How do we improve performance?

- Imagine you want to build a house. How long would it take you?

- What could you do to build that house faster?

Exploiting Parallelism

- Of the computing problems for which performance is important, many have inherent parallelism.

- E.g., computer games:
  - graphics, physics, sound, A.I. etc. can be done separately
  - Furthermore, there is often parallelism within each of these:
    - Each pixel on the screen's color can be computed independently
    - Non-contacting objects can be updated/simulated independently
    - Artificial intelligence of non-human entities done independently

- E.g., Google queries:
  - Every query is independent
    - Google searches are read-only!!

Exploiting Parallelism at the Instruction level (SIMD)

- Consider adding together two arrays:

```
void
array_add(int A[], int B[], int C[], int length) {
  int i;
  for (i = 0 ; i < length ; ++ i) {
   C[i] = A[i] + B[i];
  }
}
```

- You could write assembly for this, something like:

```
lw    $t0, 0($a0)
lw    $t1, 0($a1)
add   $t0, $t1, $t2
sw    $t2, 0($a2)
```

(plus all of the address arithmetic, plus the loop control)

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  }
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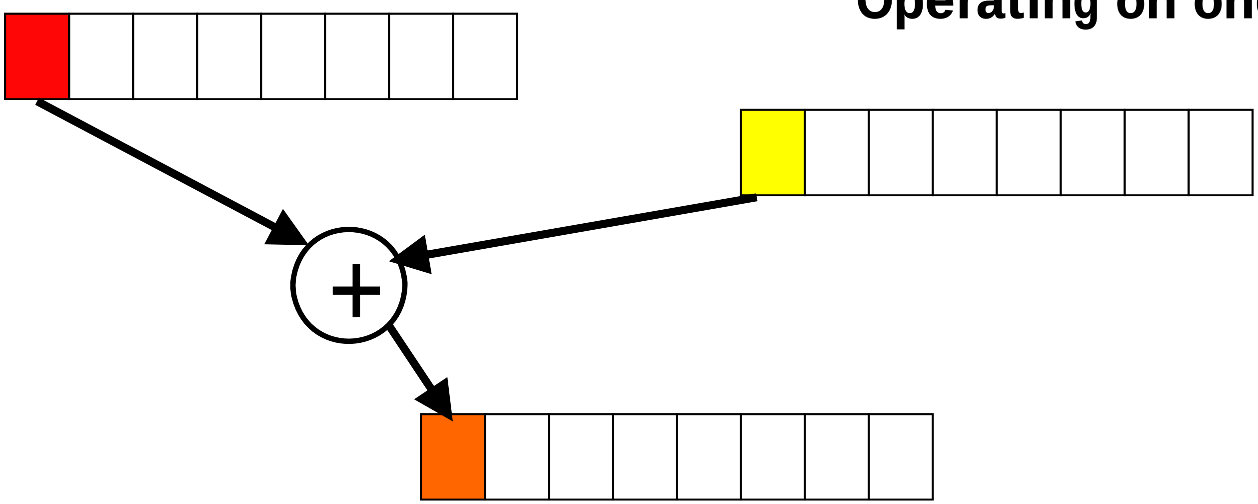
```

Operating on one element at a time



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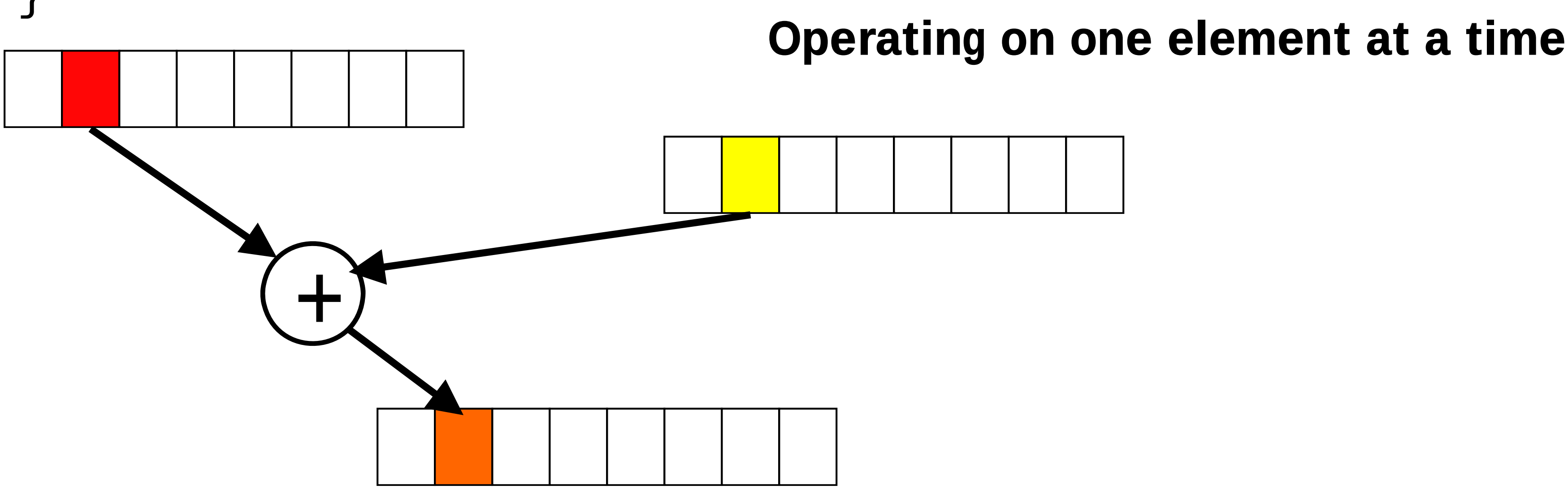

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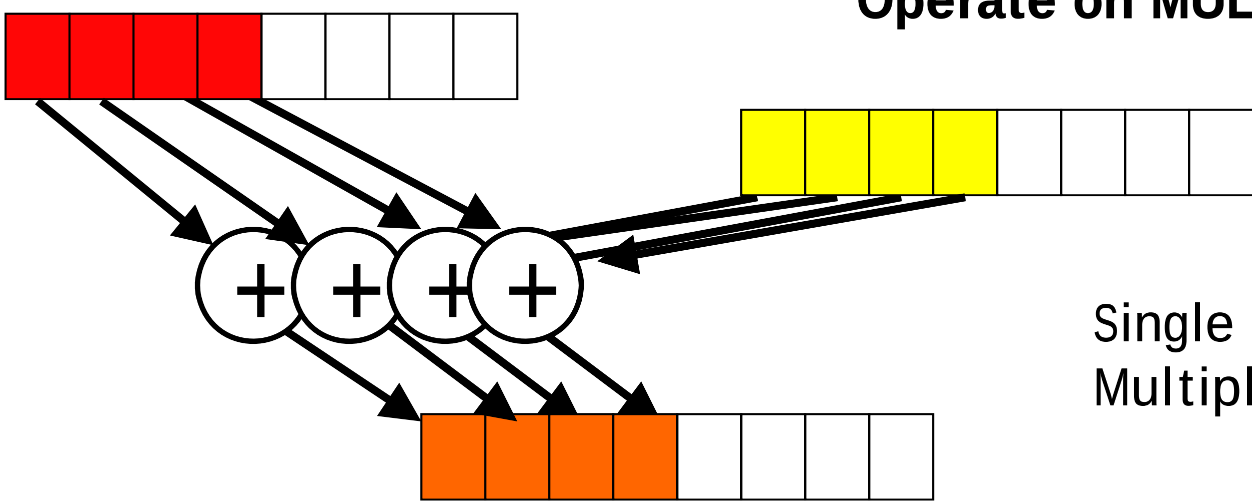
Operate on MULTIPLE elements



Single Instruction,
Multiple Data (**SIMD**)

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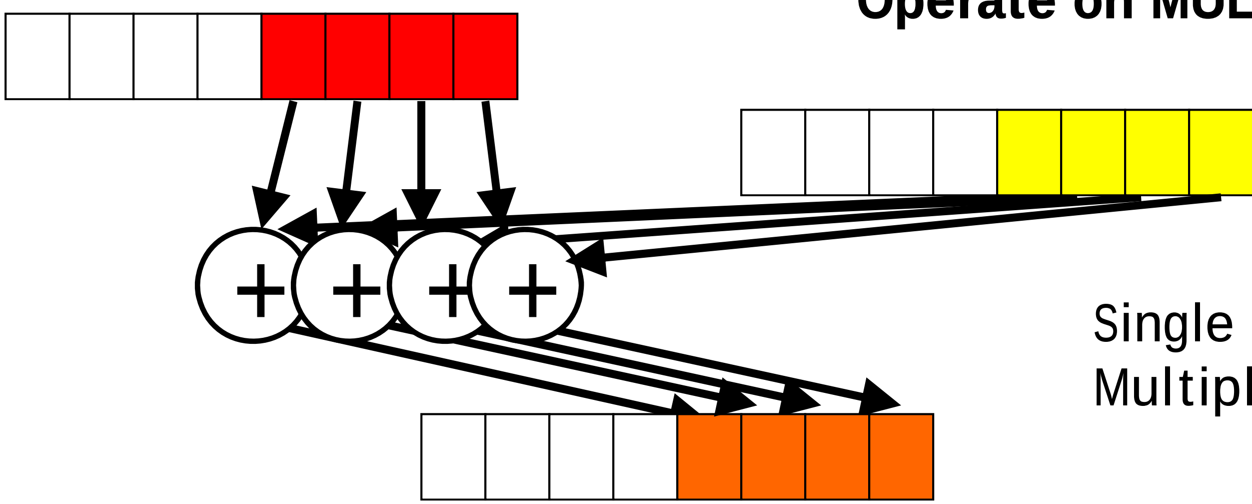


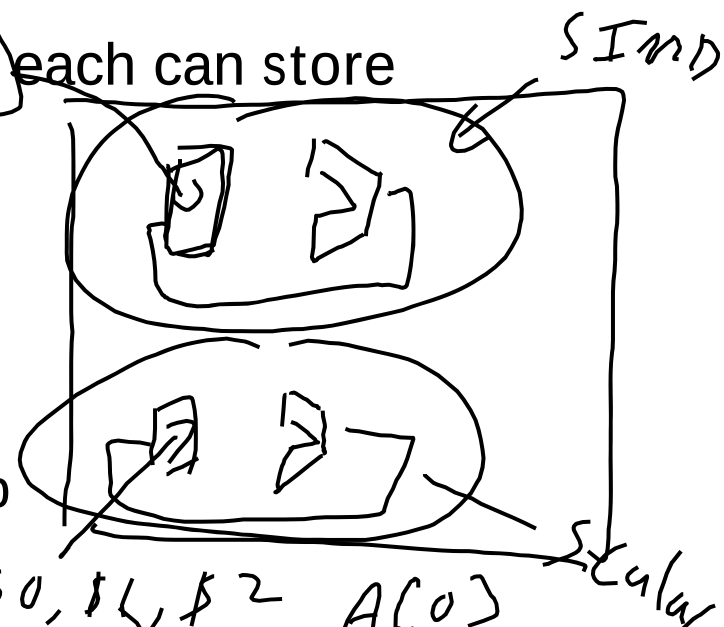
Single Instruction,
Multiple Data (**SIMD**)

Intel SSE/SSE2 as an example of SIMD

- Added new 128 bit registers (XMM0 – XMM7), each can store

32 bits =

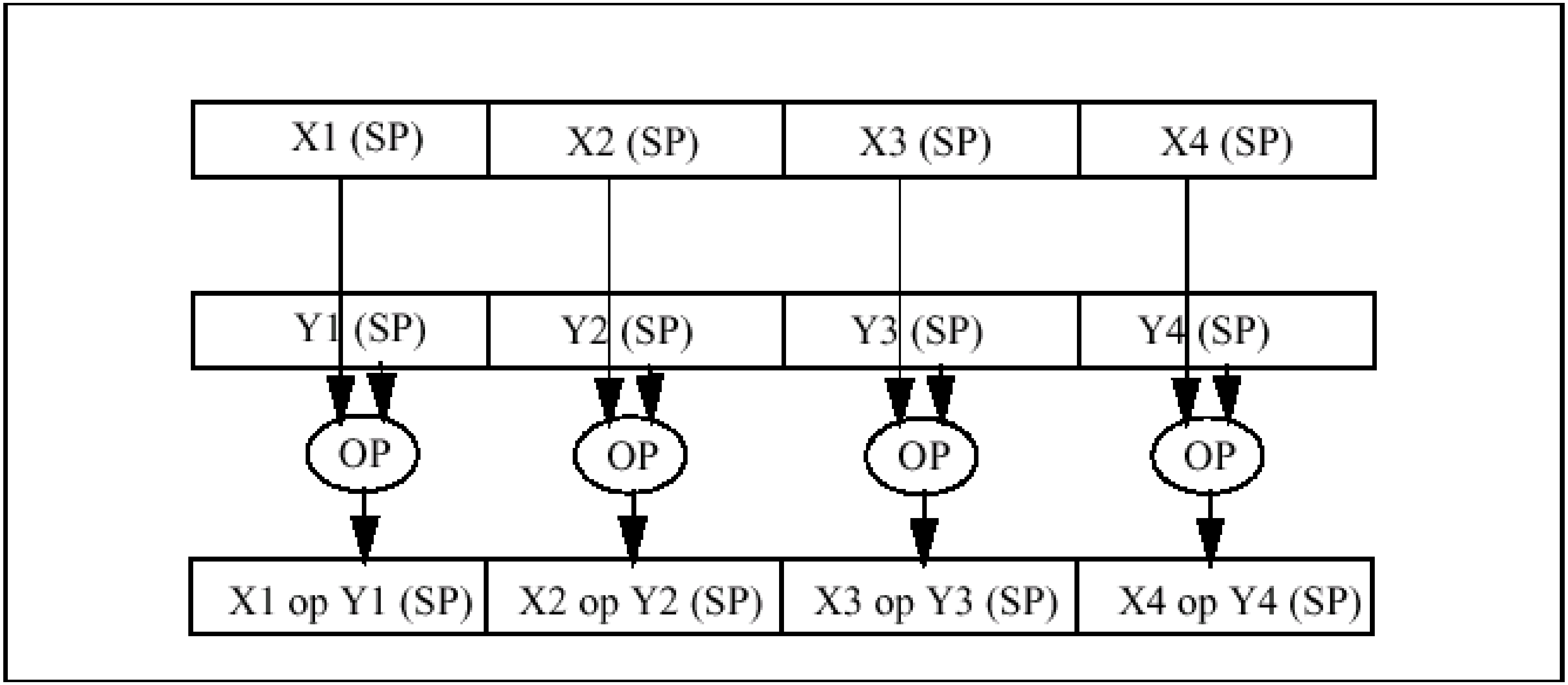
—	4 single precision FP values (SSE)	4 * 32b
—	2 double precision FP values (SSE2)	2 * 64b
—	16 byte values (SSE2)	16 * 8b
—	8 word values (SSE2)	8 * 16b
—	4 double word values (SSE2)	4 * 32b
—	1 128-bit integer value (SSE2)	1 * 128b



$0, $1, $2

	float A[3]	A[2]	A[1]	A[0]
	4.0 (32 bits)	4.0 (32 bits)	3.5 (32 bits)	-2.0 (32 bits)
	B[3]	B[2]	B[1]	B[0]
+	-1.5 (32 bits)	2.0 (32 bits)	1.7 (32 bits)	2.3 (32 bits)
	2.5 (32 bits)	6.0 (32 bits)	5.2 (32 bits)	0.3 (32 bits)
	C[3]	C[2]	C[1]	C[0]

SIMD Extensions



Packed Operations

More than 70 instructions. Arithmetic Operations supported: Addition, Subtraction, Mult, Division, Square Root, Maximum, Minimum. Can operate on Floating point or Integer data.

Clicker Question

To exploit parallelism in my code, could I put 8 characters and 2 integers into an XMM register?

128-bit

a) Yes

b) No

x86: word = 16 bits

Annotated SSE code for summing an array

%eax = A
%ebx = B
%ecx = C
%edx = i

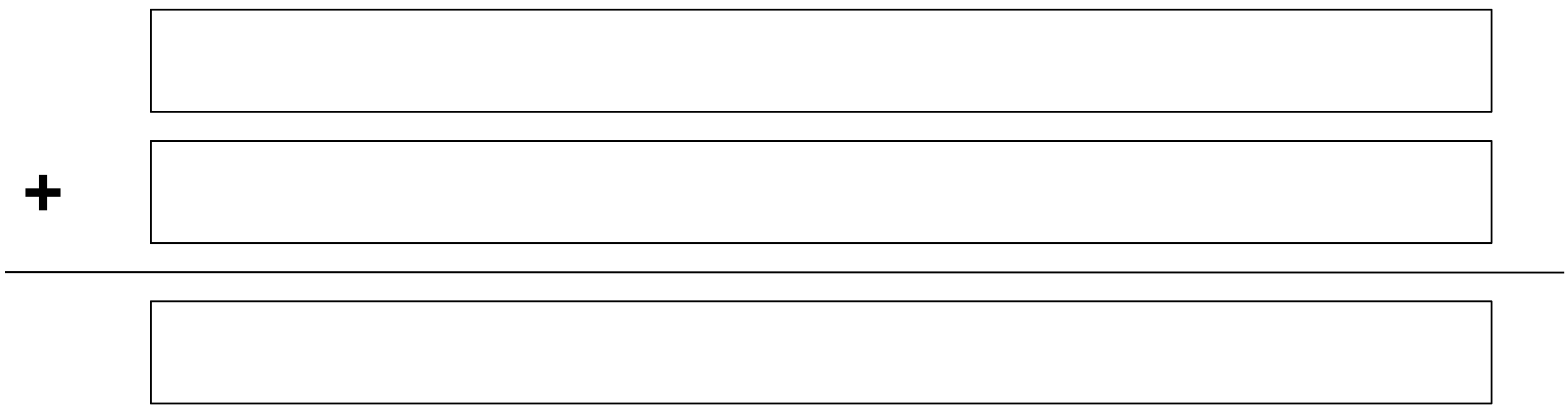
mov = data movement
dq = double-quad (128b)
a = aligned

A + 4*i

lw

```
movdqa    (%eax,%edx,4), %xmm0    # load A[i] to A[i+3]
movdqa    (%ebx,%edx,4), %xmm1    # load B[i] to B[i+3]
paddd     %xmm0, %xmm1            # CCCC = AAAA + BBBB
movdqa    %xmm1, (%ecx,%edx,4)    # store C[i] to C[i+3]
addl      $4, %edx                # i += 4
(loop control code)
```

p = packed
add = add
d = double (i.e., 32-bit integer) **why?**



Is it always that easy?

- No. Not always. Let's look at a little more challenging one.

```
unsigned
sum_array(unsigned *array, int length) {
  int total = 0;
  for (int i = 0 ; i < length ; ++ i) {
      total += array[i];
  }
  return total;
}
```

total = total

red total

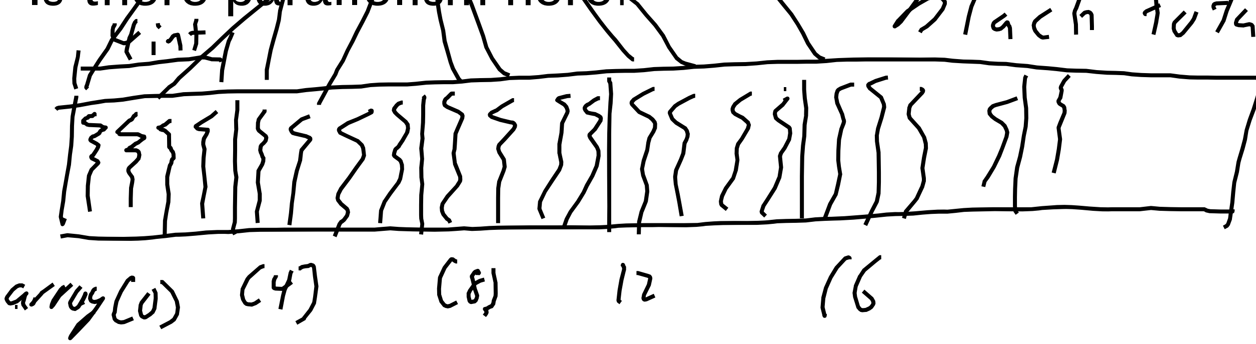
blue total

green total

black total

+ ->total

- Is there parallelism here?



Exposing the parallelism

```
unsigned
sum_array(unsigned *array, int length) {
  int total = 0;




  for (int i = 0 ; i < length ; ++ i) {
      total += array[i];
  }




  return total;
}
```

We first need to restructure the code

```
unsigned
sum_array2(unsigned *array, int length) {
  unsigned total, i;
  unsigned temp[4] = {0, 0, 0, 0};
  for (i = 0 ; i < length & ~0x3 ; i += 4) {
    temp[0] += array[i];
    temp[1] += array[i+1];
    temp[2] += array[i+2];
    temp[3] += array[i+3];
  }
  total = temp[0] + temp[1] + temp[2] + temp[3];
  for ( ; i < length ; ++ i) {
    total += array[i];
  }
  return total;
}
```

SIMD

Then we can write SIMD code for the hot part

```
unsigned
sum_array2(unsigned *array, int length) {
  unsigned total, i;
  unsigned temp[4] = {0, 0, 0, 0};
  for (i = 0 ; i < length & ~0x3 ; i += 4) {
    temp[0] += array[i];
    temp[1] += array[i+1];
    temp[2] += array[i+2];
    temp[3] += array[i+3];
  }
  total = temp[0] + temp[1] + temp[2] + temp[3];
  for ( ; i < length ; ++ i) {
    total += array[i];
  }
  return total;
}
```

Summary

- Performance is of primary concern in some applications
  — Games, servers, mobile devices, super computers

- Many important applications have parallelism
  — Exploiting it is a good way to speed up programs.

- Single Instruction Multiple Data (SIMD) does this at ISA level
  — Registers hold multiple data items, instruction operate on them
  — Can achieve factor or 2, 4, 8 speedups on kernels
  — May require some restructuring of code to expose parallelism
    - Create temporary vectors, which are then reduced
    - Deal with remainder of array (if not evenly divisible)