Invited Presentation to:
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EXAPHOBIA

Thomas Sterling

Arnaud & Edwards Professor, Department of Computer Science

Adjunct Faculty, Department of Electrical and Computer Engineering

Louisiana State University

Distinguished Visiting Scientist, Oak Ridge National Laboratory

CSRI Fellow, Sandia National Laboratories

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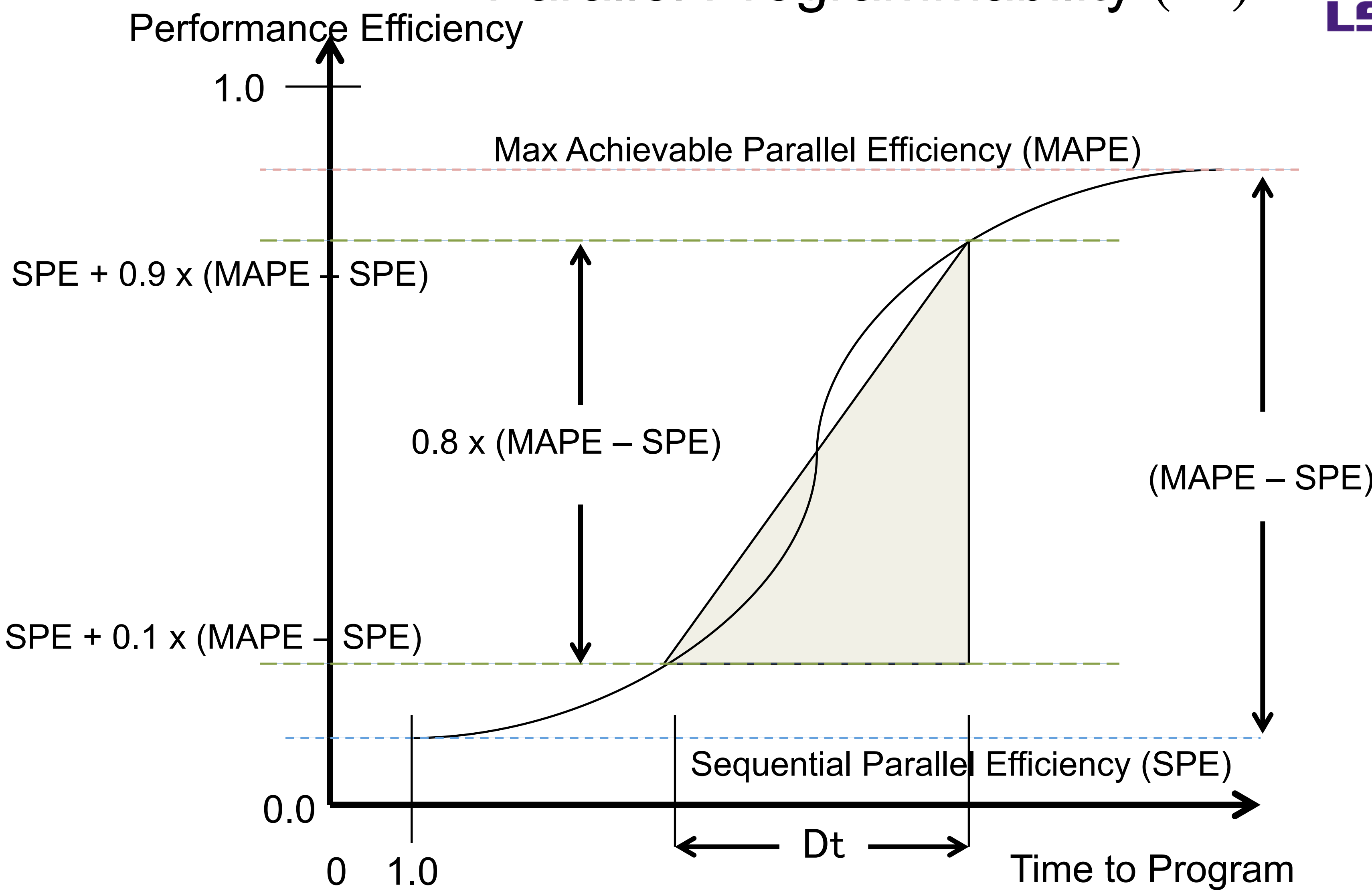
Fear and Loathing in 21st Century HPC

- 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)



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

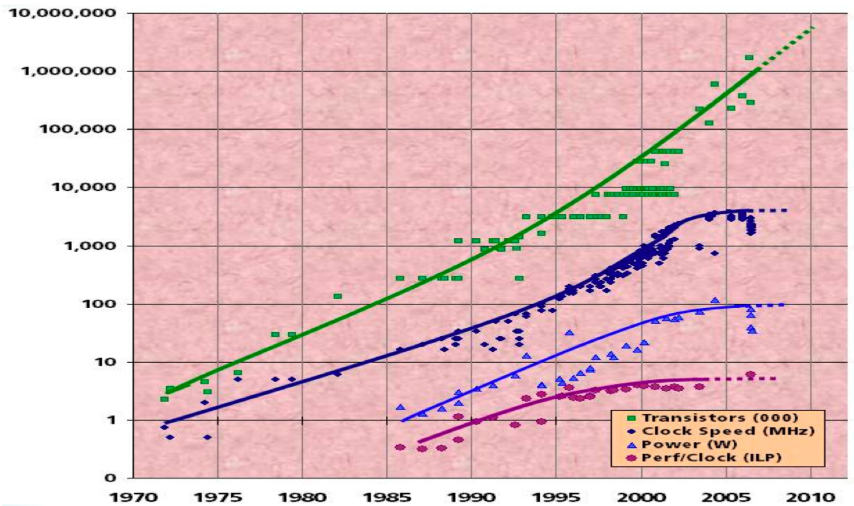


Figure courtesy of Kunle Olukotun, Lance Hammond, Herb Sutter, and Burton Smith

Changing Change

- Phase I: Sequential instruction execution

- 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(N2) 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 tim /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 virture)?
- In all of the above, how do we move past qualitative statements to quantitative predictions?