HW2 – Frequent Path Loop Invariant Code Motion

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Loop Invariant Code Motion (LICM)

```
for (int i = 0; i < n; i++) {
    x = y + z;
    a[i] = 6 * i + x * x;
}
```

Their values don't change within the loop

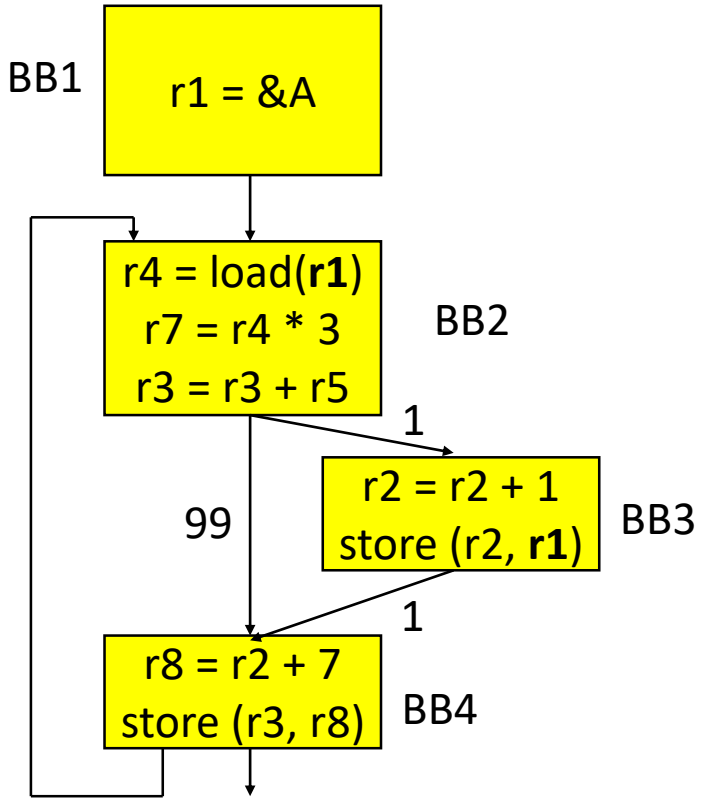
Loop Invariant Code Motion (LICM)

```
for (int i = 0; i < n; i++) {
    x = y + z;
    a[i] = 6 * i + x * x;
}
```

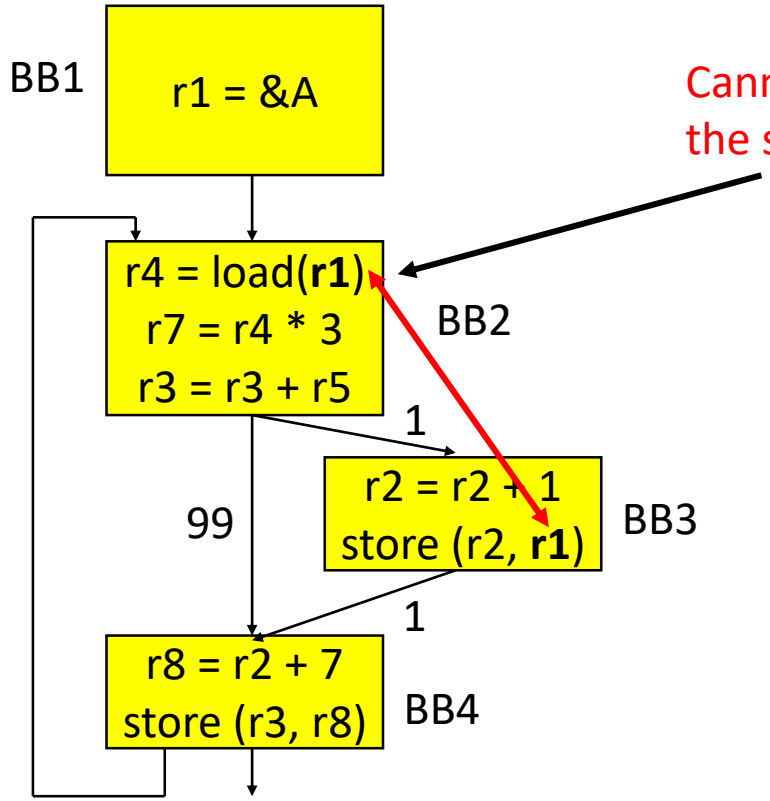
```
x = y + z;
t1 = x * x;
for (int i = 0; i < n; i++) {
        a[i] = 6 * i + t1;
}
```

- 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 code exists in LLVM!
  - /lib/Transforms/Scalar/LICM.cpp

Your Assignment: Frequent Path LICM

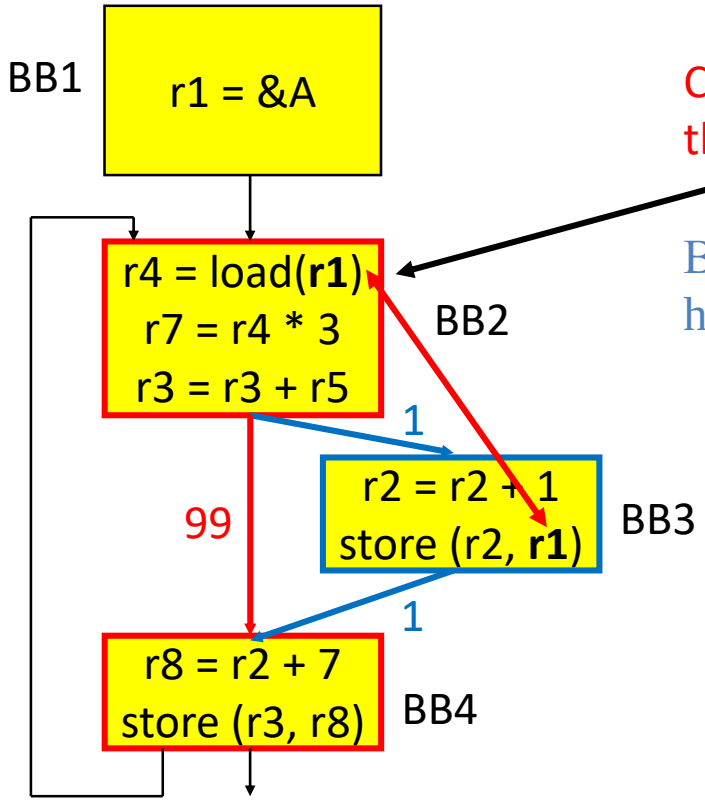


Your Assignment: Frequent Path LICM



Cannot perform LICM on load, because of the store-load dependency

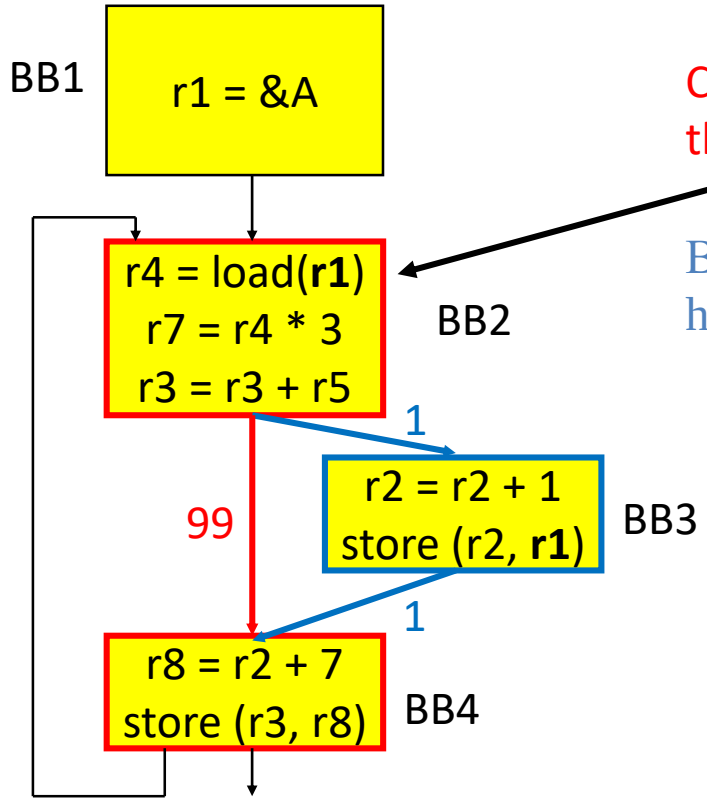
Your Assignment: Frequent Path LICM



Cannot perform LICM on load, because of the store-load dependency

But… profile data says that the store rarely happens

Your Assignment: Frequent Path LICM



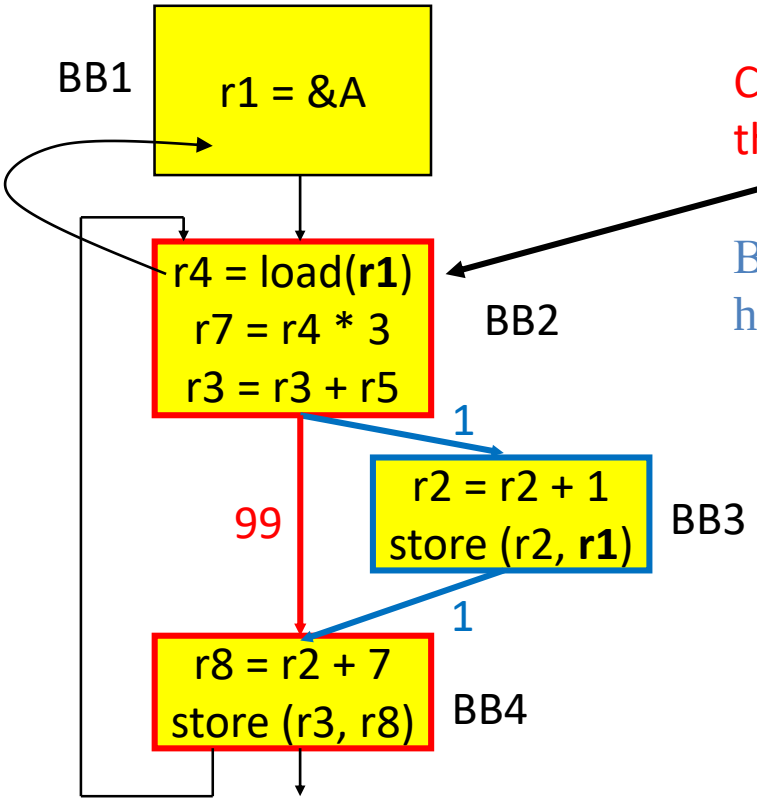
Cannot perform LICM on load, because of the store-load dependency

But… profile data says that the store rarely happens

Frequent Path LICM:

1) Ignore infrequent dependence between loads and stores

Your Assignment: Frequent Path LICM



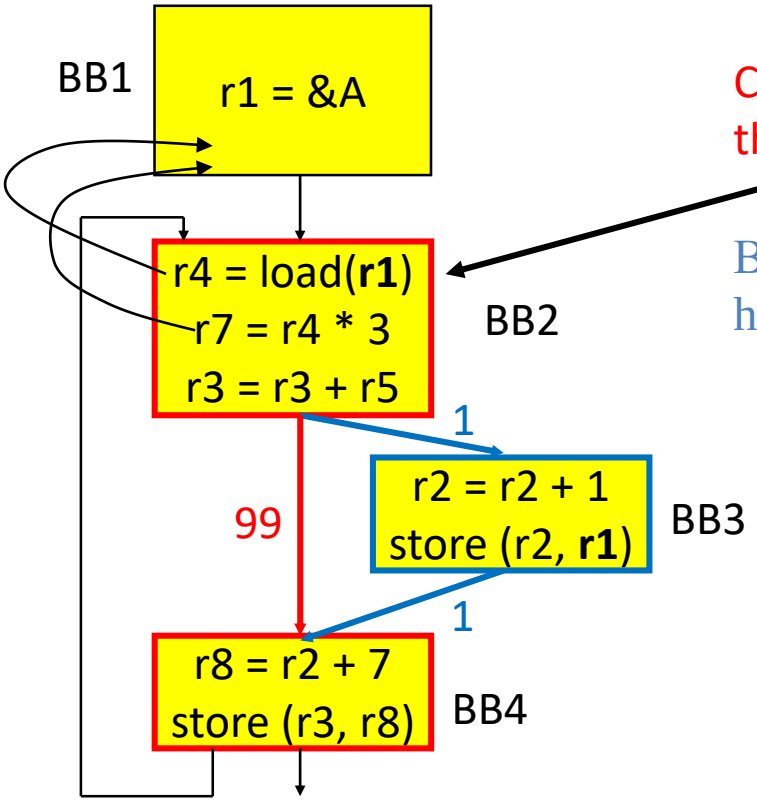
Cannot perform LICM on load, because of the store-load dependency

But… profile data says that the store rarely happens

Frequent Path LICM:

1) Ignore infrequent dependence between loads and stores
2) Perform LICM on load

Your Assignment: Frequent Path LICM



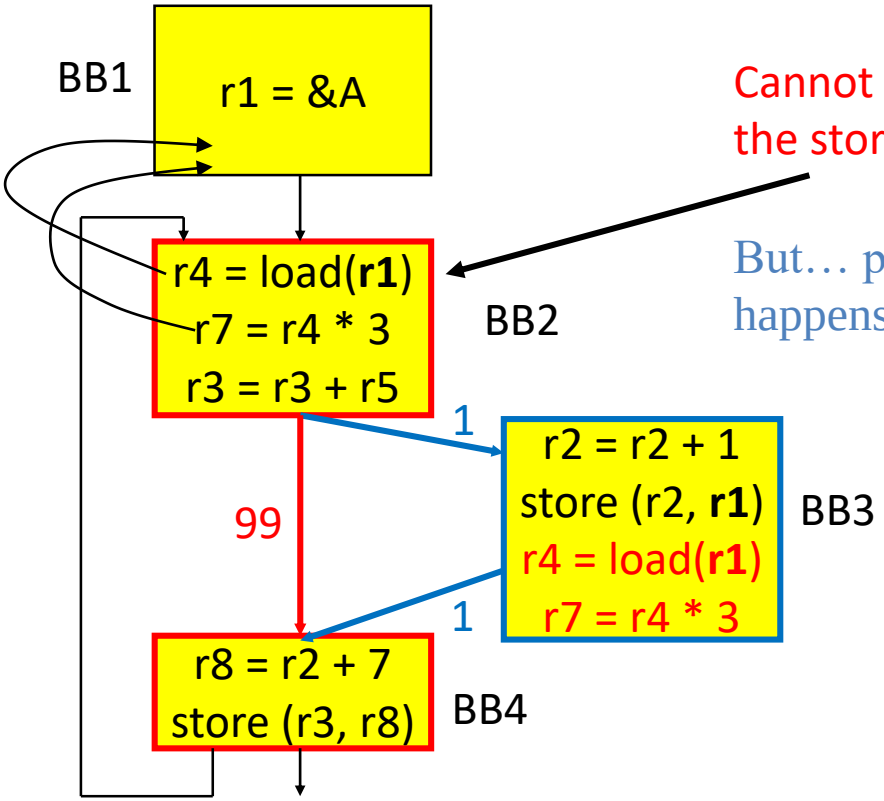
Cannot perform LICM on load, because of the store-load dependency

But… profile data says that the store rarely happens

Frequent Path LICM:

1) Ignore infrequent dependence between loads and stores
2) Perform LICM on load
3) Perform LICM on any consumers of the load that become invariant

Your Assignment: Frequent Path LICM



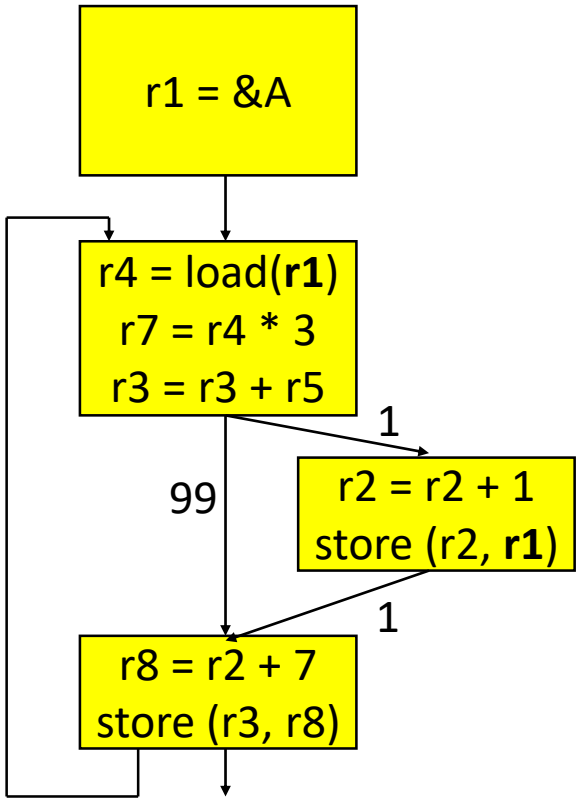
Cannot perform LICM on load, because of the store-load dependency

But… profile data says that the store rarely happens

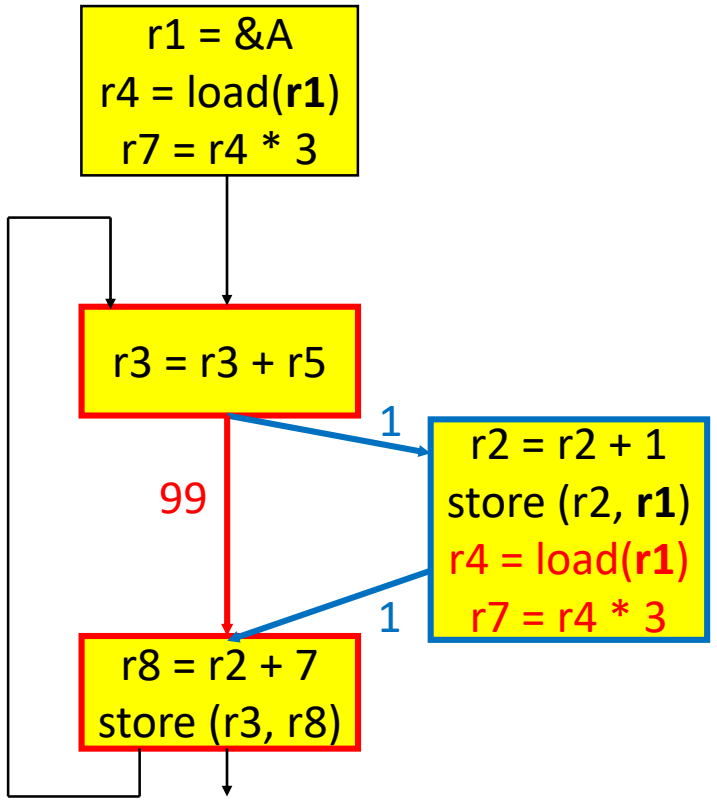
Frequent Path LICM:

1) Ignore infrequent dependence between loads and stores
2) Perform LICM on load
3) Perform LICM on any consumers of the load that become invariant
4) Insert fix-up code to restore correct execution

Your Assignment: Frequent Path LICM



Before FPLICM



After FPLICM

HW2: Frequent Path (FP) LICM

Correctness:

- Identify the Frequent Path (edge probability >= 80%)
- Find store instructions among all infrequent BBs and their dependent load instructions in frequent BBs

  destination operand of infrequent store = source operand of frequent load
- Hoist the FP invariants: Load instruction
- Replicate all hoisted instructions in the infrequent path

Performance:

- Create a heuristic that determines to perform FP LICM or not.
  - Smart heuristic should apply optimization when it's profitable.
- Hoist the profitable FP invariants.
  - Load instruction
  - Consumers of the load that become invariant* (For bonus points)

FPLICM: What constitutes to FP

Correctness:

- this can be accomplished by starting at the loop header and repeatedly following the >=80% branch until a >=80% loop backedge is taken.
- *Note: This means that the cumulative probability of a BB might be lower than 80%
- **Anything not on the frequent path is on the infrequent path.**

Performance:

- tune the parameter to achieve the highest performance gains

HW2: Useful Resources

- run.sh
  - List of commands used in HW2
  - Check correctness of your pass!
- Project Template
  - HW2PASS.cpp
  - *runOnLoop(…)* *inSubLoop(…)*
- Visualization Script – will be on piazza later
- Benchmarks
  - 6 correctness tests + README (Required)
    - Only need to hoist the dependent load instructions
    - Must generate the correct output after applying your FPLICM pass
    - Only submit the file created after your pass could run. hw2correct1.fplicm.bc => hw2correct1_base.bc. You do NOT have to test your pass on the performance benchmarks
  - 4 performance tests + README (Optional)
    - Hoist as many instructions as possible
    - Correctness first, then the performance
    - Same thing. except rename to hw2perf1_bonus.bc

LLVM Code of Interest

- The following slides present code from the LLVM codebase that may help you with HW2.
- Disclaimers:
  - Use of following API is your choice. There are many ways to do this assignment.
  - You are free to use any other code that exists in LLVM 12.0.1 or that you develop.
  - **Read the documentation/source before asking for help!**

    http://llvm.org/docs/ProgrammersManual.html#helpful-hints-for-common-operations

Code: Manipulating Basic Blocks

- SplitBlock(…) splits a BB at a specified instr, returns ptr to new BB that starts with the instr, connects the BBs with an unconditional branch
- SplitEdge(…) will insert a BB between two specified BBs
- Code found in:
  - `<llvm-src-root>/include/llvm/Transforms/Utils/BasicBlockUtils.h`
  - `<llvm-src-root>/lib/Transforms/Utils/BasicBlockUtils.cpp`

```
// I is an Instruction*
BasicBlock *BB1 = I->getParent();
BasicBlock *BB3 =
    SplitBlock(BB1, I);
BasicBlock *BB2 =
    SplitEdge(BB1, BB3);
```

Code: Creating and Inserting Instructions

- Various ways to create & insert instructions
- Hint: Instructions have a **clone()** member function
- See specific instruction constructors/member functions in:
  - `<llvm-src-root>/include/llvm/IR/Instructions.h`
- See general instruction functions available to all instructions in:
  - `<llvm-src-root>/include/llvm/IR/Instruction.h`

```
// 1) create load, insert at end of
//    specified basic block
LoadInst *LD =
    new LoadInst(Val,
                 "loadflag",
                 BB1);

// 2) create branch using Create
//    method, insert before BB1's
//    terminating instruction
Branch::Create(BB1, BB2, flag,
               BB1->getTerminator());

// 3) create a store inst that stores
//    result of LD to some variable
//    (related to next slide)
StoreInst *ST =
    new StoreInst(LD, var);
//    inserting store into code
ST->insertAfter(LD);
```

Code: Creating Variables

- Use AllocaInst to allocate memory space on the stack.

```
// 1) Create a variable in the
//    function Entry block
AllocaInst *Val = new AllocaInst(
        I->getType(),
        0,
        nullptr,
        Entry->getTerminator()
        );

// 2) store to the variable
StoreInst *ST = new StoreInst(
        Result,
        Val,
        Entry->getTerminator()
        );
```

Important: Maintaining SSA Form

- Static Single Assignment form requires unique destination registers for each instruction
  - Replicated instructions in your infrequent BB will write to different regs compared to the instructions in the preheader!
  - Store results of hoisted instrs to stack variables (see prev. slide)
  - Make sure AllocaInst's are in function's entry BB!

General Notes Regarding HW2

- **Start early!**
- Will be released on 9/20 (Mon)
- Make sure your optimization doesn't break a program!
- Start with script/template.
- Try the bonus part
- Check the piazza
- Running/Debugging
- Performance Competition: Generate correct **AND** fast bitcode