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Register allocation

Variables vs. registers

- TAC has any number of variables
- Assembly code has to deal with memory and registers
- Compiler back end must decide how to juggle the contents of the memory and registers to fit every variable as necessary

Straightforward solution

- We know how to do this, just
  - Put everything in the activation record
  - For each instruction, shuttle variables into registers
  - Combine registers
  - Put variables back into activation record
- That's fine and dandy, but it creates
  - Redundant copy instructions
  - Constant memory traffic

Register allocation

- Goal: keep variables in registers as long as possible
- In the best of cases, a variable can be in a register througout its lifetime
- If it can't, it'll need a place in the activation record

What can go in registers?

- That depends on the number of registers
- It also depends on how variables are being used
  - (You can’t make a pointer to a register)
- Main idea:

  Two variables can’t share the same register if they are live simultaneously

The basic approach

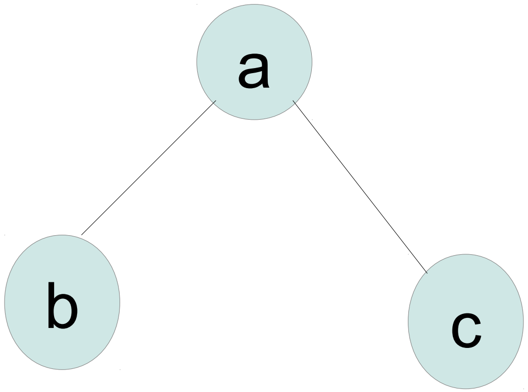
- Do live variable analysis
- Go through the sets of live variables
- When two variables appear in the same set, they *interfere*
  - Conversely, when two variables don't interfere, their live ranges are disjoint
  - Pairs like that can share the same register, because they won't need it at the same time

Interference graphs

- An interference graph is a graph where
  - every variable is a node
  - edges connect interfering variables

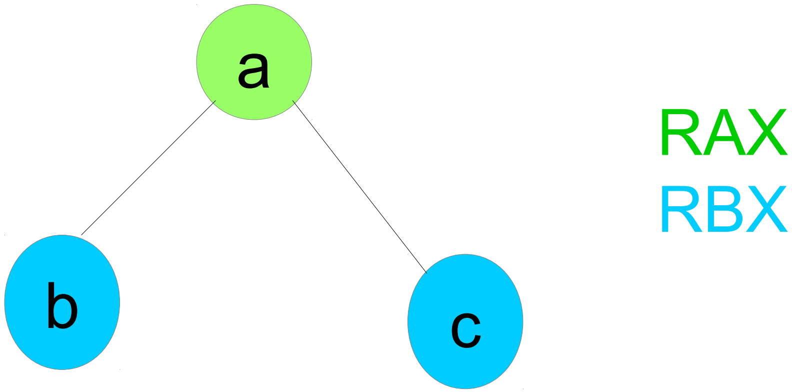
as in this one:

```
        {a}
b = a + 2
        {a, b}
c = b * b
        {c,a}
b = c + 1
        {b,a}
return b*a
        {}
```



Graph coloring

- If every register has a color, a register assignment of the interference graph is a mapping where no two neighbors have the same color



Um… "colors"?

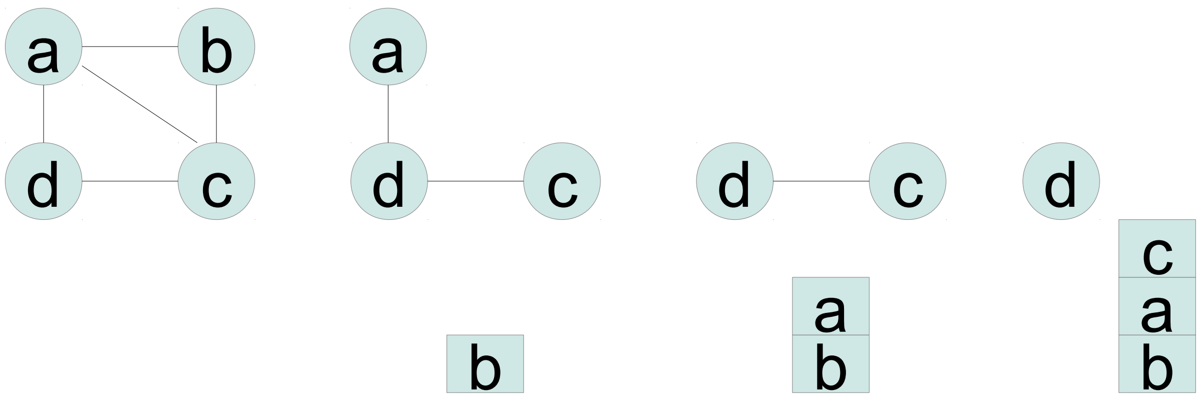
- Graph "coloring" is one of the classic problems of computer science
- If we have *k* registers, the question of whether each variable can have one is the same as whether the interference graph is *k-colorable*
- K-colorability is an NP complete problem, finding an optimal solution takes exponential time
  (as far as we know today)
- We can still approximate it with an imperfect heuristic

Practical k-coloring

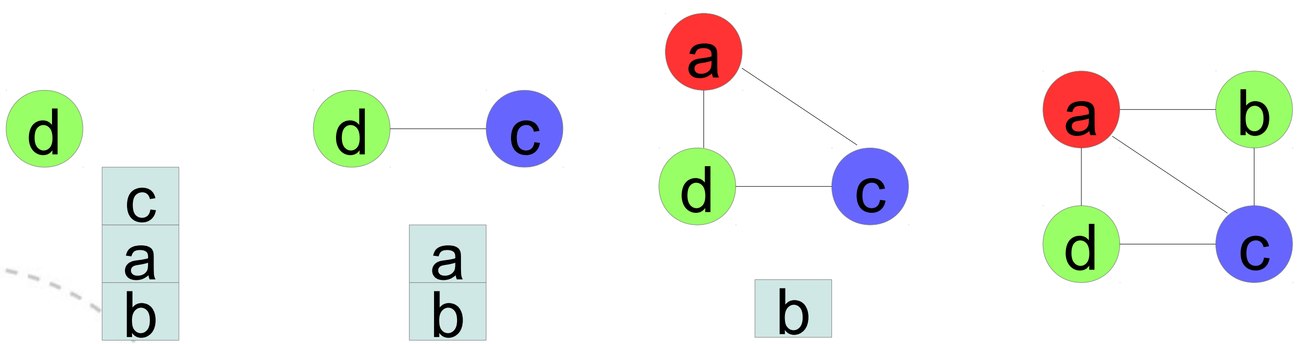
- Simplify the graph
  - Find a node with at most k-1 edges
  - Remove it from the graph, put it on a stack
  - Repeat until simplified graph is trivially k-colorable (or, until there are no nodes left, if you prefer)
- Reintroduce the nodes
  - Add nodes back (in reverse order of the simplification)
  - Color them with colors that they don't interfere with
  - Hope that total number of colors is k or smaller

Sometimes it works

- Is this graph 3-colorable?



(simplify)



(reconstruct)

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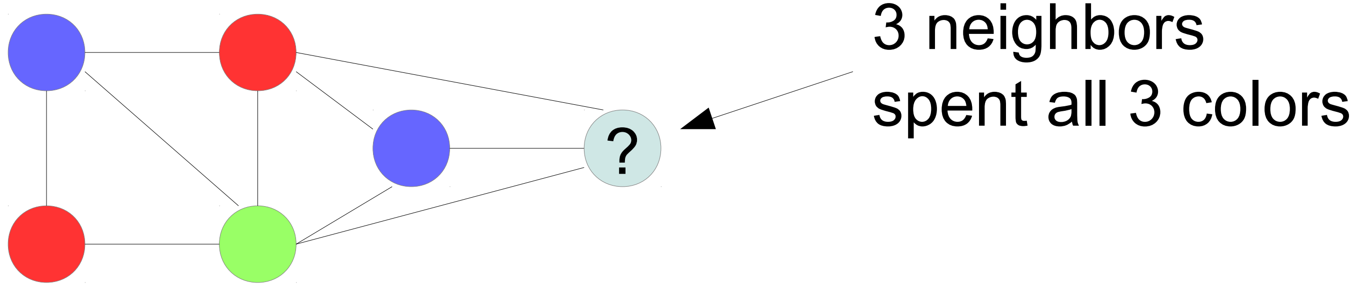
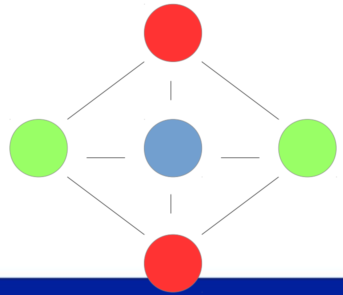
Sometimes it doesn't

- If the graph can't be colored, it'll find a form where every node has k or more neighbors

  (otherwise, there'd be a color to spare for them)



- K or more neighbors doesn't imply uncolorability



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Spilling

- When all nodes have k or more neighbors, pick one and mark it for *spilling*
  (a place in the activation record)
- Remove from graph, push on stack
- Aim for little-used nodes

Access to spilled variables

- Some additional instructions will be needed to move spilled variables back and forth to the activation record
- Simple: keep a few extra registers for shuttling data in the load-modify-store way
- Better: rewrite low-IR code with new temporary, redo liveness and register allocation

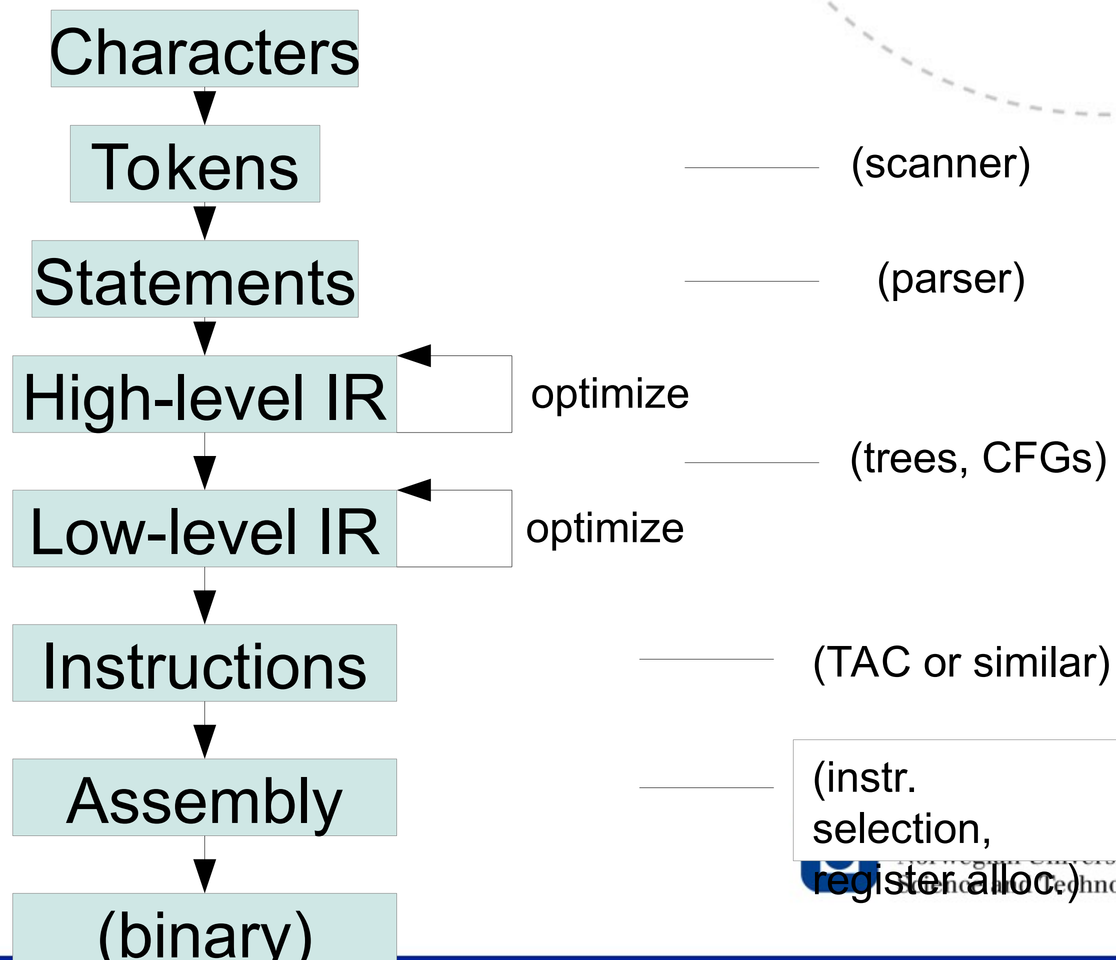
Precolored nodes

- Some variables need designated registers
  (e.g. “return value goes in RAX”)
- Treat their temporaries as special, and set their colors in the interference graph
- Simplification: Never remove pre-colored nodes
  (They don’t need to be reintroduced to get a color anyway)
- Coloring: Use the pre-colored nodes as starting point when reintroducing the rest

Big picture of code generation

- Start from low-level IR
- Build DAG of the computation
  - Global variables = static addresses
  - Arguments taken from frame pointer
  - Assume all locals and temporaries in (infinite number of) registers
- Tile the DAG, obtaining abstract assembly
- Allocate registers
  - Liveness analysis of abstract assembly
  - Assign registers and generate assembly

The whole process



The final sessions

- At the end, we'll revisit all those topics, and speed-review key elements of the techniques we've covered