EXAPHOBIA

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Fear and Loathing in 21\textsuperscript{st} Century HPC

- Disagreement about need for revolution
  - Either – it won’t work without new paradigm, i.e. change everything
  - Or – you guys said that about Pflops; how’s that working out for you?
- Vendors:
  - Don’t worry your silly little head about this, its under control, or
  - Users tell us what you want, as long as its commodity
- Application programmers:
  - We hate what we have, but
  - Don’t change anything, cuz we got legacy
- Mission critical Agencies:
  - (1) We know we need long term research, but
  - (2) Since we didn’t do that before, we can only fund short term work to catch up
  - (3) Repeat step 1
Quantifying Challenges

- **Time to Completion**
  - Strong scaling
  - Seconds

- **Parallelism**
  - Addresses Starvation
  - Machine & software
  - Granularity, average, variance, …

- **Latency**
  - Average distances for access and services (cycles, nanoseconds)

- **Overhead**
  - Extra critical-path work for managing concurrency (cycles, nanoseconds)

- **(Waiting for) Contention**
  - Waiting time in a queue for service request

- **Energy**
  - Joules
  - Ops, data movement, memory access

- **MTTI**
  - Seconds, mean/variance

- **Programmability**
  - I feel your pain
Parallel Programmability (Dt)

- **Performance Efficiency**
  - \( 0.0 \)
  - \( 1.0 \)

- **Max Achievable Parallel Efficiency (MAPE)**
  - \( \text{(MAPE – SPE)} \)

- **SPE + 0.1 \times (MAPE – SPE)**

- **SPE + 0.9 \times (MAPE – SPE)**

- **0.8 \times (MAPE – SPE)**

**Sequential Parallel Efficiency (SPE)**

**Time to Program**

\[ \text{Dt} \]
The only thing we have to change is change itself

- **Architecture**
  - Microprocessor cores
  - Memory hierarchy
- **Programming models**
  - Languages
  - Legacy codes
- **Operating systems**
  - Manage massive resources
  - Lightweight runtime systems

Figure courtesy of Kunle Olukotun, Lance Hammond, Herb Sutter, and Burton Smith
Changing Change

- Phase I: Sequential instruction execution
  - pipeline execution,
  - reservation stations,
  - ILP
- Phase II: Sequential instruction issue
  - pipeline execution,
  - reservation stations,
  - ILP
- Phase III: Vector
  - pipelined arithmetic, registers, memory access
  - Cray
- Phase IV: SIMD
  - MasPar, CM-2
- Phase V: Communicating Sequential Processes
  - MPP, clusters
  - MPI
Co-Design

- **Objective**
  - Optimal system design and operation
  - Modulated by workload characteristics

- **Challenge**
  - Division of roles and responsibilities across system layers
  - Efficiency
    - Minimize overhead, starvation, and latency effects
    - User productivity
    - Energy, reliability

- **Methodology**
  - Each system layer tuned with respect to needs of the others
  - Execution model as operational and design paradigm
    - for governing principles of operation
    - Interoperability among layers
    - Reduction of design complexity
The Execution Model Imperative

- HPC in 6th Phase Change
  - Driven by technology opportunities and challenges
  - Historically, catalyzed by paradigm shift
- Guiding principles for governing system design and operation
  - Semantics, Mechanisms, Policies, Parameters, Metrics
- Enables holistic reasoning about concepts and tradeoffs
  - Serves for Exascale the role of von Neumann architecture for sequential
- Essential for co-design of all system layers
  - Architecture, runtime and operating system, programming models
  - Reduces design complexity from O(N^2) to O(N)
- Empowers discrimination, commonality, portability
  - Establishes a phylum of UHPC class systems
- Decision chain
  - For reasoning towards optimization of design and operation
Decision Chain

• Axiom: an operation is performed at a certain place at a certain time to achieve a specified effect
• How did this happen?
• Every layer of the system contributed to the time/function event – the decision chain
• A program execution comprises the ensemble of such events across the system space and throughout the execution epoch
• There are many such paths that lead to a final result
• But not all minimize time and energy
• Understanding of the decision chain required for optimization
• Execution model required for understanding the decision chain
Conclusions – A Convergence?

• Global Address Space
  – PGAS
  – AGAS

• User multithreaded
  – Lightweight
  – Dynamic scheduling
  – Complexes
  – Codelets

• Message-driven
  – Active messages
  – Parcels

• Diversity of lightweight synchronization
  – Local control objects

• Runtime Software as key stack component
  – Support dynamic resource & task management
Panel Background

Is there a fear of Exascale? There is concern about faults, scaling, performance (latency), complex processing model (e.g., heterogeneous elements), cost (power, memory, $), impact on algorithms, narrowness of application domain, data handling for Exabyte data sets. In addition, does Exascale imply a discontinuity in programming, algorithms, debugging, etc.?
Panel Questions

• How can we overcome the fear?
  – Which fears are mistaken (after all, many were convinced that petascale systems would be impossible without new programming models)?
  – Conversely, which problems apply at a smaller scale, and hence can be addressed now and provide near-term benefits?
  – Which problems are (nearly) unique to Exascale? How do we build/test/improve algorithms, software, and applications? For example, do we need to build a much more sophisticated simulation environment?

• How can we build real excitement?
  – How do we provide evidence that Exascale systems will work well with applications?
  – How do we demonstrate that Exascale systems can enable new application areas (after all, Exascale systems may be greatly different in architecture - will that be a virtue)?

• In all of the above, how do we move past qualitative statements to quantitative predictions?