IR Optimization

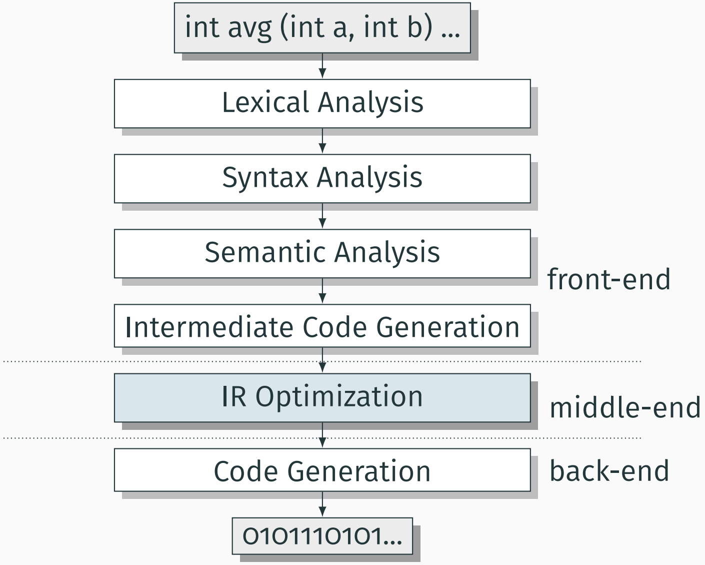
Ronghui Gu

Spring 2019

Columbia University

* Course website: https://www.cs.columbia.edu/ rgu/courses/4115/spring2019

IR Optimization



IR Optimization

Goal

- Runtime
- Memory usage
- Power Consumption

Sources?

Optimizations from IR Generation

C code:

```
int x;
int y;
bool b1;
bool b2;
bool b3;
b1 = x + x < y
b2 = x + x == y
b3 = x + x > y
```

Three-Address:

```
_t0 = x + x;
_t1 = y;
b1 = _t0 < _t1;
_t2 = x + x;
_t3 = y;
b2 = _t2 == _t3;
_t4 = x + x;
_t5 = y;
b3 = _t5 < _t4;
```

Optimizations from IR Generation

C code:

```
int x;
int y;
bool b1;
bool b2;
bool b3;
b1 = x + x < y
b2 = x + x == y
b3 = x + x > y
```

Three-Address:

```
_t0 = x + x;
_t1 = y;
b1 = _t0 < _t1;
_t2 = x + x;
_t3 = y;
b2 = _t2 == _t3;
_t4 = x + x;
_t5 = y;
b3 = _t5 < _t4;
```

Optimizations from IR Generation

C code:

```
int x;
int y;
bool b1;
bool b2;
bool b3;
b1 = x + x < y
b2 = x + x == y
b3 = x + x > y
```

Three-Address:

```
_t0 = x + x;
_t1 = y;
b1 = _t0 < _t1;


b2 = _t0 == _t1;


b3 = _t0 < _t1;
```

Optimizations from Lazy Coders

C code:

```
while (x < y + z) {
    x = x - y;
}
```

Three-Address:

```
_L0:
    _t0 = y + z;
    _t1 = x < _t0;
    bz _L1 _t1;
    x = x − y;
    jmp _L0;
_L1:
```

Optimizations from Lazy Coders

C code:

```
while (x < y + z) {
    x = x - y;
}
```

Three-Address:

```
_L0:
    _t0 = y + z;
    _t1 = x < _t0;
    bz _L1 _t1;
    x = x − y;
    jmp _L0;
_L1:
```

Optimizations from Lazy Coders

C code:

```
while (x < y + z) {
    x = x - y;
}
```

Three-Address:

```
    _t0 = y + z;
_L0:
    _t1 = x < _t0;
    bz _L1 _t1;
    x = x − y;
    jmp _L0;
_L1:
```

IR Optimization Discussion

Optimal? Undecidable!

Soundness: semantics-preserving

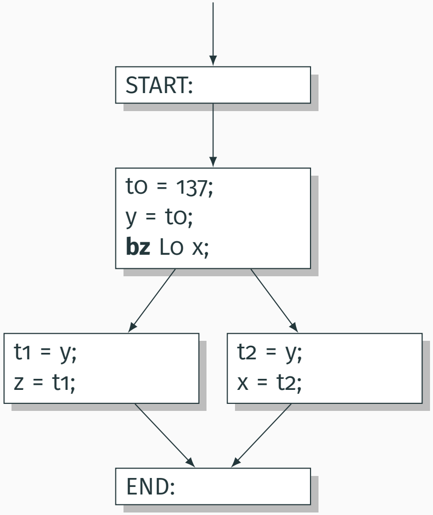
IR optimization v.s. code optimization:

`x * 0.5` $\Rightarrow$ `x » 1`

Local optimization v.s. global optimization

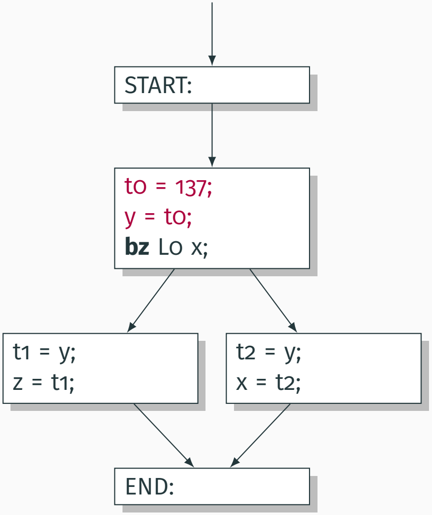
Local Optimization

```
int main() {
  int y;
  int z;
  y = 137;
  if (x == 0)
    z = y;
  else
    x = y;
}
```



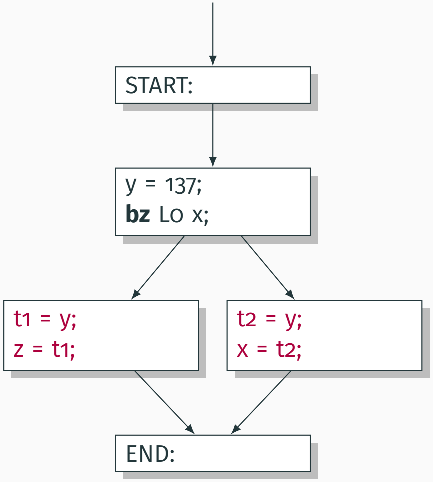
Local Optimization

```
int main() {
  int y;
  int z;
  y = 137;
  if (x == 0)
    z = y;
  else
    x = y;
}
```



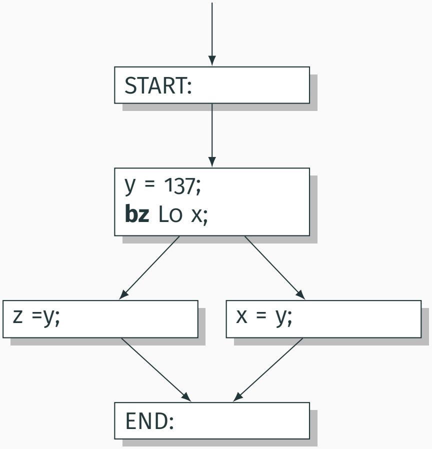
Local Optimization

```
int main() {
  int y;
  int z;
  y = 137;
  if (x == 0)
    z = y;
  else
    x = y;
}
```



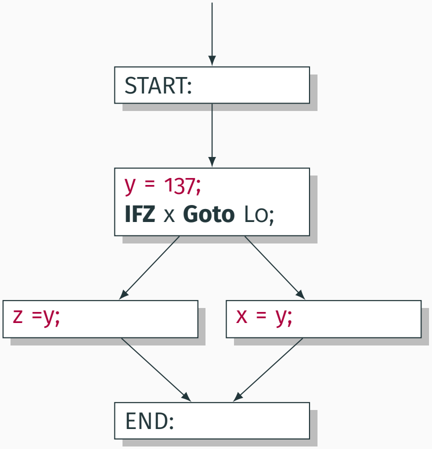
Local Optimization

```
int main() {
  int y;
  int z;
  y = 137;
  if (x == 0)
    z = y;
  else
    x = y;
}
```



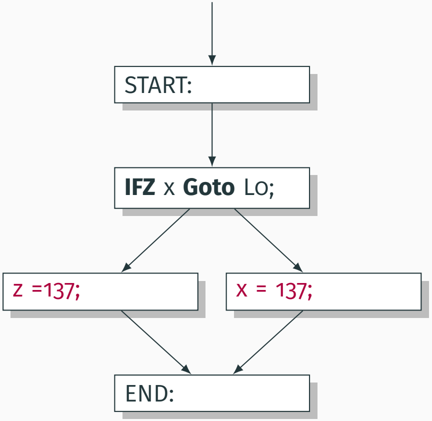
Global Optimization

```
int main() {
  int y;
  int z;
  y = 137;
  if (x == 0)
    z = y;
  else
    x = y;
}
```



Global Optimization

```
int main() {
  int y;
  int z;
  y = 137;
  if (x == 0)
    z = y;
  else
    x = y;
}
```



Local Optimization

Common Subexpression Elimination

```
v1 = a op b
.  .  .
v2 = a op b
```

If values of **`v1`**, **`a`**, and **`b`** have not changed, rewrite the code:

```
v1 = a op b
.  .  .
v2 = v1
```

Common Subexpression Elimination

C code:

```
int a;
int b;
int c;
a = 4;
c = a + b;
f(a + b);
```

Three-address code:

```
_t0 = 4;
a = _t0;
_t1 = a + b;
c = _t1;
_t2 = a + b;
param _t2
call f;
```

Common Subexpression Elimination

C code:

```
int a;
int b;
int c;
a = 4;
c = a + b;
f(a + b);
```

Three-address code:

```
_t0 = 4;
a = _t0;
_t1 = a + b;
c = _t1;
_t2 = a + b;
param _t2
call f;
```

Common Subexpression Elimination

C code:

```
int a;
int b;
int c;
a = 4;
c = a + b;
f(a + b);
```

Three-address code:

```
_t0 = 4;
a = _t0;
_t1 = a + b;
c = _t1;
_t2 = _t1;
param _t2
call f;
```

Common Subexpression Elimination

C code:

```
int a;
int b;
int c;
a = 4;
c = a + b;
f(a + b);
```

Three-address code:

```
_t0 = 4;
a = _t0;
_t1 = a + b;
c = _t1;
_t2 = c;
param _t2
call f;
```

Copy Propagation

C code:

```
int a;
int b;
int c;
a = 4;
c = a + b;
f(a + b);
```

Three-address code:

```
_t0 = 4;
a = _t0;
_t1 = a + b;
c = _t1;
_t2 = c;
param _t2
call f;
```

Copy Propagation

If we have

```
v1 = v2
```

then as long as **v1** and **v2** have not changed, we can rewrite

```
a = ...  v1 ...
```

as

```
a = ...  v2 ...
```

Copy Propagation

C code:

```
int a;
int b;
int c;
a = 4;
c = a + b;
f(a + b);
```

Three-address code:

```
_t0 = 4;
a = 4;
_t1 = a + b;
c = _t1;
_t2 = c;
param _t2
call f;
```

Copy Propagation

C code:

```
int a;
int b;
int c;
a = 4;
c = a + b;
f(a + b);
```

Three-address code:

```
_t0 = 4;
a = 4;
_t1 = a + b;
c = _t1;
_t2 = c;
param _t2
call f;
```

Copy Propagation

C code:

```
int a;
int b;
int c;
a = 4;
c = a + b;
f(a + b);
```

Three-address code:

```
_t0 = 4;
a = 4;
_t1 = 4 + b;
c = _t1;
_t2 = c;
param _t2
call f;
```

Copy Propagation

C code:

```
int a;
int b;
int c;
a = 4;
c = a + b;
f(a + b);
```

Three-address code:

```
_t0 = 4;
a = 4;
_t1 = 4 + b;
c = _t1;
_t2 = c;
param _t2
call f;
```

Copy Propagation

C code:

```
int a;
int b;
int c;
a = 4;
c = a + b;
f(a + b);
```

Three-address code:

```
_t0 = 4;
a = 4;
_t1 = 4 + b;
c = 4 + b;
_t2 = c;
param _t2
call f;
```

Copy Propagation

C code:

```
int a;
int b;
int c;
a = 4;
c = a + b;
f(a + b);
```

Three-address code:

```
_t0 = 4;
a = 4;
_t1 = 4 + b;
c = 4 + b;
_t2 = c;
param _t2
call f;
```

Copy Propagation

C code:

```
int a;
int b;
int c;
a = 4;
c = a + b;
f(a + b);
```

Three-address code:

```
_t0 = 4;
a = 4;
_t1 = 4 + b;
c = 4 + b;
_t2 = 4 + b;
param _t2
call f;
```

Dead Code Elimination

An assignment to a variable **v** is called dead if its value is never read anywhere.

Dead Code Elimination

C code:

```
int a;
int b;
int c;
a = 4;
c = a + b;
f(a + b);
```

Three-address code:

```
_t0 = 4;
a = 4;
_t1 = 4 + b;
c = 4 + b;
_t2 = 4 + b;
param _t2
call f;
```

Dead Code Elimination

C code:

```
int a;
int b;
int c;
a = 4;
c = a + b;
f(a + b);
```

Three-address code:

```
_t0 = 4;
a = 4;
_t1 = 4 + b;
c = 4 + b;
_t2 = 4 + b;
param _t2
call f;
```

Dead Code Elimination

C code:

```
int a;
int b;
int c;
a = 4;
c = a + b;
f(a + b);
```

Three-address code:

```
a = 4;
_t1 = 4 + b;
c = 4 + b;
_t2 = 4 + b;
param _t2
call f;
```

Dead Code Elimination

C code:

```
int a;
int b;
int c;
a = 4;
c = a + b;
f(a + b);
```

Three-address code:

```
_t1 = 4 + b;
c = 4 + b;
_t2 = 4 + b;
param _t2
call f;
```

Dead Code Elimination

C code:

```
int a;
int b;
int c;
a = 4;
c = a + b;
f(a + b);
```

Three-address code:

```
c = 4 + b;
_t2 = 4 + b;
param _t2
call f;
```

Dead Code Elimination

C code:

```
int a;
int b;
int c;
a = 4;
c = a + b;
f(a + b);
```

Three-address code:

```
_t2 = 4 + b;
param _t2
call f;
```

For Comparison

C code:

```
int a;
int b;
int c;
a = 4;
c = a + b;
f(a + b);
```

Three-address code:

```
_t0 = 4;
a = _t0;
_t1 = a + b;
c = _t1;
_t2 = a + b;
param _t2
call f;
```

Optimized code:

```
_t2 = 4 + b;
param _t2
call f;
```

Other Types of Local Optimization

Arithmetic simplication:

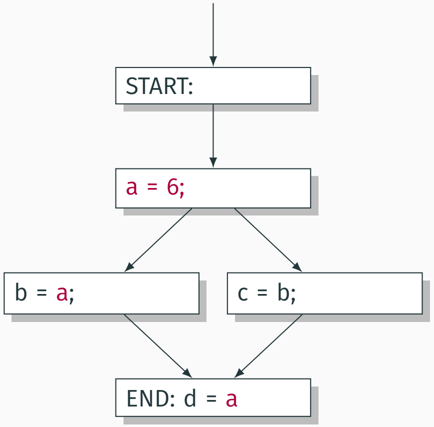
- e.g., rewrite **`x = 4 * a`** as **`x = a « 2`**

Constant folding:

- e.g., rewrite **`x = 4 * 5`** as **`x = 20`**

Global Optimization

Global Constant Propagation

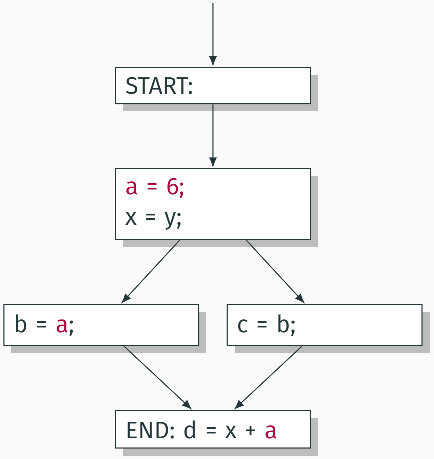


Global Optimization

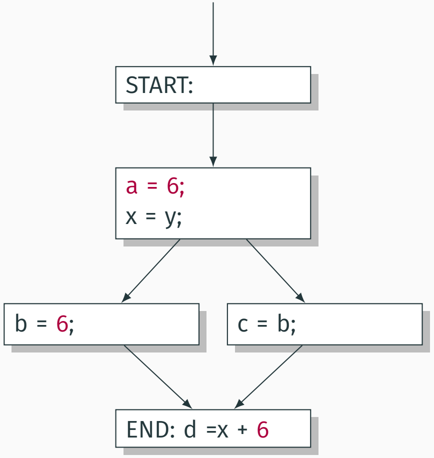
Global Constant Propagation

Replace each variable that is known to be a constant value with the constant.

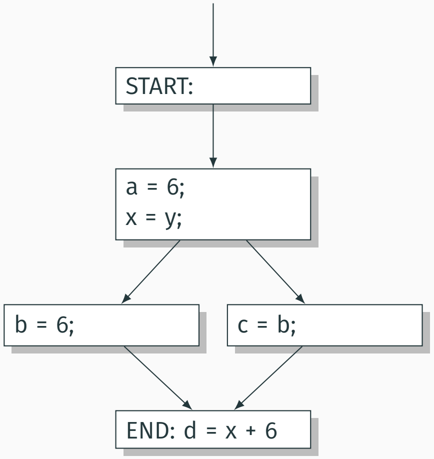
Global Constant Propagation



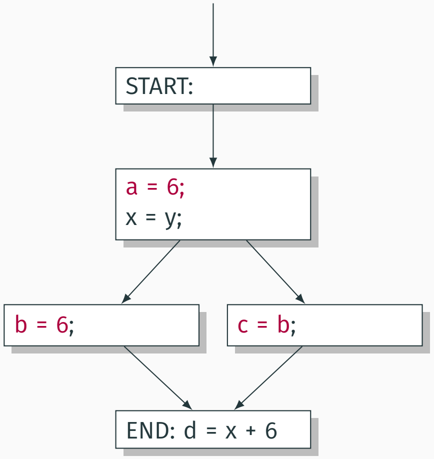
Global Constant Propagation



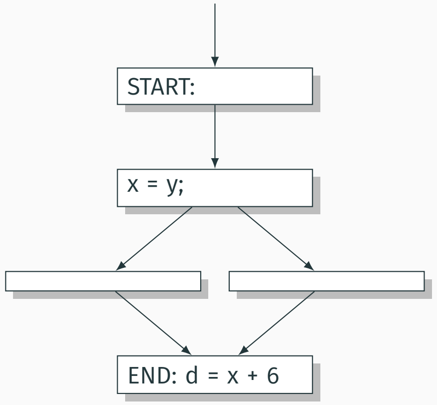
Global Dead Code Elimination



Global Dead Code Elimination



Global Dead Code Elimination


START:
x = y;
END: d = x + 6