CSc 453

Compilers and Systems Software

15 : Intermediate Code III

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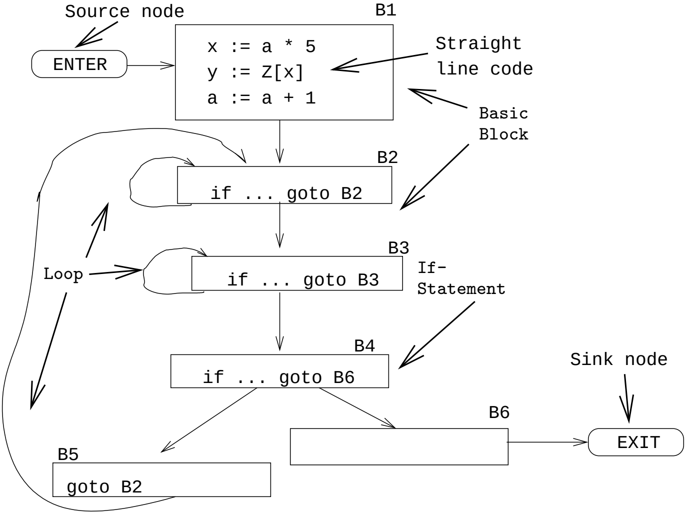
Basic Blocks and Flow Graphs

Control Flow Graphs

- We divide the intermediate code of each procedure into basic blocks. A basic block is a piece of straight line code, i.e. there are no jumps in or out of the middle of a block.
- The basic blocks within one procedure are organized as a *(control) flow graph*, or *CFG*. A flow-graph has
  - basic blocks $B_1 \cdots B_n$ as nodes,
  - a directed edge $B_1 \rightarrow B_2$ if control can flow from B_1 to B_2.
  - Special nodes $\boxed{\texttt{ENTER}}$ and $\boxed{\texttt{EXIT}}$ that are the *source* and *sink* of the graph.
- Inside each basic block can be any of the IRs we've seen: tuples, trees, DAGs, etc.



Source node

ENTER

B1

```
x := a * 5
y := Z[x]
a := a + 1
```

Straight line code

Basic Block

B2

```
if ... goto B2
```

B3

```
if ... goto B3
```

If-Statement

Loop

B4

```
if ... goto B6
```

B5

```
goto B2
```

B6

Sink node

EXIT

Control Flow Graphs. . .

Source Code:

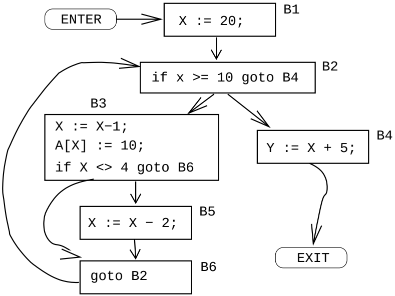
```
X := 20; WHILE X < 10 DO
   X := X-1; A[X] := 10;
   IF X = 4 THEN X := X - 2; ENDIF;
ENDDO; Y := X + 5;
```

Intermediate Code:

```
(1) X := 20
(2) if X>=10 goto (8)
(3) X := X-1
(4) A[X] := 10
(5) if X<>4 goto (7)
(6) X := X-2
(7) goto (2)
(8) Y := X+5
```

Control Flow Graphs. . .

Flow Graph:



ENTER

B1

```
X := 20;
```

B2

```
if x >= 10 goto B4
```

B3

```
X := X−1;
A[X] := 10;
if X <> 4 goto B6
```

B4

```
Y := X + 5;
```

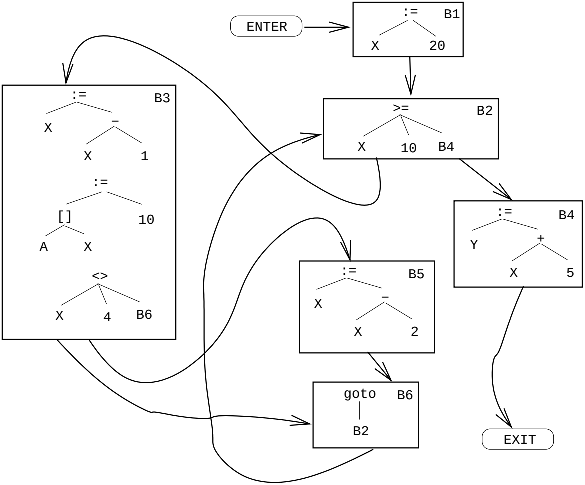
B5

```
X := X − 2;
```

B6

```
goto B2
```

EXIT


ENTER
:=
B1
X
20
>=
B2
X
10
B4
:=
B3
X
–
X
1
:=
[]
10
A
X
<>
X
4
B6
:=
B4
Y
+
X
5
:=
B5
X
–
X
2
goto
B6
B2
EXIT

Constructing Basic Blocks

Constructing Basic Blocks

- Assume that the input is a list of tuples. How do we find the beginning and end of each basic block?

1. First determine a set of **leaders**, the first tuple of basic blocks:
    1. The first tuple is a leader.
    2. Tuple `L` is a leader if there is a tuple `if ...goto L` or `goto L`.
    3. Tuple `L` is a leader if it immediately follows a tuple `if ...goto B` or `goto B`.
2. A basic block consists of a leader and all the following tuples until the next leader.

Basic Blocks...

```
P := 0; I := 1;
REPEAT
   P := P + I;
   IF P > 60 THEN
      P := 0;
      I := 5
   ENDIF;
   I := I * 2 + 1;
UNTIL I > 20;
K := P * 3
```

```
(1)    P := 0             ⇐ (Rule 1.a)
(2)    I := 1
(3)    P := P + I         ⇐ (Rule 1.b)
(4)    IF P <= 60 GOTO (7)
(5)    P := 0             ⇐ (Rule 1.c)
(6)    I := 5
(7)    T1 := I * 2        ⇐ (Rule 1.b)
(8)    I := T1 + 1
(9)    IF I <= 20 GOTO (3)
(10)   K := P * 3         ⇐ (Rule 1.c)
```

Basic Blocks. . .

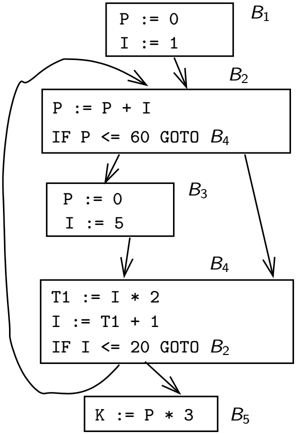
B_1: [(1) P:=0; (2) I:=1]

B_2: [(3) P:=P+I;
(4) IF P<=60 GOTO $\boxed{B_4}$]

B_3: [(5) P:=0; (6) I:=5]

B_4: [(7) T1:=I*2; (8) I:=T1+1;
(9) IF I<=20 GOTO $\boxed{B_2}$]

B_5: [(10) K:=P*3]



B_1
```
P := 0
I := 1
```

B_2
```
P := P + I
IF P <= 60 GOTO B4
```

B_3
```
P := 0
I := 5
```

B_4
```
T1 := I * 2
I := T1 + 1
IF I <= 20 GOTO B2
```

B_5
```
K := P * 3
```

Summary

Readings and References

- Read Louden:

  Flow Graphs 475–477

- Or, read the Dragon book:

  Basic Blocks 528–530
  Flow Graphs 532–534

Summary

- A Control Flow Graph (CFG) is a graph whose nodes are basic blocks. There is an edge from basic block B_1 to B_2 if control can flow from B_1 to B_2.
- Control flows in and out of a CFG through two special nodes `ENTER` and `EXIT`.
- We construct a CFG for each procedure. This representation is used during code generation and optimization.
- Java bytecode is a stack-based IR. It was never intended as an UNCOL, but people have still built compilers for Ada, Scheme and other languages that generate Java bytecode. It is painful.
- Microsoft's MSIL is the latest UNCOL attempt.

Homework

Homework I

Translate the program below into quadruples. Identify beginnings and ends of basic blocks. Build the control flow graph.

```
PROGRAM P;
VAR X : INTEGER; Y : REAL;
BEGIN
   X := 1; Y := 5.5;
   WHILE X < 10 DO
      Y := Y + FLOAT(X);
      X := X + 1;
      IF Y > 10 THEN Y := Y * 2.2; ENDIF;
   ENDDO;
END.
```

Exam Question

- Draw the control flow graph for the tuples.

```
int A[5],x,i,n;
for (i=1; i<=n; i++) {
  if (i<n) {
    x = A[i];
  } else {
    while (x>4) {
      x = x*2+A[i];
    };
  };
  x = x+5;
}
```

```
(1) i := 1
(2) IF i>n GOTO (14)
(3) IF i>=n GOTO (6)
(4) x := A[i]
(5) GOTO (11)
(6) IF x<=4 GOTO (11)
(7) T1 := x*2
(8) T2 := A[i]
(9) x := T1+T2
(10)  GOTO (6)
(11)  x := x+5
(12)  i := i+1
(13)  GOTO (2)
```