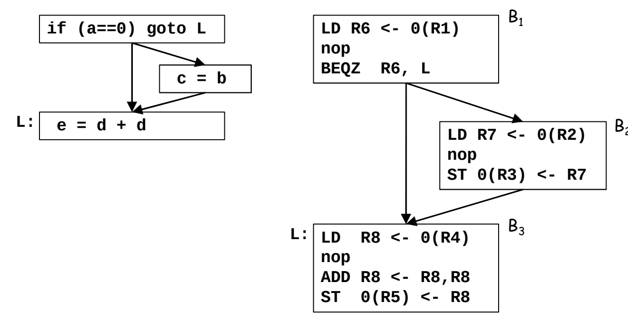
Lecture 18

Global Scheduling

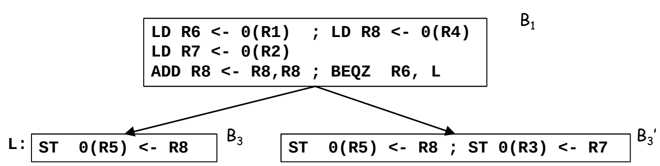
Reading: Chapter 10.4

Introduction to Global Scheduling

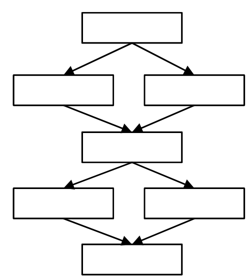
Assume each clock can execute 2 operations of any kind.



Result of Code Scheduling



Terminology



Control equivalence:

- Two operations o_1 and o_2 are *control equivalent* if o_1 is executed if and only if o_2 is executed.

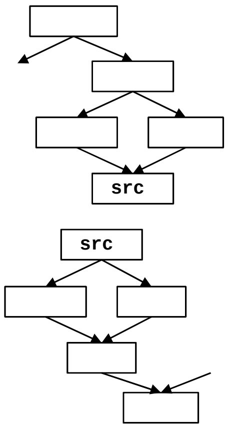
Control dependence:

- An op o_2 is *control dependent* on op o_1 if the execution of o_2 depends on the outcome of o_1.

Speculation:

- An operation o is *speculatively* executed if it is executed before all the operations it depends on (control-wise) have been executed.
- Requirements:
  - does not raise an exception
  - satisfies data dependences

Code Motions

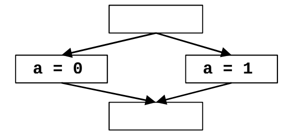


Goal: Shorten execution time probabilistically

Moving instructions up:
- Move instruction to a cut set (from entry)
- Speculation: even when not anticipated.

Moving instructions down:
- Move instruction to a cut set (from exit)
- May execute extra instruction
- Can duplicate code

A Note on Data Dependences



General-Purpose Applications

- **Lots of data dependences**
- **Key performance factor: memory latencies**
- **Move memory fetches up**
  - Speculative memory fetches can be expensive
- **Control-intensive: get execution profile**
  - Static estimation
    - Innermost loops are frequently executed
      - back edges are likely to be taken
    - Edges that branch to exit and exception routines are not likely to be taken
  - Dynamic profiling
    - Instrument code and measure using representative data

A Basic Global Scheduling Algorithm

- **Schedule innermost loops first**
- **Only upward code motion**
- **No creation of copies**
- **Only one level of speculation**

Program Representation

- **A region in a control flow graph is:**
  - a set of basic blocks and all the edges connecting these blocks,
  - such that control from outside the region must enter through a single entry block.
- **A function is represented as a hierarchy of regions**
  - The whole control flow graph is a region
  - Each natural loop in the flow graph is a region
  - Natural loops are hierarchically nested
- **Schedule regions from inner to outer**
  - treat inner loop as a black box unit
    - can schedule around it but not into it
  - ignore all the loop back edges → get an acyclic graph

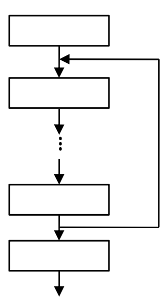
Algorithm

```
Compute data dependences;
For each region from inner to outer {
  For each basic block B in prioritized topological order {
    CandBlocks = ControlEquiv{B} ∪
                 Dominated-Successors{ControlEquiv{B}};
    CandInsts = ready operations in CandBlocks;
    For (t = 0, 1, ... until all operations from B are scheduled) {
      For (n in CandInst in priority order) {
        if (n has no resource conflicts at time t) {
          S(n) = < B, t >
          Update resource commitments
          Update data dependences
        }
      }
      Update CandInsts;
    }}}
```

Priority functions: non-speculative before speculative

Extensions

- **Prepass before scheduling: loop unrolling**
- **Especially important to move operation up loop back edges**



Summary

- **Global scheduling**
  - Legal code motions
  - Heuristics