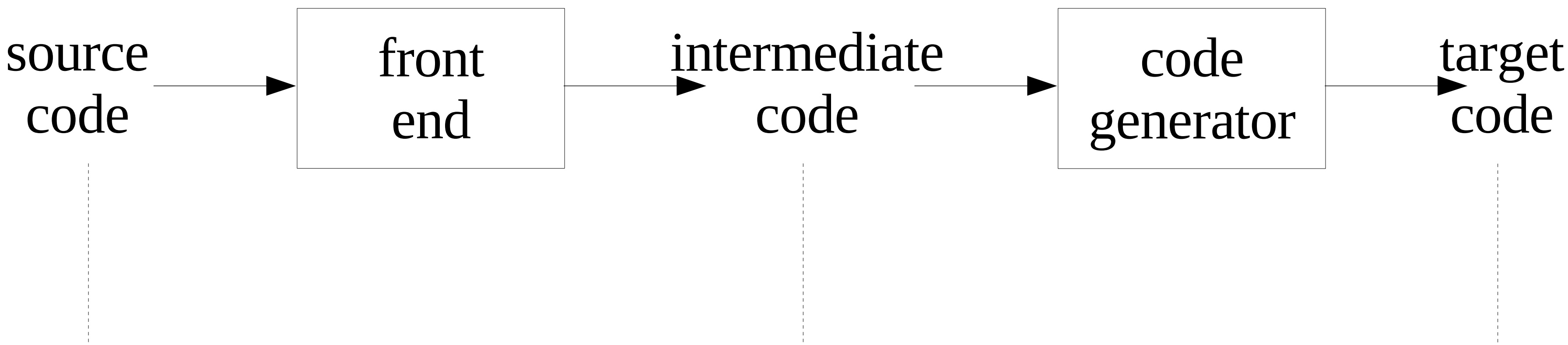
Concepts Introduced in Chapter 9

- introduction to compiler optimizations
- basic blocks and control flow graphs
- local optimizations
- global optimizations

Compiler Optimizations

- Compiler optimization is a misnomer.
- A code-improving transformation consists of a sequence of changes that preserves the semantic behavior (i.e. are safe).
- A code-improving transformation attempts to make the program
  - run faster
  - take up less space
  - consume less power
- An optimization phase consists of a sequence of code-improving transformations of the same type.

Places for Potential Improvement



user can:
profile program
change algorithm
transform loops

compiler can:
improve loops
procedure calls
address calculations

compiler can:
use registers
select instructions
do peephole transformations

Basic Blocks

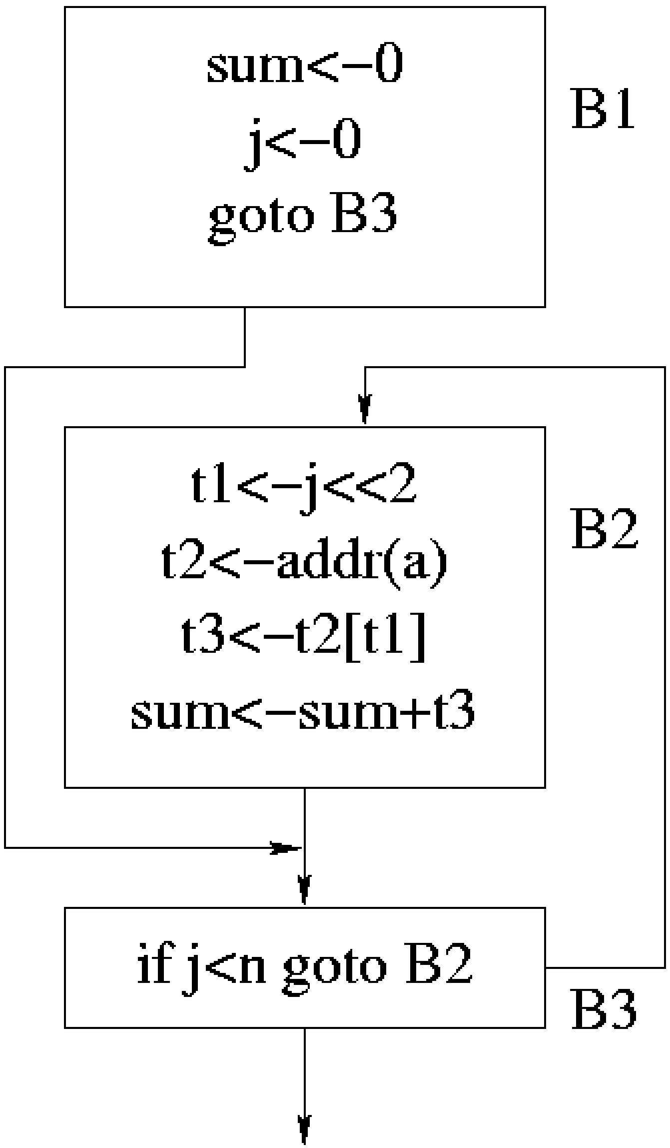
- Basic block - a sequence of consecutive statements with exactly 1 entry and 1 exit
- *leaders* are instructions that start a new basic block
  - the first three-address instruction in the intermediate code is a leader
  - any instruction that is the target of a conditional or unconditional jump is a leader
  - any instruction that immediately follows a conditional or unconditional jump is a leader

followed by Fig. 8.7, 8.9

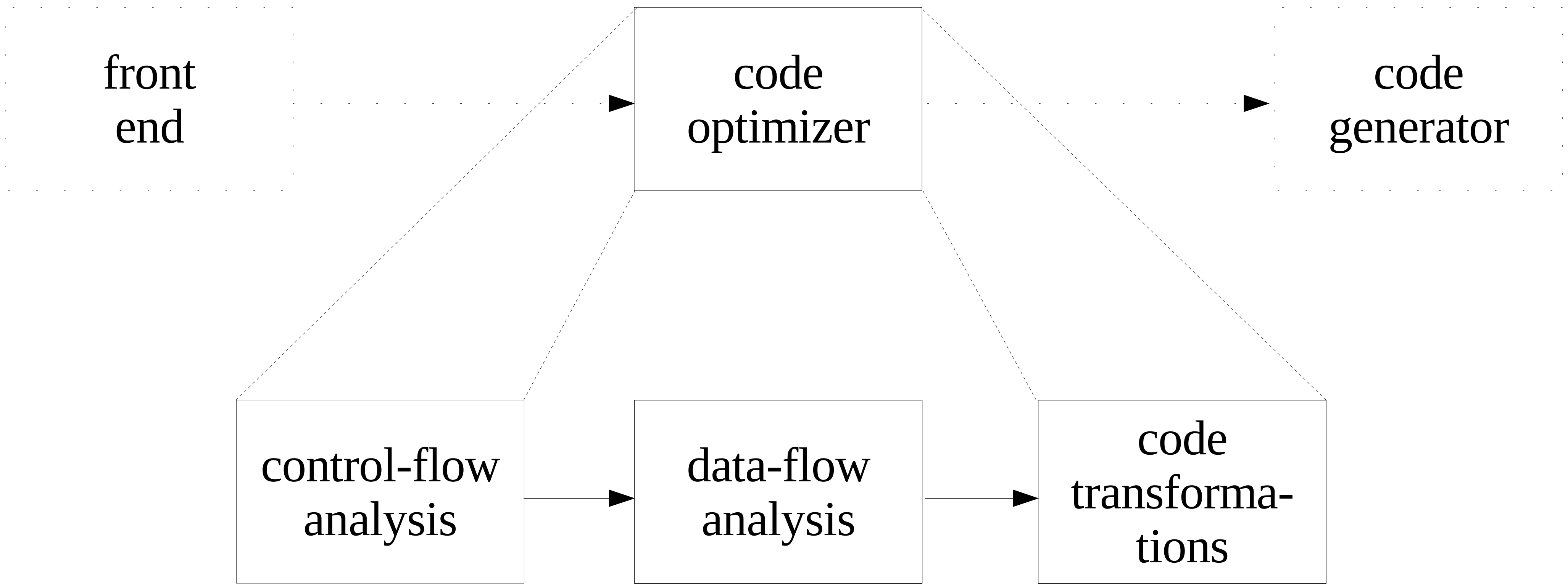
Control Flow

- Control flow graph - a directed graph where the nodes are basic blocks and block B→block C iff C can be executed immediately after B
  - there is a jump from the end of B to beginning of C
  - C follows B in program order
- B is a *predecessor* of C, and C is a *successor* of B
- Local optimizations - performed only within a basic block
- Global optimizations - performed across basic blocks

Example Control Flow Graph



Organization of the Code Optimizer



Types of Compiler Optimizations

- Function call
- Loop
- Memory access
- Control flow
- Data flow
- Machine specific

Function Call Optimizations

- Procedure integration or inlining
- Procedure specialization or cloning
- Tail recursion elimination
- Function memoization

Loop Optimizations

- Invariant code motion
- Strength reduction
- Induction variable elimination
- Unrolling
- Collapsing
- Fusion
- Software pipelining

Instruction Selection

- Accomplished by combining RTLs.
- Data dependences (links) are detected between RTLs.
- Pairs or triples of RTLs are symbolically merged.
- Legality is checked via a machine description.

Combining a Pair of RTLs

```
26          r[1] = r[30]+i;
27 {26}     r[2] = M[r[1]];  r[1]:
     ⇒
            r[2] = M[r[30]+i]; r[1] = r[30]+i;  r[1]:
     or
            r[2] = M[r[30]+i];   r[1]:
```

Combining Three RTLs

31 r[2] = M[r[3]];
32 {31} r[2] = r[2]+1;
33 {32} M[r[3]] = r[2]; r[2]:

⇒

M[r[3]] = M[r[3]]+1; r[2] = M[r[3]]+1; r[2]:

or

M[r[3]] = M[r[3]]+1; r[2]:

Cascading Instruction Selection

Actual example on PDP-11 (2 address machine)

38	r[36]=r[5];	
39 {38}	r[36]=r[36]+i;	
40	r[37]=r[5];	
41 {40}	r[37]=r[37]+i;	
42 {41}	r[40]=M[r[37]];	r[37]:
43	r[41]=1;	
44 {42}	r[42]=r[40];	r[40]:
45 {43,44}	r[42]=r[42]+r[41];	r[41]:
46 {45,39}	M[r[36]]=r[42];	r[42]:r[36]:

Cascading Instruction Selection (cont.)

38	r[36]=r[5];	
39 {38}	r[36]=r[36]+i;	
40	r[37]=r[5];	
42 {40}	r[40]=M[r[37]+i]];	r[37]:
43	r[41]=1;	
44 {42}	r[42]=r[40];	r[40]:
45 {43,44}	r[42]=r[42]+r[41];	r[41]:
46 {45,39}	M[r[36]]=r[42];	r[42]:r[36]:

Cascading Instruction Selection (cont.)

38		r[36]=r[5];	
39	{38}	r[36]=r[36]+i;	
42		r[40]=M[r[5]+i]];	
43		r[41]=1;	
44	{42}	r[42]=r[40];	r[40]:
45	{43,44}	r[42]=r[42]+r[41];	r[41]:
46	{45,39}	M[r[36]]=r[42];	r[42]:r[36]:

Cascading Instruction Selection (cont.)

38		r[36]=r[5];	
39	{38}	r[36]=r[36]+i;	
43		r[41]=1;	
44		r[42]=M[r[5]+i]];	
45	{43,44}	r[42]=r[42]+r[41];	r[41]:
46	{45,39}	M[r[36]]=r[42];	r[42]:r[36]:

Cascading Instruction Selection (cont.)

38	r[36]=r[5];	
39 {38}	r[36]=r[36]+i;	
44	r[42]=M[r[5]+i]];	
45 {44}	r[42]=r[42]+1;	
46 {45,39}	M[r[36]]=r[42];	r[42]:r[36]:

Cascading Instruction Selection (cont.)

38	r[36]=r[5];	
44	r[42]=M[r[5]+i]];	
45 {44}	r[42]=r[42]+1;	
46 {45,38}	M[r[36]+i]=r[42];	r[42]:r[36]:

Cascading Instruction Selection (cont.)

44	r[42]=M[r[5]+i]];	
45 {44}	r[42]=r[42]+1;	
46 {45}	M[r[5]+i]=r[42];	r[42]:

Cascading Instruction Selection (cont.)

M[r[5]+i]=M[r[5]+i]+1;

Example Sequence of Optimizations

```
for (sum=0, j = 0; j < n; j++)
    sum = sum + a[j];
```

⇒ after instruction selection

```
    M[r[13] + sum] = 0;
    M[r[13] + j] = 0;
    PC = L18;
L19
    r[0] = M[r[13] + j] <<2;
    M[r[13] + sum] = M[r[13] + sum] + M[r[0] + _a];
    M[r[13] + j] = M[r[13] + j] + 1;
L18
    IC = M[r[13] + j] ? M[_n];
    PC = IC < 0 →L19;
```

Example Sequence of Optimizations (cont.)

⇒ after register allocation

```
    r[2] = 0;
    r[1] = 0;
    PC = L18;
L19
    r[0] = r[1] << 2;
    r[2] = r[2] + M[r[0] + _a];
    r[1] = r[1] + 1;
L18
    IC = r[1] ? M[_n];
    PC = IC < 0 → L19;
```

Example Sequence of Optimizations (cont.)

⇒ after code motion

```
    r[2] = 0;
    r[1] = 0;
    r[4] = M[_n];
    PC = L18
L19
    r[0] = r[1] << 2;
    r[2] = r[2] + M[r[0] + _a];
    r[1] = r[1] + 1;
L18
    IC = r[1] ? r[4];
    PC = IC < 0 → L19;
```