计算机系统结构(A)

实验 5

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一. 熟悉 SIMD intrinsics 函数

- 4 个并行的单精度浮点数除法

```
__m128 _mm_div_ps (__m128 a, __m128 b)
```

- 16 个并行求8 位无符号整数的最大值

```
__m128i _mm_max_epi16 (__m128i a, __m128i b)
```

- 8 个并行的16 位带符号短整数的算术右移

```
__m128i _mm_bsrli_si128 (__m128i a, int imm8)
```

二. 阅读SIMD代码 仅关注函数的主要部分，执行 SIMD 操作的行用 ;SIMD 标识。

```
.LFB5548:
    .cfi_startproc
    endbr64
    sub rsp, 120
    .cfi_def_cfa_offset 128
    pxor    xmm6, xmm6
    movsd   xmm1, QWORD PTR .LC2[rip]          ;SIMD
    movsd   xmm10, QWORD PTR .LC0[rip]         ;SIMD
    mov rax, QWORD PTR fs:40
    mov QWORD PTR 104[rsp], rax
    xor eax, eax
    mov rax, QWORD PTR .LC3[rip]
    movsd   xmm8, QWORD PTR .LC1[rip]          ;SIMD
    mov QWORD PTR 64[rsp], 0x000000000
    movsd   QWORD PTR 48[rsp], xmm1            ;SIMD
    pxor    xmm9, xmm9
    lea rsi, .LC6[rip]
    mov edi, 1
    mov QWORD PTR 56[rsp], rax
    movapd xmm0, XMMWORD PTR 48[rsp]           ;SIMD
    movapd xmm3, xmm9                          ;SIMD
    mov eax, 6
    movsd   QWORD PTR 32[rsp], xmm10           ;SIMD
    movapd xmm2, xmm0                          ;SIMD
    movsd   QWORD PTR 40[rsp], xmm8            ;SIMD
    movapd xmm7, XMMWORD PTR 32[rsp]           ;SIMD
    addpd   xmm0, xmm0                         ;SIMD
    mov QWORD PTR 72[rsp], 0x000000000
    mulpd   xmm2, xmm6                         ;SIMD
    mov QWORD PTR 80[rsp], 0x000000000
    mulpd   xmm6, XMMWORD PTR 32[rsp]          ;SIMD
    mulpd   xmm7, XMMWORD PTR .LC5[rip]        ;SIMD
    mov QWORD PTR 88[rsp], 0x000000000
    addpd   xmm7, XMMWORD PTR 64[rsp]          ;SIMD
    addpd   xmm6, XMMWORD PTR 80[rsp]          ;SIMD
    addpd   xmm7, xmm2                         ;SIMD
    addpd   xmm6, xmm0                         ;SIMD
    movapd xmm2, xmm1                          ;SIMD
    movapd xmm0, xmm10                         ;SIMD
    movapd xmm5, xmm6                          ;SIMD
    movapd xmm4, xmm7                          ;SIMD
    movaps XMMWORD PTR 16[rsp], xmm6           ;SIMD
    movaps XMMWORD PTR [rsp], xmm7             ;SIMD
    call    __printf_chk@PLT
    movapd xmm6, XMMWORD PTR 16[rsp]           ;SIMD
```

```
    movapd xmm7, XMMWORD PTR [rsp]          ;SIMD
    pxor    xmm9, xmm9
    mov rax, QWORD PTR .LC1[rip]
    movapd xmm2, xmm9                       ;SIMD
    mov edi, 1
    lea rsi, .LC7[rip]
    unpckhpd   xmm6, xmm6                   ;SIMD
    unpckhpd   xmm7, xmm7                   ;SIMD
    movq    xmm8, rax
    movq    xmm3, rax
    mov rax, QWORD PTR .LC3[rip]
    movapd xmm5, xmm6                       ;SIMD
    movapd xmm4, xmm7                       ;SIMD
```

```
    movapd xmm0, xmm8                       ;SIMD
    movq    xmm1, rax
    mov eax, 6
    call    __printf_chk@PLT
    mov rax, QWORD PTR 104[rsp]
    xor rax, QWORD PTR fs:40
    jne .L5
    xor eax, eax
    add rsp, 120
    .cfi_remember_state
    .cfi_def_cfa_offset 8
    ret
```

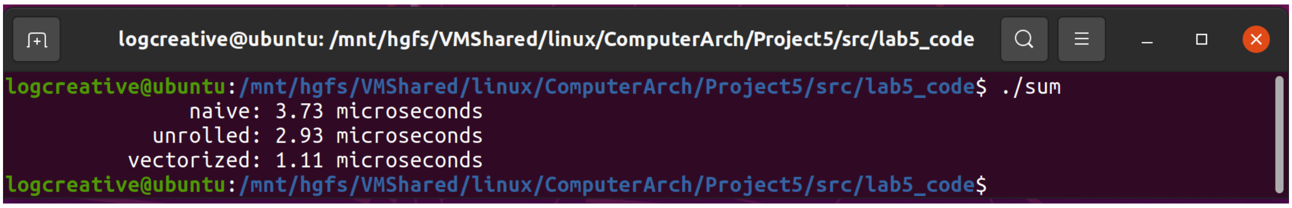
三. 书写 SIMD 代码

函数 sum_vectorized() 的实现如下。

```
static int sum_vectorized(int n, int *a)
{
    // WRITE YOUR VECTORIZED CODE HERE

    // the parallelization could only
    // apply on aligned groups
    int groups = n / 4;

    // On linux, int is 32-bit wide.
    // 128-bit = 4 int;
    // Initialize sum vector of 128-bit as zero.
    __m128i sum = _mm_setzero_si128();

    // For loop will add numbers on mod 4 basis.
    for(int i = 0; i < groups; ++i){
        // load a vector of adders.
        __m128i adder = _mm_loadu_si128(a + i * 4);

        // add the vector to a temporary variable.
        __m128i added = _mm_add_epi32(sum, adder);

        // store the value to the sum vector.
        _mm_storeu_si128(&sum, added);
    }

    int result = 0;

    // However there is some remaining numbers
    // that didn't count, whose quantity is < 4.
    int remain = n - groups * 4;
    int tip = groups * 4;

    // For each offset, calulate manually.
    for(int j = 0; j < remain; ++j)
        result += a[tip++];

    // and to get the final result, the member
```

```c
    // of the vector in sum has to be added as well,
    // in other word, 4 numbers.

    // For each right shift, get the lower 32 bit.
    // which is one unit and add to the result.
    for(int i = 0; i < 4; ++i)
        result += _mm_cvtsi128_si32(_mm_srli_si128(sum,i * 4));

    return result;
}
```

第一轮测评性能得到了改善（提升了 236%），输出结果如下：

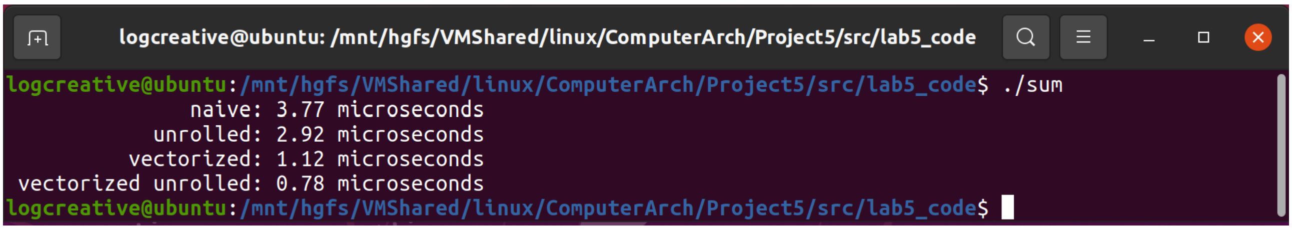


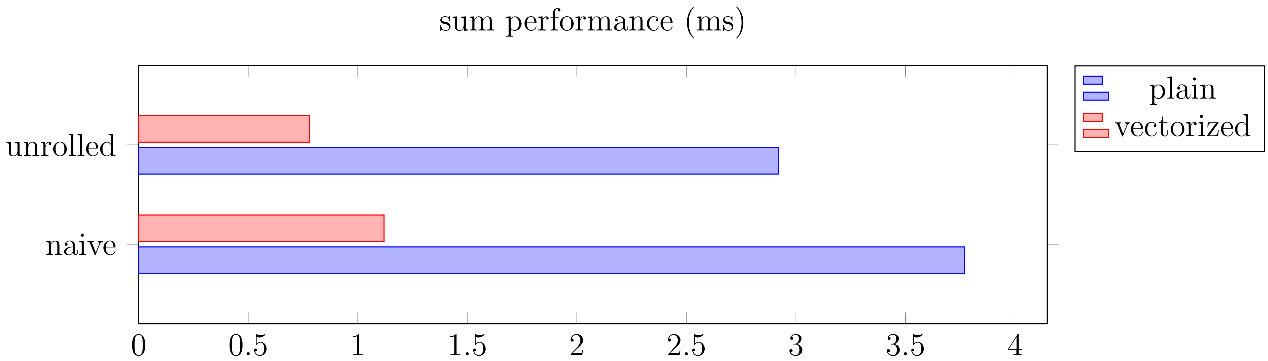
四. 循环展开

函数 sum_vectorized_unrolled() 的实现如下：

```c
static int sum_vectorized_unrolled(int n, int *a)
{
    // UNROLL YOUR VECTORIZED CODE HERE

    __m128i sum = _mm_setzero_si128();

    // For unrolled scenario,
    // every loop will contribute 128 * 4 = 512 bit operation.
    for(int i = 0; i < n / 16 * 16; i += 16){
        _mm_storeu_si128(&sum, _mm_add_epi32(sum, _mm_loadu_si128(a + i )));
        _mm_storeu_si128(&sum, _mm_add_epi32(sum, _mm_loadu_si128(a + i + 4)));
        _mm_storeu_si128(&sum, _mm_add_epi32(sum, _mm_loadu_si128(a + i + 8)));
        _mm_storeu_si128(&sum, _mm_add_epi32(sum, _mm_loadu_si128(a + i + 12)));
    }

    int result = 0;
    for(int i = n / 16 * 16; i < n; i++)
        result += a[i];

    for(int k = 0; k < 4; ++k)
        result += _mm_cvtsi128_si32(_mm_srli_si128(sum,k * 4));

    return result;
}
```

第二轮测评结果也得到了改善（提升了 274%），输出结果如下：


logcreative@ubuntu: /mnt/hgfs/VMShared/linux/ComputerArch/Project5/src/lab5_code
logcreative@ubuntu:/mnt/hgfs/VMShared/linux/ComputerArch/Project5/src/lab5_code$ ./sum
naive: 3.77 microseconds
unrolled: 2.92 microseconds
vectorized: 1.12 microseconds
vectorized unrolled: 0.78 microseconds
logcreative@ubuntu:/mnt/hgfs/VMShared/linux/ComputerArch/Project5/src/lab5_code$


sum performance (ms)
unrolled
naive
0
0.5
1
1.5
2
2.5
3
3.5
4
plain
vectorized