Code Optimization - Lab 9

COMP201 Fall 2023

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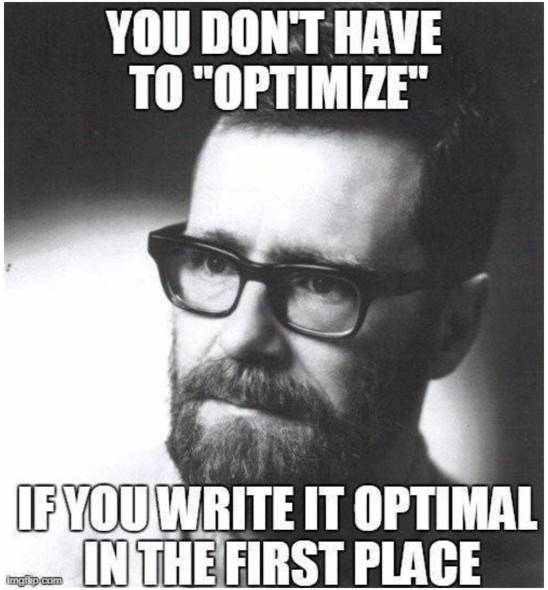
What is Code Optimization?

- A program transformation technique to:
  - **improve** the intermediate code,
  - make it **consume fewer resources** (CPU, memory),
  - reduce the **size** of the code,
  - **speed up** execution.

- It is **not** optimizing an algorithm.
  - It is beyond our scope for now.



Types of Code Optimization

- **Machine Independent Optimization**

- **Machine Dependent Optimization**

Types of Code Optimization

Machine Independent Optimization

- Improve the intermediate code to get a better target code.
- 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 'item'. Instead:
```

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do{
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```

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Types of Code Optimization

Machine Dependent Optimization

- **Goal:** Take maximum advantage of the memory hierarchy.
- After the target code is generated,
    - optimization is done according to the target machine architecture.
- Involves CPU registers,
- May have absolute memory references, rather than relative references

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Compiler Optimizations

- **GCC** 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.

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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 should re-use already existing optimized codes
- Compilers offer various optimizations

Inlining

- 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 be replaced by:

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

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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 & 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;
```

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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.

```
struct Warrior{
      double damage; double HP;
      ...
};
void main(){
      struct Warrior* hero1;
      struct Warrior* enemies[n];

      for (int i = 0; i < n; ++i) {
           enemies[i]->HP -= hero1->damage;
      }
}
```

```
void main(){
      struct Warrior* hero1;
      struct Warrior* enemies[n];
      double damage = hero1->damage;

      for (int i = 0; i < n; ++i) {
           enemies[i]->HP -= damage;
      }
}
```

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Loop Unrolling

- `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 jump to beginning of `for`) is done only **21** times rather than **101**

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

Can be 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++;
}
```

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Loop Unrolling Caveat

- An unrolled loop is larger than the "rolled" version.
  - So, **may no longer fit** into the instruction cache
  - 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 be 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++;
}
```

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Code Motion

- Replace redundant computations in a loop

- Move the computation outside the 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 be 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];

}
```

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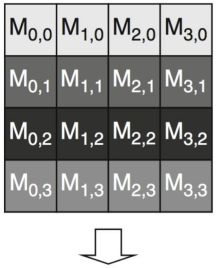
Share Common Subexpressions

```
/* 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



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Share Common Subexpressions

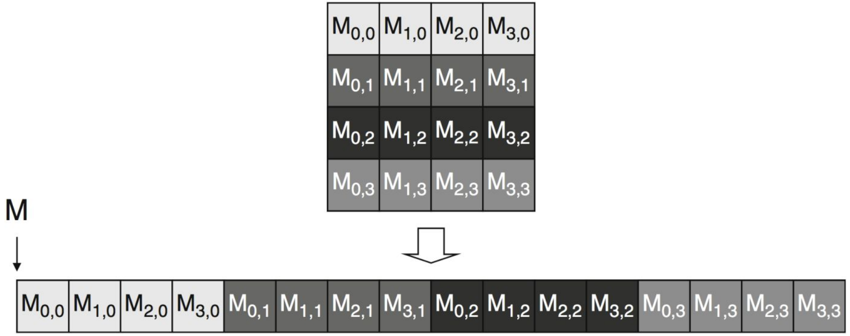
```
/* Sum neighbors of i,j */

 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



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Reduction in Strength

- Replace costly operations with simpler ones
- E.g. replace Shift/add with multiply/divide
  - E.g `x << 4; // is equivalent to x * 16;`

Loop Jamming

- 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
  - e.g **`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 be 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 */
 }
```

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Loop Inversion

Some machines have a special instruction for:

```
decrement and compare with 0.
```

Positive values interprets as **True** while **negatives** interpret as **False**

Assuming the loop is insensitive to direction:

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

Can be replaced by:

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

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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 be 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.

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

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

0 c	1 2 3 padding
4 5 6 7 x	
8 9 s	10 11 padding

Reduce Padding

- You can 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;
};
```

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References

https://gcc.gnu.org/onlinedocs/gcc/Optimize-Options.html

http://www.cs.cmu.edu/afs/cs/academic/class/15213-s19/www/schedule.html

```
(base) 192:sort doga$ cat makefile
all: compile run

compile:
	gcc main.c -o main

run:
	./main
(base) 192:sort doga$ make compile
gcc main.c -o main
(base) 192:sort doga$ make run
./main
Execution time for the normal bubble sort is 28.640430 seconds
 Execution time for the selection sort is 10.288672 seconds
Execution time for the Optimized bubble sort is 26.750361 seconds
(base) 192:sort doga$
```