More on Machine-Code Generation

- ***Problem**: given a target machine specification, how to translate the intermediate representations into **efficient** machine code ?*
- ***Solution** --- must take consideration of the machine architecture*

  1. *Code Selection*
     (emitting the machine code via **maximal-munch** or **dynamic programming**)
  2. ***Register Allocation***
     (global register allocation, spilling)
  3. ***Instruction Scheduling***
     (instruction scheduling, branch prediction, memory hierarchy optimizations)

- ***Language Trends** : assembly -> C -> ... -> higher-level languages ?*
- ***Architecture Trends** : CISC -> RISC -> ... -> superscalar -> ?*
- ***Trends**: the bridging gap is the main **challenge** to compiler writers*

Register Allocation

- ***Register allocation** often works on the intermediate representations that are <u>very much like</u> the machine code.*
- ***Input**: intermediate code that references <u>unlimited</u> number of registers; **output**: rewrite the intermediate code so that it uses the <u>limited</u> registers available on the target machine --- the machine registers.*
- ***Standard Algorithm: Graph Coloring Register Allocation***

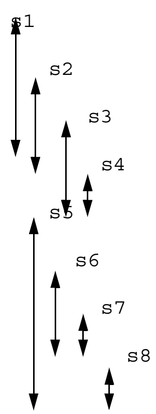
  Main idea: build a interference graph based on the live ranges of each identifiers; then color the interference graph.

  *Example: **Yorktown Allocator** (by Chaitin et al. at IBM T.J.Watson)'*

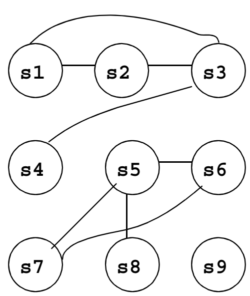
  ***Briggs's Extension** (by Briggs et al. at Rice Univ.)*

Example: Register Allocation

```
s1 := load z
s2 := load y
s3 := s1 + s2
s4 := s1 * s2
s5 := s3 + s4
s6 := load x
s7 := load w
s8 := s6 * s7
s9 := s5 + s8
```

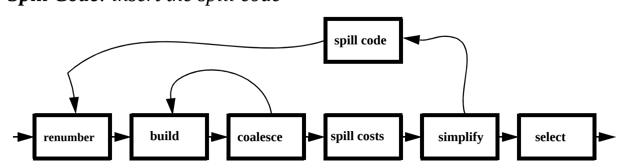


how to color the interference graph ?



Yorktown Allocator

- ***Renumber**: name all identifiers uniquely, find out their live ranges.*
- ***Build**: construct the interference graph G.*
- ***Coalesce**: eliminating copying instructions, e.g., **x = y***
- ***Spill Costs**: calculate the spill costs*
- ***Simplify**: (together with **Select**) color the graph (it is NP-complete!).*
- ***Select**: choose the actual colors (i.e., registers)*
- ***Spill Code**: insert the spill code*



Yorktown Allocator (cont'd)

- ***Build****: the interference graph characterizes the* **interference** *relation of live ranges: two live ranges* **interfere** *if there exists some point in the procedure and a possible execution of the procedure such that*

  1. both live ranges have been defined
  2. both live ranges will be used, and
  3. the live ranges have different values

- ***Simplify and Select****: assuming there are* **k** *physical registers*

  In ***Simplify***, the allocator repeatedly removes nodes with outer degree < ***k*** from the graph and pushes them onto a stack.

  In ***Select***, the nodes are popped from the stack and added back to the graph -- a color is chosen for each node.

  If ***Simplify*** encounters a graph containing only nodes of degree **>=** ***k***, then a node is chosen for spilling.

Yorktown Allocator (cont'd)

- ***Choosing Spill Nodes****: based on the weight* $\mathbf{m_n}$ *for each node* ***n***

  Chaitin's heuristics: $m_n = cost_n / degree_n$

  Alternatives: $m_n = cost_n / (degree_n * area_n)$

  where $area_n$ is a function that quantifies the impact ***n*** has on other live ranges in the program, e.g., if it is used in a loop often, $area_n$ is larger.

- ***Spilling****: if* **v** *is spilled, a* **store** *is inserted after every definition of* **v***, and a* **load** *is inserted before every use of* **v***.*

- **Bernstein** *et al. later found no single* **spilling-cost heauristics** *completely dominates the other. They propose "****best of 3****" technique:*

  Just run the algorithm using three heauristics, then choose one with the best outcome.

Briggs's Extension

- ***Simplify*** *removes nodes with degree* **<** ***k*** *in an arbitrary order. If all remaining nodes have degree* **>=** ***k***, *a spill candidate is choosed and* <u>*optimistically*</u> *pushed on the stack also, hoping a color will be found later.*

- ***Select*** *may discover that it has no color for some node. In that case, it leaves the node* <u>*uncolored*</u> *and continues with the next node.*

- *If any nodes are* <u>*uncolored*</u>*, the allocator inserts spill code accordingly and rebuild the interference graph, and tries again.*