

EECS 583 – Class 8

Classic Optimization

University of Michigan

September 25, 2023

Announcements & Reading Material

- ❖ HW2 – Get busy on it ASAP!
- ❖ Talk about course projects next class – Start thinking about forming/joining a group (3-5 students)
- ❖ 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 next Monday
 - » “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!)

Code Optimization

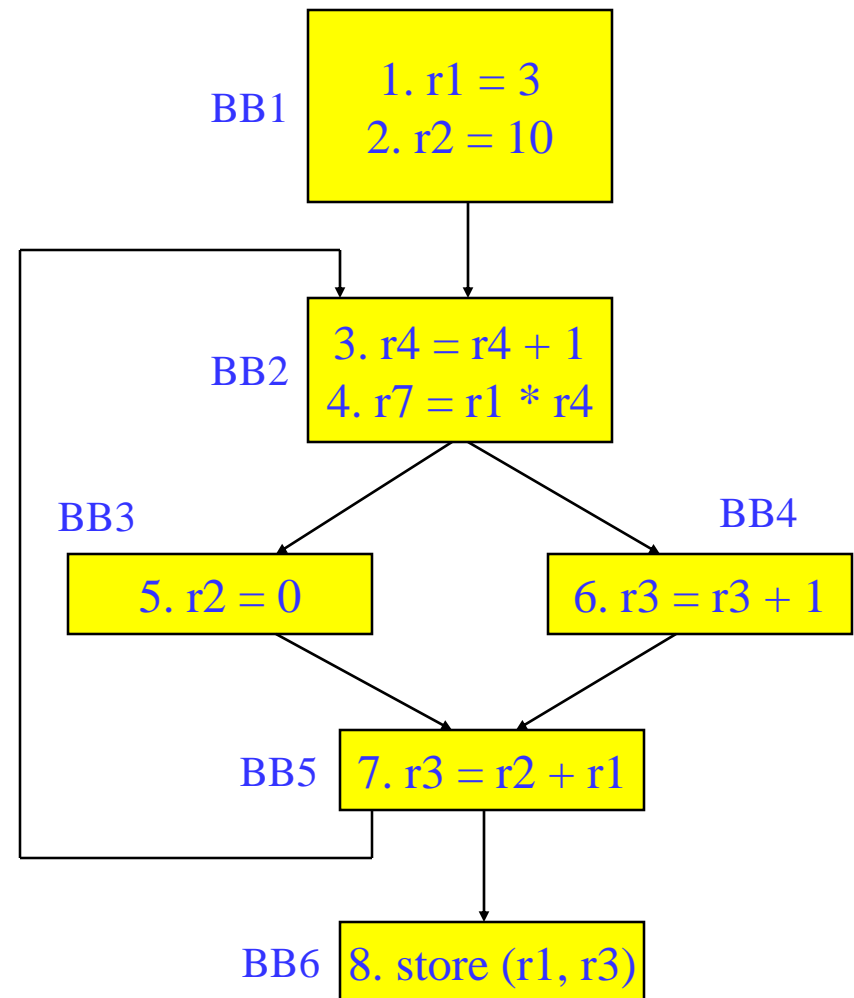
- ❖ Make the code run faster on the target processor
 - » My (Scott's) favorite topic !!
 - » Other objectives: Power, code size
- ❖ Classes of optimization
 - » 1. Classical (machine independent, done at IR level)
 - Reducing operation count (redundancy elimination)
 - Simplifying operations
 - Generally good for any kind of machine
 - » 2. Machine specific (done in llc)
 - Peephole optimizations
 - Take advantage of specialized hardware features
 - » 3. Parallelism enhancing (IR level often, but sometimes llc)
 - 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 whose 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. $\text{src1}(X)$ is a literal
 - » 3. Y consumes $\text{dest}(X)$
 - » 4. There is no definition of $\text{dest}(X)$ between X and Y (local available defs)

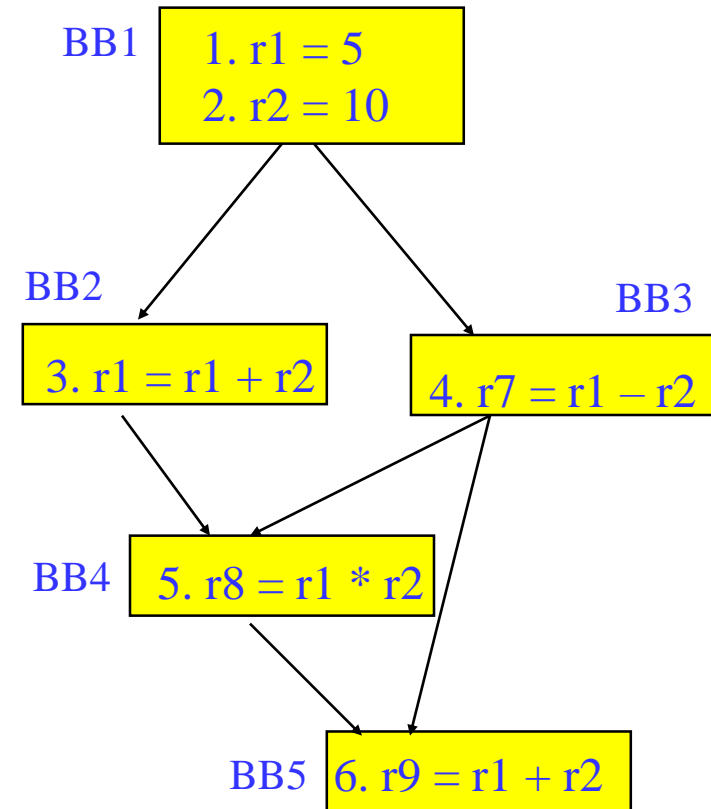
BB1

```
1. r1 = 5
2. r2 = 3
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. $\text{src1}(X)$ is a literal
 - » 3. Y consumes $\text{dest}(X)$
 - » 4. X is in $\text{a_in}(\text{BB}(Y))$ (global available defs)
 - » 5. $\text{Dest}(x)$ is not modified between the top of $\text{BB}(Y)$ and Y (local available defs)



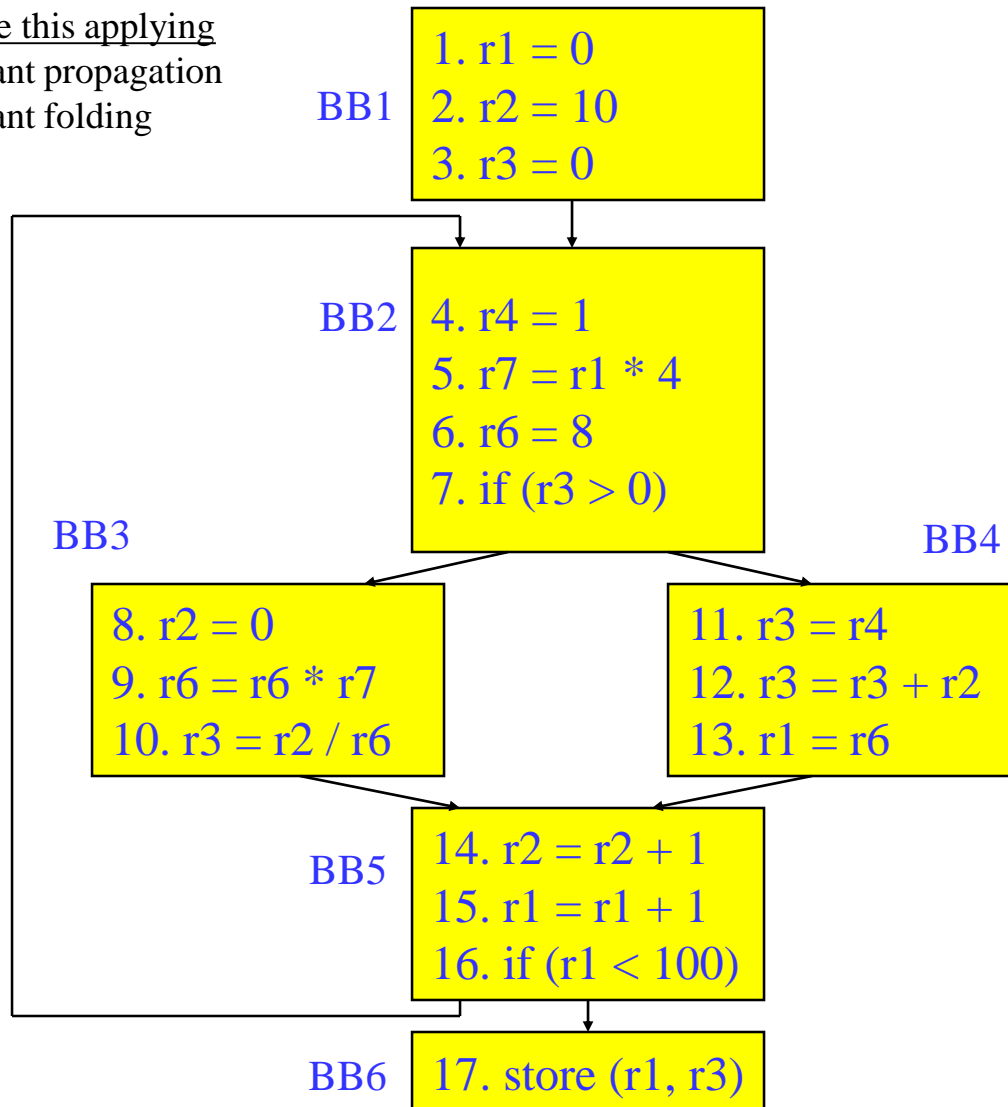
Constant Folding

- ❖ 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
 - $r1 = 3 * 4 \rightarrow r1 = 12$
 - $r1 = 3 / 0 \rightarrow ???$ Don't evaluate excepting ops!, what about floating-point?
 - » Evaluate conditional branch, replace with BRU or noop
 - if (1 < 2) goto BB2 \rightarrow BRU BB2
 - if (1 > 2) goto BB2 \rightarrow convert to a noop
- ❖ Algebraic identities
 - » $r1 = r2 + 0, r2 - 0, r2 | 0, r2 \wedge 0, r2 \ll 0, r2 \gg 0$
 - $r1 = r2$
 - » $r1 = 0 * r2, 0 / r2, 0 \& r2$
 - $r1 = 0$
 - » $r1 = r2 * 1, r2 / 1$
 - $r1 = r2$

Class Problem

Optimize this applying

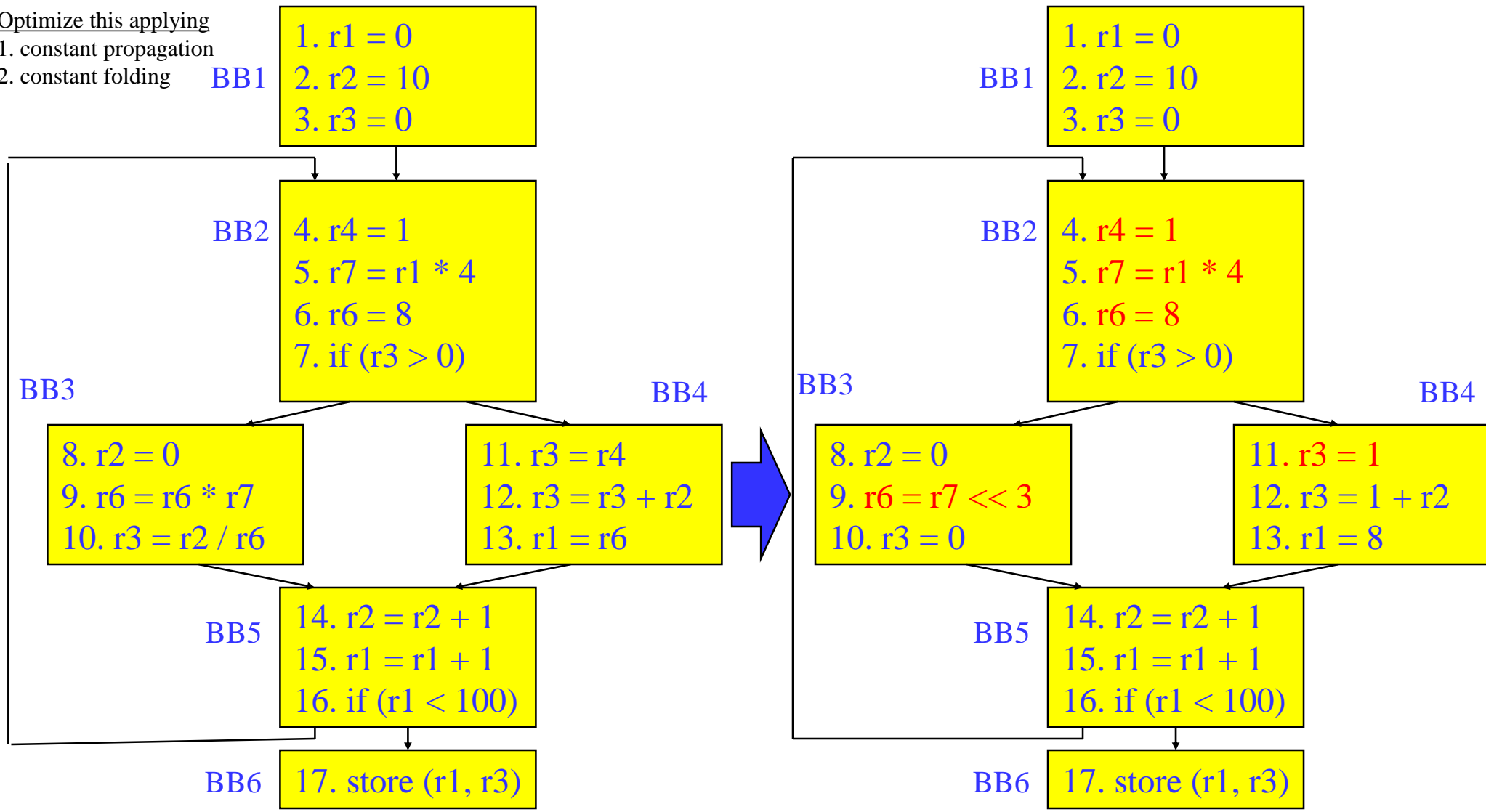
1. constant propagation
2. constant folding



Class Problem - Solution

Optimize this applying

- 1. constant propagation
- 2. constant folding



Red instructions can be deleted by subsequent dead code elimination

Forward Copy Propagation

- ❖ Forward propagation of the RHS of moves

- » $r1 = r2$

- » ...

- » $r4 = r1 + 1 \rightarrow r4 = r2 + 1$

- ❖ Benefits

- » Reduce chain of dependences

- » Eliminate the move

- ❖ Rules (ops X and Y)

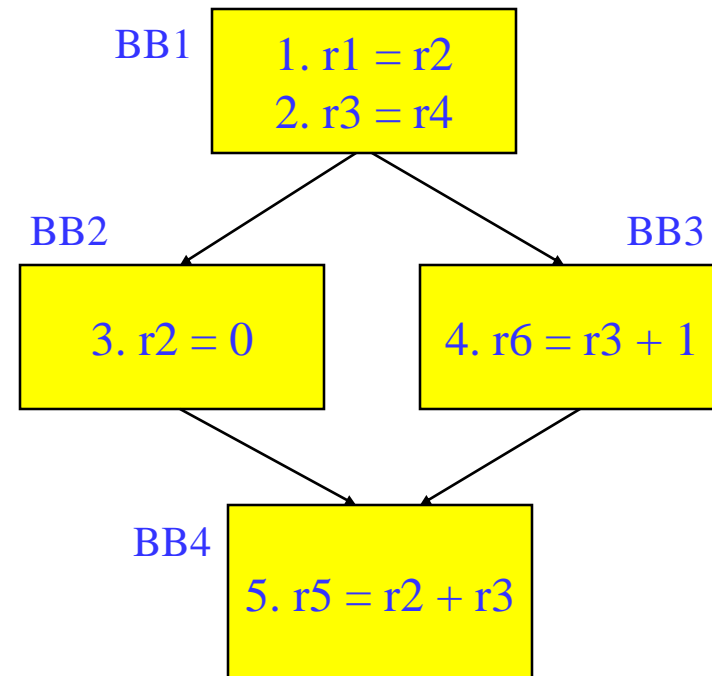
- » X is a move

- » $\text{src1}(X)$ is a register

- » Y consumes $\text{dest}(X)$

- » $X.\text{dest}$ is an available def at Y

- » $X.\text{src1}$ is an available expr at Y



CSE – Common Subexpression Elimination

- ❖ Eliminate recomputation of an expression by reusing the previous result

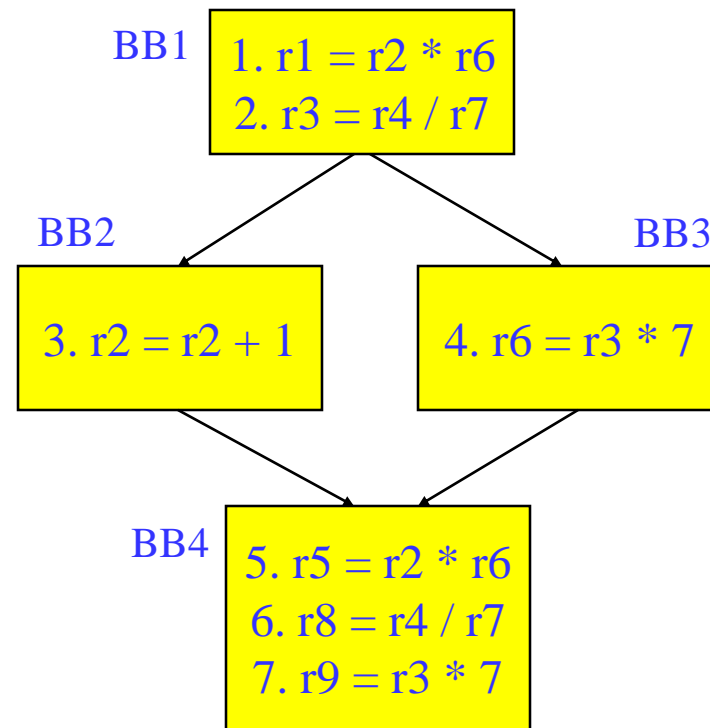
- » $r1 = r2 * r3$
- » $\rightarrow r100 = r1$
- » ...
- » $r4 = r2 * r3 \rightarrow r4 = r100$

- ❖ Benefits

- » Reduce work
- » Moves can get copy propagated

- ❖ Rules (ops X and Y)

- » X and Y have the same opcode
- » $\text{src}(X) = \text{src}(Y)$, for all srcs
- » $\text{expr}(X)$ is available at Y
- » if X is a load, then there is no store that may write to $\text{address}(X)$ along any path between X and Y

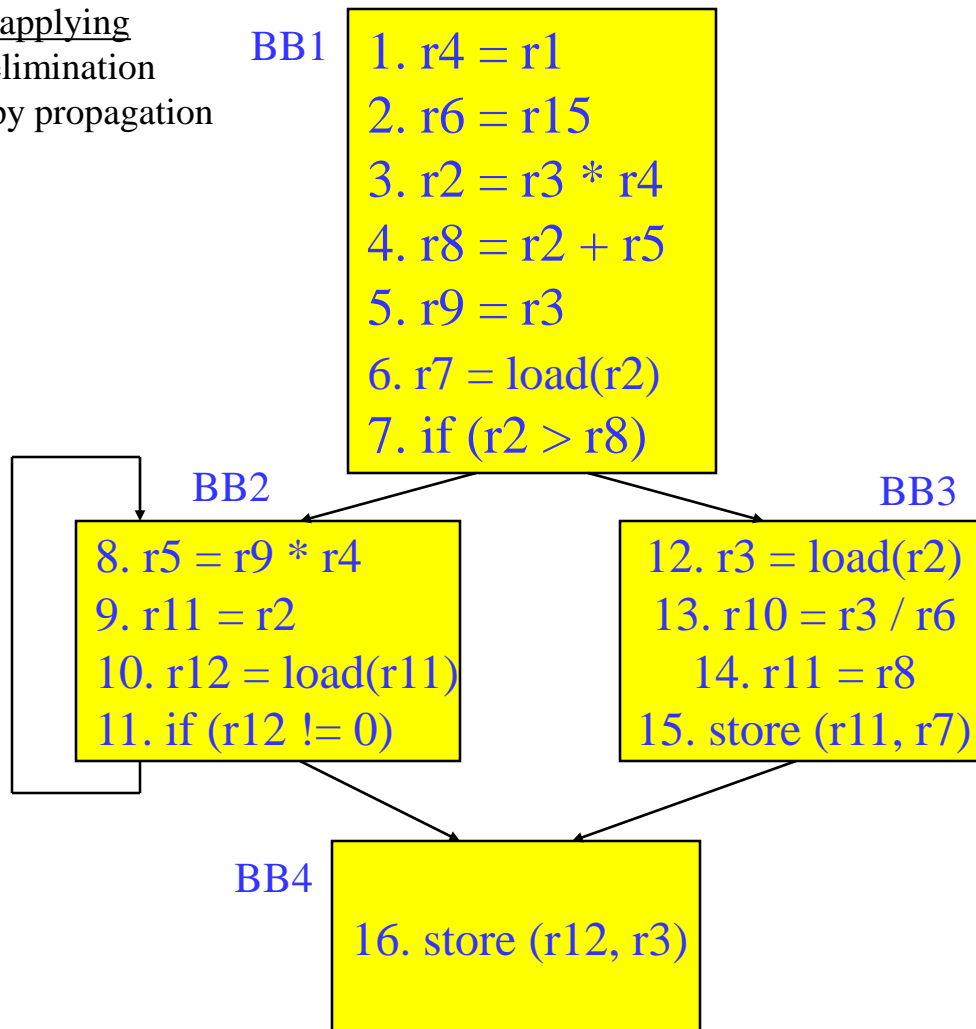


if op is a load, call it redundant load elimination rather than CSE, Redundant store elimination also possible, but applied a bit differently – think about it!

Class Problem

Optimize this applying

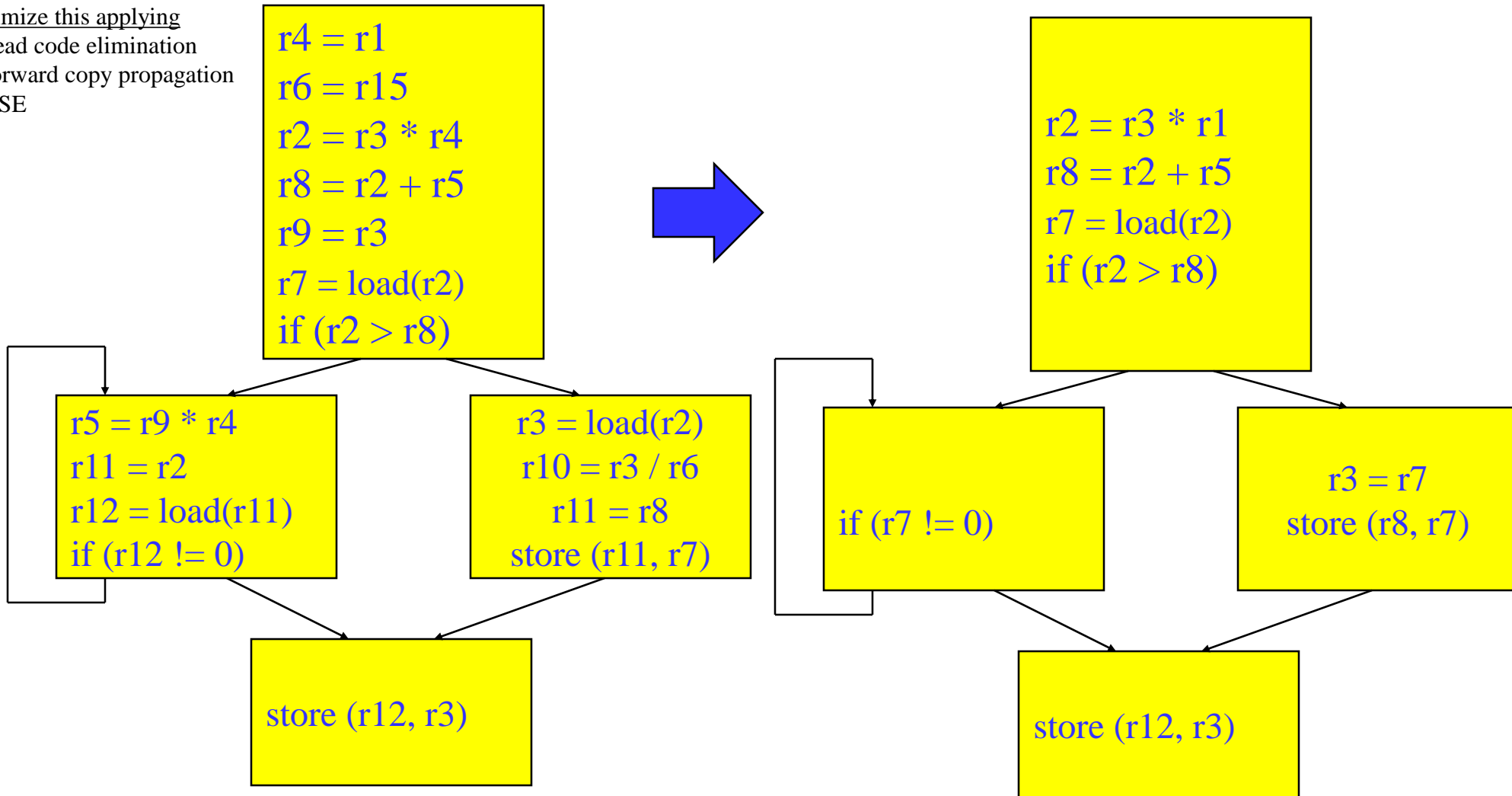
1. dead code elimination
2. forward copy propagation
3. CSE



Class Problem Solution

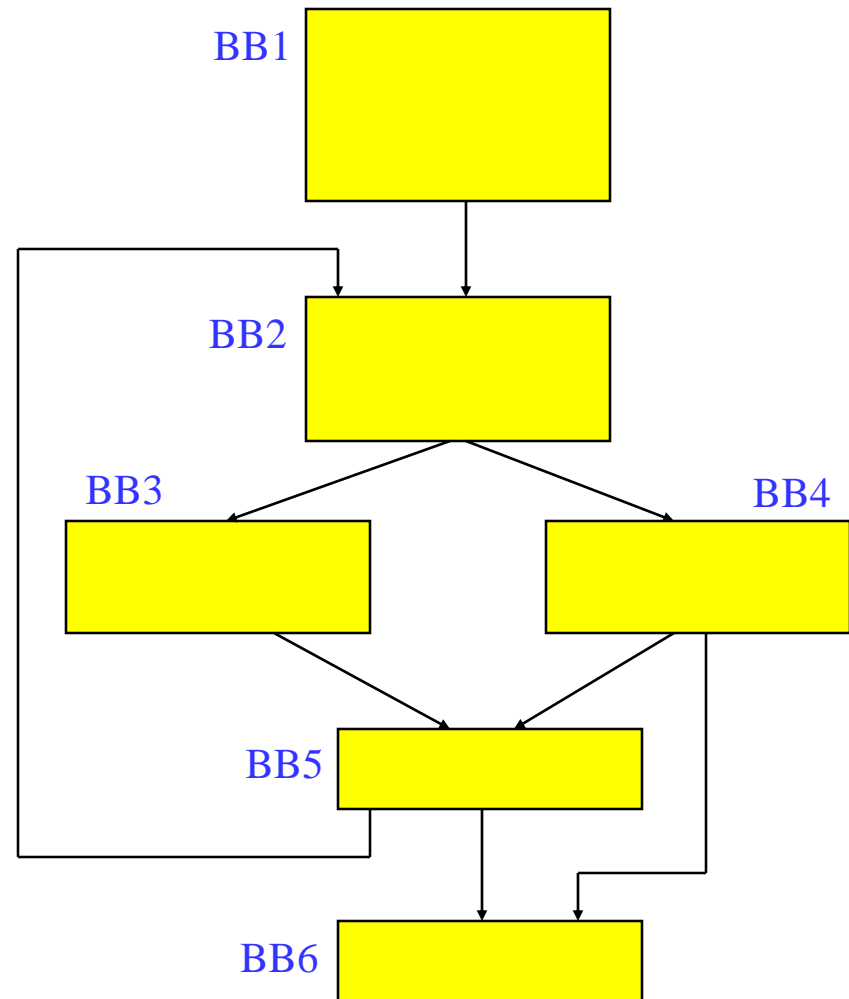
Optimize this applying

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

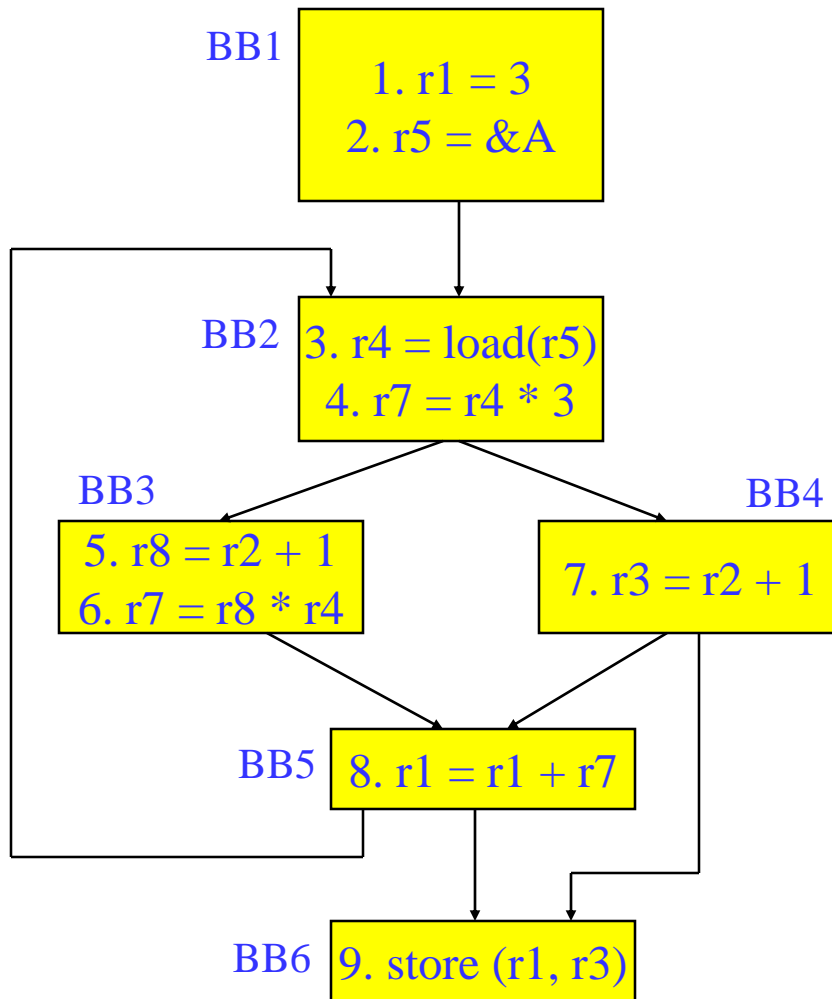


Loop Invariant Code Motion (LICM)

- ❖ Move operations whose source operands do not change within the loop to the loop preheader
 - » Execute them only 1x per invocation of the loop
- ❖ Rules
 - » X can be moved
 - » $\text{src}(X)$ not modified in loop body
 - » X is the only op to modify $\text{dest}(X)$
 - » for all uses of $\text{dest}(X)$, X is in the available defs set
 - » for all exit BB, if $\text{dest}(X)$ 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 $\text{address}(X)$ in loop

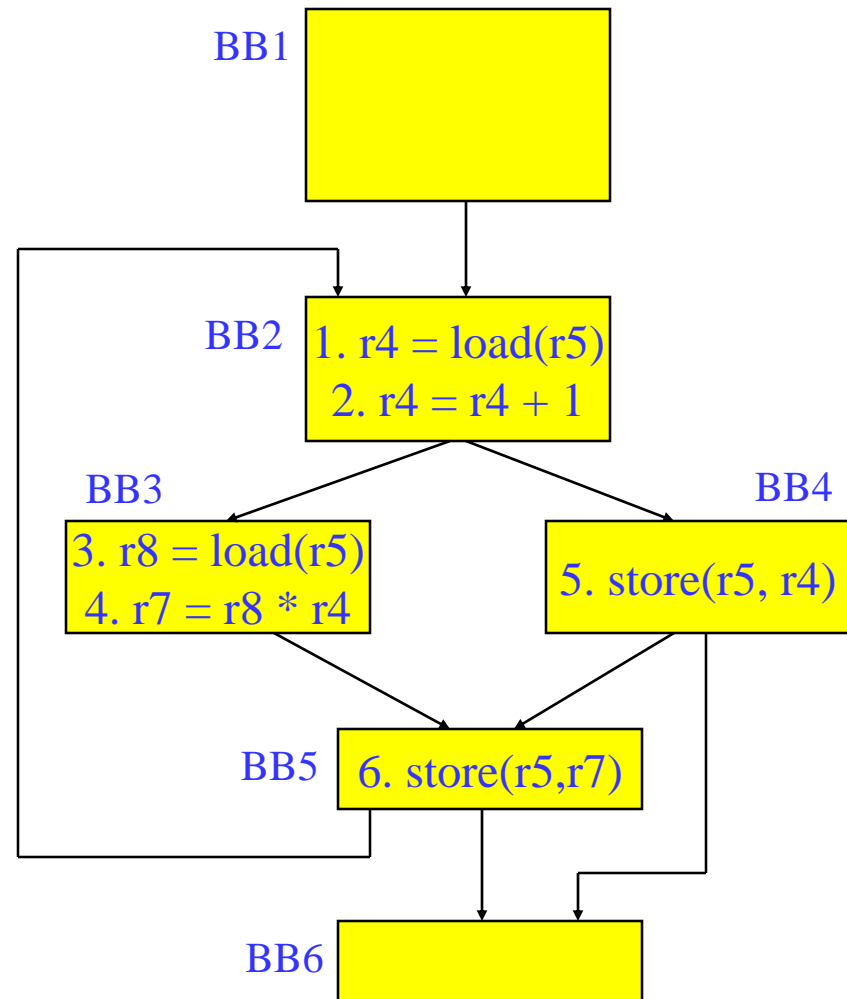


LICM Example

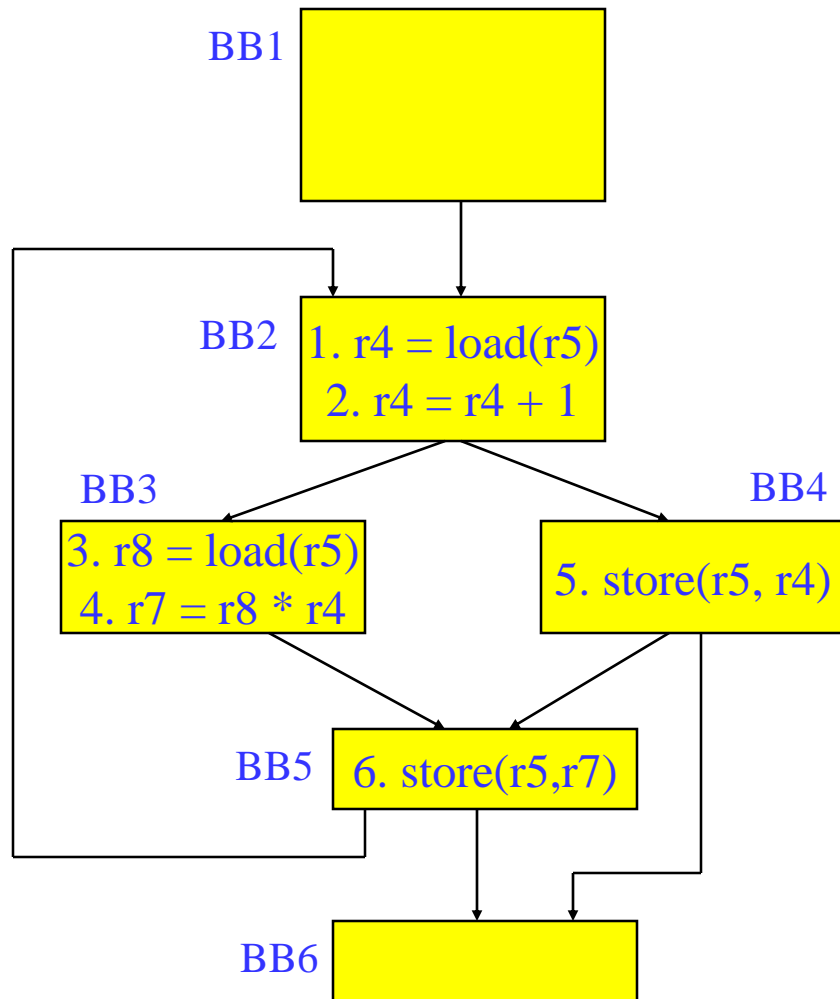


Global Variable Migration

- ❖ 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

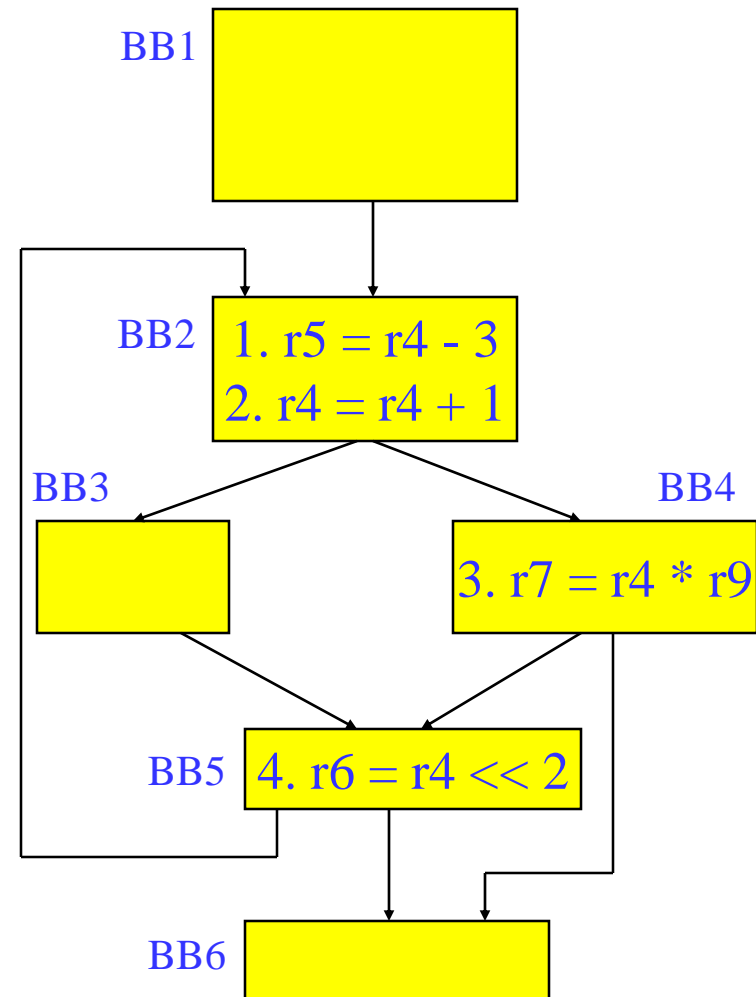


Global Variable Migration Example



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



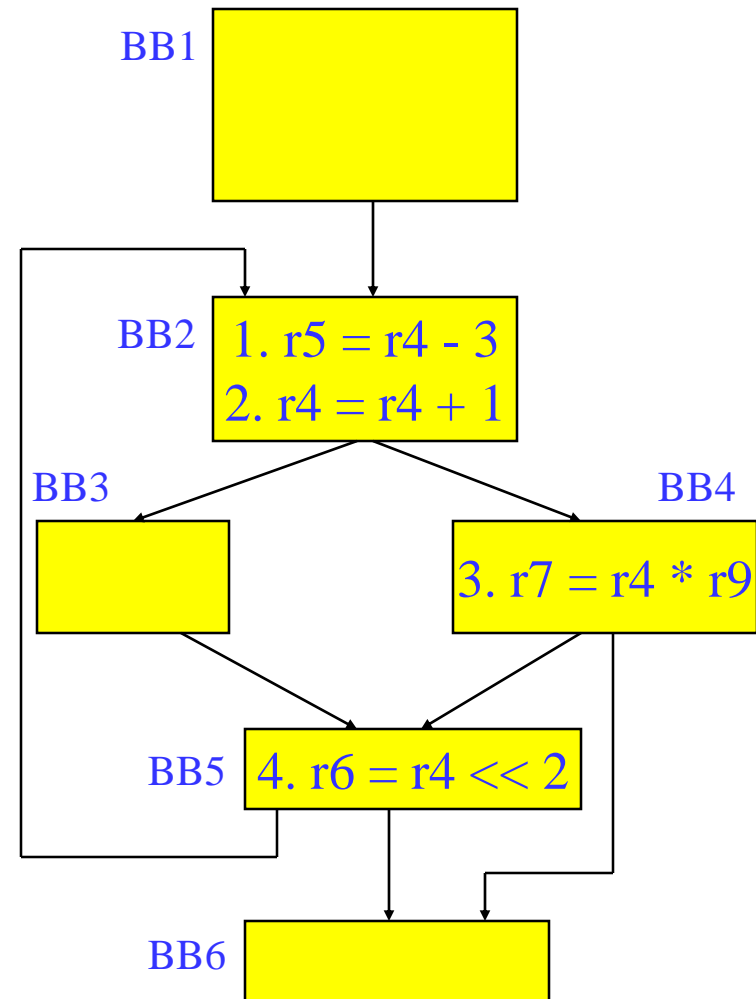
Induction Variable Strength Reduction (2)

❖ Rules

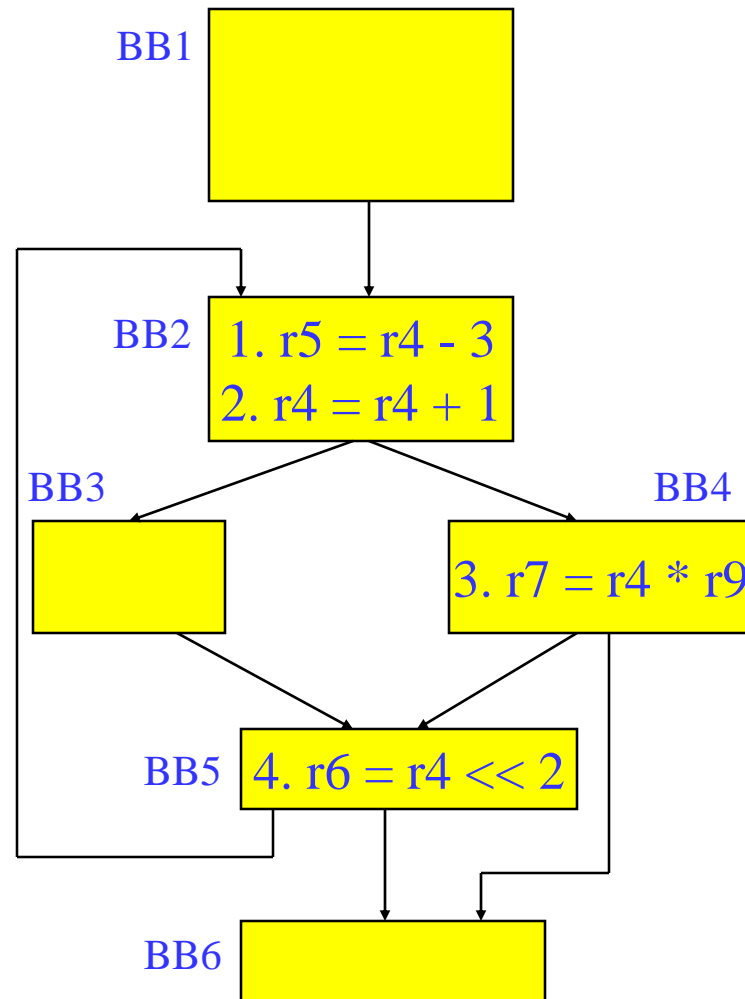
- » X is a $*$, \ll , $+$ or $-$ operation
- » $\text{src1}(X)$ is a basic ind var
- » $\text{src2}(X)$ is invariant
- » No other ops modify $\text{dest}(X)$
- » $\text{dest}(X) \neq \text{src}(X)$ for all srcs
- » $\text{dest}(X)$ is a register

❖ Transformation

- » Insert the following into the preheader
 - $\text{new_reg} = \text{RHS}(X)$
- » If $\text{opcode}(X)$ is not add/sub, insert to the bottom of the preheader
 - $\text{new_inc} = \text{inc}(\text{src1}(X)) \text{ opcode}(X) \text{ src2}(X)$
- » else
 - $\text{new_inc} = \text{inc}(\text{src1}(X))$
- » Insert the following at each update of $\text{src1}(X)$
 - $\text{new_reg} += \text{new_inc}$
- » Change $X \rightarrow \text{dest}(X) = \text{new_reg}$

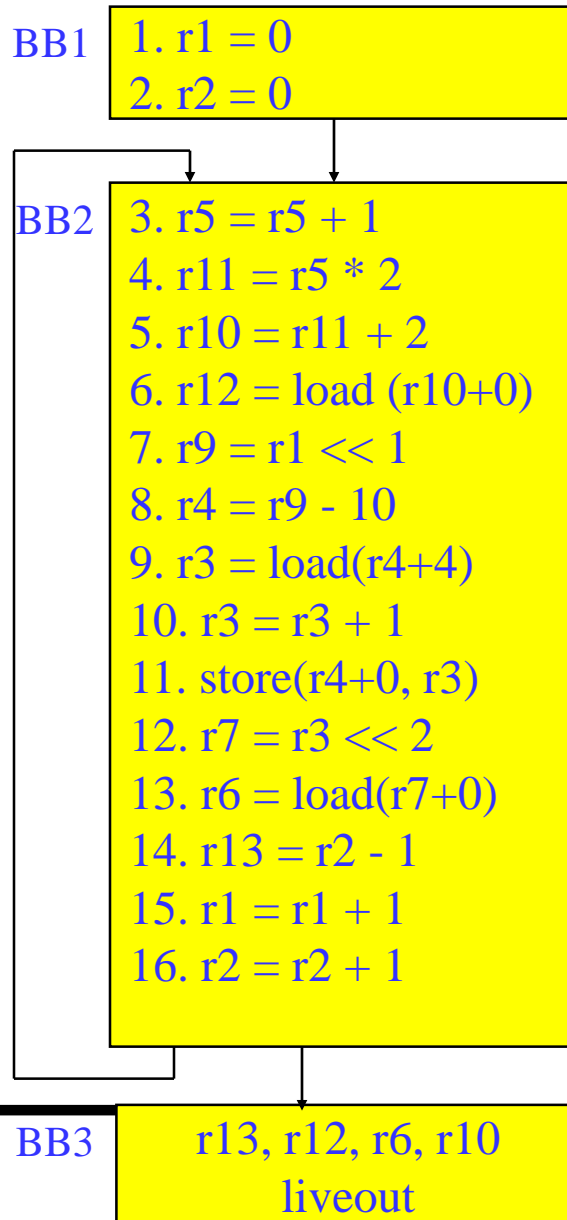


Induction Variable Strength Reduction - Example



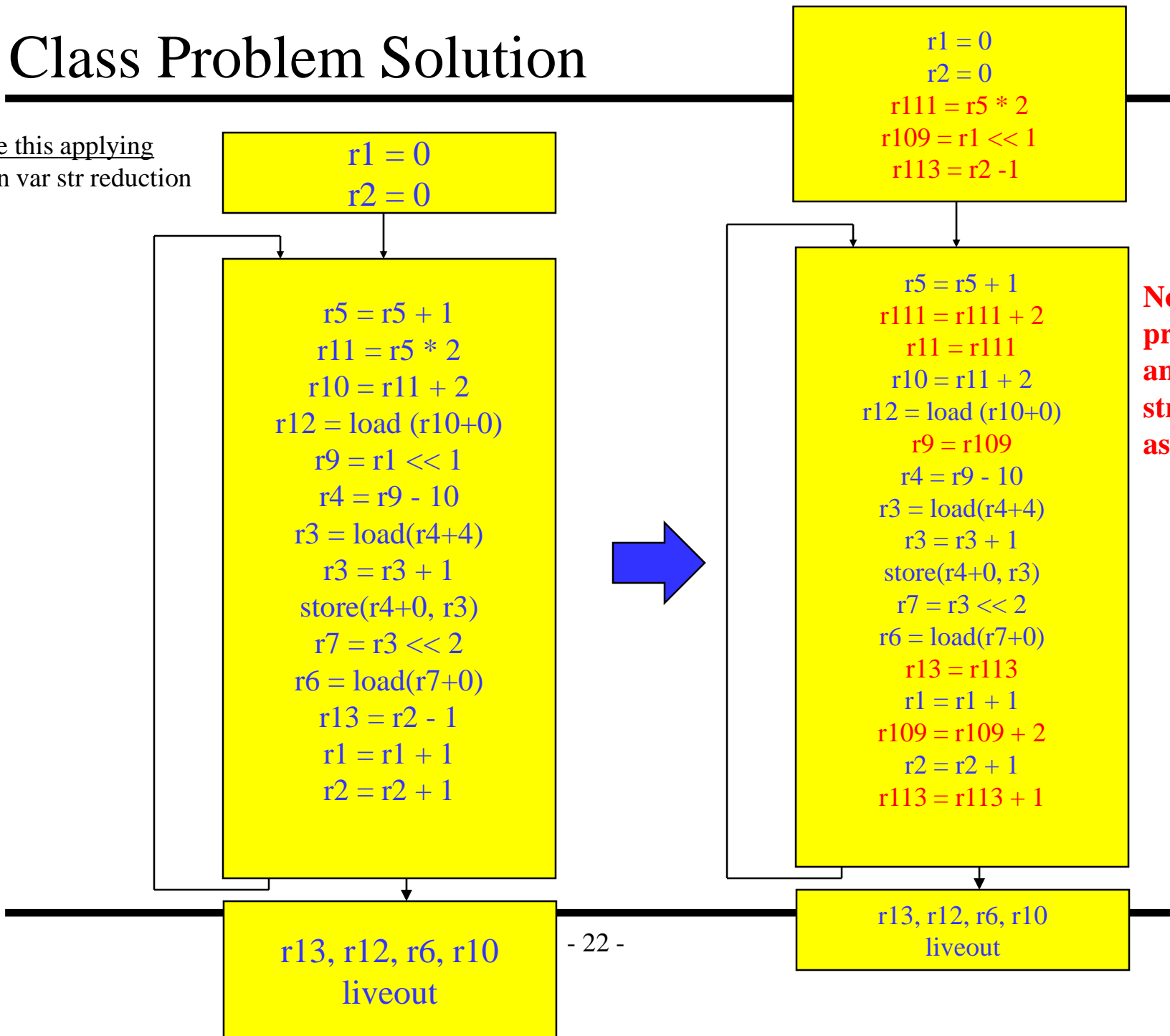
Class Problem

Optimize this applying
induction var str
reduction



Class Problem Solution

Optimize this applying
induction var str reduction



Note, after copy propagation, r10 and r4 can be strength reduced as well.