

# CS738: Advanced Compiler Optimizations

## Overview of Optimizations

Amey Karkare

karkare@cse.iitk.ac.in

<http://www.cse.iitk.ac.in/~karkare/cs738>

Department of CSE, IIT Kanpur



## Recap

- ▶ Optimizations
  - ▶ To improve efficiency of generated executable (time, space, resources, ...)
  - ▶ Maintain semantic equivalence
- ▶ Two levels
  - ▶ Machine Independent
  - ▶ Machine Dependent

## Machine Independent Code Optimizations

## Machine Independent Optimizations

- ▶ Scope of optimizations
  - ▶ Intraprocedural
    - ▶ Local
    - ▶ Global
  - ▶ Interprocedural

## Local Optimizations

- ▶ Restricted to a basic block
- ▶ Simplifies the analysis
- ▶ Not all optimizations can be applied locally
  - ▶ E.g. Loop optimizations
- ▶ Gains are also limited
- ▶ Simplify global/interprocedural optimizations

## Global Optimizations

- ▶ Typically restricted within a procedure/function
  - ▶ Could be restricted to a smaller scope, e.g. a loop
- ▶ Most compiler implement up to global optimizations
- ▶ Well founded theory
- ▶ Practical gains

## Interprocedural Optimizations

- ▶ Spans multiple procedures, files
  - ▶ In some cases multiple languages!
- ▶ Not as popular as global optimizations
  - ▶ No single theory applicable to all scenarios
  - ▶ Time consuming

A Catalog of  
Code Optimizations

## Compile-time Evaluation

- ▶ Move run-time actions to compile-time
- ▶ Constant Folding

$$\text{Volume} = \frac{4}{3} \times \pi \times r \times r \times r$$

- ▶ Compute  $\frac{4}{3} \times \pi$  at compile-time
- ▶ Applied frequently for linearizing indices of multidimensional arrays
- ▶ When should we NOT apply it?

## Compile-time Evaluation

- ▶ Constant Propagation
  - ▶ Replace a variable by its “constant” value

<div style="border: 1px solid black; padding: 5px; display: inline-block;"><math>i = 5</math> <math>\vdots</math> <math>j = i * 4</math></div>	can be replaced by	<div style="border: 1px solid black; padding: 5px; display: inline-block;"><math>i = 5</math> <math>\vdots</math> <math>j = 5 * 4</math></div>
--	--------------------	--

- ▶ May result in the application of constant folding
- ▶ When should we NOT apply it?

## Common Subexpression Elimination

- ▶ Reuse a computation if already “available”

<div style="border: 1px solid black; padding: 5px; display: inline-block;"><math>x = u + v</math> <math>\vdots</math> <math>y = u + v</math></div>	can be replaced by	<div style="border: 1px solid black; padding: 5px; display: inline-block;"><math>t = u + v</math> <math>x = t</math> <math>\vdots</math> <math>y = t</math></div>
--	--------------------	---

- ▶ How to check if an expression is already available?
- ▶ When should we NOT apply it?

## Copy Propagation

- ▶ Replace (use of) a variable by another variable
  - ▶ If they are guaranteed to have the “same value”

<div style="border: 1px solid black; padding: 5px; display: inline-block;"><math>i = k</math> <math>\vdots</math> <math>j = i * 4</math></div>	can be replaced by	<div style="border: 1px solid black; padding: 5px; display: inline-block;"><math>i = k</math> <math>\vdots</math> <math>j = k * 4</math></div>
--	--------------------	--

- ▶ May result in dead code, common subexpression
- ▶ When should we NOT apply it?

## Code Movement

- ▶ Move the code around in a program
- ▶ Benefits
  - ▶ Code size reduction
  - ▶ Reduction in the frequency of execution
- ▶ How to find out which code to move?

## Code Movement

- ▶ Code size reduction
  - ▶ Suppose the operator  $\oplus$  results in the generation of a large number of machine instructions. Then,

```
if (a < b)
    u = x $\oplus$ y
else
    v = x $\oplus$ y
```

can be replaced by

```
t = x $\oplus$ y
if (a < b)
    u = t
else
    v = t
```

- ▶ **When should we NOT apply it?**

## Code Movement

- ▶ Execution frequency reduction

```
if (a < b)
    u = ...
else
    v = x * y
    w = x * y
```

can be replaced by

```
if (a < b)
    u = ...
    t = x * y
else
    t = x * y
    v = t
    w = t
```

- ▶ **When should we NOT apply it?**

## Loop Invariant Code Movement

- ▶ Move loop invariant code out of the loop

```
for (...) {
    ...
    u = a + b
    ...
}
```

can be replaced by

```
t = a + b
for (...) {
    ...
    u = t
    ...
}
```

- ▶ **When should we NOT apply it?**

## Code Movement

Safety of code motion  
Profitability of code motion

## Other Optimizations

- ▶ Dead code elimination
  - ▶ Remove unreachable and/or unused code.
  - ▶ Can we always do it?
  - ▶ Is there ever a need to introduce unused code?
- ▶ Strength Reduction
  - ▶ Use of *low strength* operators in place of *high* strength ones.
    - ▶  $i * i$  instead of  $i * * 2$ ,  $\text{pow}(i, 2)$
    - ▶  $i << 1$  instead of  $i * 2$
  - ▶ Typically performed for integers only – Why?

## Agenda

- ▶ Static analysis and compile-time optimizations
- ▶ For the next few lectures
- ▶ *Intraprocedural* Data Flow Analysis
  - ▶ Classical Examples
  - ▶ Components

## Assumptions

- ▶ Intraprocedural: Restricted to a single function
- ▶ Input in 3-address format
- ▶ Unless otherwise specified

## 3-address Code Format

- ▶ Assignments

- $x = y \text{ op } z$

- $x = \text{op } y$

- $x = y$

- ▶ Jump/control transfer

- goto L

- if x relop y goto L

- ▶ Statements can have label(s)

- L: ...

- ▶ Arrays, Pointers and Functions to be added later when needed