V22.0474-001 Software Engineering
Spring 2008

Lecture 22: Code Optimization II

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Outline

- Project Status Check
- Code Tuning: Logic
- Code Tuning: Loops
- Code Tuning: Data Transformations
- Code Tuning: Other Techniques

Sources for today's lecture:

McConnell, Steve. *Code Complete*, Second Edition, ch. 26.

Project Status Check

Upcoming assignments

- *April 10*: Code for testing (hw8) is due.
- *April 17*: Testing report (hw9) is due.
- *April 22*: Testing presentations will take place in class:
  - Send me the slides by 10am on April 22;
  - As before, each team has 20 minutes;
  - The presentation should be given by someone new;
  - Discuss unit, integration, and system/user-testing on your own project.
- *April 29*: Testing report for other team (hw10) is due.

Project Status Check

Upcoming assignments

- *May 1*: Final project presentations
  - Each team will have 30 minutes to present their project;
  - Final presentations should present the final product as well as discuss what was accomplished and learned during the project as a whole.
- *May 7*: Spring Showcase
  - Demo your project for anyone who wants to see.
  - Refreshments will be served!
  - Invite your friends!
- *May 10*: Final project report and code is due

Code Tuning

In this lecture, we will discuss *specific code-tuning techniques*.

The *warnings and guidelines* about performance tuning we discussed last time still apply.

In particular, code-tuning usually means trading off *readability and maintainability* for *speed*.

The *effectiveness* of a specific technique will depend on your development environment.

Thus, consider this a list of things to try, but you still need to *measure* performance before and after.

Code Tuning: Logic

Stop testing when you know the answer

Which is faster?

```
if ((5 < x) && (x < 10)) {
  ...
}
```

```
if (5 < x) {
  if (x < 10) {
    ...
  }
}
```

Code Tuning: Logic

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Which is faster?

```
if ((5 < x) && (x < 10)) {
  ...
}
```

```
if (5 < x) {
  if (x < 10) {
    ...
  }
}
```

In C, C++, and Java, there is no difference because these languages have *short-circuit* evaluation. In other languages, however, the second piece of code may be faster.

Code Tuning: Logic

How can the same principle be applied to the following code?

```
negativeInputFound = false;
for (i = 0; i < count; i++) {
  if (input[i] < 0) {
    negativeInputFound = true;
  }
}
```

Code Tuning: Logic

How can the same principle be applied to the following code?

```
negativeInputFound = false;
for (i = 0; i < count; i++) {
  if (input[i] < 0) {
    negativeInputFound = true;
  }
}
```

Once a negative value has been found, it is unnecessary to continue the for loop. Some possible ways to implement this include:

- Use `break` or `goto` to end the loop when `input[i] < 0`.
- Check for `negativeInputFound` as part of the loop terminating condition.
- Use a sentinel (more on this later).

Code Tuning: Logic

How could the following code be made faster?

```
if (c == '+' || c == '=')
  ProcessMathSymbol(c);
else if (c >= '0' && c <= '9')
  ProcessDigit(c);
else if (c == ',' || c == '.' || c == '!' || c == '?')
  ProcessPunctuation(c);
else if (c == ' ')
  ProcessSpace(c);
else if ((c >= 'A' && c <= 'Z') || (c >= 'a' && c <= 'z'))
  ProcessAlpha(c);
```

Code Tuning: Logic

How could the following code be made faster?

```
if (c == '+' || c == '=')
  ProcessMathSymbol(c);
else if (c >= '0' && c <= '9')
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else if (c == ' ')
  ProcessSpace(c);
else if ((c >= 'A' && c <= 'Z') || (c >= 'a' && c <= 'z'))
  ProcessAlpha(c);
```

Order Tests by Frequency

By reordering the tests to put the common cases first, we can avoid many unnecessary tests.

Code Tuning: Logic

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  ProcessSpace(c);
else if ((c >= 'A' && c <= 'Z') || (c >= 'a' && c <= 'z'))
  ProcessAlpha(c);
```

Order Tests by Frequency

By reordering the tests to put the common cases first, we can avoid many unnecessary tests.

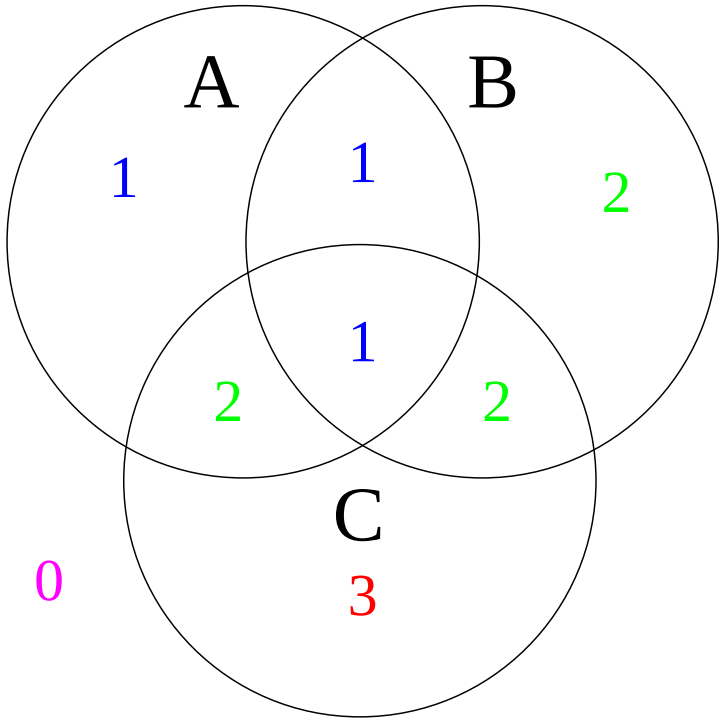
Compare Performance of Similar Logic Structures

We could also rewrite the code using `switch` and `case`. Would this be faster? It's unclear. The only reliable way to find out is to measure it.

Code Tuning: Logic

Suppose you wanted to categorize an object into one of four categories (0, 1, 2, 3) based on which groups A, B, or C it belongs to as follows.

How would you do it?



Code Tuning: Logic

One solution:

```
if ((isA(x) && !isC(x)) || (isA(x) && isB(x) && isC(x))) {
  category = 1;
}
else if ((isB(x) && !isA(x)) || (isA(x) && isC(x) && !isB(x))) {
  category = 2;
}
else if (isC(x) && !isA(x) && !isB(x)) {
  category = 3;
}
else {
  category = 0;
}
```

How can this be improved?

Code Tuning: Logic

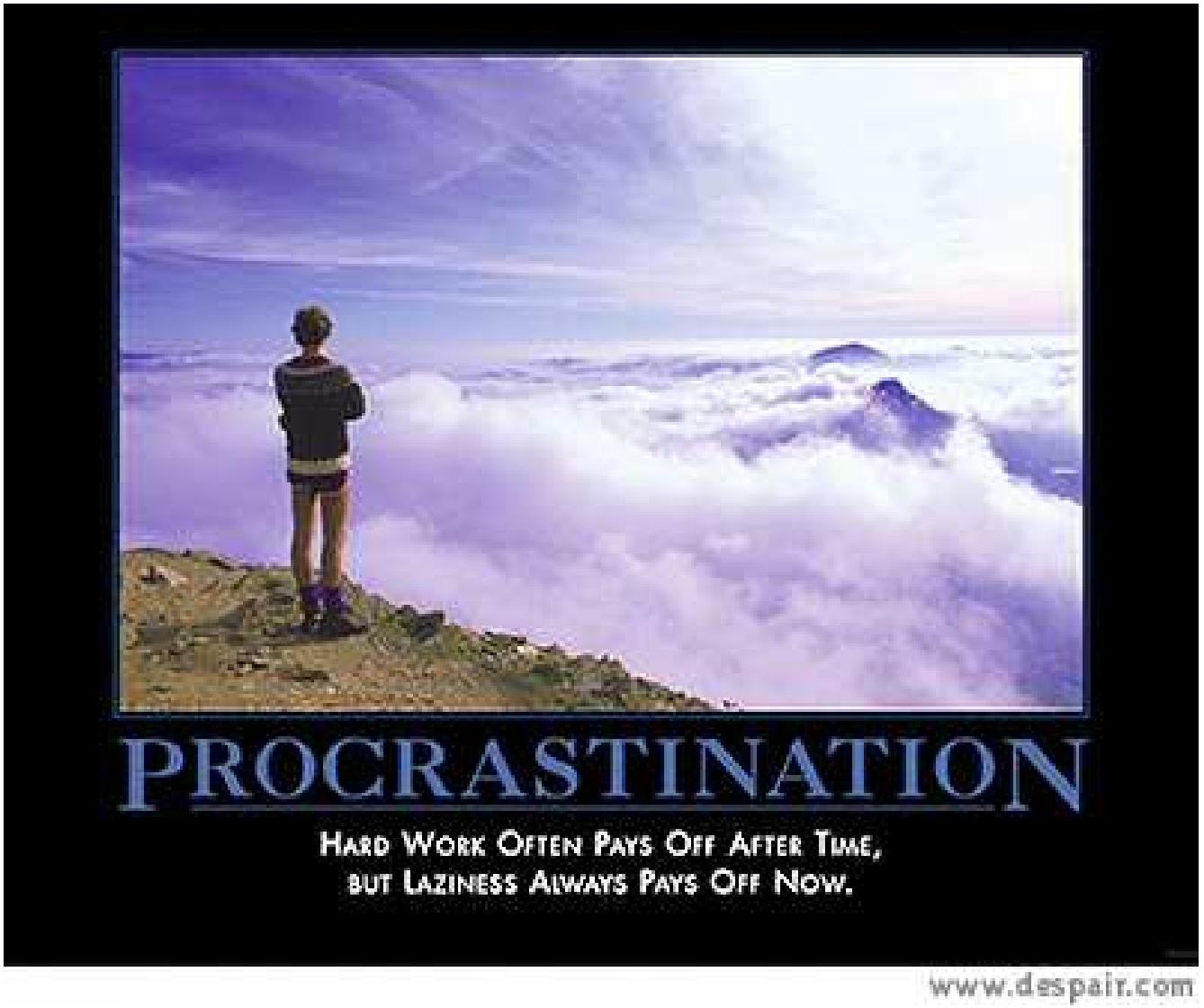
Substitue Table Lookups for Complicated Expressions

Here is a faster solution:

```
// define categoryTable
static int categoryTable[2][2][2] = {
   // !b!c !bc  b!c  bc
      0,   3,   2,   2,  // !a
      1,   2,   1,   1   // a
};
...
category = categoryTable[isA(x)][isB(x)][isC(x)];
```

A *lookup table*, if well-documented, is faster and easier to maintain than a complicated chain of if-then-else.

Code Tuning: Logic



How can you apply this principle in programming?

Code Tuning: Logic

Use Lazy Evaluation

In programming, laziness means waiting to do work until you know it will be needed.

> For example, suppose you have a table of 5000 values that might be used, but only a few hundred are actually used in any run of the program. Rather than pre-computing all 5000 values, you may want to wait and compute only the values you need when you need them.
>
> Note that if most of the 5000 values are used, or if values are used many many times, it may be faster to pre-compute everything.

As usual, you have to *know your application* and *measure*.

Code Tuning: Loops

Unswitching

How can this code be made faster?

```
for (i = 0; i < count; i++) {
  if (sumType == SUMTYPE_NET)
    netSum += amount[i];
  else
    grossSum += amount[i];
}
```

Code Tuning: Loops

Unswitching

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for (i = 0; i < count; i++) {
  if (sumType == SUMTYPE_NET)
    netSum += amount[i];
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The test `sumType == SUMTYPE_NET` is repeated on each iteration. The loop can be rewritten as follows:

Code Tuning: Loops

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if (sumType == SUMTYPE_NET) {
  for (i = 0; i < count; i++)
    netSum += amount[i];
}
else {
  for (i = 0; i < count; i++)
    grossSum += amount[i];
}
```

Code Tuning: Loops

Jamming or “Loop Fusion”

How would you speed up the following code?

```
for (i=0; i < employeecount; i++) {
  employeeName[i] = "";
}
for (i=0; i < employeecount; i++) {
  employeeEarnings[i] = 0;
}
```

Code Tuning: Loops

Jamming or "Loop Fusion"

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```
for (i=0; i < employeecount; i++) {
  employeeName[i] = "";
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for (i=0; i < employeecount; i++) {
  employeeEarnings[i] = 0;
}
```

The two loops can be "fused" as follows:

```
for (i=0; i < employeecount; i++) {
  employeeName[i] = "";
  employeeEarnings[i] = 0;
}
```

What do you have to worry about before doing loop fusion?

Code Tuning: Loops

Jamming or “Loop Fusion”

How would you speed up the following code?

```
for (i=0; i < employeecount; i++) {
  employeeName[i] = "";
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for (i=0; i < employeecount; i++) {
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The two loops can be “fused” as follows:

```
for (i=0; i < employeecount; i++) {
  employeeName[i] = "";
  employeeEarnings[i] = 0;
}
```

What do you have to worry about before doing loop fusion?

If there are dependencies between the two loops, you have to check that the fused loop still does the right thing.

Also, note that many compilers perform this optimization automatically.

Code Tuning: Loops

Unrolling

Recall that last time we gave an example of a loop that iterated 10 times. The "unrolled" code was 10 times larger but also a bit faster. This principle can be applied to any loop. Consider the following:

```
i = 0;
while (i < count) {
  a[i] = i;
  i++;
}
```

Here is the loop after one unrolling:

```
i = 0;
while (i < count - 1) {
  a[i] = i;
  a[i+1] = i+1;
  i += 2;
}
if (i == count) {
  a[count-1] = count-1;
}
```

Code Tuning: Loops

This technique can be extended. Loops can be unrolled *twice*, *three times*, etc.

Additional unrolls *complicate* the code significantly for *decreasing* performance gains.

As with loop fusion, loop unrolling is done *automatically* by many compilers.

Code Tuning: Loops

Minimizing the Work Inside Loops

How could you make this code faster?

```
for (i = 0; i < rateCount; i++) {
  netRate[i] = baseRate[i] * rates->discounts->factors->net;
}
```

Code Tuning: Loops

Minimizing the Work Inside Loops

How could you make this code faster?

```
for (i = 0; i < rateCount; i++) {
  netRate[i] = baseRate[i] * rates->discounts->factors->net;
}
```

We can move the complicated expression outside the loop. In this case, the result improves both readability and (in many cases) performance.

```
quantityDiscount = rates->discounts->factors->net;
for (i = 0; i < rateCount; i++) {
  netRate[i] = baseRate[i] * quantityDiscount;
}
```

Code Tuning: Loops

Sentinel Values

Consider the following loop:

```
found = false;
i = 0;
while ((!found) && (i < count)) {
  if (item[i] == testValue) {
    found = true;
  }
  else {
    i++;
  }
}

if (found) {
  ...
}
```

How could you reduce the number of conditions checked for each loop?

Code Tuning: Loops

By using a *sentinel*, we can combine all three tests into one:

```
// Make sure there is space for at least count+1 objects
item[count] = testValue;

i = 0;
while (item[i] != testValue) {
  i++;
}

// Check if item was really found
if (i < count) {
  ...
}
```

Code Tuning: Loops

By using a *sentinel*, we can combine all three tests into one:

```
// Make sure there is space for at least count+1 objects
item[count] = testValue;

i = 0;
while (item[i] != testValue) {
  i++;
}

// Check if item was really found
if (i < count) {
  ...
}
```

Sentinels can be applied to nearly any situation in which you use linear search.

Of course, if you can avoid linear search, that's even better...

Code Tuning: Loops

Putting the Busiest Loop on the Inside

Which is faster?

```
for (row = 0; row < 100; row++) {
  for (column = 0; column < 5; column++) {
    sum += table[row][column];
  }
}
```

or

```
for (column = 0; column < 5; column++) {
  for (row = 0; row < 100; row++) {
    sum += table[row][column];
  }
}
```

Code Tuning: Loops

Putting the Busiest Loop on the Inside

Which is faster?

```
for (row = 0; row < 100; row++) {
  for (column = 0; column < 5; column++) {
    sum += table[row][column];
  }
}
```

or

```
for (column = 0; column < 5; column++) {
  for (row = 0; row < 100; row++) {
    sum += table[row][column];
  }
}
```

Total loops executed: 600 in first case, 505 in second case.

Code Tuning: Loops

Putting the Busiest Loop on the Inside

Which is faster?

```
for (row = 0; row < 100; row++) {
  for (column = 0; column < 5; column++) {
    sum += table[row][column];
  }
}
```

or

```
for (column = 0; column < 5; column++) {
  for (row = 0; row < 100; row++) {
    sum += table[row][column];
  }
}
```

Total loops executed: 600 in first case, 505 in second case.

But what about cache performance?

Code Tuning: Loops

Putting the Busiest Loop on the Inside

Which is faster?

```
for (row = 0; row < 100; row++) {
  for (column = 0; column < 5; column++) {
    sum += table[row][column];
  }
}
```

or

```
for (column = 0; column < 5; column++) {
  for (row = 0; row < 100; row++) {
    sum += table[row][column];
  }
}
```

Total loops executed: 600 in first case, 505 in second case.

But what about cache performance?

It's hard to say which is faster. You would have to *measure*.

Code Tuning: Loops

Strength Reduction

Suppose you know that multiplication is much more expensive than addition. How could you rewrite this loop?

```
for (i=0; i < saleCount; i++) {
  commission[i] = (i+1) * revenue * baseCommission * discount;
}
```

Code Tuning: Loops

Strength Reduction

Suppose you know that multiplication is much more expensive than addition. How could you rewrite this loop?

```
for (i=0; i < saleCount; i++) {
  commission[i] = (i+1) * revenue * baseCommission * discount;
}
```

You can replace multiplication with addition as follows:

```
incrementalCommission = revenue * baseCommission * discount;
cumulativecommission = incrementalCommission;
for (i=0; i < saleCount; i++) {
  commission[i] = cumulativeCommission;
  cumulativeCommission += incrementalCommission;
}
```

Code Tuning: Data Transformations

Use Integers Rather Than Floating-Point Numbers

Integer addition and multiplication tend to be faster than floating point. Even changing a loop index from floating point to integer can save significant time.

Use the Fewest Array Dimensions Possible

If you can rewrite a multi-dimensional array as a one-dimensional array, it may save some time (at the expense of readability).

Minimize Array References

Every time you access an array, you have to do some pointer arithmetic and a dereference. If you can avoid it, this may speed things up. For example, you could store a commonly used array value in a temporary variable.

Code Tuning: Data Transformations

Use Supplementary Indexes

- *String-Length Index*

  Instead of calling `strlen` every time you want to compute the length of a `char*`, store the length as an extra variable with the `char*`. The `std::string` class does this for you. You can apply this principle to other similar situations.

- *Independent, Parallel Index Structure*

  Suppose you have big data structures and each one is identified by a unique integer id. If you are searching or maniuplating the data structures, it may be easier to manipulate the indexes instead: Create an auxilliary data structure containing just the index and a pointer to the big data structure and manipulate that instead. This is a standard database technique.

Code Tuning: Data Transformations

Use Caching

The idea behind caching is to save the result of common expensive computations so you don't have to compute them again.

For example, suppose you are computing the height of a binary tree:

```
class Tree {
private:
  Tree* left;
  Tree* right;
public:
  ...
  int height(Tree* t);
};

int Tree::height(Tree* t)
{
  if (t->isLeaf()) return 1;
  else return 1+max(t->left()->height(),t->right()->height());
}
```

Code Tuning: Data Transformations

If we know there will be many calls to `height`*, how can we speed up this routine?*

Code Tuning: Data Transformations

If we know there will be many calls to `height`*, how can we speed up this routine?*

Here's one possible version, using caching:

```
class Tree {
  ...
  int savedHeight;
public:
  Tree(Tree* l, Tree *r) : ... savedHeight(-1) {}
  ...
};

int Tree::height(Tree* t)
{
  if (savedHeight == -1) {
    if (t->isLeaf()) savedHeight = 1;
    else savedHeight =
      1 + max(t->left()->height(), t->right()->height());
  }
  return savedHeight;
}
```

Code Tuning: Other Techniques

- Exploit algebraic identities
- Precompute values that are known at compile time
- Be wary of system libraries
- Use inlining
- Recode in a low-level language