Getting Started
with
Automatic Compiler Vectorization

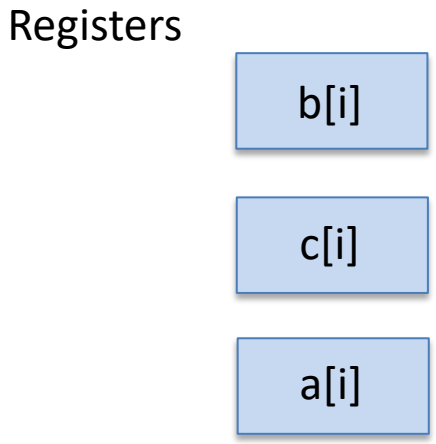
Parallellism is Key to Performance

- Types of parallelism
  - Task-based (MPI)
  - Threads (OpenMP, pthreads)
  - Vector processing

Scalar Processing

- Processor uses one element from each array on each loop iteration.

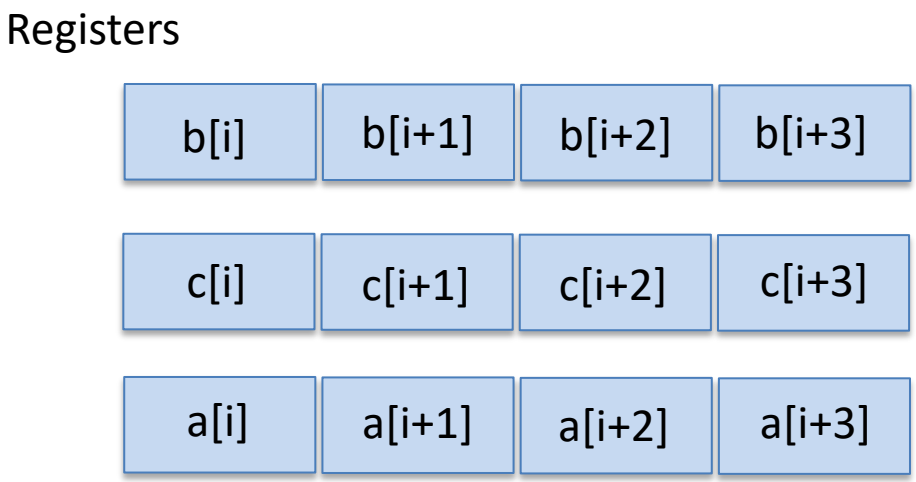
```
#define N 32

float a[N], b[N], c[N];

for (int i = 0; i < N; i++) {
        a[i] = b[i] + c[i];
}
```



Vector (SIMD) Processing

- Compiler unrolls the loop body a number of times.

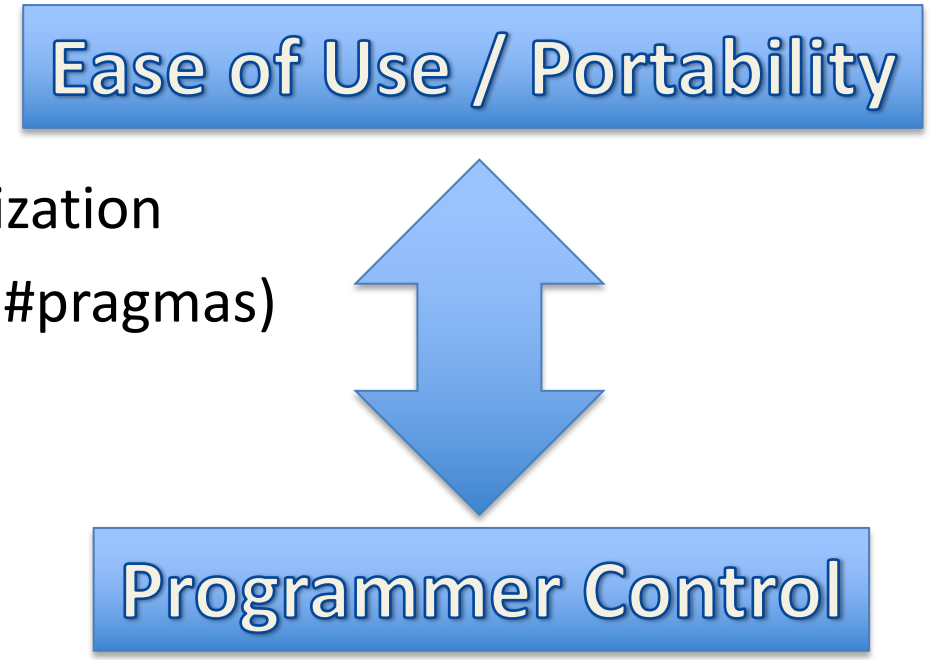
```
#define N 32

float a[N], b[N], c[N];

for (int i = 0; i < N; i=i+4) {
        a[i] = b[i] + c[i];
        a[i+1] = b[i+1] + c[i+1];
        a[i+2] = b[i+2] + c[i+2];
        a[i+3] = b[i+3] + c[i+3];
}
```



- Processor performs the same operation on a number of scalars (simultaneously)

Techniques

- Automatic Compiler Vectorization
- Compiler hints (directives / #pragmas)
- SIMD / Vector intrinsics
- Assembler instructions



Requirements / Guidelines

- Compiler optimization –O2 or higher
- Loop trip count known at runtime.
- A single entry and single exit
- Straight-line code
- Inner-most loop
- No function calls

Manage the Compiler Report

- Vectorization is enable by default
- -qopt-report-phase=vec
- -qopt-report=[1-5]
  - Provides increasing levels of detail
- -qopt-report-routine:func1, func2

Exercise

Test.cpp

```
#include <math.h>
void foo(float * theta, float * sth) {
      for (int i = 0; i < 128; i++) {
            sth[i] = sin(theta[i] + 3.1415927);
      }
}
```

```
$ icpc –qopt-report-phase=vec \
      –qopt-report=5 \
      –qopt-report-routine:foo \
      -c \
      Test.cpp
```

Test.optrpt (1)

Begin optimization report for: foo(float *, float *)

Report from: Vector optimizations [vec]

Good

LOOP BEGIN at Test.cpp(3,5)
<Multiversioned v1>
…
remark #15300: LOOP WAS VECTORIZED
…
LOOP END

Bad

LOOP BEGIN at Test.cpp(3,5)
<Multiversioned v2>
remark #15304: loop was not vectorized: non-vectorizable loop instance from multiversioning
LOOP END

Aliasing

- Add a command-line option to tell compiler that function arguments are not aliased.

```
$ icpc –qopt-report-phase=vec \
      –qopt-report=5 \
      –qopt-report-routine:foo \
      -c \
      -fargument-noalias \
      Test.cpp
```

- Results in a single vectorized version of loop.

Test.optrpt (2)

Begin optimization report for: foo(float *, float *)

Report from: Vector optimizations [vec]

LOOP BEGIN at T1.cpp(3,5)
remark #15389: vectorization support: reference theta has unaligned access [T1.cpp(4,18)]
remark #15389: vectorization support: reference sth has unaligned access [T1.cpp(4,9)]
remark #15381: vectorization support: unaligned access used inside loop body
remark #15305: vectorization support: vector length 4
remark #15309: vectorization support: normalized vectorization overhead 0.081
remark #15417: vectorization support: number of FP up converts: single precision to double precision 1 [T1.cpp(4,18)]
remark #15418: vectorization support: number of FP down converts: double precision to single precision 1 [T1.cpp(4,9)]
remark #15300: LOOP WAS VECTORIZED
remark #15450: unmasked unaligned unit stride loads: 1
remark #15451: unmasked unaligned unit stride stores: 1
remark #15475: --- begin vector loop cost summary ---
remark #15488: --- end vector loop cost summary ---
LOOP END

Alignment

- Tell the compiler that arrays are aligned.

```
#include <math.h>
void foo(float *theta, float *sth) {
      __assume_aligned(theta, 32);
      __assume_aligned(sth, 32);
      for (int i = 0; i < 128; i++) {
            sth[i] = sin(theta[i] + 3.1415927);
      }
}
```

Test.optrpt (3)

```
LOOP BEGIN at Test.cpp(3,5)
remark #15388: vectorization support: reference theta has aligned access   [ Test.cpp(6,18) ]
remark #15388: vectorization support: reference sth has aligned access   [ Test.cpp(6,9) ]
remark #15305: vectorization support: vector length 8
remark #15309: vectorization support: normalized vectorization overhead 0.006
remark #15417: vectorization support: number of FP up converts: single precision to double
precision 1      [ Test.cpp(6,18) ]
remark #15418: vectorization support: number of FP down converts: double precision to
single precision    1   [ Test.cpp(6,9) ]
remark #15300: LOOP WAS VECTORIZED
remark #15448: unmasked aligned unit stride loads: 1
remark #15449: unmasked aligned unit stride stores: 1
remark #15475: --- begin vector loop cost summary ---
remark #15476: scalar loop cost: 113
remark #15477: vector loop cost: 20.000
remark #15478: estimated potential speedup: 5.640
remark #15482: vectorized math library calls: 1
remark #15487: type converts: 2
remark #15488: --- end vector loop cost summary ---
LOOP END
```

Avoid type conversions

- Specify float (f) on function call and literal value.

```
#include <math.h>
void foo(float *theta, float *sth) {
      __assume_aligned(theta, 32);
      __assume_aligned(sth, 32);
      for (int i = 0; i < 128; i++) {
            sth[i] = sinf(theta[i] + 3.1415927f);
      }
}
```

T1.optrpt (4)

LOOP BEGIN at Test.cpp(5,5)
remark #15388: vectorization support: reference theta has aligned access [Test.cpp(6,18)]
remark #15388: vectorization support: reference sth has aligned access [Test.cpp(6,9)]
remark #15305: vectorization support: vector length 8
remark #15309: vectorization support: normalized vectorization overhead 0.013
remark #15300: LOOP WAS VECTORIZED
remark #15448: unmasked aligned unit stride loads: 1
remark #15449: unmasked aligned unit stride stores: 1
remark #15475: --- begin vector loop cost summary ---
remark #15476: scalar loop cost: 110
remark #15477: vector loop cost: 9.870
remark #15478: estimated potential speedup: 11.130
remark #15482: vectorized math library calls: 1
remark #15488: --- end vector loop cost summary ---
LOOP END

Resources

- https://software.intel.com/en-us/articles/vectorization-diagnostics-for-intelr-c-compiler-150-and-above
- https://software.intel.com/en-us/articles/vectorization-essential
- https://software.intel.com/sites/default/files/8c/a9/CompilerAutovectorizationGuide.pdf
- https://software.intel.com/en-us/articles/get-a-helping-hand-from-the-vectorization-advisor
- https://software.intel.com/en-us/mkl
- https://software.intel.com/en-us/intel-parallel-universe-magazine