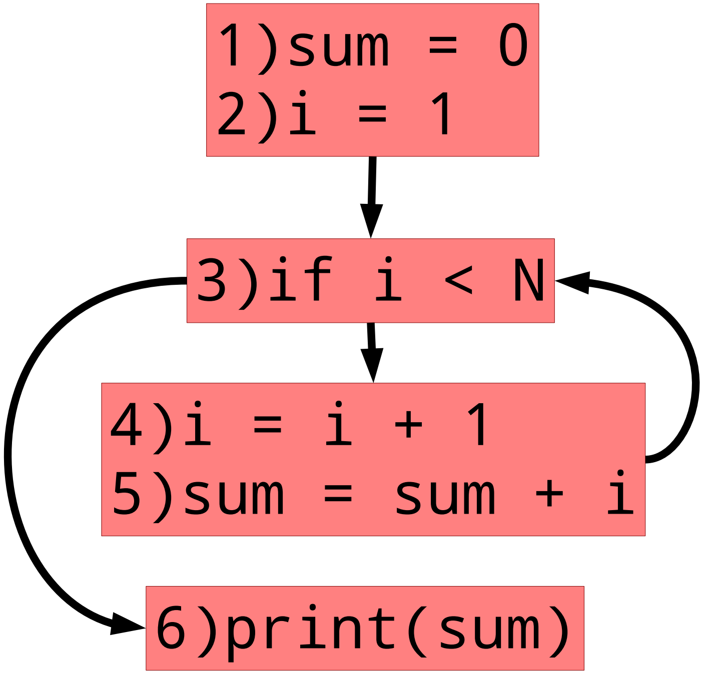
Control Flow Trace



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

All Equivalent

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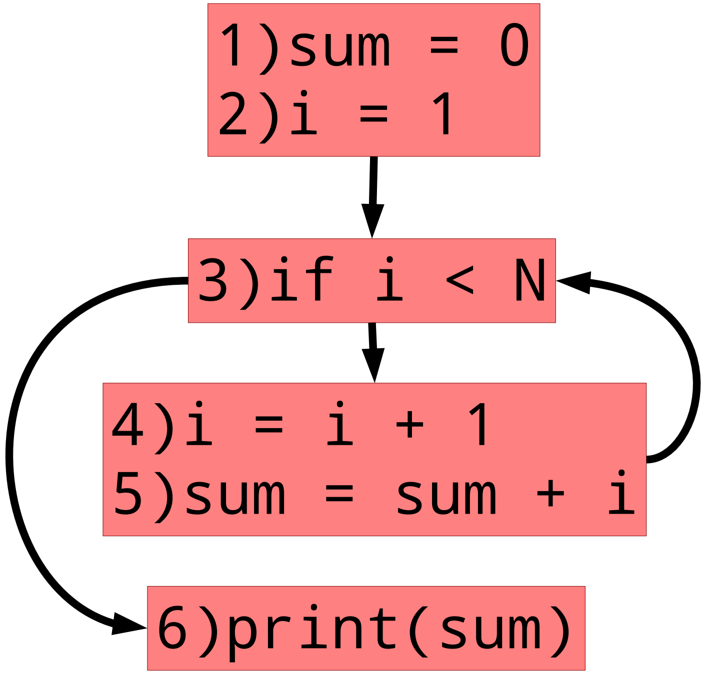

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```
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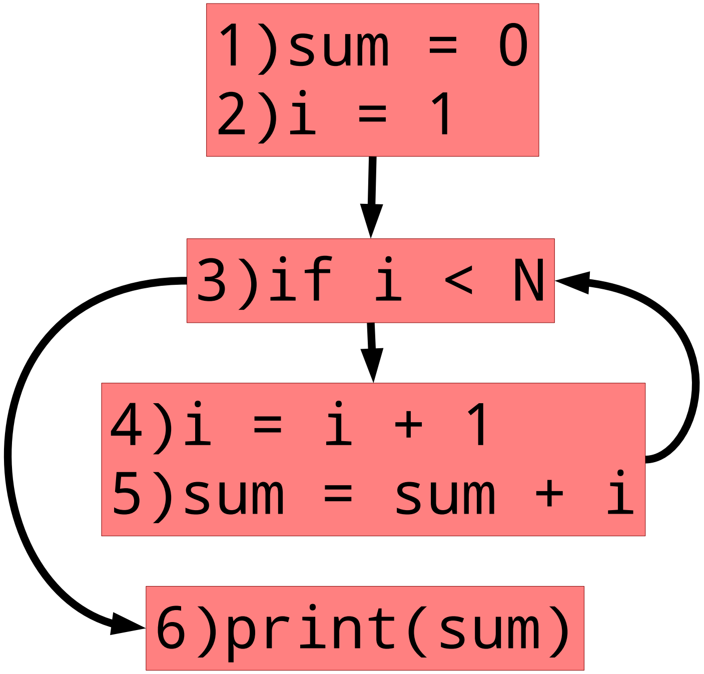
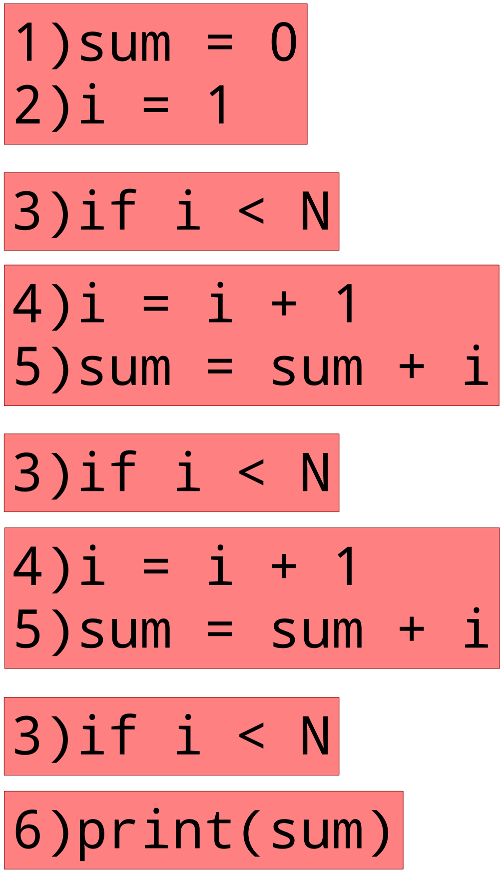




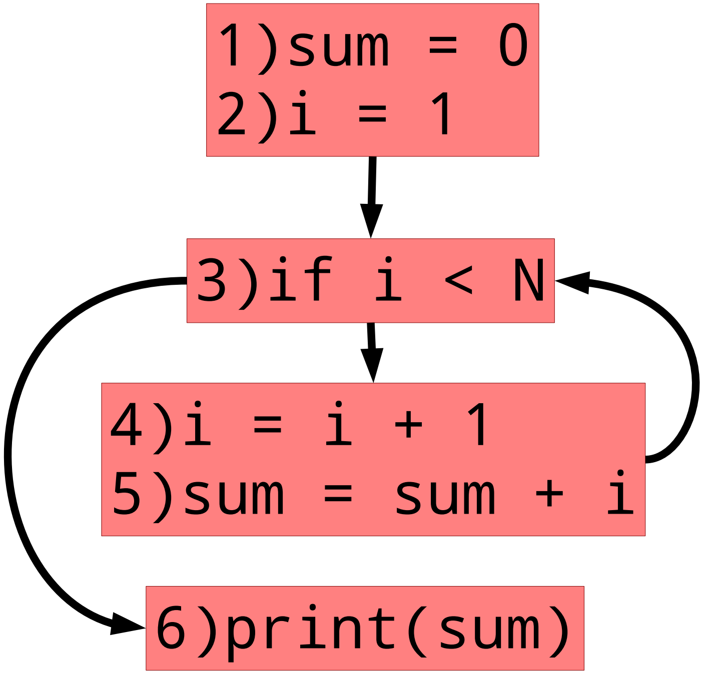
$1_1\ 2_1\ 3_1\ 4_1\ 5_1\ 3_2\ 4_2\ 5_2\ 3_3\ 6_1$

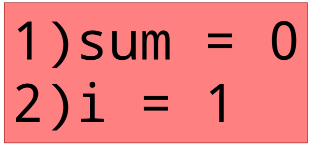
$1_1\ 3_1\ 4_1\ 3_2\ 4_2\ 3_3\ 6_1$

TTF

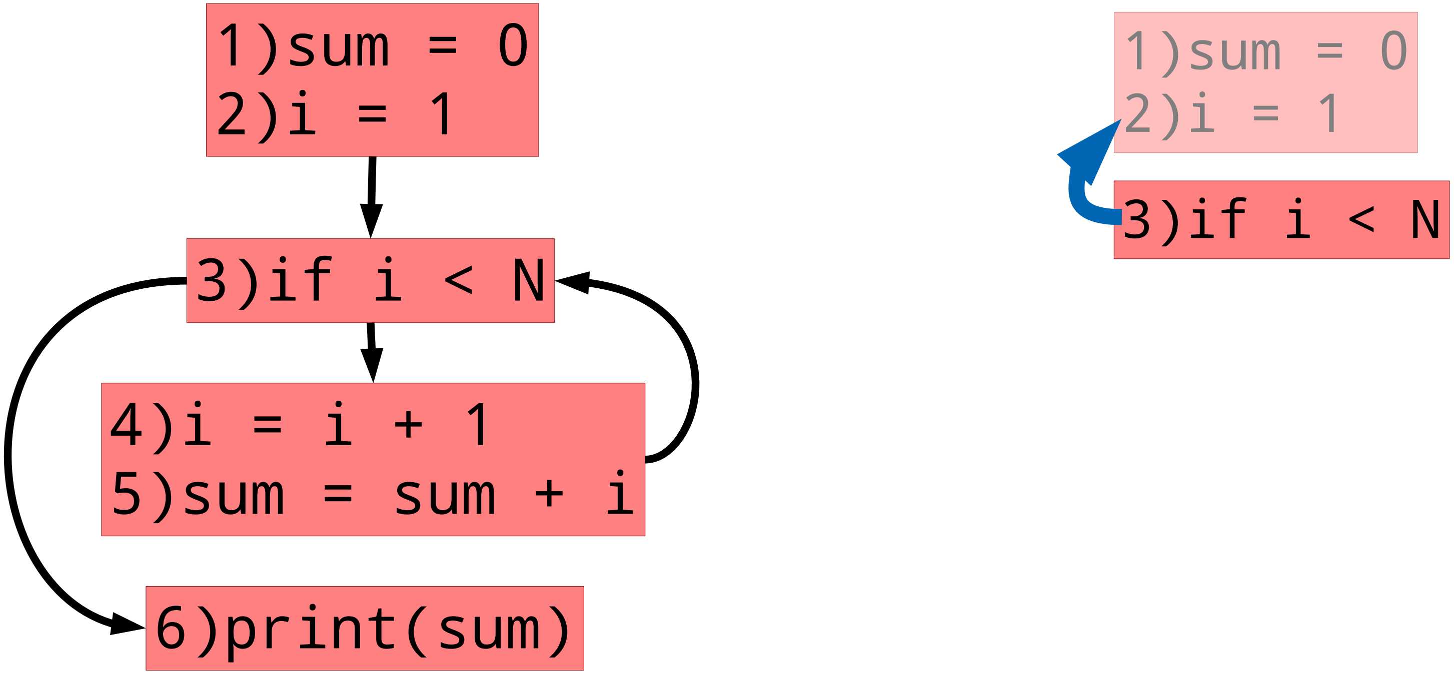
} All Equivalent

Dynamic Dependence Graph





Dynamic Dependence Graph



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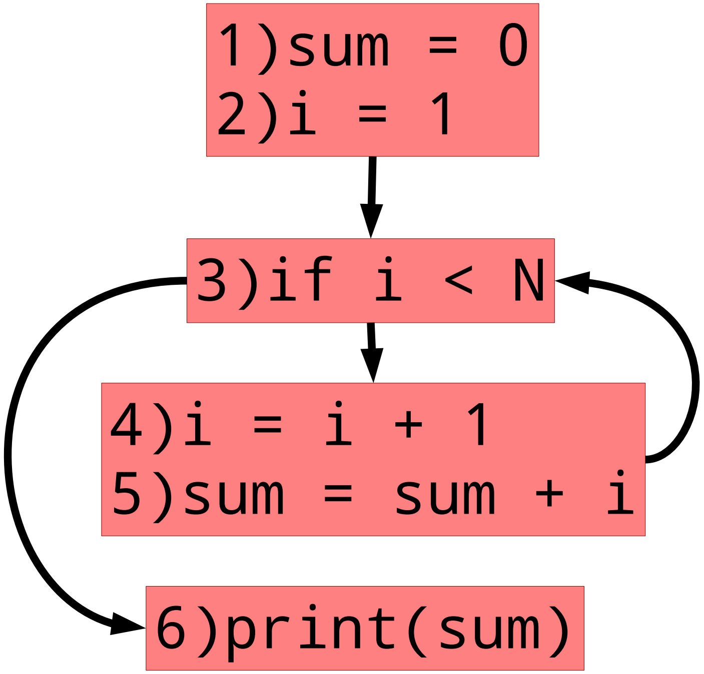

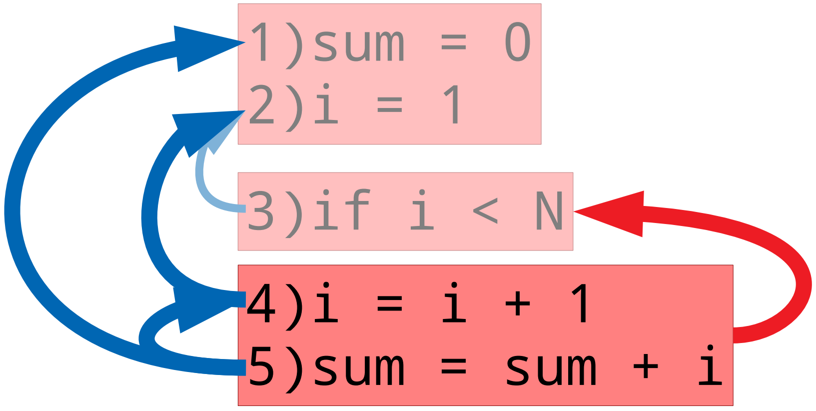

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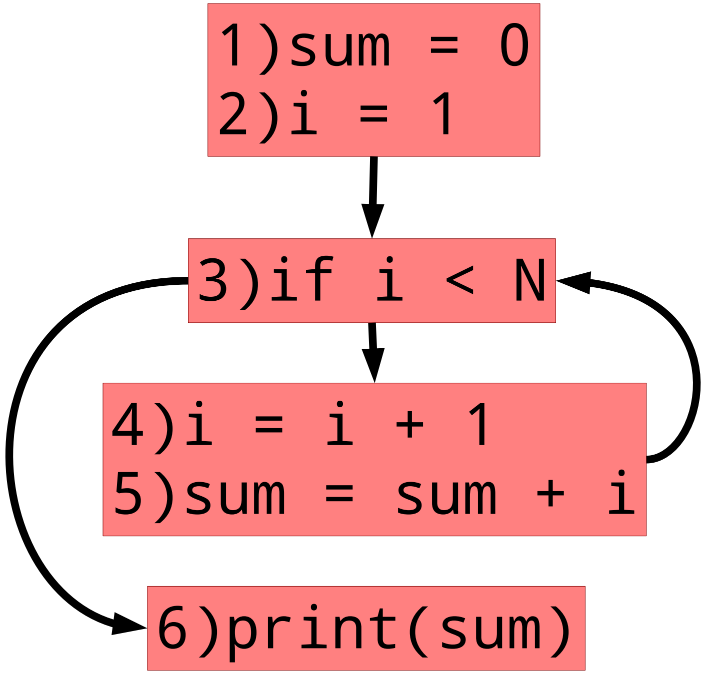

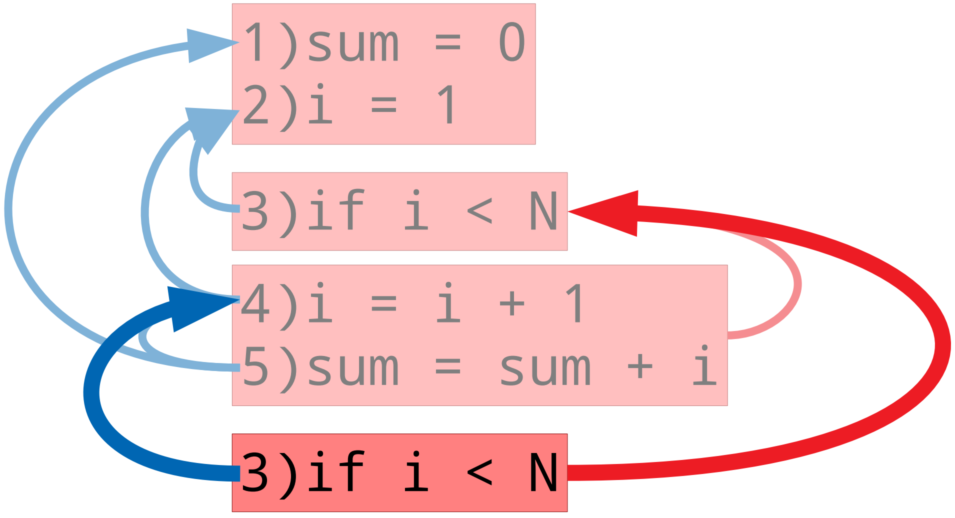

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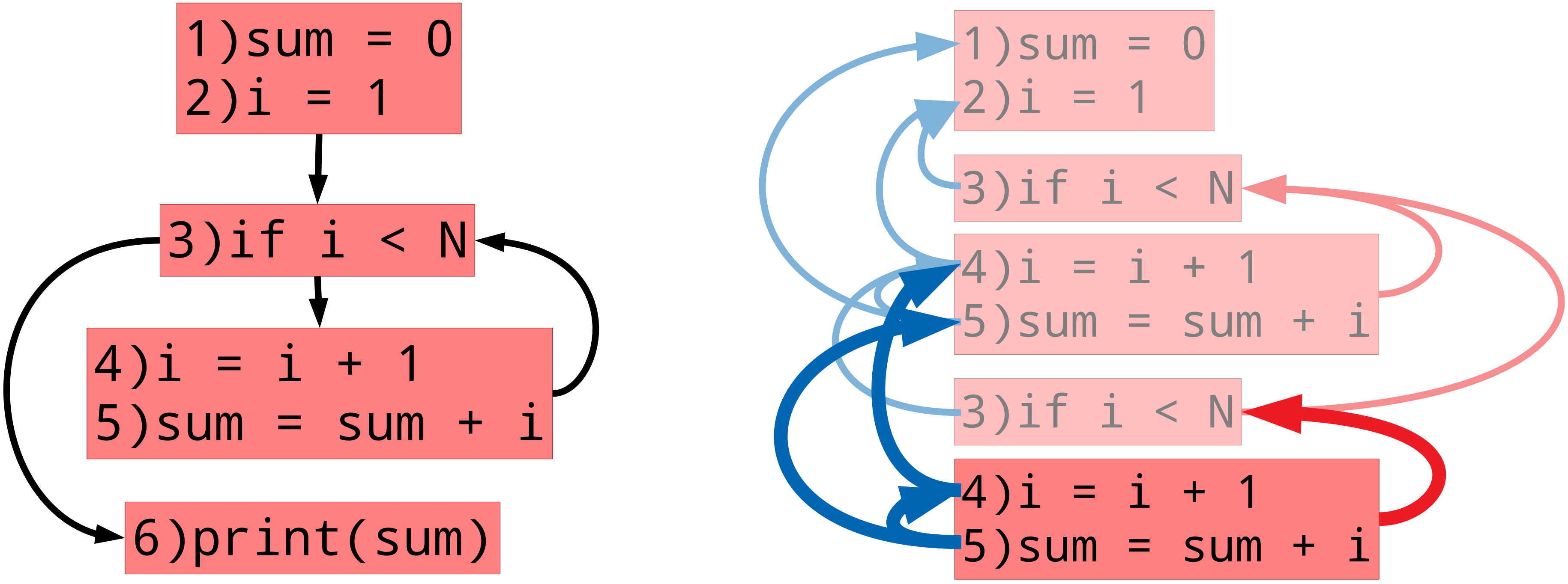

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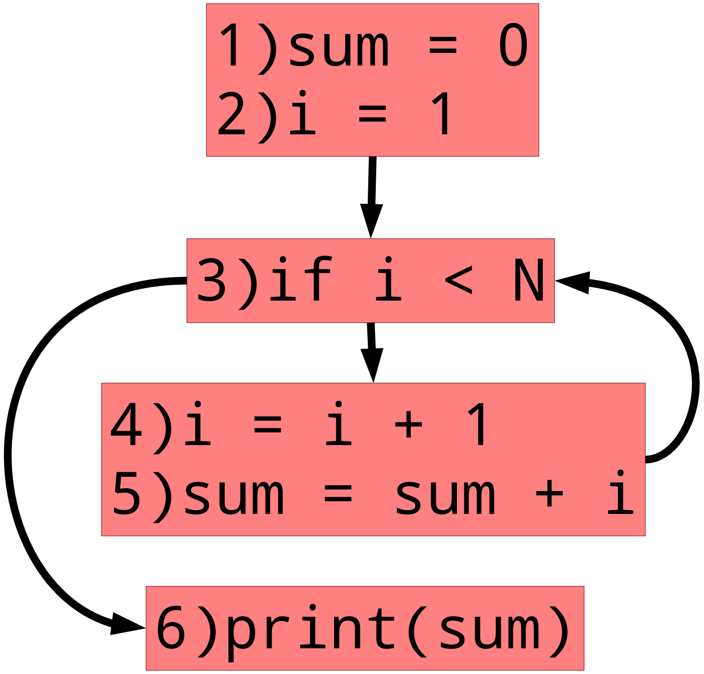

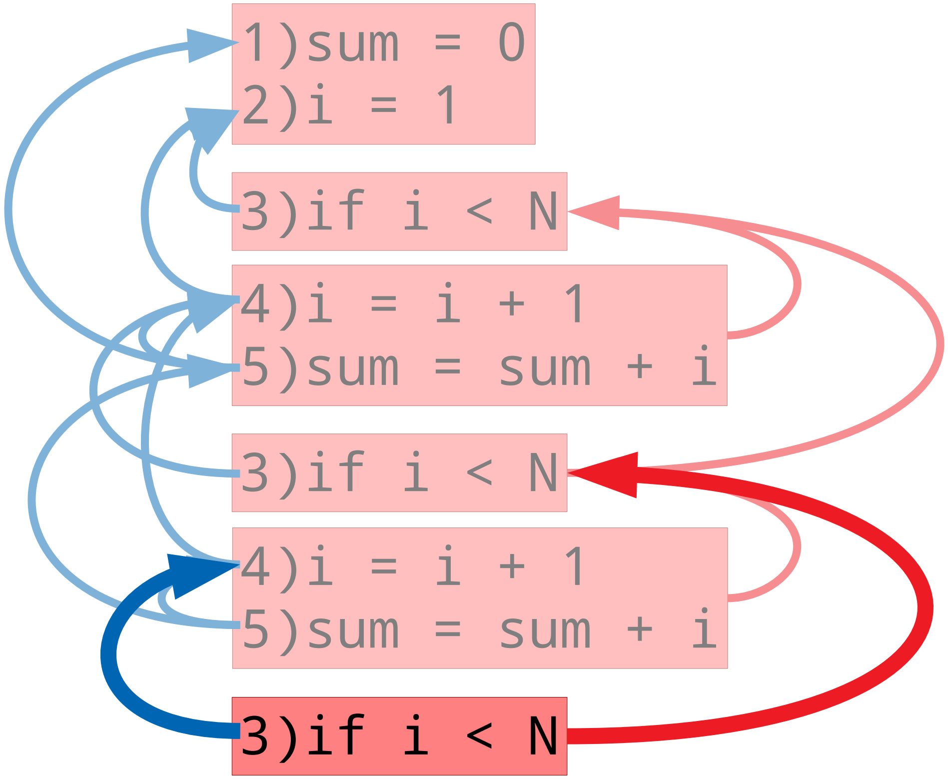

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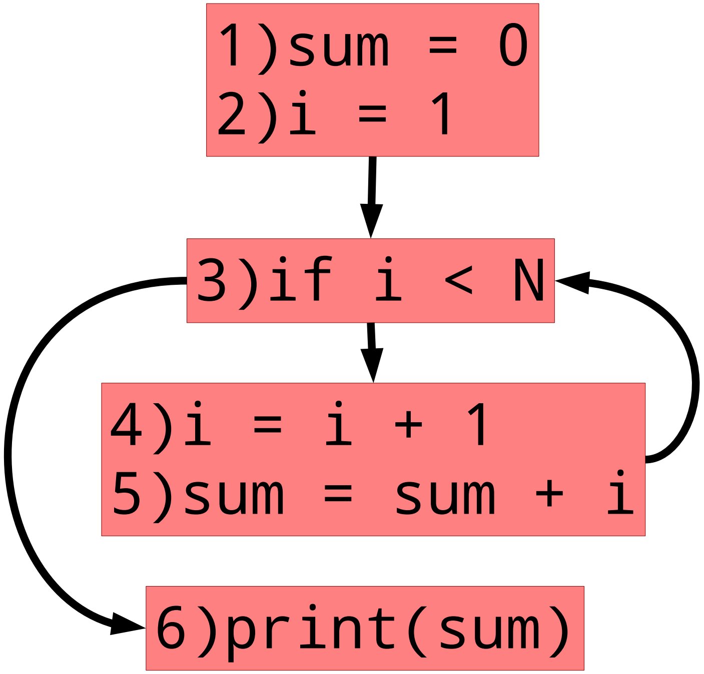

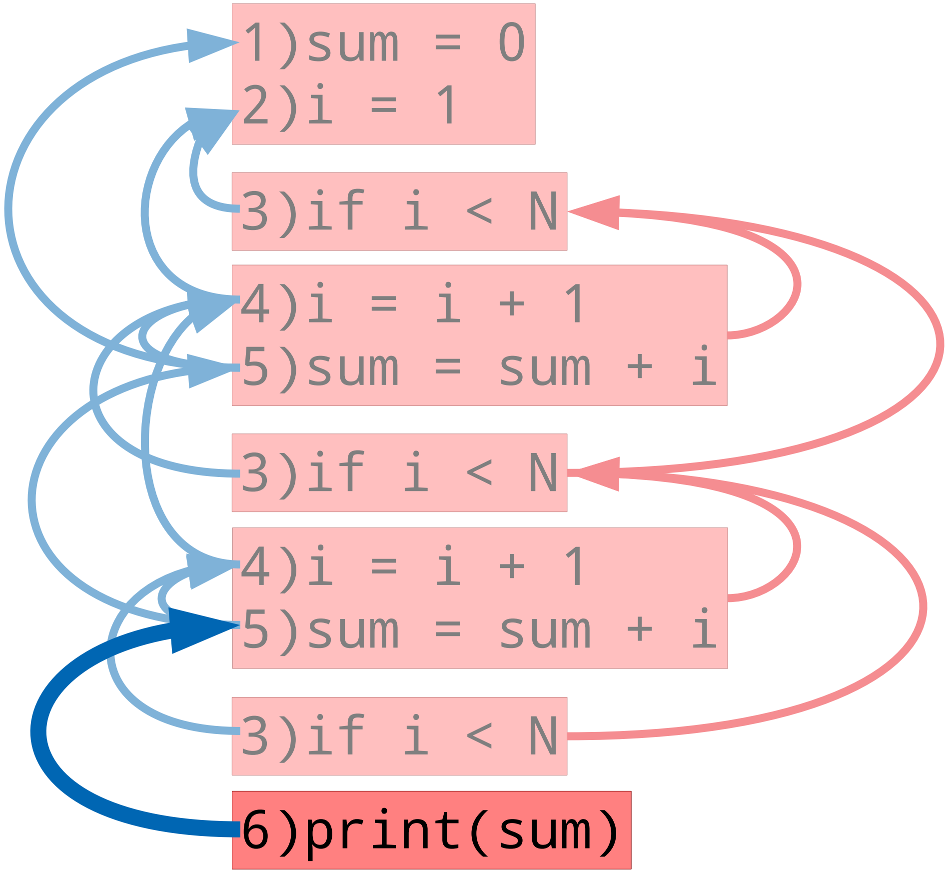

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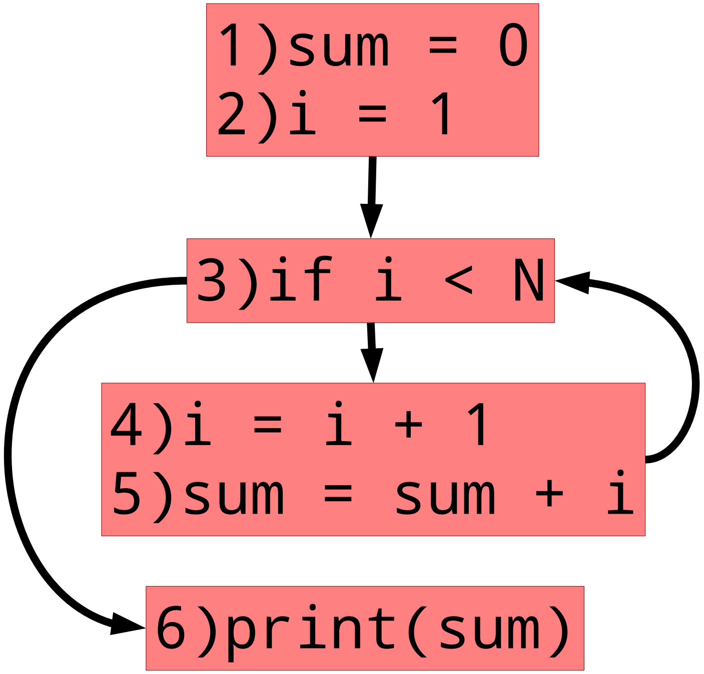

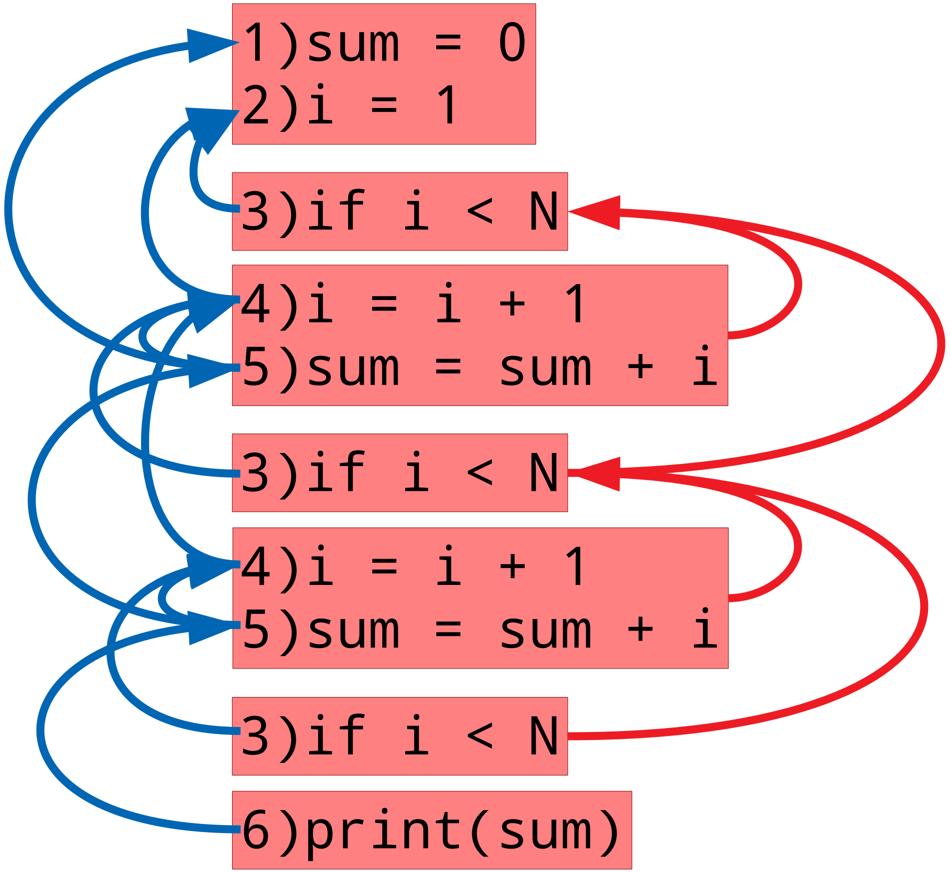

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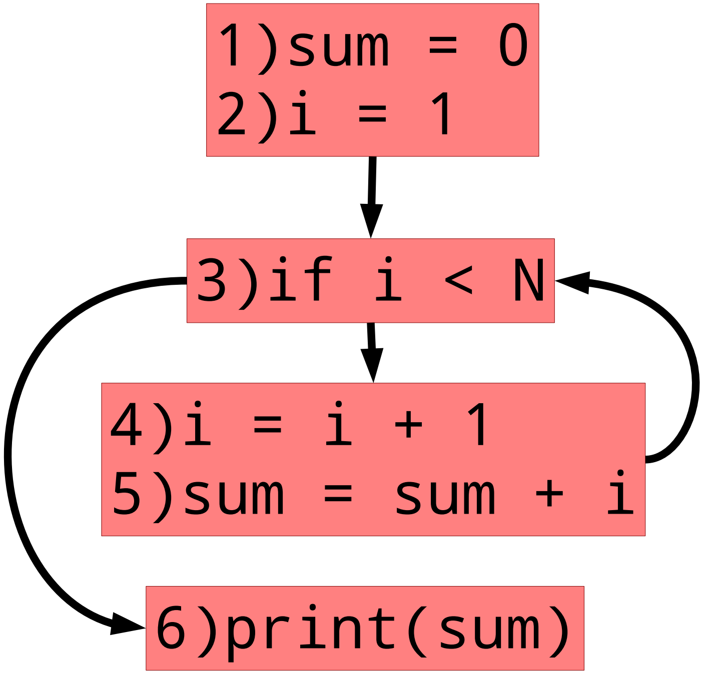
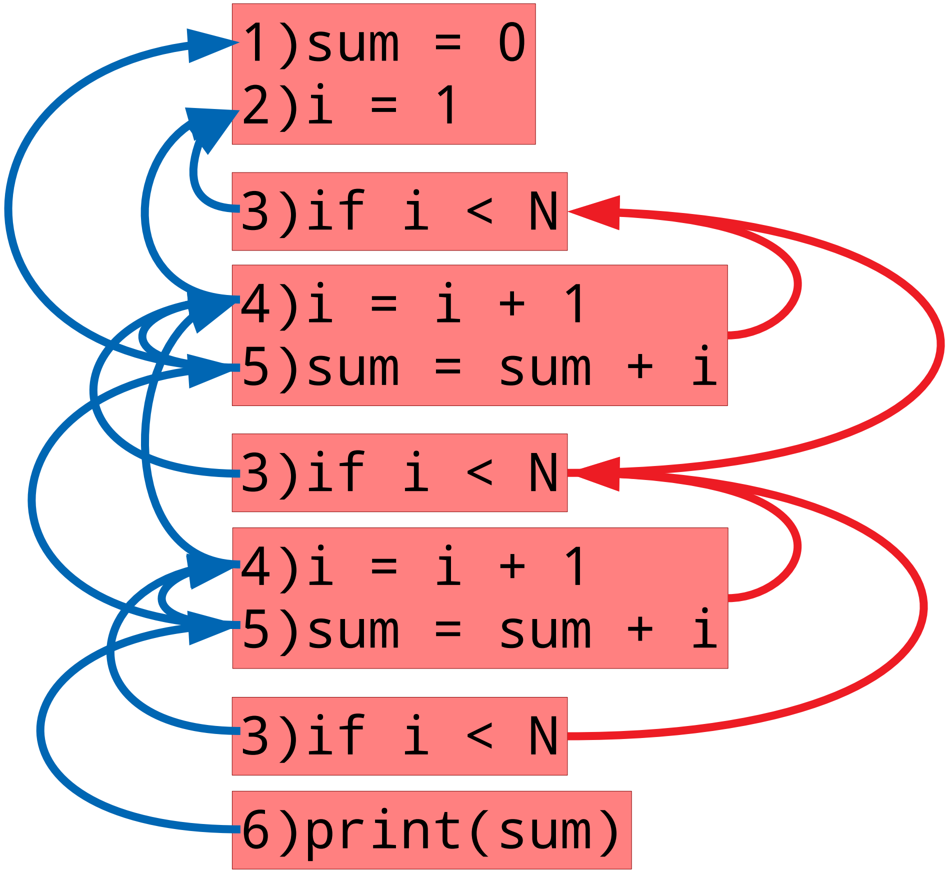
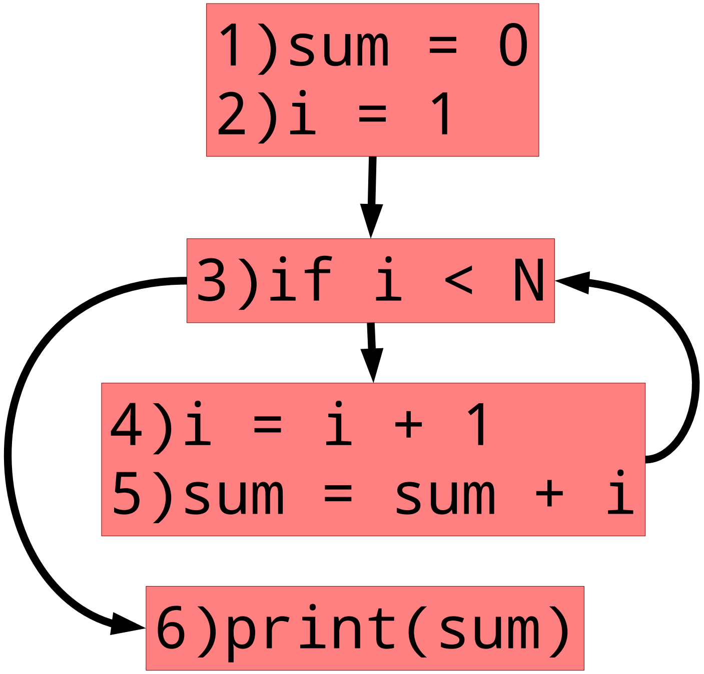
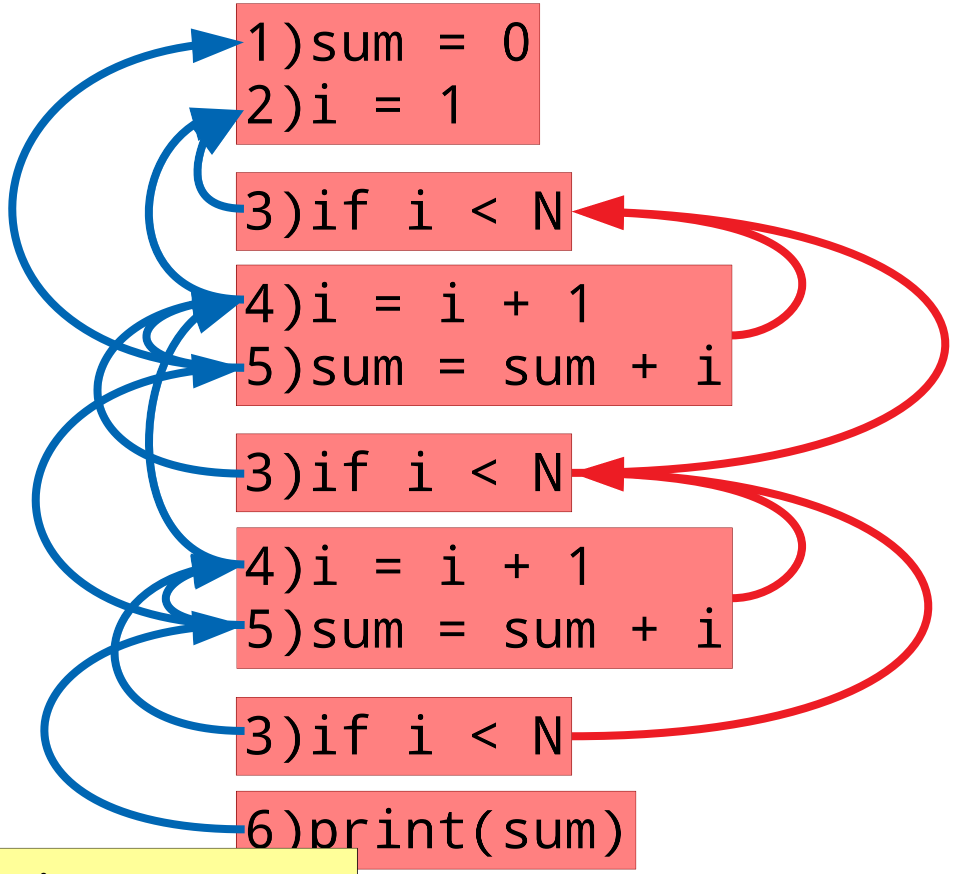




Notably a *bit* difficult for people to wade through.

Dynamic Dependence Graph

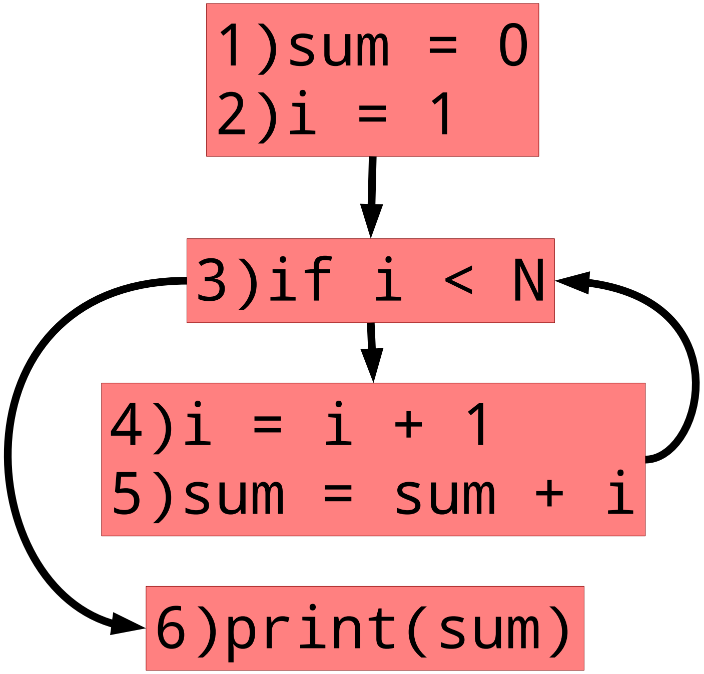


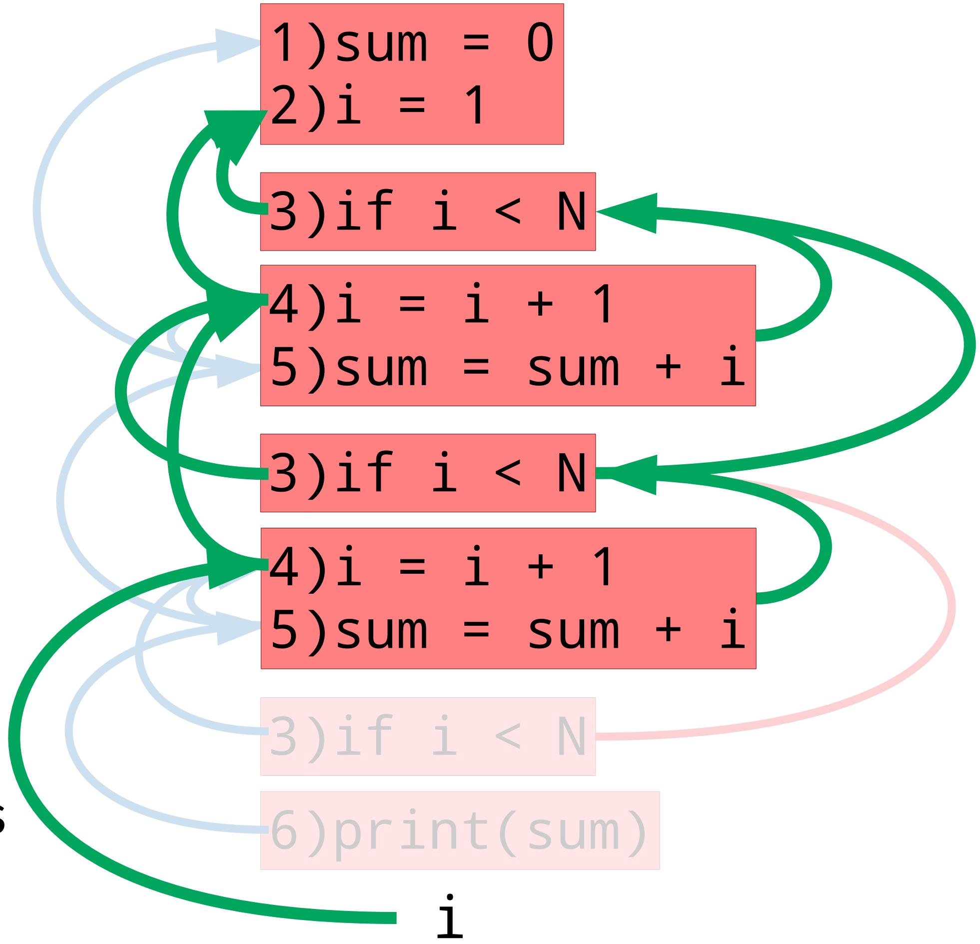


Notably a *bit* difficult for people to wade through.

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

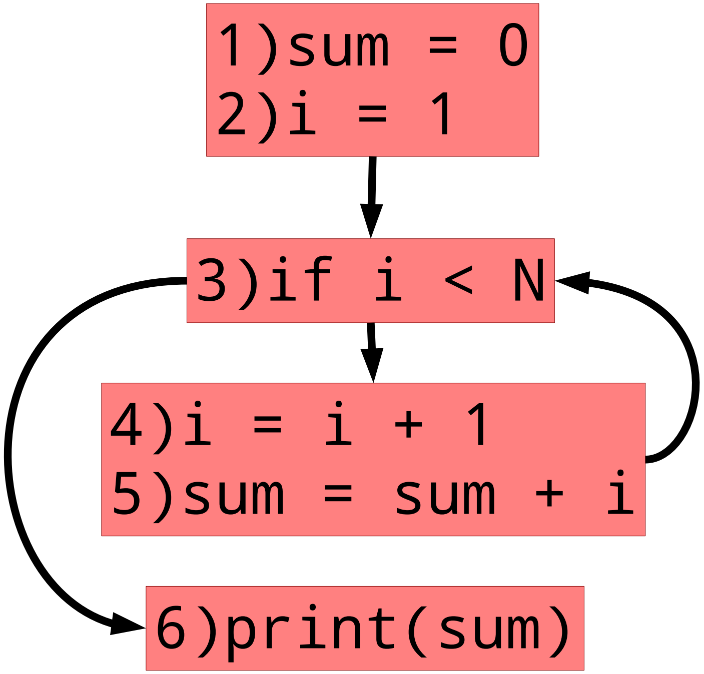
Dynamic Dependence Graph

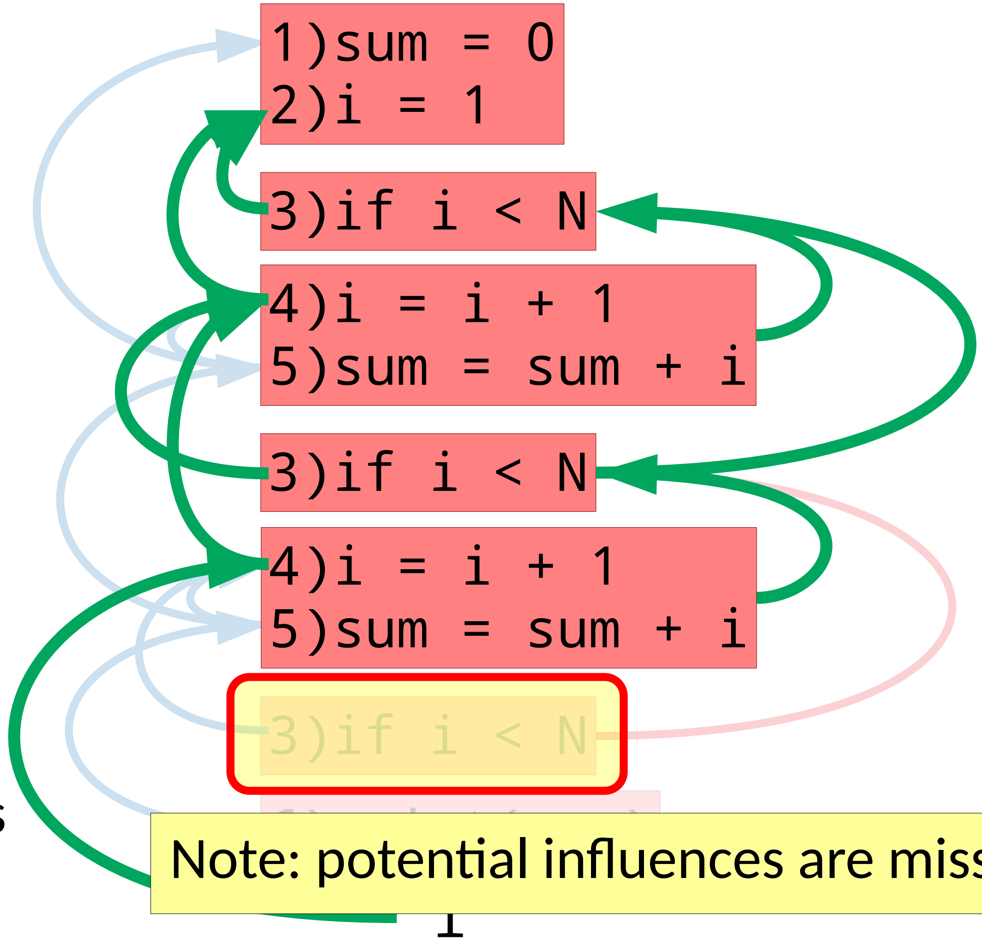




Slicing (static or dynamic) computes a transitive closure of dependences

Dynamic Dependence Graph





Slicing (static or dynamic) computes a transitive closure of dependences

Note: potential influences are missed!

Dynamic Dependence Graphs

Capture a notion of ***observed*** influence

Dynamic Dependence Graphs

Capture a notion of ***observed*** influence

- **Debugging:** What caused a bug?

Dynamic Dependence Graphs

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Capture a notion of ***observed*** influence

- **Debugging:** What caused a bug?
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- …

Dynamic Dependence Graphs

Capture a notion of ***observed*** influence

- **Debugging:** What caused a bug?
- **Security:** How did sensitive information leak?
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- …

Prioritizing, pruning, & bundling information is often critical when applying slicing

Summary

- Different tasks may benefit from representing programs in different ways
- Thinking of the right representation for the task you have is important