CMSC 430
Introduction to Compilers
Fall 2016

Optimization

Introduction

- An *optimization* is a transformation "expected" to
  - Improve running time
  - Reduce memory requirements
  - Decrease code size

- No guarantees with optimizers
  - Produces "improved," not "optimal" code
  - Can sometimes produce worse code

Why are optimizers needed?

- Reduce programmer effort
  - Don’t make programmers waste time doing simple opts
- Allow programmer to use high-level abstractions without penalty
  - E.g., convert dynamic dispatch to direct calls
- Maintain performance portability
  - Allow programmer to write code that runs efficiently everywhere
  - Particularly a challenge with GPU code

Two laws and a measurement

- Moore's law
  - Chip density doubles every 18 months
  - Until now, has meant CPU speed doubled every 18 months
    - These days, moving to multicore instead
- Proebsting's Law
  - Compiler technology doubles CPU power every 18 years
    - Difference between optimizing and non-optimizing compiler about 4x
    - Assume compiler technology represents 36 years of progress
- Worse: runtime performance swings of up to 10% can be expected with no changes to executable
  - http://dl.acm.org/citation.cfm?id=1508275

Dimensions of optimization

- Representation to be optimized
  - Source code/AST
  - IR/bytecode
  - Machine code
- Types of optimization
  - Peephole — across a few instructions (often, machine code)
  - Local — within basic block
  - Global — across basic blocks
  - Interprocedural — across functions

Dimensions of optimization (cont'd)

- Machine-independent
  - Remove extra computations
  - Simplify control structures
  - Move code to less frequently executed place
  - Specialize general purpose code
  - Remove dead/useless code
  - Enable other optimizations
- Machine-dependent
  - Replace complex operations with simpler/faster ones
  - Exploit special instructions (MMX)
  - Exploit memory hierarchy (registers, cache, etc)
  - Exploit parallelism (ILP, VLIW, etc)

Selecting optimizations

- Three main considerations
  - Safety — will optimizer maintain semantics?
    - Tricky for languages with partially undefined semantics!
  - Profitability — will optimization improve code?
  - Opportunity — could optimization often enough to make it worth implementing?

- Optimizations interact!
  - Some optimizations enable other optimizations
    - E.g., constant folding enables copy propagation
  - Some optimizations block other optimizations

Some classical optimizations

- Dead code elimination

```
    jmp L
    /* unreachable */
L:  ...
```

```
if true then
   ...
else
   /* unreachable */
```

```
a = 5 /* dead */
a = 6
```

  - Also, unreachable functions or methods

- Control-flow simplification
  - Remove jumps to jumps

```
    jmp L
    /* unreachable */
L:  goto M
M:  ...
```

⇨

```
    jmp M
    /* unreachable */
M:  ...
```

More classical optimizations

- Algebraic simplification

```
x = a + 0   ⇒   x = a
x = a * 0   ⇒   x = 0
```

  - Be sure simplifications apply to modular arithmetic
- Constant folding
  - Pre-compute expressions involving only constants

```
a = 5
b = 6
x = a + b
/* a,b dead */
```

const fold ⇒

```
a = 5
b = 6
x = 11
/* a,b dead */
```

dead code elim ⇒

```
x = 11
```

- Special handling for idioms
  - Replace multiplication by shifting
  - May need constant folding to enable sometimes

More classical optimizations

- Common subexpression elimination

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

⇒

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

- Copy propagation

```
b = a
c = b
/* b dead */
```

⇒ *copy prop*

```
b = a
c = a
/* b dead */
```

⇒ *dead code elim*

```
c = a
```

Example

Fortran (!) source code:

```
          .
          .
          .
          sum = 0
          do 10 i = 1, n
    10    sum = sum + a(i) * a(i)
          .
          .
          .
```

Three-address code

Code	
`1.  sum = 0`	sum = 0
`2.  i = 1` `3.  if i > n goto 15`	init for loop and check limit

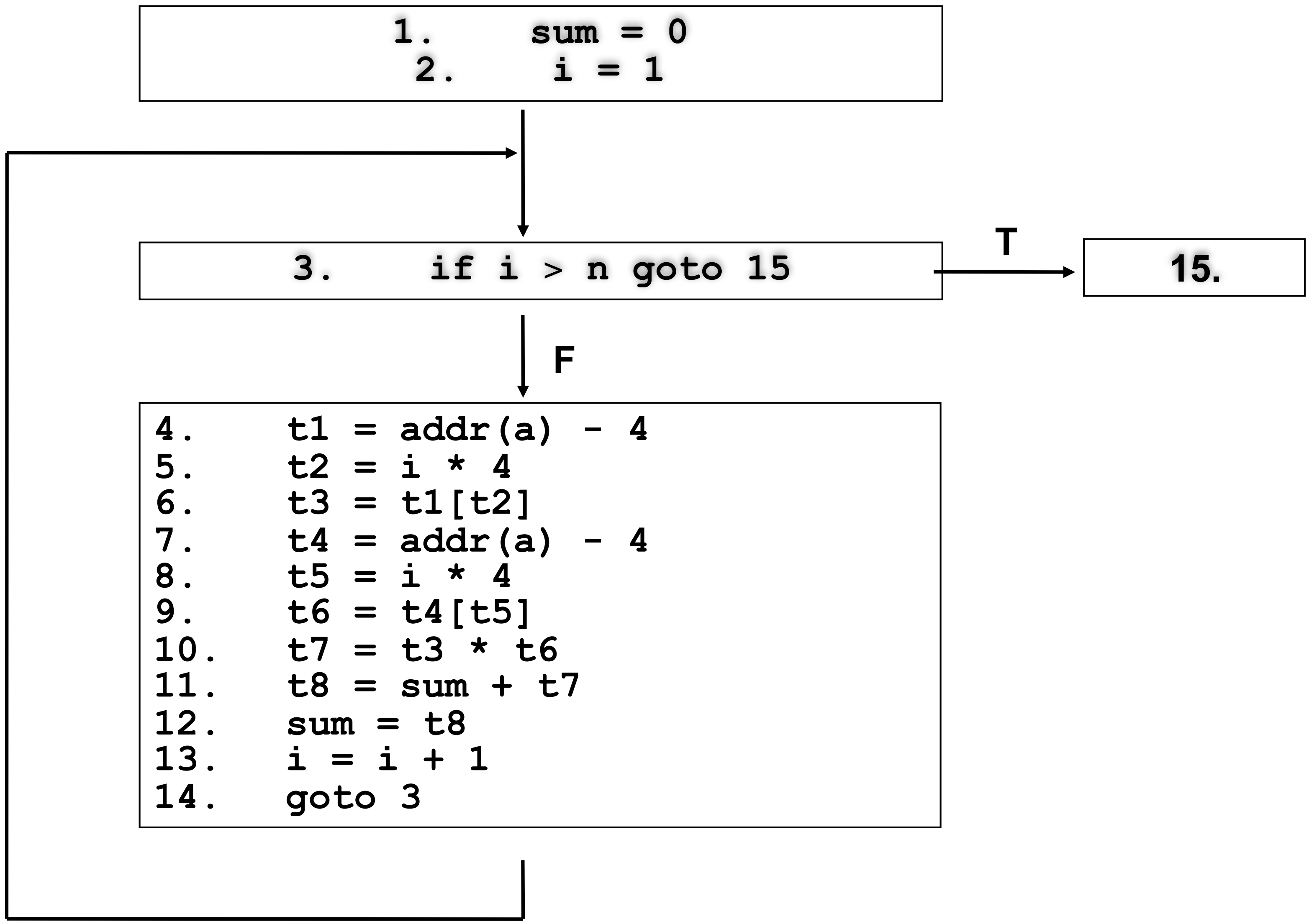
`4.  t1 = addr(a) - 4`
`5.  t2 = i * 4`
`6.  t3 = t1[t2]`
	a[i]

`7.  t4 = addr(a) - 4`
`8.  t5 = i * 4`
`9.  t6 = t4[t5]`
	a[i]

`10. t7 = t3 * t6`	a[i] * a[i]
`11. t8 = sum + t7` `12. sum = t8`	increment sum

`13. i = i + 1`
`14. goto 3`
`15.`
	Incr. loop counter back to loop check

Control-flow graph



Common subexpression elimination

```
1.      sum = 0
2.      i = 1
3.      if i > n goto 15
4.      t1 = addr(a) - 4
5.      t2 = i * 4
6.      t3 = t1[t2]
7.      t4 = addr(a) - 4
8.      t5 = i * 4
9.      t6 = t4[t5]
10.     t7 = t3 * t6
10a.    t7 = t3 * t3
11.     t8 = sum + t7
12.     sum = t8
13.     i = i + 1
14.     goto 3
15.
```

Copy propagation

```
1.      sum = 0
2.      i = 1
3.      if i > n goto 15
4.      t1 = addr(a) - 4
5.      t2 = i * 4
6.      t3 = t1[t2]
10a.    t7 = t3 * t3
11.     t8 = sum + t7
12.     sum = t8
12a.    sum = sum + t7
13.     i = i + 1
14.     goto 3
15.
```

Invariant code motion

```
1.      sum = 0
2.      i = 1
2a.     t1 = addr(a) - 4
3.      if i > n goto 15
4.      t1 = addr(a) - 4
5.      t2 = i * 4
6.      t3 = t1[t2]
10a.    t7 = t3 * t3
12a.    sum = sum + t7
13.     i = i + 1
14.     goto 3
15.
```

Strength reduction

```
1.      sum = 0
2.      i = 1
2a.     t1 = addr(a) - 4
2b.     t2 = i * 4
3.      if i > n goto 15
5.      t2 = i * 4
6.      t3 = t1[t2]
10a.    t7 = t3 * t3
12a.    sum = sum + t7
12b.    t2 = t2 + 4
13.     i = i + 1
14.     goto 3
15.
```

Loop test adjustment

```
1.      sum = 0
2.      i = 1
2a.     t1 = addr(a) - 4
2b.     t2 = i * 4
2c.     t9 = n * 4
3.      if i > n goto 15
3a.     if t2 > t9 goto 15
6.      t3 = t1[t2]
10a.    t7 = t3 * t3
12a.    sum = sum + t7
12b.    t2 = t2 + 4
13.     i = i + 1
14.     goto 3a
15.
```

Induction variable elimination

```
1.      sum = 0
2.      i = 1
2a.     t1 = addr(a) - 4
2b.     t2 = i * 4
2c.     t9 = n * 4
3a.     if t2 > t9 goto 15
6.      t3 = t1[t2]
10a.    t7 = t3 * t3
12a.    sum = sum + t7
12b.    t2 = t2 + 4
13.     i = i + 1
14.     goto 3a
15.
```

Constant propagation

```
1.      sum = 0
2.      i = 1
2a.     t1 = addr(a) - 4
2b.     t2 = i * 4
2d.     t2 = 4
2c.     t9 = n * 4
3a.     if t2 > t9 goto 15
6.      t3 = t1[t2]
10a.    t7 = t3 * t3
12a.    sum = sum + t7
12b.    t2 = t2 + 4
14.     goto 3a
15.
```

Dead code elimination

```
1.      sum = 0
2.      i = 1
2a.     t1 = addr(a) - 4
2d.     t2 = 4
2c.     t9 = n * 4
3a.     if t2 > t9 goto 15
6.      t3 = t1[t2]
10a.    t7 = t3 * t3
12a.    sum = sum + t7
12b.    t2 = t2 + 4
14.     goto 3a
15.
```

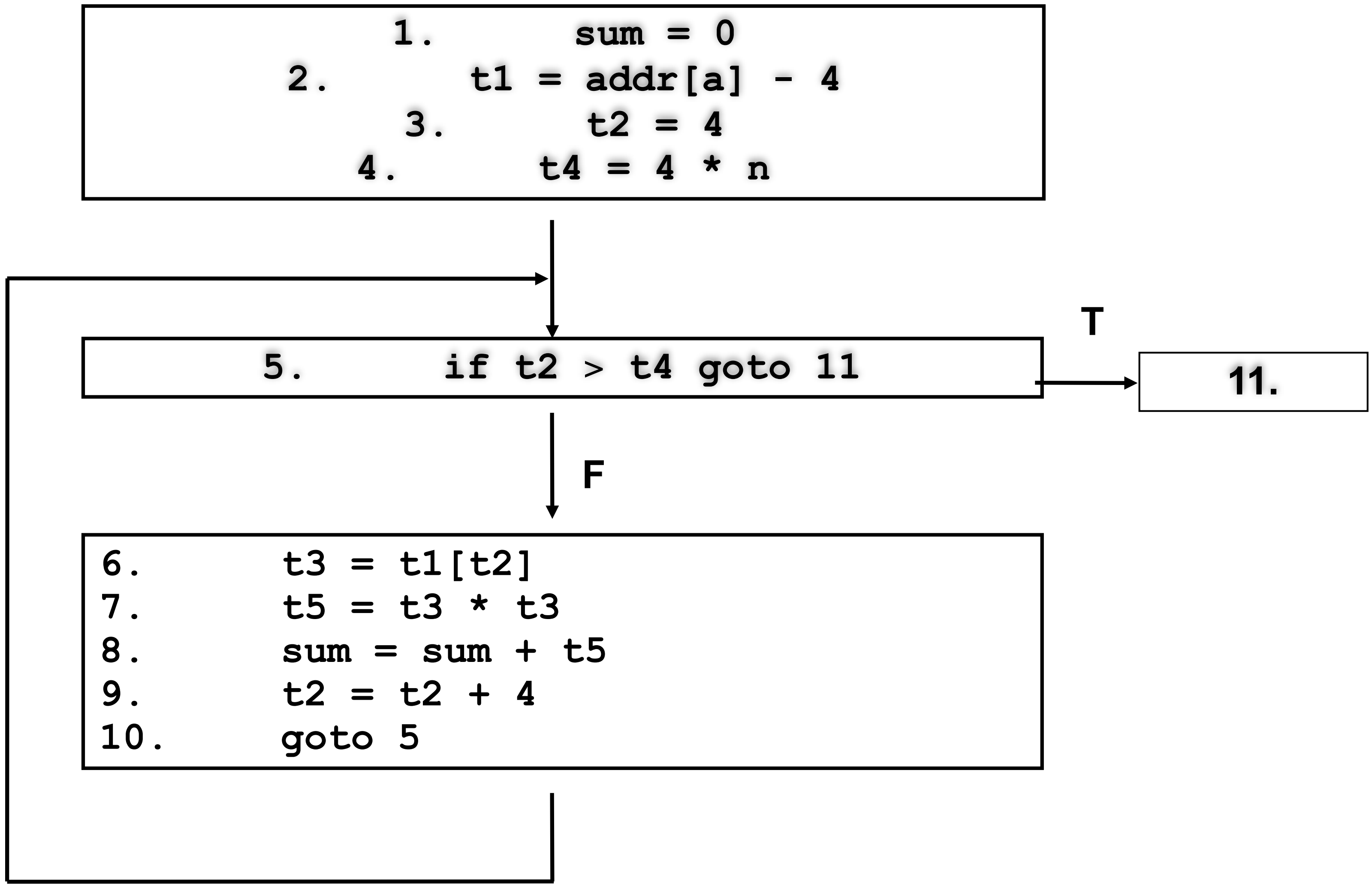
Final optimized code

```
1.      sum = 0
2.      t1 = addr(a) - 4
3.      t2 = 4
4.      t4 = n * 4
5.      if t2 > t4 goto 11
6.      t3 = t1[t2]
7.      t5 = t3 * t3
8.      sum = sum + t5
9.      t2 = t2 + 4
10.     goto 5
11.
```

unoptimized: 8 temps, 11 stmts in innermost loop
optimized: 5 temps, 5 stmts in innermost loop

1 index addressing	2 index addressing
1 multiplication	3 multiplications
2 additions	2 additions & 2 subtractions
1 jump	1 jump
1 test	1 test
	1 copy

CFG of final optimized code



General code motion

```
n = 1; k = 0; m = 3;
read x;
while (n < 10) {
  if (2 + x ≥ 5) k = 5;
  if (3 + k == 3) m = m + 2;
  n = n + k + m;
}
```

General code motion (cont'd)

```
1. n = 1; 2. k = 0; 3. m = 3;

4. read x;

5. while (n  < 10) {

6.     if (2 * x ≥ 5) 7. k := 5;

8.     if (3 + k == 3) 9. m := m + 2;

10.    n = n + k + m;

11. }
```

- Invariant within loop and therefore moveable
- Unaffected by definitions in loop and guarded by invariant condition
- Moveable after we move statements 6 and 7
- Not moveable because may use def of m from statement 9 on previous iteration

General code motion, result

```
n = 1; k = 0; m = 3;
read x;
while (n < 10) {
  if (2 * x ≥ 5) k = 5;
  if (3 + k == 3) m = m + 2;
  n = n + k + m;
}
```

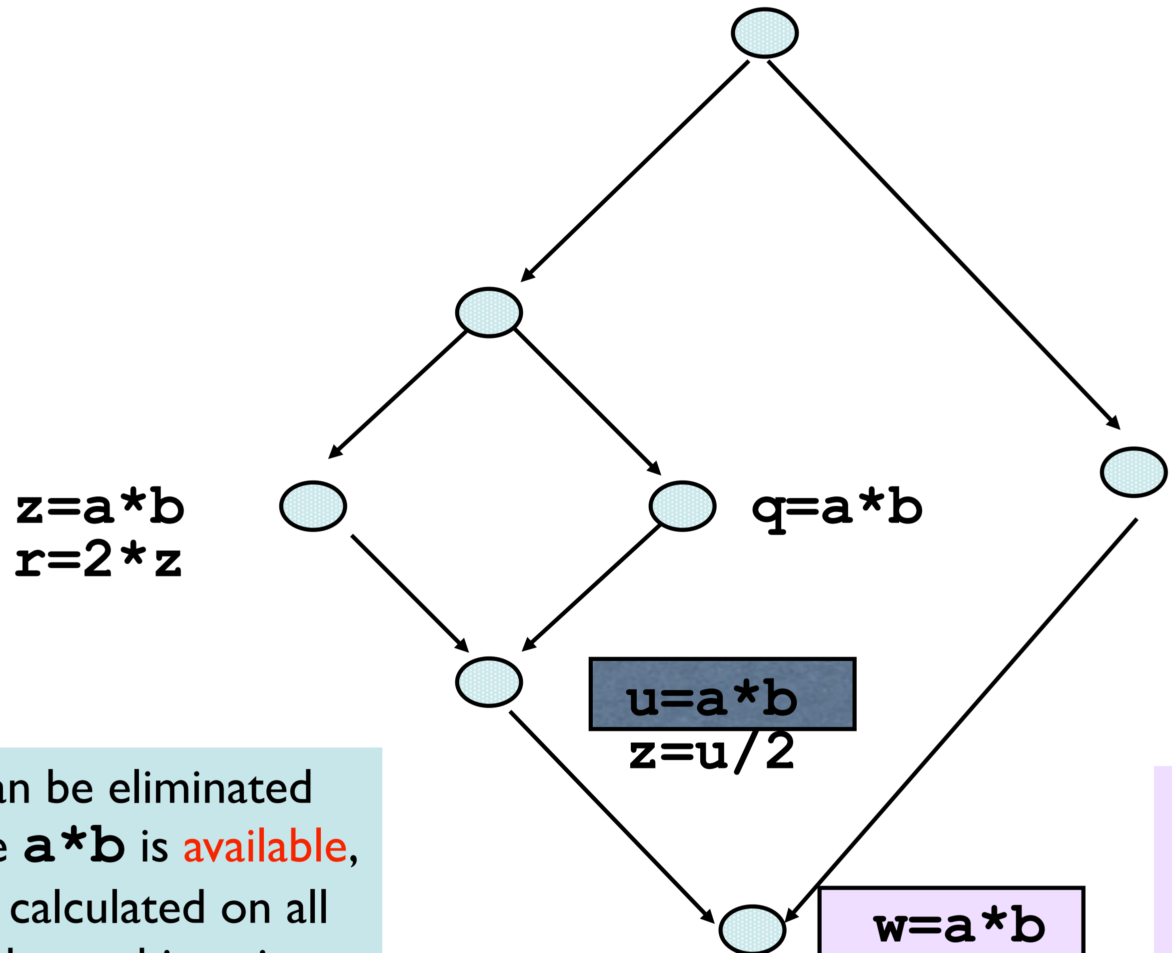
```
n = 1; k = 0; m = 3;
read x;
if (2 * x ≥ 5) k = 5;
t1 = (3 + k == 3);
while (n < 10) {
  if (t1) m = m + 2;
  n = n + k + m;
}
```

Code specialization

```
n = 1; k = 0; m = 3;
read x;
if (2 * x ≥ 5) k := 5;
t1 = (3 + k == 3);
if (t1)
  while (n < 10) {
    m = m + 2;
    n = n + k + m;
  }
else
  while (n < 10)
    n = n + k + m;
```

Specialization of while loop depending on value of `t1`

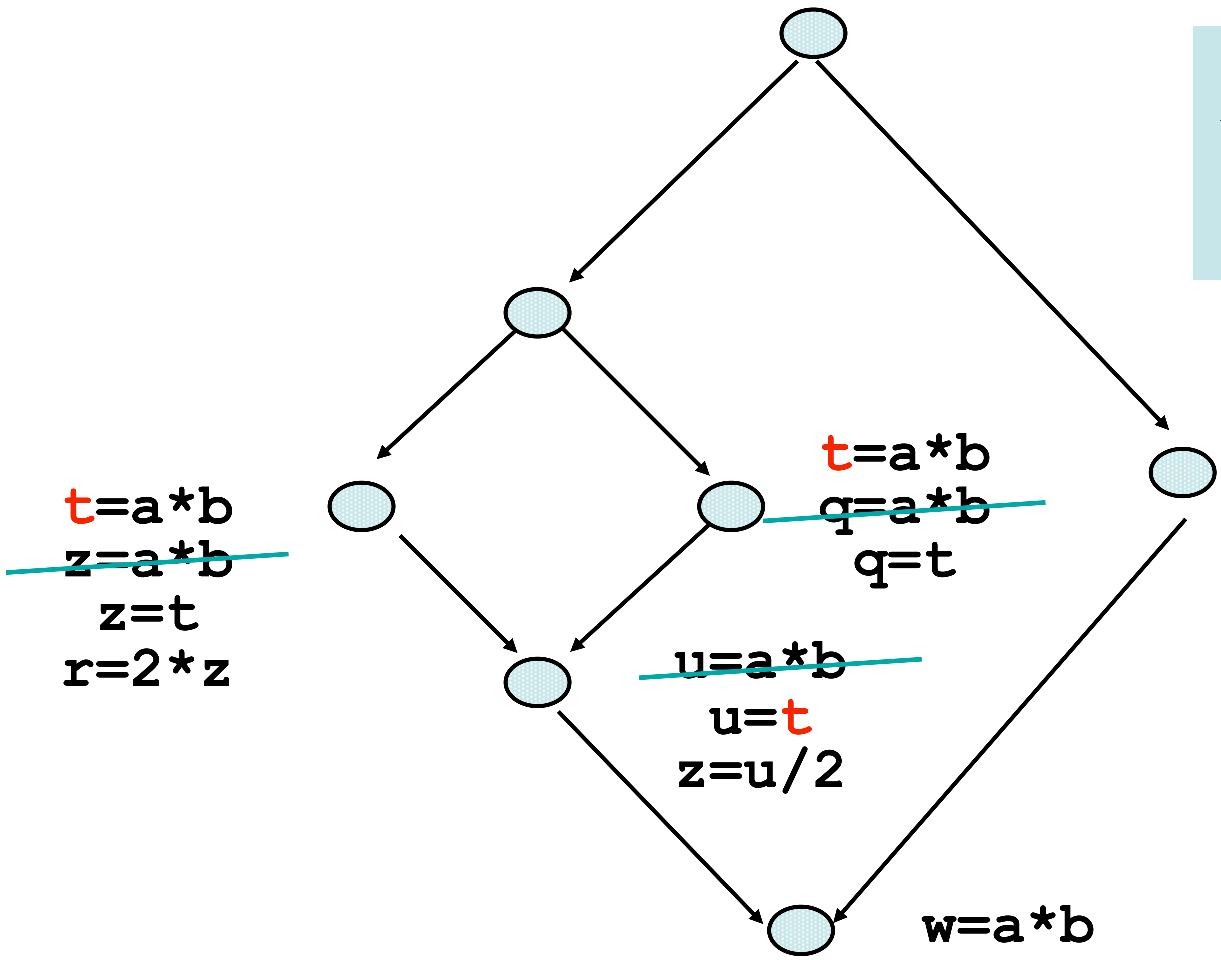
(Global) common subexpr elim



Can be eliminated since **a*b** is available, i.e., calculated on all paths to this point.

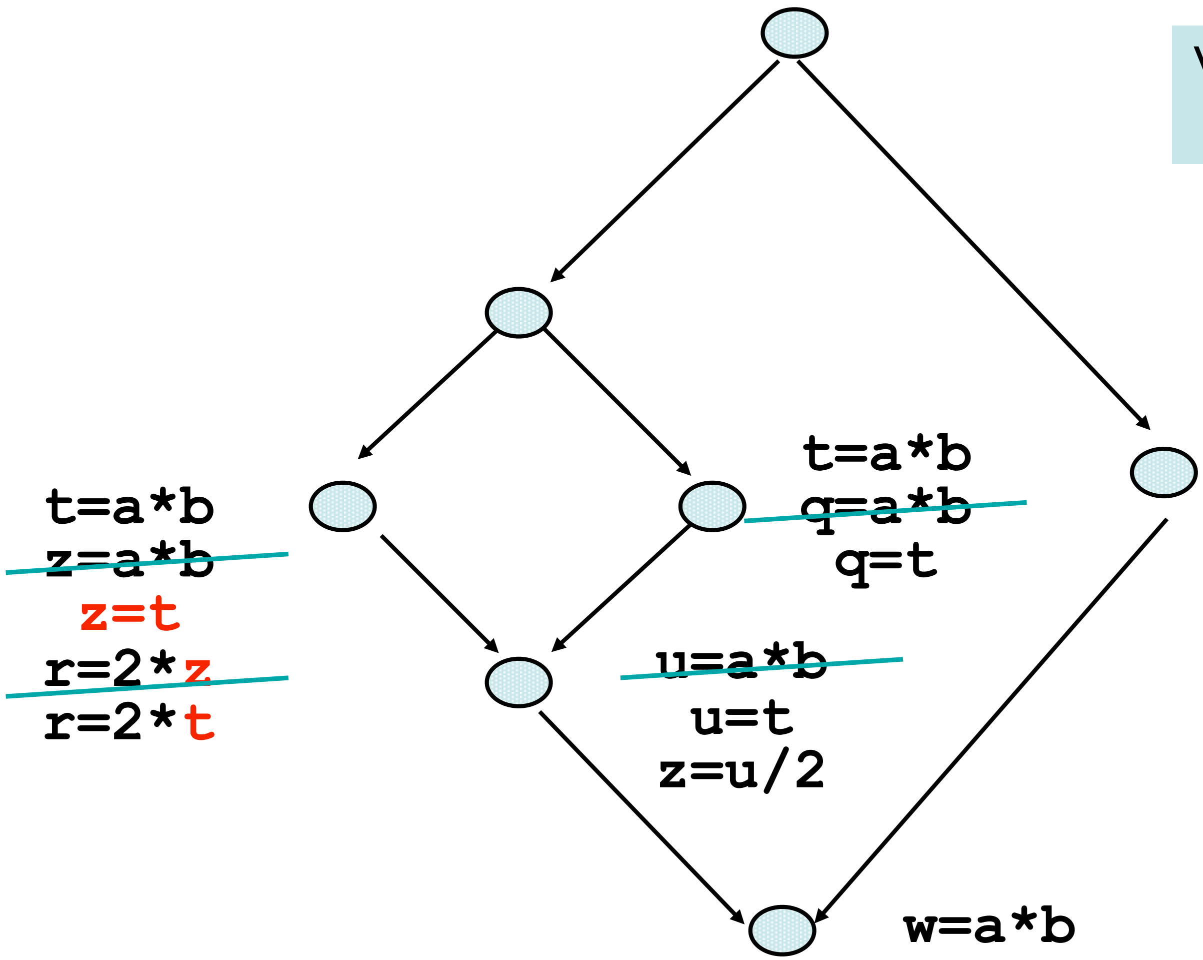
Cannot be eliminated since **a*b** is not available on all path reaching this point.

(Global) common subexpr elim



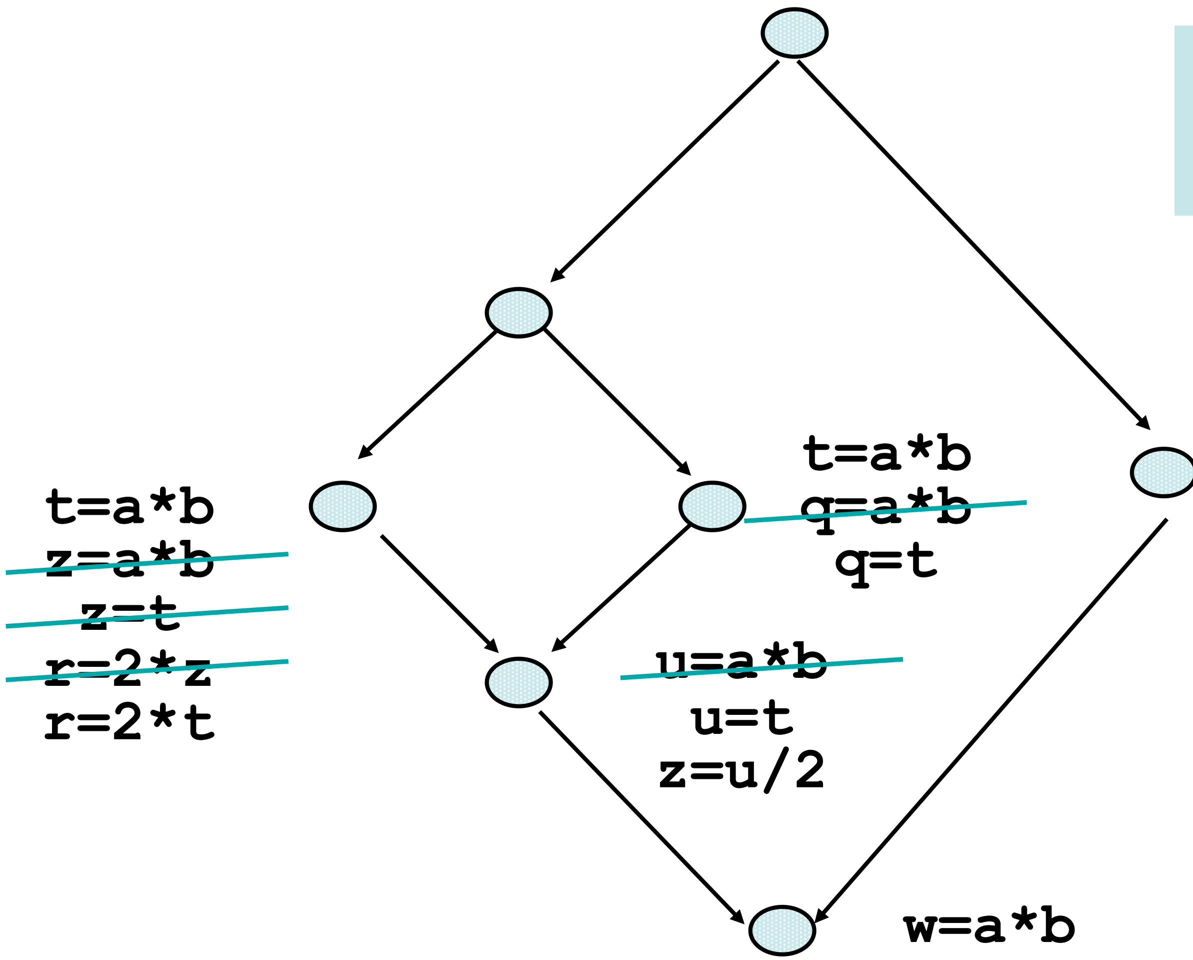
Ensure a*b is assigned to the same variable **t** so it can be used for the assignment to u.

Copy propagation



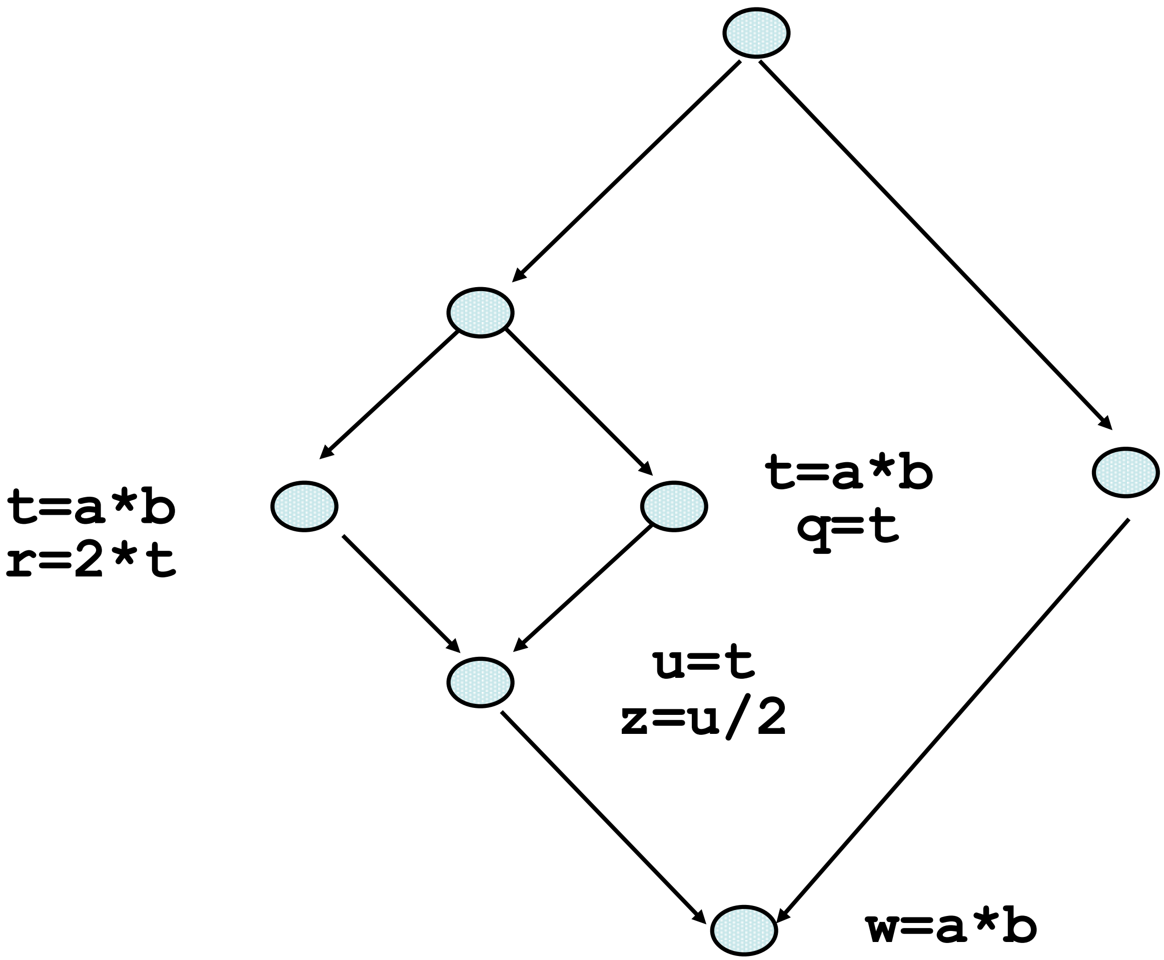
We can then forward substitute t for z…

Dead code elimination

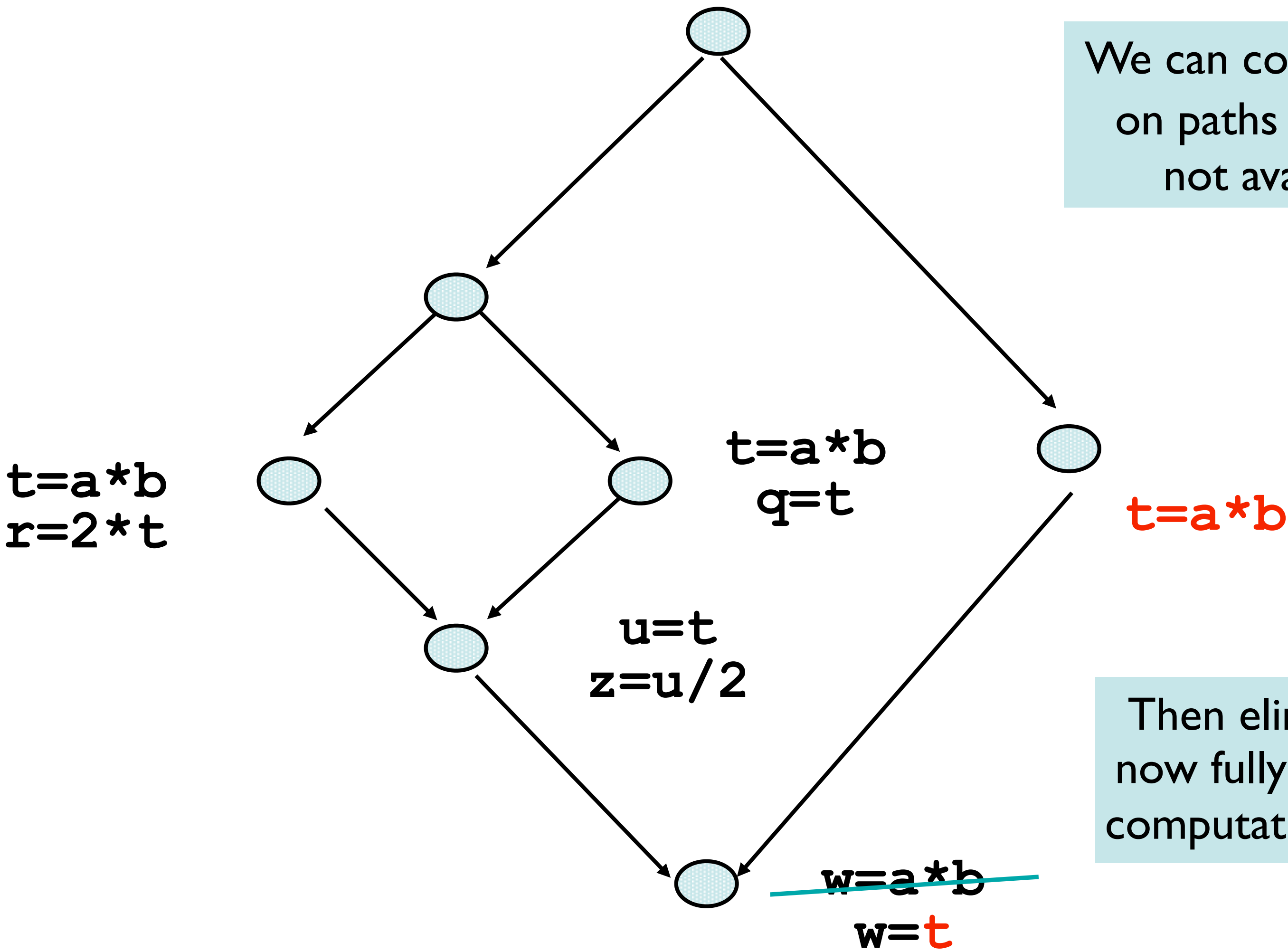


…and eliminate the assignment to z since it is now dead code.

What else can we do?



Partial redundancy elimination



We can compute **a*b** on paths where it is not available…

Then eliminate the now fully redundant computation of **a*b**