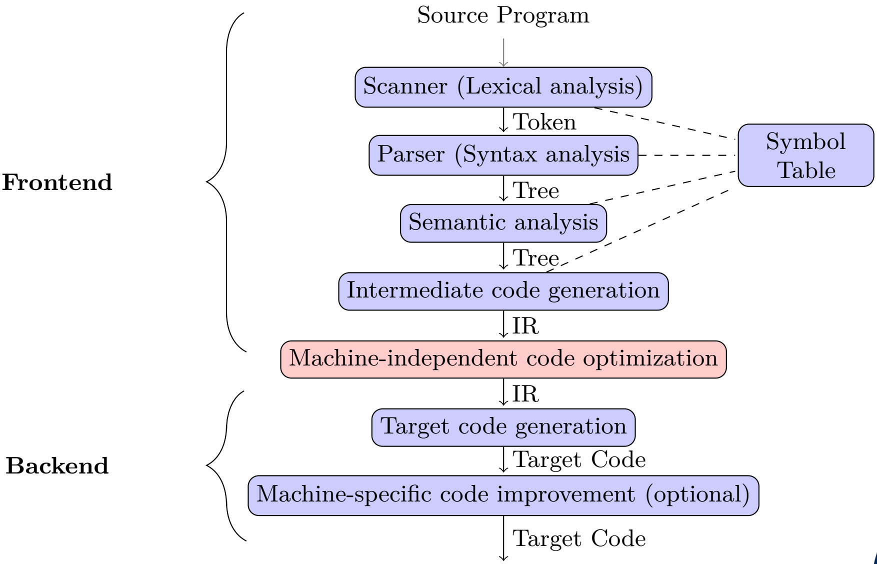
Optimizations

Lecture 21

Section 8.5, 9.1

Rokan Uddin Faruqui

Associate Professor
Dept of Computer Science and Engineering
University of Chittaong, Bangladesh
Email: *rokan@cu.ac.bd*


Source Program
Scanner (Lexical analysis)
Token
Parser (Syntax analysis
Tree
Semantic analysis
Tree
Intermediate code generation
IR
Machine-independent code optimization
IR
Target code generation
Target Code
Machine-specific code improvement (optional)
Target Code
Symbol Table
Frontend
Backend

Optimizations

local optimizations – within a basic block,

global optimizations – between basic blocks.

Outline

DAG for basic blocks

Three-address code to DAG structure:

- One leaf per initial value.
- One node per statement, with an edge to the node representing the operand value(s).
- Inner node is labelled by operator, and list of variables, which computes the value.
- Output nodes are those labelled with live exit variables.

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DAG optimization uses

- Local common subexpressions.
- Dead code elimination.
- Apply algebraic simplifications.
- Reorder statements that do not depend on one other.

Local common subexpressions

- Eliminate instructions that has already been computed.

$$
\begin{aligned}
a &= b + c \\
b &= a - d \\
c &= b + c \\
d &= a - d
\end{aligned}
$$

Local common subexpressions

- Eliminate instructions that has already been computed.

$$
\begin{aligned}
{\color{blue} a} &{\color{blue} = b + c} \\
{\color{red} b} &{\color{red} = a - d} \\
{\color{blue} c} &{\color{blue} = b + c} \\
{\color{red} d} &{\color{red} = a - d}
\end{aligned}
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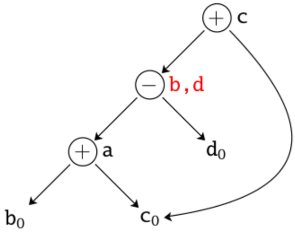

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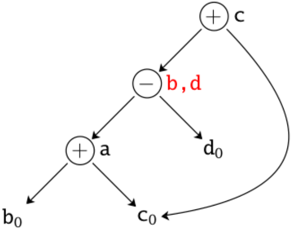
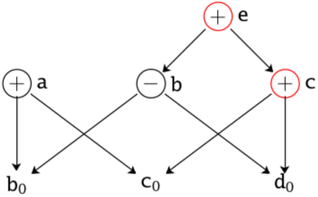


Dead code elimination

- Eliminate instructions that compute values that are never used

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



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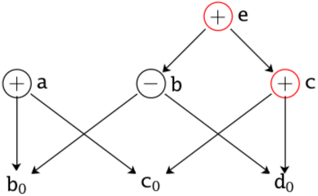


Algebraic Identities

- Apply algebraic simplification rules.

$$x + 0 = 0 + x = x$$

$$x - 0 = x$$

$$x \times 1 = 1 \times x = x$$

$$x/1 = x$$

$$2 + 2 = 4 (\text{constant folding})$$

$$\text{Expensive} \text{Cheaper}$$

$$x^2 = x \times x (\text{lib function})$$

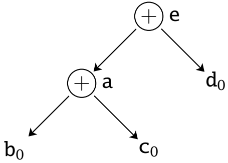
$$2 \times x = x + x$$

$$x/2 = x \times 0.5$$

Algebraic Identities

- **Commutativity** with local common subexpressions.
- **Associativity** with composite expressions....

$$a = c + b$$
$$e = c + d + b$$



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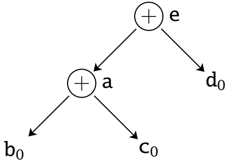
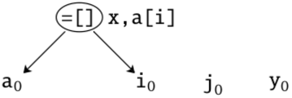


Array References

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



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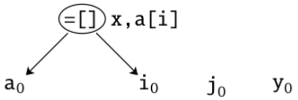

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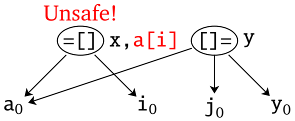

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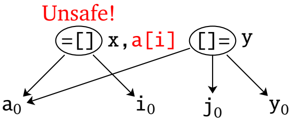

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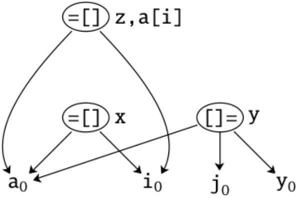

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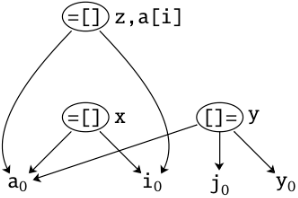


Remarks

- The entire memory is a single array!
- In C: no check of bounds of arrays, so memory can be arbitrarily updated.

Outline

1. Local Optimization

2. Global Optimization

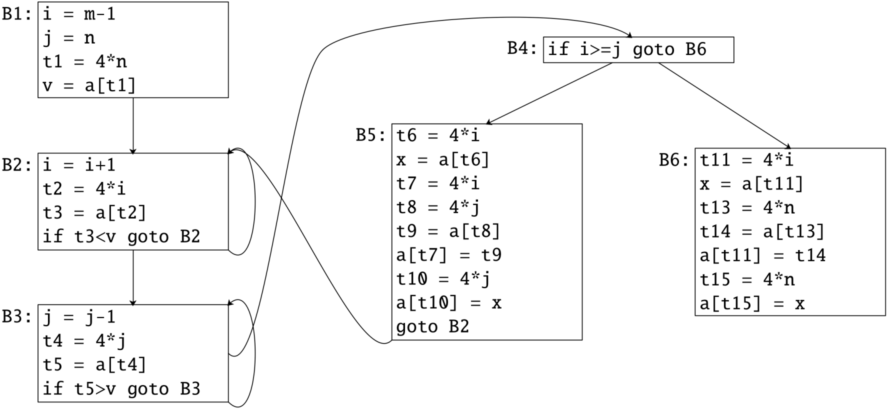
Example: quicksort

```
void quicksort(int a[], int m, int n) {
int i, j, v, x; if (n <= m) return;
/*fragment starts here*/
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;
/*fragment end here*/
  quicksort(a,m,j); quicksort(a,i+1,n);
}
```

Three-address code for fragments of qsort

```
(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
```

Basic blocks for quick sort: first try



Local Common Subexpression Elimination

B5:

```
t6 = 4*i
x = a[t6]
t7 = 4*i
t8 = 4*j
t9 = a[t8]
a[t7] = t9
t10 = 4*j
a[t10] = x
goto B2
```

⇒

B5:

```
t6 = 4*i
x = a[t6]
t8 = 4*j
t9 = a[t8]
a[t6] = t9
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$\Rightarrow$

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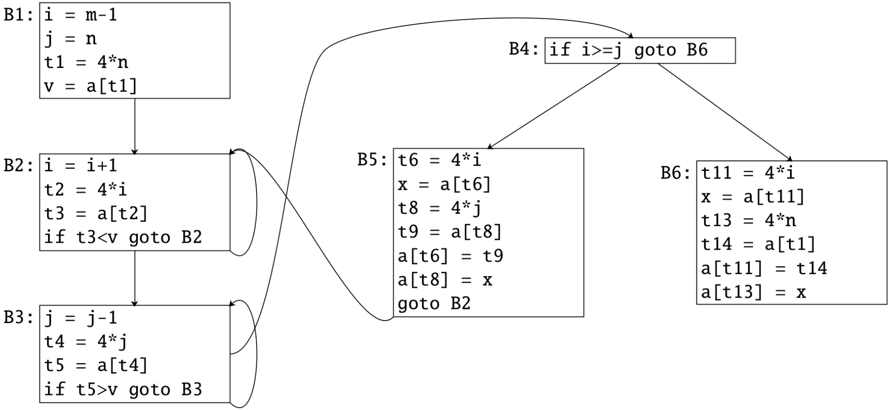
Global Common Subexpression Elimination



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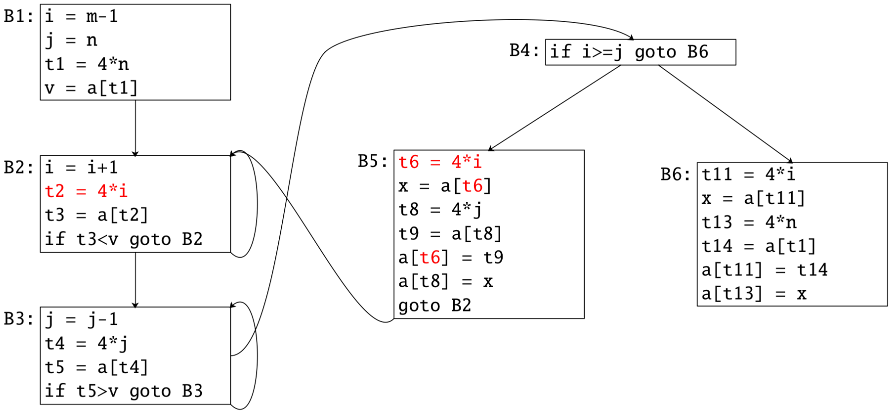

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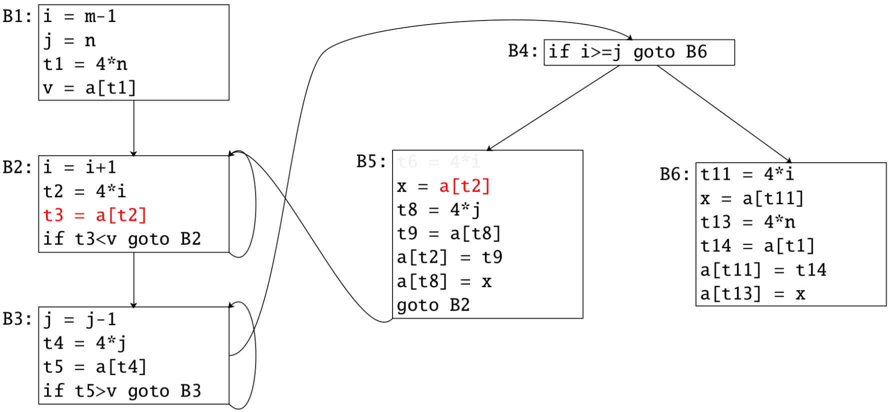

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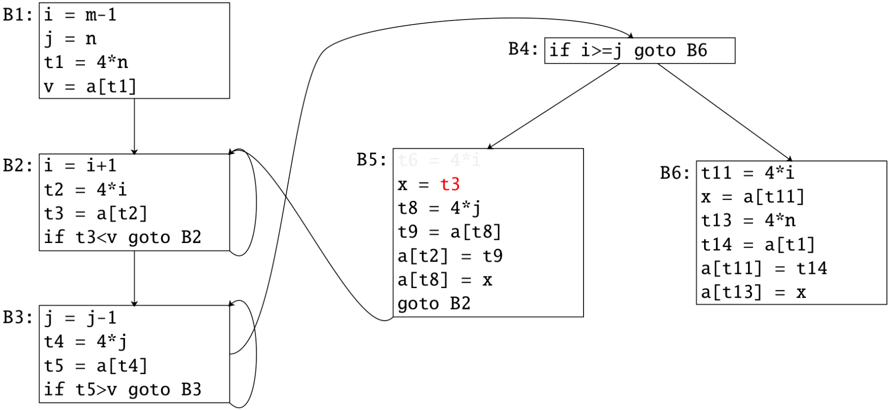

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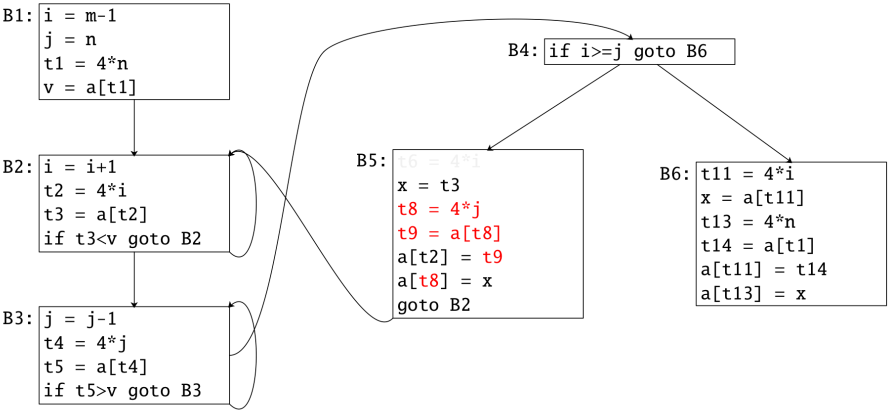

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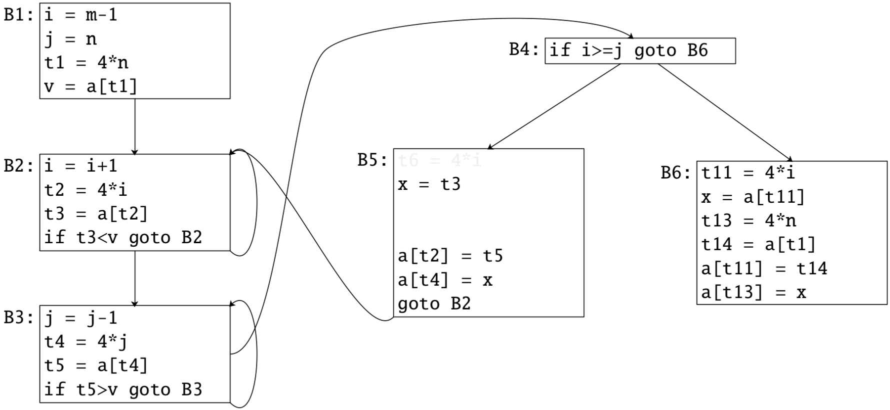

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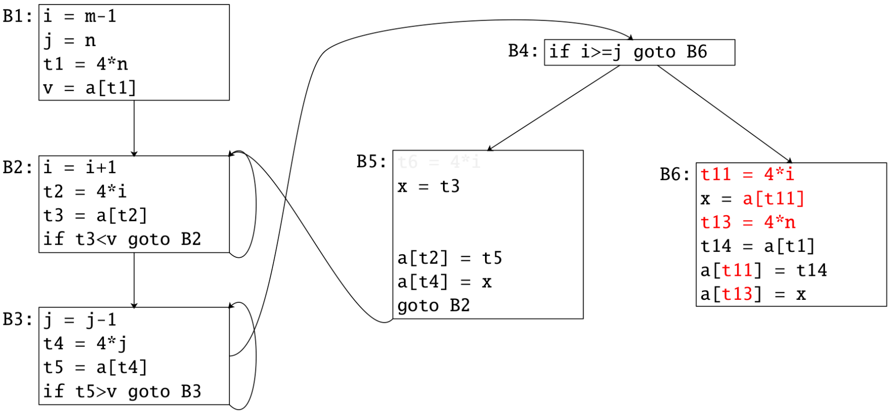

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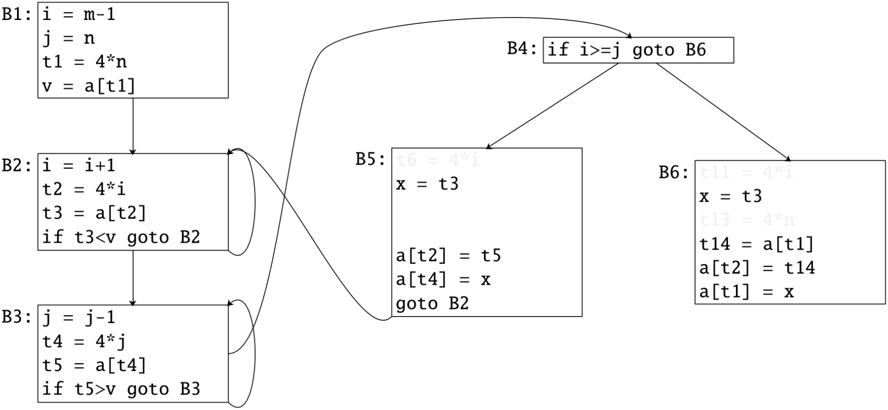

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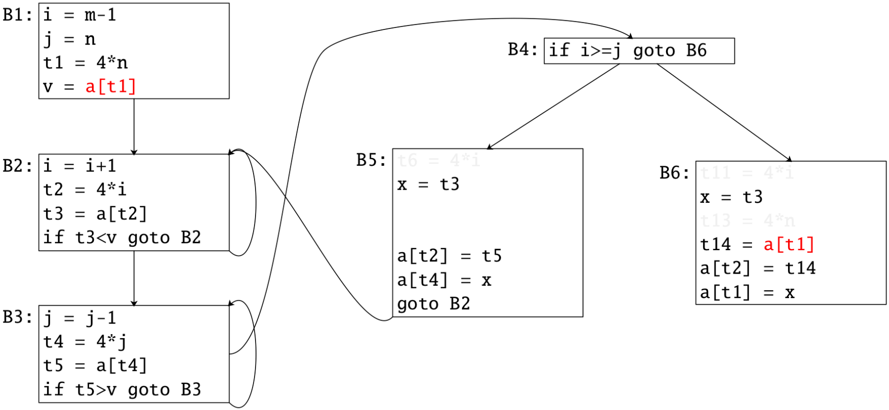

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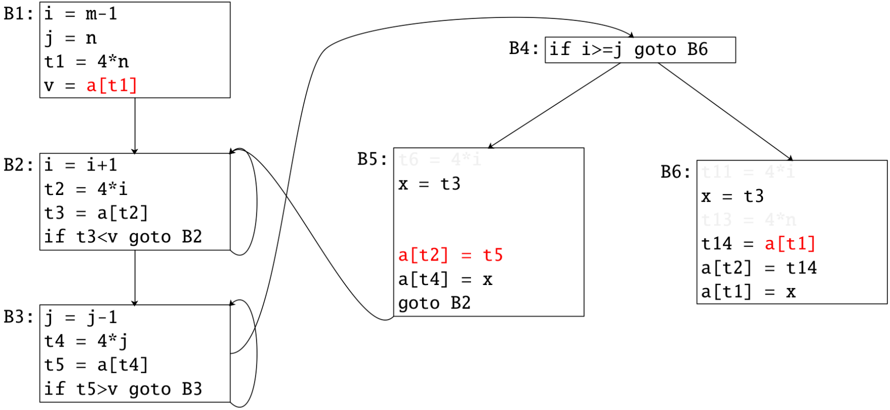
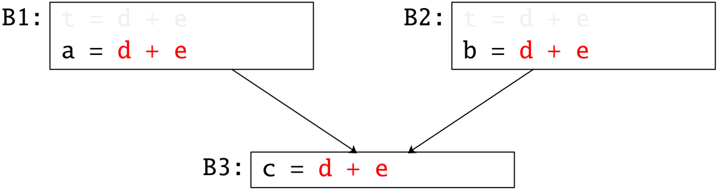


Copy Propagation



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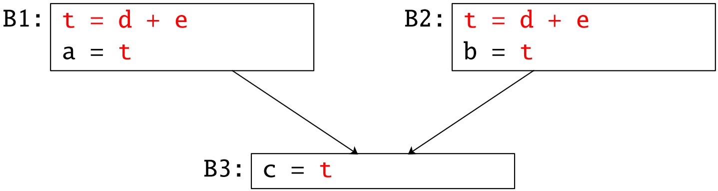

Dead-code Elimination

if (debug) print

debug = FALSE

Code Motion

```
while (i <= limit-2) /*not changing limit*/
```

becomes

```
t = limit-2;
while (i <= t) /*not changing limit or t*/
```

Summary

Reduce redundancy but preserve semantics!

- Global Common Subexpressions.
- Copy Propagation.
- Dead-code Elimination.
- Code Motion.