Vectorisation

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Overview

- Vector registers
- SIMD construct
- Declare SIMD construct to vectorise functions

Vectorisation

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Modern hardware has wide registers Overview on x86 system

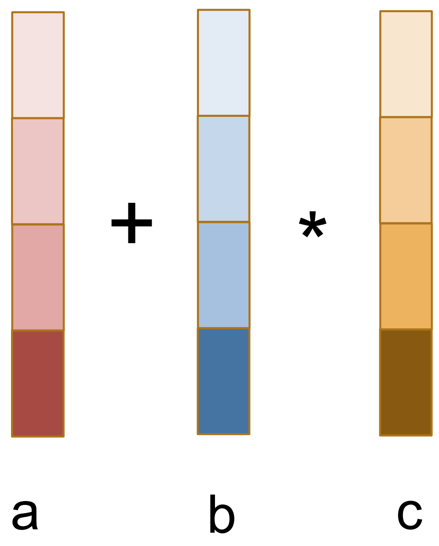
Instruction set	Register width	Single prec. words	Double prec. words	Typical hardware
SSE, SSE2	128 bit	4	2	modern x86
AVX, AVX2	256 bit	8	4	x86 since 2011
AVX-512	512 bit	16	8	Skylake Knights Landing

- Concept also exists in non-x86 hardware, examples:
  - ARM: NEON
  - IBM Power: VSX

Example: AVX2 FMA instruction

- AVX: 256 bit registers - 4 doubles
- Single instruction - 8 flops:

$$a_1 + b_1 * c_1$$
$$a_2 + b_2 * c_2$$
$$a_3 + b_3 * c_3$$
$$a_4 + b_4 * c_4$$



- Enable via compiler option:
  - Without cross compilation:
    - » GCC: `-march=native -O3`
    - » Intel: `-xHost -O3`
  - Cross compilation: explicit specification

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Basic example for SIMD deployment

```
do i=1, n
   a(i) = b(i) + c(i)
enddo
```

- Execute multiple loop iterations simultaneously
- Reduce loop count accordingly
- Iterations need to be independent

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What needs to be done for SIMD (Simplified)

```
do i=1, n, 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)
enddo
```

- Execute multiple loop iterations simultaneously
- Iterations need to be independent
- Compiler might need to add a peel

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Basic example for SIMD deployment

```
for (i=1; i<n; i++)
  {
   a[i] = b[i] + c[i]
  }
```

- Execute multiple loop iterations simultaneously
- Reduce loop count accordingly
- Iterations need to be independent

What needs to be done for SIMD (Simplified)

```
for (i=0; i<n; 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];
  }
```

- Execute multiple loop iterations simultaneously
- Reduce loop count accordingly
- Compiler might need to add a peel

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Automatic vectorisation

- Modern compilers vectorise many loops automatically
  - Choose right instruction set and optimisation level
    - GNU: `-O3 -march=native`
    - Intel: `-O3 –xHost`
  - Compilers can report on vectorisation
    - GNU: `-fopt-info-vec -fopt-info-vec-missed`
    - Intel: `-qopt-report -qopt-report-phase=vec`
- Compiler needs help in complex situations
  - OpenMP SIMD construct: portable way to help

SIMD construct

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simd construct (Fortran)

- Assure compiler that the following loop can be vectorised

```
!$omp simd
do i = 1, n
   a(i) = a(i) + b(i)
enddo
```

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simd construct in C

- Assure compiler that the following loop can be vectorised

```
#pragma omp simd
for (i = 1; i < n; i++)
  {
    a[i] = a[i] + b[i];
  }
```

Clauses for `simd` construct

- Data sharing:

  `private, lastprivate, reduction`

- The is no `default(none)` here!

- Number of loops associated with construct

  `collapse(n)`

Clauses for `simd` construct (cont.)

- Clause `safelen` allows vectorisation of certain dependencies

```
!$omp simd safelen(7)
do i = 1, n
   a(i) = a(i) + a(i+7)
enddo
```

- Allowed to load up to 7 values in the register
- This would be difficult to parallelise

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Clauses for `simd` construct (cont.)

- Clause `safelen` allows vectorisation of certain dependencies

```
#pragma omp simd safelen(7)
for (i = 1; i < n; i++)
   a[i] = a[i] + a[i+7];
```

- Allowed to load up to 7 values in the register
- This would be difficult to parallelise

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Clauses `simdlen`

- Clause `simdlen`: <u>preferred</u> number of consecutive iterations:

```
!$omp simd simdlen(4)
do i = 1, n
  a(i) = a(i) + b(i)
enddo
```

- This will suggests to do 4 iterations simultaneously

Clauses `simdlen`

- Clause `simdlen`: preferred number of consecutive iterations:

```
#pragma omp simd simdlen(4)
for (i = 1; i < n; i++)
  {
    a[i] = a[i] + b[i];
  }
```

- This suggests to do 4 iterations simultaneously

Clause `linear`

- Declare a linear relationship between iteration (≠ loop index) and a variable

```
j=0
!$omp simd linear(j:2)
do i = 1, N, 3
  j = j + 2
  a(i) = b(j)
enddo
```

- Data sharing clause, `j` is now private

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Clause `linear`

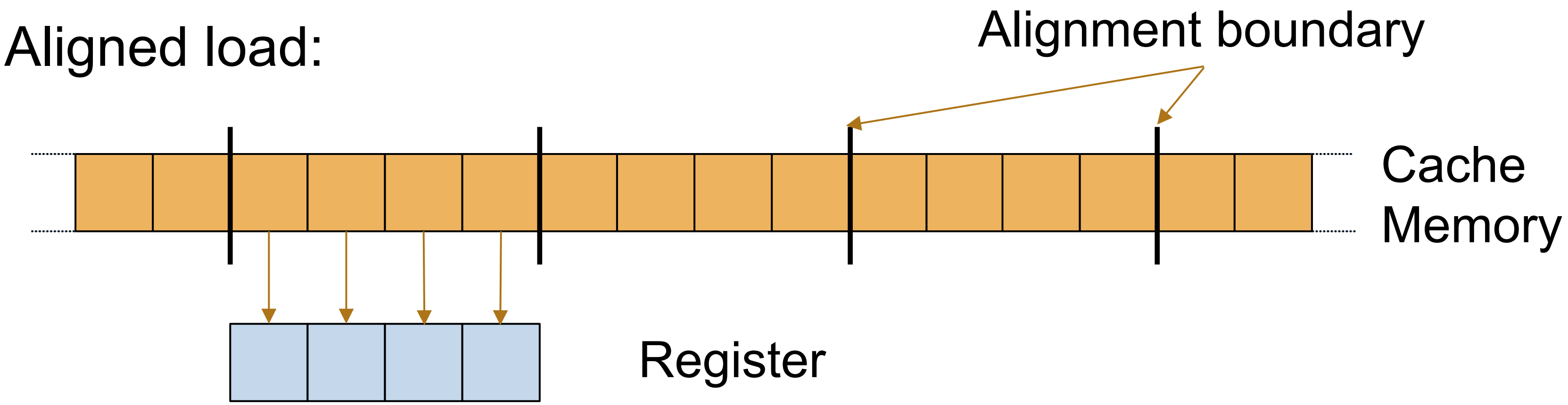
- Declare a linear relationship between iteration (≠ loop index) and a variable

```
j=0;
#pragma omp simd linear(j:2)
for (i = 1; i < n; i++)
  {
     j = j + 2;
     a[i] = b[j];
  }
```

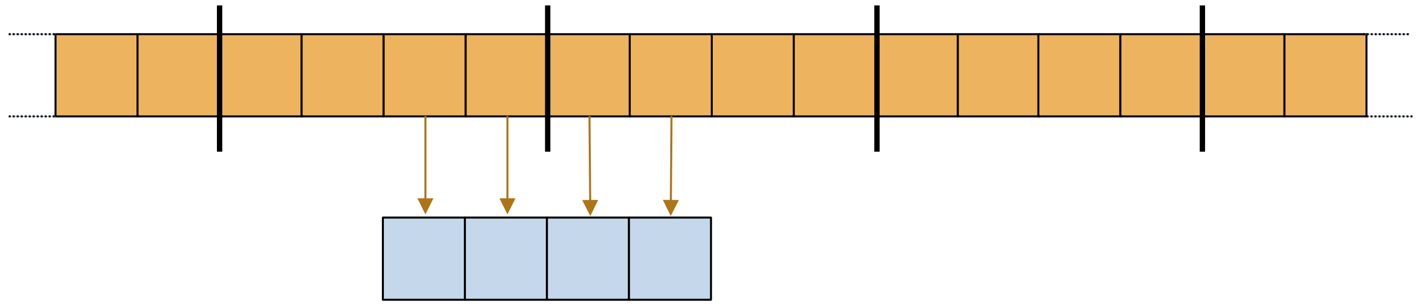
- Data sharing clause, `j` is now private

SIMD and data alignment

- Aligned load:



- Un-aligned load (typically not supported)



SIMD and data alignment

- Byte alignment of data
  - An address is e.g. 32-byte-aligned if:

    byte-address is divisible by 32
- SIMD loads/stores typically have alignment requirements
  - Unaligned data needs either
    - » Peel loops – load individual number until boundary
    - » Crossload
  - Checking requires extra code – performance impact

Aligning data

- There is no function in OpenMP ☹
- In C one might want to lib-functions from stdlib:

```
int posix_memalign(void **memptr, size_t alignment, size_t size);
void *aligned_alloc( size_t alignment, size_t size );
```

- In Fortran
  - Wrap `posix_memalign` or `aligned_alloc`
  - Compiler specific tools:
    - » Example: Intel compiler

      ```
      ifort -align array32byte
      ```

      aligns all arrays at 32-byte boundaries

Advanced optimisation: `aligned`

- If you understand/control your data alignment
- Declare it to the system (e.g. 32 byte alignment)

```
!$omp simd aligned(x,32)
Do i = 1, N
   x(i) = 2.0D0 * x(i)
enddo
```

- If correct, this will reduce overheads (peeled loops)
- If false, illegal instructions
- No optional parameter – implementation default alignment

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Advanced optimisation: `aligned`

- If you understand/control your data alignment
- Declare it to the system (e.g. 32 byte alignment)

```
#pragma omp simd aligned(x,32)
for (i = 1; i<N; i++)
   x[i] = 2.0D0 * x[i];
```

- If correct, this will reduce overheads (peeled loops)
- If false, illegal instructions
- No optional parameter – implementation default alignment

Vectorisation of functions and subroutine

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Function/subroutine calls in loop

- Try to avoid calls in loop, due to performance impact
- Use `declare simd` to create vector versions of functions and subroutines

```
function addfunc(a,b)
!$omp declare simd(addfunc)
   implicit none
   double precision :: a, b, addfunc
   addfunc = a + b
end function addfunc
```

Using a simd-ised function

- The function can be used in a `simd` loop

```
!$omp simd
do i = 1, N
   c(i) = addfunc(a(i), b(i))
enddo
```

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Function/subroutine calls in loop

- Try to avoid calls in loop, due to performance impact
- Use `declare simd` to create vector versions
- Required in the header **and** source file!

```
#pragma omp declare simd
double addfunc(double a, double b) {
   double r;
   r = a + b;
   return r;
}
```

Using a simd-ised function

- The function can be used in a `simd` loop

```
#pragma omp simd
for (i = 1; i < N; i++)  {
   c[i] = addfunc(a[i], b[i])
}
```

Clauses for `declare simd`

- Discussed before:
  - `simdlen(`*`length`*`)`
  - `linear(`*`linear-list[ : linear-step]`*`)`
  - `aligned(`*`arg-list[ : alignment]`*`)`
- Specific clauses
  - `uniform(`*`argument-list`*`)`

    value invariant for all invocations
  - `inbranch`

    always called inside a conditional statement
  - `notinbranch`

    never called inside a conditional statement

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Example 1

```
function vecop(a, b, i, offset)
!$omp declare simd(vecop) uniform(a,b,offset) &
!$omp linear(i:1)
   integer :: i
   double precision :: a(*), b(*), offset, vecop
   vecop = a(i) + b(i) + offset
end function vecop
```

- GCC 6.3, 8.3, 9.2 and clang 9.0.1 will not compile this!
  - Complain about a and b in `uniform`
  - Possible workaround: scalar code
- Intel does compile this

Using function vecop

```
double precision :: a(N), b(N)
...
!$omp simd
Do i = 1, N
  a(i) = vecop(a, b, i, 3.1d0)
enddo
```

Example 2

```
function cube(x)
!$omp declare simd inbranch
   implicit none
   double precision :: cube, x
   cube = x*x*x
end function cube
```

- This will generate code with a mask and suppress the unmasked version

Using the cube function

```
double precision :: x(N), y(N)
...
!$omp simd simdlen(4)
do i = 1, N
  if( y(i).gt.0.0d0 ) then
     y(i) = cube(x(i))
  endif
enddo
```

- Will operate on 4 long vectors, but not do the operation on lane, where condition is false (applying masking)

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Combined contructs

- Distribute a loop and simd-ise it:

```
!$omp do simd
```

- Start parallel region, distribute a loop and simd-ise it:

```
!$omp parallel do simd
```

- Modified schedule

```
!$omp do simd schedule(simd:static, 11)
```

  – new chunksize = (chunksize/simdlen) * simdlen

  – always a multiple of the simdlen

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Summary

- Using the `SIMD` construct to assist in loop vectorisation

- `declare SIMD` construct to allow vectorised function calls

- Some compilers allow for SIMD part of OpenMP only
  - Intel: `-qopenmp-simd`

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