Parallel Computing & Accelerators

John Urbanic
Pittsburgh Supercomputing Center
Parallel Computing Scientist
This is the 50,000 ft. view of the parallel computing landscape. We want to orient you a bit before parachuting you down into the trenches to deal with OpenACC. The plan is that you walk away with a knowledge of not just OpenACC, but also where it fits into the world of High Performance Computing.
FLOPS we need: Climate change analysis

<table>
<thead>
<tr>
<th>Simulations</th>
<th>Extreme data</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Cloud resolution, quantifying uncertainty, understanding tipping points, etc., will drive climate to exascale platforms</td>
<td>• “Reanalysis” projects need 100× more computing to analyze observations</td>
</tr>
<tr>
<td>• New math, models, and systems support will be needed</td>
<td>• Machine learning and other analytics are needed today for petabyte data sets</td>
</tr>
<tr>
<td></td>
<td>• Combined simulation/observation will empower policy makers and scientists</td>
</tr>
</tbody>
</table>

Courtesy Horst Simon, LBNL
Exascale combustion simulations

- **Goal:** 50% improvement in engine efficiency
- **Center for Exascale Simulation of Combustion in Turbulence (ExaCT)**
  - Combines M&S and experimentation
  - Uses new algorithms, programming models, and computer science

*Courtesy Horst Simon, LBNL*
Recent simulations achieve unprecedented scale of $65 \times 10^9$ neurons and $16 \times 10^{12}$ synapses.
Moore's Law abandoned serial programming around 2004

Courtesy Liberty Computer Architecture Research Group
Moore’s Law is not dead yet. Maybe.

### Intel process technology capabilities

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Feature Size</td>
<td>90nm</td>
<td>65nm</td>
<td>45nm</td>
<td>32nm</td>
<td>22nm</td>
<td>16nm</td>
<td>14nm</td>
<td>10nm</td>
<td>7nm</td>
</tr>
<tr>
<td>Integration Capacity</td>
<td>2</td>
<td>4</td>
<td>8</td>
<td>16</td>
<td>32</td>
<td>64</td>
<td>128</td>
<td>256</td>
<td>...</td>
</tr>
</tbody>
</table>

- Transistor for 90nm Process: 50nm
- Influenza Virus: 100nm

Source: Intel [234x94] Transistor for 90nm Process (Source: Intel)

Source: CDC [574x74] Influenza Virus (Source: CDC)
At end of day, we keep using all those new transistors.

Moore's Law – The number of transistors on integrated circuit chips (1971-2016)

Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important as other aspects of technological progress – such as processing speed or the price of electronic products – are strongly linked to Moore's law.
That Power and Clock Inflection Point in 2004…
didn’t get better.

Fun fact: At 100+ Watts and <1V, currents are beginning to exceed 100A at the point of load!
Not a new problem, just a new scale...

Cray-2 with cooling tower in foreground, circa 1985
And how to get more performance from more transistors with the same power.

A 15% Reduction In Voltage Yields

**RULE OF THUMB**

<table>
<thead>
<tr>
<th>Frequency Reduction</th>
<th>Power Reduction</th>
<th>Performance Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>15%</td>
<td>45%</td>
<td>10%</td>
</tr>
</tbody>
</table>

**SINGLE CORE**

Area = 1  
Voltage = 1  
Freq = 1  
Power = 1  
Perf = 1

**DUAL CORE**

Area = 2  
Voltage = 0.85  
Freq = 0.85  
Power = 1  
Perf = ~1.8
Parallel Computing

One woman can make a baby in 9 months.

Can 9 women make a baby in 1 month?

But 9 women can make 9 babies in 9 months.

First two bullets are Brook’s Law. From *The Mythical Man-Month.*
Prototypical Application: Serial Weather Model
First Parallel Weather Modeling Algorithm: Richardson in 1917

Courtesy John Burkhardt, Virginia Tech
Weather Model: Shared Memory (OpenMP)

Four meteorologists in the same room sharing the map.

Fortran:

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

C/C++:

```c
#pragma omp parallel for
for(i=1; i<=n; i++)
    a[i] = b[i] + c[i];
```
call MPI_Send( numbertosend, 1, MPI_INTEGER, index, 10, MPI_COMM_WORLD, errcode)
.
.
call MPI_Recv( numbertoreceive, 1, MPI_INTEGER, 0, 10, MPI_COMM_WORLD, status, errcode)
.
.
call MPI_Barrier(MPI_COMM_WORLD, errcode)
.
50 meteorologists using a telegraph.
1 meteorologists coordinating 1000 math savants using tin cans and a string.

```c
#pragma acc kernels
for (i=0; i<N; i++)  {
    double t = (double)((i+0.05)/N);
    pi += 4.0/(1.0+t*t);
}

__global__ void saxpy_kernel( float a, float* x, float* y, int n ){
    int i;
    i = blockIdx.x*blockDim.x + threadIdx.x;
    if( i <= n ) x[i] = a*x[i] + y[i];
}
```
The pieces fit like this…

- OpenMP
- OpenACC
- MPI
<table>
<thead>
<tr>
<th>#</th>
<th>Site</th>
<th>Manufacturer</th>
<th>Computer</th>
<th>CPU Interconnect [Accelerator]</th>
<th>Cores</th>
<th>Rmax [Tflops]</th>
<th>Rpeak [Tflops]</th>
<th>Power (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>RIKEN Center for Computational Science Japan</td>
<td>Fujitsu</td>
<td>Fugaku</td>
<td>ARM 8.2A+ 48C 2.2GHz Torus Fusion Interconnect</td>
<td>7,299,072</td>
<td>415,530</td>
<td>513,854</td>
<td>28.3</td>
</tr>
<tr>
<td>2</td>
<td>DOE/SC/ORNL United States</td>
<td>IBM</td>
<td>Summit</td>
<td>Power9 22C 3.0 GHz Dual-rail Infiniband EDR NVIDIA V100</td>
<td>2,414,592</td>
<td>148,600</td>
<td>200,794</td>
<td>10.1</td>
</tr>
<tr>
<td>3</td>
<td>DOE/NNSA/LLNL United States</td>
<td>IBM</td>
<td>Sierra</td>
<td>Power9 3.1 GHz 22C Infiniband EDR NVIDIA V100</td>
<td>1,572,480</td>
<td>94,640</td>
<td>125,712</td>
<td>7.4</td>
</tr>
<tr>
<td>4</td>
<td>National Super Computer Center in Wuxi China</td>
<td>NRCPC</td>
<td>Sunway TaihuLight</td>
<td>Sunway SW26010 260C 1.45GHz</td>
<td>10,649,600</td>
<td>93,014</td>
<td>125,435</td>
<td>15.3</td>
</tr>
<tr>
<td>5</td>
<td>National Super Computer Center in Guangzhou China</td>
<td>NUDT</td>
<td>Tianhe-2 (MilkyWay-2)</td>
<td>Intel Xeon E5-2692 2.2 GHz TH Express-2 Intel Xeon Phi 31S1P</td>
<td>4,981,760</td>
<td>61,444</td>
<td>100,678</td>
<td>18.4</td>
</tr>
<tr>
<td>6</td>
<td>Eni S.p.A Italy</td>
<td>Dell</td>
<td>HPC5</td>
<td>Xeon 24C 2.1 GHz Infiniband HDR NVIDIA V100</td>
<td>669,760</td>
<td>35,450</td>
<td>51,720</td>
<td>2.2</td>
</tr>
<tr>
<td>7</td>
<td>Eni S.p.A Italy</td>
<td>NVIDIA</td>
<td>Selene</td>
<td>EPYC 64C 2.25GHz Infiniband HDR NVIDIA A100</td>
<td>272,800</td>
<td>27,580</td>
<td>34,568</td>
<td>1.3</td>
</tr>
<tr>
<td>8</td>
<td>Texas Advanced Computing Center/Univ. of Texas United States</td>
<td>Dell</td>
<td>Frontera</td>
<td>Intel Xeon 8280 28C 2.7 GHz InfiniBand HDR</td>
<td>448,448</td>
<td>23,516</td>
<td>38,745</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Cineca Italy</td>
<td>IBM</td>
<td>Marconi100</td>
<td>Power9 16C 3.0 GHz Infiniband EDR NVIDIA V100</td>
<td>347,776</td>
<td>21,640</td>
<td>29,354</td>
<td>1.5</td>
</tr>
<tr>
<td>10</td>
<td>Swiss National Supercomputing Centre (CSCS) Switzerland</td>
<td>Cray</td>
<td>Piz Daint Cray XC50</td>
<td>Xeon E5-2690 2.6 GHz Aries NVIDIA P100</td>
<td>387,872</td>
<td>21,230</td>
<td>27,154</td>
<td>2.4</td>
</tr>
</tbody>
</table>
We can do better. We have a role model.

- Straight forward extrapolation results in a real time human brain scale simulation at about 1 - 10 Exaflop/s with 4 PB of memory
- Current plans envision Exascale computers in 2021 with a power consumption of at best 20 - 30 MW
- The human brain takes 20W
- Even under best assumptions our brain will still be a million times more power efficient

Courtesy Horst Simon, LBNL
Why you should be (extra) motivated.

- This parallel computing thing is no fad.
- The laws of physics are drawing this roadmap.
- If you get on board (the right bus), you can ride this trend for a long, exciting trip.

Let’s learn how to use these things!