Compilerconstructie

najaar 2018

http://www.liacs.leidenuniv.nl/~vlietrvan1/coco/

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college 9, vrijdag 23 november 2018
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Code Optimization (1)

8.5 Optimization of Basic Blocks

To improve running time of code

- Local optimization: within block
- Global optimization: across blocks

Local optimization benefits from DAG representation of basic block

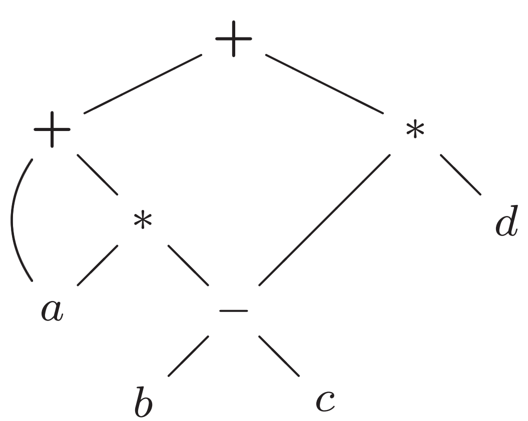
A slide from lecture 6:

6.2 Three-Address Code

- Linearized representation of syntax tree / syntax DAG
- Sequence of instructions: $x = y$ *op* z

Example: $a + a * (b - c) + (b - c) * d$

Syntax DAG

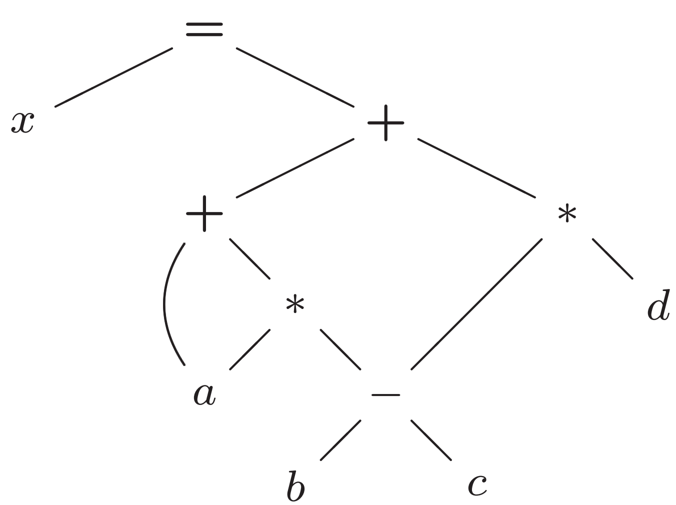


Three-address code

```
t1 = b - c
t2 = a * t1
t3 = a + t2
t4 = t1 * d
t5 = t3 + t4
```

Example: $x = a + a * (b - c) + (b - c) * d$

Syntax DAG

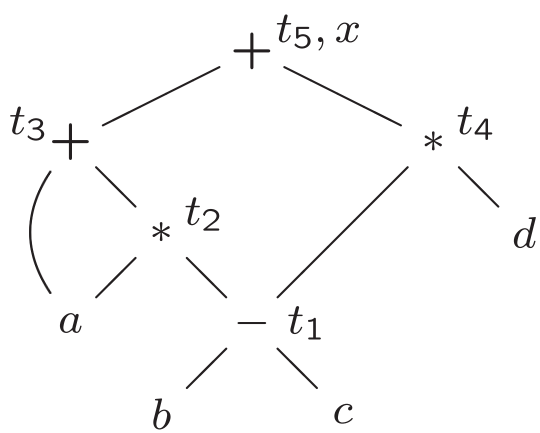


Three-address code

```
t1 = b - c
t2 = a * t1
t3 = a + t2
t4 = t1 * d
t5 = t3 + t4
x = t5
```

Example: $x = a + a * (b - c) + (b - c) * d$

DAG representation of basic block



Three-address code

```
t1 = b - c
t2 = a * t1
t3 = a + t2
t4 = t1 * d
t5 = t3 + t4
x = t5
```

8.5.1 DAG Representation of Basic Blocks

1. A node for initial value of each variable appearing in block
2. A node N for each statement s in block
   Children of N are nodes corresponding to last definitions of operands used by s
3. Node N is labeled by operator applied at s
   N has list of variables for which s is last definition in block
4. *Output nodes* $\approx$ live on exit

Example:

```
a = b + c
b = a - d
c = b + c
d = a - d
```

8.5.2 Finding Local Common Subexpressions

- Use value-number method to detect common subexpressions

- Remove redundant computations

Example:

```
a = b + c
b = a - d
c = b + c
d = a - d
```

Local Common Subexpression Elimination

- Use value-number method to detect common subexpressions
- Remove redundant computations

Example:

`a = b + c`	`a = b + c`
`b = a - d`	`b = a - d`
`c = b + c`	`c = b + c`
`d = a - d`	`d = b`

Local Common Subexpression Elimination

- Use value-number method to detect common subexpressions
- Remove redundant computations

Example, if b is not live on exit:

`a = b + c`	`a = b + c`
`b = a - d`	`d = a - d`
`c = b + c`	`c = d + c`
`d = a - d`	

Different assignments to same variable

```
d=a+b
e=d+c
d=b+c
c=a+d
```

DAG. . .
reconstructing code. . .

8.5.3 Dead Code Elimination

- Remove roots with no live variables attached

- If possible, repeat

Example:

```
a = b + c
b = b - d
c = c + d
e = b + c
```

No common subexpression

If c and e are not live. . .

Dead Code Elimination

- Remove roots with no live variables attached

- If possible, repeat

Example:

`a = b + c`	`a = b + c`
`b = b - d`	`b = b - d`
`c = c + d`	
`e = b + c`	

No common subexpression

If c and e are not live. . .

8.5.5 Representation of Array References

```
x = a[i]
y = x+z
z = a[i]
```

DAG. . .

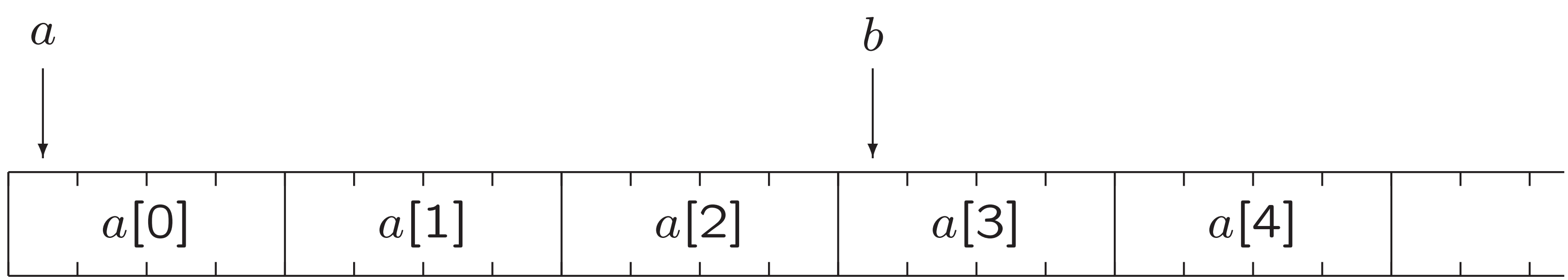
Representation of Array References

```
x = a[i]
a[j] = y
z = a[i]
```

DAG. . .

Representation of Array References

```
b = 12 + a
x = b[i]
a[j] = y
z = b[i]
```



DAG. . .

8.5.6 Pointer Assignments and Procedure Calls

```
a = b + c
e = a - d
c = b + c
b = a - d
```

DAG. . .

Pointer Assignments vs. Common Subexpressions

```
p = &a
a = b + c
e = a - d
*p = y
c = b + c
b = a - d
```

DAG. . .

Pointer Assignments vs. Common Subexpressions

```
a = b + c
e = a - d
*p = y
c = b + c
b = a - d
```

DAG. . .

Pointer Assignments vs. Dead Code

```
a = b + c
b = b - d
c = c + d
e = b + c
x = *p
```

DAG. . .

If c and e are not live. . .

To summarize:

```
*q = y
x = *p
```

Procedure calls. . .

8.5.4 The Use of Algebraic Identities

and other algebraic transformations

(cf. assignment 3)

Algebraic identities:

$$\begin{aligned} x + 0 &= 0 + x &= x \\ x * 1 &= 1 * x &= x \end{aligned}$$

Reduction in strength:

$$\begin{aligned} x^2 &= x * x & \text{(cheaper)} \\ 2 * x &= x + x & \text{(cheaper)} \\ x/2 &= x * 0.5 & \text{(cheaper)} \end{aligned}$$

Constant folding:

$$2 * 3.14 = 6.28$$

Algebraic Transformations

Common subexpressions resulting from commutativity / associativity of operators:

$$\begin{aligned} x * y &= y * x \\ c + d + b &= (b + c) + d \end{aligned}$$

Common subexpressions generated by relational operators:

$$x > y \;\Leftrightarrow\; x - y > 0$$

8.5.7 Reassembling Basic Blocks From DAG's

Order of instructions:

A. Order of instructions must respect order of nodes in DAG

B. Uses of same array may cross each other only if both are array accesses

C. No statement may cross procedure call or assignment through pointer

8.5.7 Reassembling Basic Blocks From DAG's

Order of instructions:

A. Order of instructions must respect order of nodes in DAG

B. Uses of same array may cross each other only if both are array accesses

C. No statement may cross procedure call or assignment through pointer

D. Assignments to same variable may not cross each other

8.7 Peephole Optimization

- Examines short sequence of instructions in a window (peep-hole) and replace them by faster/shorter sequence
- Applied to intermediate code or target code
- Typical optimizations
  - Redundant instruction elimination
  - Eliminating unreachable code
  - Flow-of-control optimization
  - Algebraic simplification
  - Use of machine idioms

8.7.1 Eliminating Redundant Loads and Stores

Naive code generator may produce

```
ST  a, R0
LD  R0, a
```

N.B.: optimize only within basic block

8.7.2 Eliminating Unreachable Code

Example:

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

Jump over jump

Eliminating Unreachable Code

Example:

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

How to recognize that label `L1` can be removed?

Eliminating Unreachable Code

Example:

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

If `debug` is set to 0 at beginning of program, . . .

8.7.2 Eliminating Unreachable Code

Example:

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

Even without jump over jump. . .

8.7.3 Flow-of-Control Optimizations

Example 1:

```
     goto L1
     ...
L1:  goto L2
```

Example 3:

```
     goto L1
     . . .
L1:  if a < b goto L2
L3:
```

8.7.3 Flow-of-Control Optimizations

Example 1:

```
     goto L1                                   goto L2
     ...                                       ...
L1:  goto L2                              L1:  goto L2
```

Example 3:

```
     goto L1                                   if a < b goto L2
     . . .                                     goto L3
L1:  if a < b goto L2                          ...
L3:                                       L3:
```

9.1 The Principal Sources of Optimization

Causes of redundancy

- At source level

- Side effect of high-level programming language, e.g., $A[i][j]$

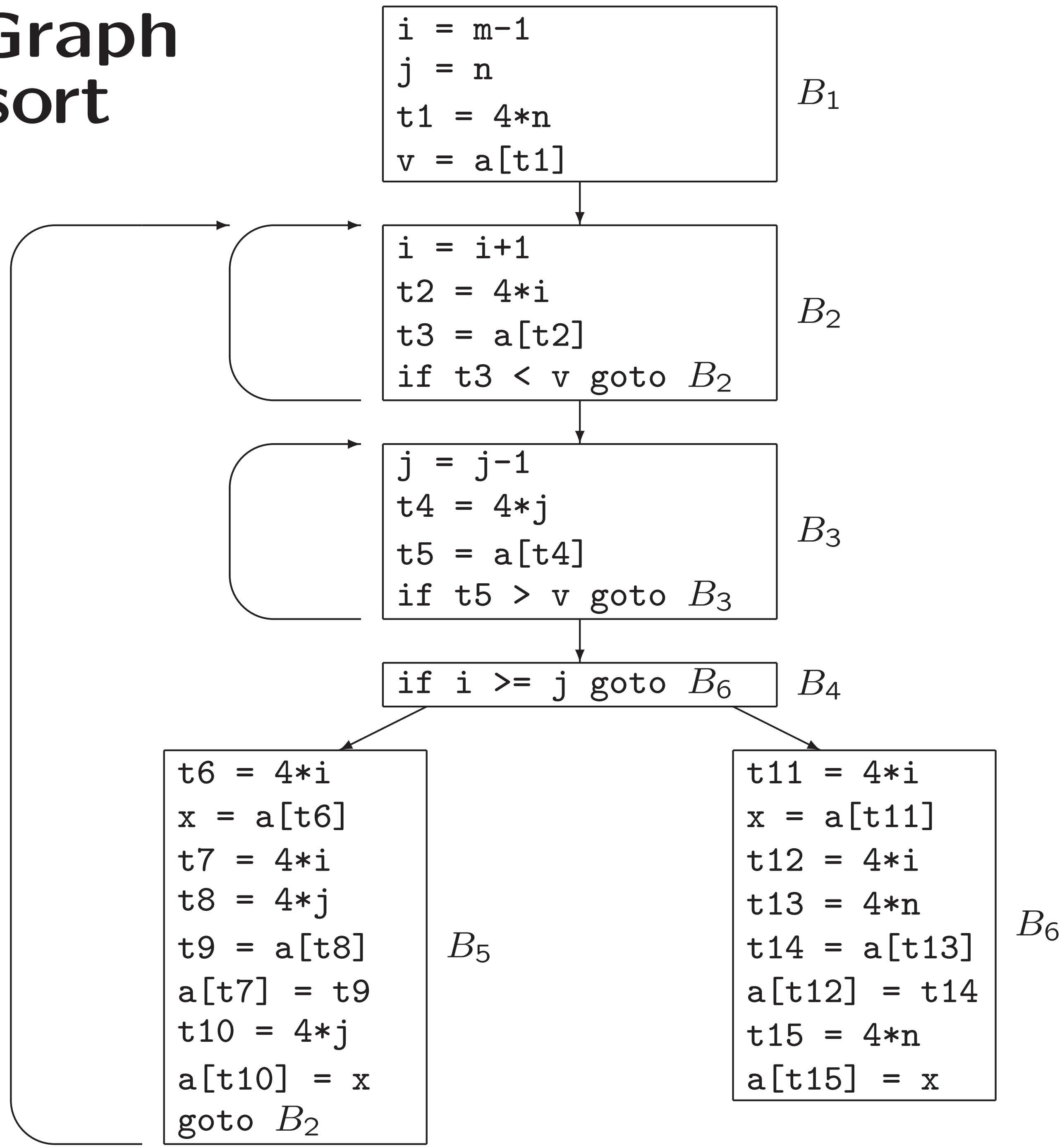
9.1.2 A Running Example: Quicksort

```
void quicksort (int m, int n)
    /* recursively sorts 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; /* swap a[i], a[j] */
    }
    x = a[i]; a[i] = a[n]; a[n] = x; /* swap a[i], a[n] */

    quicksort(m,j); quicksort(i+1,n);
}
```

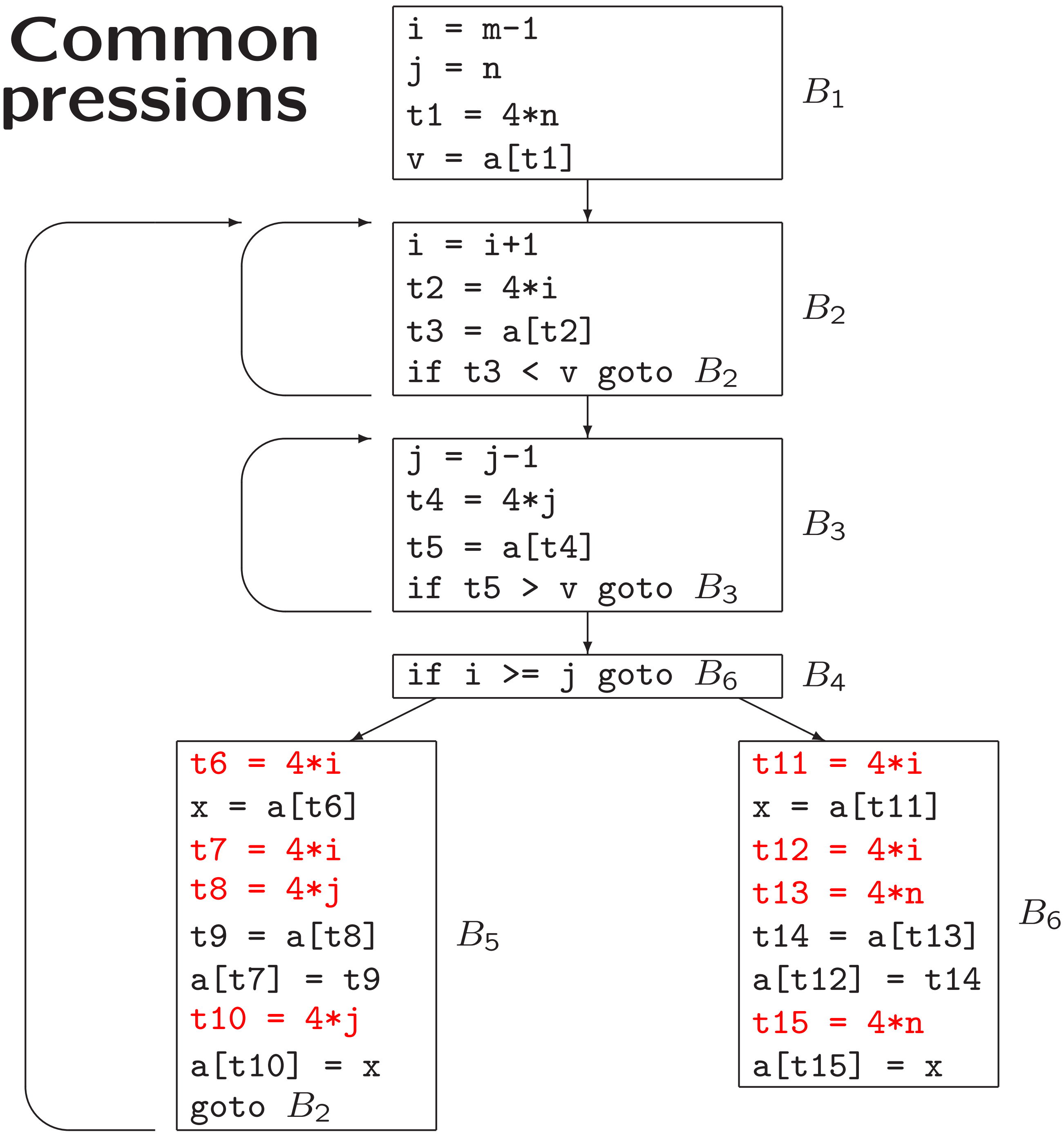
Three-Address Code Quicksort

```
→   (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
```

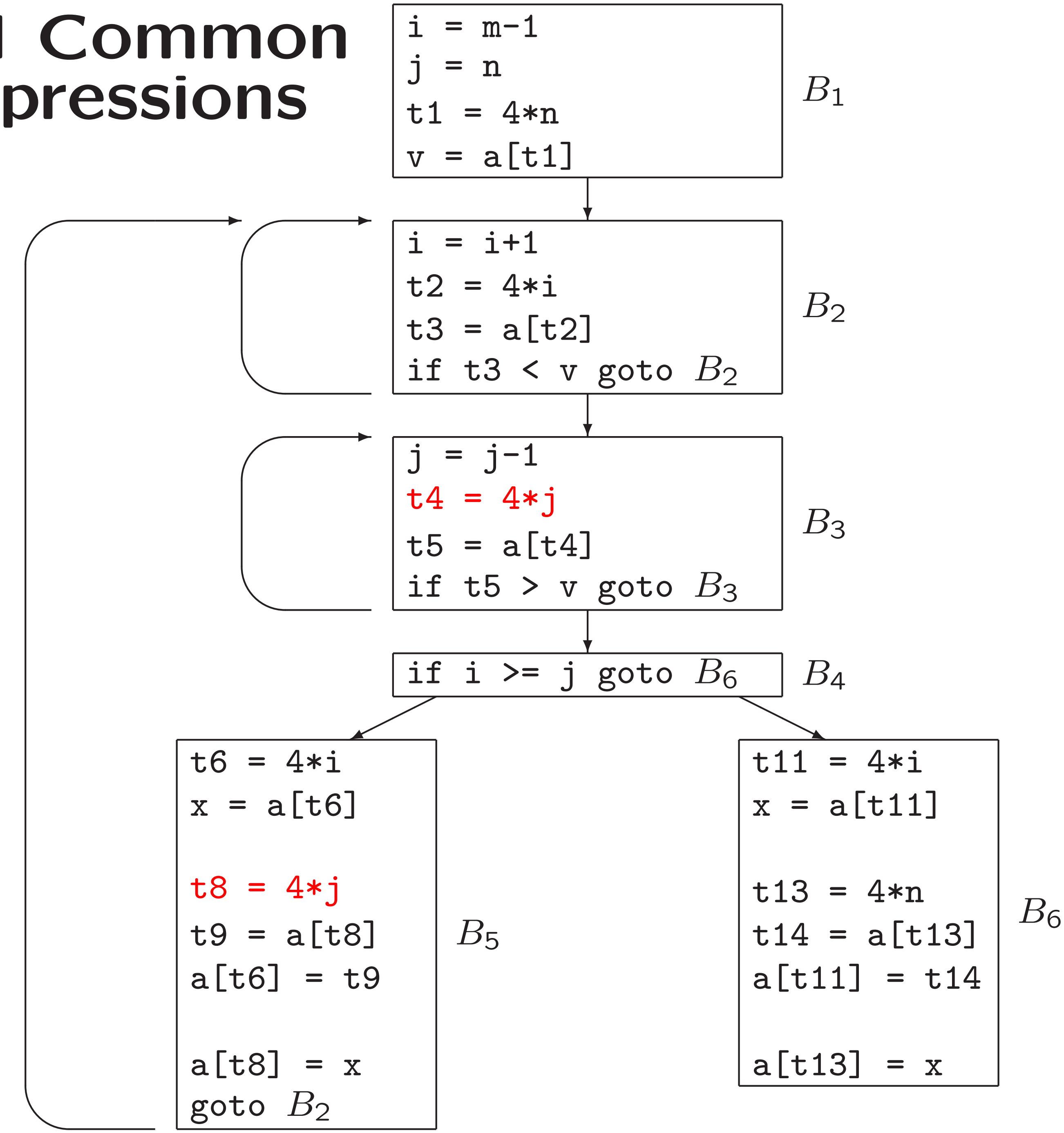
Flow Graph Quicksort



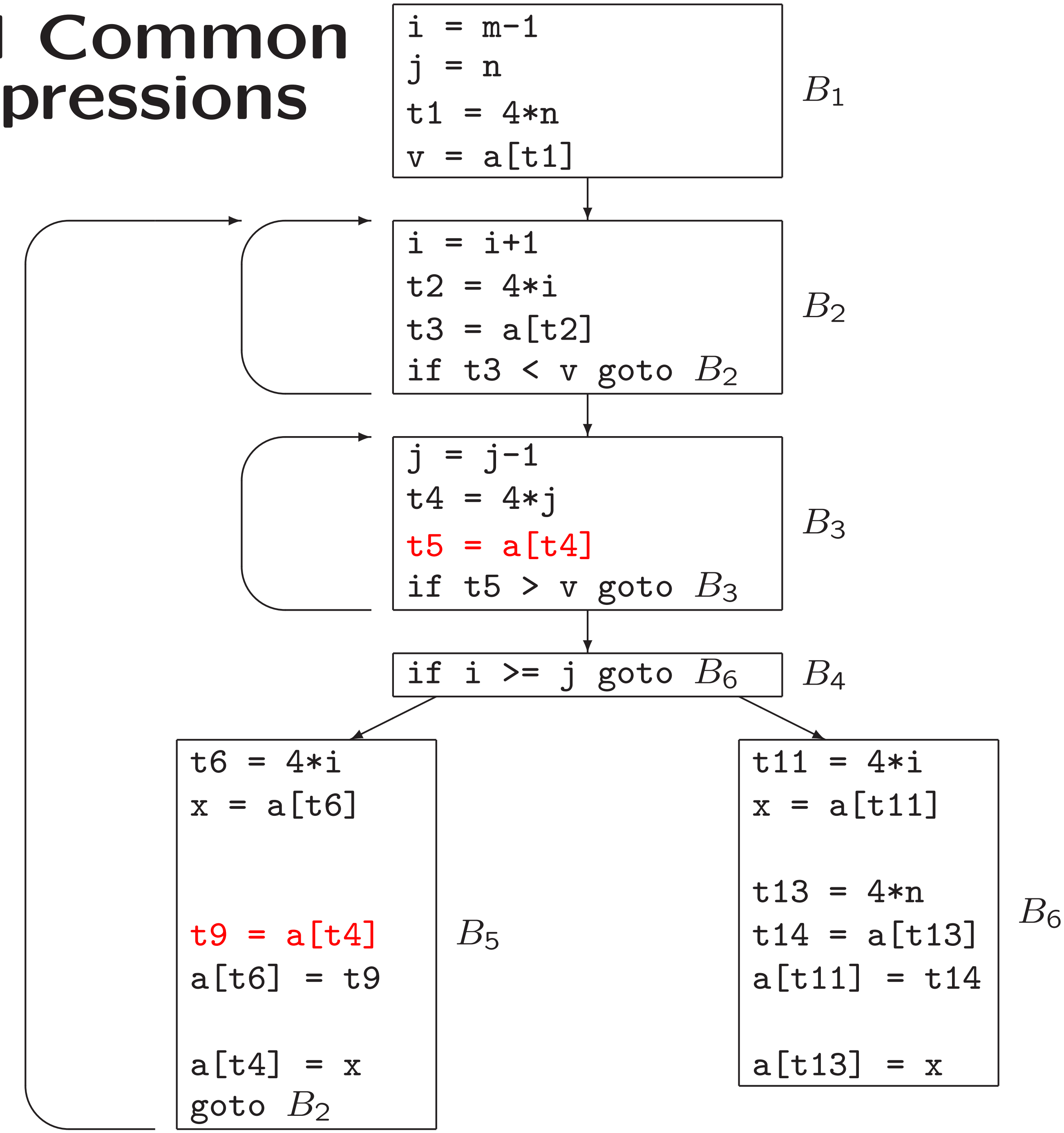
Local Common Subexpressions



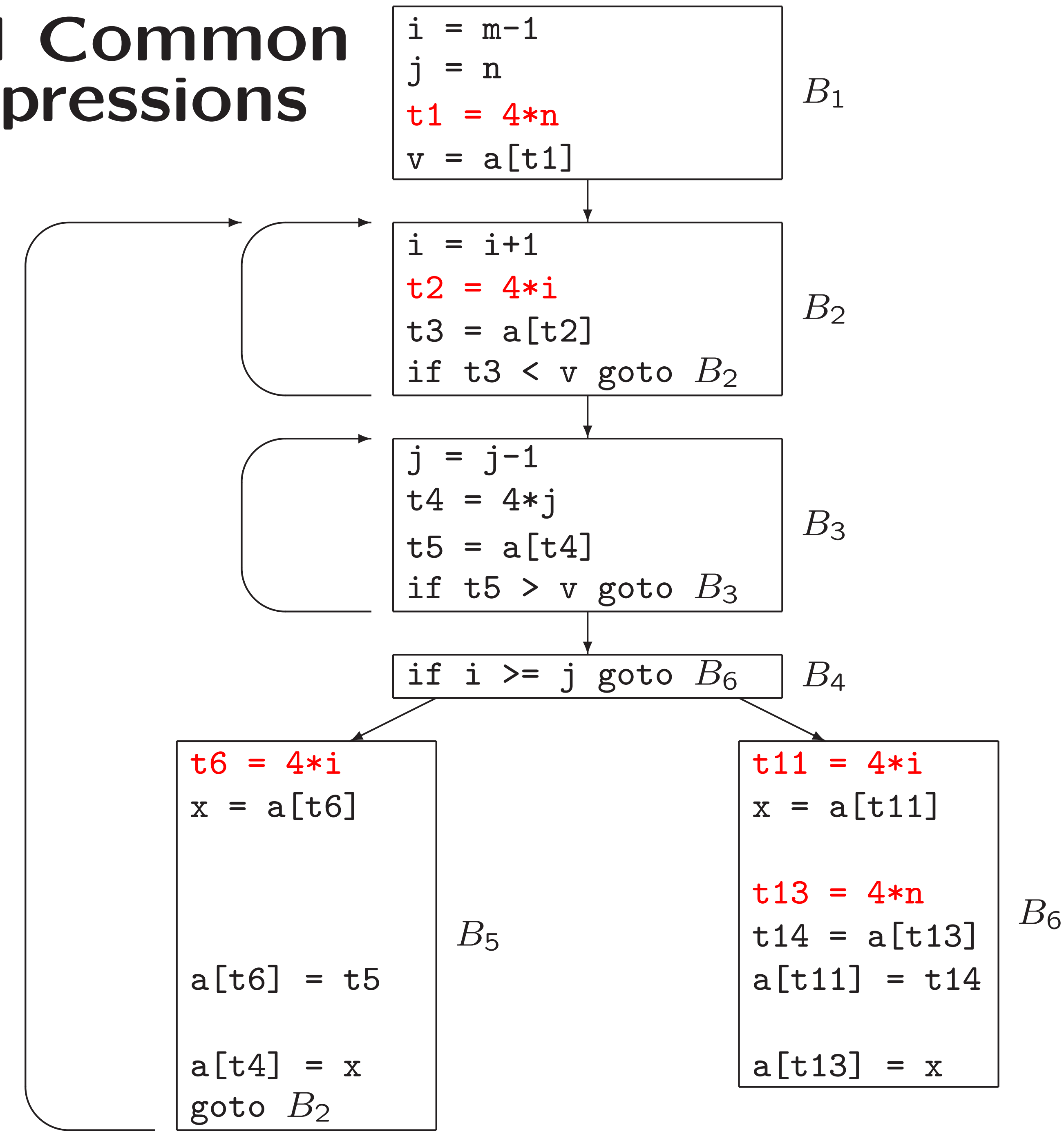
Global Common Subexpressions



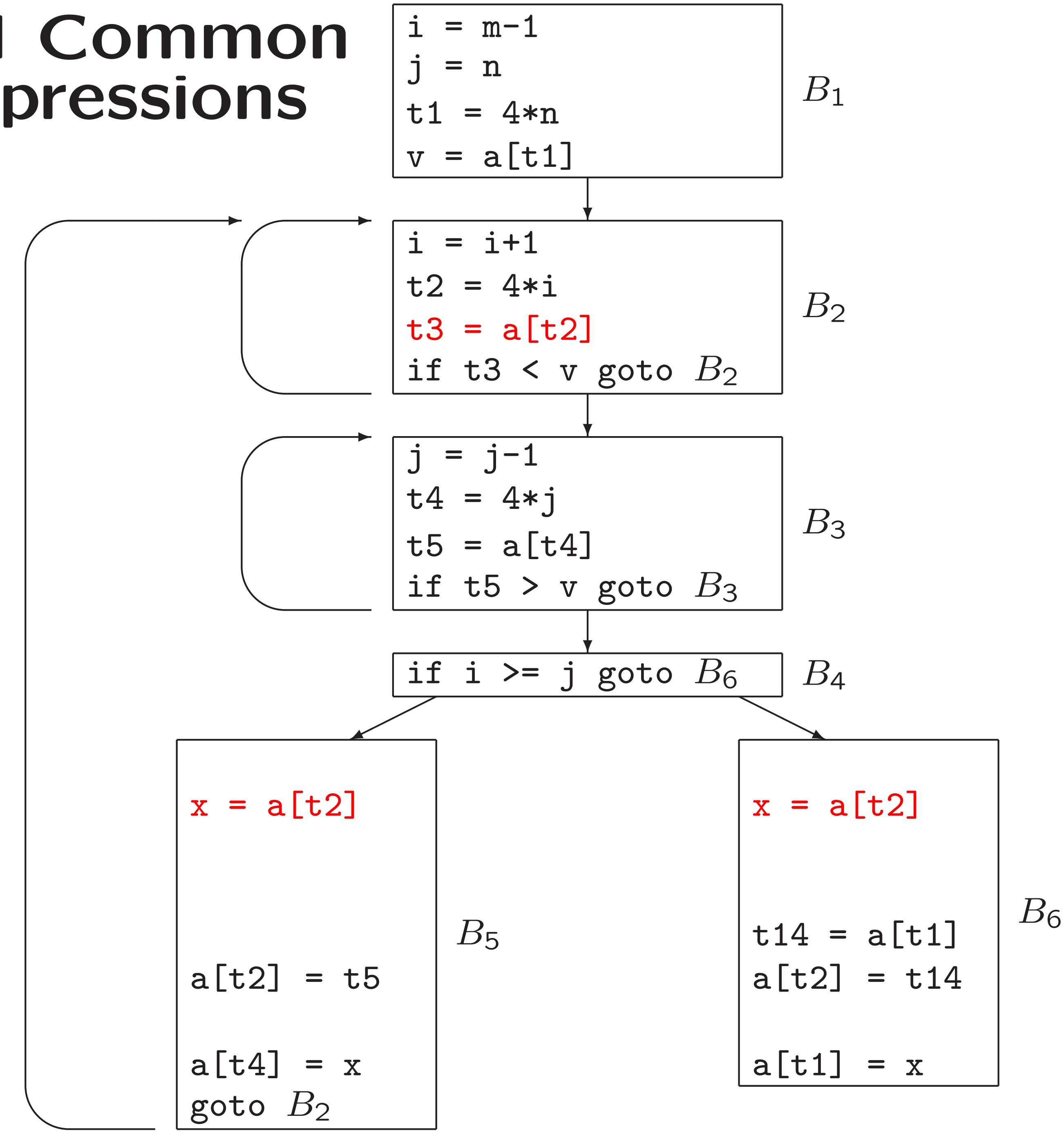
Global Common Subexpressions



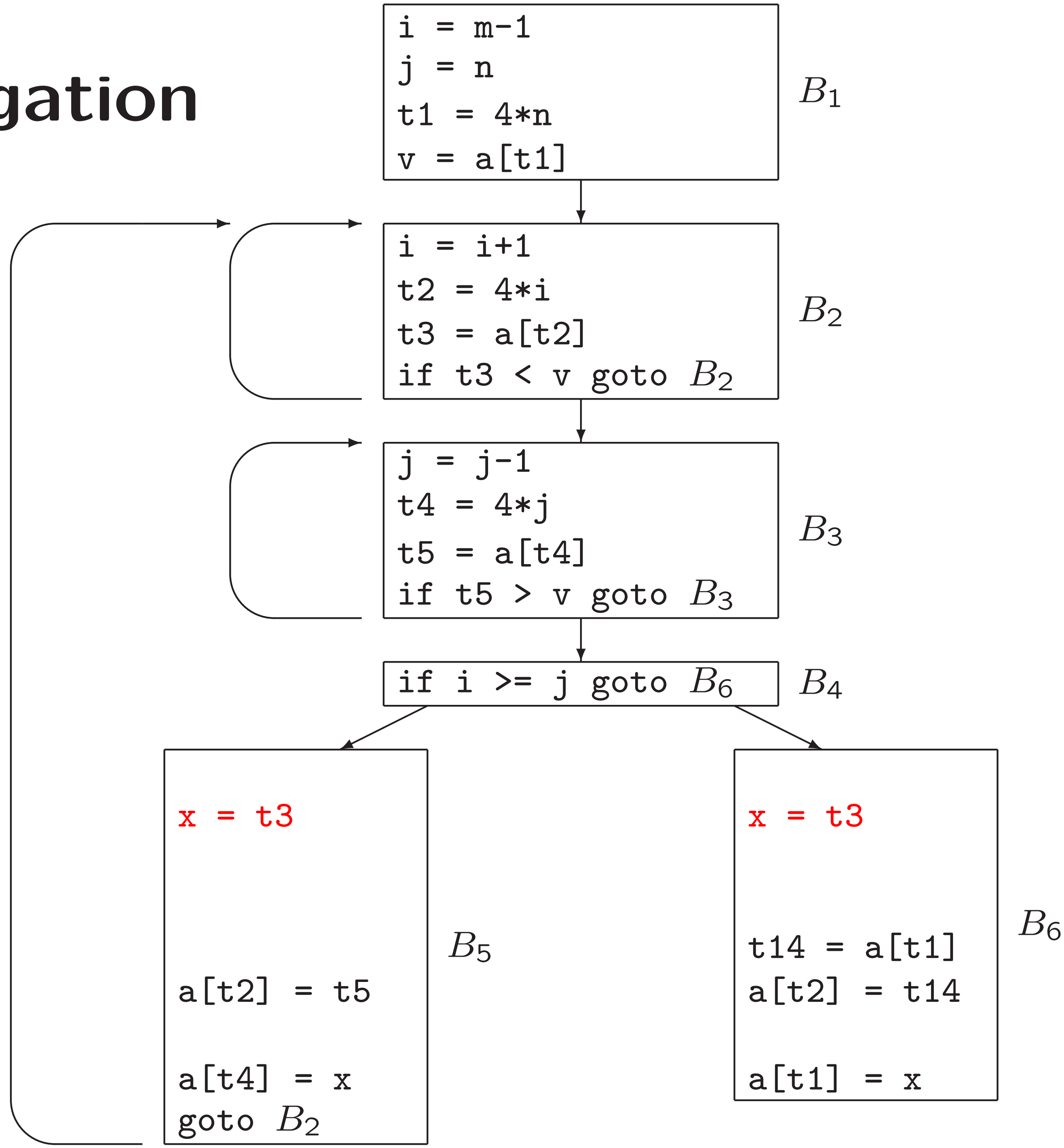
Global Common Subexpressions



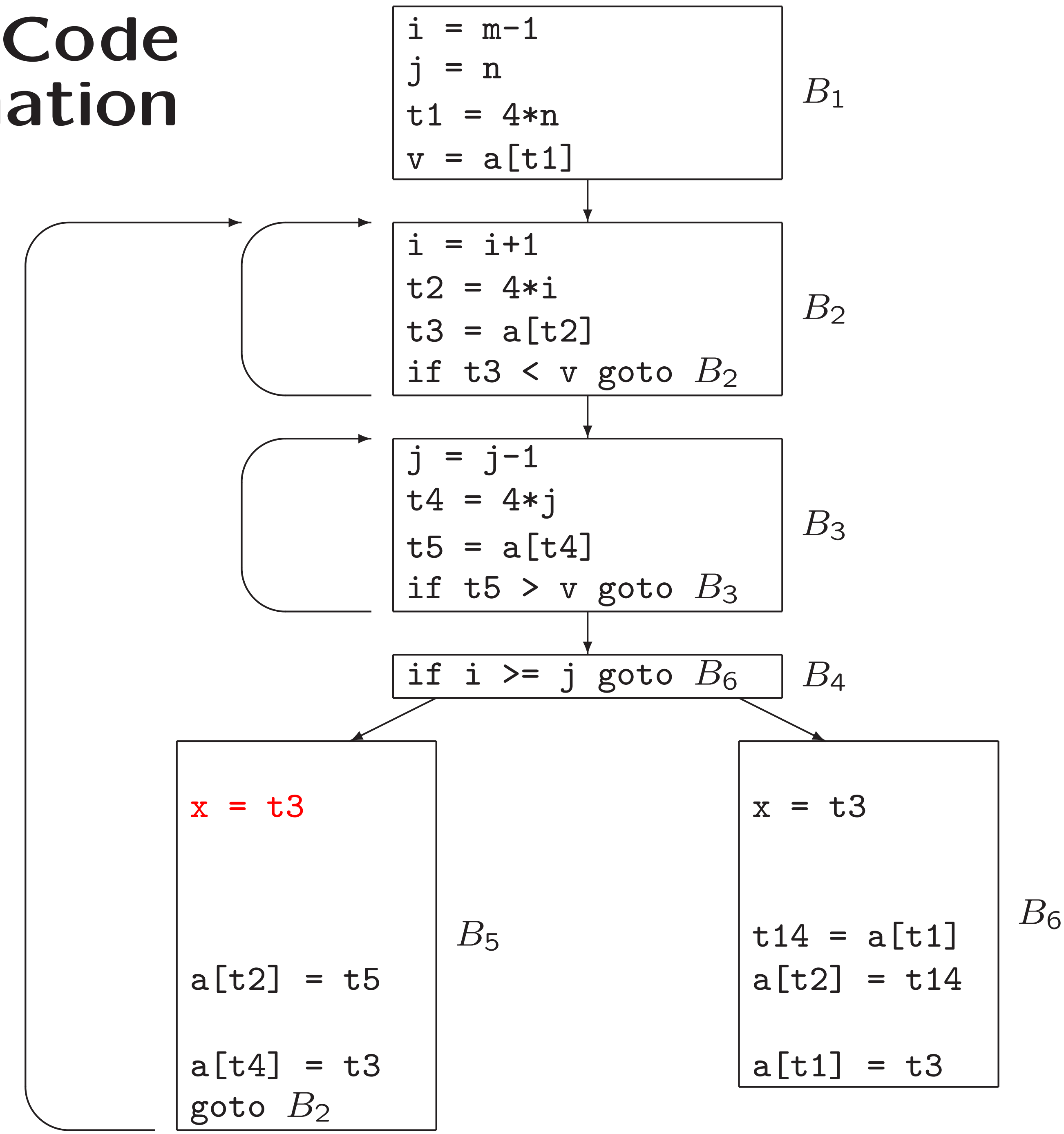
Global Common Subexpressions



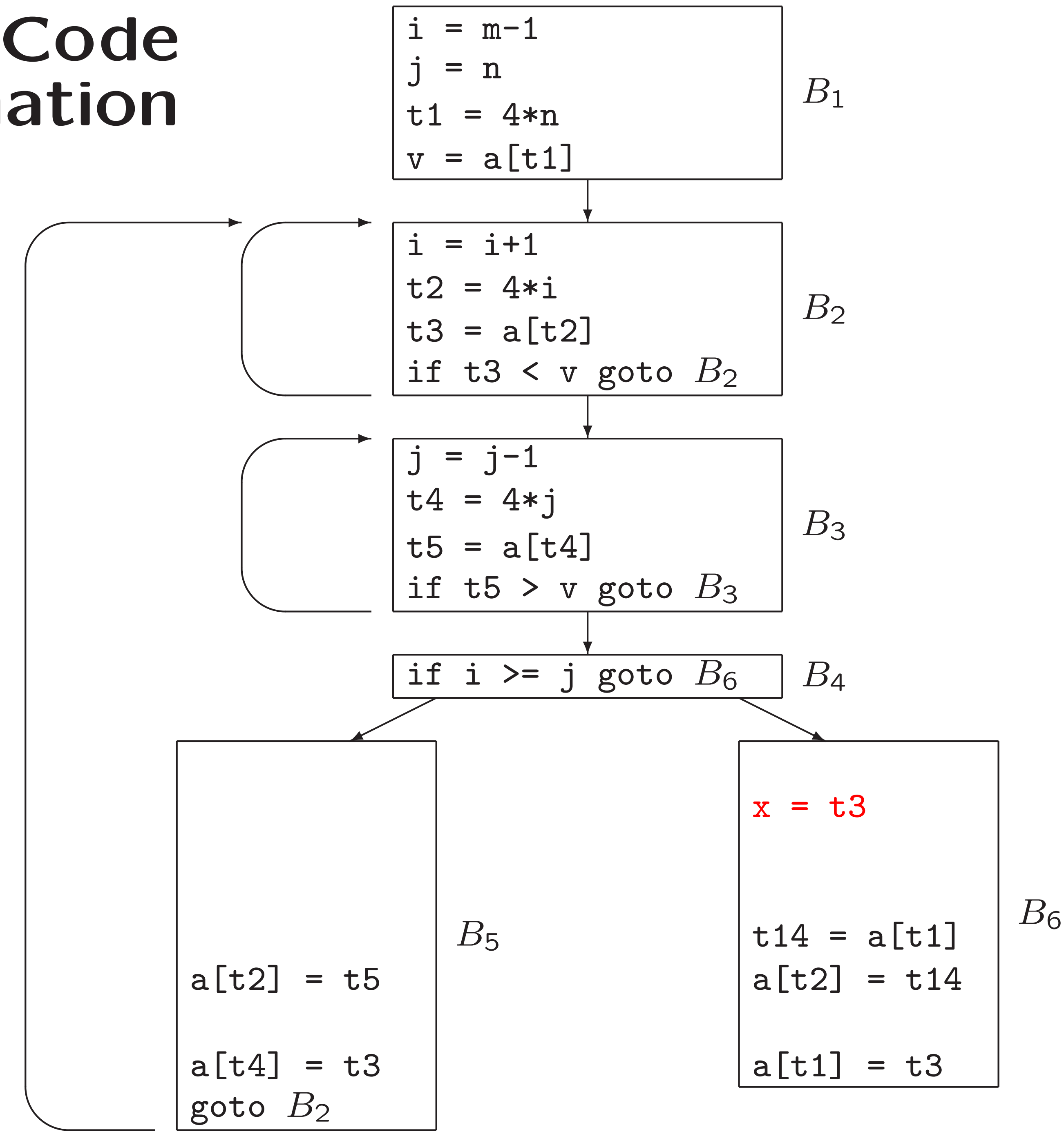
Copy Propagation



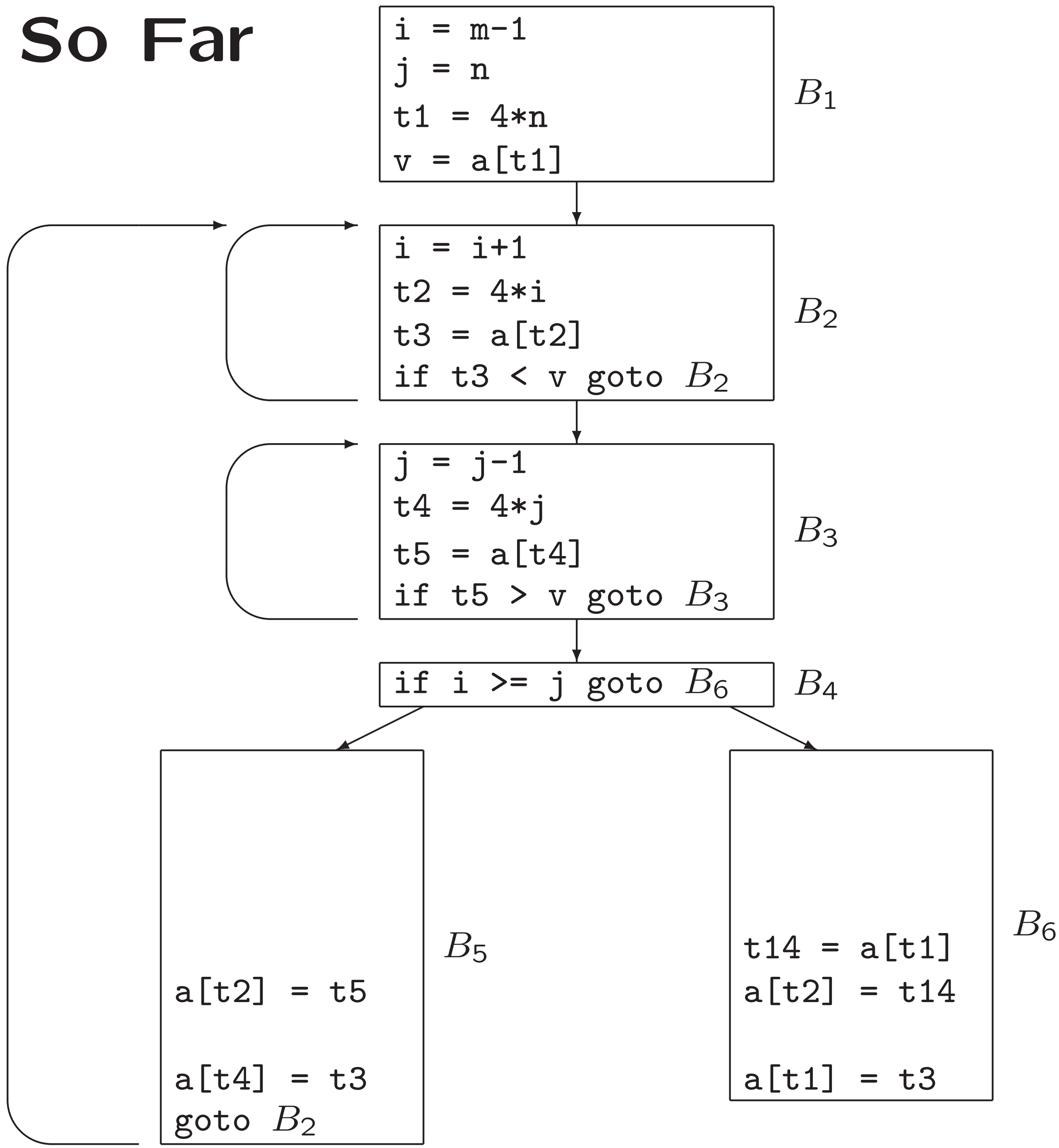
Dead-Code Elimination



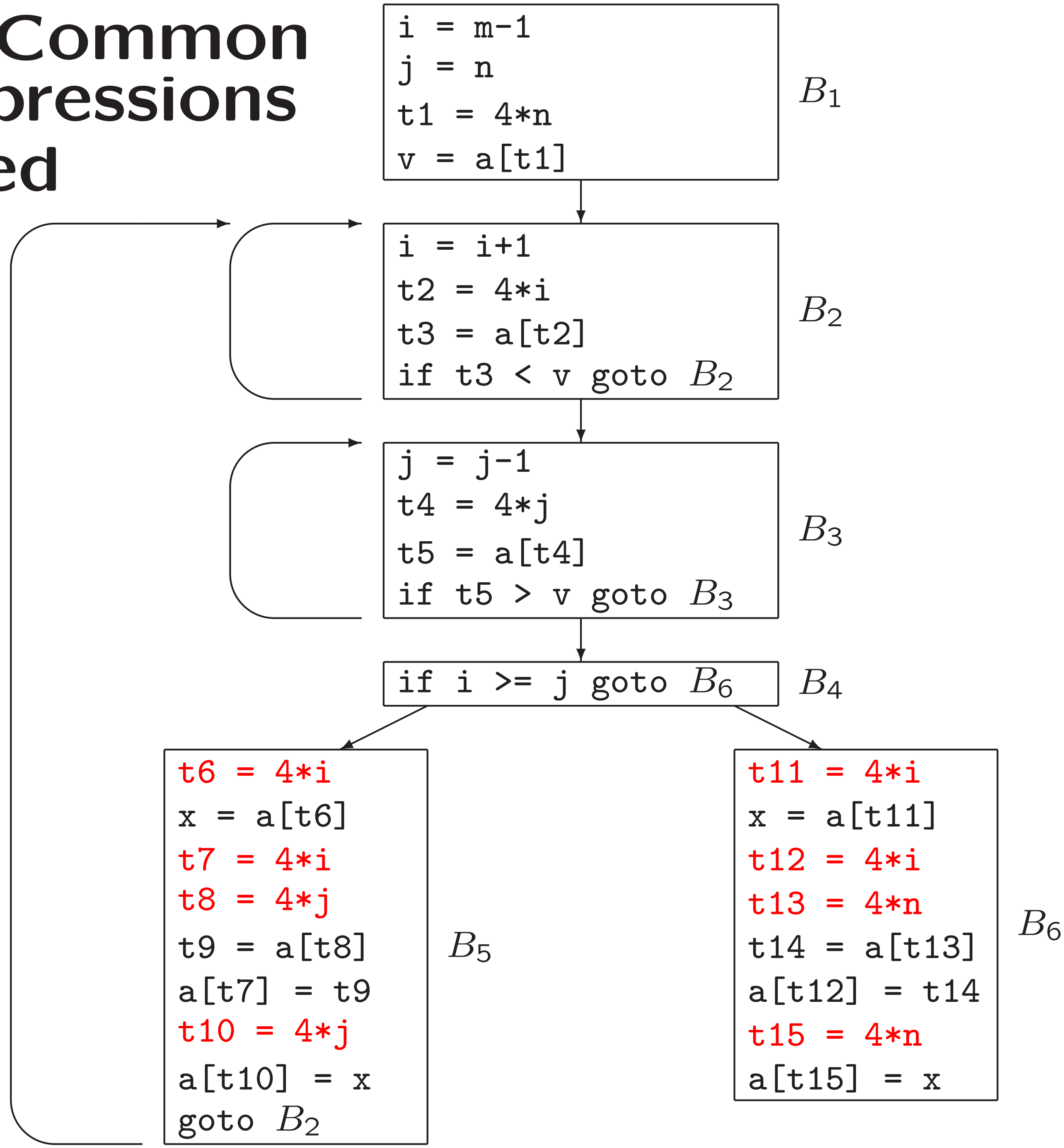
Dead-Code Elimination



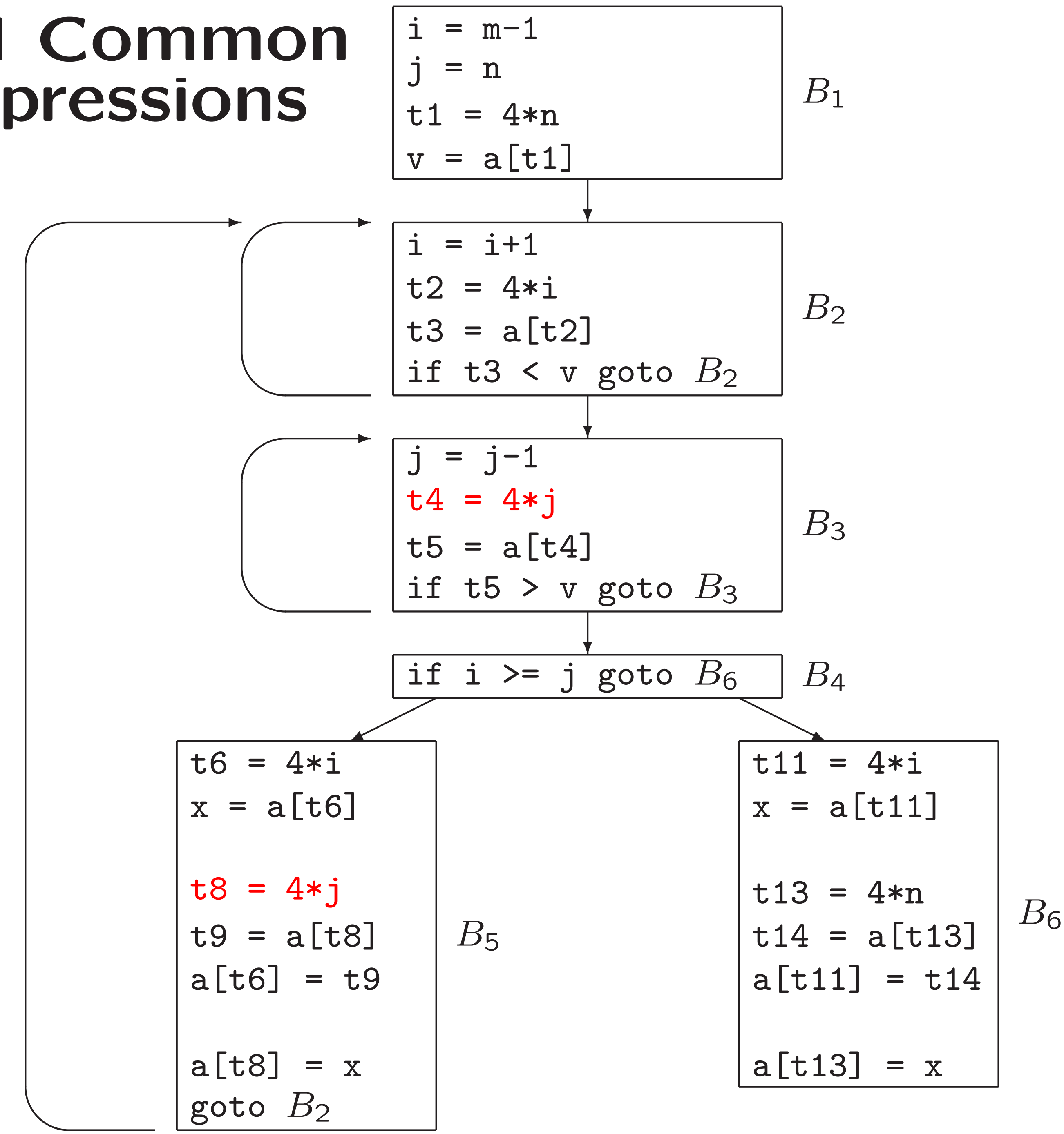
Result So Far



Local Common Subexpressions revisited



Global Common Subexpressions



Code Motion

- loop-invariant computation
- compute before loop
- Example:

```
while (i <= limit-2)  /* statement does not change limit */
```

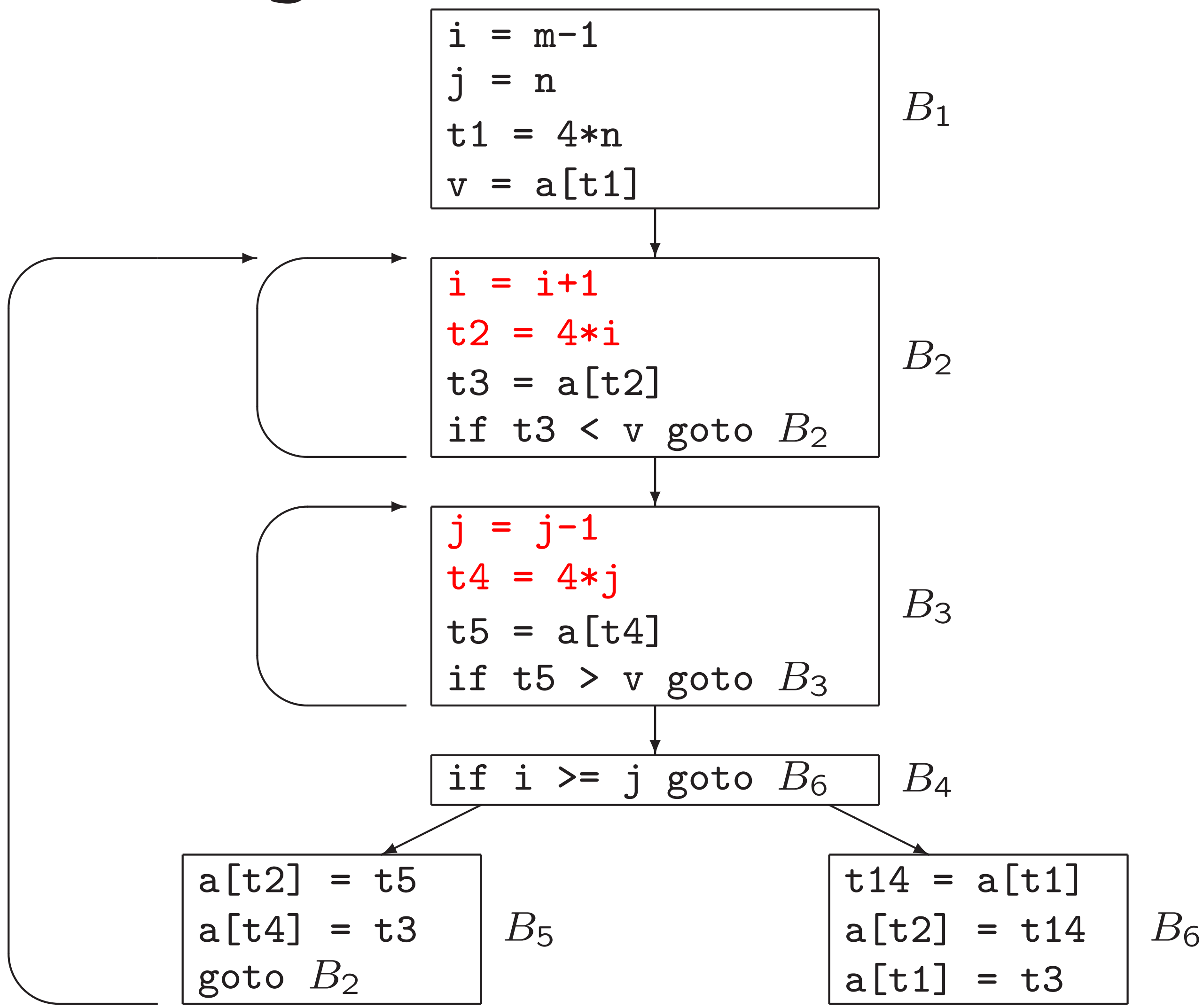
After code-motion

```
t = limit-2
while (i <= t)  /* statement does not change limit or t */
```

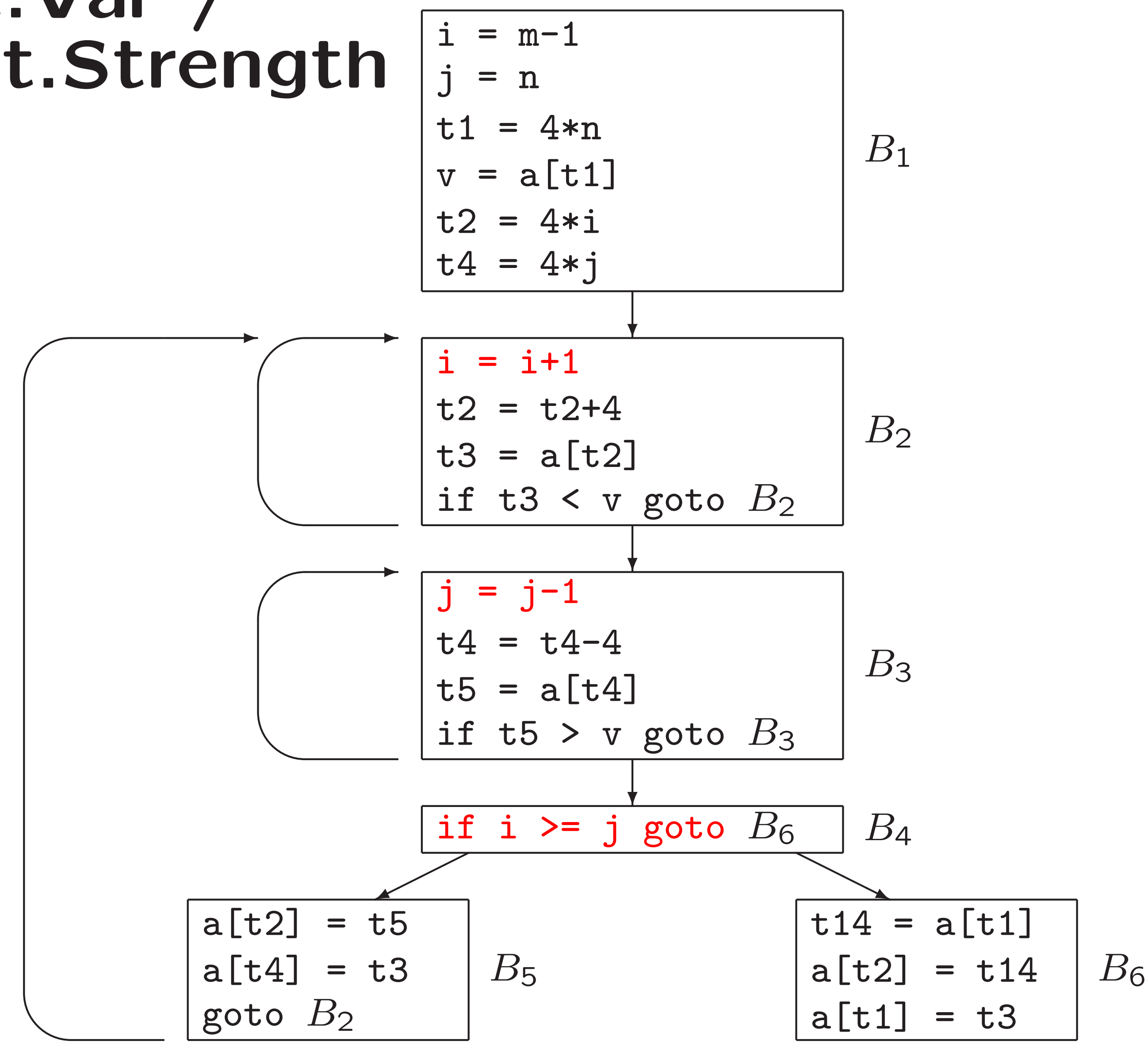
Induction Variables and Reduction in Strength

- Induction variable: each assignment to x of form $x = x + c$
- Reduction in strength: replace expensive operation by cheaper one

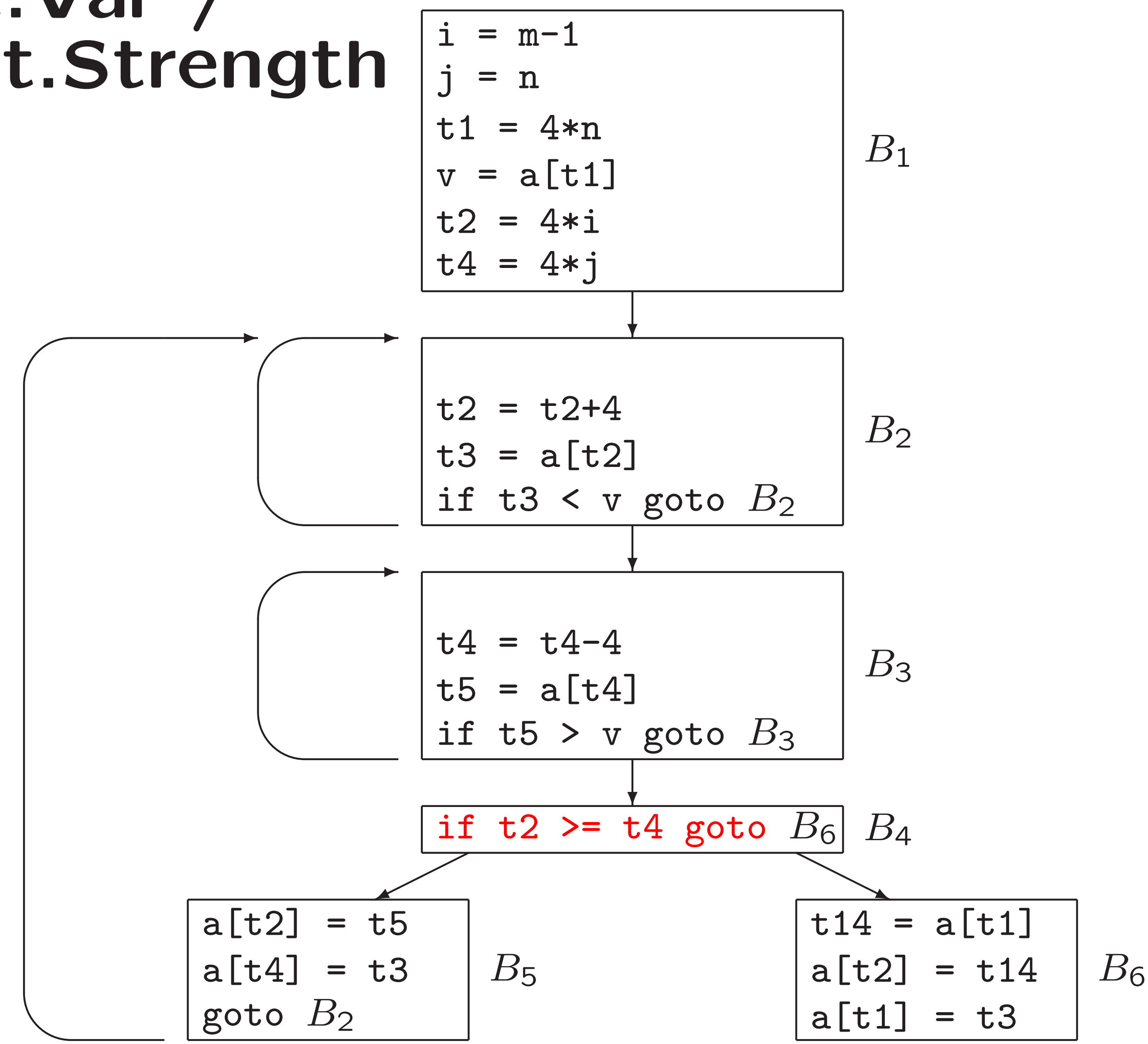
Induct.Var / Reduct.Strength



Induct.Var / Reduct.Strength

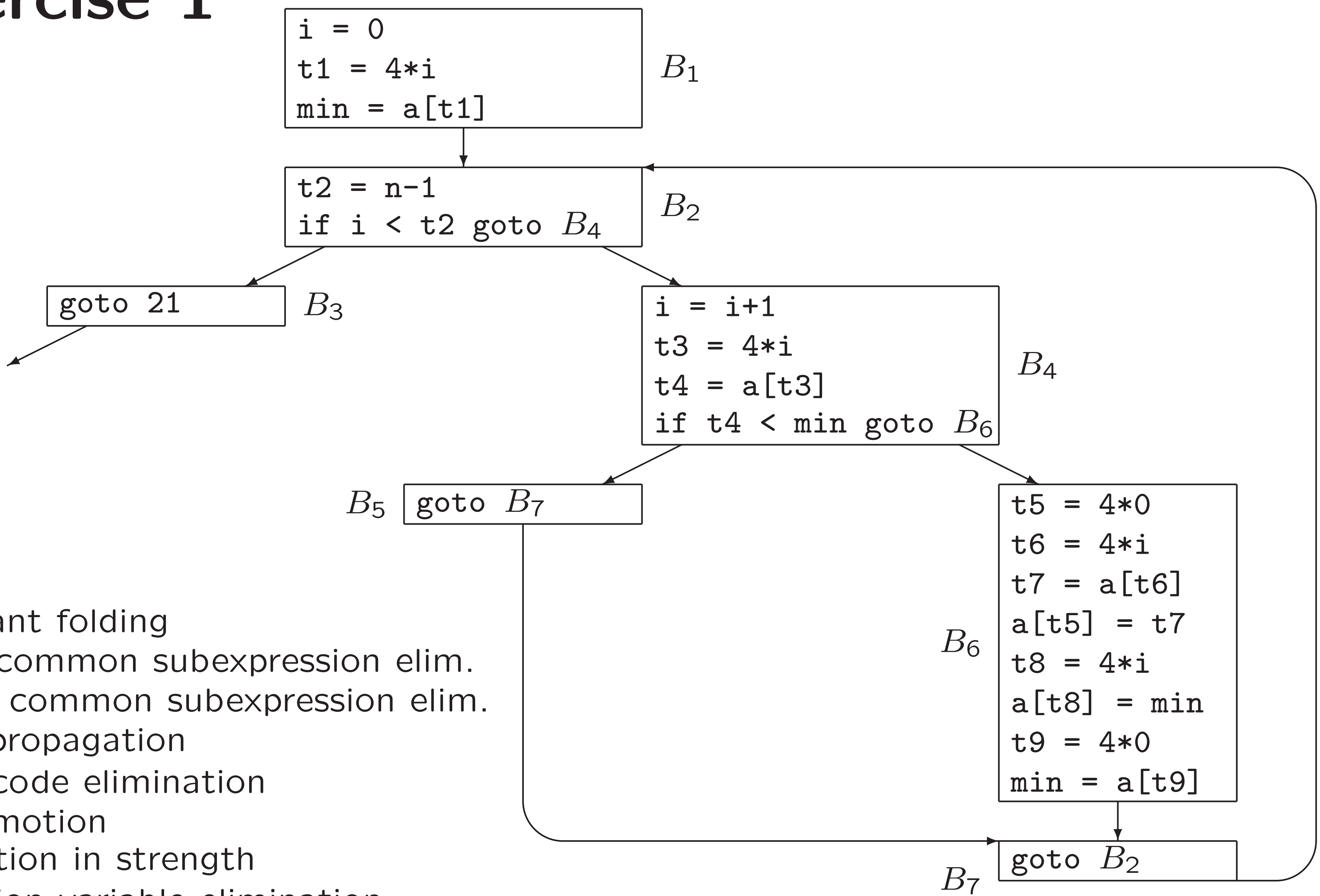


Induct.Var / Reduct.Strength



Exercise 1

Flow Graph Exercise 1



Constant folding
Local common subexpression elim.
Global common subexpression elim.
Copy propagation
Dead-code elimination
Code motion
Reduction in strength
Induction-variable elimination

Volgende week

- Practicum over opdracht 4
- Inleveren 13 december
- Vrijdag 7 december: laatste hoor-/werkcollege

Compilerconstructie

college 9
Code Optimization

Chapters for reading:
8.5, 8.7
9.intro, 9.1