Algorithms and Computation in Signal Processing

special topic course 18-799B
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22nd lecture Mar. 31, 2005

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Organization

- Overview
  - Idea, benefits, reasons, restrictions
  - State-of-the-art floating-point SIMD extensions
  - History and related technologies
  - How to use it
- Writing code for Intel's SSE
  - Instructions
  - Common building blocks
  - Examples: WHT, matrix multiplication, FFT
- Selected topics
  - BlueGene/L
  - Complex arithmetic and instruction-level parallelism
  - Things that don't work as expected
- Conclusion: How to write good vector code

Blackboard

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BlueGene/L Supercomputer

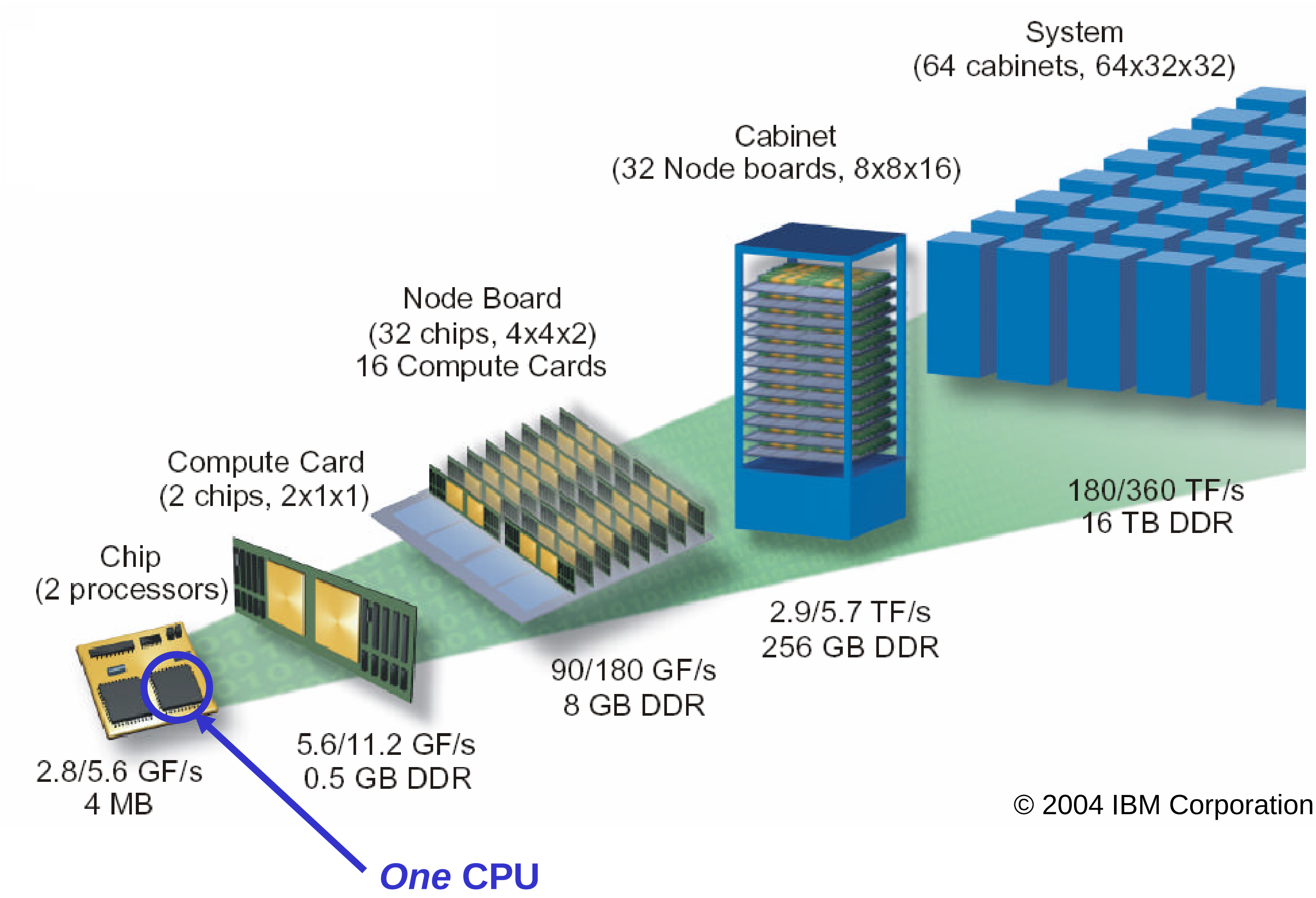
System at Lawrence Livermore National Laboratory (LLNL)

- Aims at #1 in Top 500 list of supercomputers
- 65,536 processors
  PowerPC 440 FP2 @ 700 MHz
- 360 Tflop/s peak performance
- 16 TByte RAM
- In operation by end of 2005

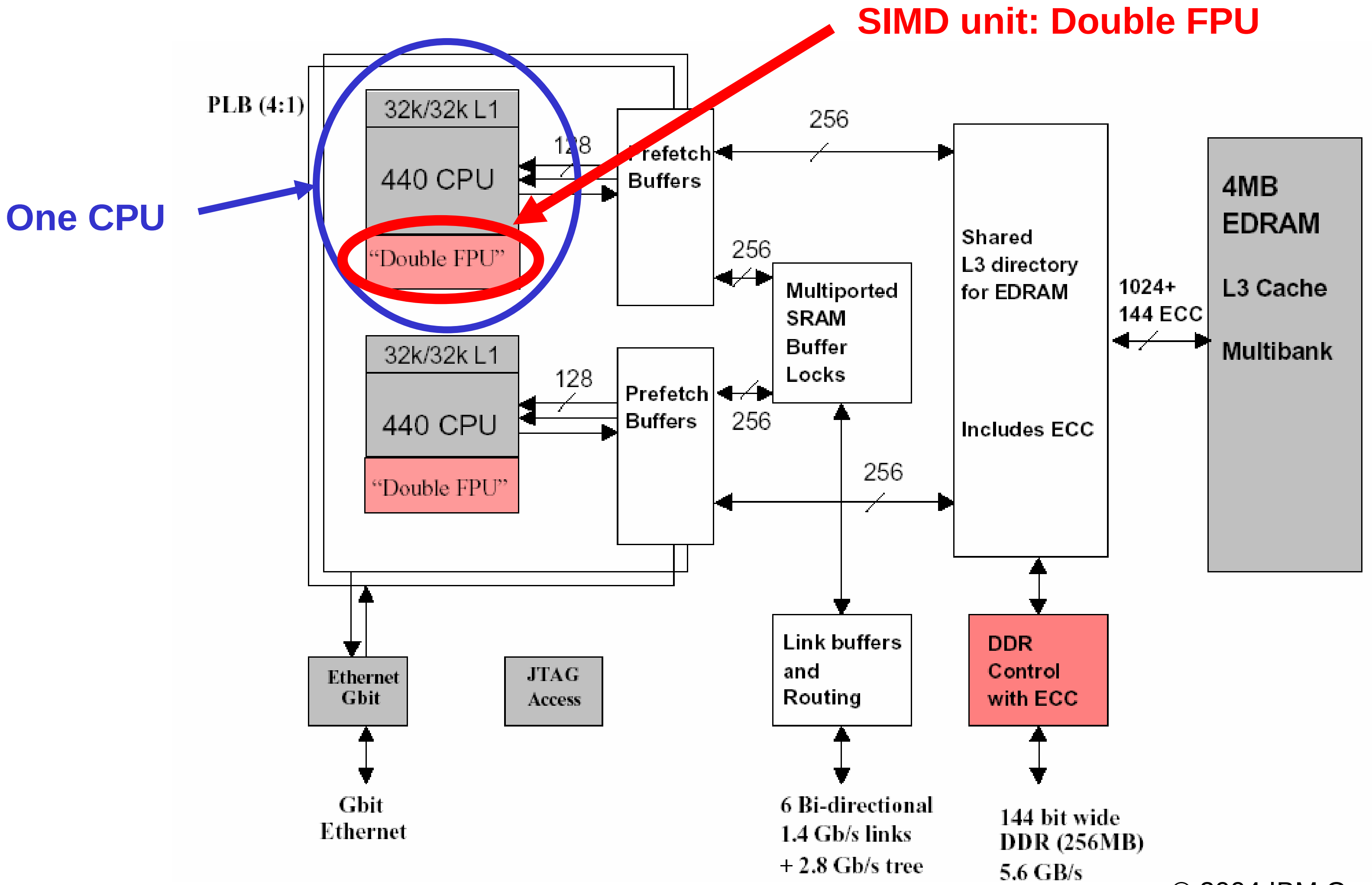
Smaller systems will be commercially available

- Other national labs, universities, Japan, Germany,…
- BlueGene/L consortium: open to everybody, community effort

The BlueGene/L System at LLNL



BlueGene/L CPU: PowerPC 440 FP2



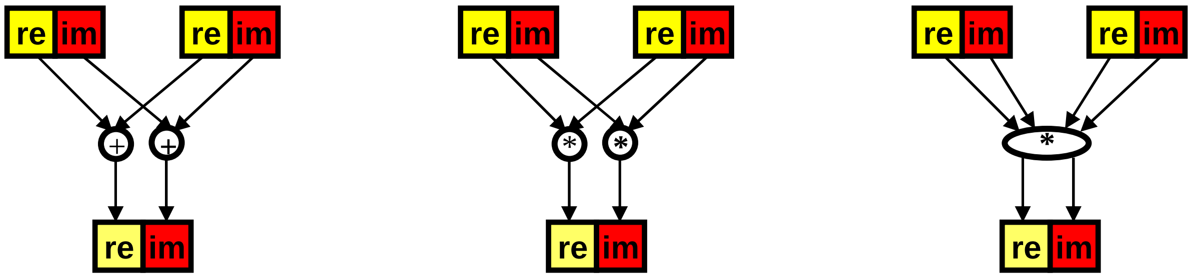
The Double FPU

BlueGene/L Double FPU: Two coupled FPUs

- Scalar and two-way vector FPU instructions
- Per cycle: Either two-way FMA or two-way move, and one two-way load or store
- Double precision

Supports complex arithmetic and two-way SIMD

- 20 instructions supporting complex multiply-add
- Implicit parallel, cross and copy operations
- Vector sign changes and cross moves



Parallel add = 1 instr.
Complex add

Parallel mul = 1 instr.

Complex mul = 2 instr.
(6 flops)

Vectorization Overhead

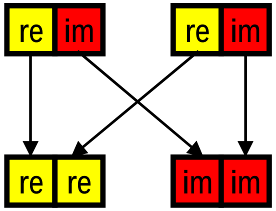
Complex arithmetic

- Native mode for BlueGene/L Double FPU
- However, many codes use real arithmetic
- Real codes require vectorization

Real vector code = faster computation but overhead

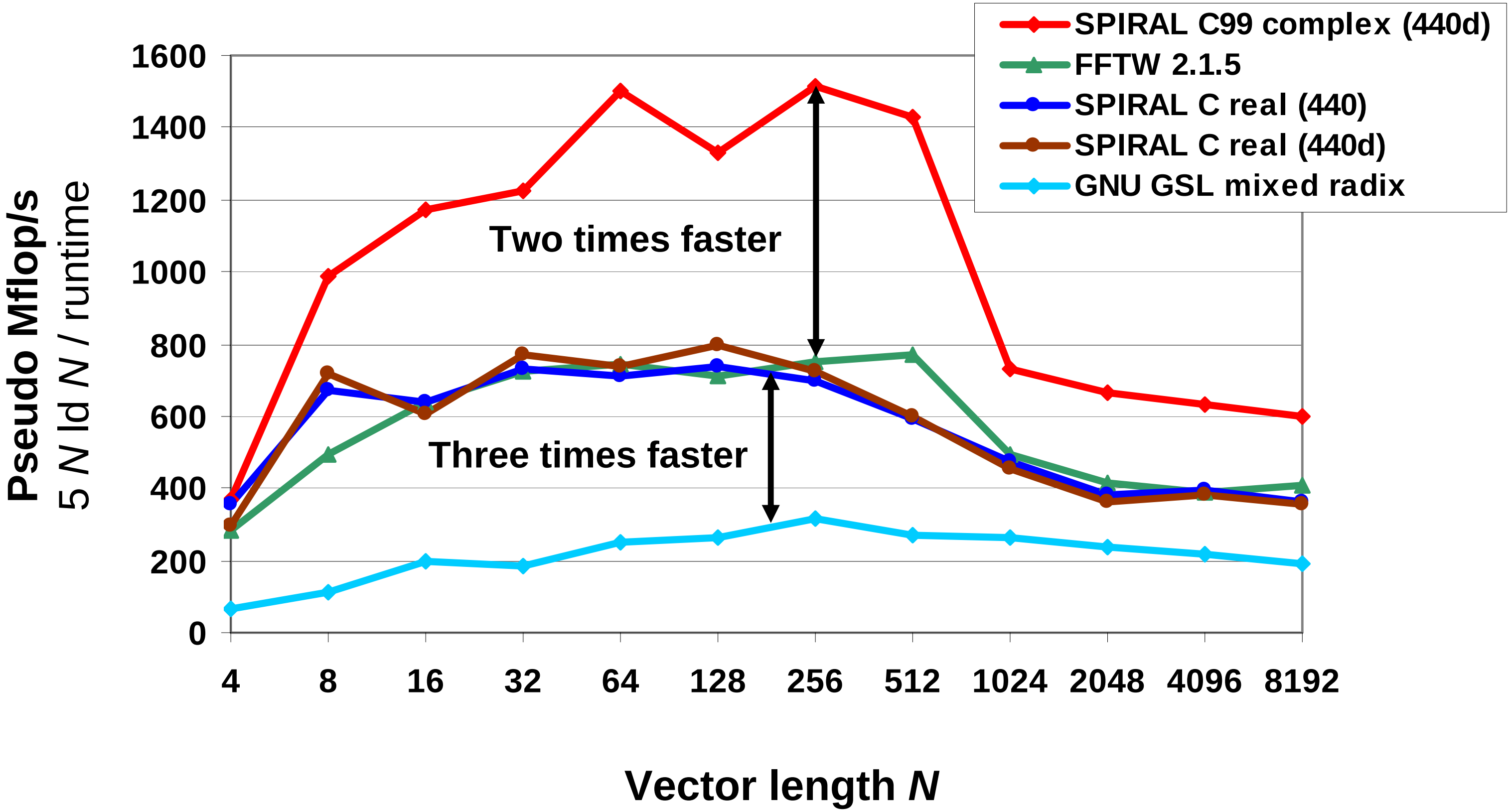
- Overhead: prepare data for parallel computation
- Goal: minimize or eliminate these reorder operations

BlueGene/L: Expensive data reorganization



- Work in parallel on real and imaginary parts
- One copy and two cross-copies
  On BlueGene/L: 3 cycles = 12 flops

Benchmark: DFT, 2-powers, BlueGene/L



BlueGene/L DD2 prototype at IBM T.J. Watson Research Center
Single BlueGene/L CPU at 700 MHz (one Double FPU), IBM XL C compiler

- **Utilization of complex FPU via C99 _Complex double**
- **Factor 2 over real code with compiler vectorization (IBM XL C)**

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Example: Complex Multiplication SSE3

Complex C99 code + compiler vectorization
works reasonably well

Complex code features intrinsic
2-way vector parallelism

The Corresponding Assembly Code

SSE3:

```
movapd   xmm0, XMMWORD PTR A
movddup  xmm2, QWORD PTR   B
mulpd    xmm2, xmm0
movddup  xmm1, QWORD PTR   B+8
shufpd   xmm0, xmm0, 1
mulpd    xmm1, xmm0
addsubpd xmm2, xmm1
movapd   XMMWORD PTR C, xmm2
```

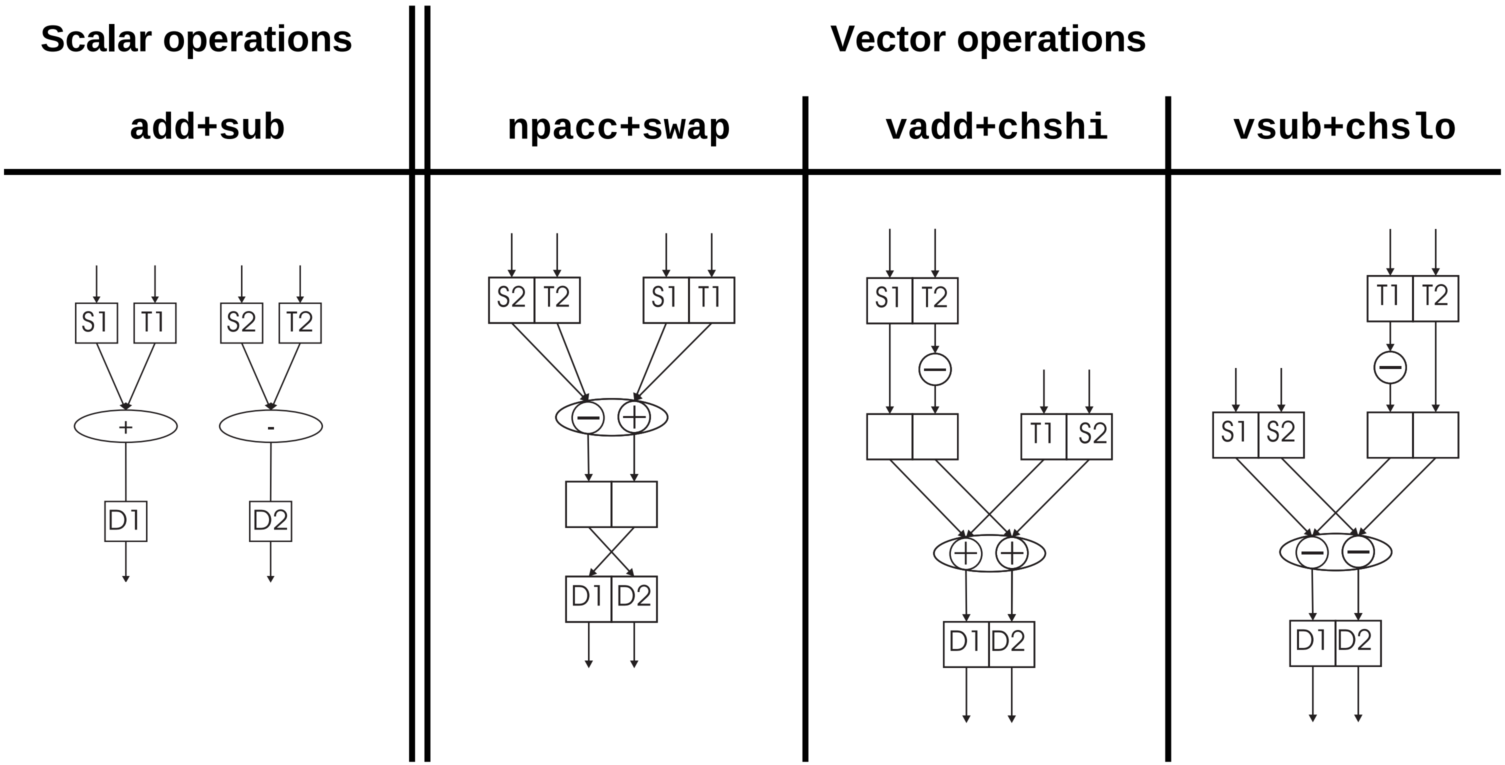
SSE2:

```
movsd    xmm3, QWORD PTR A
movapd   xmm4, xmm3
movsd    xmm5, QWORD PTR A+8
movapd   xmm0, xmm5
movsd    xmm1, QWORD PTR B
mulsd    xmm4, xmm1
mulsd    xmm5, xmm1
movsd    xmm2, QWORD PTR B+8
mulsd    xmm0, xmm2
mulsd    xmm3, xmm2
subsd    xmm4, xmm0
movsd    QWORD PTR C, xmm4
addsd    xmm5, xmm3
movsd    QWORD PTR C, xmm5
```

In SSE2 scalar code is better

Example: 3DNow! Basic Block Vectorization

- Utilizing instruction-level parallelism
- Inter-operand and intra-operand vector instructions



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Things that don't work as expected

- Intel SSE/SSE2/SSE3
  - SSE2 can't do complex arithmetic well
  - Early application notes showed really bad code examples (split radix FFT)
  - Intel Compiler doesn't vectorize despite pragmas,…
- Intel Itanium processor family (IPF)
  - No intrinsic interface to IPF native vector instruction
  - Can only use 4-way SSE intrinsics to program 2-way IPF
  - With Itanium 2, no vectorization speed-up possible any more
- AMD 3DNow! and AMD64
  - AMD64 can do 3DNow! and SSE2 in parallel – have fun!
  - For a long time they had no compiler support
  - K7: One intra operand instruction is just missing (++,+-, --; -+??)

Things that don't work as expected (2)

- Motorola/IBM AltiVec
  - No unaligned memory access (raises exception)
  - Subvector access: the actually read/written vector element depends on the memory address referenced (!!)
  - A general shuffle requires a 128 bit register "howto" operand
  - Only fused-multiply-add (FMA) instruction – have to add explicitly (0,0,0,0) for multiplication only
  - For a while, the GNU C compiler was buggy and the only compiler available
- IBM Double FPU (BlueGene/L)
  - One shuffle *or* one vector FMA per cycle
  - Data reorganization prohibitively expensive
  - Have to fold that into special FMAs and multiply by one

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How to Write Good Vector Code?

- Take the "right" algorithm and the "right" data structures
  - Fine grain parallelism
  - Correct alignment in memory
  - Contiguous arrays
- Use a good compiler (e. g., vendor compiler)
- First: Try compiler vectorization
  - Right options, pragmas and dynamic memory functions
    (Inform compiler about data alignment, loop independence,…)
  - Check generated assembly code *and* runtime
- If necessary: Write vector code yourself
  - Most expensive subroutine first
  - Use intrinsics, no (inline) assembly
  - Important: Understand the ISA

Remaining time: Discussion