Parallel Computing & Accelerators

John Urbanic
Pittsburgh Supercomputing Center
Parallel Computing Scientist
Purpose of this talk

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**

- Cloud resolution, quantifying uncertainty, understanding tipping points, etc., will drive climate to exascale platforms
- New math, models, and systems support will be needed

*Extreme data*

- "Reanalysis" projects need 100× more computing to analyze observations
- Machine learning and other analytics are needed today for petabyte data sets
- Combined simulation/observation will empower policy makers and scientists

*Courtesy Horst Simon, LBNL*
Qualitative Improvement of Simulation with Higher Resolution (2011)
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.
Waiting for Moore’s Law to save your serial code start getting bleak in 2004

Source: published SPECInt data
Moore’s Law is not at all dead…

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>
</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>11nm</td>
<td>8nm</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>
</tr>
<tr>
<td>(Billions of Transistors)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Transistor for 90nm Process
Source: Intel

Influenza Virus
Source: CDC
That Power and Clock Inflection Point in 2004... didn’t get better.

Source: Kogge and Shalf, IEEE CISE

Courtesy Horst Simon, LBNL
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.

### 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>

A 15% Reduction In Voltage Yields

---

**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

A 15\% Reduction In Voltage Yields

**RULE OF THUMB**

- Frequency Reduction
- Power Reduction
- Performance Reduction
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
Four meterologists in the same room sharing the map.
Weather Model: Distributed Memory (MPI)

50 meterologists using telegraphs.
Weather Model: Accelerator (OpenACC)

1 meterologist coordinating 1000 savants using tin cans and a string.
The pieces fit like this…
<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>National Super Computer Center in Guangzhou China</td>
<td>NRCPC</td>
<td>Sunway TaihuLight</td>
<td>Sunway SW26010 260C 1.45GHz</td>
<td>10,649,600</td>
<td>320,049</td>
<td>425,455</td>
<td>15.3</td>
</tr>
<tr>
<td>2</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>3,120,000</td>
<td>33,862</td>
<td>54,902</td>
<td>17.8</td>
</tr>
<tr>
<td>3</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>361,760</td>
<td>19,590</td>
<td>25,326</td>
<td>2.2</td>
</tr>
<tr>
<td>4</td>
<td>Japan Agency for Marine-Earth Science Japan</td>
<td>ExaScaler</td>
<td>Gyoukou</td>
<td>Xeon D-1571 1.3GHz Infiniband EDR</td>
<td>19,860,000</td>
<td>19,135</td>
<td>28,192</td>
<td>1.3</td>
</tr>
<tr>
<td>5</td>
<td>DOE/SC/Oak Ridge National Laboratory United States</td>
<td>Cray</td>
<td>Titan Cray XK7</td>
<td>Opteron 6274 2.2 GHz Gemini NVIDIA K20x</td>
<td>560,640</td>
<td>17,590</td>
<td>27,112</td>
<td>8.2</td>
</tr>
<tr>
<td>6</td>
<td>DOE/NNSA/LLNL United States</td>
<td>IBM</td>
<td>Sequoia BlueGene/Q</td>
<td>Power BQC 1.6 GHz Custom</td>
<td>1,572,864</td>
<td>17,173</td>
<td>20,132</td>
<td>7.8</td>
</tr>
<tr>
<td>7</td>
<td>DOE/NNSA/LANL/SNL United States</td>
<td>Cray</td>
<td>Trinity Cray XC40</td>
<td>Xeon E5-2698v3 2.3 GHz Aries Intel Xeon Phi 7250</td>
<td>979,968</td>
<td>17,173</td>
<td>20,132</td>
<td>7.8</td>
</tr>
<tr>
<td>8</td>
<td>DOE/SC/LBNL/NERSC United States</td>
<td>Cray</td>
<td>Cori Cray XC40</td>
<td>Aries Intel Xeon Phi 7250</td>
<td>622,336</td>
<td>14,014</td>
<td>27,880</td>
<td>3.9</td>
</tr>
<tr>
<td>9</td>
<td>Joint Center for Advanced High Performance Computing Japan</td>
<td>Fujitsu</td>
<td>Oakforest Primeergy</td>
<td>Intel OPA Intel Xeon Phi 7250</td>
<td>556,104</td>
<td>13,554</td>
<td>24,913</td>
<td>2.7</td>
</tr>
<tr>
<td>10</td>
<td>RIKEN Advanced Institute for Computational Science (AICS) Japan</td>
<td>Fujitsu</td>
<td>K Computer</td>
<td>SPARC64 VIIIfx 2.0 GHz Tofu</td>
<td>705,024</td>
<td>10,510</td>
<td>11,280</td>
<td>12.6</td>
</tr>
</tbody>
</table>
We can do better. We have a role model.

- Straightforward extrapolation results in a real-time human brain scale simulation at about 1 - 10 Exaflop/s with 4 PB of memory.
- Current predictions envision Exascale computers in 2020 with a power consumption of at best 20 - 30 MW.
- The human brain takes 20W.
- Even under best assumptions in 2020 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!