CS738: Advanced Compiler Optimizations

Welcome & Introduction

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About the Course

- Program Analysis

[1] "Democracy is the government of the people, by the people, for the people" - Abraham Lincoln

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- Analysis of a Program, by a Program, for a Program[1]

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  - Of a Program – User Program

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  - Of a Program – User Program
  - By a Program – Analyzer (Compiler, Runtime)

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  - Of a Program – User Program
  - By a Program – Analyzer (Compiler, Runtime)
  - For a Program – Optimizer, Verifier
- Transforming user program based on the results of the analysis

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Expectations from You

- Basic Compiler Knowledge

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- Write Code

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- Willingness to understand and modify large code bases

Expectations from You

- Basic Compiler Knowledge
- Write Code
- Willingness to understand and modify large code bases
- Read and present state-of-the-art research papers

Your Expectations

? Share through the Google Form

Quick Quizzes (QQs)

- There will be small quizzes (10-15 min duration) during the class.

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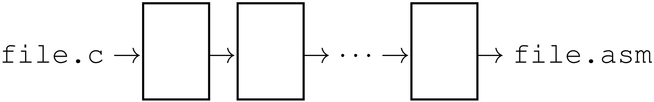
- Always keep a pen and some loose papers handy.

QQ #1 (Ungraded)

- What are the various phases of a typical compiler? (5 minutes)



Assignments

- Short assignments to apply the lecture material.

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- 4–5 Assignments for the semester

Using Program Analysis

- Compiler Code Optimizations

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- Why are optimizations important?

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- Why not write optimized code to begin with?

Using Program Analysis

- Compiler Code Optimizations
- Why are optimizations important?
- Why not write optimized code to begin with?
- Where do optimizations fit in the compiler flow?

Code Optimization

- Machine Independent

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  - Remove redundancy introduced by the Programmer

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  - Remove redundancy not required by later phases of compiler
  - Take advantage of algebraic properties of operators
- Machine dependent
  - Take advantage of the properties of target machine
- Optimization must preserve the semantics of the original program!

Machine Independent Optimizations

Motivational Example

```
void quicksort(int m, int n)
/* recursively sort a[m] through a[n] */
{
    int i, j;
    int v, x;
    if(n <= m) return;
    i = m-1; j = n; v = a[n];
    while (1) {
        do i = i+1; while (a[i] < v);
        do j = j-1; while (a[j] > v);
        if (i > j) break;
        x = a[i]; a[i] = a[j]; a[j] = x;
    }
    x = a[i]; a[i] = a[n]; a[n] = x;
    quicksort(m,j); quicksort(i+1,n);
}
```

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        if (i > j) break;
        x = a[i]; a[i] = a[j]; a[j] = x;
    }
    x = a[i]; a[i] = a[n]; a[n] = x;
    quicksort(m,j); quicksort(i+1,n);
}
```

```
( 1) i = m-1
( 2) j = n
( 3) t1 = 4*n
( 4) v = a[t1]
( 5) i = i+1
( 6) t2 = 4*i
( 7) t3 = a[t2]
( 8) if t3 < v goto (5)
( 9) j = j-1
(10) t4 = 4*j
(11) t5 = a[t4]
(12) if t5 > v goto (9)
(13) if i >= j goto (23)
(14) t6 = 4*i
(15) x = a[t6]
(16) t7 = 4*i
(17) t8 = 4*j
(18) t9 = a[t8]
(19) a[t7] = t9
(20) t10 = 4*j
(21) a[t10] = x
(22) goto (5)
(23) t11 = 4*i
(24) x = a[t11]
(25) t12 = 4*i
(26) t13 = 4*n
(27) t14 = a[t13]
(28) a[t12] = t14
(29) t15 = 4*n
(30) a[t15] = x
```

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(19)  a[t7] = t9
(20)  t10 = 4*j
(21)  a[t10] = x
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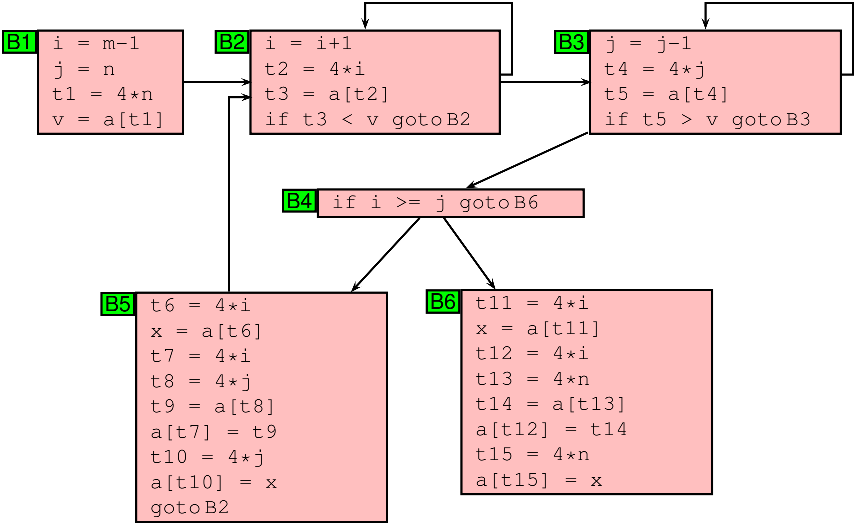
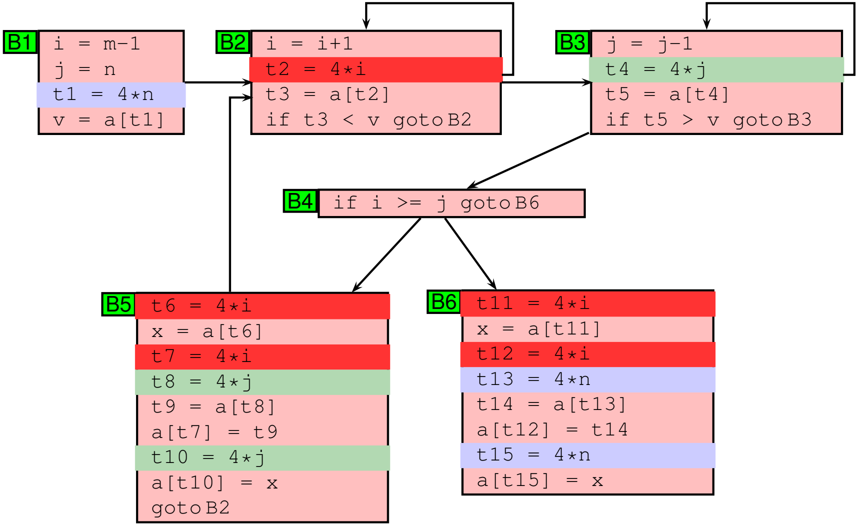
(26)  t13 = 4*n
(27)  t14 = a[t13]
(28)  a[t12] = t14
(29)  t15 = 4*n
(30)  a[t15] = x
```

Common Subexpression Elimination



Common Subexpression Elimination



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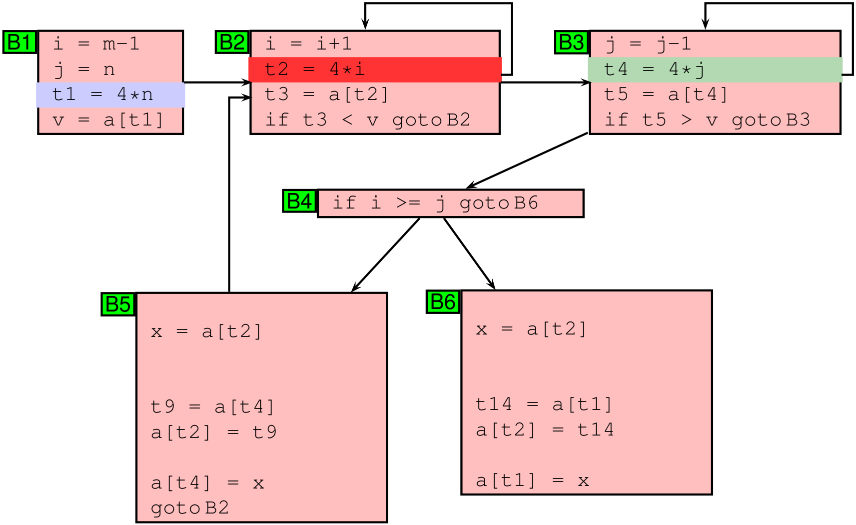

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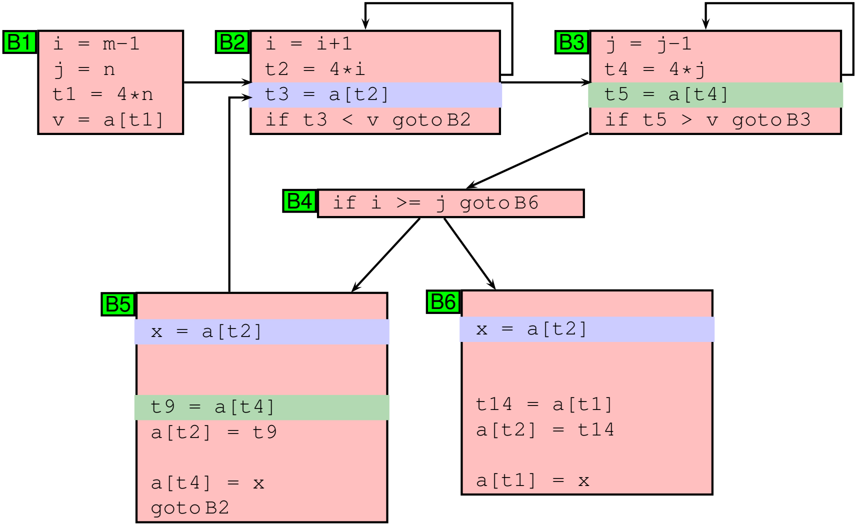

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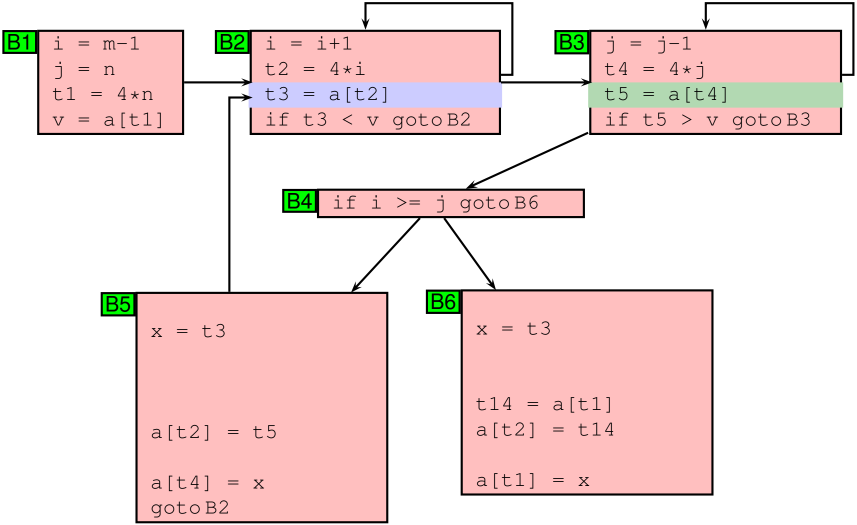

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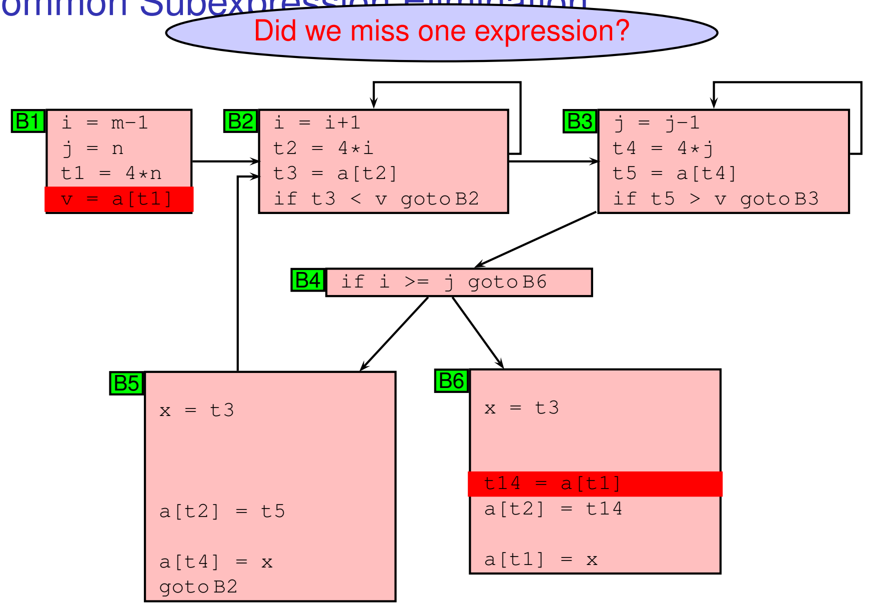
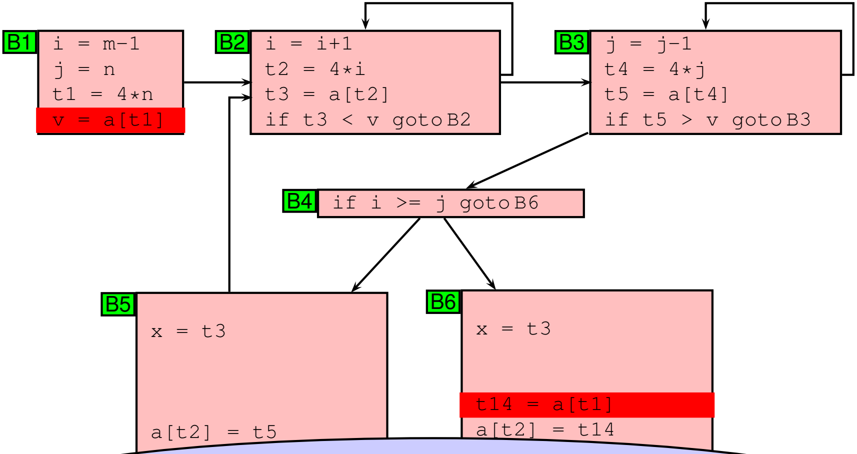


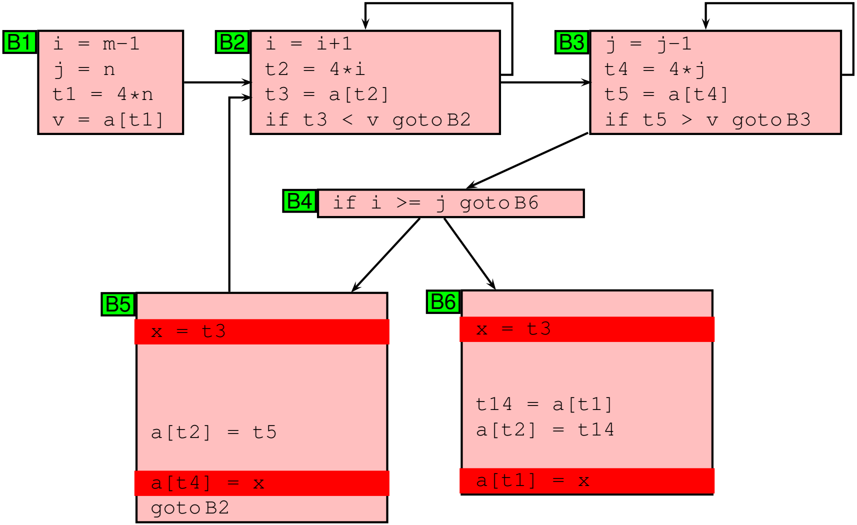
Common Subexpression Elimination

Did we miss one expression?



Elimination not safe as a[] is modified on path
B1→B2→B3→B4→B5→B2→B3→B4→B6

Copy Propagation



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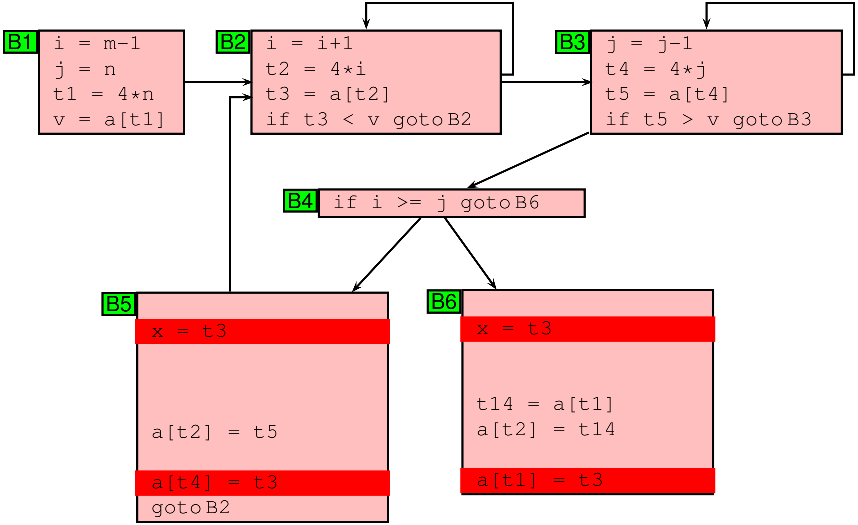

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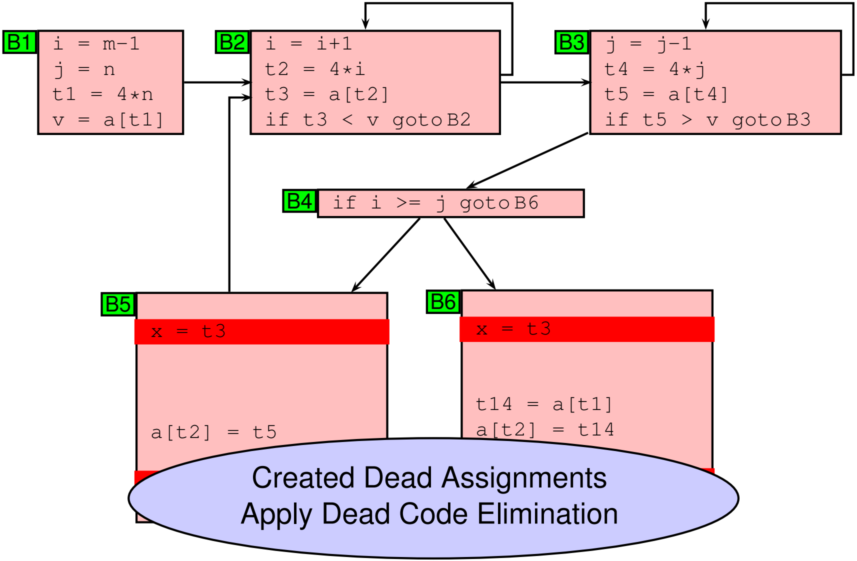

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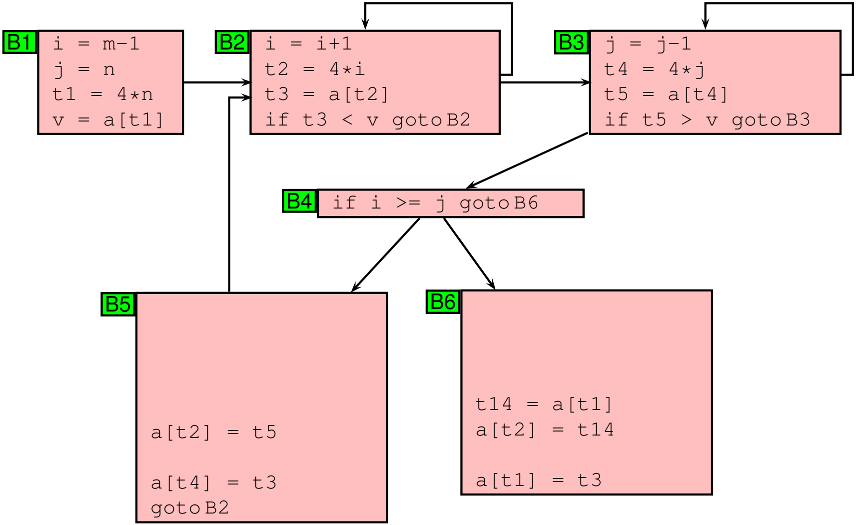
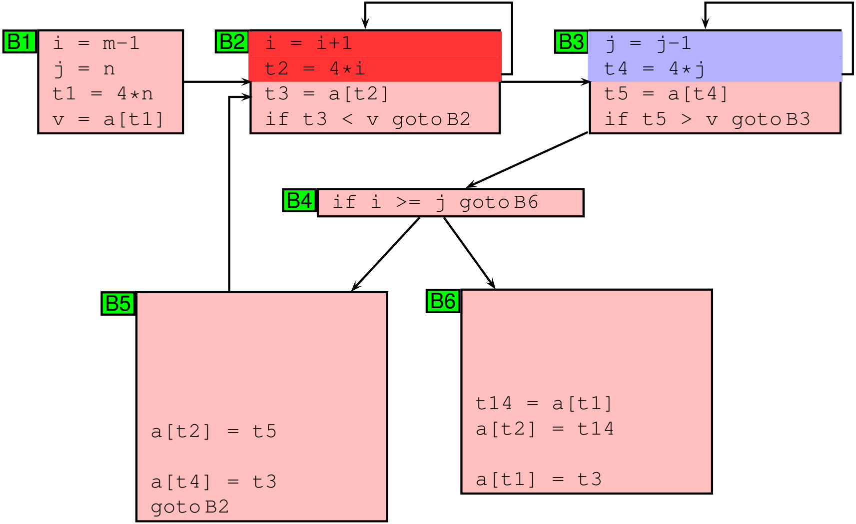


Strength Reduction



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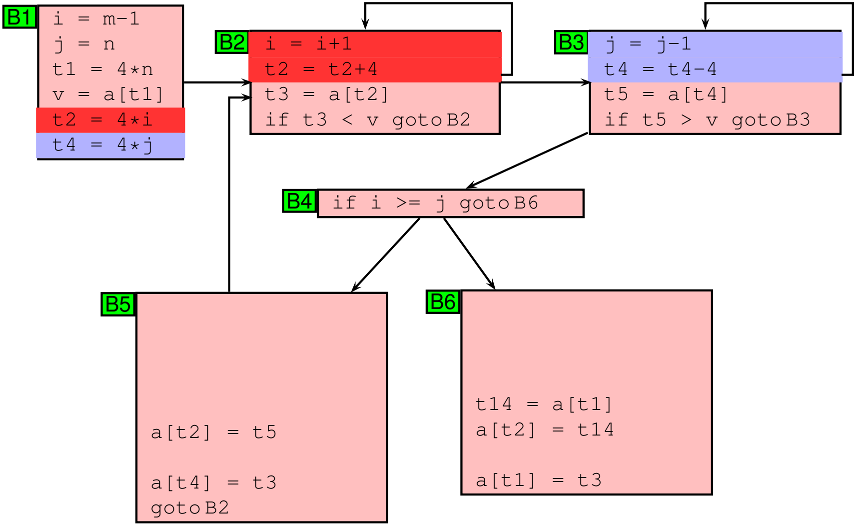
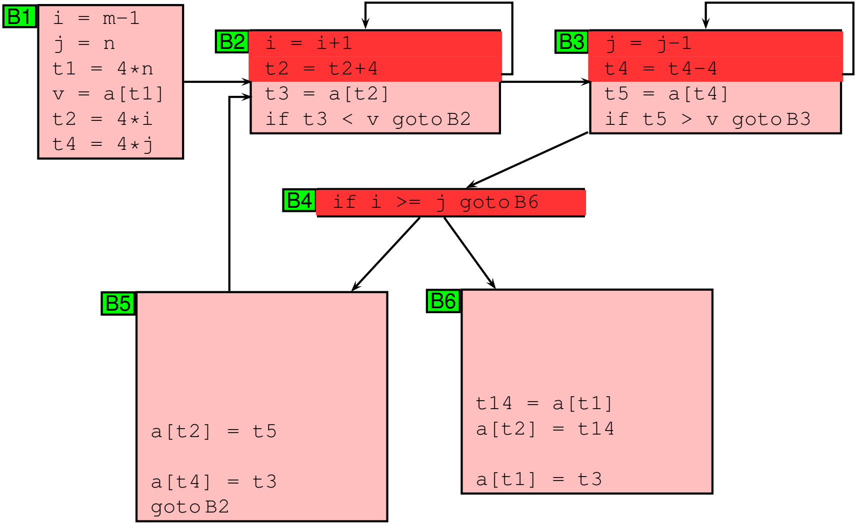
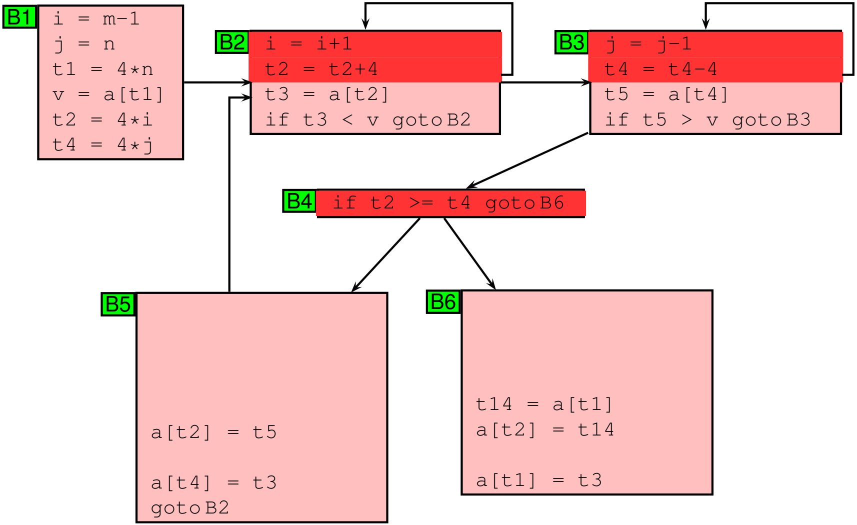


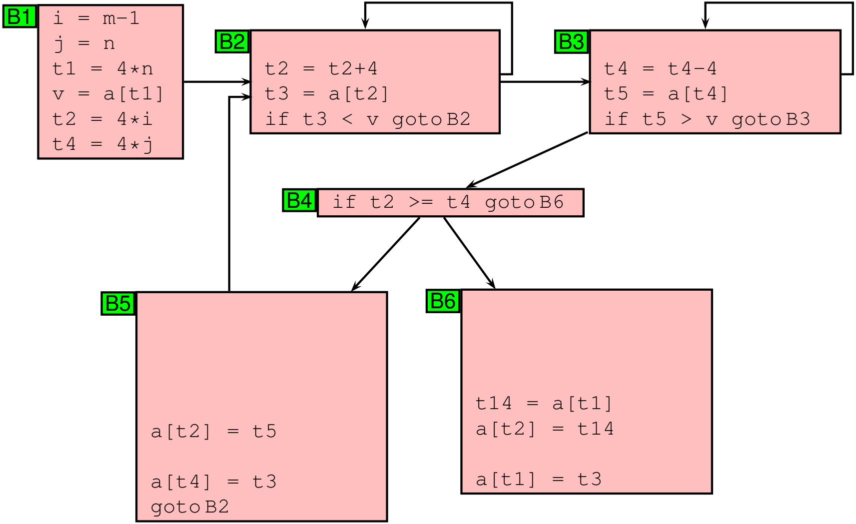
Induction Variable Elimination



Induction Variable Elimination



Dead Code Elimination (Again!)



Benefits

B#	# Stmts before Opts	# Stmts after Opts
B1	4	6
B2	4	3
B3	4	3
B4	1	1
B5	9	3
B6	8	3

- **Assumptions:**

Benefits

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- **Assumptions:**
  - Unit cost for each stmt

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- **Assumptions:**
  - Unit cost for each stmt
  - Outer loop: 10 iterations

Benefits

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- **Assumptions:**
  - Unit cost for each stmt
  - Outer loop: 10 iterations
  - Inner loops: 100 iterations each

Benefits

B#	# Stmts before Opts	# Stmts after Opts
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B4	1	1
B5	9	3
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- **Assumptions:**
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  - Outer loop: 10 iterations
  - Inner loops: 100 iterations each
- **Cost of Execution:**

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  - Outer loop: 10 iterations
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    1*4 + 100*4 + 100*4 + 10*1 + 10*9 + 1*8 = 912

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- **Assumptions:**
  - Unit cost for each stmt
  - Outer loop: 10 iterations
  - Inner loops: 100 iterations each
- **Cost of Execution:**
  - **Original Program:**
    1*4 + 100*4 + 100*4 + 10*1 + 10*9 + 1*8 = 912
  - **Optimized Program:**
    1*6 + 100*3 + 100*3 + 10*1 + 10*3 + 1*3 = 649

Machine Dependent Optimizations

Peephole Optimizations

- Target code often contains redundant instructions and suboptimal constructs

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- Examine a short sequence of target instruction (peephole) and replace by a shorter or faster sequence

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- Target code often contains redundant instructions and suboptimal constructs
- Examine a short sequence of target instruction (peephole) and replace by a shorter or faster sequence
- Peephole is a small moving window on the target systems

Peephole Optimizations: Examples

- Redundant loads and stores

Peephole Optimizations: Examples

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- Consider the code sequence

$$\begin{array}{ll} \texttt{move} & R_0\texttt{,}\ \ a \\ \texttt{move} & a\texttt{,}\ \ R_0 \end{array}$$

Peephole Optimizations: Examples

- Redundant loads and stores
- Consider the code sequence

$$\texttt{move}\ \ R_0\texttt{,}\ \ a$$
$$\texttt{move}\ \ a\texttt{,}\ \ R_0$$

- Is instruction 2 redundant? Can we always remove it?

Peephole Optimizations: Examples

- Redundant loads and stores
- Consider the code sequence

$$\texttt{move}\ \ R_0\texttt{,}\ \ a$$
$$\texttt{move}\ \ a\texttt{,}\ \ R_0$$

- Is instruction 2 redundant? Can we always remove it?
  - YES, if it does not have label

Peephole Optimizations: Unreachable code

- Consider the following code

```
int debug = 0;
if (debug) {
    print debugging info
}
```

Peephole Optimizations: Unreachable code

- Consider the following code

```
int debug = 0;
if (debug) {
    print debugging info
}
```

- This may be translated as

```
    int debug = 0;
    if (debug == 1) goto L1
    goto L2
L1: print debugging info
L2:
```

Peephole Optimizations: Unreachable code

- Eliminate Jumps

```
    int debug = 0;
    if (debug != 1) goto L2
    print debugging info
L2:
```

Peephole Optimizations: Unreachable code

- Eliminate Jumps

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     int debug = 0;
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     print debugging info
L2:
```

- Constant propagation

```
     int debug = 0;
     if (0 != 1) goto L2
     print debugging info
L2:
```

Peephole Optimizations: Unreachable code

- Constant folding and simplification: Since `if` condition is always true, the code becomes:

```
    goto L2
    print debugging info
L2:
```

Peephole Optimizations: Unreachable code

- Constant folding and simplification: Since `if` condition is always true, the code becomes:

```
    goto L2
    print debugging info
L2:
```

- The print statement is now unreachable. Therefore, the code becomes

```
L2:
```

Peephole Optimizations: Jump Optimizations

- Replace jump-over-jumps

```
     goto L1
     ⋮
L1: goto L2
```

Peephole Optimizations: Jump Optimizations

- Replace jump-over-jumps

goto L1 ⋮ L1: goto L2	can be replaced by	goto L2 ⋮ L1: goto L2

Peephole Optimizations: Simplify Algebraic Expressions

- Remove

```
x = x + 0;
x = x * 1;
```

Peephole Optimizations: Strength Reduction

- Replace $X^\wedge 2$ by $X * X$

Peephole Optimizations: Strength Reduction

- Replace $X^\wedge 2$ by $X * X$
- Replace multiplication by left shift

Peephole Optimizations: Strength Reduction

- Replace $X^{\wedge}2$ by $X * X$
- Replace multiplication by left shift
- Replace division by right shift

Peephole Optimizations: Use of Faster Instructions

- Replace

  Add #1, R

  by

  Inc R

Course Logistics

Evaluation

- Assignments
- Course project
- Mid semester exam (? for online offering)
- End semester exam (? for online offering)
- Quizzes/Class participation
- Refer to course webpage for details.