Linear-Scan Register Allocation

CS 352

Lecture 12

11/28/07

Introduction

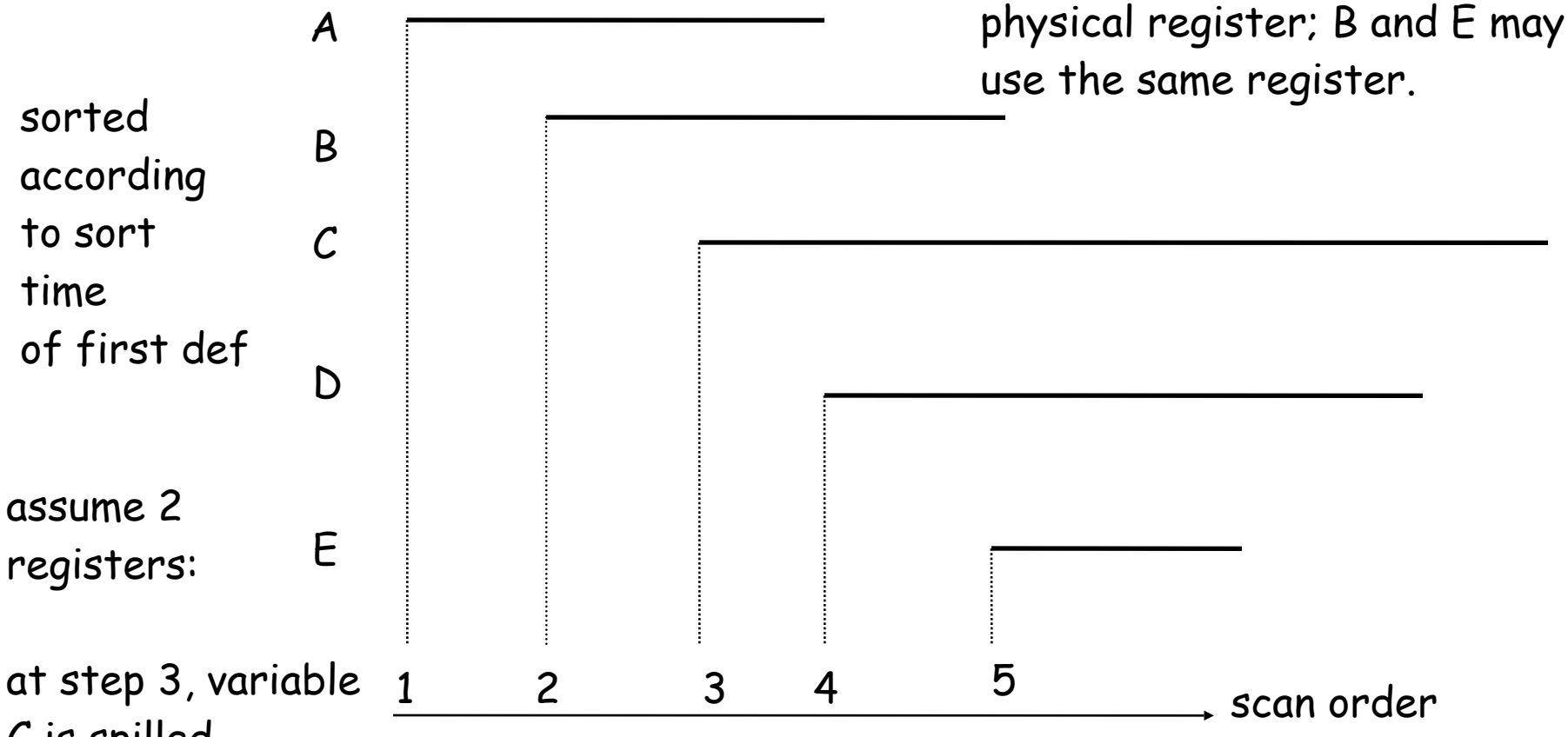
- A simple local allocation algorithm
- Assume code is already scheduled
- Build a linear ordering of live ranges (also called live intervals or lifetimes)
- Scan the live range and assign registers until you run out of them – then spill

Live Interval

- Assume some numbering of instructions in the IR
- [i,j] is said to be a live interval for variable v if
  - there is no instruction with number j' > j such that v is live at j'
  - No instruction with number i' < i such that v is live at i'
- Conservative approximation of live ranges:
  - There may be subranges of [i,j] in which v is not live.

Basic Idea

A and D may use the same physical register; B and E may use the same register.



at step 3, variable C is spilled.

Summary

- Linear scan register allocation is composed of 4 simple steps:
  - Order the instructions in linear fashion
    - Many have proposed heuristics for finding the best linear order
  - Calculate the set of live intervals
    - Each temporary is given a live interval
  - Allocate a register to each interval
    - If a register is available, then allocation is possible
    - Otherwise, an already allocated register is chosen (register spill occurs)
  - Rewrite the code according to the allocation
    - Actual registers replace temporary or virtual registers
    - Spill code is generated

The Algorithm

```
LinearScanRegisterAllocation
   active ← {}
   foreach live interval i in order of increasing
                  start point
      ExpireOldIntervals(i)
      if length(active) = R then
         SpillAtInterval(i)
      else
        register[i] ← a free register
        add i  to active, sorted by increasing end point
```

The Algorithm

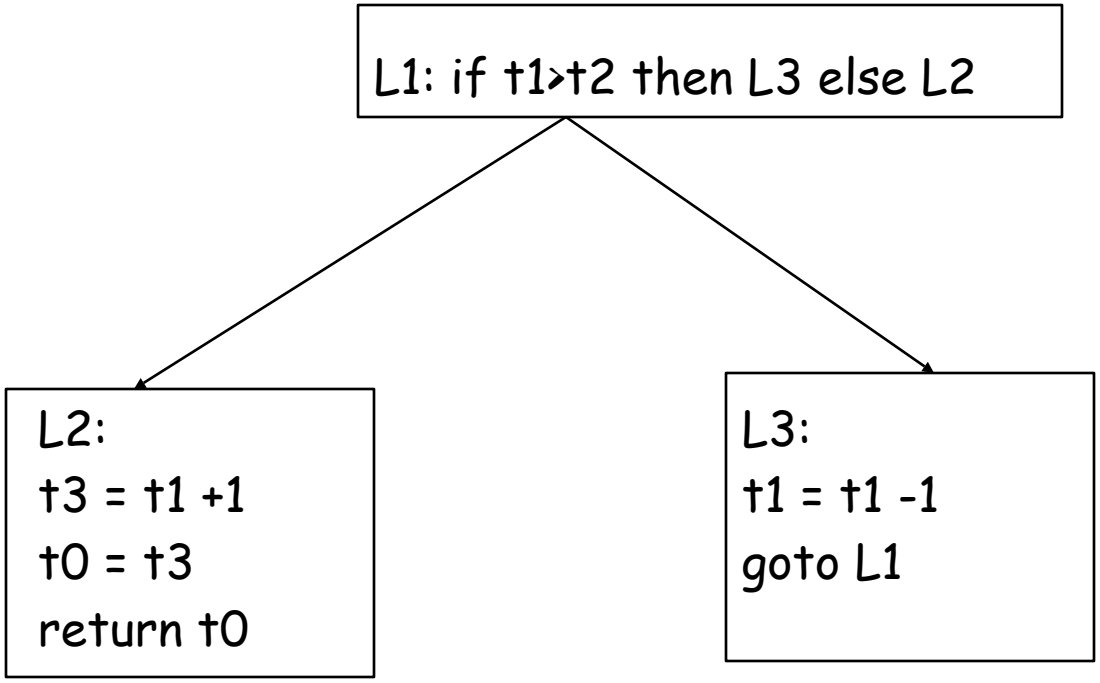
```
ExpireOldIntervals(i)
  foreach interval j in active, in order of
    increasing end point:
      if endpoint[j] >= startpoint[i]
        then return
      remove j from active
      add register[j] to pool of free registers
```

The Algorithm

```
SpillAtInterval(i)
  spill ← last interval in active
  if endpoint[spill] >= endpoint[i]
     then register[i] ← register[spill]
          location[spill] ← new stack loc.
          remove spill from active
          add i to active, sorted by increasing end point
     else location[i] ← new stack location
```

Example

- Given the following CFG:



Example

- Find a linear ordering of instructions:
  - The a priori choice of ordering affects performance
  - Exhaustive search not feasible
  - One possible ordering: (based on IR)

```
0: L1: if t1 > t2 then L3 else L2;
1: L3: t1 = t1 - 1
2:     goto L1;
3: L2: t3 = t1 + 1;
4:     t0 = t3;
5:     return t0
```

Computing Live Intervals

```
0: L1: if t1 > t2 then L3 else L2;
1: L3: t1 = t1 - 1
2:     goto L1;
3: L2: t3 = t1 + 1;
4:     t0 = t3;
5:     return t0
```

Live Intervals:

t0[4,5] t2[0,2] only overlap is t2 and t1

t1[0,3] t3[3,4]

Allocate registers to intervals

- Maintain three lists:
  - Free: set of available registers
  - Alloc: set of allocated registers
  - Active: list of active intervals ordered by increasing end points
- Assign registers:
  - Order the intervals in order of increasing end points
  - Scan the list of intervals; select the next ti
  - Free all registers assigned to intervals in Active whose interval is less than or equal to start of ti
  - If a free register exists in Free, allocate it
  - If Free is empty, then spill:
    - If last interval on the Active list end beyond the interval for ti, then ti is given that register, and ti's interval is added to active
    - If ti's interval ends at the same point or beyond the last interval in Active, then ti is given a stack location

Allocate registers to intervals

t2[0,2]

t1[0,3]

t3[3,4]

t0[4,5]

Free = {r1,r2}

Active = {}

Alloc = {}

-- Looking at t2,Allocate r1

Free = {r2}

Active = {t2:[0,2]}

Alloc = {r1:t2}

-- Looking at t1, Allocate r2

Active = {t1:[0,3], t2:[0,2]

Free = {}

Alloc = {r1:t2,r2:t1}

Allocate registers to intervals

t2[0,2]

t1[0,3]

t3[3,4]

t0[4,5]

More intervals to process

start of interval 3

Free = {r1}

Alloc = {r2:t1}

-- Looking at t3, allocate r1

Active = {r1:t3,r2:t1}

start of interval 4

Free = {r2}

Alloc = {r1:t3}

-- Looking at t0, allocate r2

Active = {r1:t3,r2:t0}

Consider a different ordering

t1[0,5]

t2[0,5]

t3[1,2]

t0[2,3]

Free = {r1,r2}

Active = {}

Alloc = {}

-- Looking at t1,Allocate r1

Free = {r2}

Active = {t1:[0,5]}

Alloc = {r1:t1}

-- Looking at t2, Allocate r2

Active = {t1:[0,5], t2:[0,5]

Free = {}

Example (cont)

t1[0,5]

t2[0,5]

t3[1,2]

t0[2,3]

More intervals to process

Active = {t2:[0,5], t1:[0,5]

start of interval 1

Alloc = {r2:t2, r1:t1}

-- Looking at t3

-- Free is empty

-- End of t1 > t3

-- t3 allocated to r1, t1 on stack

Free = {}

Active = {t3:[1,2], t2:[0,5]}

Alloc = {r1:t3,r2:t2}

Example (cont)

t1[0,5]

t2[0,5]

t3[1,2]

t0[2,3]

Alloc = {r1:t3, r2:t2}

-- start of interval 2

-- Looking at t0

-- Free is empty (spill needed)

-- end of t2 > end of t0

-- t0 is allocated to r2, t2 on stack

Rewriting the code

- Code is rewritten with assigned registers and spill code inserted
- Spill code is additional code that may increase cycle time:

```
0: L1: t1(r1) > t2(r2) then L3 else L2
1:   spill(t1(r1)) and free r1
2: L2: t3(r1) = t1(stk) + 1
3:   spill(t0(r2)) and free r2
4:       t0(r2) = t3(r1)
5:       return t0(r2)
6: L3: t1(stk) = t1(stk) – 1
7:       goto L1
```