Optimization

ASU Textbook Chapter 9

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Introduction

- **For some compiler, the intermediate code is a pseudo code of a virtual machine.**
  - **Interpreter of the virtual machine is invoked to execute the intermediate code.**
  - **No machine-dependent code generation is needed.**
  - **Usually with great overhead.**
  - **Example:**
    - ▷ *Pascal: P-code for the virtual P machine.*
    - ▷ *JAVA: Byte code for the virtual JAVA machine.*
- **Optimization.**
  - **Machine-dependent issues.**
  - **Machine-independent issues.**

Machine-dependent issues (1/2)

- **Input and output formats:**
  - **The formats of the intermediate code and the target program.**
- **Memory management:**
  - **Alignment, indirect addressing, paging, segment, . . .**
  - **Those you learned from your assembly language class.**
- **Instruction cost:**
  - **Special machine instructions to speed up execution.**
  - **Example:**
    - ▷ ***Increment by 1.***
    - ▷ ***Multiplying or dividing by 2.***
    - ▷ ***Bit-wise manipulation.***
    - ▷ ***Operators applied on a block of memory space.***
  - **Pick a fastest instruction combination for a certain target machine.**

Machine-dependent issues (2/2)

- **Register allocation:**
  - **C language allows the user to management a pool of registers.**
  - **Some language leaves the task to compiler.**
  - **Idea: save mostly used intermediate result in a register. However, finding an optimal solution for using a limited set of registers is NP-hard.**
  - **Example:**

```
t := a + b          load  R0,a          load   R0,a
                    load  R1,b          add    R0,b
                    add   R0,R1         store  R0,T
                    store R0,T
```

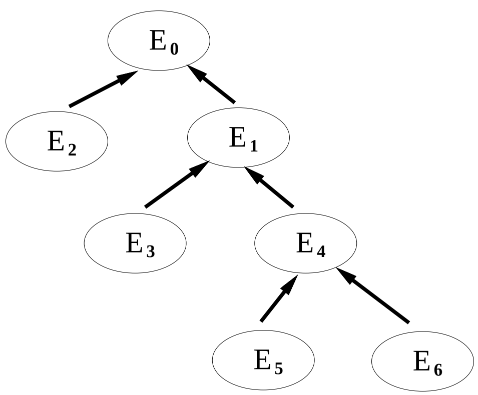
  - **Heuristic solutions: similar to the ones used for the swapping problem.**

Machine-independent issues

- **Dependence graphs.**
- **Basic blocks and flow graphs.**
- **Structure-preserving transformations.**
- **Algebraic transformations.**
- **Peephole optimization.**

Dependence graphs

- **Issues:**
  - In an expression, assume its dependence graph is given.
  - We can evaluate this expression using any topological ordering.
  - There are many legal topological orderings.
  - Pick one to increase its efficiency.
- **Example:**

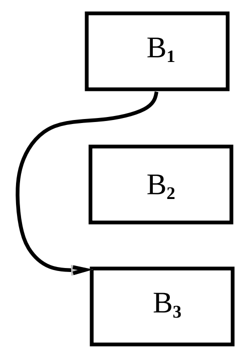


order#1	reg#	order#2	reg#
E2	1	E6	1
E3	2	E5	2
E5	3	E4	1
E6	4	E3	2
E4	3	E1	1
E1	2	E2	2
E0	1	E0	1

- **On a machine with only 2 free registers, some of the intermediate results in order#1 must be stored in the temporary space.**
  - STORE/LOAD takes time.

Basic blocks and flow graphs

- **Assumption: the input is an intermediate code program.**
- **Basic block: a sequence of intermediate code such that**
  - **Jump statements, if any, are at the end of the sequence.**
  - **Codes in other basic block can only jump to the beginning of this sequence, but not in the middle.**
  - **Example:**
    - $t_1 := a * a$
    - $t_2 := a * b$
    - $t_3 := 2 * t_2$
    - $\boldsymbol{goto\ outter}$
- **Flow graph: represent the program using a flow chart-like graph where nodes are basic blocks and edges are flow of control.**



How to find basic blocks

- **How to find leaders, which are the first statements of basic blocks.**
  - **The first statement of a program is a leader.**
  - **For all conditional and unconditional goto:**
    - ▷ ***Its target is a leader.***
    - ▷ ***Its next statement is also a leader.***
- **Using leaders to partition the program into basic blocks.**
- **Ideas for optimization:**
  - **Two basic blocks are equivalent if they compute the same expressions.**
  - **Use transformation techniques below to perform machine-independent optimization.**

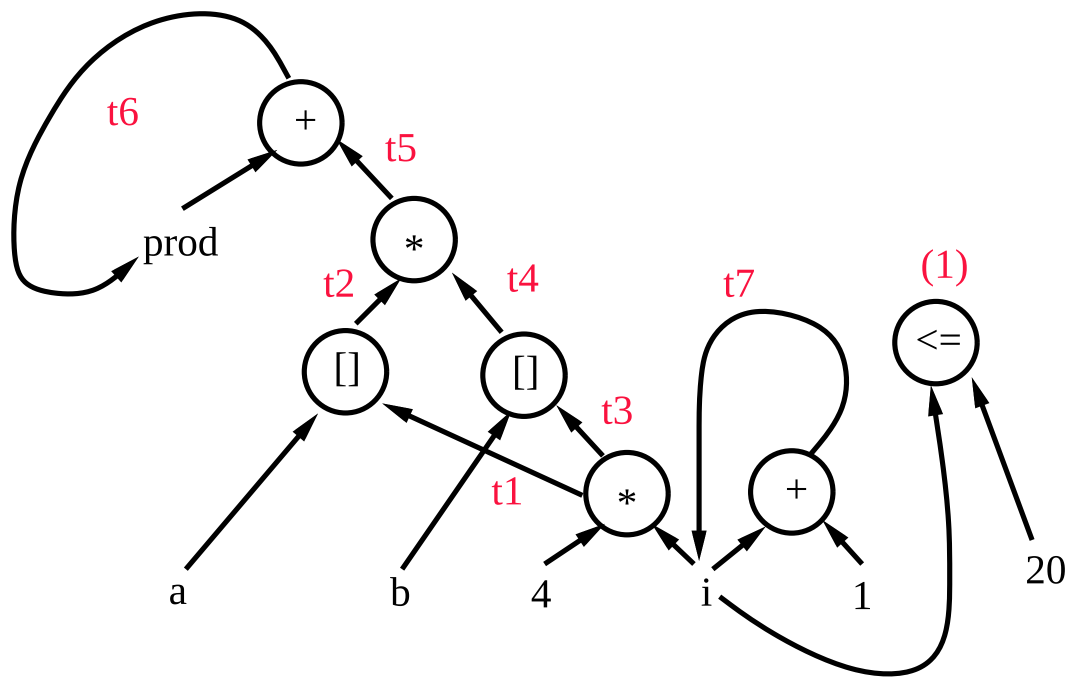
Finding basic blocks — examples

- **Example: Three-address code for computing the dot product of two vectors a and b.**
  - $prod := 0$
  - $i := 1$
  - $\textbf{\textit{loop:}}\ t_1 := 4 * i$
  - $t_2 := a[t_1]$
  - $t_3 := 4 * i$
  - $t_4 := b[t_3]$
  - $t_5 := t_2 * t_4$
  - $t_6 := prod + t_5$
  - $prod := t_6$
  - $t_7 := i + 1$
  - $i := t_7$
  - $\textbf{\textit{if}}\ i \leq 20\ \textbf{\textit{goto loop}}$
  - $\cdots$
- **There are three blocks in the above example.**

DAG representation of a basic block

- **Inside a basic block:**
  - **Expressions can be expressed using a DAG that is similar to the idea of a dependence graph.**
  - **Graph might not be connected.**
- **Example:**

(1) $t_1 := 4 * i$
(2) $t_2 := a[t_1]$
(3) $t_3 := 4 * i$
(4) $t_4 := b[t_3]$
(5) $t_5 := t_2 * t_4$
(6) $t_6 := prod + t_5$
(7) $prod := t_6$
(8) $t_7 := i + 1$
(9) $i := t_7$
(10) if $i \leq 20$ **goto (1)**



Structure-preserving transformations

- **Techniques: using the information contained in the flow graph and DAG representation of basic blocks to do optimization.**
  - **Common sub-expression elimination.**

a := b+c b := a−d c := b+c d := a−d	→	a := b+c b := a−d c := b+c d := b

  - **Dead-code elimination: remove unreachable codes.**
  - **Renaming temporary variables: better usage of registers and avoiding using unneeded temporary variables.**
  - **Interchange of two independent adjacent statements, which might be useful in discovering the above three transformations.**
    - ▷ ***Same expressions that are too far away to store E_1 into a register.***
    - ▷ ***Example:***

```
t1 := E1
t2 := const
...
tn := E1
```

    - ▷ ***The order of dependence cannot be altered after the exchange.***
    - ▷ ***Example:***

```
...
t2 := a + b
...
tn := t1 + c
```

Algebraic transformations

- **Algebraic identities:**
  - $x + 0 == 0 + x == x$
  - $x - 0 == x$
  - $x * 1 == 1 * x == x$
  - $x/1 == x$
- **Reduction in strength:**
  - $x^2 == x * x$
  - $2.0 * x == x + x$
  - $x/2 == x * 0.5$
- **Constant folding:**
  - $2 * 3.14 == 6.28$
- **Standard representation for subexpression by commutativity and associativity:**
  - $n * m == m * n$.
  - $b < a == a > b$.

Peephole optimization (1/2)

- **Idea:**
  - Statement by statement translation might generate redundant codes.
  - Locally improve the target code performance by examine a short sequence of target instructions (called a peephole) and do optimization on this sequence.
  - Complexity depends on the "window size".
- **Techniques: remove redundant codes.**
  - Redundant loads and stores.
    - ▷ $MOV\ R_0, a$
    - ▷ $MOV\ a, R_0$
  - Unreachable codes.
    - ▷ *An unlabeled instruction immediately following an unconditional jump may be removed.*
    - ▷ *If statements based on constants: If debug then $\cdots$.*

Peephole optimization (2/2)

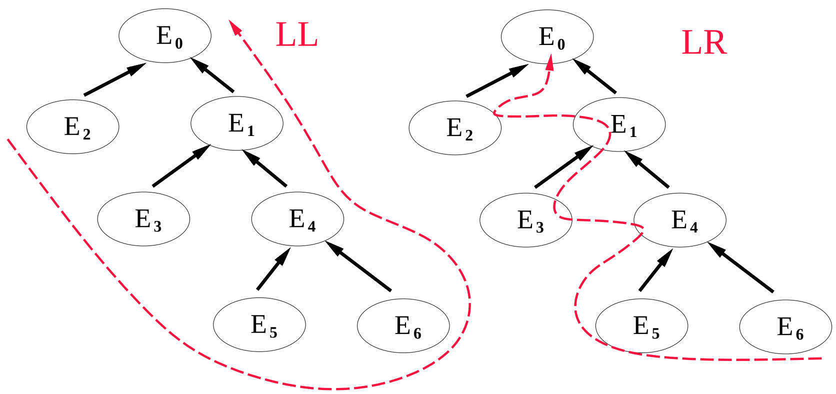
- **More techniques:**
  - **Flow of control optimization:**

goto L1	*goto L2*
...	...
L1: goto L2	*L1: goto L2*

  - **Algebraic simplification.**
  - **Use of special machine idioms.**
  - **Better usage of registers.**
  - **Loop unwrapping.**

Correctness after optimization

- **When side effects are expected, different evaluation orders may produce different results for expressions.**



  - **Assume E_5 is a procedure call with the side effect of changing some values in E_6.**
  - **LL and LR parsing produce different results.**
- **Watch out precisions when doing algebraic simplification.**
  - **if** $(x = 321.00000123456789 - 321.00000123456788) > 0$ **then** $\cdots$
- **Need to make sure code before and after optimization produce the same result.**
- **Complications arise when debugger is also involved.**