Code Optimization - Lab 9

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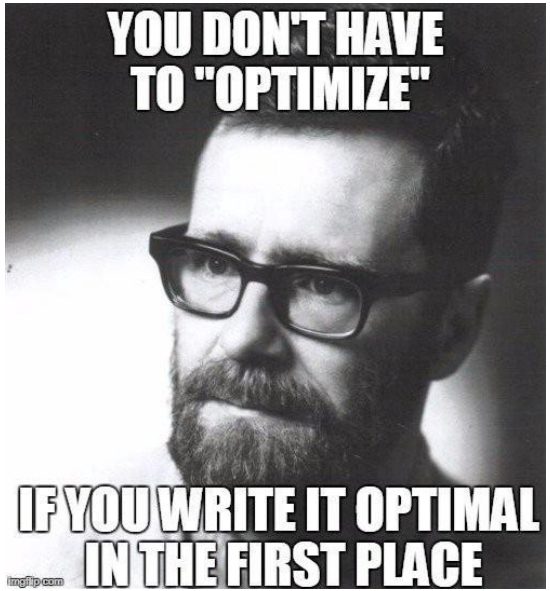
KOÇ UNIVERSITY

What is code Optimization?

The code optimization in the synthesis phase is a program transformation technique, which tries to improve the intermediate code by making it consume fewer resources (i.e. CPU, Memory) so that faster-running machine code will result.

Optimizing an algorithm is beyond the scope of the code optimization phase. So the program is optimized. And it may involve reducing the size of the code.



Types of Code Optimization

Machine Independent Optimization -This code optimization phase attempts to improve the intermediate code to get a better target code as the output. The part of the intermediate code which is transformed here does not involve any CPU registers or absolute memory locations.

```
do
{
   item = 10;
   value = value + item;
} while(value<100);
```

this code involves repeated assignment of the identifier item, instead:

```
Item = 10;
do
{
   value = value + item;
} while(value<100);
```

Types of Code Optimization

Machine Dependent Optimization – Machine-dependent optimization is done after the target code has been generated and when the code is transformed according to the target machine architecture. It involves CPU registers and may have absolute memory references rather than relative references. Machine-dependent optimizers put efforts to take maximum advantage of the memory hierarchy.

Compiler Optimizations

- Gcc compiler supports automatic optimizations.
- Without any optimization option, the compiler's goal is to reduce the cost of compilation and to make debugging produce the expected results.
- Turning on optimization flags makes the compiler attempt to improve the performance and/or code size at the expense of compilation time and possibly the ability to debug the program.
- Most optimizations are completely disabled at -O0 or if an -O level is not set on the command line, even if individual optimization flags are specified. Similarly, -Og suppresses many optimization passes.

Compiler Optimizations

- **-O or -O1 option (Optimize).** the compiler tries to reduce code size and execution time, without performing any optimizations that take a great deal of compilation time.

- **-O2 (Optimize even more)**. GCC performs nearly all supported optimizations that do not involve a space-speed tradeoff. As compared to -O, this option increases both compilation time and the performance of the generated code.

- **-O3 (Optimize yet more)**. -O3 turns on all optimizations specified by -O2 and also more options such as loop unrolling and jamming.

- **-Os (Optimize for size)**. -Os enables all -O2 optimizations except those that often increase code size.

  ...

Machine Independent Techniques

- Techniques are various and vast
- Be Careful about time you spend on optimization
- With practice, you can write your codes optimized in the first place and optimize it further after having a base code
- Profiling is an invaluable tool
- In practice you must re-use already existing optimized codes
- Compilers offer various optimizations

Inlining

- If necessary, C functions can be recoded as macros to obtain similar speedup on compilers with no inlining capability. This should be done after the code is completely debugged.

- No function call! fewer instructions!

```
int foo(a, b)
  {
      a = a - b;
      b++;
      a = a * b;
      return a;
  }
```

Can replaced by:

```
#define foo(a, b) (((a)-(b)) * ((b)+1))
```

Avoid Pointer Dereference in Loop

- Pointer dereferencing creates lots of trouble in memory. So better assign it to some temporary variable and then use that temporary variable in the loop.

```
int a = 0;
int* iptr = &a;
for (int i = 1; i < 11; ++i) {
    *iptr = *iptr + i;
}
```

```
int a = 0;
int* iptr = &a;
// Dereferencing pointer outside loop and use temp var
int temp = *iptr;
for (int i = 1; i < 11; ++i) {
    temp = temp + i;
}
// Updating pointer using final value of temp
*iptr = temp;
```

Loop Unrolling

- Many compilers (e.g. gcc -funroll-loops) will do this, but if you know that yours doesn't you can change your source code a bit to get the same effect.

- This way the test for i < 100 and the branch back up to the top of the loop only get executed 21 times rather than 101.

```
for (i = 0; i < 100; i++){
    do_stuff(i);
}
```

Can replaced by:

```
for (i = 0; i < 100; ){
    do_stuff(i); i++;
    do_stuff(i); i++;
    do_stuff(i); i++;
    do_stuff(i); i++;
    do_stuff(i); i++;
}
```

Loop Unrolling Caveat

- An unrolled loop is larger than the "rolled" version and so may no longer fit into the instruction cache (on machines which have them). This will make the unrolled version slower.

- Also, in this example, the call to do_stuff() overshadows the cost of the loop, so any savings from loop unrolling are insignificant in comparison to what you'd achieve from inlining in this case.

```
for (i = 0; i < 100; i++){
    do_stuff(i);
}
```

Can replaced by:

```
for (i = 0; i < 100; ){
    do_stuff(i); i++;
    do_stuff(i); i++;
    do_stuff(i); i++;
    do_stuff(i); i++;
    do_stuff(i); i++;
}
```

Code Motion

- Reduce frequency with which computation performed if it will always produce same result.
- Especially moving code out of loop

```
void foo(double *a, double *b,long i, long n){
     long j;
     for (j = 0; j < n; j++)
     a[n*i+j] = b[j];
}
```

Can replaced by:

```
void foo(double *a, double *b,long i, long n){
     long j;
     int ni = n*i;
     for (j = 0; j < n; j++)
          a[ni+j] = b[j];
}
```

Share Common Subexpressions

```
/* Sum neighbors of i,j */
up    = val[(i-1)*n + j ];
down  = val[(i+1)*n + j ];
left  = val[i*n + j-1];
right = val[i*n + j+1];
sum   = up + down + left + right;
```

3 multiplications

```
leaq 1(%rsi), %rax # i+1
leaq -1(%rsi), %r8 # i-1
imulq %rcx, %rsi # i*n
imulq %rcx, %rax # (i+1)*n
imulq %rcx, %r8 # (i-1)*n
addq %rdx, %rsi # i*n+j
addq %rdx, %rax # (i+1)*n+j
addq %rdx, %r8 # (i-1)*n+j
```

- Especially problematic if this function is getting called inside a loop

Share Common Subexpressions

```
/* Sum neighbors of i,j */
long inj = i*n + j;
up       = val[inj - n];
down     = val[inj + n];
left     = val[inj - 1];
right    = val[inj + 1];
sum      = up + down + left + right;
```

1 multiplication

```
imulq %rcx, %rsi # i*n
addq %rdx, %rsi # i*n+j
movq %rsi, %rax # i*n+j
subq %rcx, %rax # i*n+j-n
leaq (%rsi,%rcx), %rcx # i*n+j+n
```

- Reuse portions of expressions
- GCC will do this with –O1

Reduction in Strength

- Replace costly operation with simpler one for example replace Shift, add instead of multiply or divide
  - E.g 16*x --> x << 4

```
for (i = 0; i < n; i++) {
    int ni = n*i;
    for (j = 0; j < n; j++)
        a[ni + j] = b[j];
}
```

Can replaced by:

```
int ni = 0;
for (i = 0; i < n; i++) {
    for (j = 0; j < n; j++)
        a[ni + j] = b[j];
    ni += n;
}
```

Loop Jamming

- The idea is to combine adjacent loops which loop over the same range of the same variable.
- incrementing and testing of i is done only half as often
- Assuming nothing in the second loop indexes forward (for example array[i+3]),

```
for (i = 0; i < MAX; i++)   /* initialize 2d array to 0's */
      for (j = 0; j < MAX; j++)
          a[i][j] = 0.0;
for (i = 0; i < MAX; i++)   /* put 1's along the diagonal */
      a[i][i] = 1.0;
```

Can replaced by:

```
for (i = 0; i < MAX; i++){
     for (j = 0; j < MAX; j++)
         a[i][j] = 0.0;       /* initialize 2d array to 0's */
     a[i][i] = 1.0;           /* put 1's along the diagonal */
 }
```

Loop Inversion

- Some machines have a special instruction for decrement and compare with 0.
- Assuming the loop is insensitive to direction
- Positive values interprets as True while negative values interprets as False

```
for (i = 1; i < MAX; i++){
      ...
  }
```

Can replaced by:

```
for (i = MAX; i--; ){
      ...
  }
```

Table Lookup

- Consider using lookup tables especially if a computation is iterative or recursive, e.g. convergent series or factorial.

- If the table is too large to type, you can have some initialization code compute all the values on startup

```
long factorial(int i){
     if (i == 0)
         return 1;
     else
         return i * factorial(i - 1);
}
```

Can replaced by:

```
static long factorial_table[] =
      {1, 1, 2, 6, 24, 120, 720 /* etc */};
long factorial(int i){
     return factorial_table[i];
}
```

Stack Usage

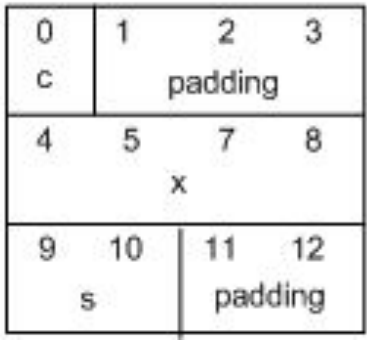
- A typical cause of stack-related problems is having large arrays as local variables.
- In that case the solution is to rewrite the code so it can use a static or global array, or perhaps allocate it from the heap.
- Similar solution applies to functions which have large structs as locals or parameters.

Recap: Struct Padding

- Generally when a struct is stored in RAM, it is padded to correspond to the word-size of the architecture of the CPU.
- Additional padding is provided for arrays to make the first bytes of each item in the array a multiple of the item size.

```
/* Assume 32 bit Architecture
   Sizeof foo = 12 bytes */

struct foo {
  char   c;
  int    x;
  short  f;
};
```



Reduce Padding

- On machines with alignment restrictions you can sometimes save a tiny amount of space by arranging similarly-typed fields together in a structure with the most restrictively aligned types first.
- A typical use of char or short variables is to hold a flag or mode bit. You can combine several of these flags into one byte using bit-fields at the cost of data portability.

```
/* sizeof = 64 bytes
*/
struct foo {
  float   a;
  double  b;
  float   c;
  double  d;
  short   e;
  long    f;
  short   g;
  long    h;
  char    i;
  int     j;
  char    k;
  int     l;
};
```

```
/* sizeof = 48 bytes
*/
struct foo {
  double  b;
  double  d;
  long    f;
  long    h;
  float   a;
  float   c;
  int     j;
  int     l;
  short   e;
  short   g;
  char    i;
  char    k;
};
```

References

https://gcc.gnu.org/onlinedocs/gcc/Optimize-Options.html
http://www.cs.cmu.edu/afs/cs/academic/class/15213-s19/www/schedule.html