Code Tuning Techniques

CPSC 315 – Programming Studio
adapted from John Keyser’s 315 slides

Tuning Code

• Tuning can be at several “levels” of code
  - Routine level to system level
• No “do this and improve code” technique
  - Same technique can increase or decrease performance, depending on situation
  - Must measure to see what effect is
• Remember:
  Tuning code can make it harder to understand and maintain!

Logical Approaches:
Stop Testing Once You Know the Answer

• Short-Circuit Evaluation
  if ((a > 1) and (a < 4))
  if (a > 1)
     if (a < 4)
  - Note: Some languages (C++/Java) do this automatically

Tuning Code

• We’ll describe several categories of tuning, and several specific cases
  - Logical Approaches
  - Tuning Loops
  - Transforming Data
  - Tuning Expressions
  - Others
Logical Approaches:
Stop Testing Once You Know the Answer

• Breaking out of “Test Loops”
flag = False;
for (i=0; i<10000; i++) {
    if (a[i] < 0) flag = True;
}

• Several options:
  − Use a break command (or goto!)
  − Change condition to check for Flag
  − Sentinel approach

Logical Approaches:
Stop Testing Once You Know the Answer

• Change Condition to Check for Flag
flag = False;
for (i=0; (i<10000) && !flag; i++) {
    if (a[i] < 0) {
        flag = True;
        break();
    }
}

• Sentinel Approach
flag = False;
for (i=0; i<10000; i++) {
    if (a[i] < 0) {
        flag = True;
        i=10000;
    }
}

Logical Approaches:
Stop Testing Once You Know the Answer

• Break Command
flag = False;
for (i=0; i<10000; i++) {
    if (a[i] < 0) {
        flag = True;
        break();
    }
}

Logical Approaches:
Stop Testing Once You Know the Answer

• Sentinel Approach
flag = False;
for (i=0; i<10000; i++) {
    if (a[i] < 0) {
        flag = True;
        i=10000;
    }
}
Logical Approaches: Order Tests by Frequency

- Test the most common case first
  - Especially in switch/case statements
  - Remember, compiler may reorder, or not short-circuit
- Note: it’s worthwhile to compare performance of logical structures
  - Sometimes switch is faster, sometimes if-then
- Generally a useful approach, but can potentially make tougher-to-read code
  - Organization for performance, not understanding

Logical Approaches: Use Lookup Tables

- Table lookups can be much faster than following a logical computation
- Example: diagram of logical values:

```
if ((a && !c) || (a && b && c)) {
    val = 1;
} else if ((b && !a) || (a && c && !b)) {
    val = 2;
} else if (c && !a && !b) {
    val = 3;
} else {
    val = 0;
}
```

```
static int valtable[2][2][2] = {
    // !b!c   !bc    b!c    bc
    0, 3, 2, 2, // !a
    1, 2, 1, 1, // a
};
val = valtable[a][b][c]
```
Logical Approaches: Lazy Evaluation

- Idea: wait to compute until you’re sure you need the value
  - Often, you never actually use the value!
- Tradeoff overhead to maintain lazy representations vs. time saved on computing unnecessary stuff

Class listofnumbers {
    private int howmany;
    private float* list;
    private float median;

    float getMedian() {
        return median;
    }

    void addNumber(float num) {
        //Add number to list
        //Compute Median
    }
}

Logical Approaches: Tuning Loops: Unswitching

- Remove an if statement unrelated to index from inside loop to outside

```c
for (i=0; i<n; i++)
    if (type == 1)
        sum1 += a[i];
    else
        sum2 += a[i];
```

```c
if (type == 1)
    for (i=0; i<n; i++)
        sum1 += a[i];
else
    for (i=0; i<n; i++)
        sum2 += a[i];
```
Tuning Loops: Jamming

- Combine two loops
  ```c
  for (i=0; i<n; i++)
        sum[i] = 0.0;
  for (i=0; i<n; i++)
        rate[i] = 0.03;
  for (i=0; i<n; i++) {
        sum[i] = 0.0;
        rate[i] = 0.03;
  }
  ```

Tuning Loops: Unrolling

- Do more work inside loop for fewer iterations
  - Complete unroll: no more loop...
  - Occasionally done by compilers (if recognizable)
  ```c
  for (i=0; i<n; i++)
        a[i] = i;
  ```
  ```c
  for (i=0; i<(n-1); i+=2) {
    a[i] = i;
    a[i+1] = i+1;
  }
  if (i == n-1)
    a[n-1] = n-1;
  ```

Tuning Loops: Minimizing Interior Work

- Move pointer/memory references and repeated computation outside
  ```c
  for (i=0; i<n; i++) {
    balance[i] += purchase->allocator->indiv->borrower;
    amounttopay[i] = balance[i]*(prime+card)*pcentpay;
  }
  ```

  ```c
  newamt = purchase->allocator->indiv->borrower;
  payrate = (prime+card)*pcentpay;
  for (i=0; i<n; i++) {
    balance[i] += newamt;
    amounttopay[i] = balance[i]*payrate;
  }
  ```

Tuning Loops: Sentinel Values

- Test value placed after the end of the array to guarantee termination
  ```c
  i=0;
  found = FALSE;
  while (!(found) && (i<n)) {
    if (a[i] == testval)
      found = TRUE;
    else
      i++;
  }
  if (found) //Value found
    savevalue = a[n];
    a[n] = testval;
    i=0;
  while (a[i] != testval)
    i++;
  if (i<n) // Value found (loop terminated before reaching end)
    ```
Tuning Loops: Busiest Loop on Inside

- Reduce overhead by calling fewer loops
  
  ```c
  for (i=0; i<100; i++)  // 100
    for (j=0; j<10; j++) // 100x10=1000
dosomething(i,j);
  Total of 1100 loop iterations
  ```

- For:
  
  ```c
  for (j=0; j<10; j++) // 10
    for (i=0; i<100; i++) // 10x100=1000
dosomething(i,j);
  Total of 1010 loop iterations
  ```

Tuning Loops: Strength Reduction

- Replace multiplication involving loop index by addition
  
  ```c
  for (i=0; i<n; i++)
      a[i] = i*conversion;
```

Transforming Data: Integers Instead of Floats

- Integer math tends to be faster than floating point
- Use ints instead of floats where appropriate
- Likewise, use floats instead of doubles
- Need to test on system...

Transforming Data: Fewer Array Dimensions

- Express as 1D arrays instead of 2D/3D as appropriate
  - Beware of assumptions on memory organization
  ```c
  for (i=0; i<rows; i++)
      for (j=0; j<cols; j++) 
        a[i][j] = 0.0;
  ```

```c
for (i=0; i<rows*cols; i++)
a[i] = 0.0;
```
Transforming Data: Minimize Array Refs

- Avoid repeated array references
  - Like minimizing interior work
  ```
  for (i=0; i<r; i++)
    for (j=0; j<c; j++)
      a[j] = b[j] + c[i];
  ```
  ```
  for (i=0; i<r; i++) {
    temp = c[i];
    for (j=0; j<c; j++)
      a[j] = b[j] + temp;
  }
  ```

Transforming Data: Use Supplementary Indexes

- Sort indices in array rather than elements themselves
  ```
  ```
  - Tradeoff extra dereference in place of copies

Transforming Data: Use Caching

- Store data instead of (re-)computing
  - e.g. store length of an array (ended by sentinel) once computed
  - e.g. repeated computation in loop
- Overhead in storing data is offset by
  - More accesses to same computation
  - Expense of initial computation

Transforming Data: Use Caching

- Store data instead of (re-)computing
  - e.g. store length of an array (ended by sentinel) once computed
  - e.g. repeated computation in loop
- Overhead in storing data is offset by
  - More accesses to same computation
  - Expense of initial computation

Tuning Expressions: Algebraic Identities and Strength Reduction

- Avoid excessive computation
  - `sqrt(x) < sqrt(y)` equivalent to `x < y`
- Combine logical expressions
  - `!a || !b` equivalent to `!(a && b)` -- 3 vs. 2 ops
- Use trigonometric/other identities
- Right/Left shift to multiply/divide by 2
- e.g. Efficient polynomial evaluation
  - `A*x*x*x + B*x*x + C*x + D = (((A*x+B)*x+C)*x+D`
Tuning Expressions: Compile-Time Initialization

- Known constant passed to function can be replaced by value.

\[
\text{log2val} = \frac{\log(\text{val})}{\log(2)};
\]

\[
\text{const double LOG2} = 0.69314718;
\]

\[
\text{log2val} = \frac{\log(\text{val})}{\text{LOG2}};
\]

Tuning Expressions: Avoid System Calls

- Avoid calls that provide more computation than needed
  - e.g. if you need an integer log, don't compute floating point logarithm
  - Could count # of shifts needed
  - Could program an if-then statement to identify the log (only a few cases)

Tuning Expressions: Use Correct Types

- Avoid unnecessary type conversions
- Use floating-point constants for floats, integer constants for ints

Tuning Expressions: Precompute Results

- Storing data in tables/constants instead of computing at run-time
- Even large precomputation can be tolerated for good run-time
- Examples
  - Store table in file
  - Constants in code
  - Caching
  - Function look-up tables
Tuning Expressions:
Eliminate Common Subexpressions

- Anything repeated several times can be computed once ("factored" out) instead
  - Compilers pretty good at recognizing, now

\[
a = b + \frac{c}{d} - e\times\frac{c}{d} + f\times\frac{d}{c};
\]

\[
t = \frac{c}{d};
\]

\[
a = b + t - e\times t + f\div t;
\]

Other Tuning:
Inlining Routines

- Avoiding function call overhead by putting function code in place of function call
  - Also called Macros
- Some languages support directly (C++: \texttt{inline})
- Compilers tend to minimize overhead already, anyway

Other Tuning:
Recoding in Low-Level Language

- Rewrite sections of code in lower-level (and probably much more efficient) language
- Lower-level language depends on starting level
  - Python -> C++
  - C++ -> assembler
- Should only be done at bottlenecks
- Increase can vary greatly, can easily be worse

Other Tuning:
Buffer I/O

- Buffer input and output
  - Allows more data to be processed at once
  - Usually there is overhead in sending output, getting input
Other Tuning:
Handle Special Cases Separately

- After writing general purpose code, identify hot spots
  - Write special-case code to handle those cases more efficiently
- Avoid overly complicated code to handle all cases
  - Classify into cases/groups, and separate code for each

Other Tuning:
Use Approximate Values

- Sometimes can get away with approximate values
- Use simpler computation if it is “close enough”
  - e.g. integer sin/cos, truncate small values to 0.

Other Tuning:
Recompute to Save Space

- Opposite of Caching!
- If memory access is an issue, try not to store extra data
- Recompute values to avoid additional memory accesses, even if already stored somewhere

Code Tuning Summary

- Tuning is a “last” step, and should only be applied when it is needed
- Always test your changes
  - Often will not improve or even make worse
  - If there is no improvement, go back to earlier version
- Usually, code readability is more important than performance benefit gained by tuning