OpenMP 4.0: a Significant Paradigm Shift in High-level Parallel Computing (Not just Shared Memory anymore)

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Acknowledgement and Disclaimer

- Numerous people internal and external, in industry and academia, have made contributions, influenced ideas, written part of this presentations, and offered feedbacks to form part of this talk.
- I even lifted this acknowledgement and disclaimer from some of them.

- But I claim all credit for errors, and stupid mistakes. **These are mine, all mine!**
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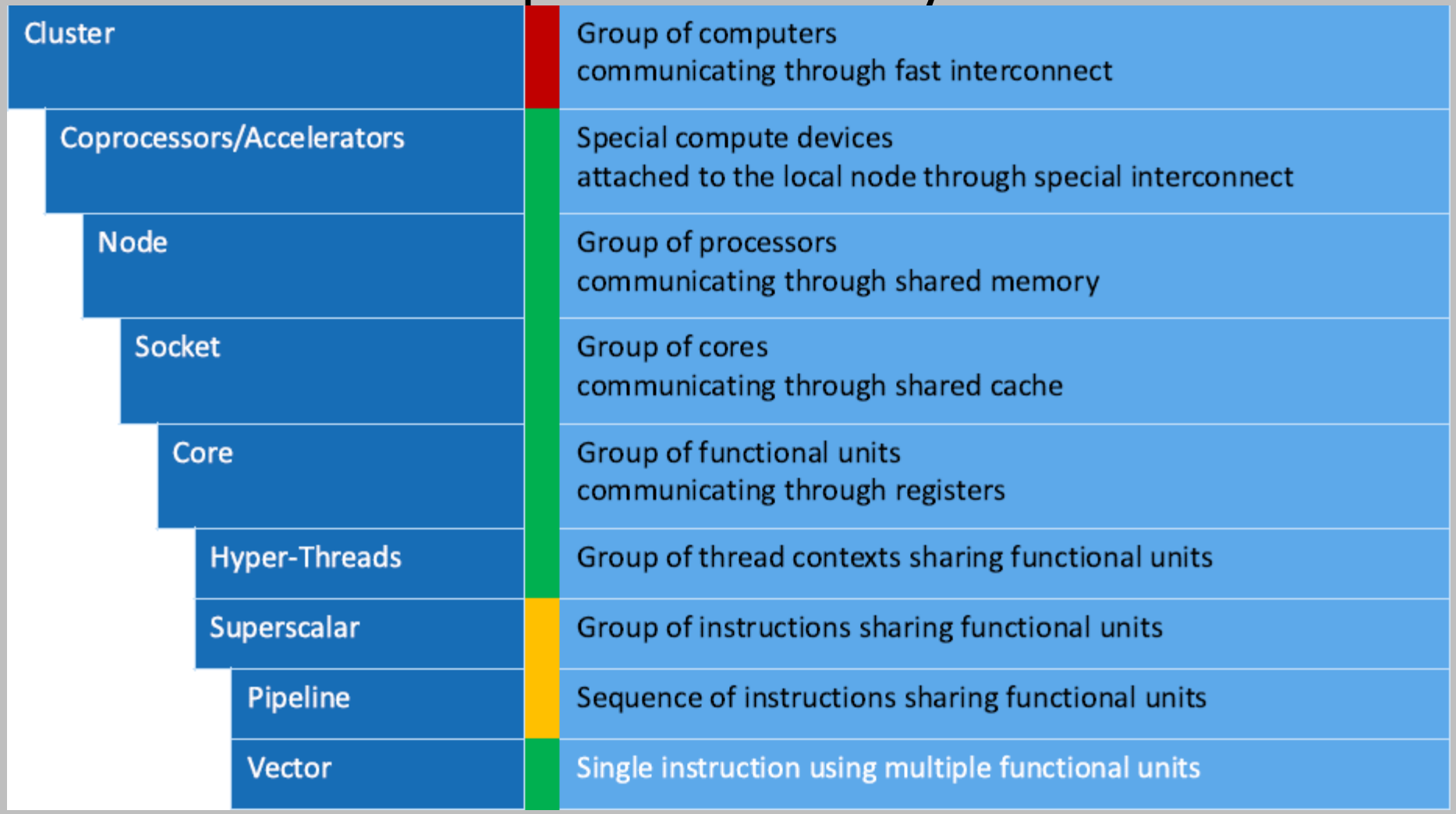
OpenMP SIMD Subcommittee

- Technical leads
  - Xinmin Tian - Intel
- Active subcommittee members
  - Michael Klemm – Intel (courtesy for slides)
  - Alex Duran - BSC
  - Xavier Martotell- BSC
  - Kelvin Li - IBM
  - Nowal Copty – Oracle/Sun

What levels of parallelism is supported by OpneMP in today's hardware?



SIMD Language Extensions

- IBM currently has 7 SIMD architectures
  - VMX, VMX128, VSX, SPE, BGL, BGQ, QPX
  - Each has its own proprietary language extension
  - Code written for one language extension can't be moved without a rewrite
  - We don't even have compatibility within our own company
- Outside our company Intel has 7 SIMD architectures
  - MMX, SSE, SSE2, SSE3, SSE4, AVX, AVX-512/MIC
  - MMX, SSEx, AVX each have a different language extension
  - Code written for one language extension can't be moved without a rewrite

“The Great Hope”- Auto-Vectorizing compilers

- SIMD floating point entered the market 10 years ago
  - (Intel Pentium III, Motorola G4, AMD K6-2)
- Software industry held its breath waiting for a “magic” auto-vectorizing compiler (including Microsoft)
- Despite 15 years of research and development the industry still doesn’t have a good auto-vectorizing compiler
- Industry instead ended up with primitive language support
  - Multiple non-compatible language extensions
  - Compiler intrinsics
- Using intrinsics humans still produce superior vector code but at great pain

Why autovectorization fail?

- SIMD register width has increased from 128-256-512, 1024 soon
- Instructions are more powerful and complex
  - Hard for compiler to select proper instruction
  - Code pattern needs to be recognized by the compiler
  - Precision requirements often inhibit SIMD codegen

What sort of loops can be vectorized?

- Countable
- Single entry, single exit
- Straight-line code
- Innermost loop of a nest
- No function calls
- Certain non-contiguous memory access
- Some Data dependencies
- Efficient Alignment
- Mixed data types
- Non-unit stride between elements
- Loop body too complex (register pressure)

Industry needs better language support for SIMD

- 80% of Cell programmers time spent vectorizing code
- Need to reduce programming effort
  - Fewer code modifications to vectorize
  - Rapid conversion of scalar to vector code
- Code portability
  - Don’t rewrite for every SIMD architecture
- Less code maintenance
  - Intrinsics impossible to maintain
  - Easier to rewrite then figuring out what the code is doing
- Support required vendor-specific extensions before OpenMP 4.0

SIMD Loop Construct

- Vectorize a loop nest
  - → Cut loop into chunks that fit a SIMD vector register
  - → No parallelization of the loop body

- Syntax (C/C++)

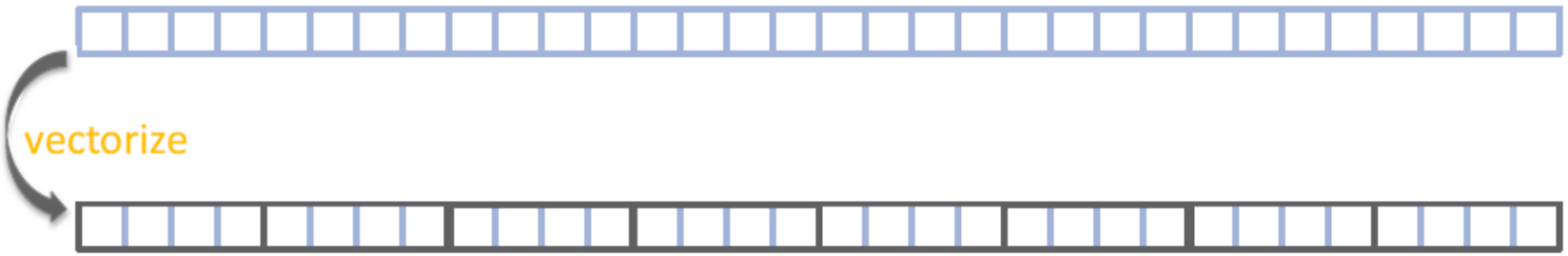
```
#pragma omp simd [clause[[,] clause],…]
for-loops
```

- Syntax (Fortran)

```
!$omp simd [clause[[,] clause],…]
do-loops
```

Sum product Example

```
void sprod(float *a, float *b, int n) {
  float sum = 0.0f;
#pragma omp simd reduction(+:sum)
  for (int k=0; k<n; k++)
    sum += a[k] * b[k];
  return sum;
}
```



Data Sharing Clauses

- `private(var-list):`
  Uninitialized vectors for variables in *var-list*

- `firstprivate(var-list):`
  Initialized vectors for variables in *var-list*

- `reduction(op:var-list):`
  Create private variables for *var-list* and apply reduction operator *op* at the end of the construct

SIMD Loop Clause

- `safelen (length)`
  - → Maximum number of iterations that can run concurrently without breaking a dependence
  - → in practice, maximum vector length
- `linear (list[:linear-step])`
  - → The variable's value is in relationship with the iteration number
    - → $x_i = x_{orig} + i * \text{linear-step}$
- `aligned (list[:alignment])`
  - → Specifies that the list items have a given alignment
  - → Default is alignment for the architecture
- `collapse (n)`

SIMD Worksharing Construct

- Parallelize and vectorize a loop nest
  - → Distribute a loop's iteration space across a thread team
  - → Subdivide loop chunks to fit a SIMD vector register

- Syntax (C/C++)

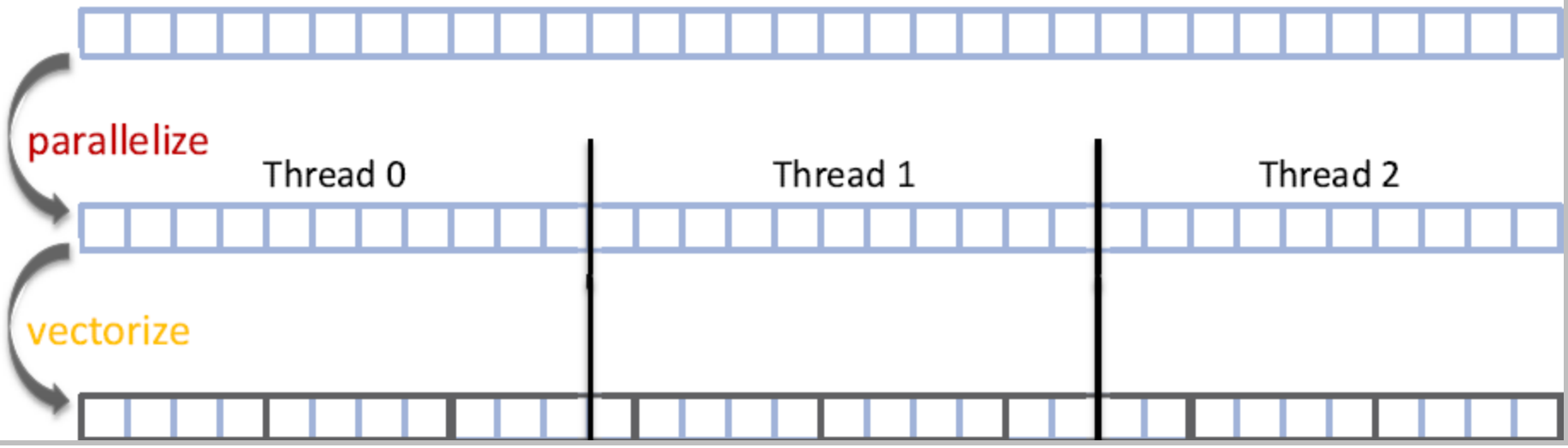
```
#pragma omp for simd [clause[[,] clause],…]
for-loops
```

- Syntax (Fortran)

```
!$omp do simd [clause[[,] clause],…]
do-loops
```

Parallelize and vectorize

```
void sprod(float *a, float *b, int n) {
  float sum = 0.0f;
#pragma omp for simd reduction(+:sum)
  for (int k=0; k<n; k++)
    sum += a[k] * b[k];
  return sum;
}
```



SIMD Function Vectorization

```
float min(float a, float b) {
    return a < b ? a : b;
}

float distsq(float x, float y) {
    return (x - y) * (x - y);
}

void example() {
#pragma omp parallel for simd
    for (i=0; i<N; i++) {
        d[i] = min(distsq(a[i], b[i]), c[i]);
}   }
```

SIMD Function Vectoraization

- Declare one or more functions to be compiled for calls from a SIMD-parallel loop

- Syntax (C/C++):

```
#pragma omp declare simd [clause[[,] clause],…]
[#pragma omp declare simd [clause[[,] clause],…]]
[…]
function-definition-or-declaration
```

- Syntax (Fortran):

```
!$omp declare simd (proc-name-list)
```

SIMD Function Vectorizaiton

```
#pragma omp declare simd
float min(float a, float b) {
    return a < b ? a : b;
}

#pragma omp declare simd
float distsq(float x, float y) {
    return (x - y) * (x - y);
}

void example() {
#pragma omp parallel for simd
    for (i=0; i<N; i++) {
        d[i] = min(distsq(a[i], b[i]), c[i]);
}   }
```

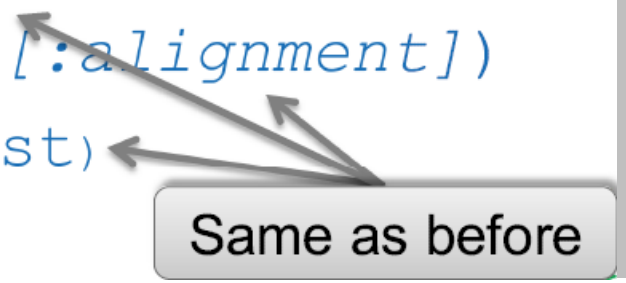
```
vec8 min_v(vec8 a, vec8 b) {
    return a < b ? a : b;
}
```

```
vec8 distsq_v(vec8 x, vec8 y)
    return (x - y) * (x - y);
}
```

```
vd = min_v(distsq_v(va, vb), vc)
```

SIMD Function Vectorization

- `simdlen (length)`
  - → generate function to support a given vector length
- `uniform (argument-list)`
  - → argument has a constant value between the iterations of a given loop
- `inbranch`
  - → function always called from inside an if statement
- `notinbranch`
  - → function never called from inside an if statement
- `linear (argument-list[:linear-step])`
- `aligned (argument-list[:alignment])`
- `reduction (operator:list)`



inbranch

```
#pragma omp declare simd inbranch
float do_stuff(float x) {
    /* do something */
    return x * 2.0;
}

void example() {
#pragma omp simd
    for (int i = 0; i < N; i++)
        if (a[i] < 0.0)
            b[i] = do_stuff(a[i]);
}
```

```
vec8 do_stuff_v(vec8 x, mask m) {
    /* do something */
    vmulpd x{m}, 2.0, tmp
    return tmp;
}
```

```
for (int i = 0; i < N; i+=8) {
    vcmp_lt &a[i], 0.0, mask
    b[i] = do_stuff_v(&a[i], mask);
}
```

My blogs and email address

- **ISOCPP.org Director, VP**
  http://isocpp.org/wiki/faq/wg21#michael-wong
  OpenMP CEO: http://openmp.org/wp/about-openmp/
  My Blogs: http://ibm.co/pCvPHR
  C++11 status: http://tinyurl.com/43y8xgf
  Boost test results
  http://www.ibm.com/support/docview.wss?rs=2239&context=SSJT9L&uid=swg27006911
  C/C++ Compilers Feature Request Page
  http://www.ibm.com/developerworks/rfe/?PROD_ID=700
  Chair of WG21 SG5 Transactional MemoryM:
  https://groups.google.com/a/isocpp.org/forum/?hl=en&fromgroups#!forum/tm

FRAGEN?

Ich freue mich auf Ihr Feedback!

Vielen Dank!

Michael Wong