Program Analysis

https://www.cse.iitb.ac.in/~karkare/cs618/

Welcome & Introduction

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Program Analysis: About the course

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- Analysis of a Program, by a Program, for a Program

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- of a Program - User Program

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- 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, ...

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- Understand and modify large code base
  - GCC, LLVM, SOOT
- Read state of the art research papers
  - Discussions in class

Your Expectations

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- ?

Quick Quizzes (QQs)

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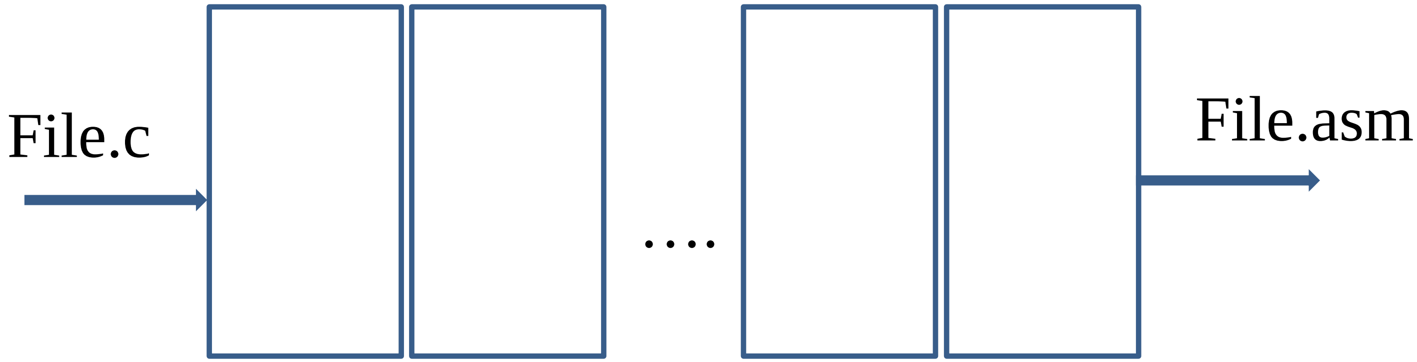
- These can be announced or **un-announced (surprize** quizzes).
- Always bring a pen and some loose papers to the class

QQ #1 (Ungraded)



- What are the various phases of compilers that you know? (5 minutes)

Assignments / Exercises

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- Short assignments to apply the lecture material.

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- 4-5 Assignments for the semester

Using Program Analysis

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- Compiler Code Optimizations

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- Why are optimizations important?

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- 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

Code Optimization

- Machine Independent
  - Remove redundancy introduced by the Programmer
  - Remove redundancy not required by later phases of compiler
  - Take advantage of algebraic properties of operators

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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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    x = a[i]; a[i] = a[j]; a[j] = x;
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  x = a[i]; a[i] = a[n]; a[n] = x;
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```

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(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)
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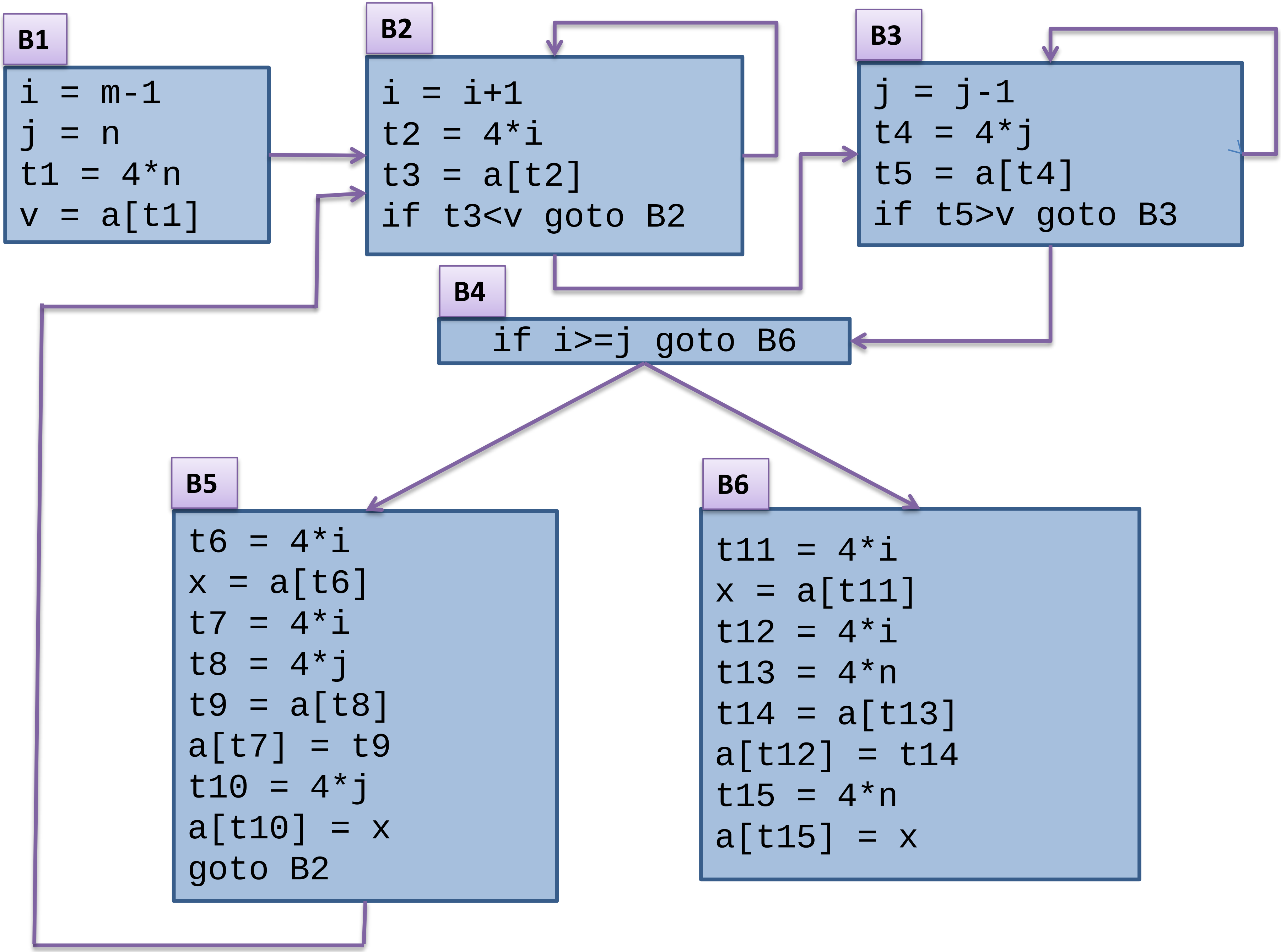
B1
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t1 = 4*n
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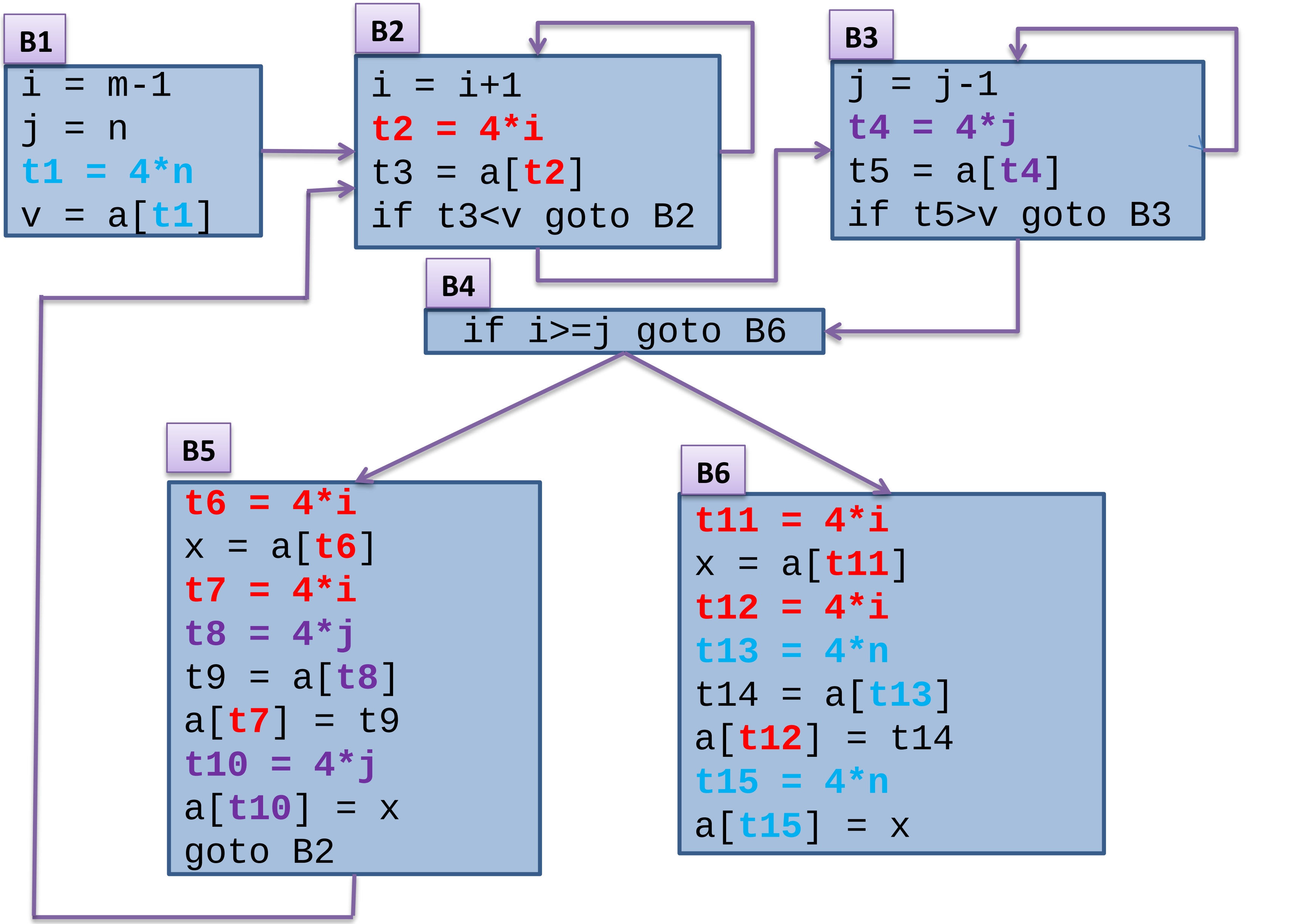
Common Subexpression Elimination



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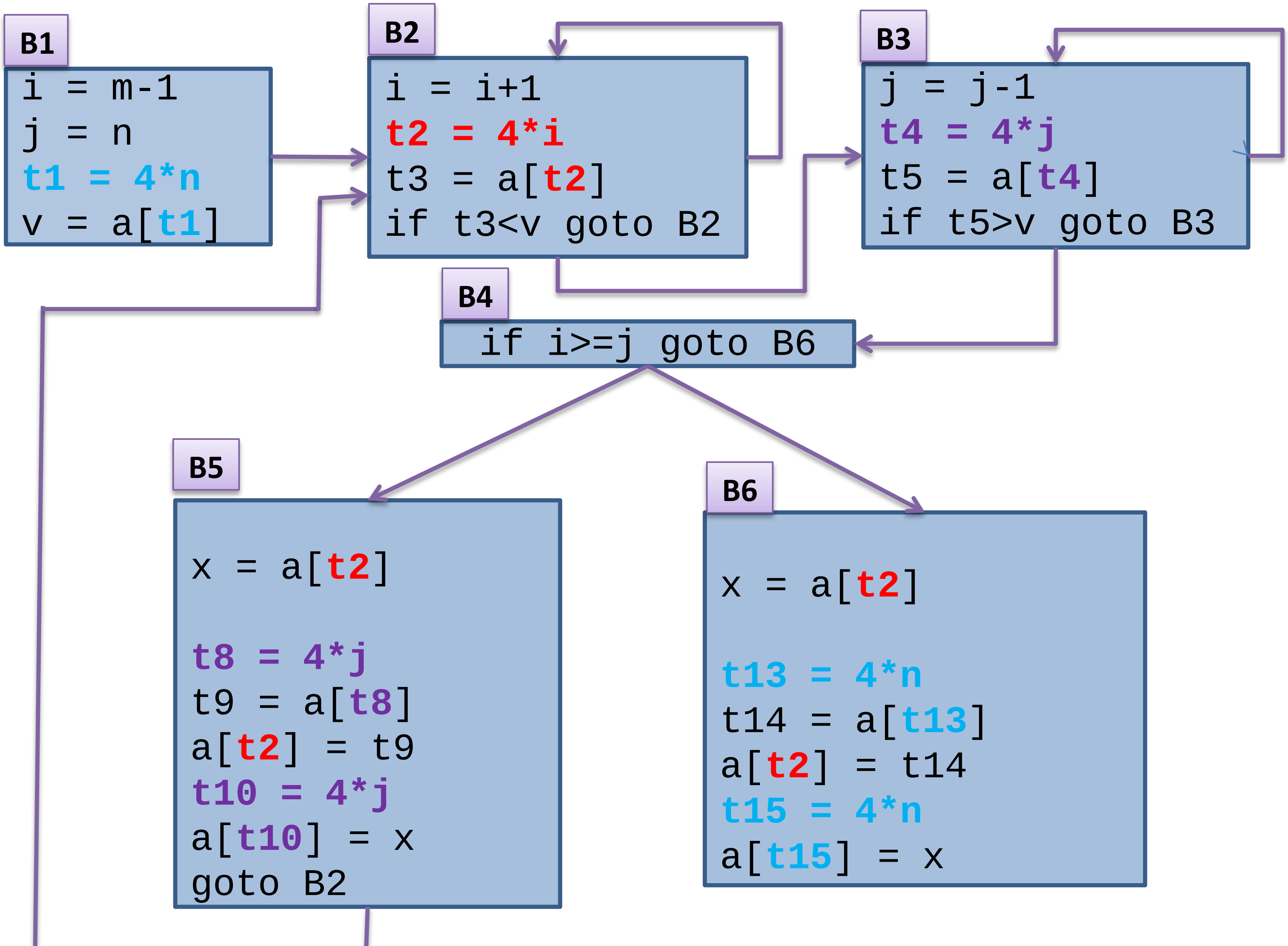

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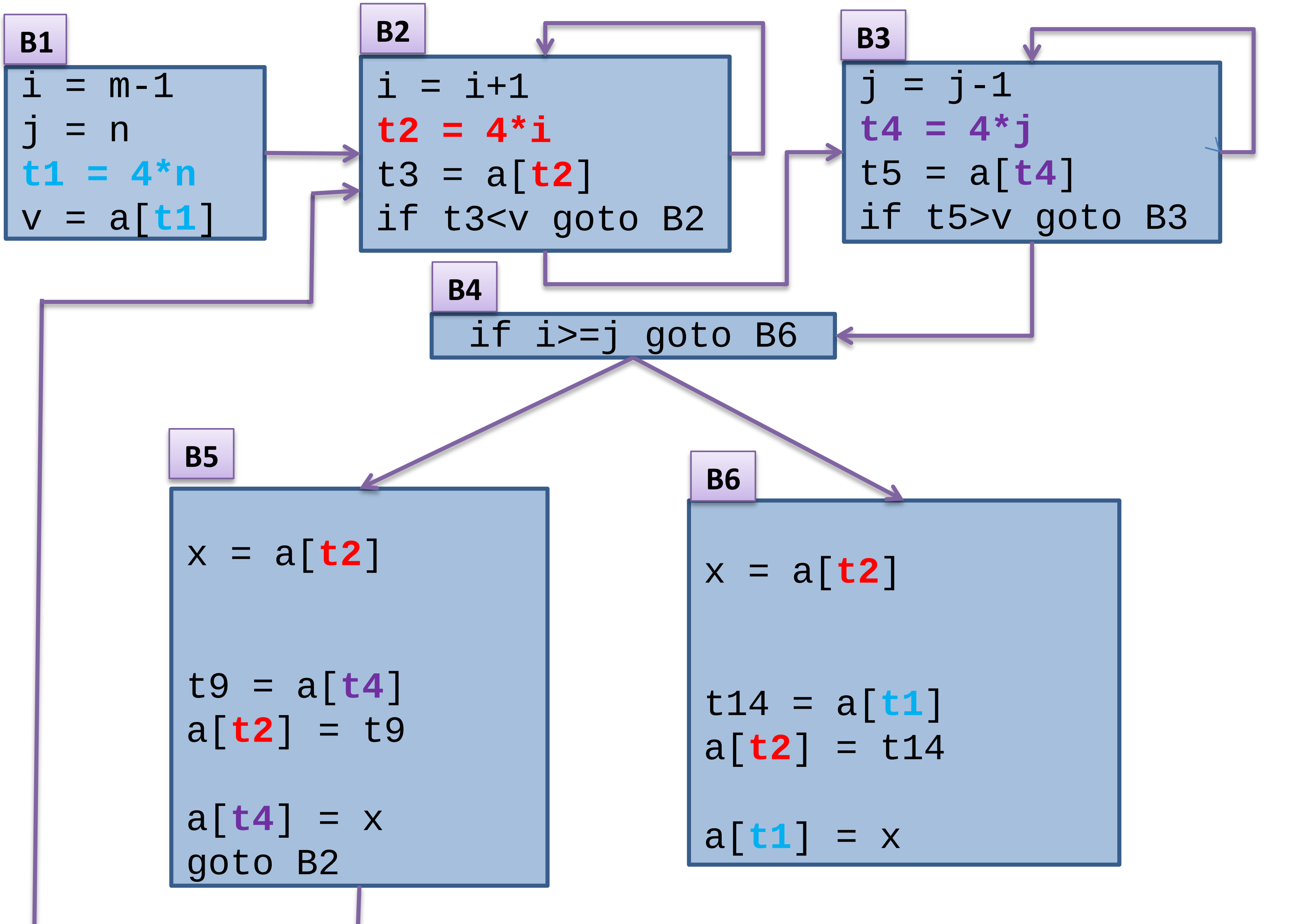

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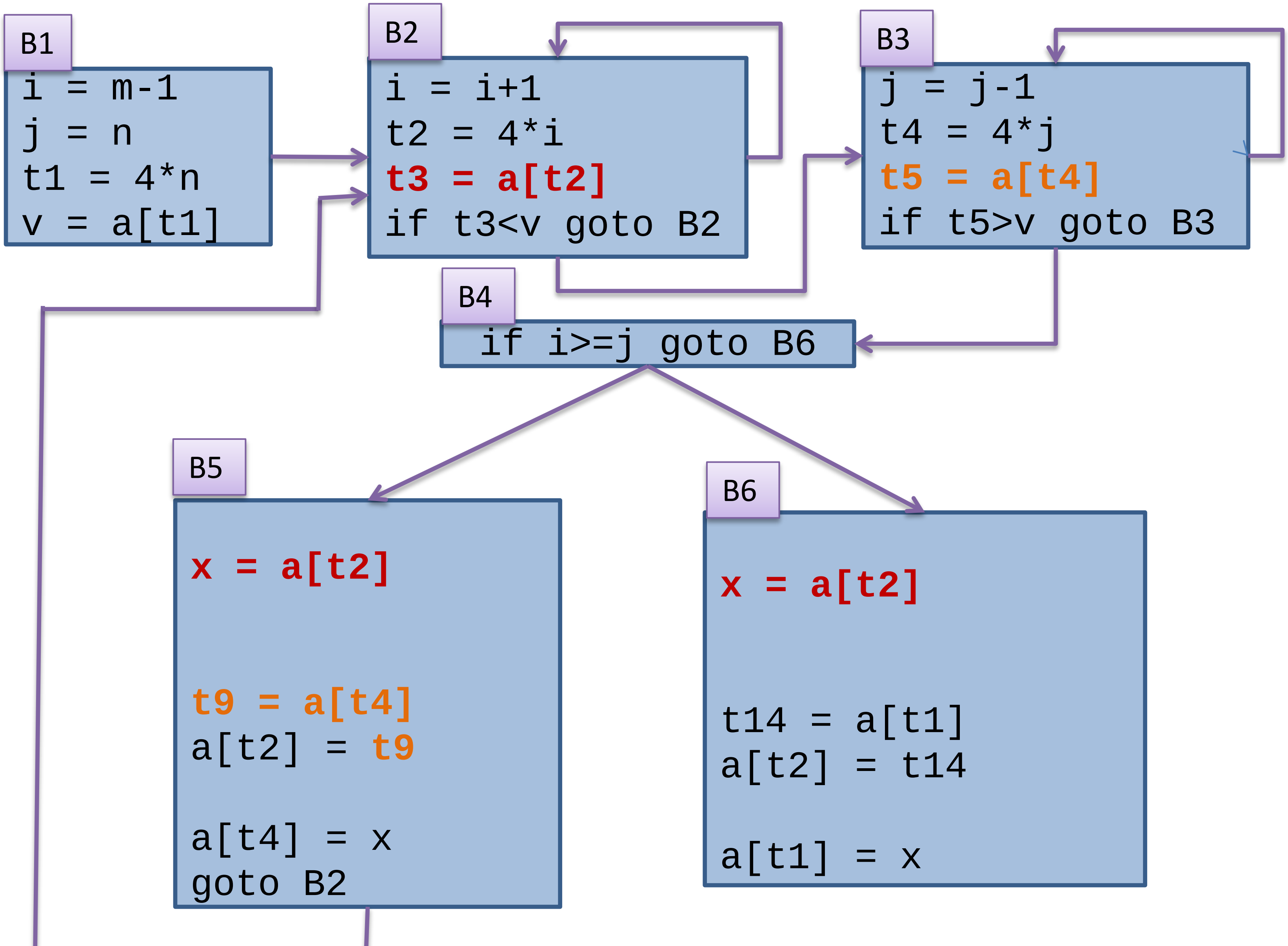

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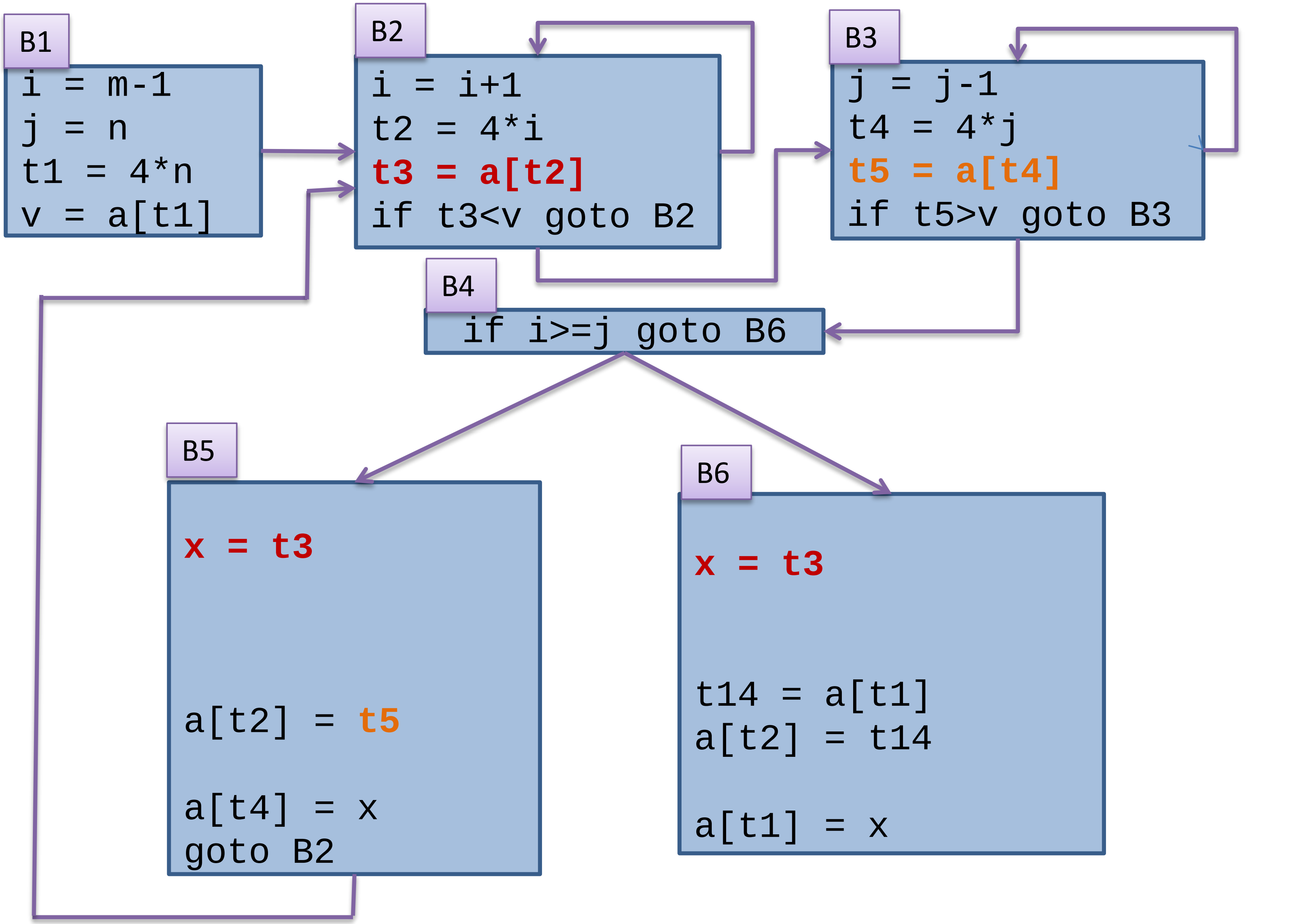
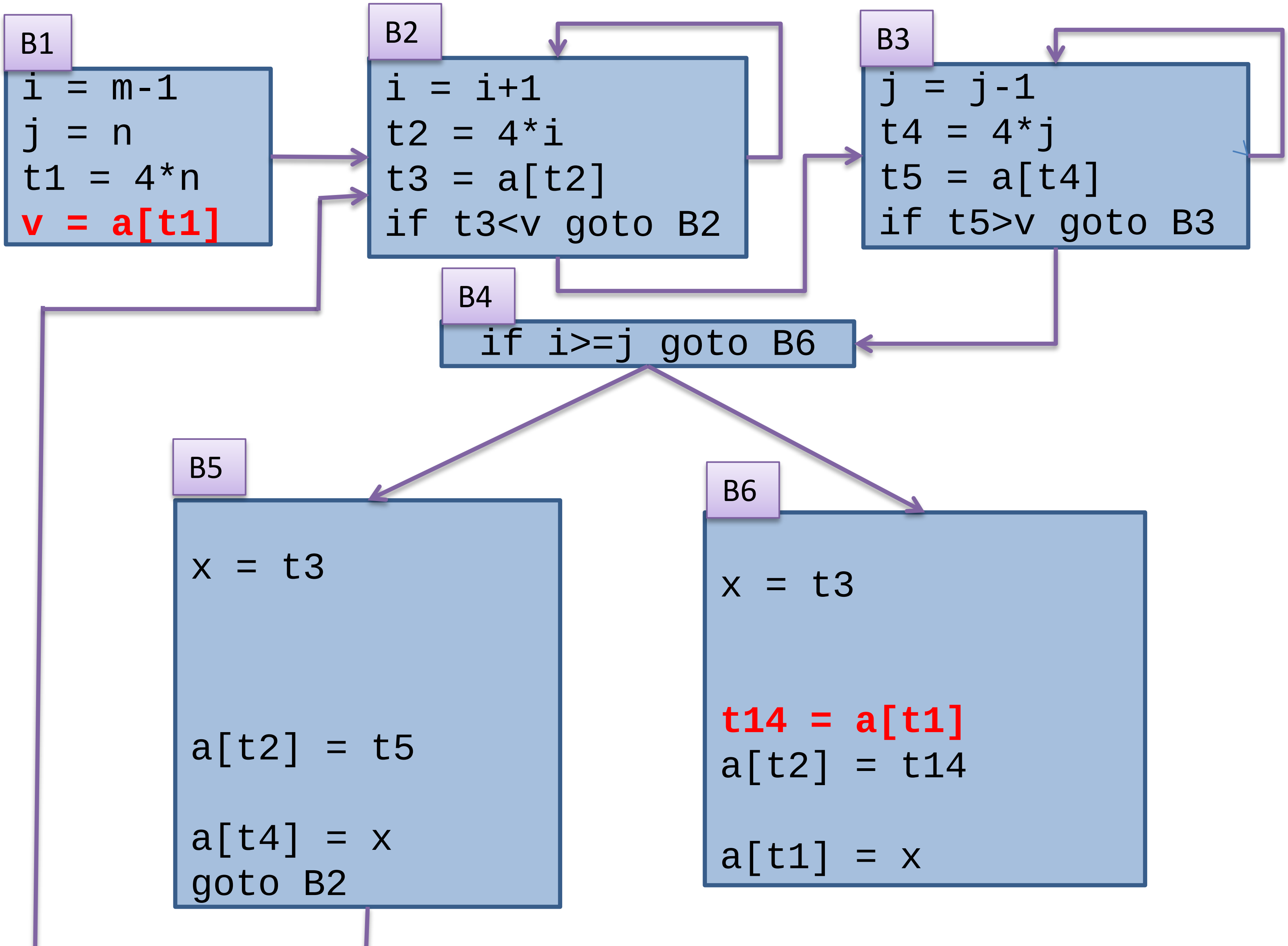
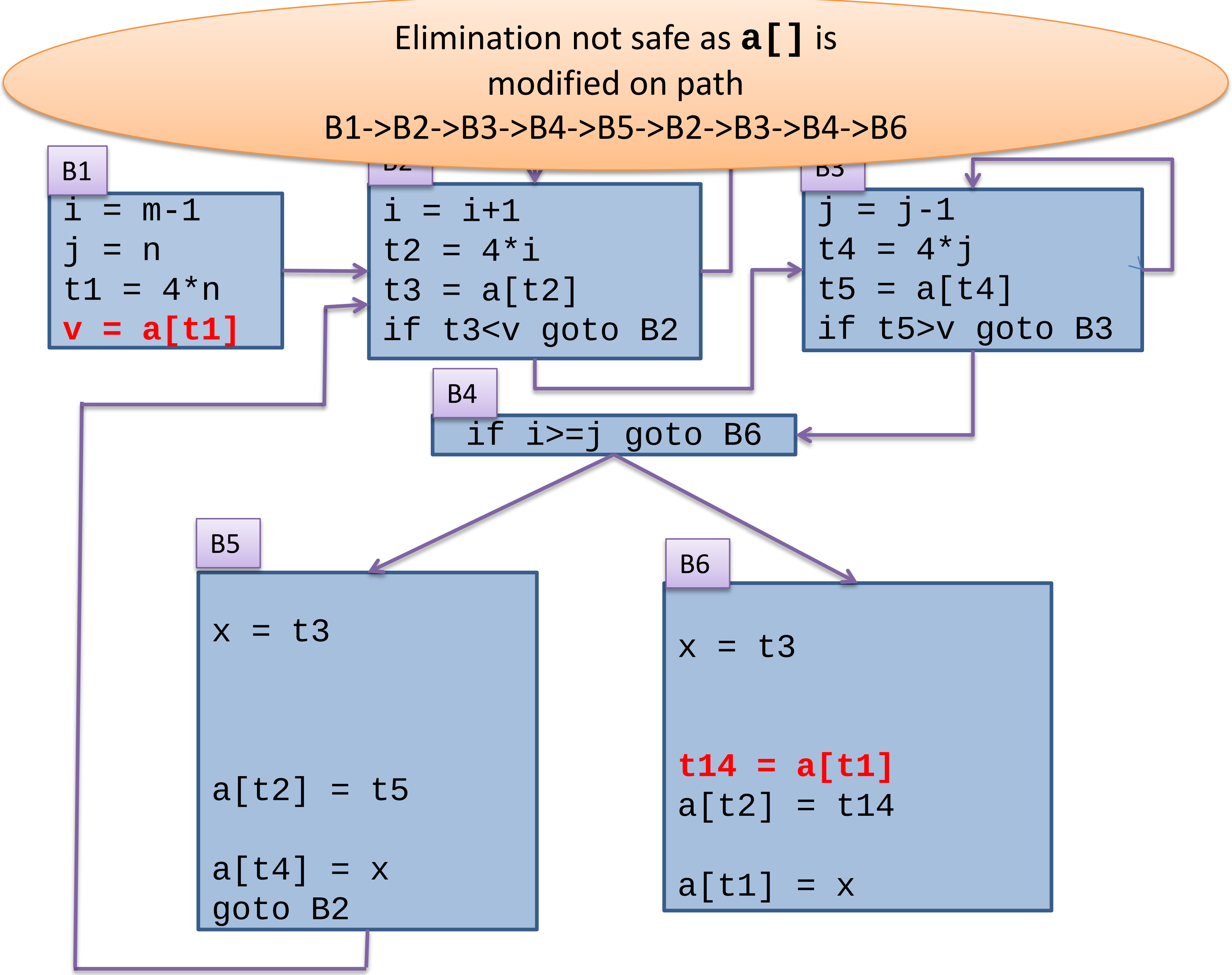


Did I miss one common subexpression?




Elimination not safe as a[] is modified on path B1->B2->B3->B4->B5->B2->B3->B4->B6
B1
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if t5>v goto B3
B4
if i>=j goto B6
B5
x = t3
a[t2] = t5
a[t4] = x
goto B2
B6
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t14 = a[t1]
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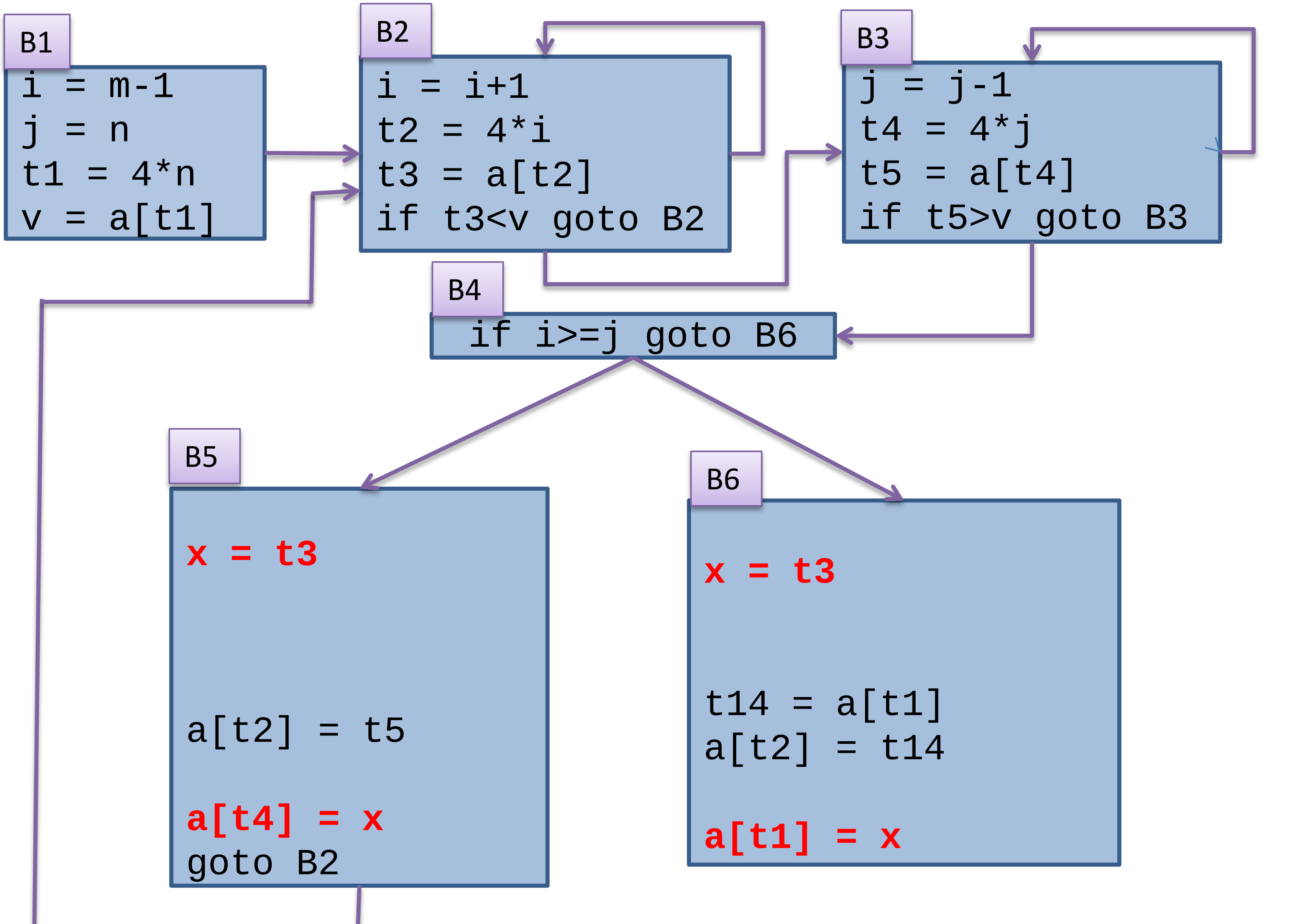
Copy Propagation



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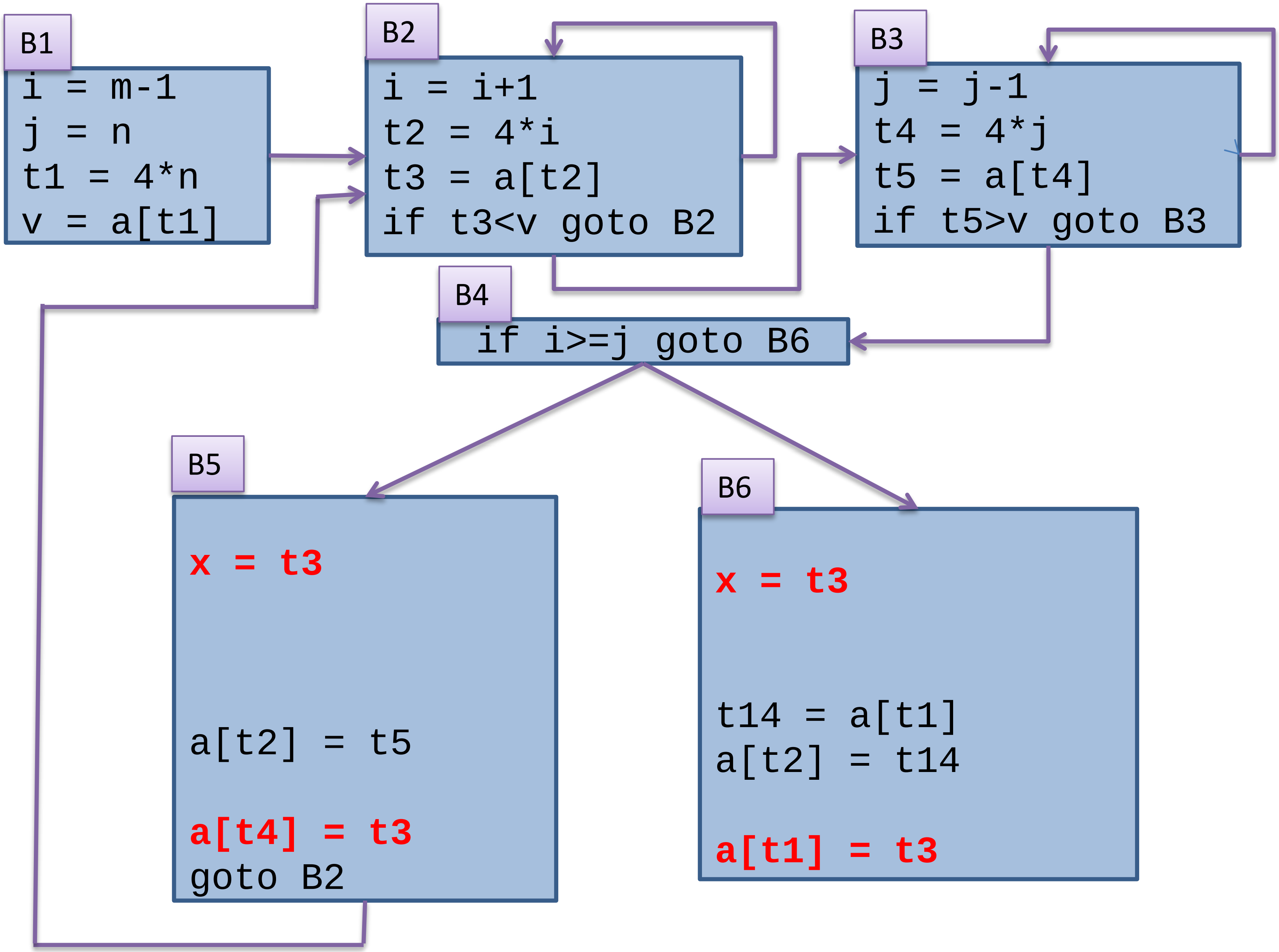
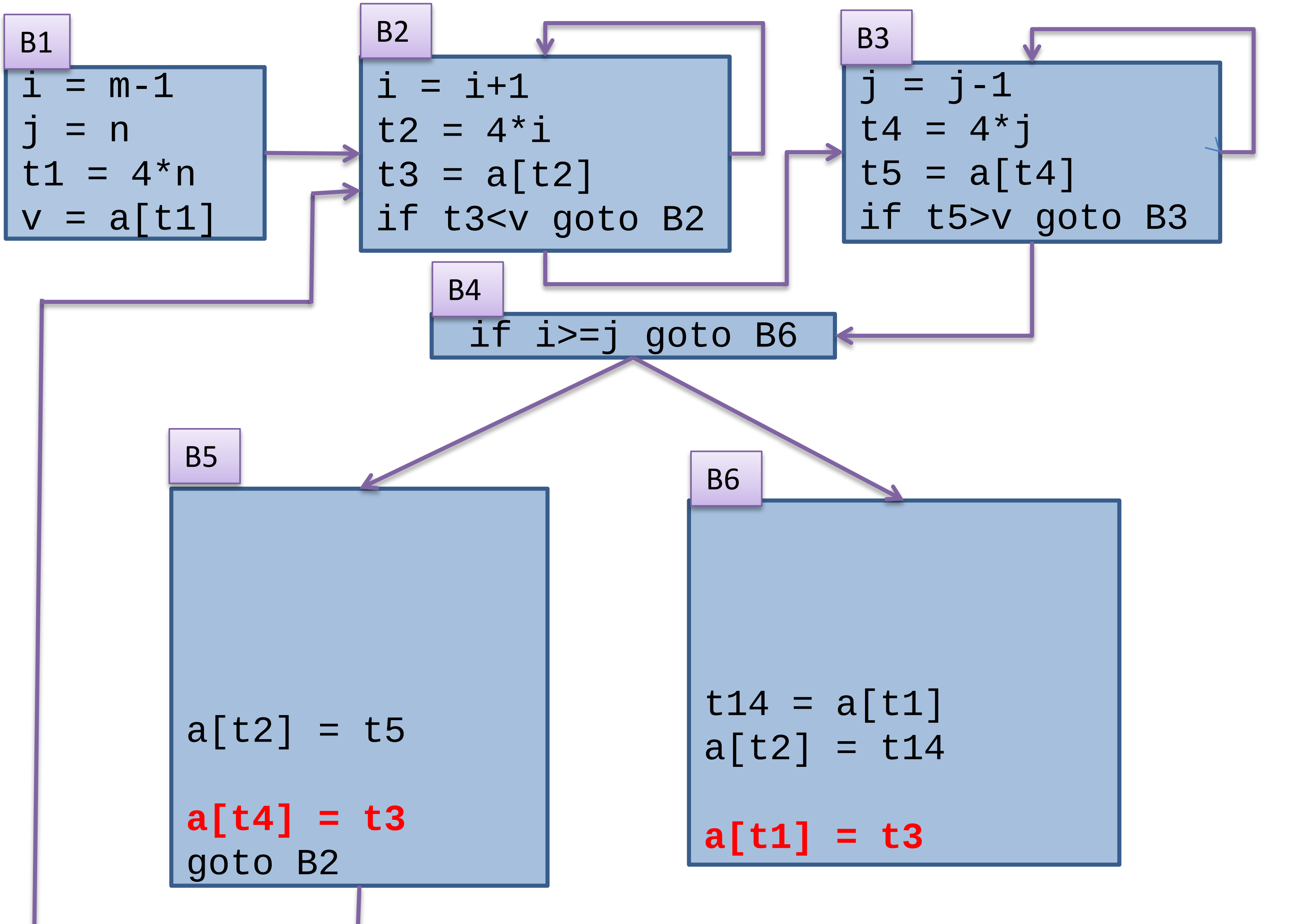
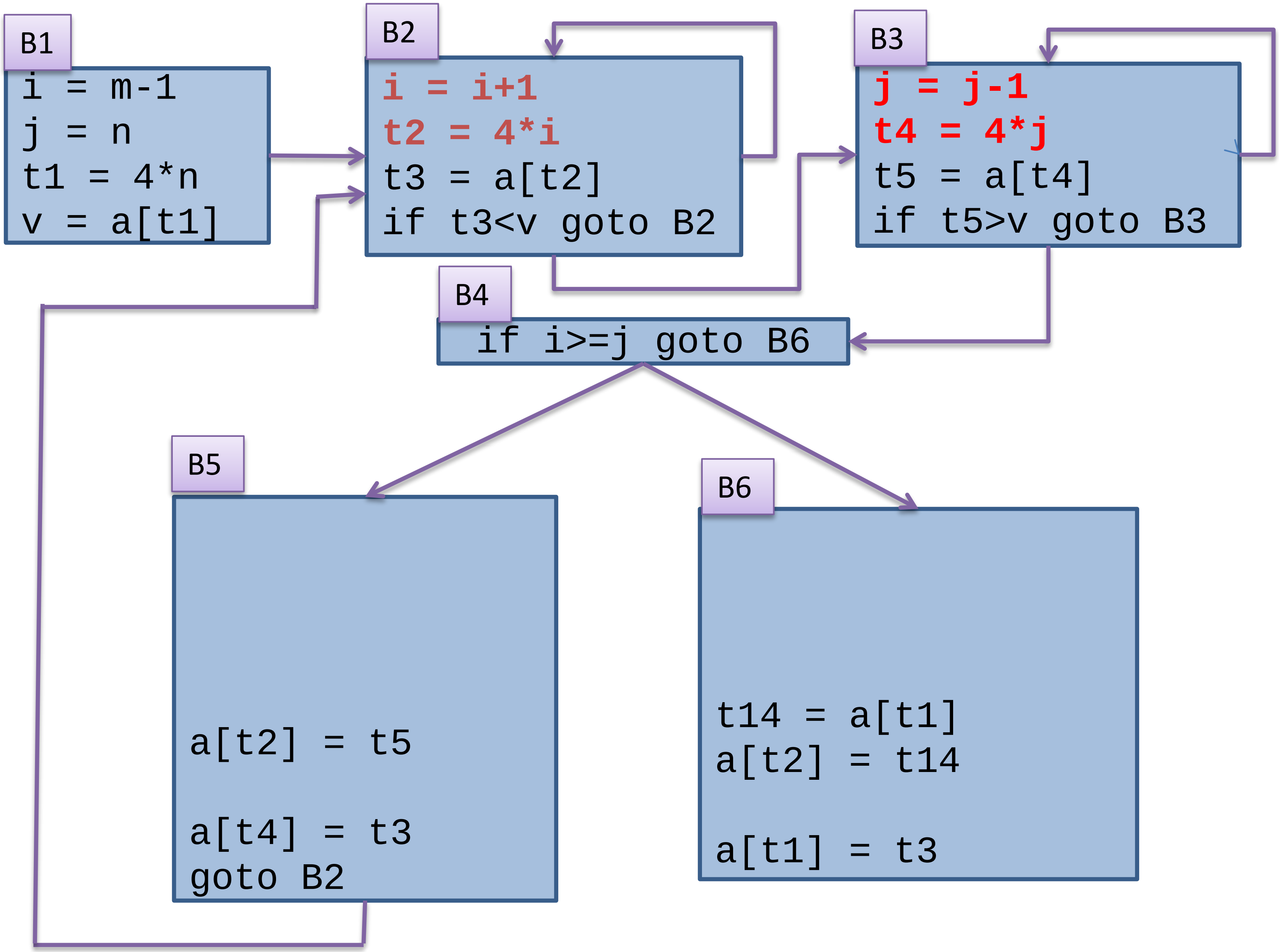


Dead Code Elimination



Strength Reduction



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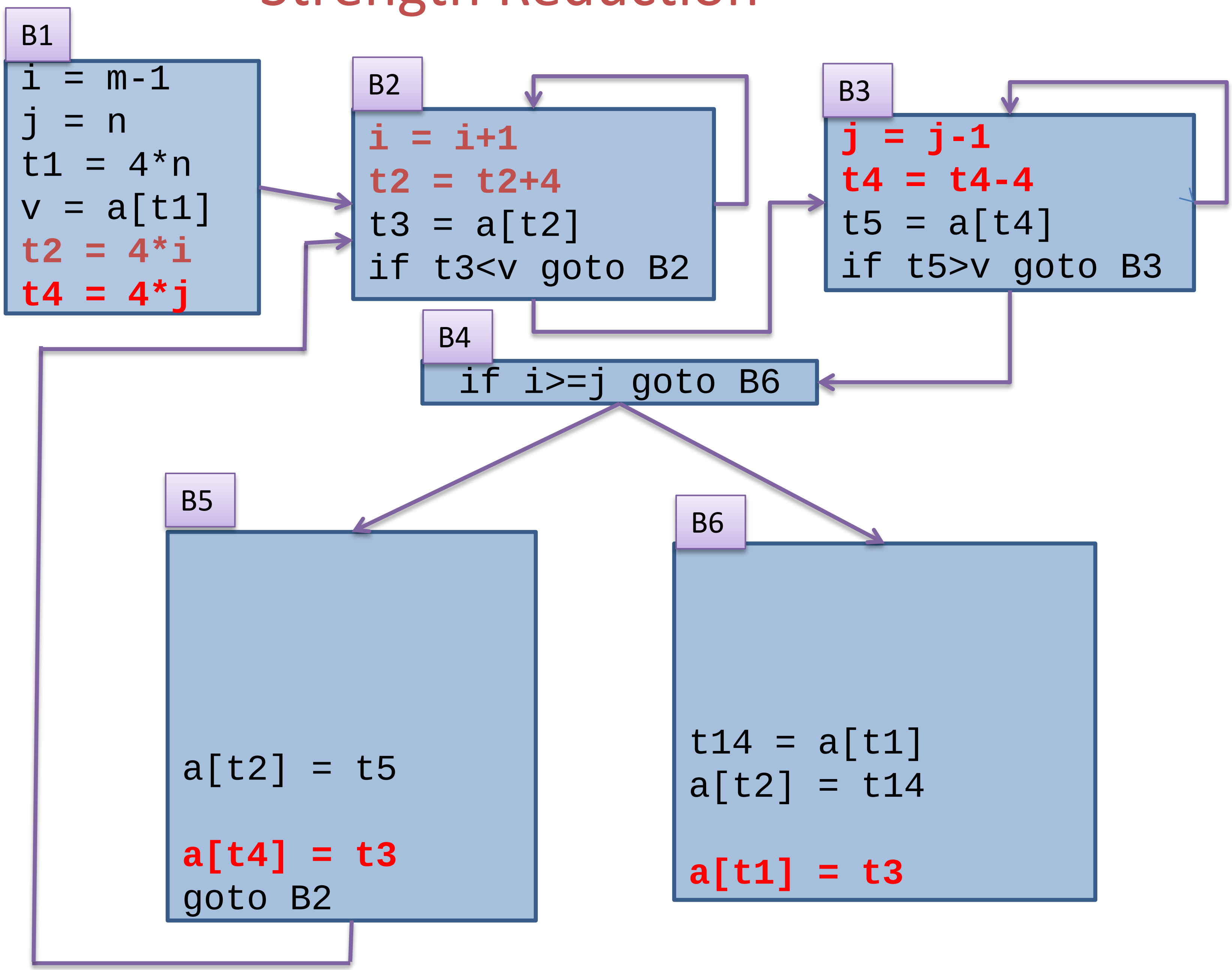
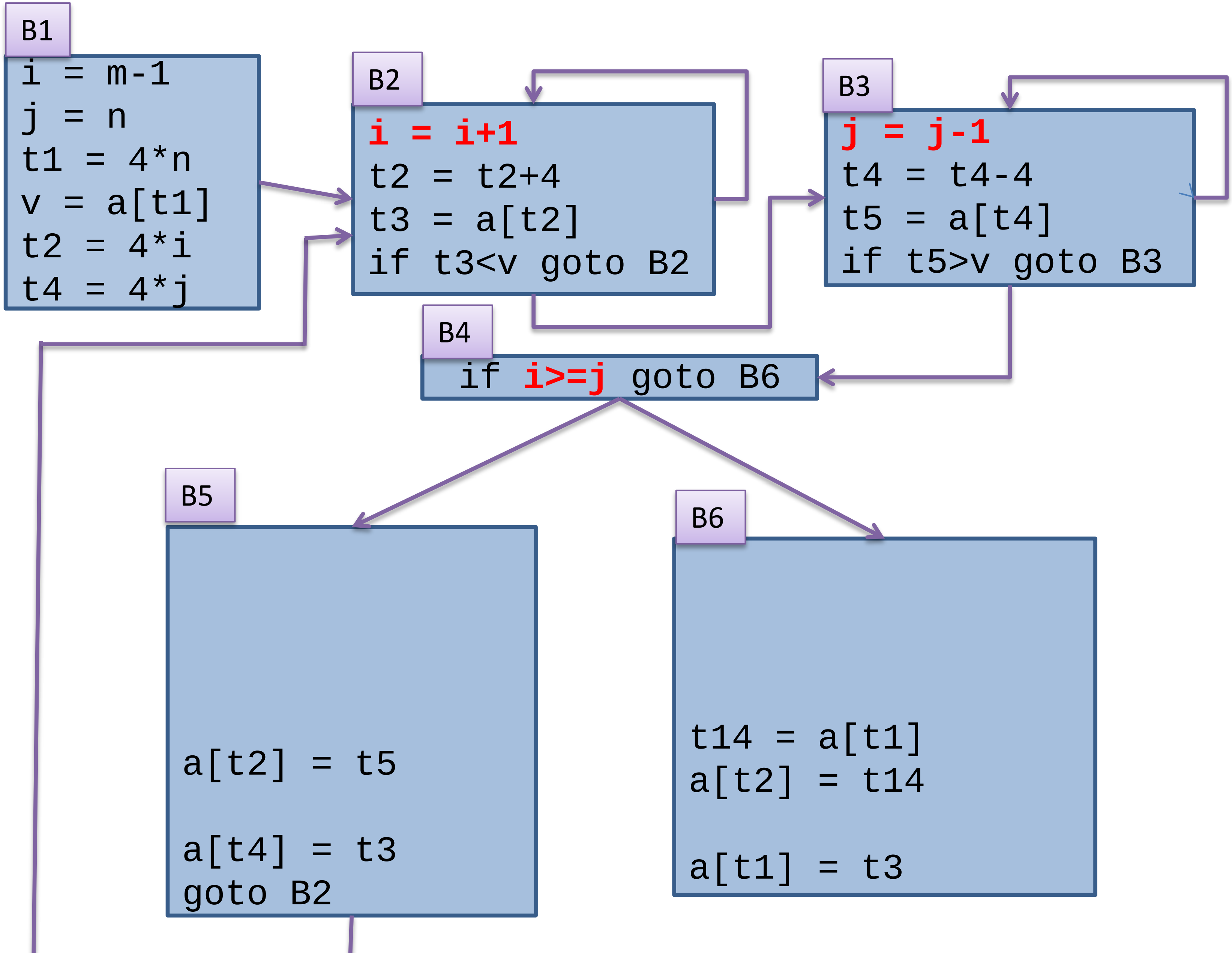
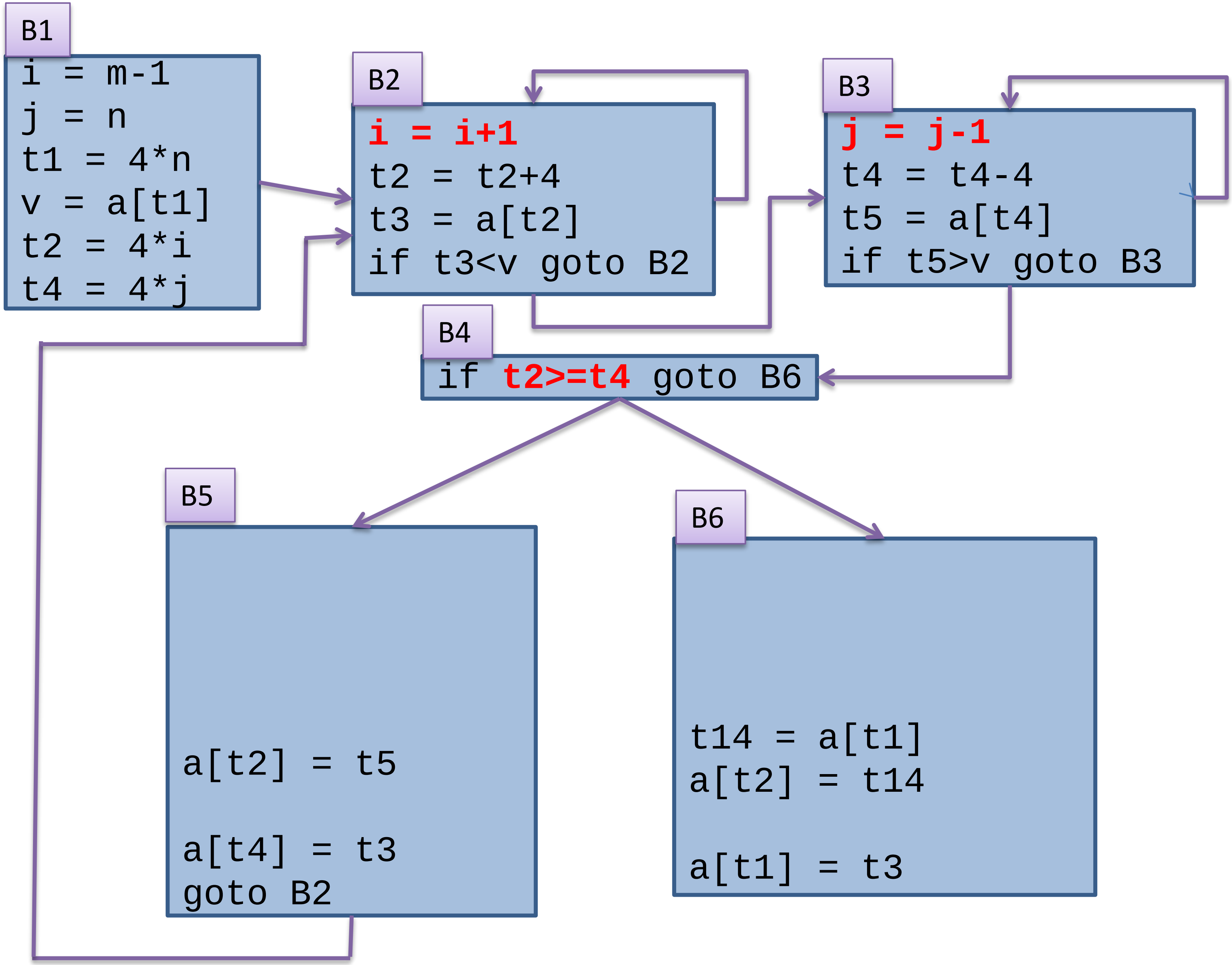


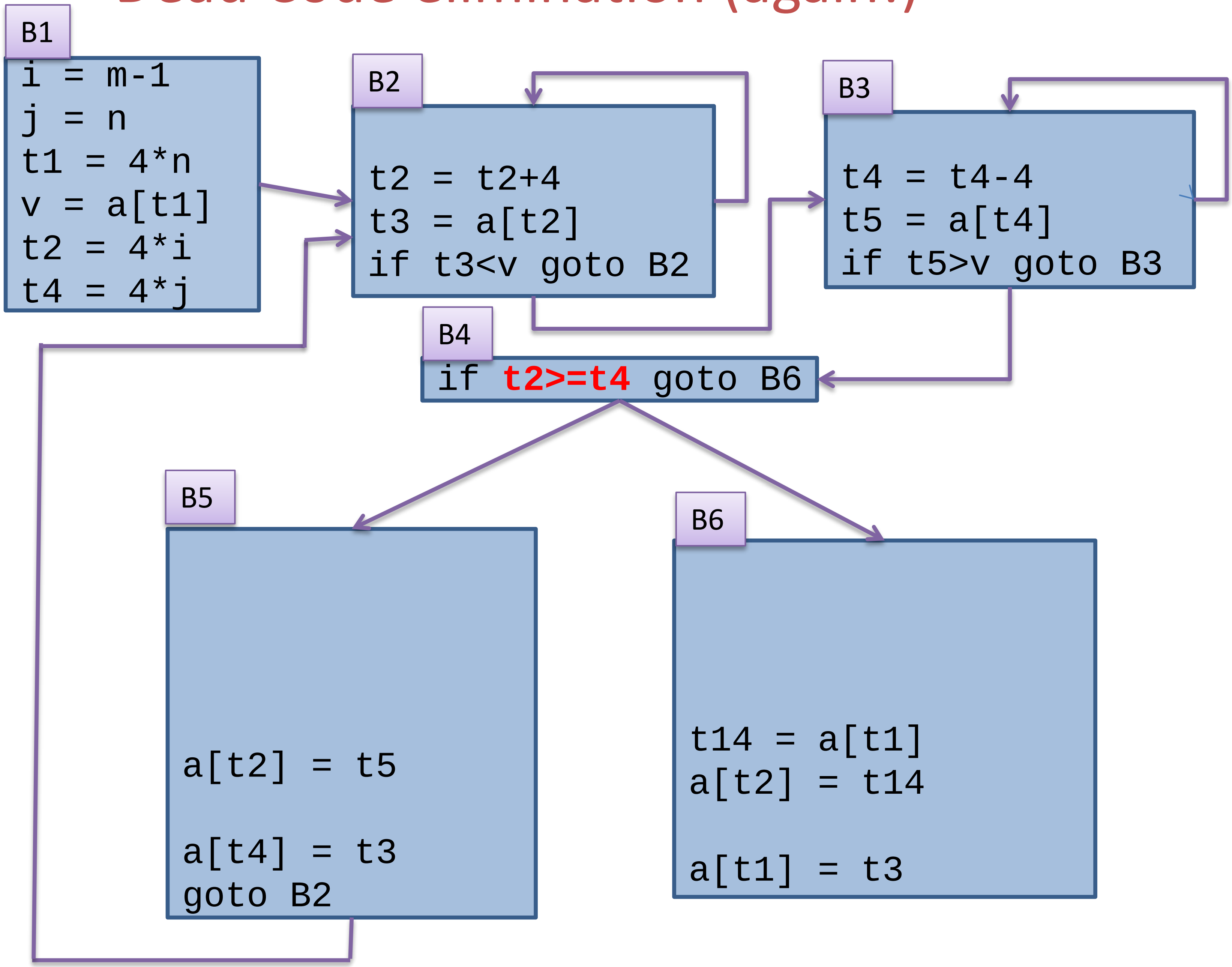
Induction Variable elimination



Induction Variable elimination



Dead Code elimination (again!)



Benefits

Block	# Stmt before Optimizations	# Stmt after Optimizations
B1	4	**6**
B2	4	**3**
B3	4	**3**
B4	1	**1**
B5	9	**3**
B6	8	**3**

Benefits

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B3	4	3
B4	1	**1**
B5	9	3
B6	8	3

Assume: Unit cost for statements, 10 iterations of outer loop, 100 iterations of each inner loop

Cost of execution:

ORIGINAL: 1*4 + 100*4 + 100*4 + 10*1 + 10*9 + 1*8 = 912

OPTIMIZED: 1*6 + 100*3 + 100*3 + 10*1 + 10*3 + 1*3 = 649

Machine Dependent Optimizations

Peephole Optimization

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- target code often contains redundant instructions and suboptimal constructs

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Peephole Optimization

- 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 optimization examples…

Redundant loads and stores

- Consider the code sequence

Move R_0, a

Move a, R_0

Peephole optimization examples…

Redundant loads and stores

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Move a, R_0

- Instruction 2 can always be removed if it does not have a label.

Peephole optimization examples…

Unreachable code

- Consider following code sequence

```
#define debug 0
if (debug) {
        print debugging info
}
```

Peephole optimization examples…

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this may be translated as

```
        if debug == 1 goto L1
        goto L2
L1: print debugging info
L2:
```

Peephole optimization examples…

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this may be translated as

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        if debug == 1 goto L1
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L1: print debugging info
L2:
```

Eliminate jumps

```
        if debug != 1 goto L2
                print debugging information
L2:
```

Unreachable code example …

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constant propagation

```
        if 0 <> 1 goto L2
            print debugging information
L2:
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Unreachable code example …

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Evaluate boolean expression. Since if condition is always true the code becomes

```
        goto L2
        print debugging information
L2:
```

Unreachable code example …

constant propagation

```
        if 0 <> 1 goto L2
            print debugging information
L2:
```

Evaluate boolean expression. Since if condition is always true the code becomes

```
        goto L2
        print debugging information
L2:
```

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

```
L2:
```

Peephole optimization examples…

- flow of control: replace jump over jumps

```
     goto L1                         goto L2
                   by                     …
     …                                    …
                                  L1: goto L2
     …
L1 : goto L2
```

Peephole optimization examples…

- flow of control: replace jump over jumps

```
     goto L1                    goto L2
     …           by                ...
     …                             ...
L1 : goto L2                L1: goto L2
```

- Simplify algebraic expressions

  remove x := x+0 or x:=x*1

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  - Replace X^2 by X*X
  - Replace multiplication by left shift
  - Replace division by right shift

Peephole optimization examples…

- Strength reduction
  - Replace X^2 by X*X
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- Use faster machine instructions

  replace Add #1,R

  by Inc R

Course Logistics

Proposed Evaluation

Assignments	**5%-10%**
Course Project	**30%-40%**
(Proposal	**5%)**
(Report	**15%)**
(Presentation	**15%)**
Mid semester exam	**10%-20%**
End semester exam	**25%-35%**
Quizzes/Class Participation	**5%**

Project

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- You need to implement some non-trivial analysis/optimization using one of the open source infrastructure
  - For e.g., some paper published in last 10 years

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- **Bonus** marks for publishable results

Project

- Major part of the course
- You need to implement some non-trivial analysis/optimization using one of the open source infrastructure
  - For e.g., some paper published in last 10 years
- You are encouraged to suggest your own projects
- **Bonus** marks for publishable results
- Individual OR Group of **2**

Assignment #1

Assignment #1

- Select one of the compiler infrastructure mentioned on the course webpage and
  a) Download it
  b) Build it
  c) Submit a report
  d) one page about the infrastructure, and the optimizations present in it.
  e) one page about the most interesting optimization found, with example

Assignment #1

- You can try more than one tool, even something not mentioned on the webpage.
- But submit report for only **one**.
  - Preferably the one you plan to use for your project.

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- You can try more than one tool, even something not mentioned on the webpage.
- But submit report for only **one**.
  - Preferably the one you plan to use for your project.
- DEADLINE: July 30th, End of Day (before Midnight)
- See course website for submission details (TBD)

https://www.cse.iitb.ac.in/~karkare/cs618/