CS412/413

Introduction to Compilers

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Lecture 28: Register Allocation

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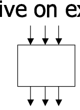
Register Allocation

- Want to replace variables with some fixed set of registers if possible
- Main Idea: cannot allocate two variables to the same register if they are both live at some program point
- Need to know which variables are live at each instruction

Register Allocation

- For every node n in CFG now have out[n] : which variables (temporaries) are live on exit from node.



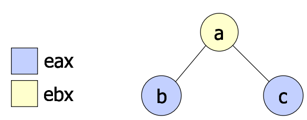
- If two variables are in same live set, can't be allocated to the same register – they interfere with each other
- How do we assign registers to variables?

Inference Graph

- Nodes of graph: variables
- Edges = variables that interfere with each other

```
            a
b = a + 2;
            a,b
c = b*b;
            a,c
b = c + 1;
            a,b
return b*a;
```

- Register assignment is graph coloring

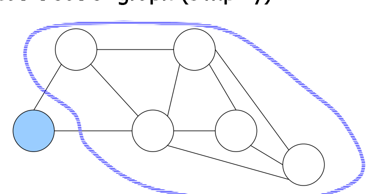


Graph Coloring

- Questions:
  - Can we efficiently find a coloring of the graph whenever possible?
  - Can we efficiently find the optimum coloring of the graph?
  - How can we choose registers to avoid mov instructions?
  - What do we do when there aren't enough colors (registers) to color the graph?

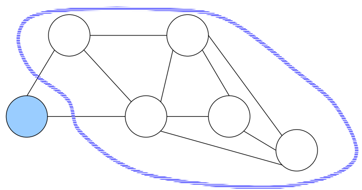
Coloring a Graph

- Simple algorithm for finding a K-coloring of a graph: (Assume K=3)
- Step 1: find some node with at most K-1 edges and cut it out of graph (simplify)



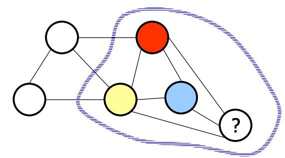
Simple Algorithm

- Once coloring is found for simplified graph, selected node can be colored using free color
- Step 2: simplify until graph contain no nodes, unwind adding nodes back & assigning colors



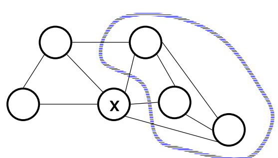
Failure of Heuristic

- If graph cannot be colored, it will reduce to a graph in which every node has at least K neighbors
- May happen even if graph is colorable in K!
- Finding K-coloring is NP-hard problem (requires search)



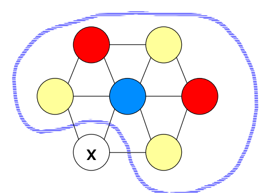
Spilling

- Once all nodes have K or more neighbors, pick a node and mark it for spilling (storage on stack). Remove it from graph, continue as before
- Try to pick node not used much, not in inner loop



Optimistic Coloring

- Spilled node may be K-colorable; when assigning colors, try to color it and only spill if necessary.
- If not colorable, record this node as one to be spilled, assign it a stack location and keep coloring



Accessing Spilled Variables

- Need to generate additional instructions to get spilled variables out of stack and back in again
- Naive approach: always keep extra registers handy for shuttling data in and out
- Better approach: rewrite code introducing a new temporary, rerun liveness analysis and register allocation

Rewriting Code

- Example: add t1, t2
- Suppose that t2 is selected for spilling and assigned to stack location [ebp-24]
- Invent new variable t35 for just this instruction, rewrite:

```
mov –24(%ebp), t35
add t35, t1
```

- Advantage: t35 doesn’t interfere with as much as t2 did. Now rerun algorithm; fewer or no variables will spill.

Precolored Nodes

- Some variables are pre-assigned to registers
- mul instruction has
  use[I] = eax, def[I] = { eax, edx }
- call instruction kills caller-save regs:
  def[I] = { eax, ecx, edx }
- To properly allocate registers, treat these register uses as special temporary variables and enter into interference graph as precolored nodes

Precolored Nodes

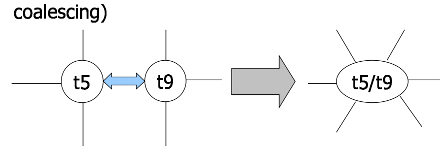
- Can't simplify graph by removing a pre-colored node
- Precolored nodes: starting point of coloring process
- Once simplified graph is all colored nodes, add other nodes back in and color them

Optimizing Move Instructions

- Code generation produces a lot of extra mov instructions
  mov t5, t9
- If we can assign t5 and t9 to same register, we can get rid of the mov
- Idea: if t5 and t9 are not connected in inference graph, coalesce them into a single variable. mov will be redundant.

Coalescing

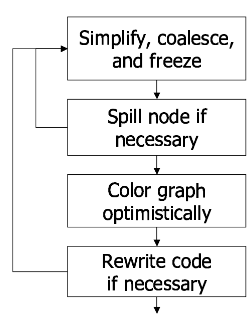
- Problem: coalescing two nodes can make the graph uncolorable
- High-degree nodes can make graph harder to color, even impossible
- Avoid creation of high-degree (>K) nodes (conservative coalescing)



Simplification + Coalescing

- Start by simplifying as much as possible without removing nodes that are either the source or destination of a mov (move-related nodes)
- Coalesce some pair of move-related nodes as long as low-degree node results; delete corresponding mov instruction(s)
- If can neither simplify nor coalesce, take a move-related pair and freeze the mov instruction, do not consider nodes move-related

High-level Algorithm



Summary

- Register allocation pseudo-code in Appel, Chapter 11
- Now have seen all the machinery needed to produce optimized code:
  - Lexer, parser, semantic analysis
  - High IR to low IR
  - Control flow graphs
  - Dataflow analysis
  - Instruction selection
  - Register allocation