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Multiobjective Optimization of Power, Energy, Performance, and Resilience

Prasanna Balaprakash, Paul Hovland (lead), Stefan Wild
Argonne National Laboratory
Ray Chen, Jeff Hollingsworth
University of Maryland
Ananta Tiwari
San Diego Supercomputer Center

Multiobjective Optimization

- The problem of empirically optimizing a code can be posed as the mathematical optimization problem
- Increasingly, multiple metrics are of interest simultaneously
- When the relative weights or constraints on these objectives are not known at search time, autotuning becomes a *multiobjective optimization problem:*

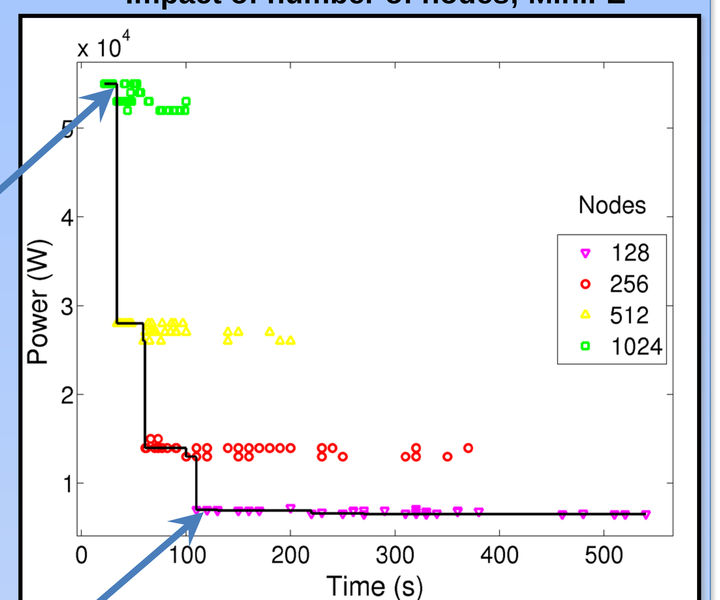
$$\min_{x \in \mathcal{X}} F(x) = [F_1(x), \ldots, F_p(x)]$$

THE OBJECTIVES $F_i(x)$
•$F_1(x),\ldots,F_p(x)$ are p **possibly conflicting objectives** that need to be optimized simultaneously
•Can capture average, median, quantile (e.g., worst-case) empirical performance
•Often stochastic/noisy (from measurement and/or run)
•Depends on machine and input size (or distribution over inputs)
•Assumes no *a priori* weights available for the objectives
•Examples: run time, power, energy, failure rate

THE DECISIONS x
•Integer (unroll factor, register tiling, +examples)
•"Continuous" (algorithmic parameters, internal tolerances)
•Each *x* generates a code variant (e.g., through source-to-source or compiler-based transformation)

THE CONSTRAINTS ($\mathcal{X}$)
•Ensuring feasibility of transformation
•Correctness of output, maximum temperature, etc.

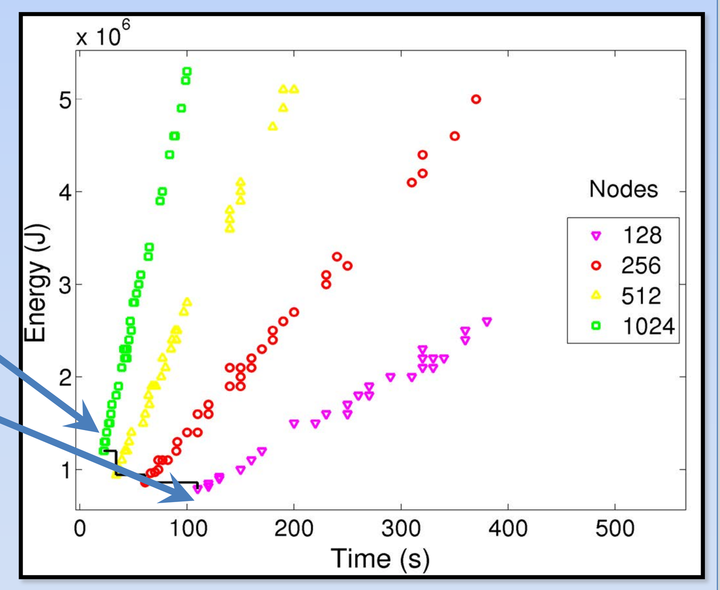
Blue Gene/Q:
Impact of number of nodes; MiniFE



Illustrative example on three objectives on IBM BG/Q

Minimizing run time is conflicting with **power consumption**

Minimizing energy consumption conflicts with **run time**



Multi objective optimization concerns the study of optimizing two or more objectives simultaneously.

Even if there is a unique optimal (software/hardware) decision when any of the objectives is considered in isolation, there may be an entire set of solutions when the objectives are considered collectively.

GOAL:

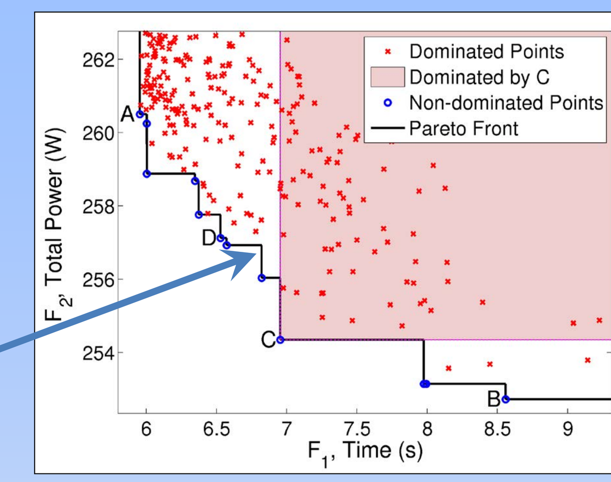
Develop multi objective optimization framework that allows exploration of the tradeoffs

Existence of these tradeoffs can motivate hardware designers to expose a richer and more appropriate set of knobs to future administrators and software designers

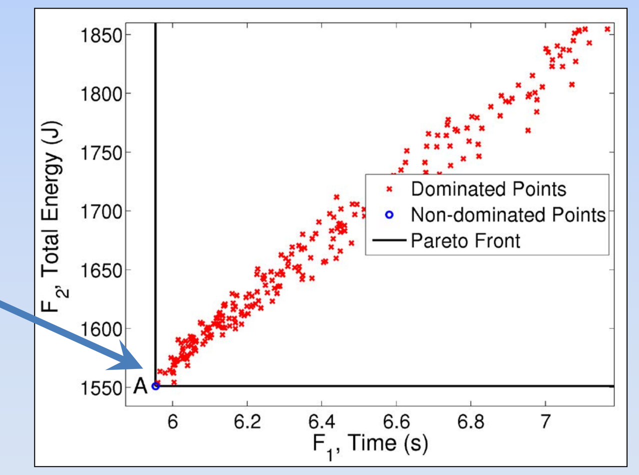
A framework that is sufficiently general and can be easily extended to incorporate new hardware-and software-based power/energy knobs as they become available

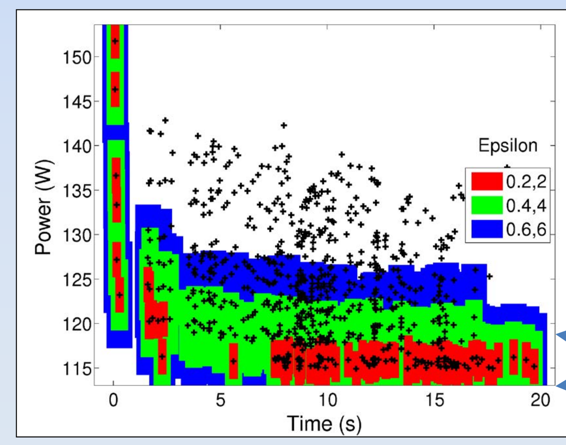
Pareto Optimality

Arises when several objectives need to be optimized simultaneously
➢ Code variants now live both in a decision space and in an objective space



- Pareto front contains significantly richer information than one obtains from single-objective formulations
- Code variants for which no other variant is better in all objectives are said to be ***nondominated* or *Pareto optimal***
- For search algorithms, only certain regions of the objective space are of interest
  - The ideal and nadir point define the range of objective that include all possible optimal tradeoffs
- When multiple objectives are **not competing** the Pareto front corresponds to a single point, which simultaneously minimizes both objectives





- For many time-power-energy multi-objective problems, there can be measurement error in each objective
  - Consequently, we have a **relaxed Pareto front** that potentially consists of a cloud of points

Conditions for Energy Time Tradeoff

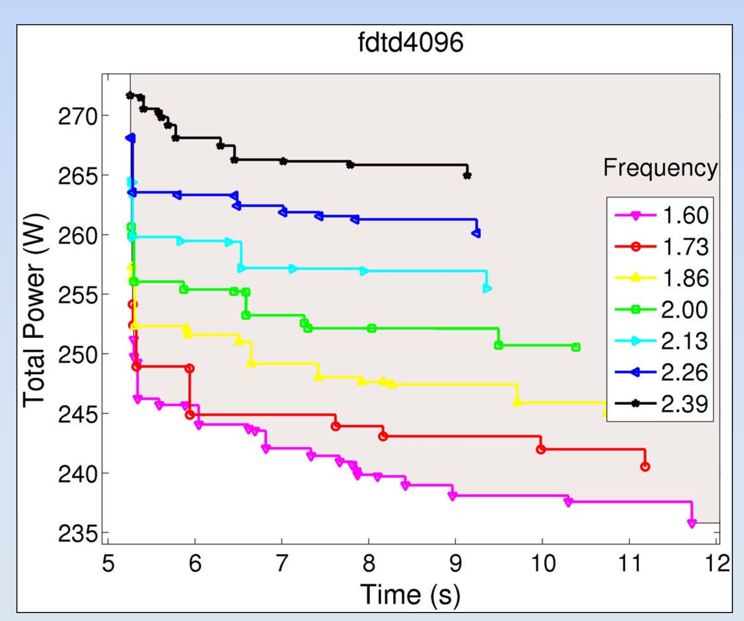
- Because of the relationship between power and energy, all points on the energy-time Pareto front have a corresponding point on the power-time Pareto front
- Number of non-dominated points for energy-time is bounded by the number of non-dominated points for power-time
- A necessary condition for *x* to be a non-dominated point on the energy-time Pareto front is

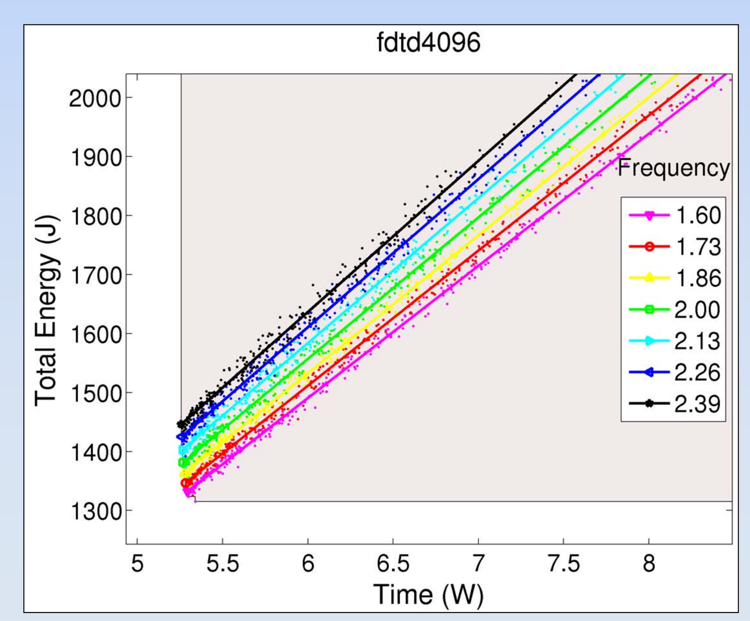
$$P(x) \le \frac{P(x^{(1)})T(x^{(1)})}{T(x)}$$

- To observe tradeoff, the power savings must outpace the product of idle power and relative slow-down:

$$P(x^{(1)}) - P(x) \ge \frac{T(x) - T(x^{(1)})}{T(x^{(1)})} P_I$$

Ex: Intel Xeon E5530: Impact of frequency scaling; SPAPT fdtd kernel



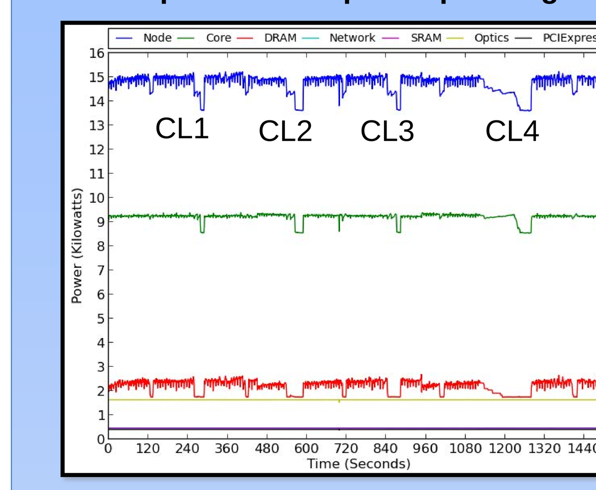


Tradeoff Studies

Ex: Blue Gene/Q: Energy-time tradeoff with multilevel FTI checkpoint library; CORAL benchmarks

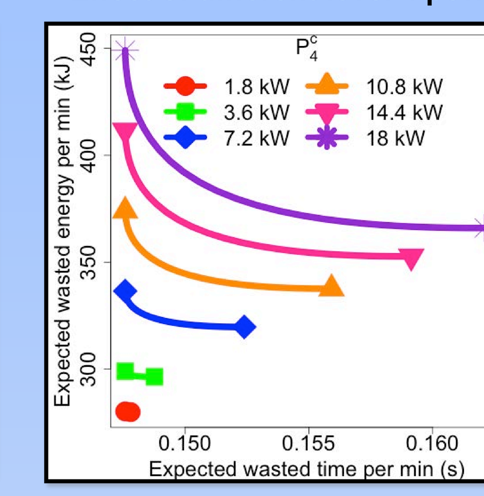
- Analytical models for expected run time and energy consumption for multilevel checkpointing
- Characterize the Pareto-optimal solution set and investigate the tradeoffs time and energy
- Power consumption measurements of large-scale executions on an IBM Blue Gene/Q with several applications
- Analyzed several system-level parameters for multilevel checkpointing that can potentially impact the tradeoffs

Component level power profiling



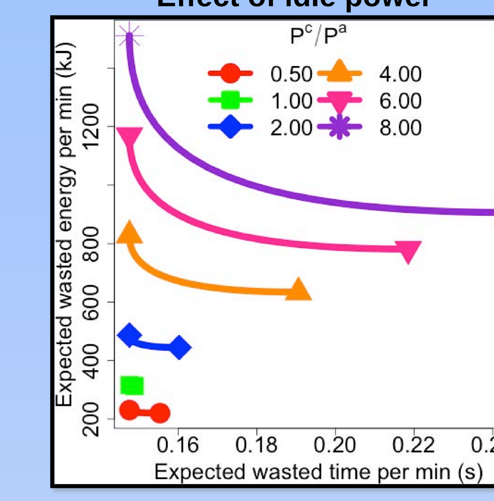
- CL 1: Local checkpoint
- CL 2: Local checkpoint + Partner-copy
- CL 3: Local checkpoint + RS coding
- CL 4: Parallel file system

Effect of different level 4 power



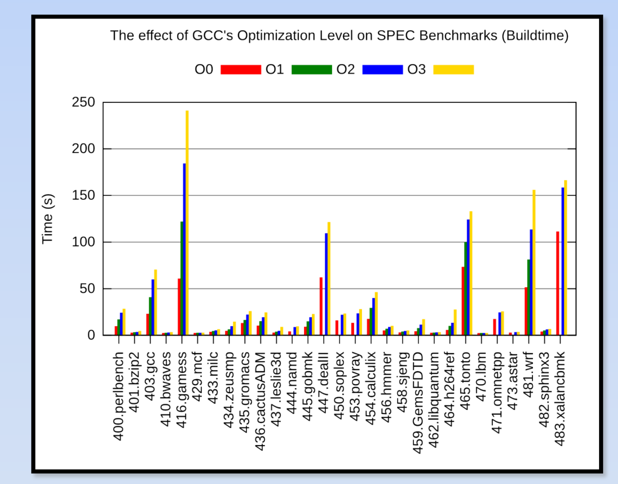
Increasing level 4 power relative to other levels has a significant impact on the observed tradeoff

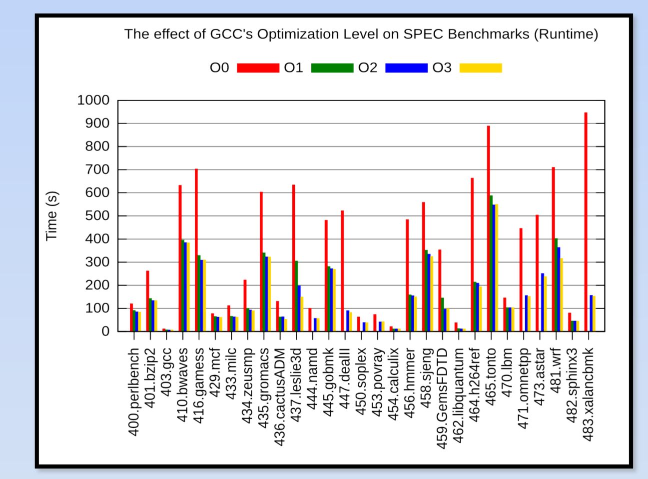
Effect of idle power

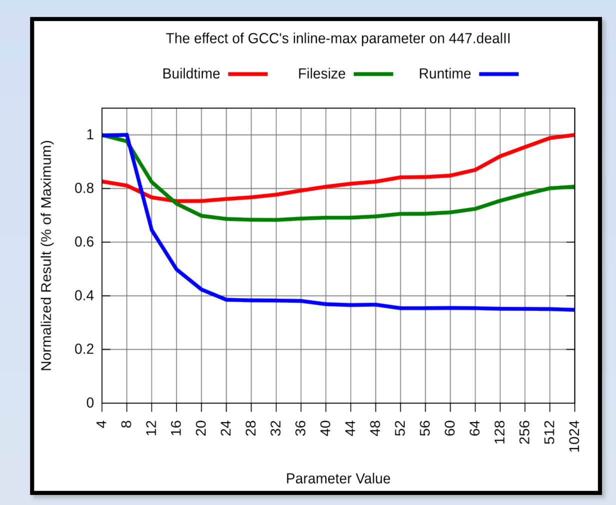


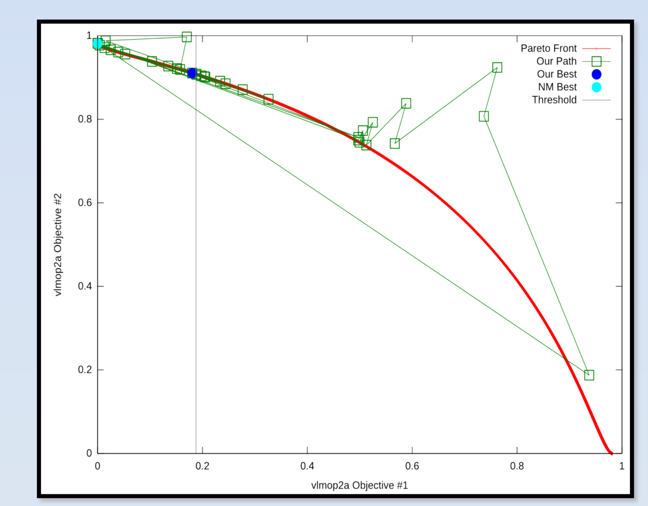
- Ratio of checkpoint and idle power
- Significant impact on the tradeoff

Ex: Three simultaneous objectives: Build time, file size, and execution time









Our studies show that in some settings objectives of interest can be strictly correlated and there is a single, "ideal" decision point; in others, significant tradeoffs exist.

Future Investigations

- Develop multi objective optimization algorithms for autotuning search
- Identify appropriate use cases
- Study other tradeoffs:
  - Resilience versus memory footprint;
  - Memory footprint versus execution time; Memory footprint versus energy

"Can search algorithms save large-scale automatic performance tuning?" Balaprakash, Wild, & Hovland, *iWAPT 2011*.
"Online adaptive code generation and tuning ." Tiwari & Hollingsworth, *IPDPS 2011*.
"Energy-Performance Tradeoffs in Multilevel Checkpoint Strategies." Balaprakash, Wild, & Hovland et al, Preprint ANL/MCS-P5138-0514, 2014.
"Multi-objective optimization of HPC kernels for performance, power, and energy" Balaprakash, Tiwari, & Wild, PMBS, 2013

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Argonne NATIONAL LABORATORY
UNIVERSITY OF MARYLAND
SDSC SAN DIEGO SUPERCOMPUTER CENTER
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