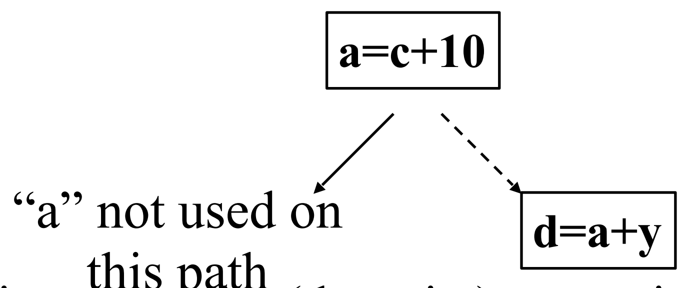
Static Program Analysis Part III

Data Flow Analysis

- Data-flow analysis provides information for compiling and SE tasks by computing the flow of different types of data to points in the program
- For structured programs, data-flow analysis can be performed on an AST
- In general, intra-procedural (global) data-flow analysis is performed on the Control Flow Graph
- Exact solutions to most problems are undecidable
  - May depend on input
  - May depend on outcome of a conditional statement
  - May depend on termination of loop
- We compute approximations of the exact solution

Data Flow Analysis for Testing

- *Data-flow testing*
  – suppose that a statement assigns a value but the use of that value is never executed under test



  – need <u>definition-use pairs (du-pairs):</u> associations between definitions and uses of the same variable or memory location

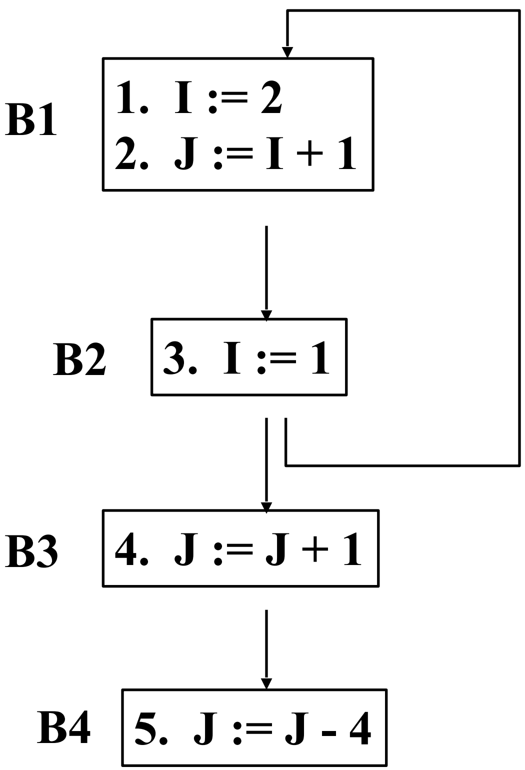
Data Flow Analysis for Debugging

- *Debugging*
  - suppose that **a** has the incorrect value in the statement

a=c+y

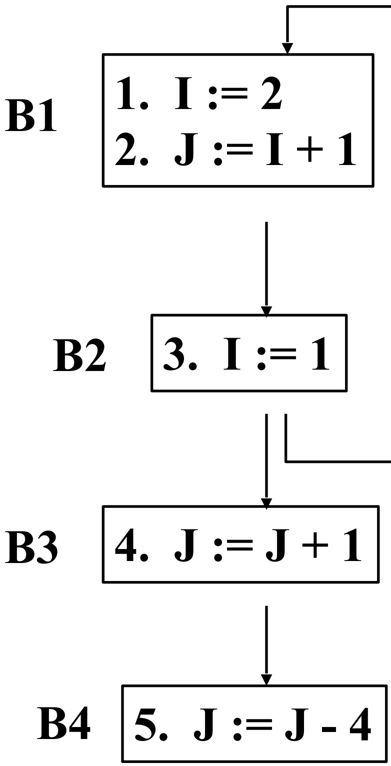
  - need data dependence information: statements that can affect the incorrect value at this point

Data Flow Problems – Reaching & Uses



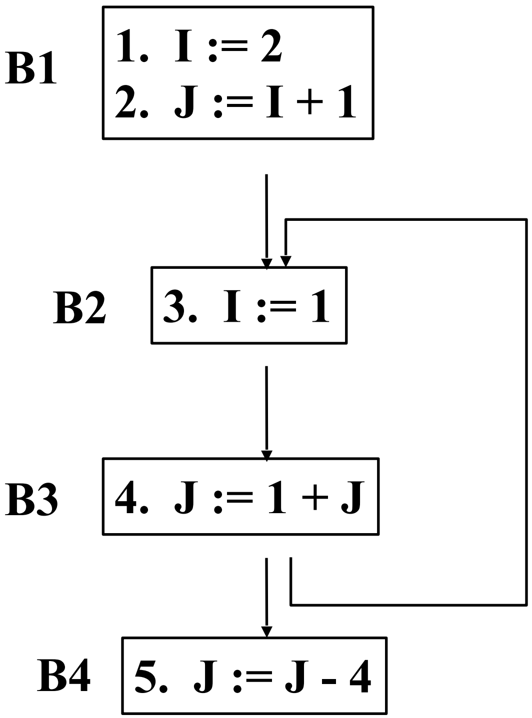
- Compute the flow of data to points in the program - e.g.,
  - Where does the assignment to I in statement 1 reach?
  - Where does the expression computed in statement 2 reach?
  - Which uses of variable J are reachable from the end of B1?
  - Is the value of variable I live after statement 3?
- Interesting points before and after basic blocks or statements

Data Flow Problems – Reaching Definitions



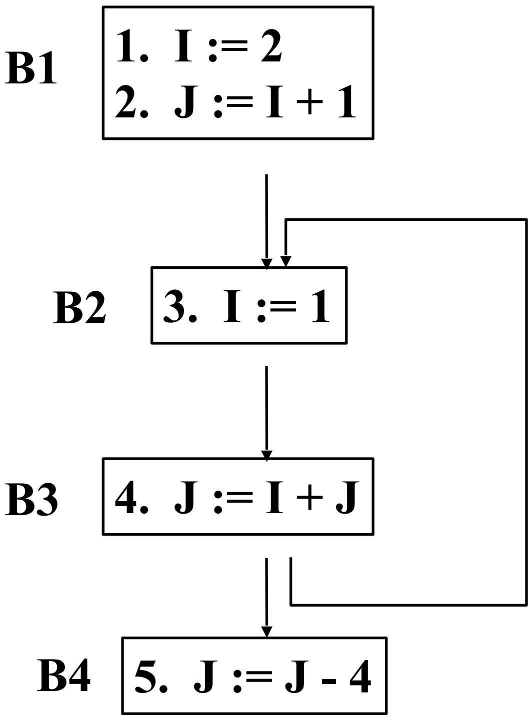
- A *definition* of a variable or memory location is a point or statement where that variable gets a value - e.g., input statement, assignment statement.
- X *reaches* a point P if there exists a control-flow path in the CFG from the definition to P with no other definitions of X on the path (called a *definition-clear path*)
- Such a path may exist in the graph but may not be executable (i.e., there may be no input to the program that will cause it to be executed); such a path is *infeasible*.

Data Flow Problems – Reachable Uses



- A *use* of a variable or memory location is a point or statement where that variable is referenced but not changed - e.g., used in a computation, used in a conditional, output
- Use of X is *reachable* from a point P if there exists a control-flow path in the CFG from the P to the use with no definitions of X on the path
- Reachable uses also called *upwards exposed uses*

Reachable Uses Example



- Definitions:
  - I: 1, 3
  - J: 2, 4, 5
- Uses:
  - I: 2, 4
  - J: 4, 5
- Reachable Uses:
  - I from 1: 2
  - I from 3: 4
  - J from 2: 4
  - J from 4: 4, 5
  - J from 5:

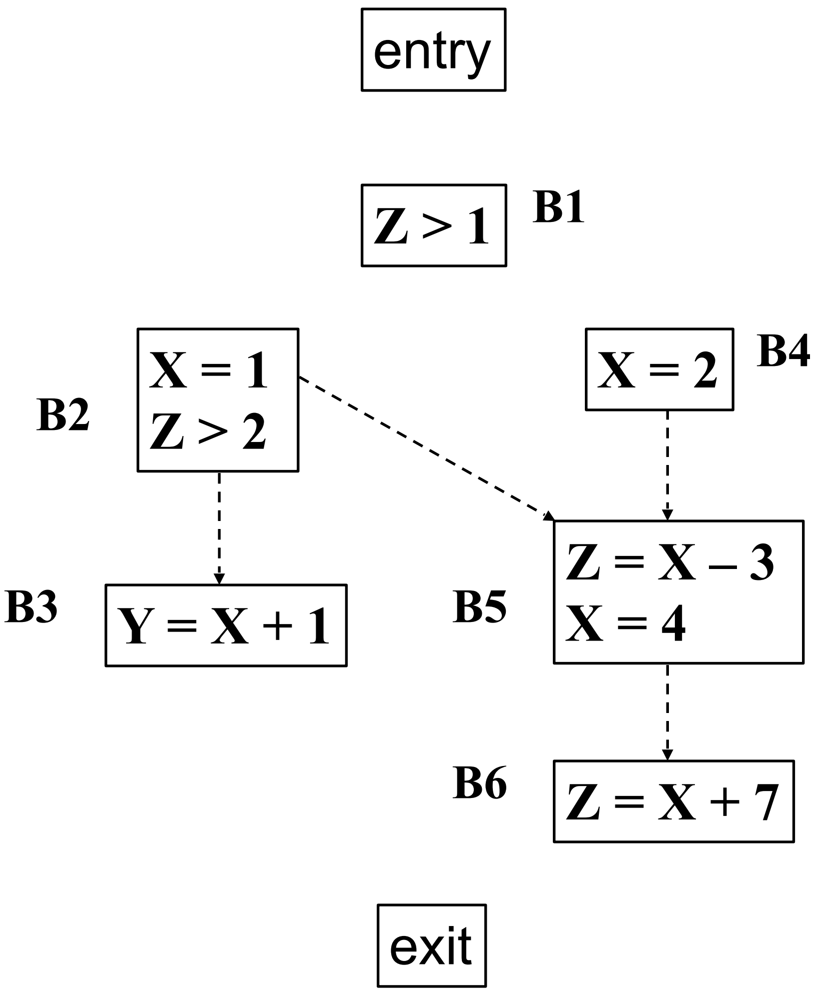
DU-Chains, UD-chains, Webs

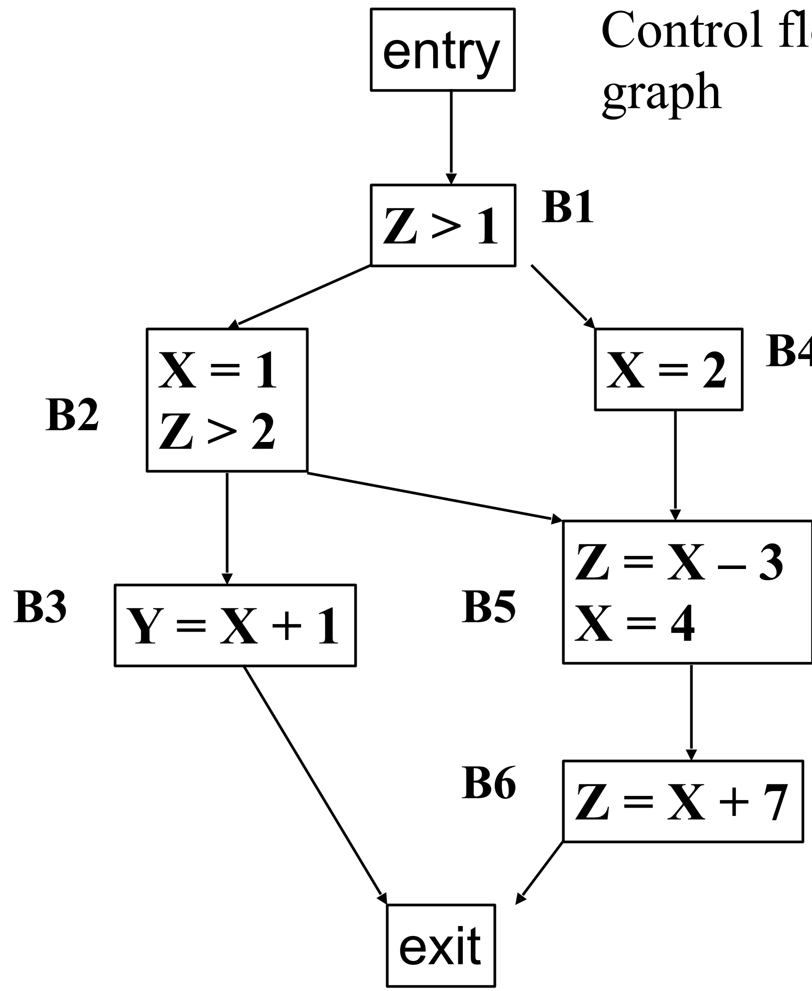
- A *definition-use chain* or DU-chain for a definition D of variable V connects the D to all uses of V that it can reach
- A *use-definition chain* or UD-chain for a use U of variable V connects U to all definitions of V that reach it
- A *web* for a variable is the maximal union of intersecting DU-chains

Data-Dependence

- A *data-dependence graph* has one node for every basic block and one edge representing the flow of data between the two nodes
- X is *data dependent* on Y iff there exists a variable **v** such that:
  - Y has a definition of **v** and
  - X has a use of **v** and
  - There exists a control path from Y to X along which **v** is not redefined
- Different types of data dependence edges can be defined
  - Flow: def to use (most common)
  - Anti: use to def
  - Out: def to def

Data (flow) Dependence Graph





Control flow graph

Control Dependence

- A statement S1 is *control dependent* on a statement S2 if the outcome of S2 determines whether S1 is reached in the CFG
- We define control dependence for language constructs
- Control dependencies can be derived for arbitrary control flow using the concept of post dominator of **conditional** instructions

Definitions

```
if Y then B1 else B2;
```

- X is control dependent on Y iff X is in B1 or B2

```
while Y do B;
```

- X is control dependent on Y iff X is in B

Program-Dependence Graph

- A *program dependence graph* (PDG) for a program P is the combination of the control-dependence graph for P and the data-dependence graph for P
- Can be used for
  - Redundant code analysis
  - I/O relation analysis
  - Program slicing

Compute a PDG

```
read (n)
i := 1
sum := 0
product := 1
while i <= n do
     sum := sum + i
     product := product * i
     i := i + 1
write (sum)
write (product)
```

Identify control dependencies via CFG and conditionals

Identify data dependencies via definition/uses

Computing a PDG

```
1.  read (n)
2.  i := 1
3.  sum := 0
4.  product := 1
5.  while i <= n do
6.      sum := sum + i
7.      product := product * i
8.      i := i + 1
9.  write (sum)
10. write (product)
```

6,7,8 are control dependent on 5

DU-Chains:
(1,5)
(2,5), (2,6), (2,7), (2,8),
(8,5), (8,6), (8,7), (8,8)
(3,6), (3,9), (6,6), (6,6),
(6,9)
(4,7), (4,10), (7,7), (7,10)

PDG