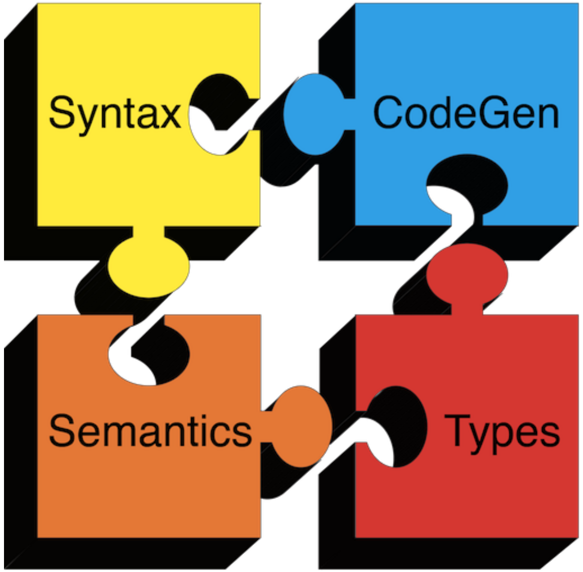

Compilers

Local Optimization

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Local Optimization

- The simplest form of optimization
- Optimize one basic block
  - No need to analyze the whole procedure body

Local Optimization

x: Int

- Some statements can be deleted

  x := x + 0

  x := x * 1

Algebraic Simplifications

- Some statements can be simplified

x := x * 0	⇒	x := 0
y := y ** 2	⇒	y := y * y
x := x * 8	⇒	x := x << 3
x := x * 15	⇒	t := x << 4; x := t - x

(on some machines << is faster than *; but not on all!)

Local Optimization

- Operations on constants can be computed at compile time
  - If there is a statement x := y op z
  - And y and z are constants
  - Then y op z can be computed at compile time

constant folding

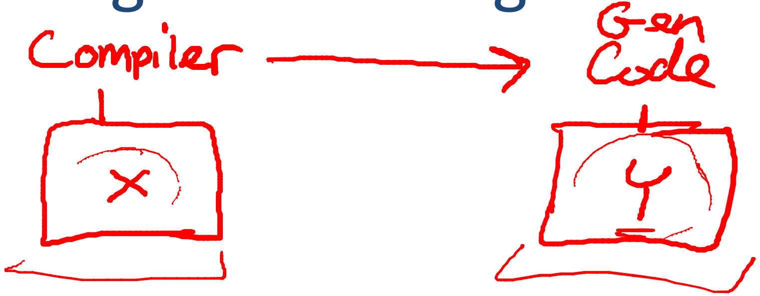
- Example: x := 2 + 2 $\Rightarrow$ x := 4
- Example: if 2 < 0 jump L can be deleted

false

if 2 > 0 jump L $\Rightarrow$ jump L

Local Optimization

- Constant folding can be dangerous.



cross-compiler

X and Y are different archs.

$a := \underline{1.5 + 3.7}$

$a := 5.2$

$a := 5.19$

Local Optimization

- Eliminate unreachable basic blocks:
  - Code that is unreachable from the initial block
    - E.g., basic blocks that are not the target of any jump or "fall through" from a conditional

- Removing unreachable code makes the program smaller
  - And sometimes also faster
    - Due to memory cache effects
    - Increased spatial locality

- Why would unreachable basic blocks occur?

#define DEBUG 0

if (DEBUG) then $\Rightarrow$ if (0) then

libraries

result of optimizations

- Some optimizations are simplified if each register occurs only once on the left-hand side of an assignment

- Rewrite intermediate code in *single assignment* form

x := z + y		b := z + y
a := x	⇒	a := b
x := 2 * x		x := 2 * b

(b is a fresh register)

  – More complicated in general, due to loops

Local Optimization

:= x

y ← x :=

- If
  - Basic block is in single assignment form
  - A definition x := is the first use of x in a block
- Then
  - When two assignments have the same rhs, they compute the same value
- Example:

x := y + z		x := y + z
…	⇒	…
w := y + z		w := x

(the values of x, y, and z do not change in the … code)

common subexpression elimination

Local Optimization

- If w := x appears in a block, replace subsequent uses of w with uses of x
  - Assumes single assignment form

copy propagation

- Example:

```
b := z + y                b := z + y
a := b          ⇒         a := b
x := 2 * a                x := 2 * b
```

- Only useful for enabling other optimizations
  - Constant folding
  - Dead code elimination

Local Optimization

- Example:

$$
\begin{array}{ll}
a := 5 & \\
x := \underbrace{2 * a}_{} & 10 \\
y := \underbrace{x + 6}_{} = 16 & \\
t := \underbrace{x * y}_{x * 16} &
\end{array}
\Rightarrow
\begin{array}{l}
a := 5 \\
x := 10 \\
y := 16 \\
t := \cancel{x << 4}
\end{array}
$$

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If

w := rhs appears in a basic block

w does not appear anywhere else in the program

Then

the statement w := rhs is dead and can be eliminated

– Dead = does not contribute to the program's result

Example: (a is not used anywhere else)

~~x~~ b := z + y		b := z + y		b := z + y
a := ~~x~~ b	⇒	a := b	⇒	x := 2 * b
x := 2 * ~~a~~ b		x := 2 * b		

Local Optimization

- Each local optimization does little by itself

- Typically optimizations interact
  - Performing one optimization enables another

- Optimizing compilers repeat optimizations until no improvement is possible
  - The optimizer can also be stopped at any point to limit compilation time

- Initial code:

```
a := x ** 2
b := 3
c := x
d := c * c
e := b * 2
f := a + d
g := e * f
```

- Algebraic optimization:

```
a := x ** 2
b := 3
c := x
d := c * c
e := b * 2
f := a + d
g := e * f
```

- Algebraic optimization:

```
a := x * x
b := 3
c := x
d := c * c
e := b << 1
f := a + d
g := e * f
```

- Copy propagation:

```
a := x * x
b := 3
c := x
d := c * c
e := b << 1
f := a + d
g := e * f
```

- Copy propagation:

```
a := x * x
b := 3
c := x
d := x * x
e := 3 << 1
f := a + d
g := e * f
```

- Constant folding:

```
a := x * x
b := 3
c := x
d := x * x
e := 3 << 1
f := a + d
g := e * f
```

- Constant folding:

```
a := x * x
b := 3
c := x
d := x * x
e := 6
f := a + d
g := e * f
```

- Common subexpression elimination:

```
a := x * x
b := 3
c := x
d := x * x
e := 6
f := a + d
g := e * f
```

- Common subexpression elimination:

```
a := x * x
b := 3
c := x
d := a
e := 6
f := a + d
g := e * f
```

- Copy propagation:

a := x * x
b := 3
c := x
d := a
e := 6
f := a + d
g := e * f

- Copy propagation:

```
a := x * x
b := 3
c := x
d := a
e := 6
f := a + a
g := 6 * f
```

- Dead code elimination:

```
a := x * x
b := 3
c := x
d := a
e := 6
f := a + a
g := 6 * f
```

- Dead code elimination:

$$a := x * x$$

$$\cancel{f := a + a} \qquad 2 * a$$

$$g := 6 * f \qquad g := 12 * a$$

- This is the final form

Local Optimization

Which of the following are valid local optimizations for the given basic block? Assume that only g and x are referenced outside of this basic block.

1 a := 1
2 b := 3
3 c := a + x
4 d := a * 3
5 e := b * 3
6 f := a + b
7 g := e - f

- [ ] Copy propagation: Line 4 becomes d := a * b.
- [ ] Common subexpression elimination: Line 5 becomes e := d.
- [ ] Dead code elimination: Line 3 is removed.
- [ ] After many rounds of valid optimizations, the entire block can be reduced to g := 5.