Unit12
Code Optimization

Introduction

- Criteria for Code-Improving Transformation:
  - Meaning must be preserved (correctness)
  - Speedup must occur on average.
  - Work done must be worth the effort.

- Opportunities:
  - Programmer (algorithm, directives)
  - Intermediate code
  - Target code

Peephole Optimizations

1. A Simple but effective technique for locally improving the code is peephole optimization,
2. a method for trying to improve the performance of the program
3. by examining a short sequence of instructions and replacing these instructions by a shorter or faster sequence whenever possible.

Characteristics of peephole optimization

1. Redundant instruction elimination
2. Flow of control information
3. Algebraic Simplification
4. Use of machine Idioms

Peephole Optimizations

- **Constant Folding**

  `x := 32` becomes `x := 64`

  `x := x + 32`

- **Unreachable Code**

  `goto L2`

  `x := x + 1` ← No need

- **Flow of control optimizations**

  `goto L1` becomes `goto L2`

  …

  `L1: goto L2` ← No needed if no other L1 branch

Peephole Optimizations

- **Algebraic Simplification**

  `x := x + 0` ← No needed

- **Dead code**

  `x := 32` ← where x not used after statement

  `y := x + y` → `y := y + 32`

- **Reduction in strength**

  `x := x * 2` → `x := x + x`

  → x := x << 1

Basic Block Level

1. Common subexpression elimination
2. Constant Propagation
3. Copy Propagation
4. Dead code elimination
5. …

Flow Graphs

- A *flow graph* is a graphical depiction of a sequence of instructions with control flow edges
- A flow graph can be defined at the intermediate code level or target code level

Basic Blocks

- A *basic block* is a sequence of consecutive instructions with exactly one entry point and one exit point (with natural flow or a branch instruction)

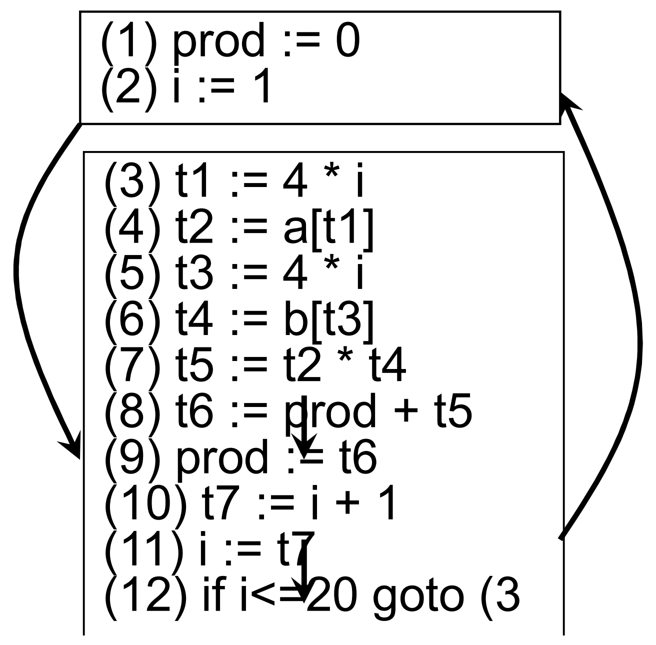
Example

```
t1 := a * a
t2 := a * b
t3 := 2 * t2
t4 := t1 + t2
t5 := b * b
t6 := t4 + t5
```

Basic Blocks and Control Flow Graphs

- A *control flow graph* (CFG) is a directed graph with basic blocks B_i as vertices and with edges $B_i \rightarrow B_j$ iff B_j can be executed immediately after B_i

```
(1) prod := 0
(2) i := 1
(3) t1 := 4 * i
(4) t2 := a[t1]
(5) t3 := 4 * i
(6) t4 := b[t3]
(7) t5 := t2 * t4
(8) t6 := prod + t5
(9) prod := t6
(10) t7 := i + 1
(11) i := t7
(12) if i<=20 goto (3)
```

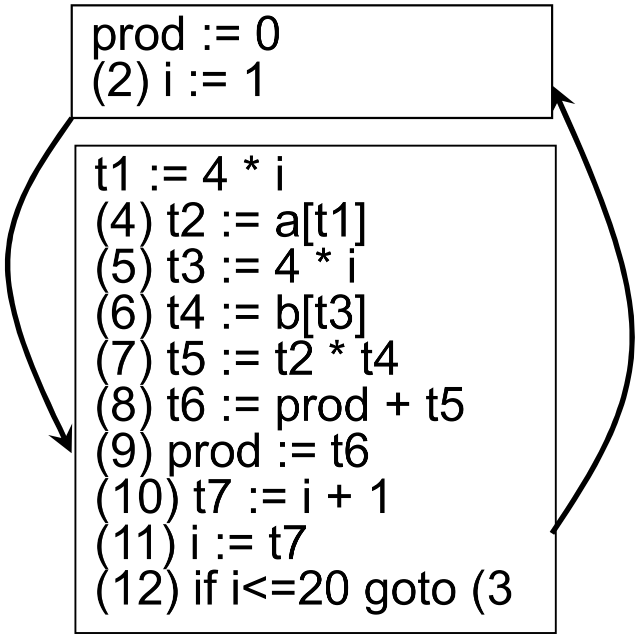


```
(1) prod := 0
(2) i := 1
```

```
(3) t1 := 4 * i
(4) t2 := a[t1]
(5) t3 := 4 * i
(6) t4 := b[t3]
(7) t5 := t2 * t4
(8) t6 := prod + t5
(9) prod := t6
(10) t7 := i + 1
(11) i := t7
(12) if i<=20 goto (3
```

Successor and Predecessor Blocks

- Suppose the CFG has an edge $B_1 \rightarrow B_2$
  - Basic block B_1 is a *predecessor* of B_2
  - Basic block B_2 is a *successor* of B_1



Partition Algorithm for Basic Blocks

Input: A sequence of three-address statements
Output: A list of basic blocks with each three-address statement in exactly one block

1. Determine the set of *leaders*, the first statements if basic blocks
   a) The first statement is the leader
   b) Any statement that is the target of a goto is a leader
   c) Any statement that immediately follows a goto is a leader
2. For each leader, its basic block consist of the leader and all statements up to but not including the next leader or the end of the program

Common expression can be eliminated

Simple example: a[i+1] = b[i+1]

- t1 = i+1
- t2 = b[t1]
- t3 = i + 1
- a[t3] = t2

- t1 = i + 1
- t2 = b[t1]
- t3 = i + 1 $\leftarrow$
  no longer live
- a[t1] = t2

Constant propagation

Now, suppose i is a constant:

```
i = 4
t1 = i+1
t2 = b[t1]
a[t1] = t2
```

```
i = 4
t1 = 5
t2 = b[t1]
a[t1] = t2
```

```
i = 4
t1 = 5
t2 = b[5]
a[5] = t2
```

Final Code:

```
i = 4
t2 = b[5]
a[5] = t2
```

Optimizations on CFG

- Must take control flow into account
  - Common Sub-expression Elimination
  - Constant Propagation
  - Dead Code Elimination
  - Partial redundancy Elimination
  - …
- Applying one optimization may raise opportunities for other optimizations.

Three Address Code of Quick Sort

1	$i = m - 1$
2	$j = n$
3	$t_1 = 4 * n$
4	$v = a[t_1]$
5	$i = i + 1$
6	$t_2 = 4 * i$
7	$t_3 = a[t_2]$
8	if $t_3 < v$ goto (5)
9	$j = j – 1$
10	$t_4 = 4 * j$
11	$t_5 = a[t_4]$
12	if $t_5 > v$ goto (9)
13	if $i >= j$ goto (23)
14	$t_6 = 4 * i$
15	$x = a[t_6]$

16	$t_7 = 4 * I$
17	$t_8 = 4 * j$
18	$t_9 = a[t_8]$
19	$a[t_7] = t_9$
20	$t_{10} = 4 * j$
21	$a[t_{10}] = x$
22	goto (5)
23	$t_{11} = 4 * I$
24	$x = a[t_{11}]$
25	$t_{12} = 4 * i$
26	$t_{13} = 4 * n$
27	$t_{14} = a[t_{13}]$
28	$a[t_{12}] = t_{14}$
29	$t_{15} = 4 * n$
30	$a[t_{15}] = x$

Find The Basic Block

1	$i = m - 1$
2	$j = n$
3	$t_1 = 4 * n$
4	$v = a[t_1]$
5	$i = i + 1$
6	$t_2 = 4 * i$
7	$t_3 = a[t_2]$
8	if $t_3 < v$ goto (5)
9	$j = j – 1$
10	$t_4 = 4 * j$
11	$t_5 = a[t_4]$
12	if $t_5 > v$ goto (9)
13	if i >= j goto (23)
14	$t_6 = 4 * i$
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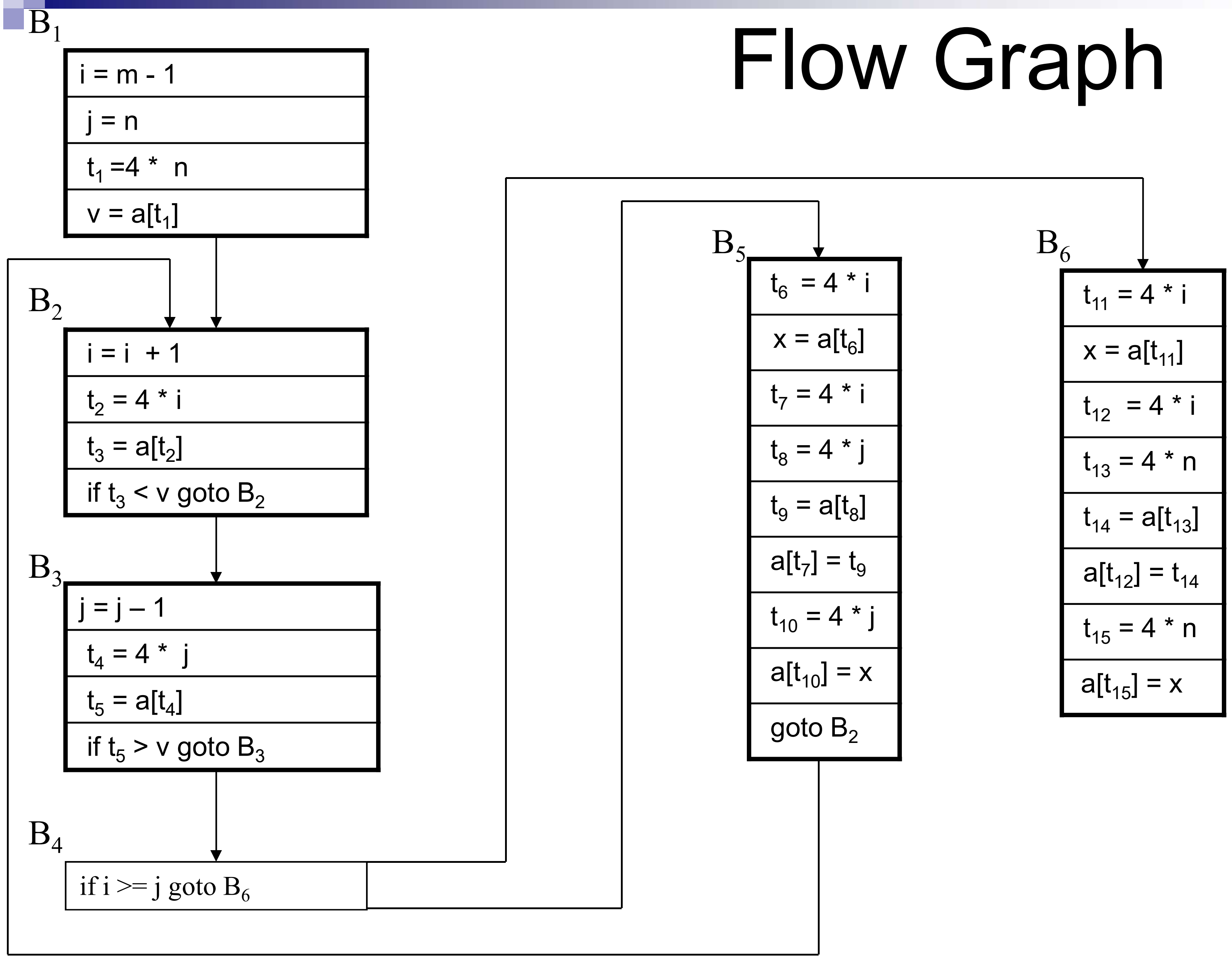
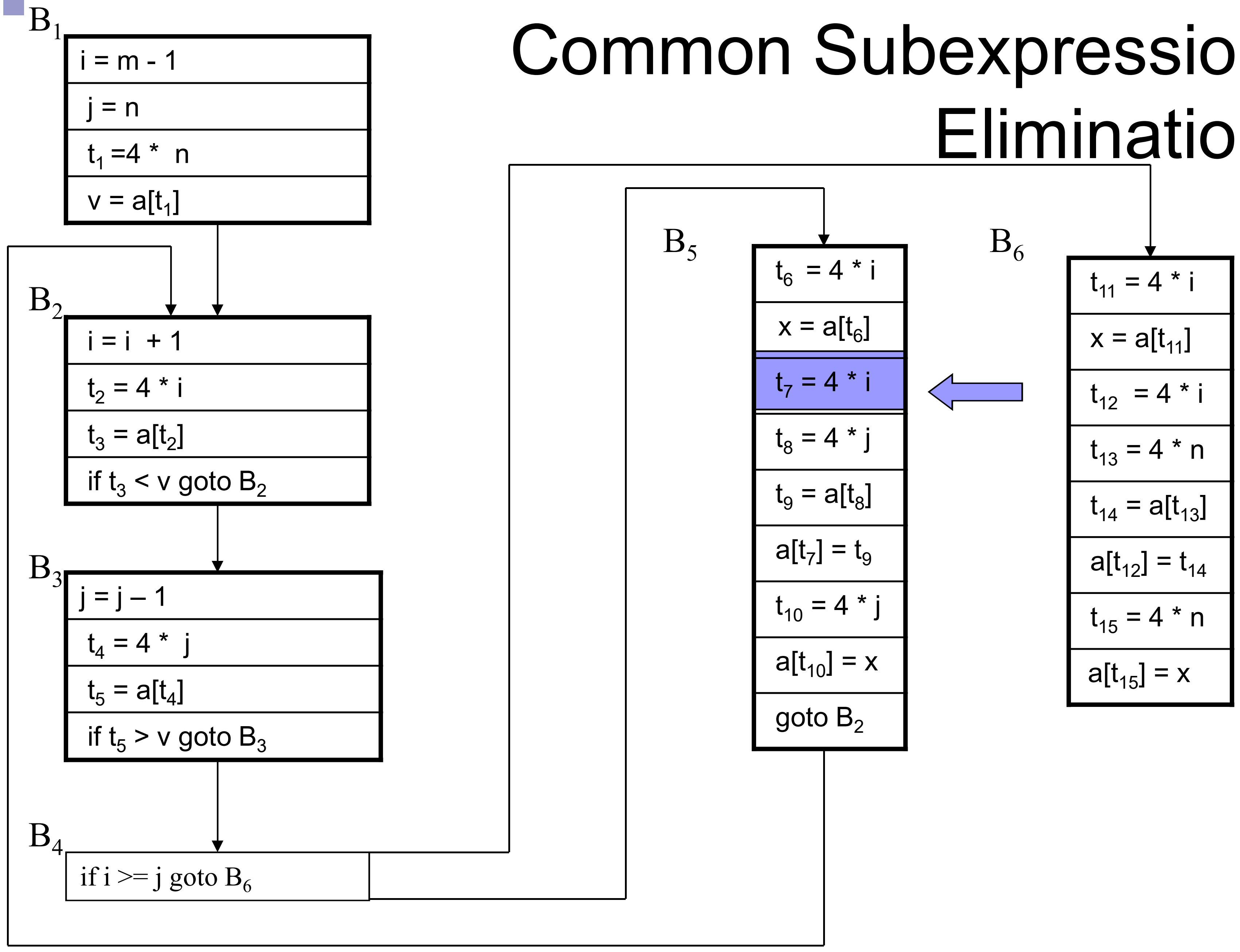
16	$t_7 = 4 * I$
17	$t_8 = 4 * j$
18	$t_9 = a[t_8]$
19	$a[t_7] = t_9$
20	$t_{10} = 4 * j$
21	$a[t_{10}] = x$
22	goto (5)
23	$t_{11} = 4 * i$
24	$x = a[t_{11}]$
25	$t_{12} = 4 * i$
26	$t_{13} = 4 * n$
27	$t_{14} = a[t_{13}]$
28	$a[t_{12}] = t_{14}$
29	$t_{15} = 4 * n$
30	$a[t_{15}] = x$

Flow Graph

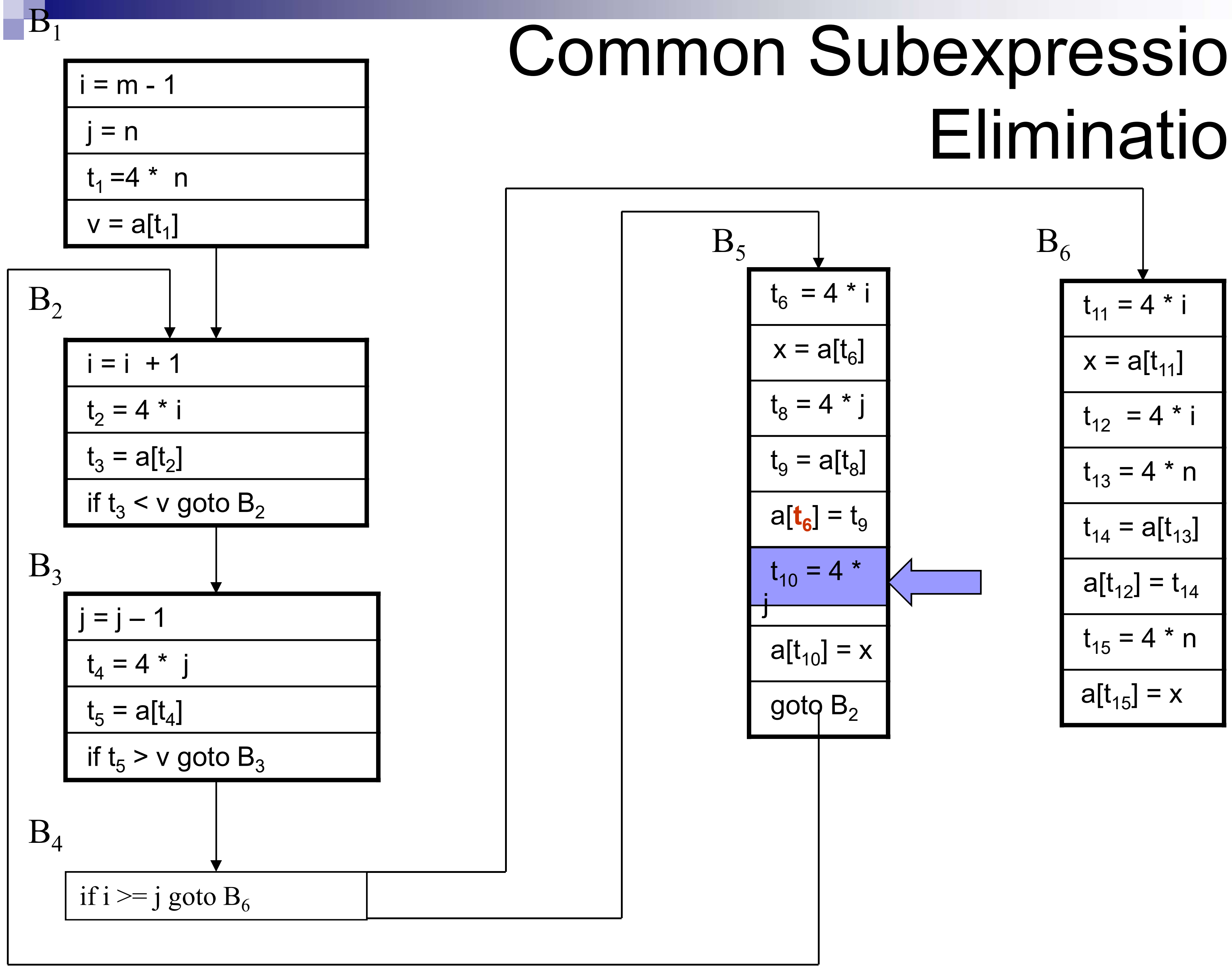


B_1
$i = m - 1$
$j = n$
$t_1 = 4 * n$
$v = a[t_1]$
B_2
$i = i + 1$
$t_2 = 4 * i$
$t_3 = a[t_2]$
if $t_3 < v$ goto B_2
B_3
$j = j – 1$
$t_4 = 4 * j$
$t_5 = a[t_4]$
if $t_5 > v$ goto B_3
B_4
if $i >= j$ goto B_6
B_5
$t_6 = 4 * i$
$x = a[t_6]$
$t_7 = 4 * i$
$t_8 = 4 * j$
$t_9 = a[t_8]$
$a[t_7] = t_9$
$t_{10} = 4 * j$
$a[t_{10}] = x$
goto B_2
B_6
$t_{11} = 4 * i$
$x = a[t_{11}]$
$t_{12} = 4 * i$
$t_{13} = 4 * n$
$t_{14} = a[t_{13}]$
$a[t_{12}] = t_{14}$
$t_{15} = 4 * n$
$a[t_{15}] = x$

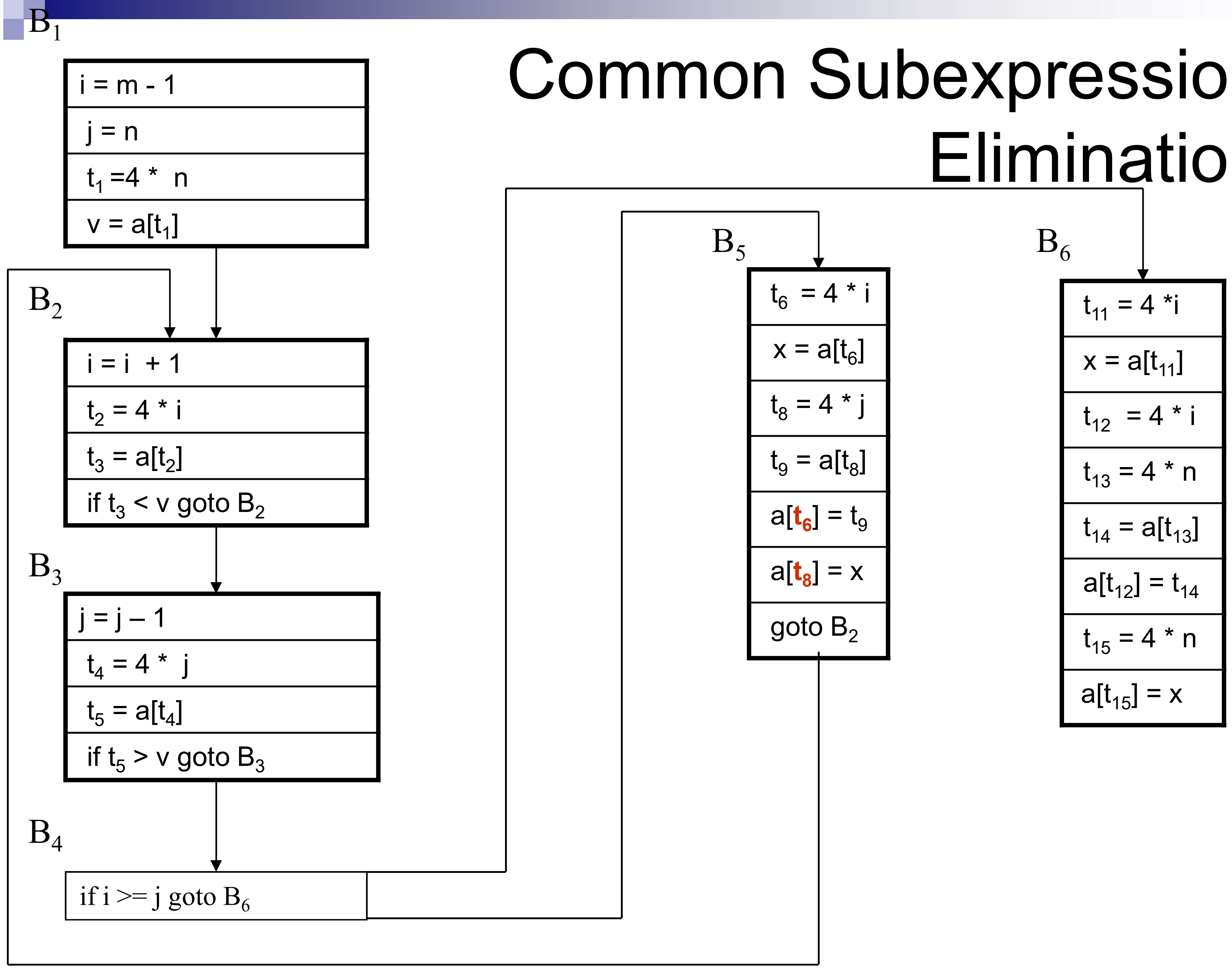
Common Subexpression Elimination



Common Subexpression Elimination



Common Subexpression Elimination



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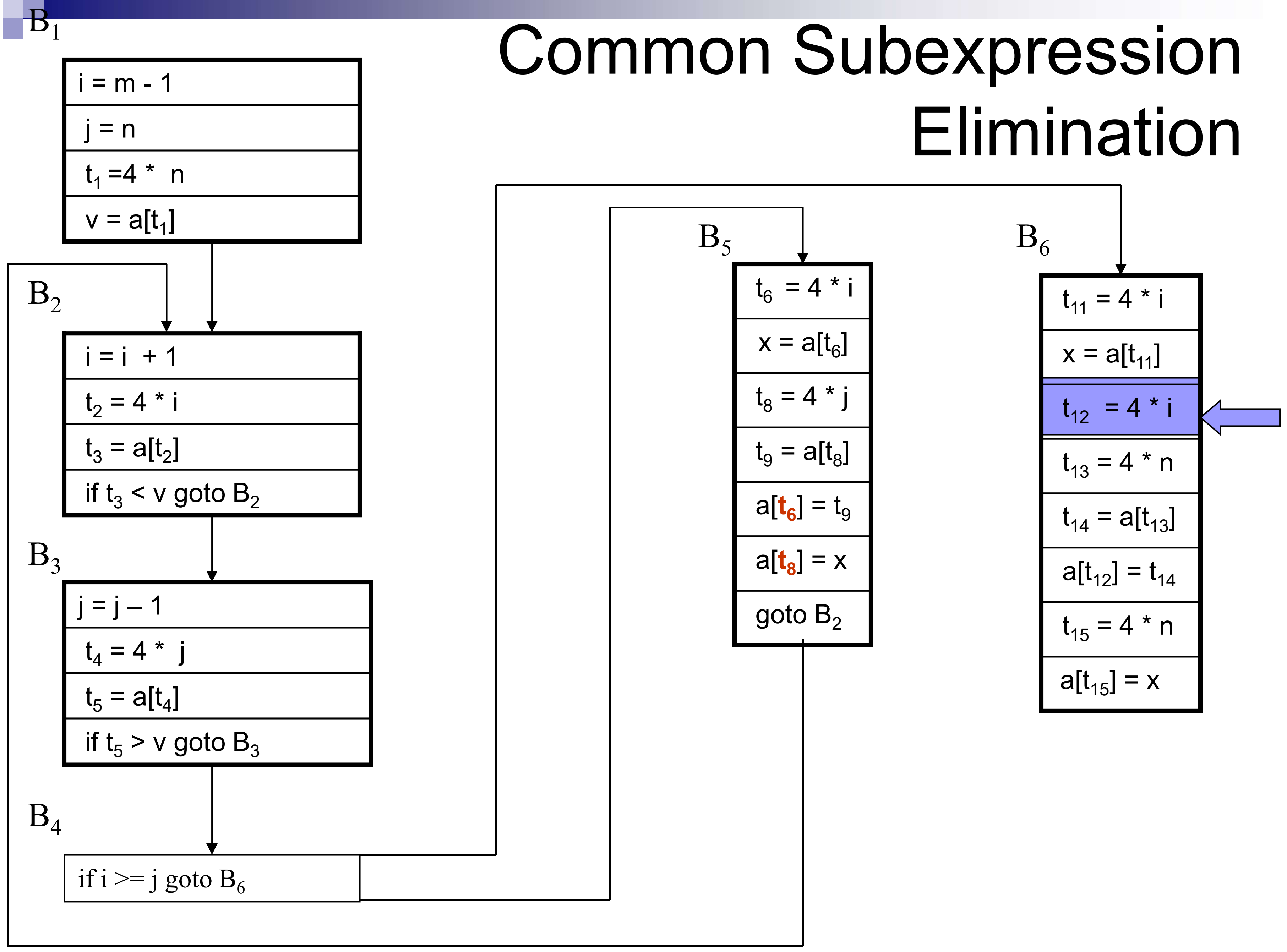
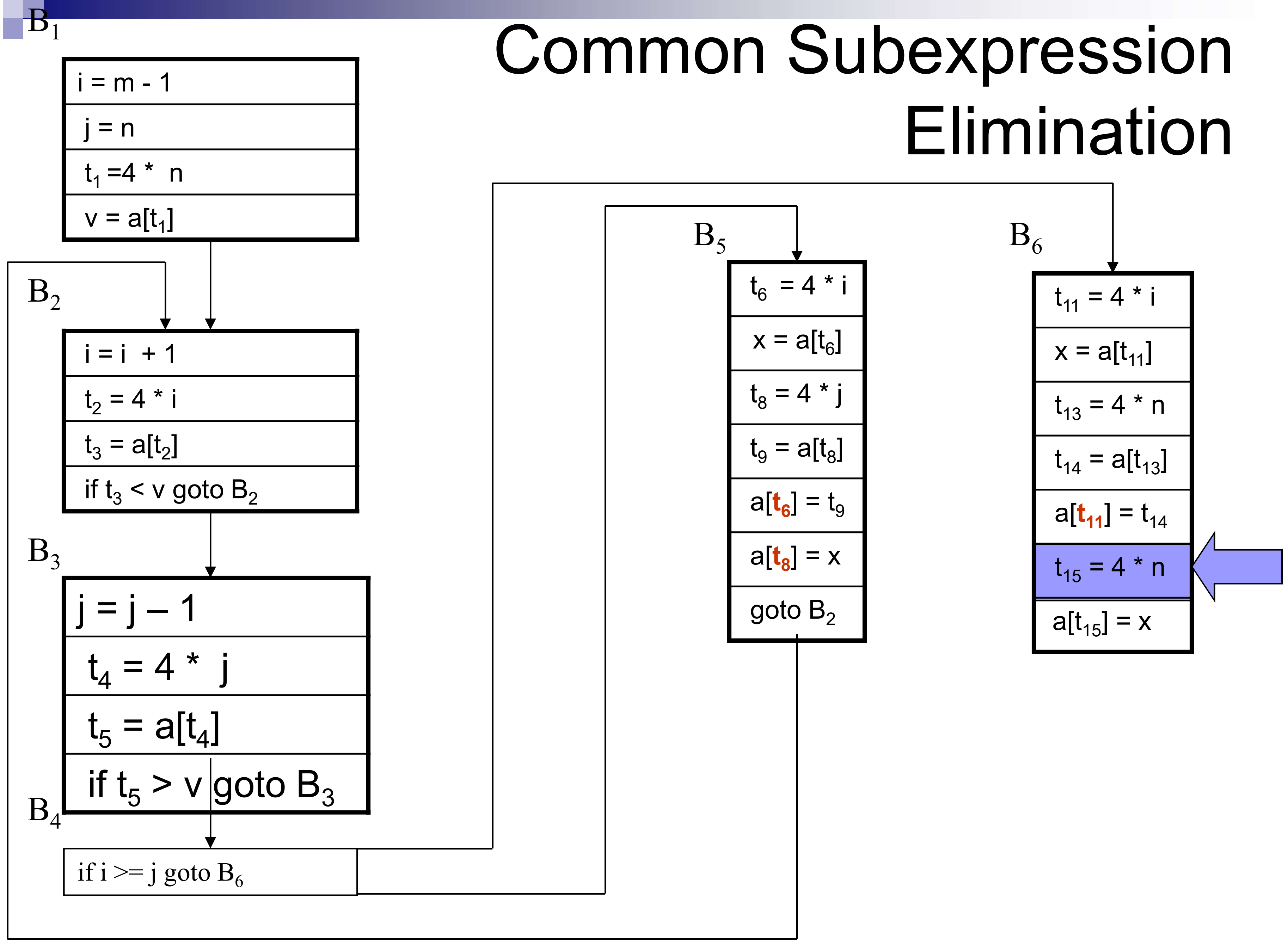
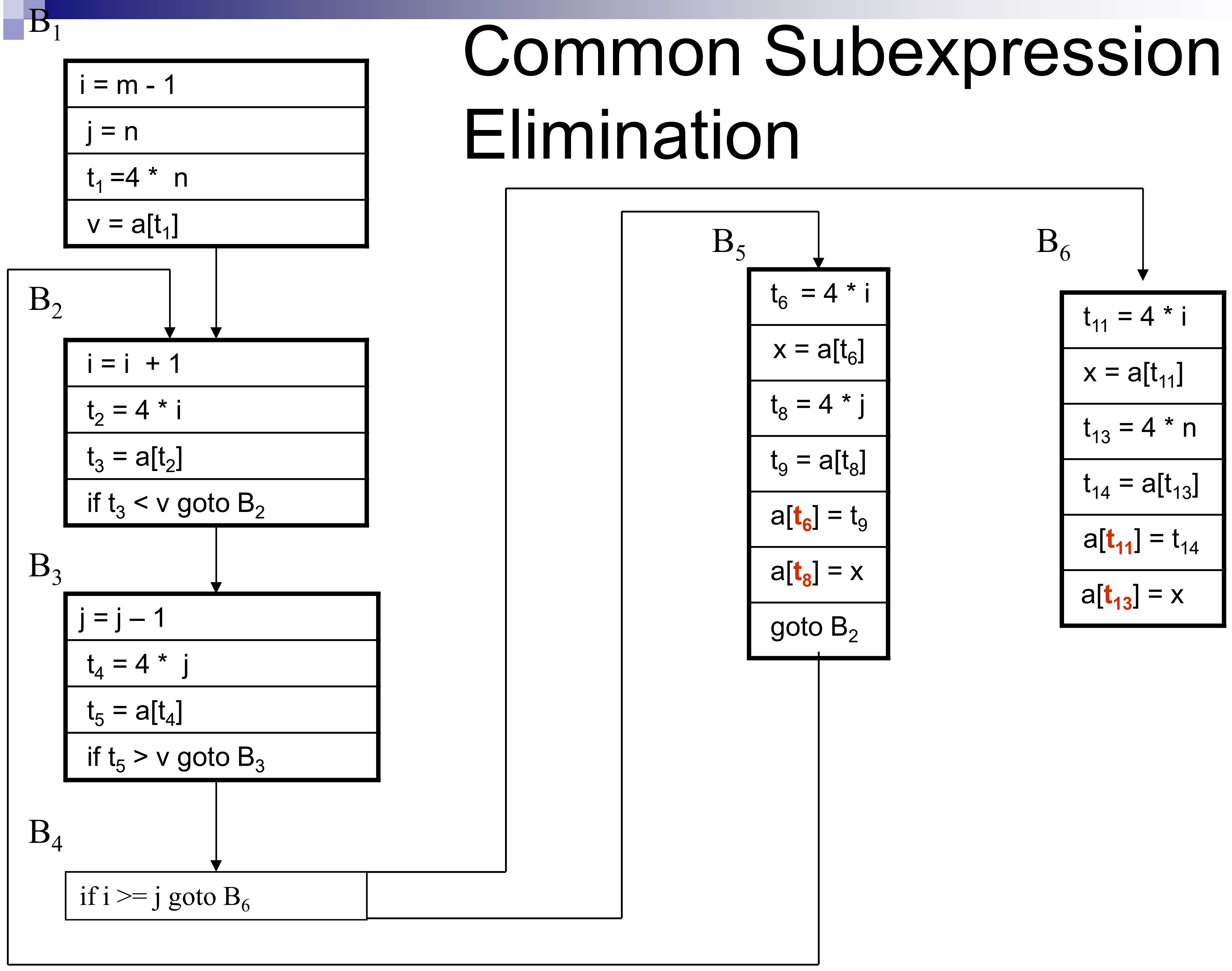


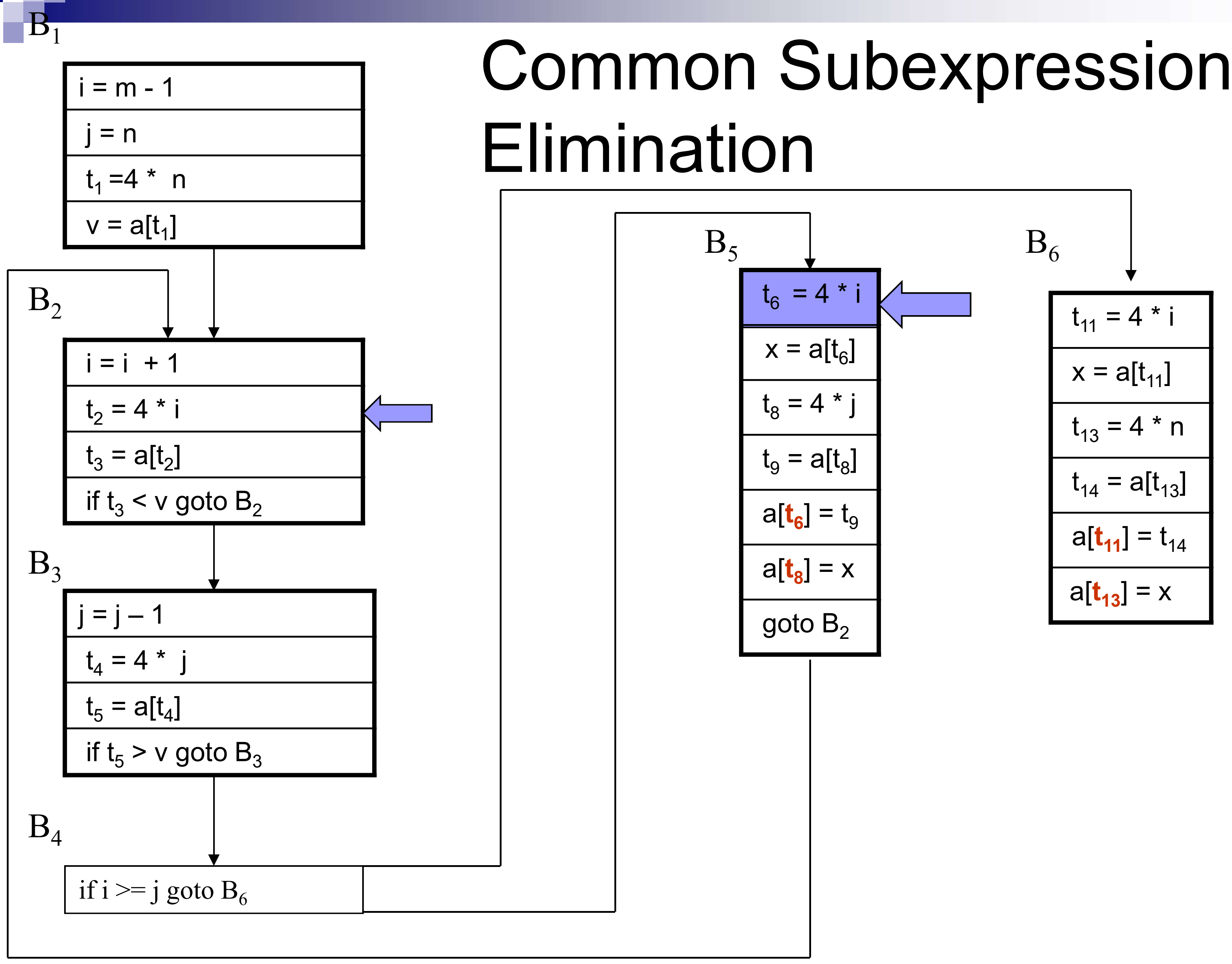
Common Subexpression Elimination



Common Subexpression Elimination



Common Subexpression Elimination



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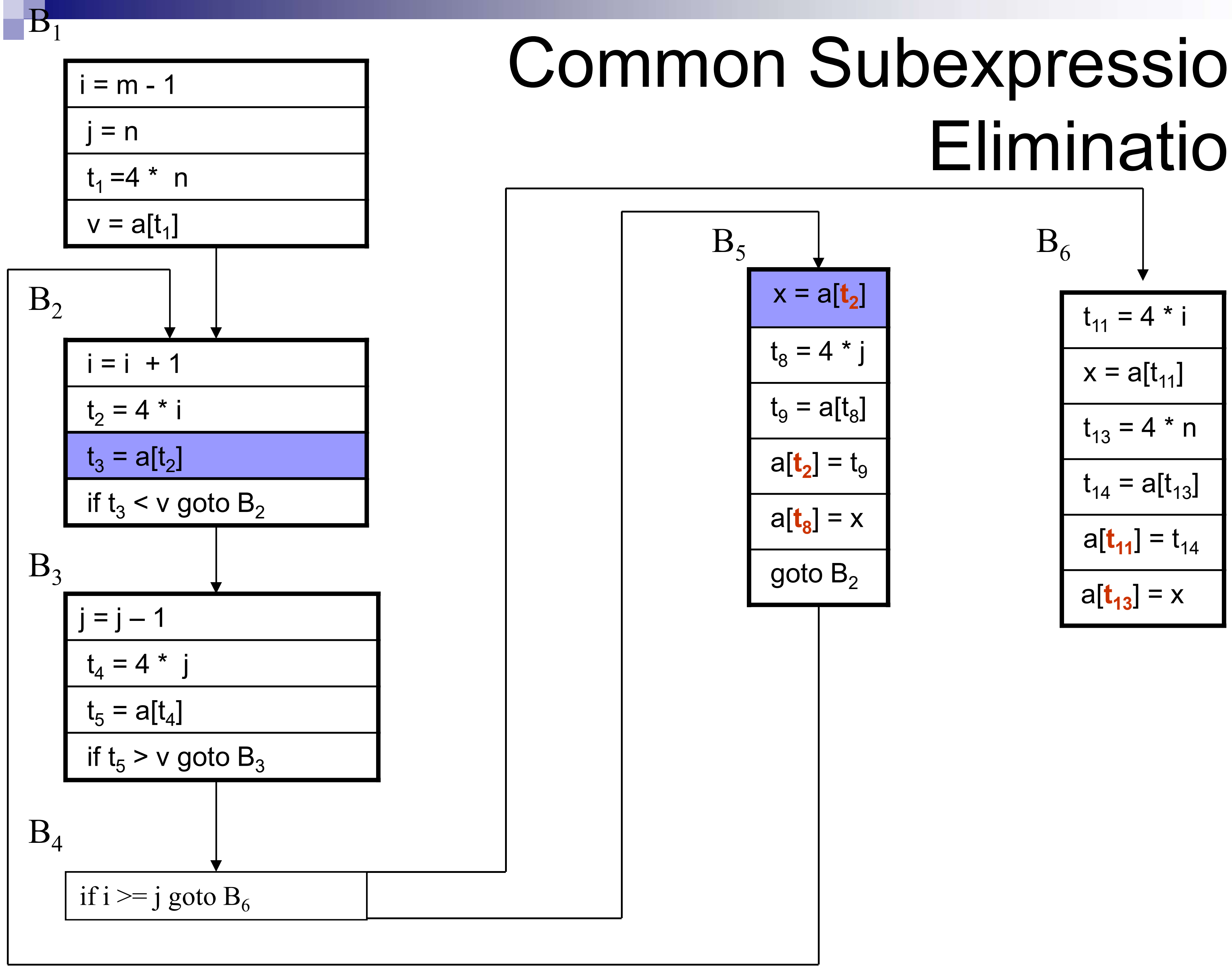
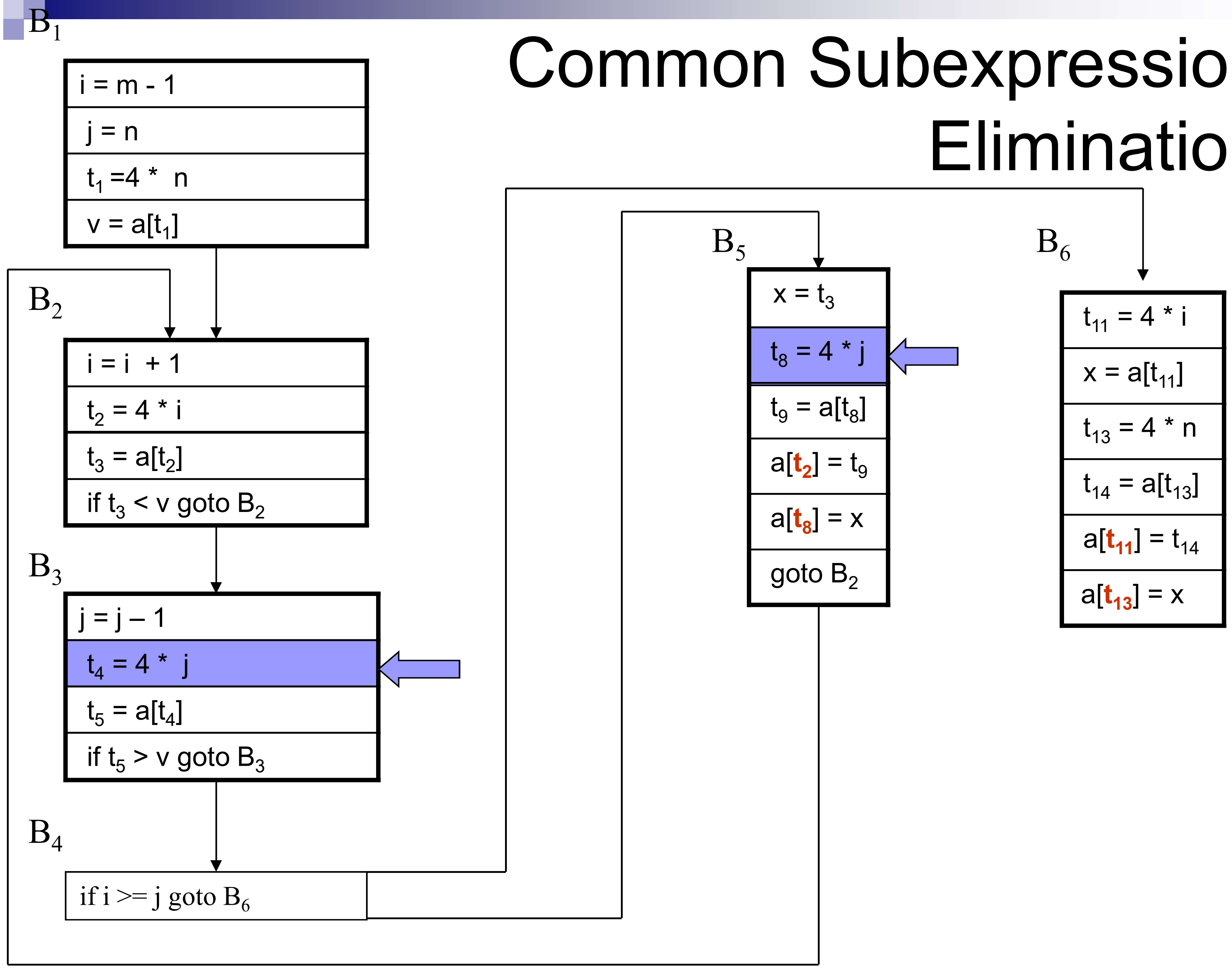


Common Subexpression Elimination



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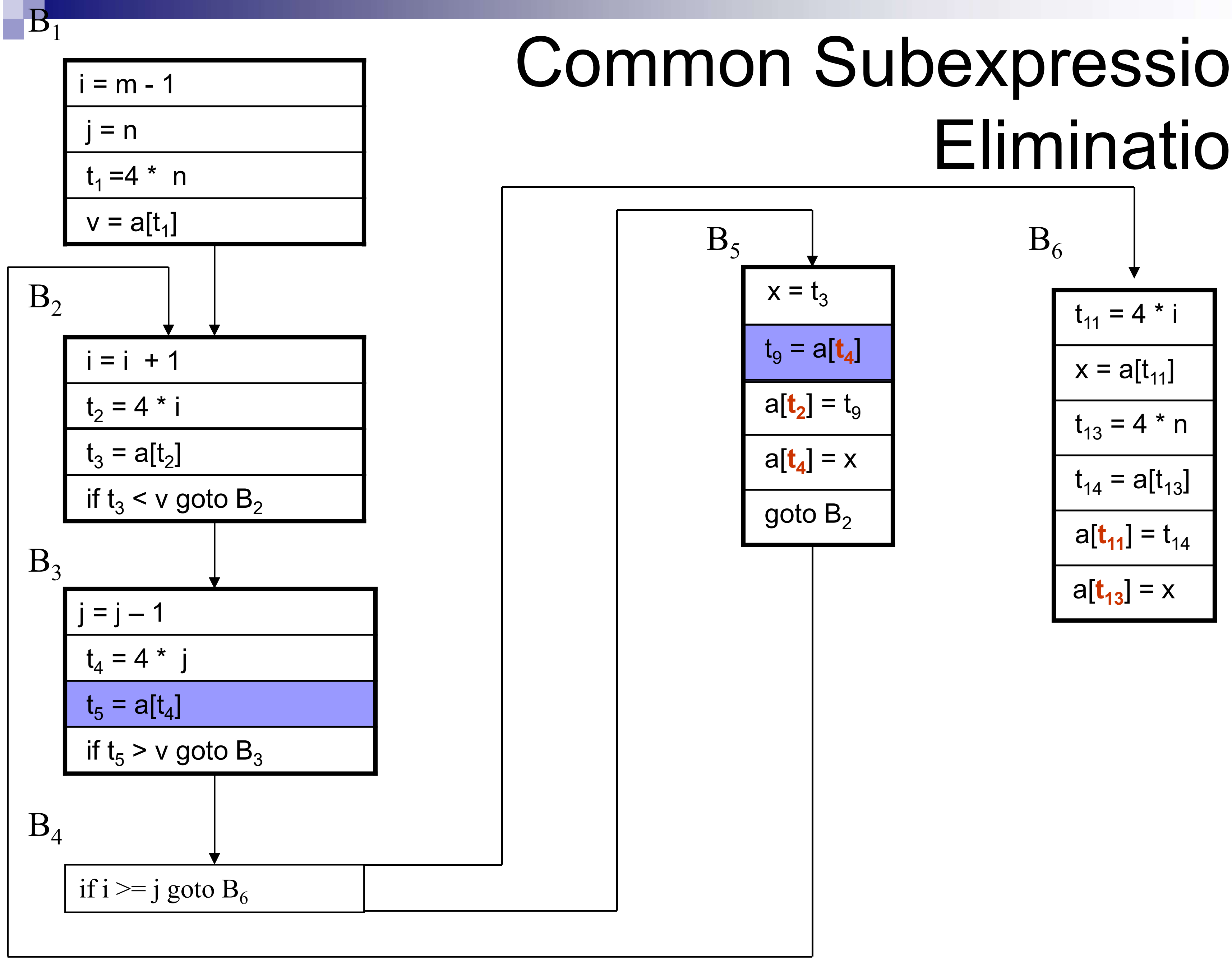

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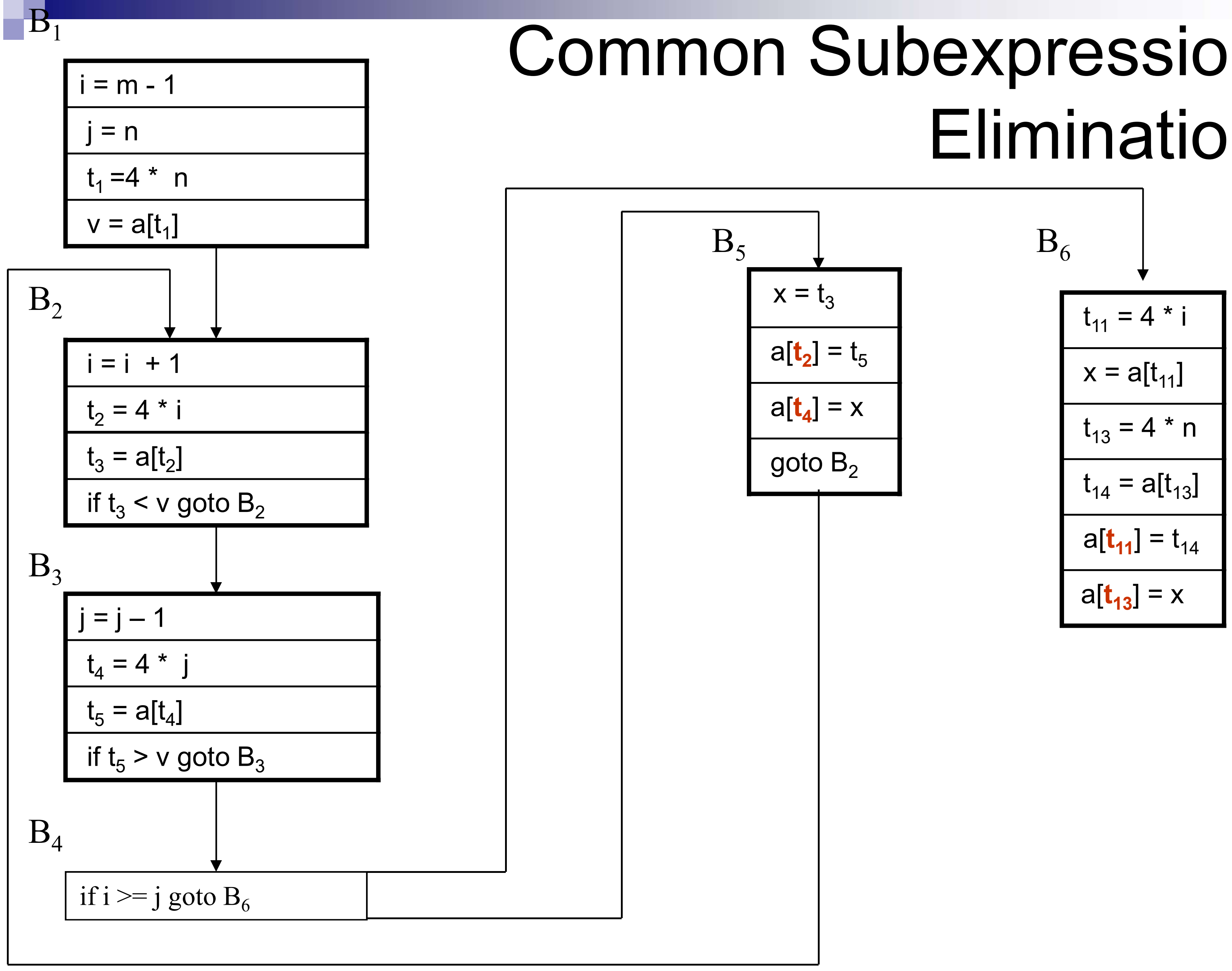

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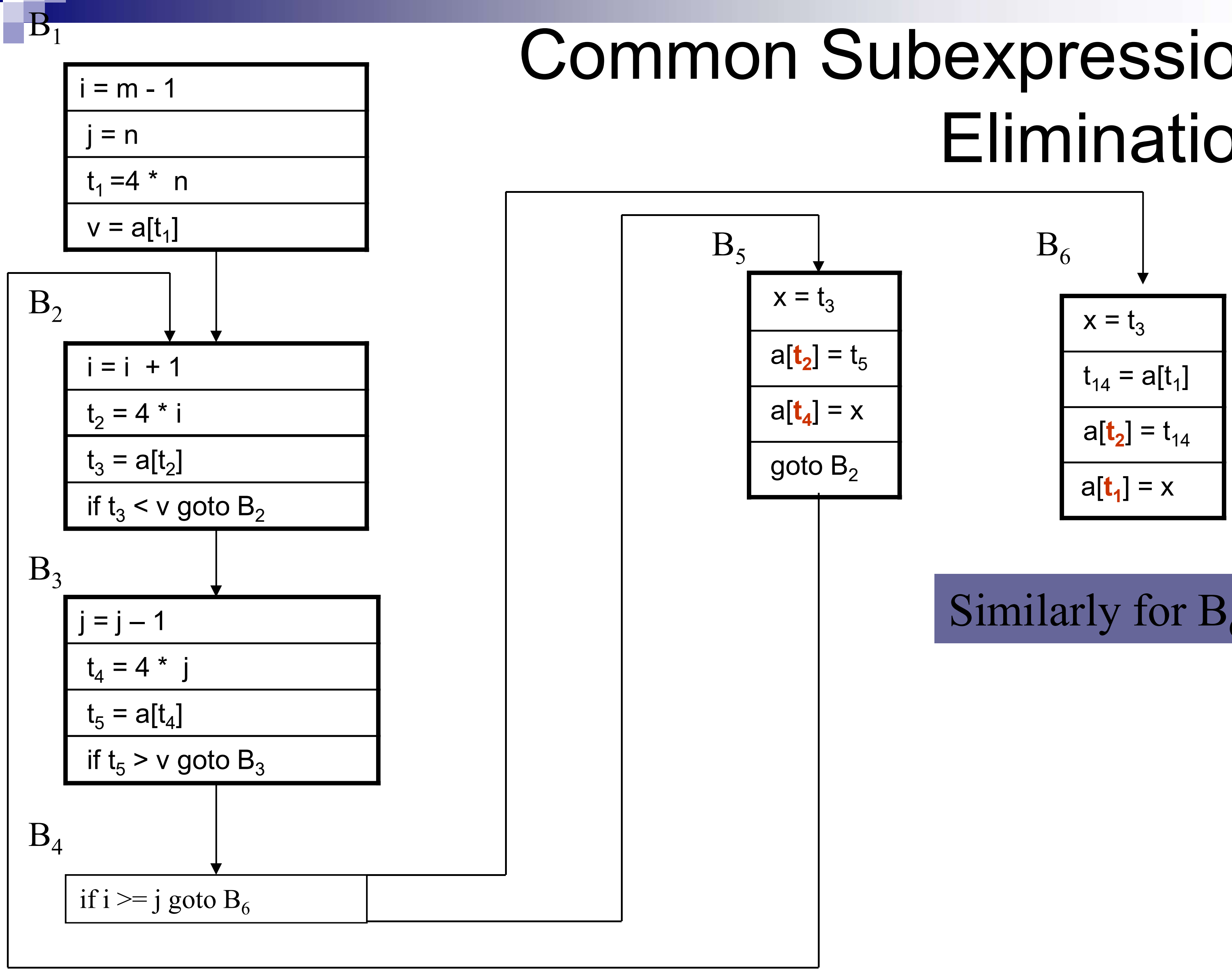
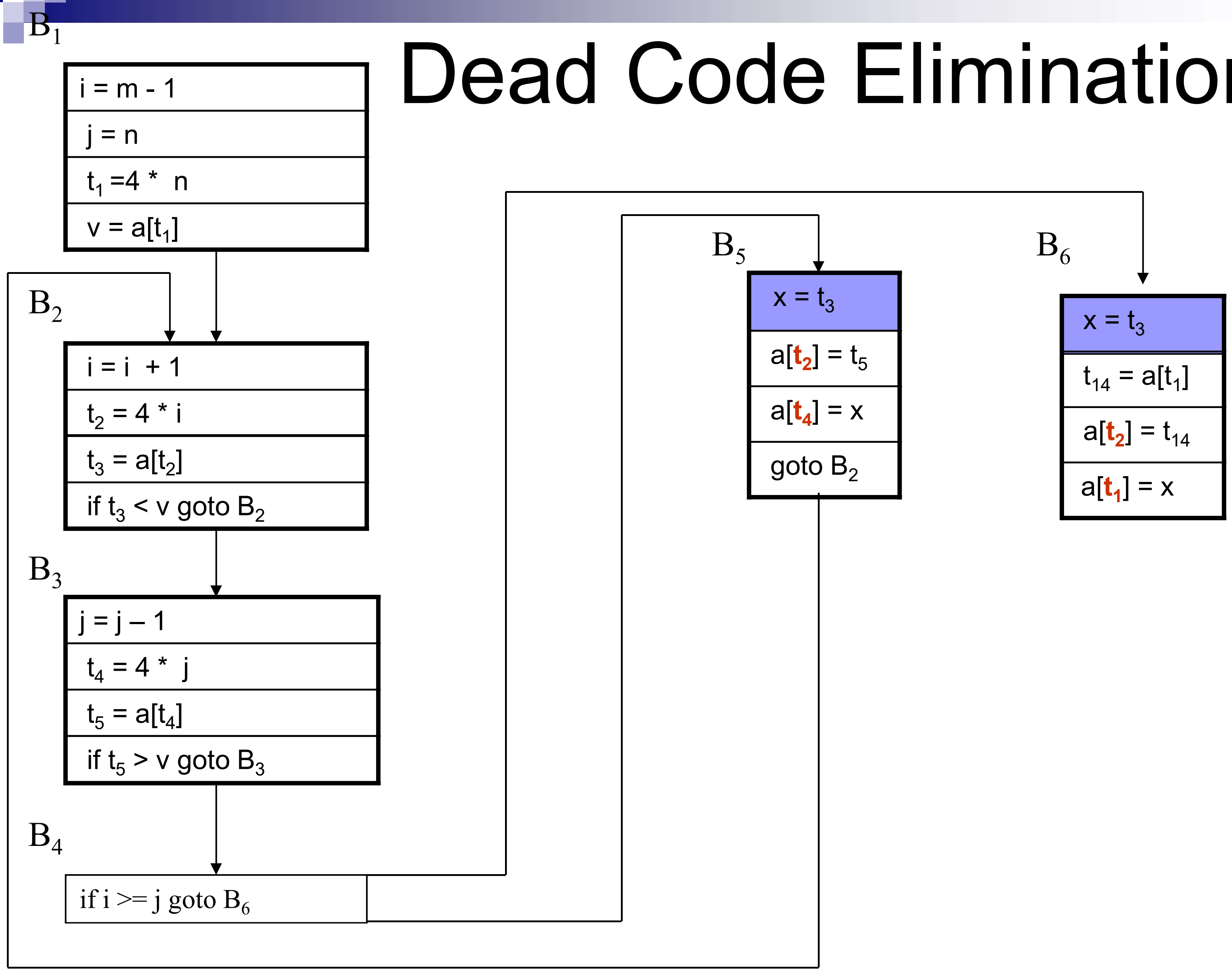
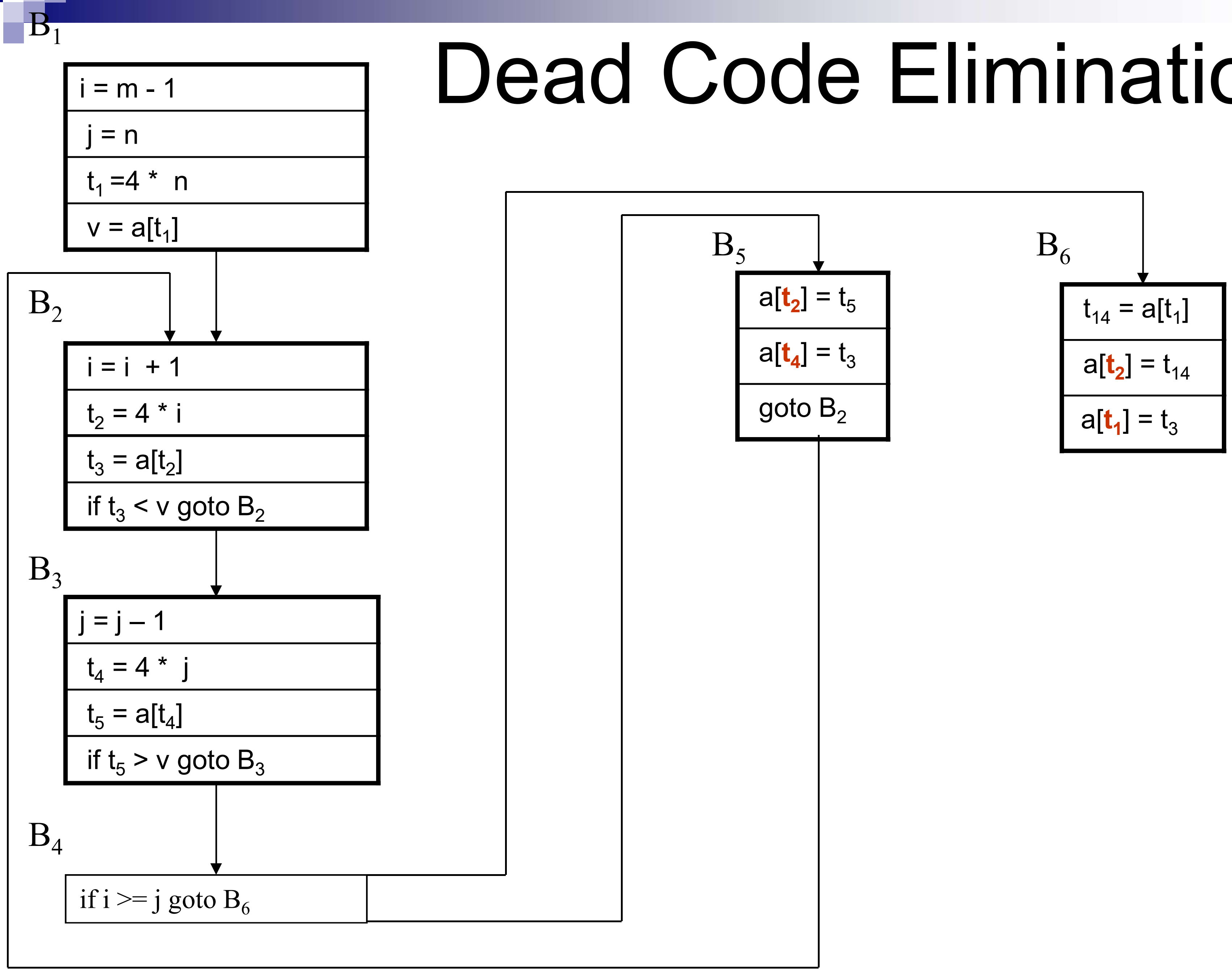


Similarly for B_6

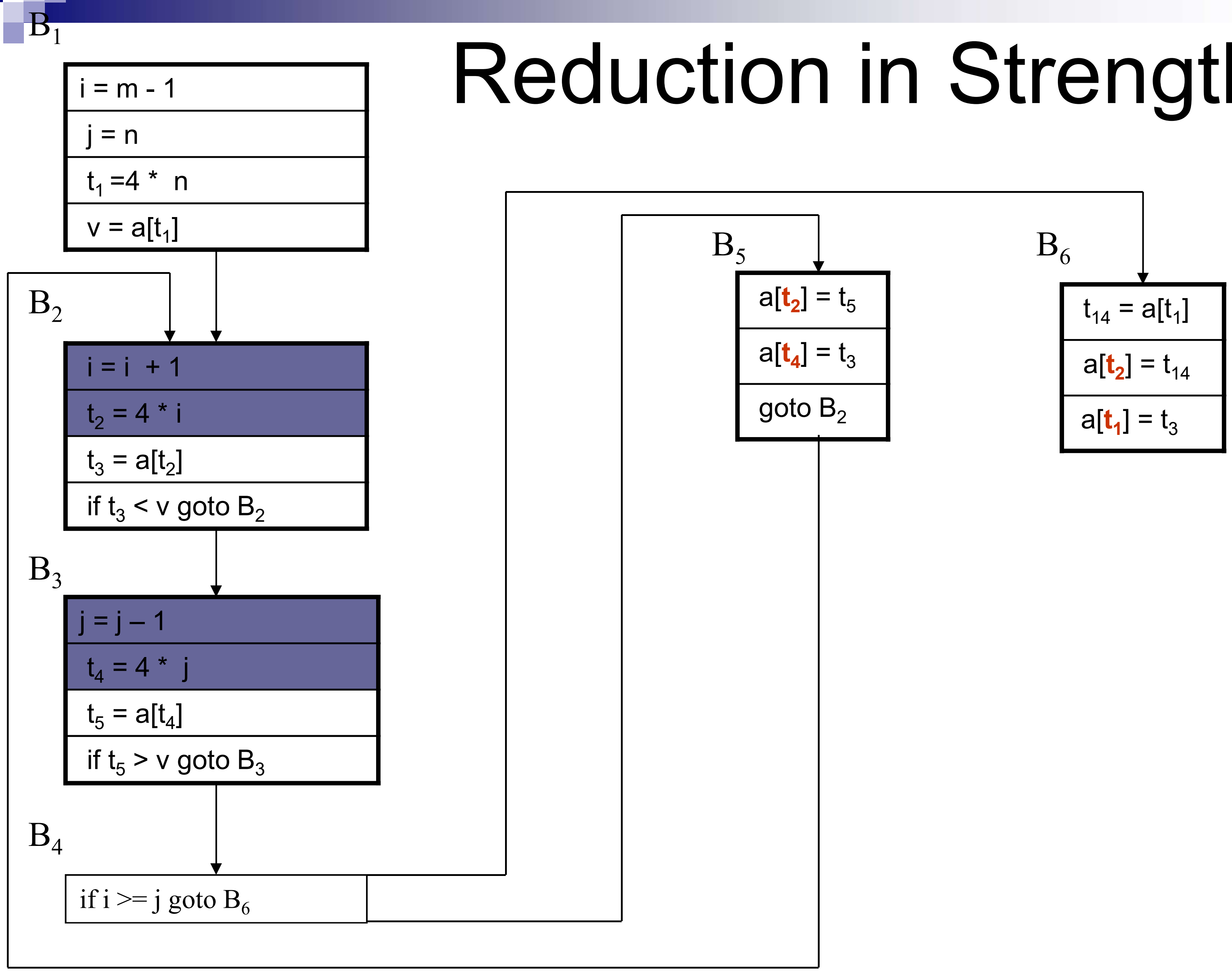
Dead Code Elimination



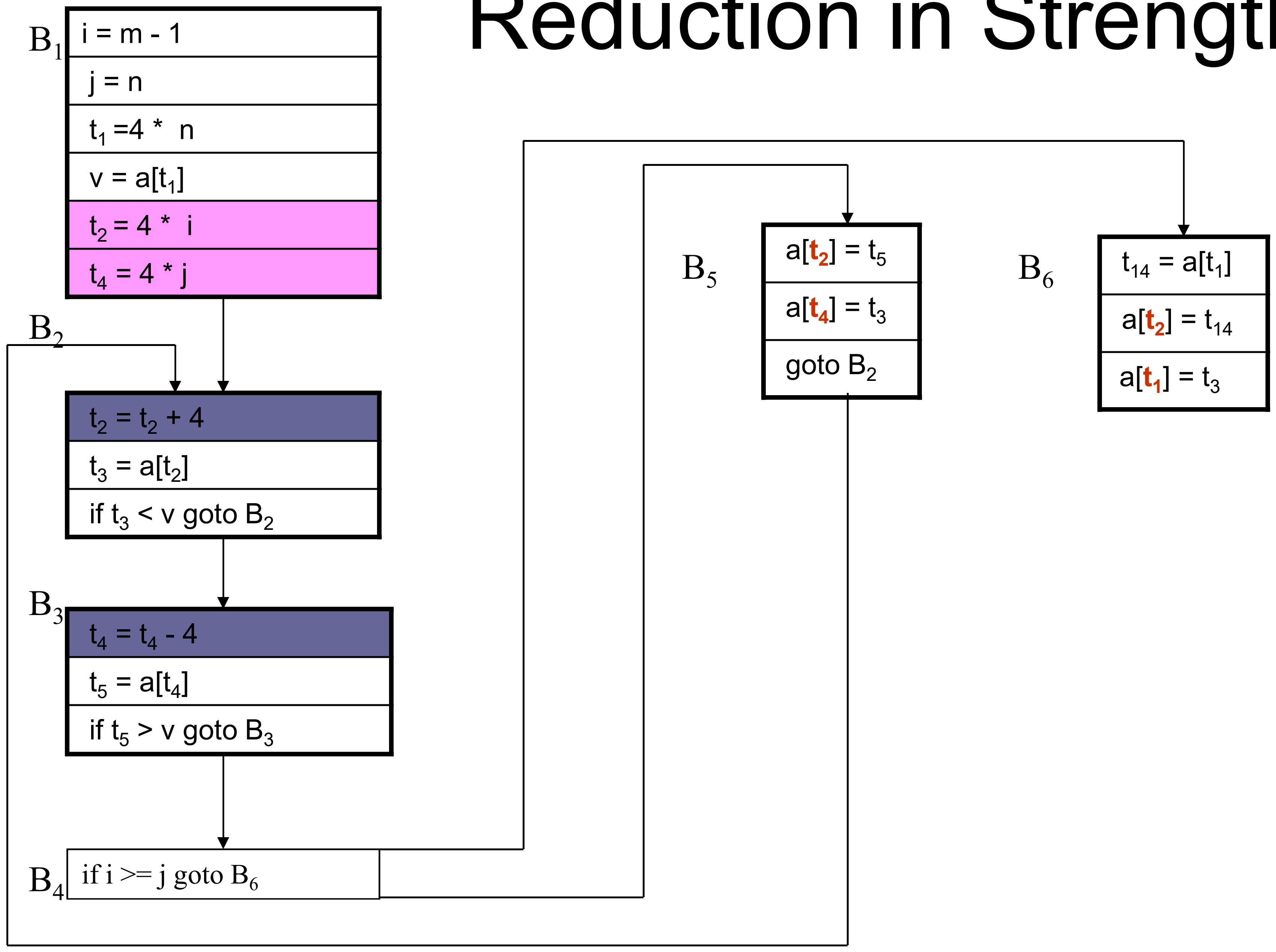
Dead Code Elimination



Reduction in Strength



Reduction in Strength


B$_1$
$i = m - 1$
$j = n$
$t_1 = 4 * n$
$v = a[t_1]$
$t_2 = 4 * i$
$t_4 = 4 * j$
B$_2$
$t_2 = t_2 + 4$
$t_3 = a[t_2]$
if $t_3 < v$ goto B$_2$
B$_3$
$t_4 = t_4 - 4$
$t_5 = a[t_4]$
if $t_5 > v$ goto B$_3$
B$_4$
if i >= j goto B$_6$
B$_5$
$a[t_2] = t_5$
$a[t_4] = t_3$
goto B$_2$
B$_6$
$t_{14} = a[t_1]$
$a[t_2] = t_{14}$
$a[t_1] = t_3$