EECS 583 – Class 8

Classic Optimization

University of Michigan

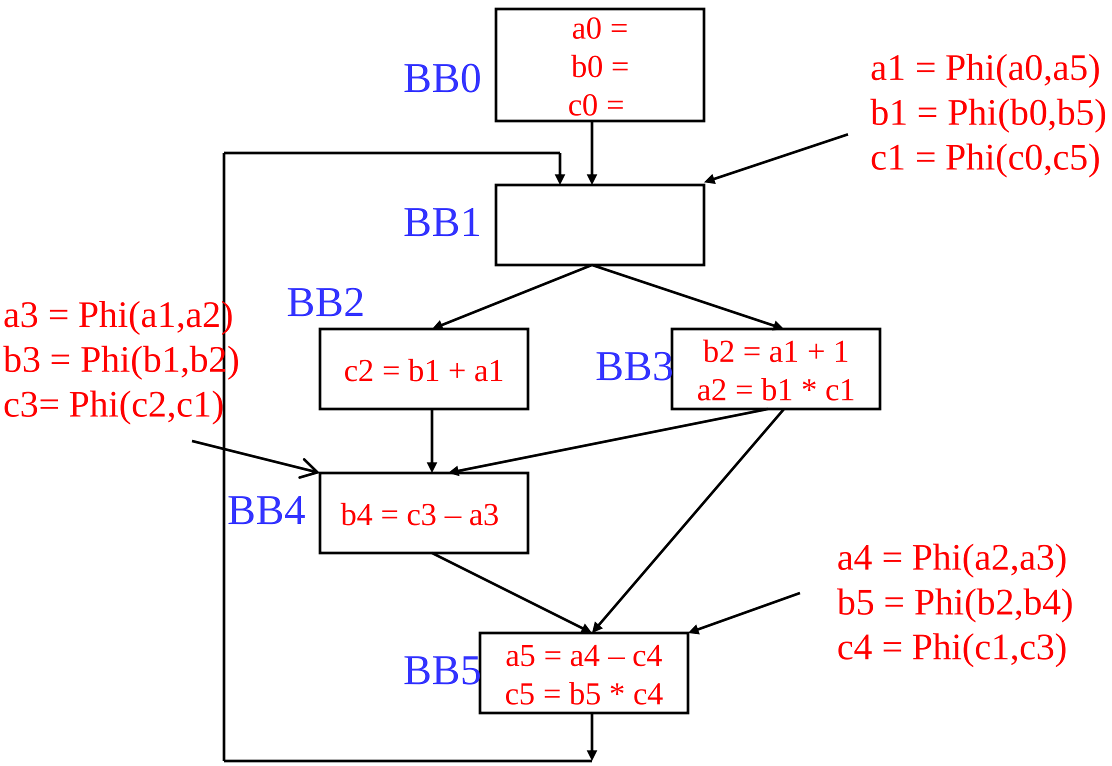
October 1, 2018

Announcements & Reading Material

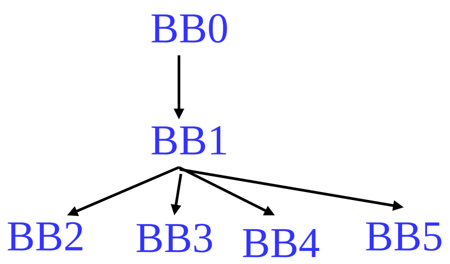
- HW2 – Get busy on it ASAP!
- Today's class
  - » *Compilers: Principles, Techniques, and Tools*, A. Aho, R. Sethi, and J. Ullman, Addison-Wesley, 1988, 9.9, 10.2, 10.3, 10.7 Edition 1; 8.5, 8.7, 9.1, 9.4, 9.5 Edition 2
- Material for Wednesday
  - » "Compiler Code Transformations for Superscalar-Based High-Performance Systems," S. Mahlke, W. Chen, J. Gyllenhaal, W. Hwu, P. Chang, and T. Kiyohara, *Proceedings of Supercomputing '92*, Nov. 1992, pp. 808-817
  - » And if you want more on ILP optimizations: D. J. Kuck, The Structure of Computers and Computations. New York, NY: John Wiley and Sons, 1978. (optional!)

Class Problem From Last Time – Answer

Rename the variables



Dominator tree



Dominance frontier

BB	DF
0	-
1	-
2	4
3	4, 5
4	5
5	1

Code Optimization

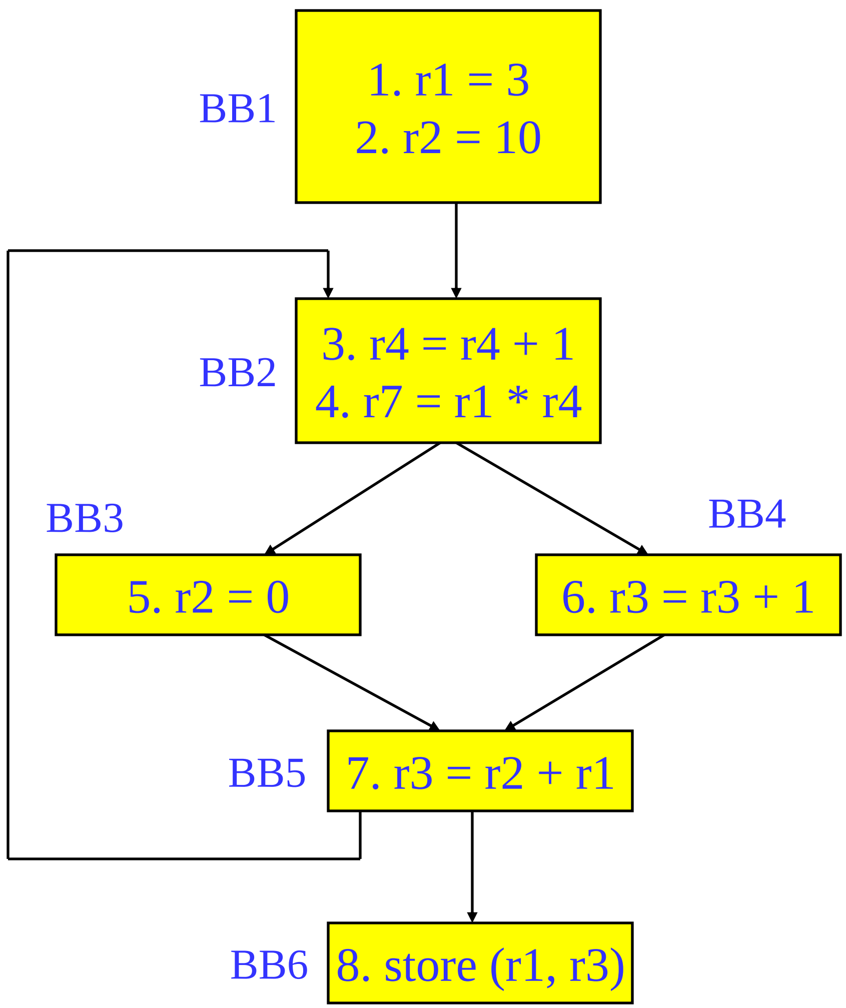
- Make the code run faster on the target processor
  - My (Scott's) favorite topic !!
  - Other objectives: Power, code size
- Classes of optimization
  - 1. Classical (machine independent)
    - Reducing operation count (redundancy elimination)
    - Simplifying operations
    - Generally good for any kind of machine
  - 2. Machine specific
    - Peephole optimizations
    - Take advantage of specialized hardware features
  - 3. Parallelism enhancing
    - Increasing parallelism (ILP or TLP)
    - Possibly increase instructions

A Tour Through the Classical Optimizations

- For this class – Go over concepts of a small subset of the optimizations
  - What it is, why its useful
  - When can it be applied (set of conditions that must be satisfied)
  - How it works
  - Give you the flavor but don't want to beat you over the head
- Challenges
  - Register pressure?
  - Parallelism verses operation count

Dead Code Elimination

- Remove any operation who's result is never consumed
- Rules
  - X can be deleted
    - no stores or branches
  - DU chain empty or dest register not live
- This misses some dead code!!
  - Especially in loops
- Better Algorithm
  - Critical operation
    - store or branch operation
  - Any operation that does not directly or indirectly feed a critical operation is dead
  - Trace UD chains backwards from critical operations
  - Any op not visited is dead



Local Constant Propagation

- Forward propagation of moves of the form
  - » rx = L (where L is a literal)
  - » Maximally propagate
- Consider 2 ops, X and Y in a BB, X is before Y
  - » 1. X is a move
  - » 2. src1(X) is a literal
  - » 3. Y consumes dest(X)
  - » 4. There is no definition of dest(X) between X and Y

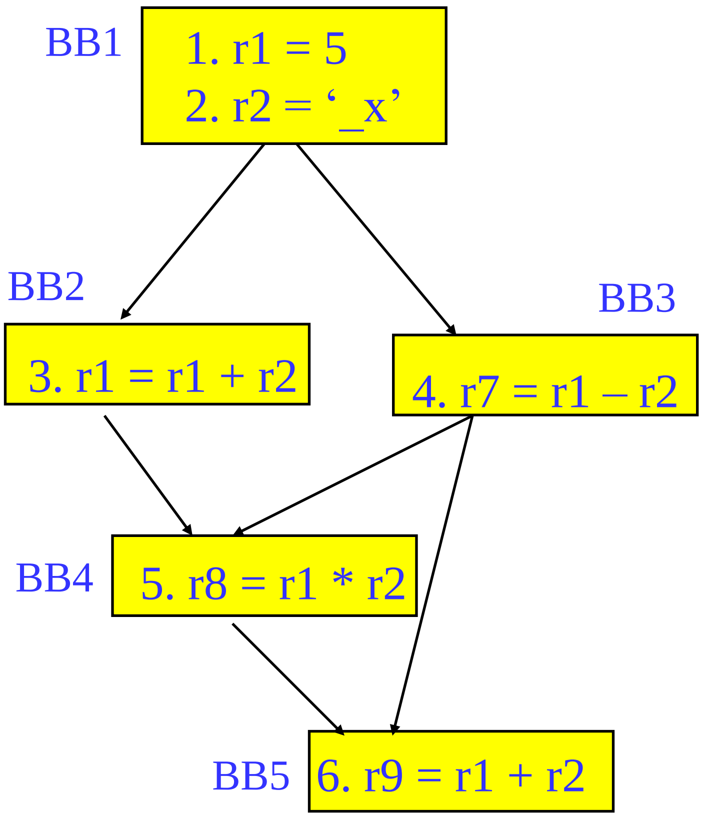
BB1

1. r1 = 5
2. r2 = '_x'
3. r3 = 7
4. r4 = r4 + r1
5. r1 = r1 + r2
6. r1 = r1 + 1
7. r3 = 12
8. r8 = r1 - r2
9. r9 = r3 + r5
10. r3 = r2 + 1
11. r10 = r3 – r1

Note, ignore operation format issues, so all operations can have literals in either operand position

Global Constant Propagation

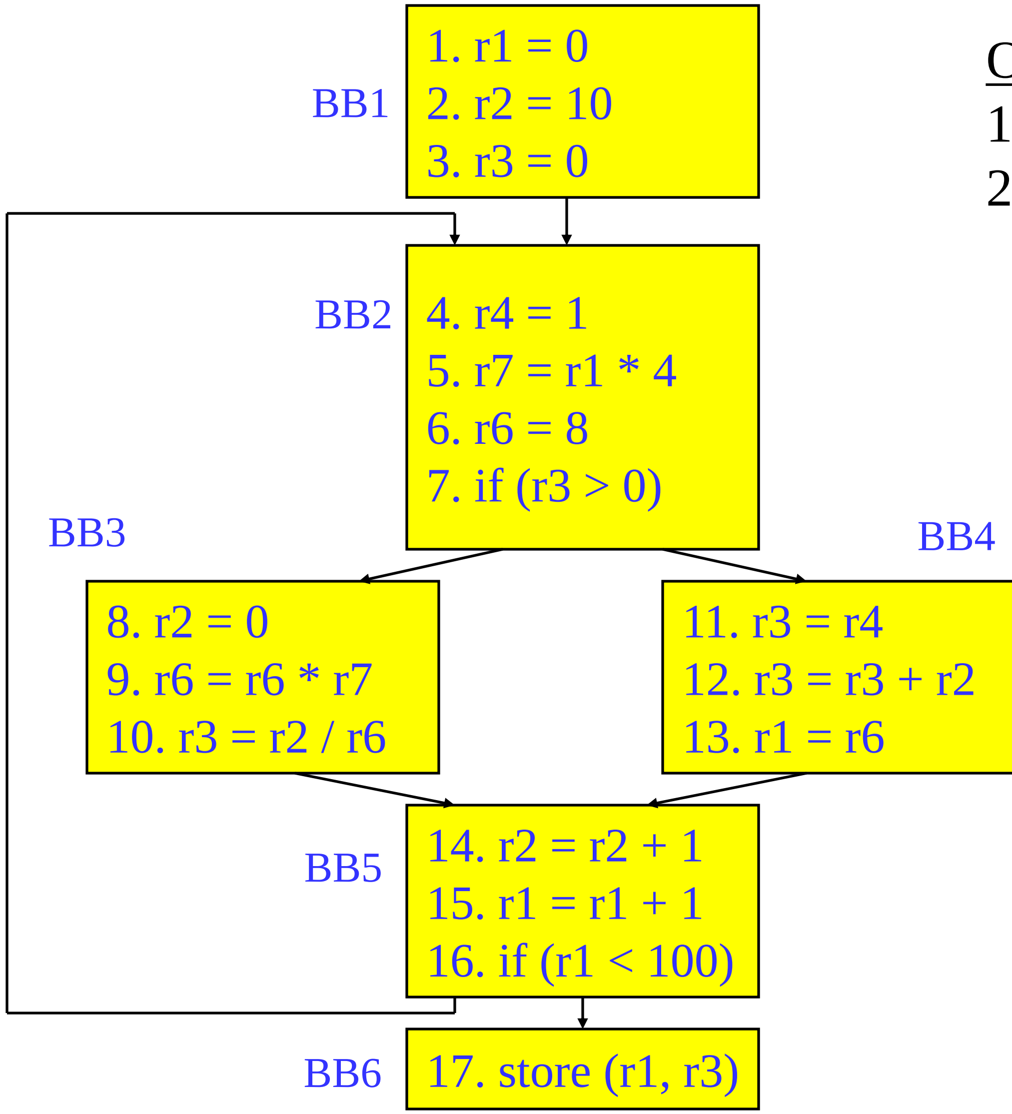
- Consider 2 ops, X and Y in different BBs
  - 1. X is a move
  - 2. src1(X) is a literal
  - 3. Y consumes dest(X)
  - 4. X is in a_in(BB(Y))
  - 5. Dest(x) is not modified between the top of BB(Y) and Y



Constant Folding

- Simplify 1 operation based on values of src operands
  - Constant propagation creates opportunities for this
- All constant operands
  - Evaluate the op, replace with a move
    - r1 = 3 * 4 → r1 = 12
    - r1 = 3 / 0 → ??? Don't evaluate excepting ops !, what about floating-point?
  - Evaluate conditional branch, replace with BRU or noop
    - if (1 < 2) goto BB2 → BRU BB2
    - if (1 > 2) goto BB2 → convert to a noop
- Algebraic identities
  - r1 = r2 + 0, r2 – 0, r2 | 0, r2 ^ 0, r2 << 0, r2 >> 0
    - r1 = r2
  - r1 = 0 * r2, 0 / r2, 0 & r2
    - r1 = 0
  - r1 = r2 * 1, r2 / 1
    - r1 = r2

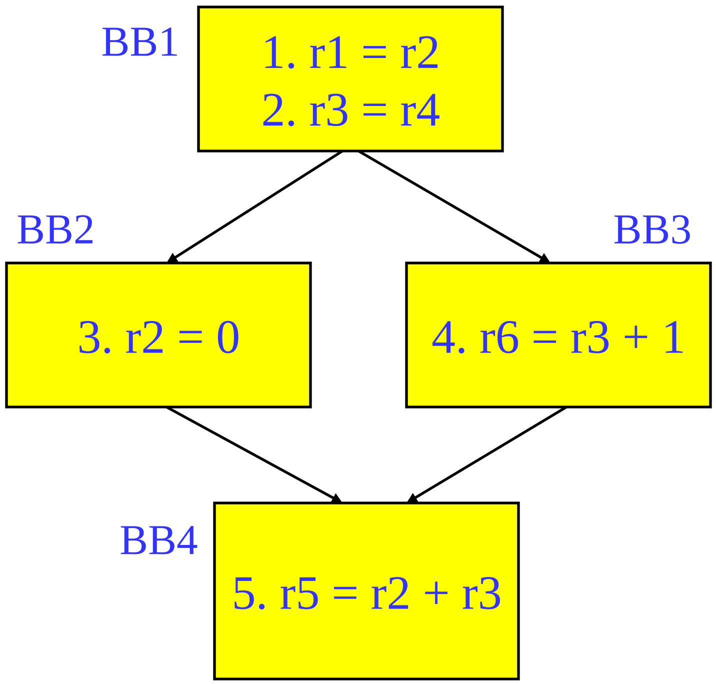
Class Problem



Optimize this applying
1. constant propagation
2. constant folding

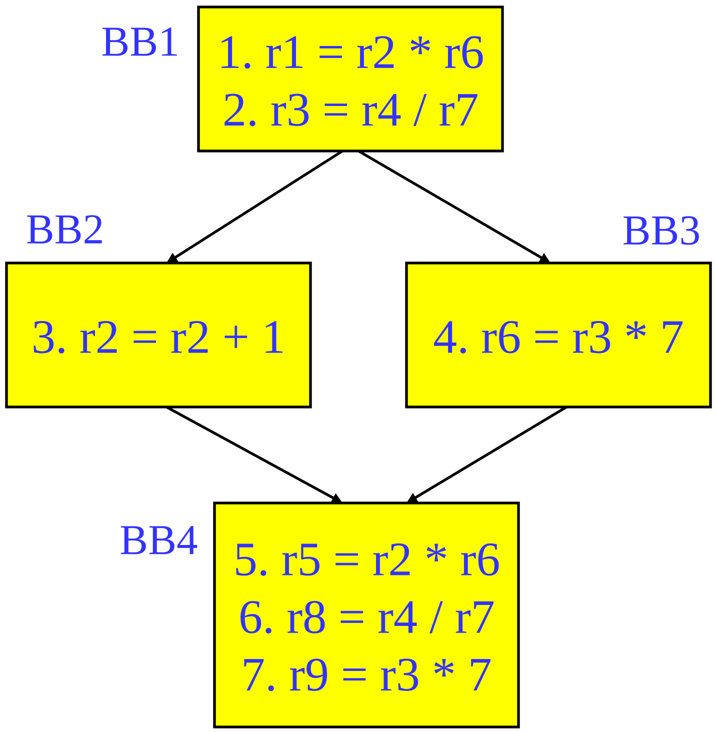
Forward Copy Propagation

- Forward propagation of the RHS of moves
  - r1 = r2
  - …
  - r4 = r1 + 1 → r4 = r2 + 1
- Benefits
  - Reduce chain of dependences
  - Eliminate the move
- Rules (ops X and Y)
  - X is a move
  - src1(X) is a register
  - Y consumes dest(X)
  - X.dest is an available def at Y
  - X.src1 is an available expr at Y



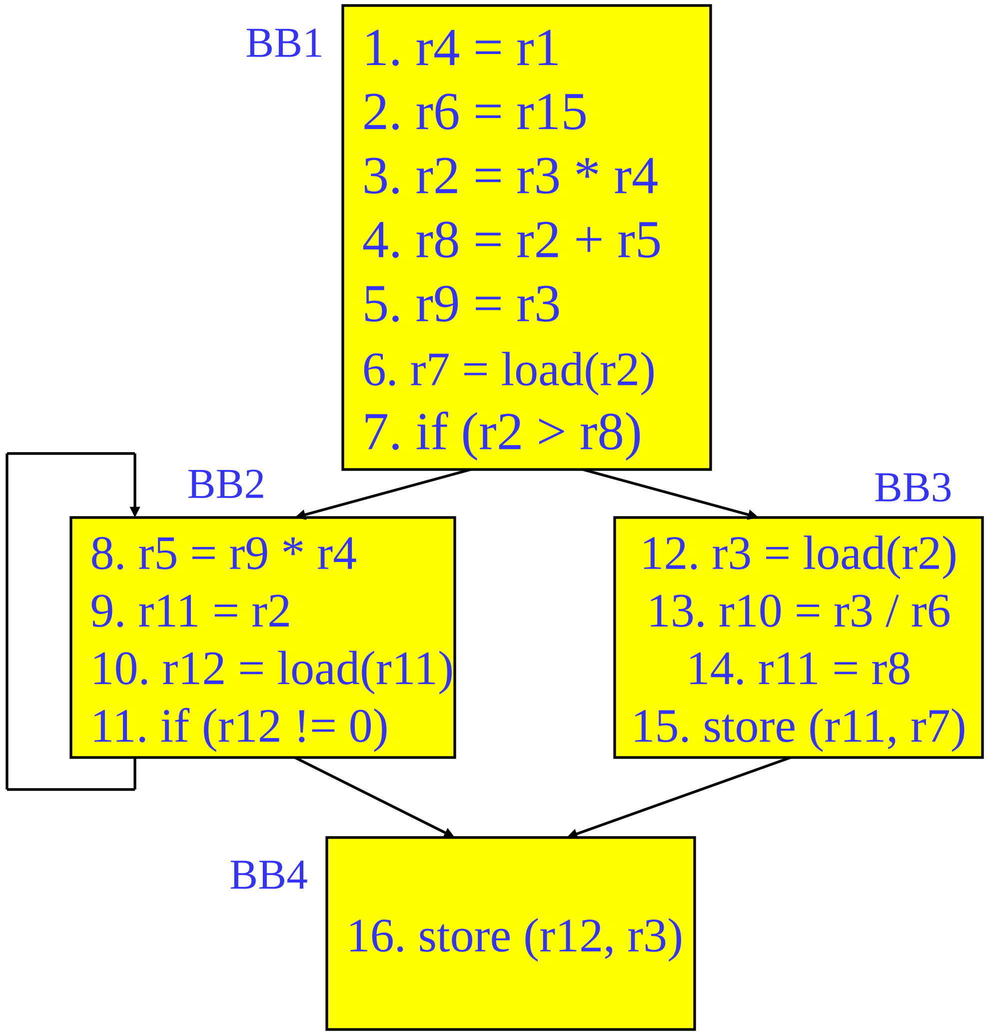
CSE – Common Subexpression Elimination

- Eliminate recomputation of an expression by reusing the previous result
  - r1 = r2 * r3
  - → r100 = r1
  - …
  - r4 = r2 * r3 → r4 = r100
- Benefits
  - Reduce work
  - Moves can get copy propagated
- Rules (ops X and Y)
  - X and Y have the same opcode
  - src(X) = src(Y), for all srcs
  - expr(X) is available at Y
  - if X is a load, then there is no store that may write to address(X) along any path between X and Y



if op is a load, call it redundant load elimination rather than CSE

Class Problem

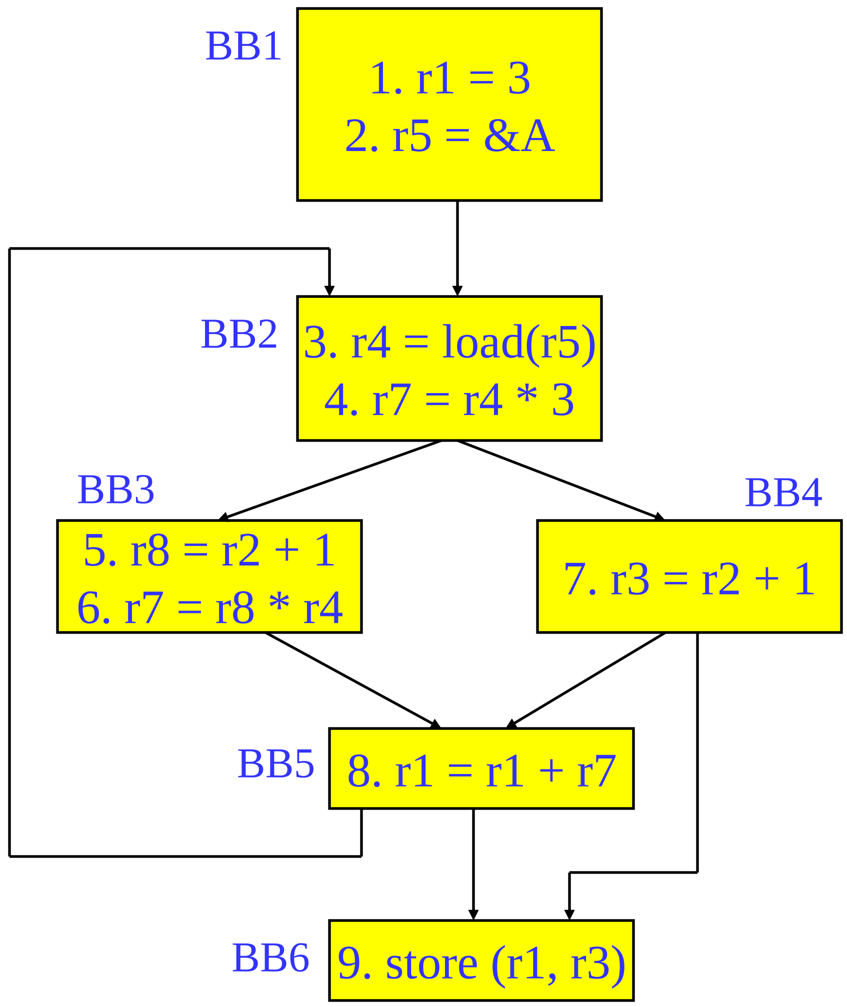


<u>Optimize this applying</u>

1. dead code elimination
2. forward copy propagation
3. CSE

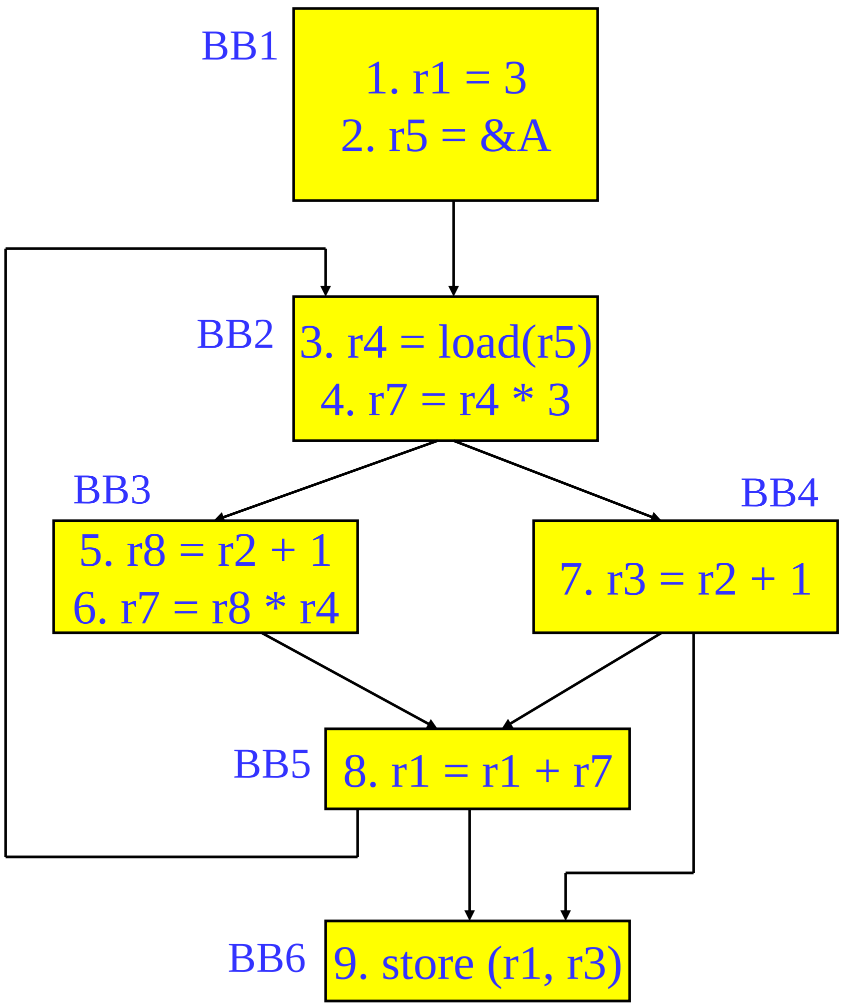
Loop Invariant Code Motion (LICM)

- Move operations whose source operands do not change within the loop to the loop preheader
  - » Execute them only 1x per invocation of the loop
  - » Be careful with memory operations!
  - » Be careful with ops not executed every iteration



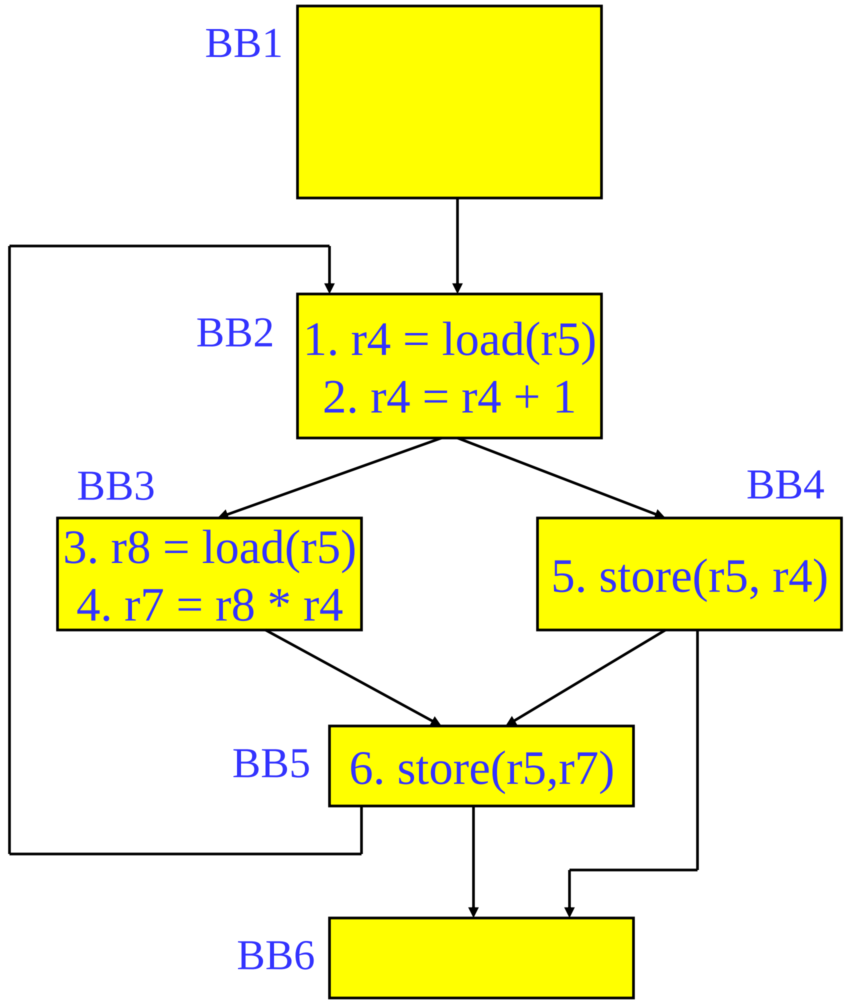
LICM (2)

- Rules
  - » X can be moved
  - » src(X) not modified in loop body
  - » X is the only op to modify dest(X)
  - » for all uses of dest(X), X is in the available defs set
  - » for all exit BB, if dest(X) is live on the exit edge, X is in the available defs set on the edge
  - » if X not executed on every iteration, then X must provably not cause exceptions
  - » if X is a load or store, then there are no writes to address(X) in loop



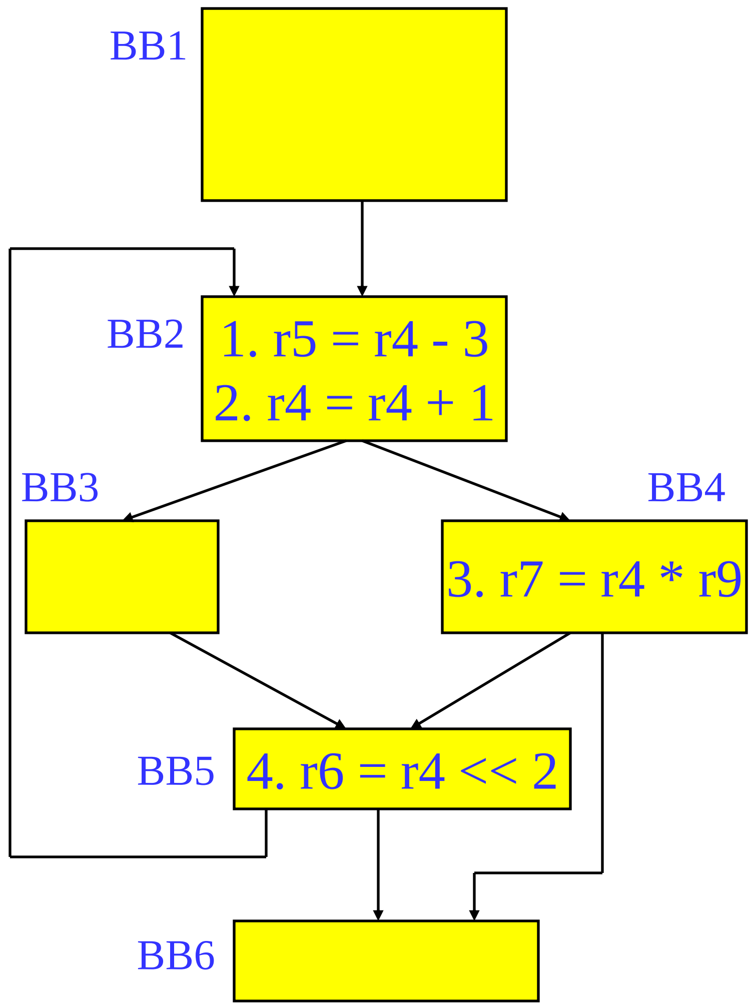
Global Variable Migration

- Assign a global variable temporarily to a register for the duration of the loop
  - Load in preheader
  - Store at exit points
- Rules
  - X is a load or store
  - address(X) not modified in the loop
  - if X not executed on every iteration, then X must provably not cause an exception
  - All memory ops in loop whose address can equal address(X) must always have the same address as X



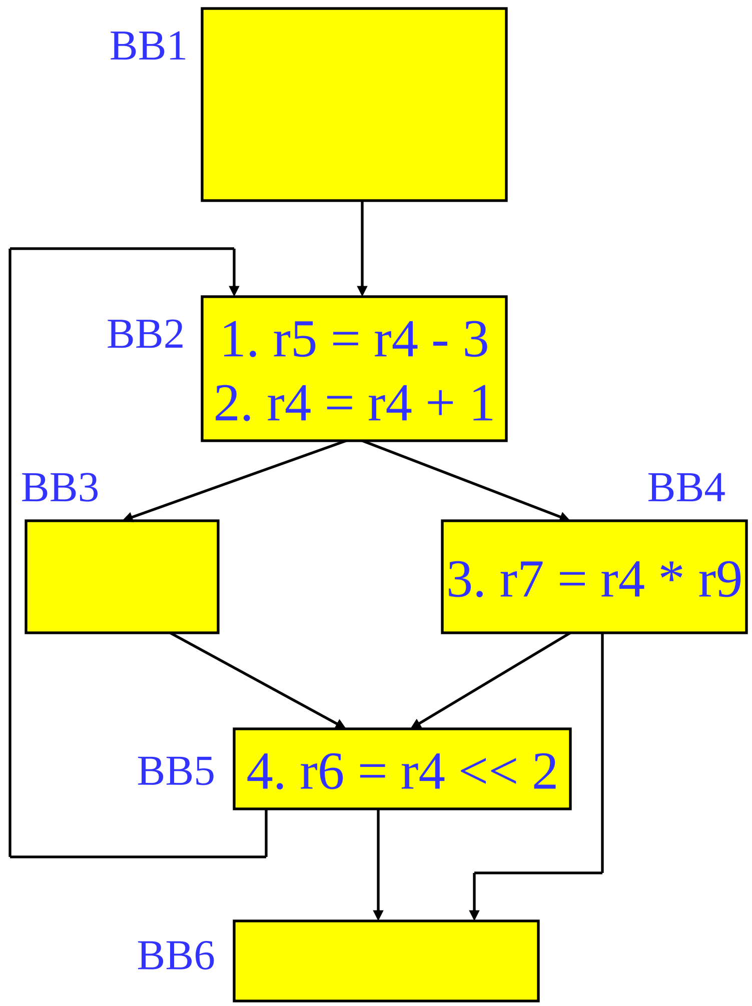
Induction Variable Strength Reduction

- Create basic induction variables from derived induction variables
- Induction variable
  - » BIV (i++)
    - 0,1,2,3,4,...
  - » DIV (j = i * 4)
    - 0, 4, 8, 12, 16, ...
  - » DIV can be converted into a BIV that is incremented by 4
- Issues
  - » Initial and increment vals
  - » Where to place increments



Induction Variable Strength Reduction (2)

- Rules
  - X is a *, <<, + or – operation
  - src1(X) is a basic ind var
  - src2(X) is invariant
  - No other ops modify dest(X)
  - dest(X) != src(X) for all srcs
  - dest(X) is a register
- Transformation
  - Insert the following into the preheader
    - new_reg = RHS(X)
  - If opcode(X) is not add/sub, insert to the bottom of the preheader
    - new_inc = inc(src1(X)) opcode(X) src2(X)
  - else
    - new_inc = inc(src1(X))
  - Insert the following at each update of src1(X)
    - new_reg += new_inc
  - Change X → dest(X) = new_reg



Class Problem

Optimize this applying induction var str reduction

BB1
1. r1 = 0
2. r2 = 0

BB2
3. r5 = r5 + 1
4. r11 = r5 * 2
5. r10 = r11 + 2
6. r12 = load (r10+0)
7. r9 = r1 << 1
8. r4 = r9 - 10
9. r3 = load(r4+4)
10. r3 = r3 + 1
11. store(r4+0, r3)
12. r7 = r3 << 2
13. r6 = load(r7+0)
14. r13 = r2 - 1
15. r1 = r1 + 1
16. r2 = r2 + 1

BB3
r13, r12, r6, r10 liveout