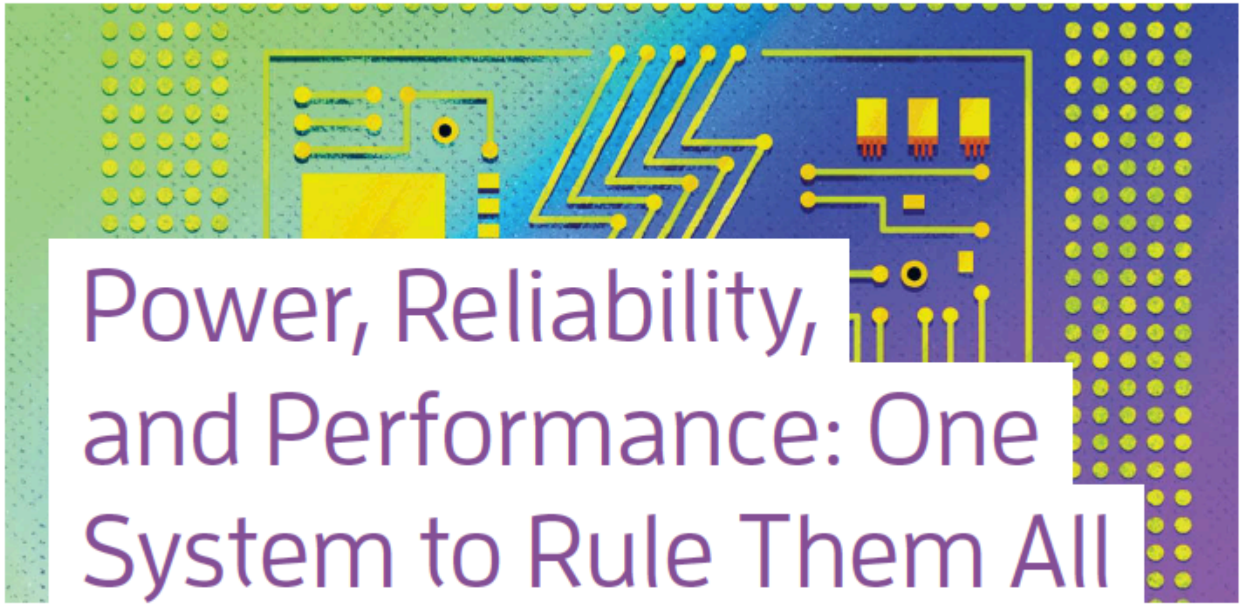
Charm++ as an Energy Efficient Runtime

COVER FEATURE **ENERGY-EFFICIENT COMPUTING**



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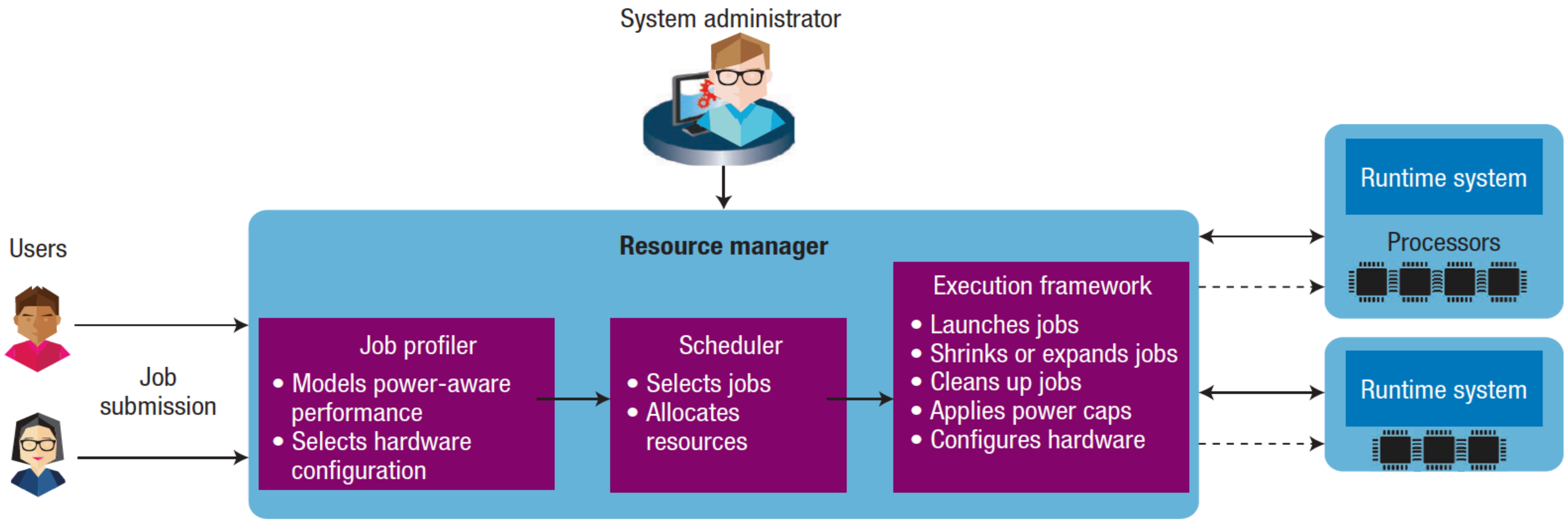
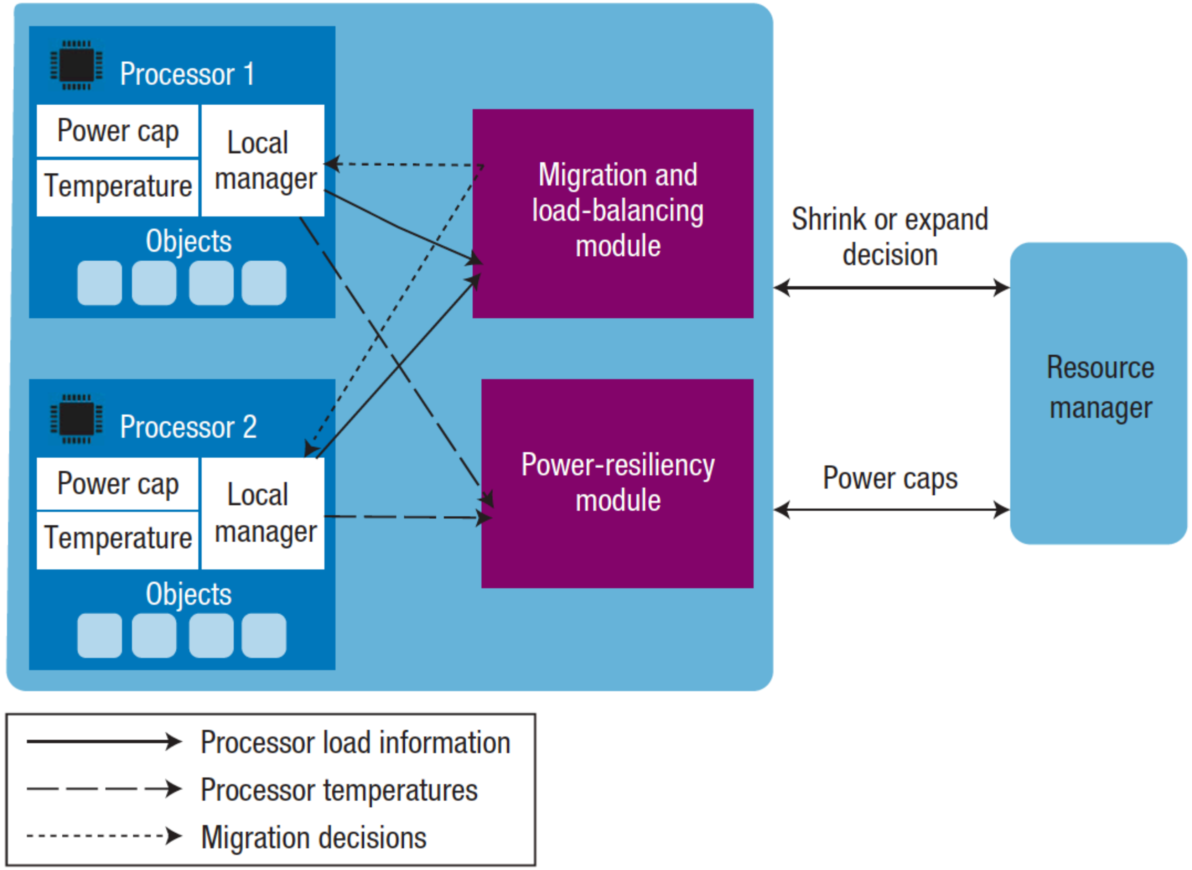
Interaction Between the Runtime System and the Resource Manager



- ✓ Allows dynamic interaction between the system resource manager or scheduler and the job runtime system
- ✓ Meets system-level constraints such as power caps and hardware configurations
- ✓ Achieves the objectives of both datacenter users and system administrators

Components of Charm++ with Its Interactions



Charm++ has three main components:

- **Local manager:** tracks local information such as object loads, CPU temperatures
- **Load-balancing module:** makes load-balancing decisions and redistributes load
- **Power-resiliency module:** ensures that the CPU temperatures remain below the temperature threshold, change the power cap

Support for Proactive Cooling Decisions with Neural Network-Based Temperature Prediction

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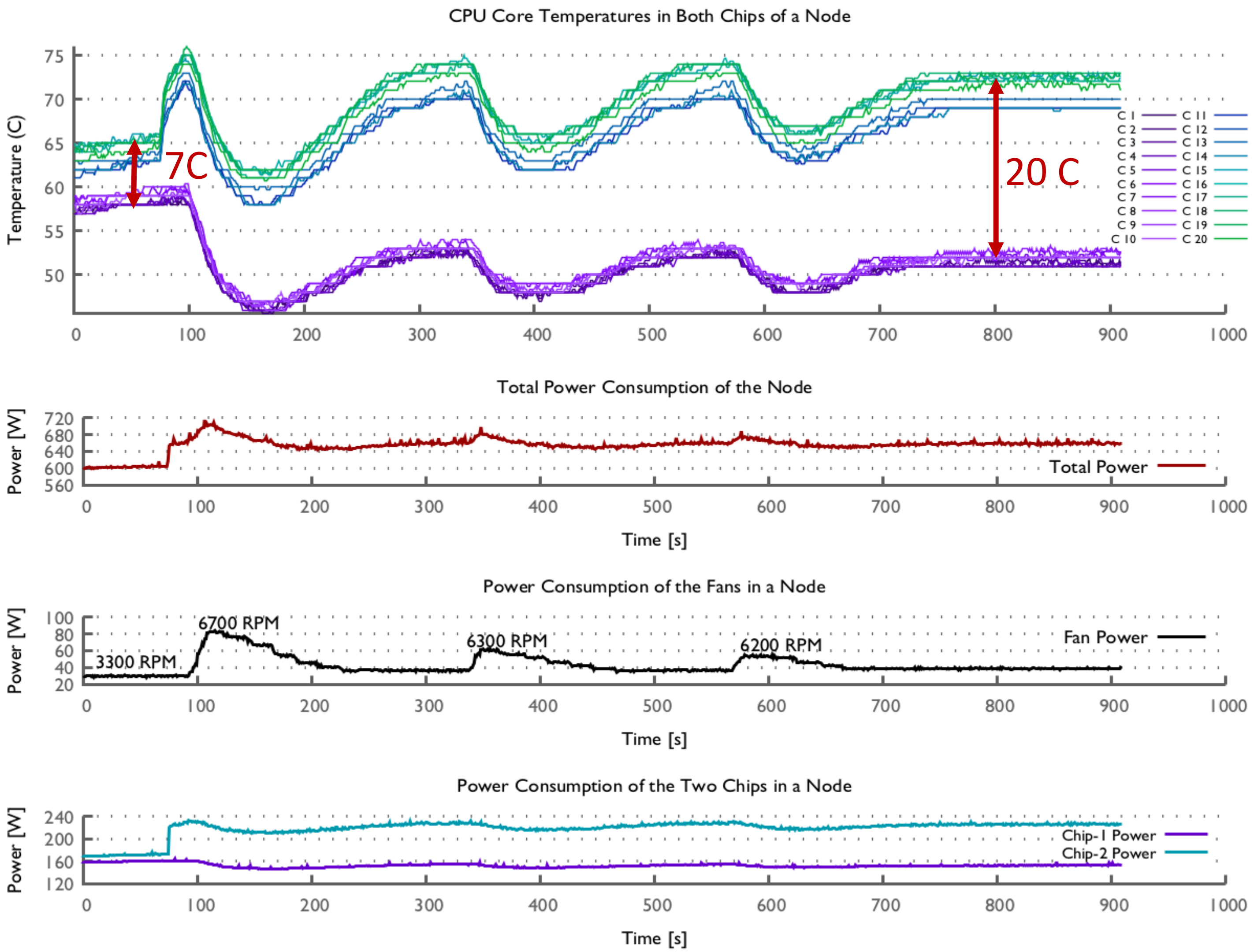
Motivation

1. Pressure of reducing the power consumption and carbon footprint of datacenters and supercomputers is increasing

2. Other expected problems include:
   - Larger process variations, temperature variations
   - More heat dissipation
   - Denser nodes with different components in the node such as GPUs, co-processors that have different temperature, cooling characteristics

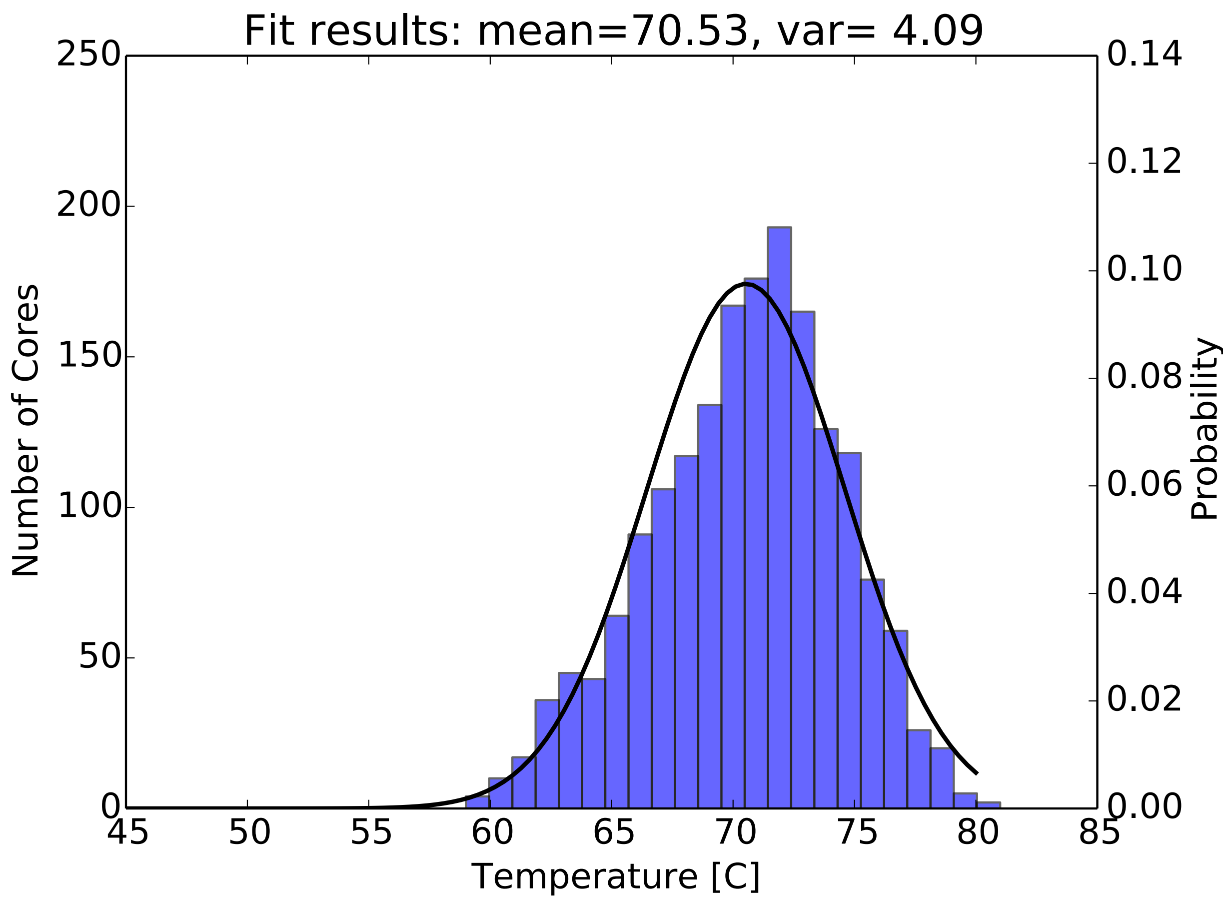
Motivation

- **Temperature variations among cores:**
  - 7 C in idle temperatures
  - 9 C in all active temperatures
  - 20 C idle/active mixed
- **Synchronous fan control:**
  - 4 independent fans in the node
  - Fans all act together and cause even further temperature variation
- **Reactive cooling behavior:**
  - 54 W jump in fan power
  - 10 minutes stabilization time with a regular workload

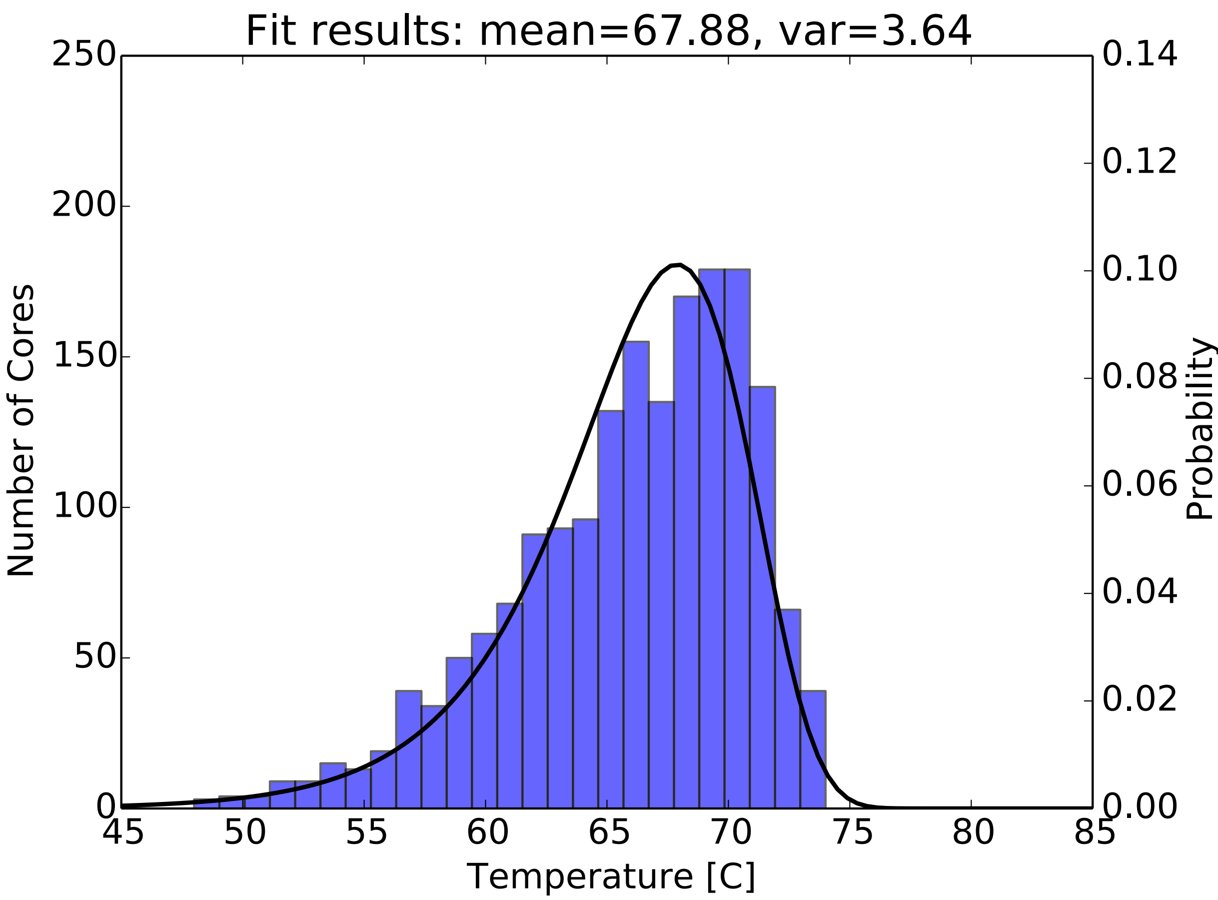


Temperature Variation in Large Scale

Temperature distribution of 1800 cores



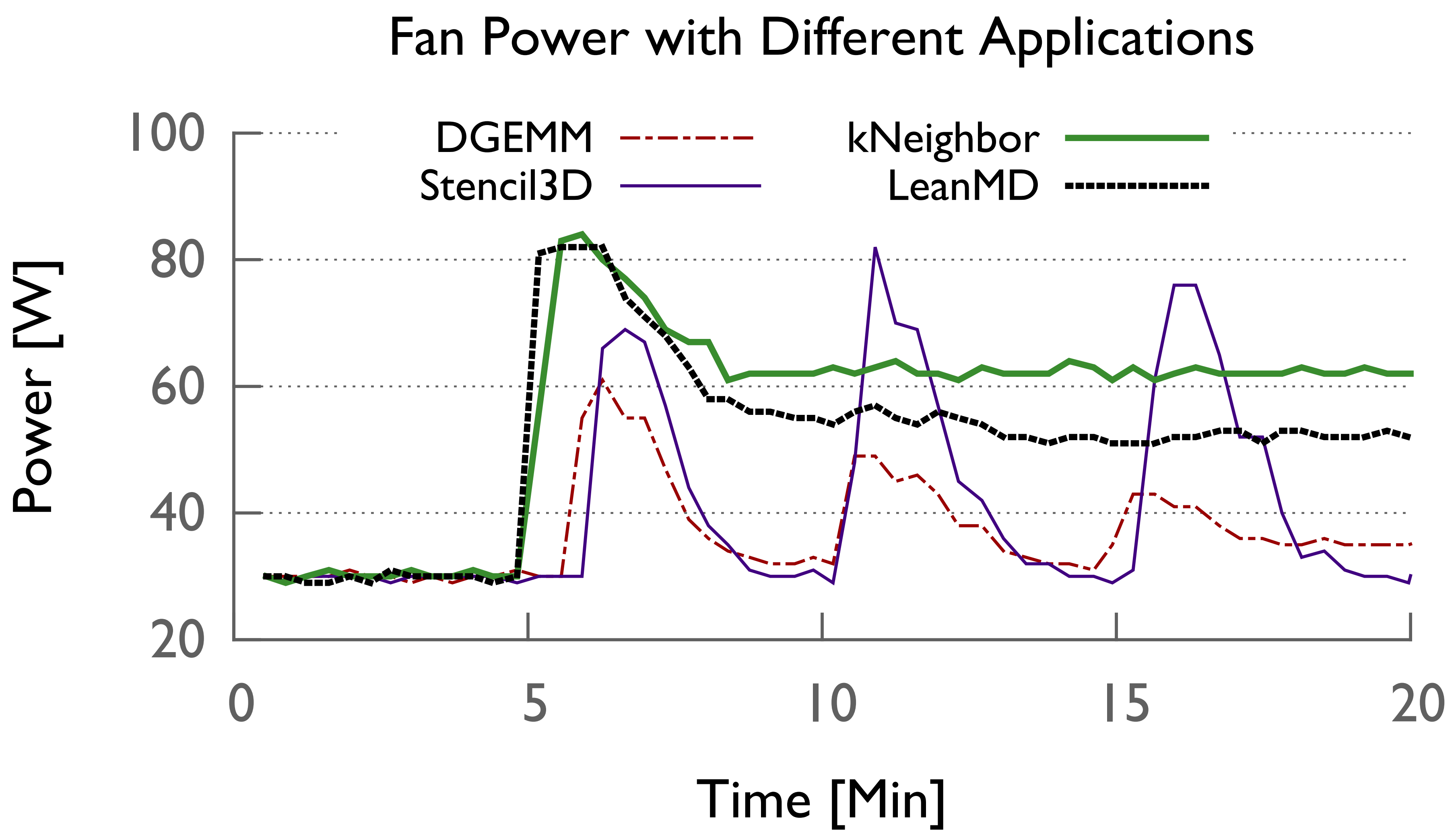
Cori at NERSC – Intel Haswell



Minsky at IBM POWER8

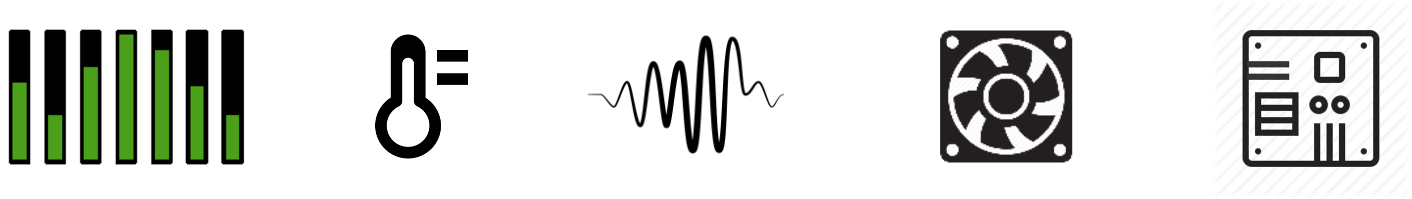
Oscillatory Cooling Behavior

Fan Behavior of Different Applications



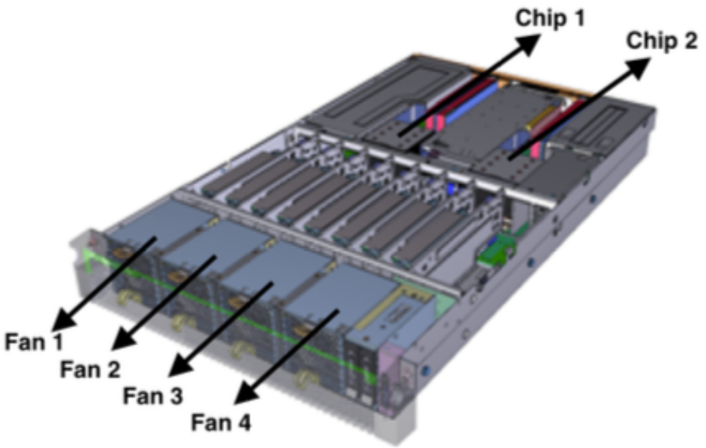
Why Temperature Modeling is Difficult?

- There are lots of parameters affecting the core temperatures:
  - Complex workloads
  - Ambient temperature
  - Core frequencies
  - Fan speed level
  - Physical layout
  - Hardware variations



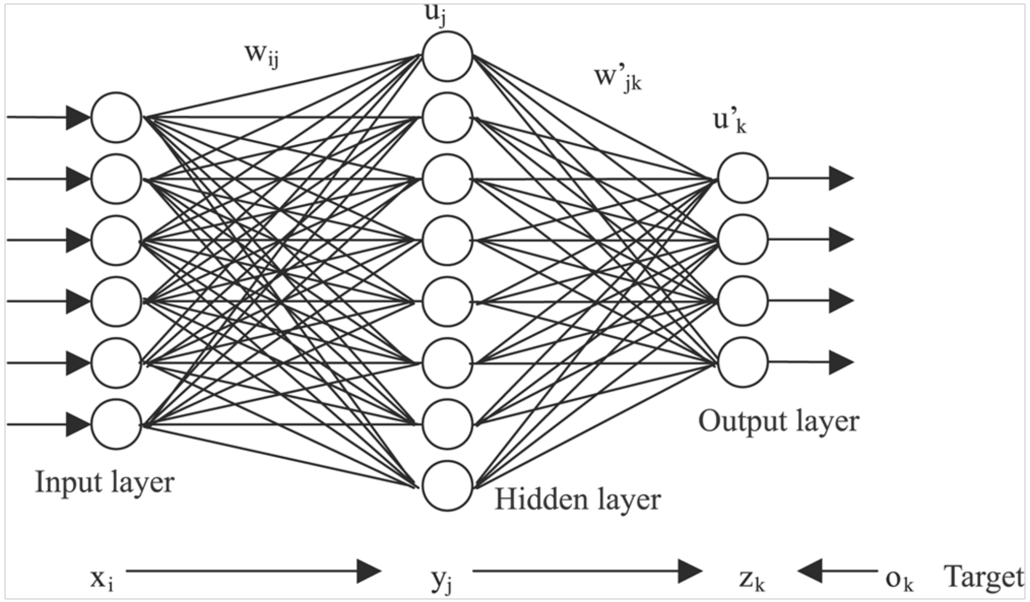
- Combination of these parameters create an exponential modeling space
  - 10 different cores
  - 0-100 CPU utilization levels
  - 44 different frequency levels
  - 3000 RPM-10000 RPM fan speed levels
  - 4 fans

❖ $(10^{10}) * 44 * (10^4) = \sim 2^{52}$



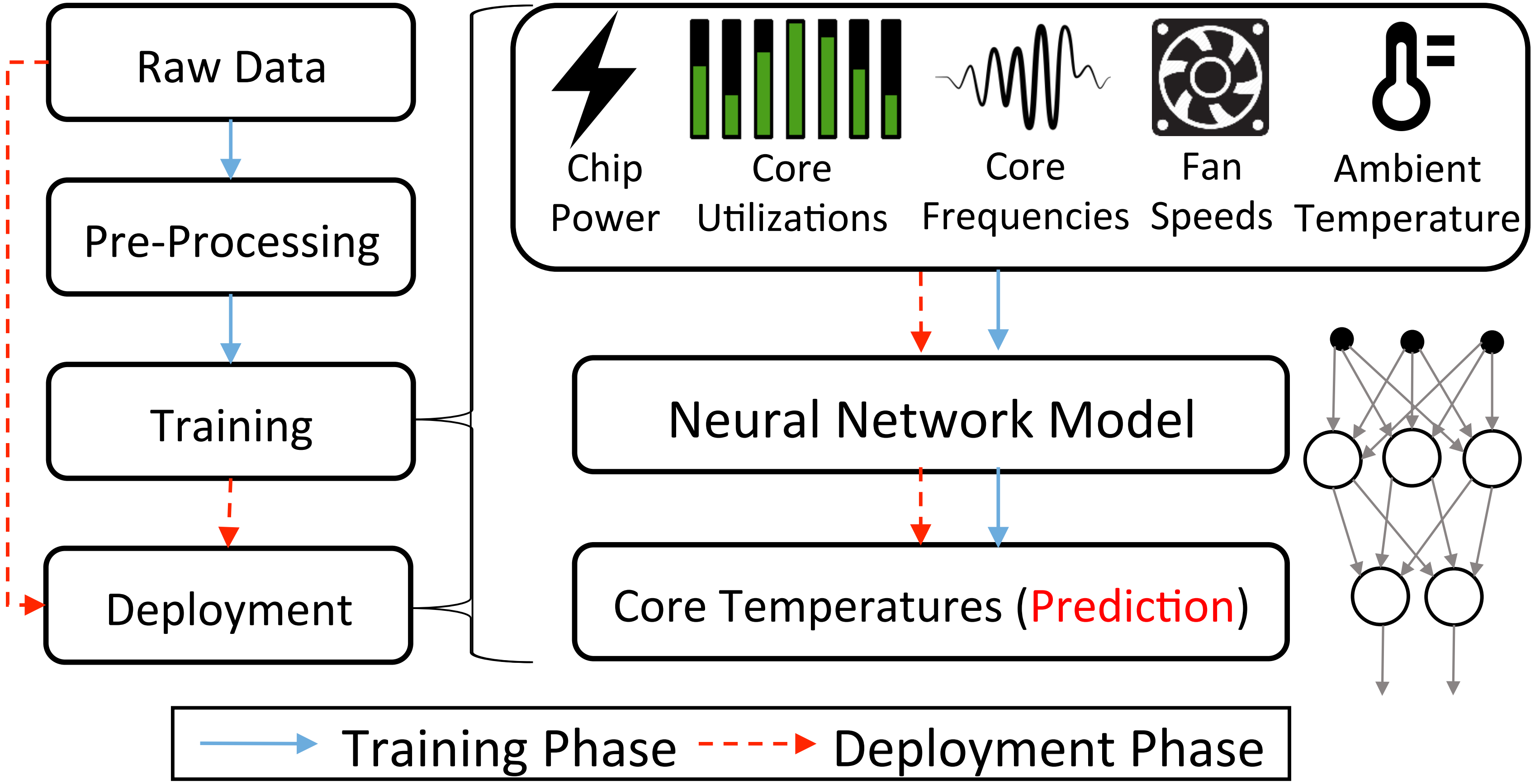
Neural Networks for Temperature Modeling

- Neural networks are good because:
  - They can capture linear and non-linear behavior between input and output parameters
  - They work well in noisy data
  - They do not need for formulation of an objective function
- Neural networks has been used in HPC for:
  - Energy and power modeling [1]
  - Performance modeling [2]
  - Temperature modeling
    - For GPU temperature modeling [3]
    - For coarse-grained data center level modeling [4]



1. A. Tiwari, M. A. Laurenzano, L. Carrington, and A. Snavely. Modeling power and energy usage of HPC kernels. In *Parallel and Distributed Processing Symposium Workshops & PhD Forum (IPDPSW)*, IEEE, 2012.
2. B. C. Lee, D. M. Brooks, B. R. de Supinski, M. Schulz, K. Singh, and S. A. McKee. Methods of inference and learning for performance modeling of parallel applications. In *Proceedings of the 12th ACM SIGPLAN Symposium on Principles and Practice of Parallel Programming*, PPoPP '07, 2007.
3. A. Sridhar, A. Vincenzi, M. Ruggiero, and D. Atienza. Neural network-based thermal simulation of integrated circuits on GPUs. *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems* 31.
4. L. Wang, G. von Laszewski, F. Huang, J. Dayal, T. Frulani, and G. Fox. Task scheduling with ann-based temperature prediction in a data center: a simulation-based study. *Engineering with Computers*, 2011.

Neural Networks for Temperature Prediction

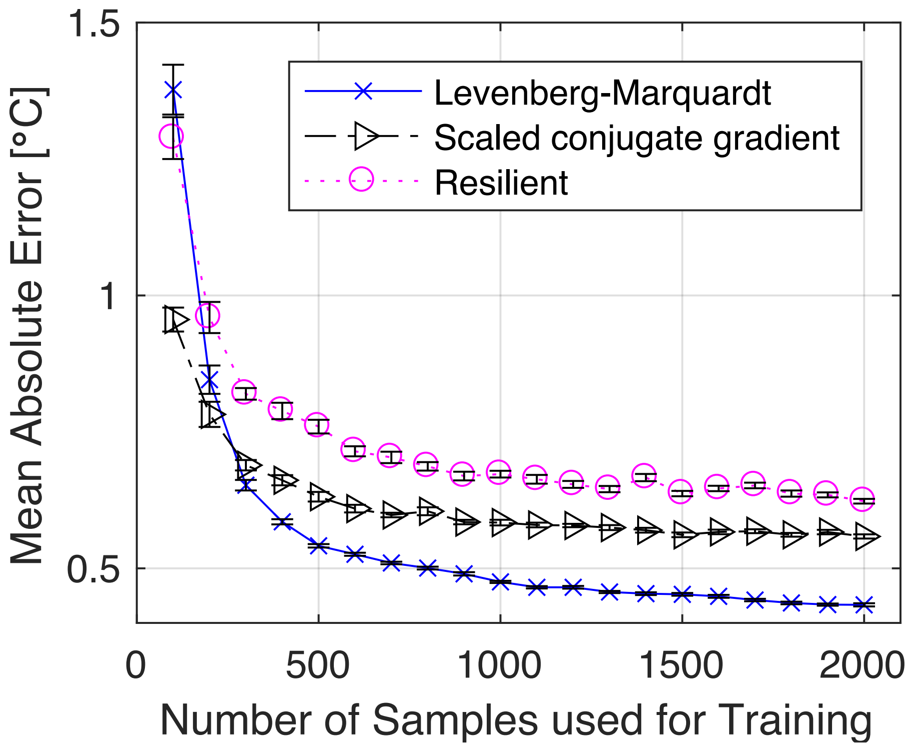


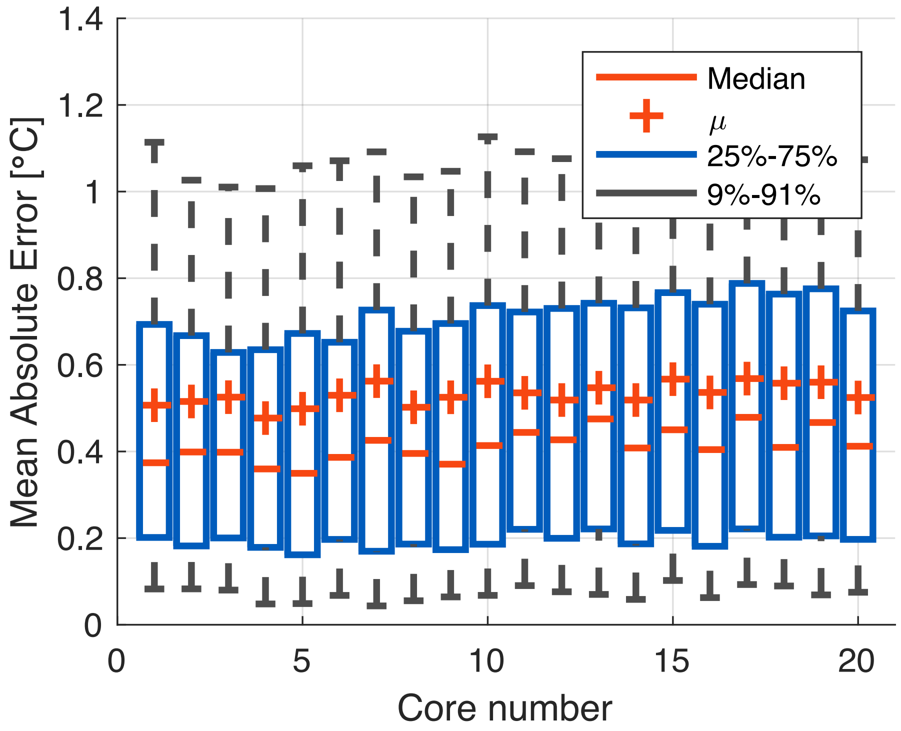
Experimental Setup:

- Firestone cluster at IBM with Power 8 processors
- 1 node = 2 sockets, 20 physical cores, 160 SMT cores
- OCC, and BMC for temperature, power readings

Neural Network Configuration and Validation

- We test different back-propagation algorithms with different time and memory requirements.





- Other configurations include number of layers, and number of neurons.

Model Guided Proactive Cooling Decisions

1. Fan control
   - This can reduce chip-to-chip temperature variations.
   - What should be the fan speed level to be able keep the chips at a certain temperature limit?

2. Load balancing
   - This can remove core-to-core, as well as chip-to-chip temperature variations.
   - What would the core temperatures become if a certain amount of data is moved from one core to another?

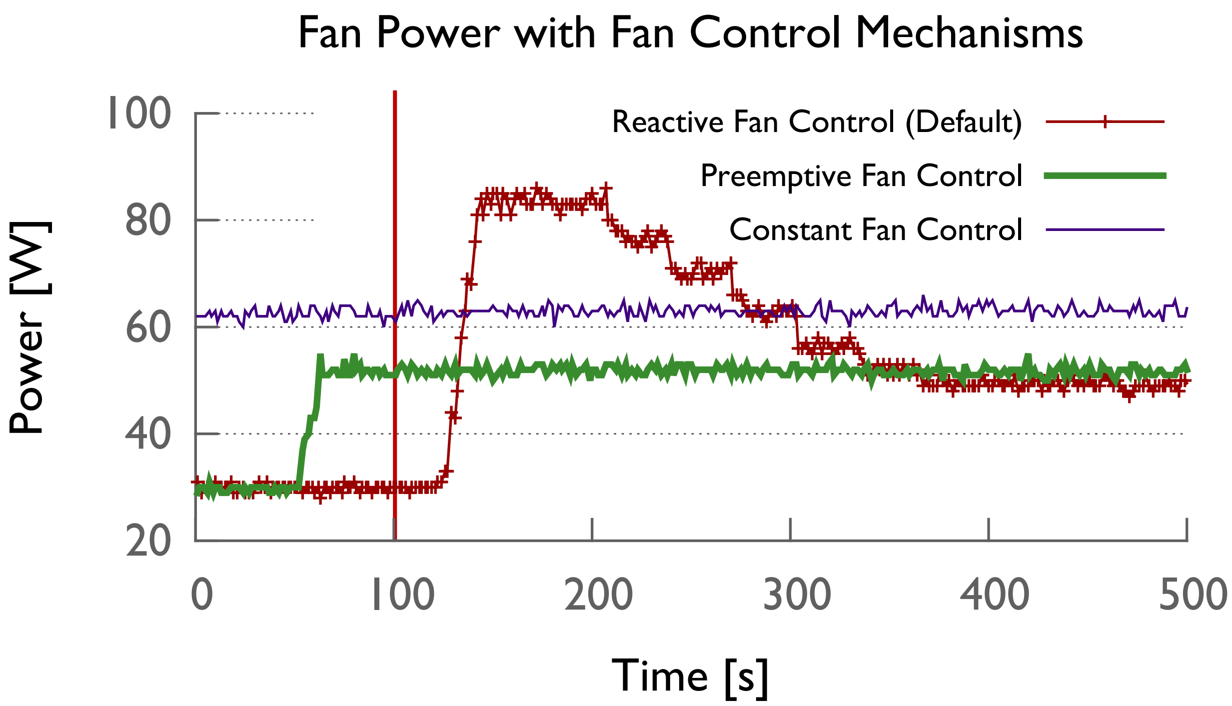
3. DVFS
   - Chip-level DVFS can reduce chip-to-chip, core level DVFS core-to-core temperature variations.
   - What frequency level we need to set for the cores to stay under a temperature limit for a workload?

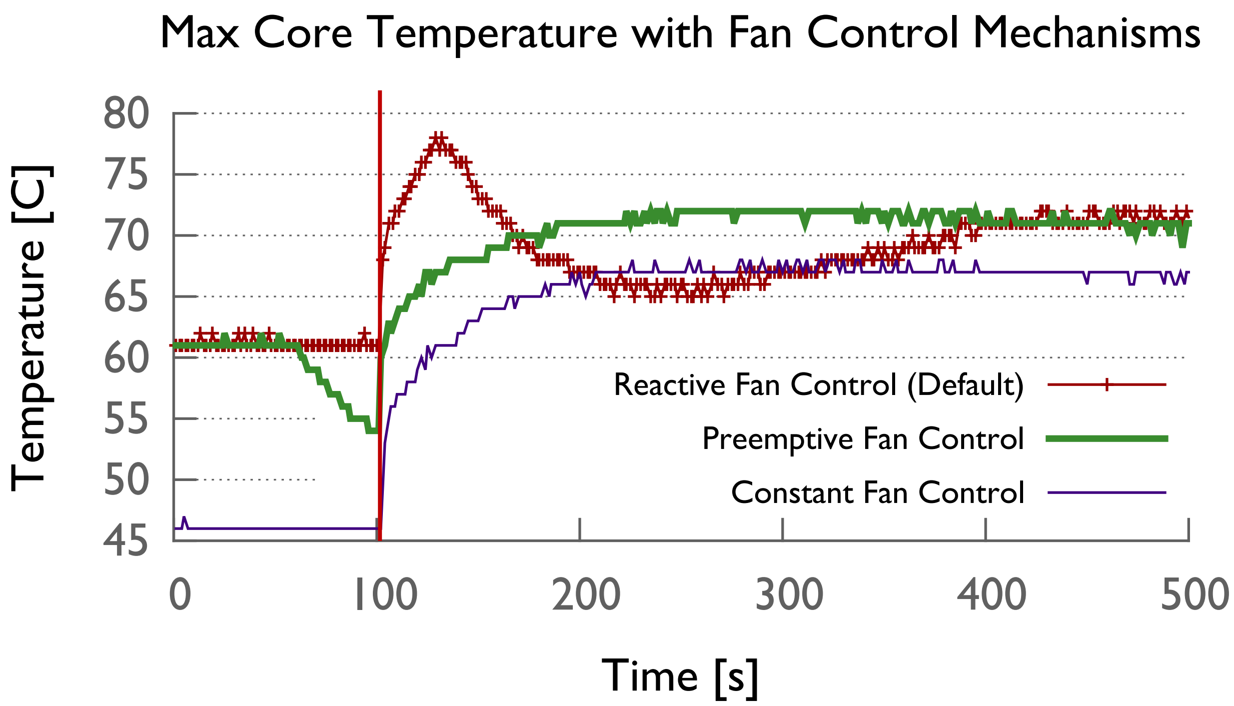
Model Guided Proactive Cooling Decisions

1. Fan control
   - This can reduce chip-to-chip temperature variations.
   - What should be the fan speed level to be able keep the chips at a certain temperature limit?

Proactive Fan Control Mechanism

- The key idea is cool the processor proactively, for example, before the application starts.

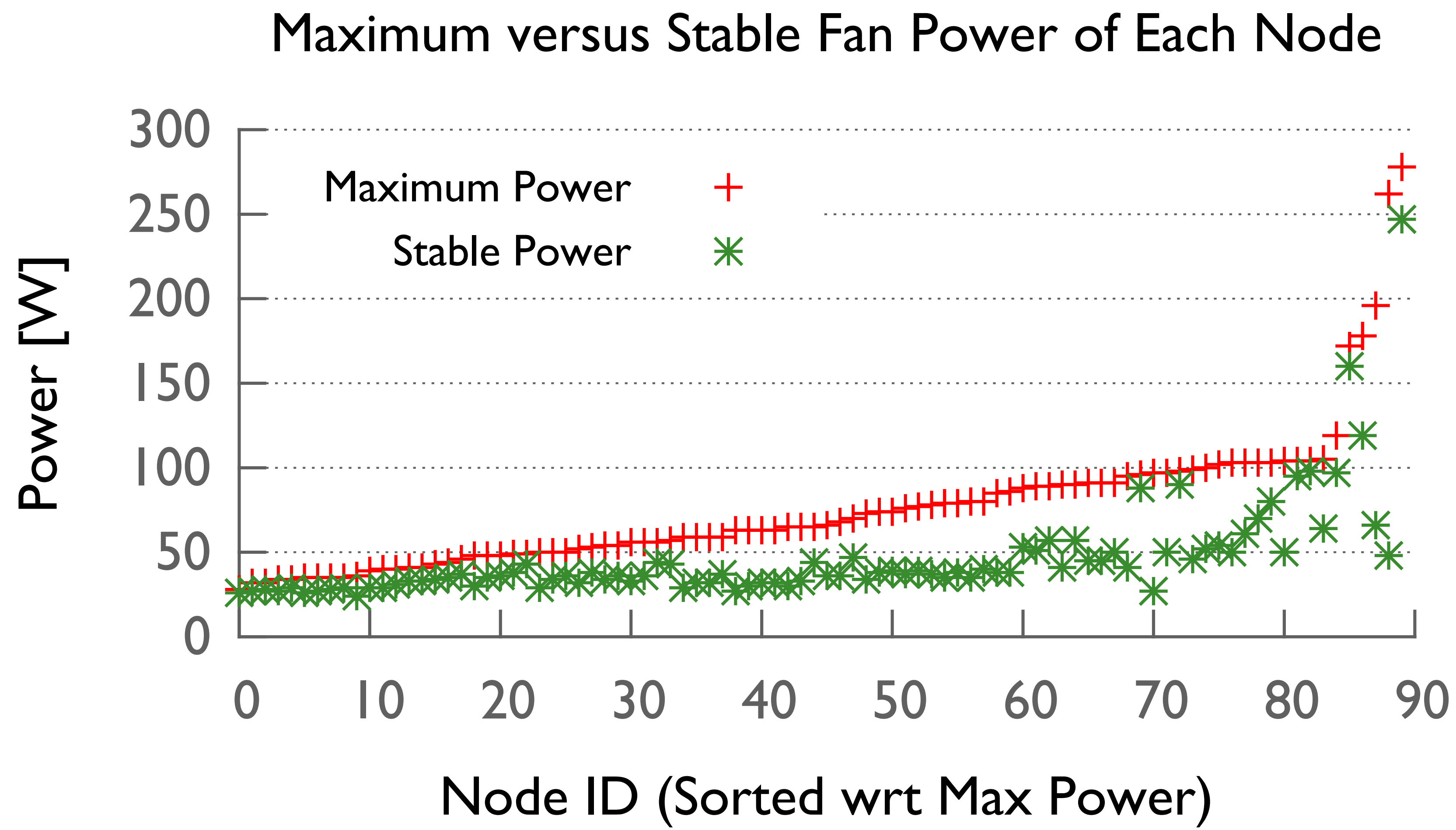




- Preemptive fan-control removes temperature peaks, and is able to keep the temperature as the same level as reactive fan control.

- It can be done via job scheduler, and/or runtime without taking over the total control of the fan.

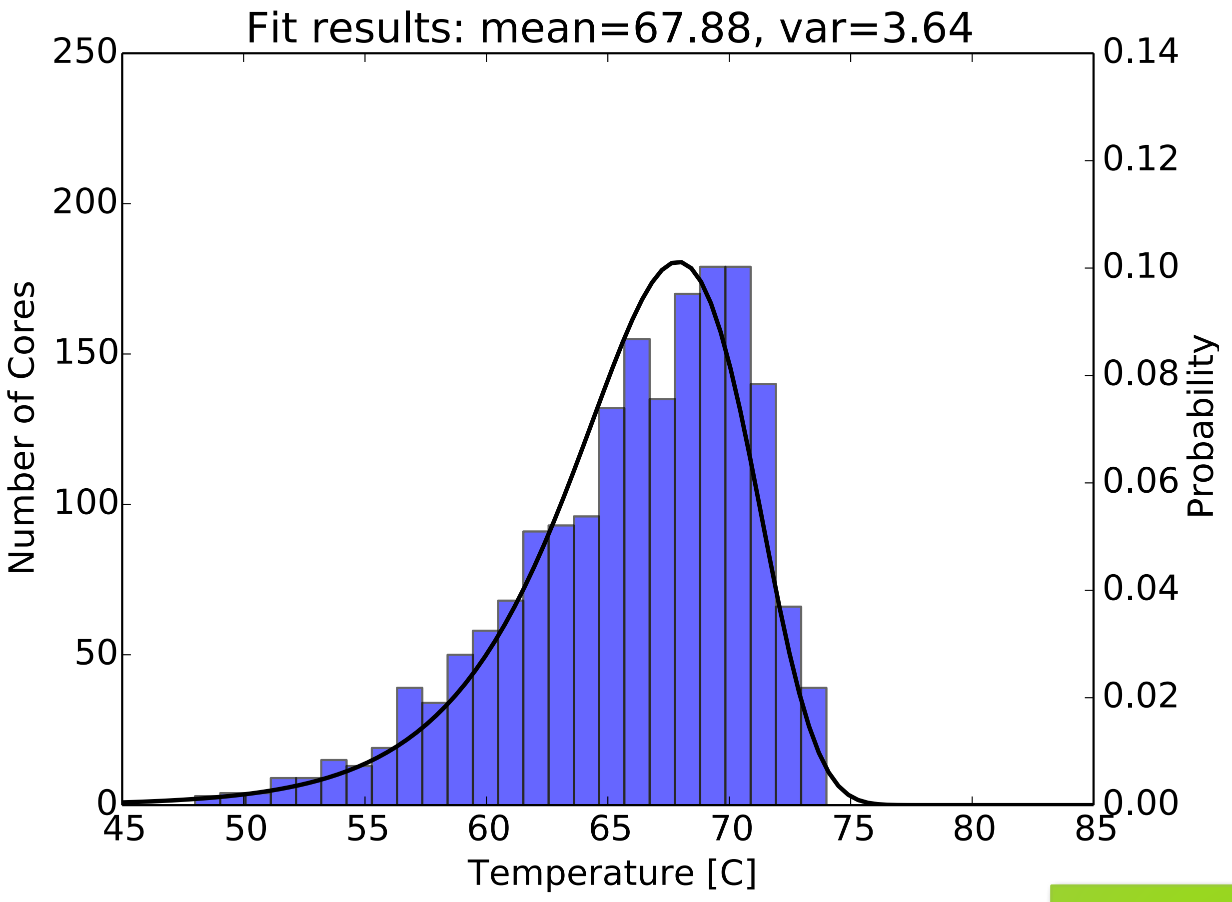
Power Reductions With Proactive Cooling



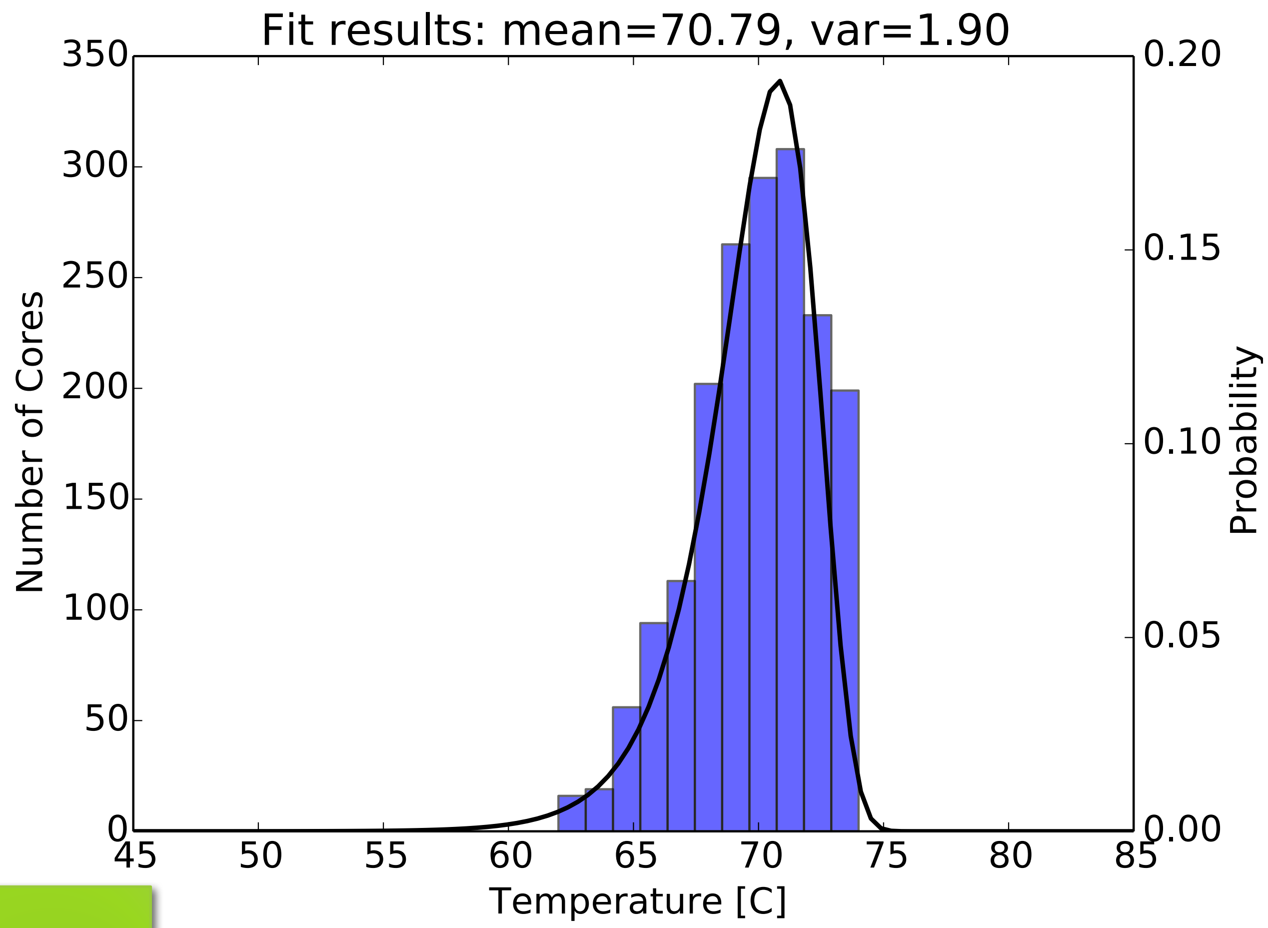
35% reduction in fan power

Power Reduction = Maximum Power – Stable Power

Decoupling the Fans



BEFORE



AFTER

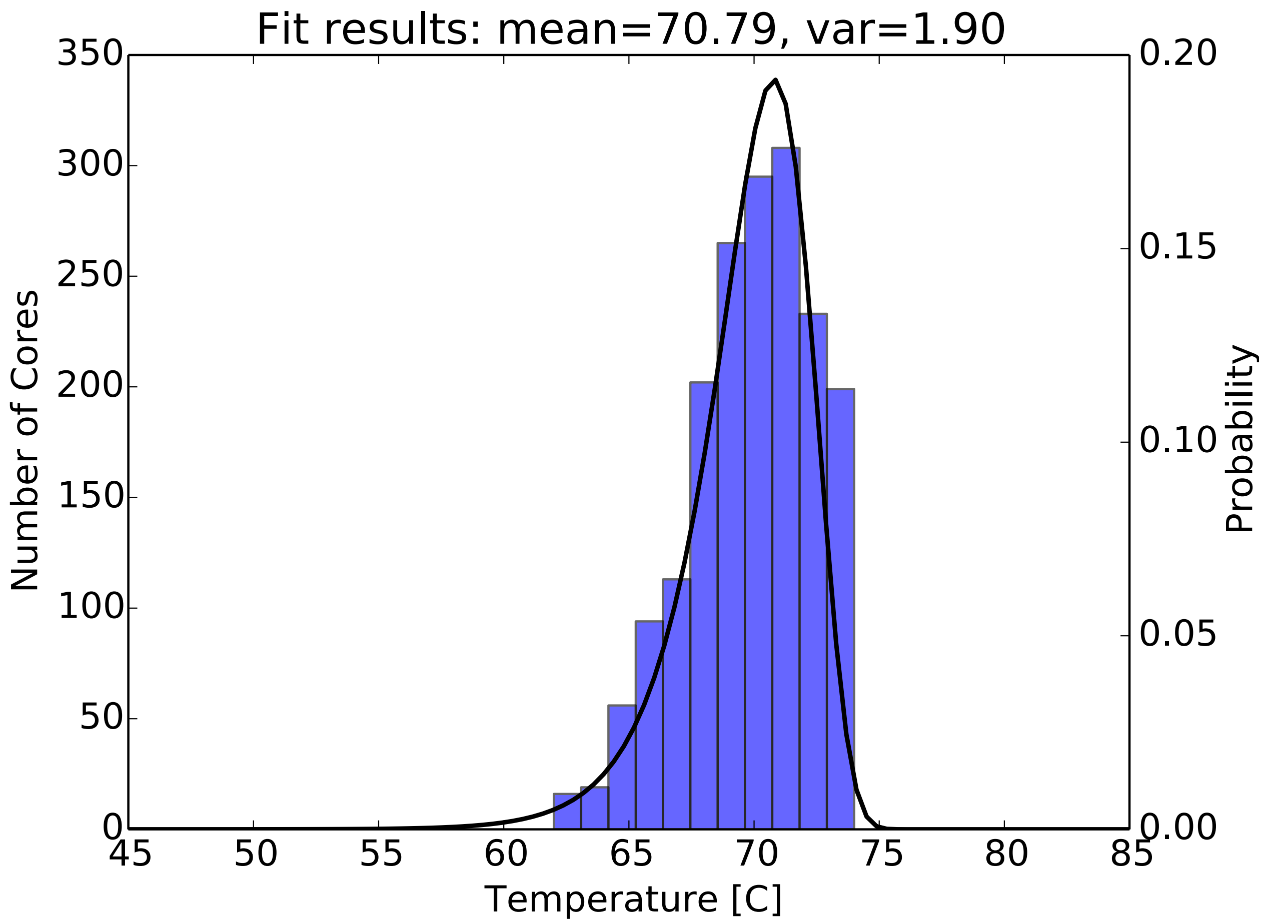
18% reduction in fan power

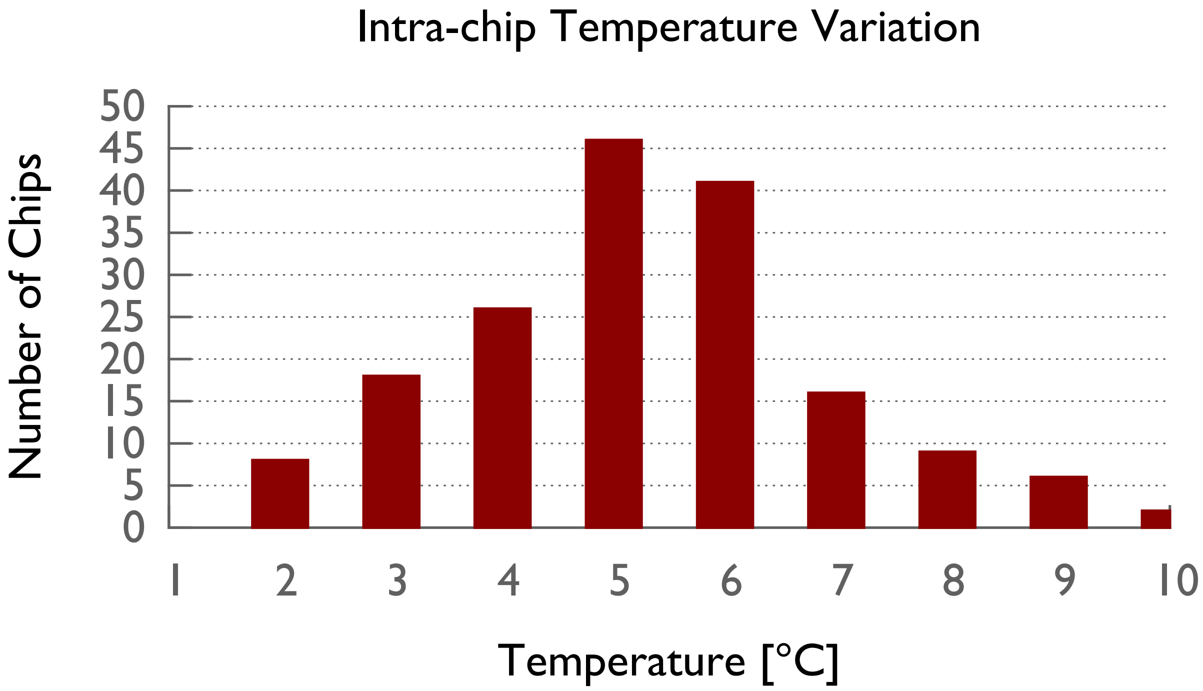
Total Reduction in Fan Power

Optimization \ Benchmarks	DGEMM	Stencil3D	kNeighbor	LeanMD	Average
Reactive Fan Control	5868 W	13433 W	6769 W	6770 W	8210 W
Preemptive Fan Control	3893 W	8526 W	4381 W	4224 W	5256 W
Preemptive and Decoupled Fan Control	3179 W	7972 W	3765 W	3569 W	4621 W
Total Power Reduction (%)	45.8	59.3	55.6	52.7	53.3

53% reduction
in fan power on average

Remaining Temperature Variation





- DVFS?
- Load Balancing?

Temperature-Aware Load Balancing With Charm++

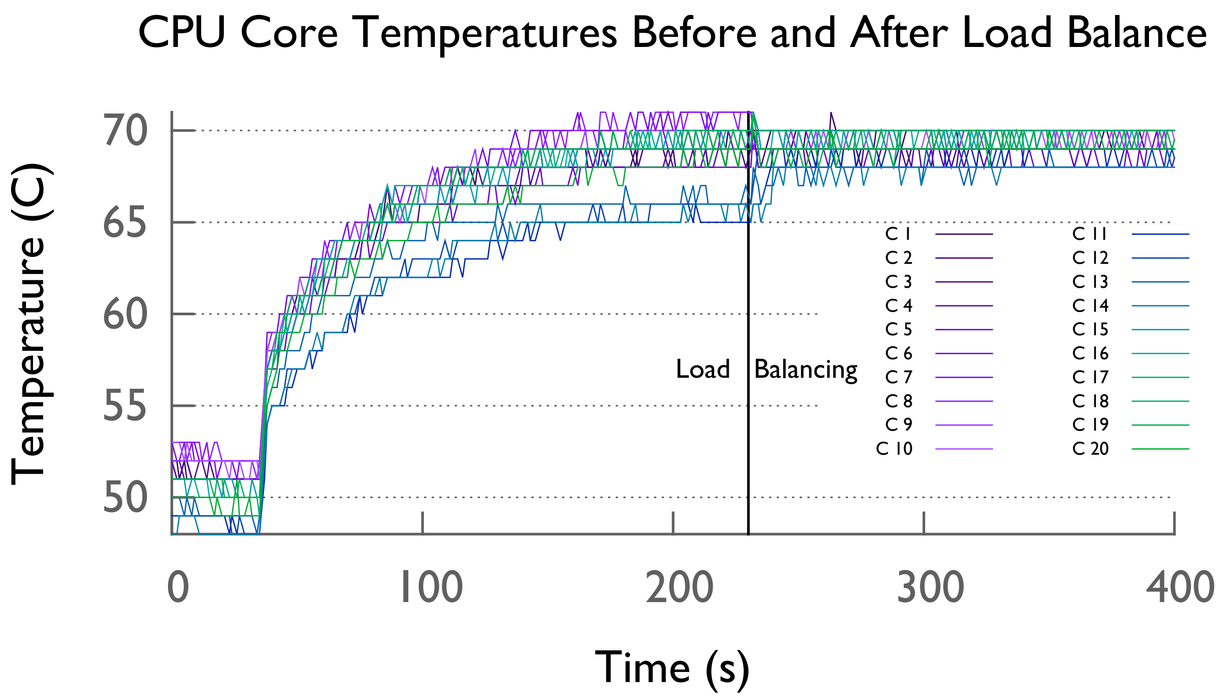
- Load balancing can help reduce the temperature variations, but how do we decide how much load to move?

- Charm++ [1] has an runtime database which stores:
  - Number of tasks per process
  - Load of each object (in terms of execution time)
  - Communication load of each object

- Load balancing is triggered periodically with customizable periods

- We implement our temperature-aware model guided load balancing algorithm.

- Load balancing has potential to remove both chip and core level variations.



1. B. Acun, et al. Parallel programming with migratable objects: charm++ in practice. *In SC14: International Conference for High Performance Computing, Networking, Storage and Analysis*, pages 647-658. IEEE, 2014.

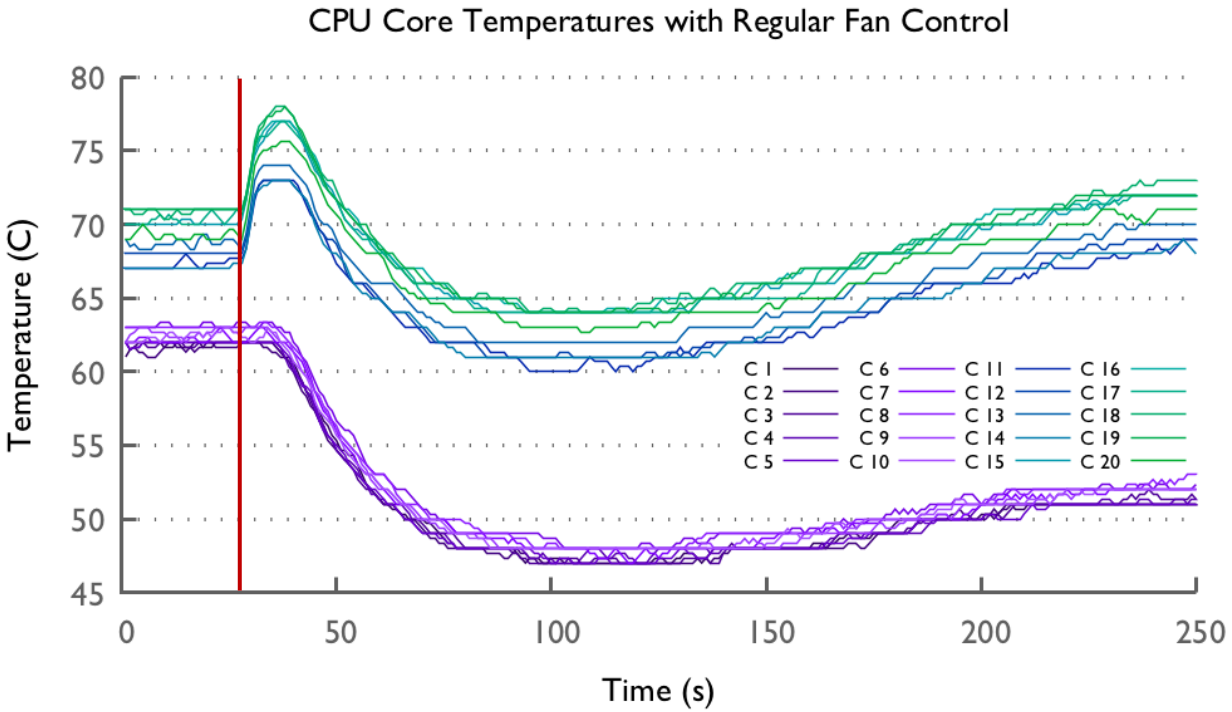
Conclusion

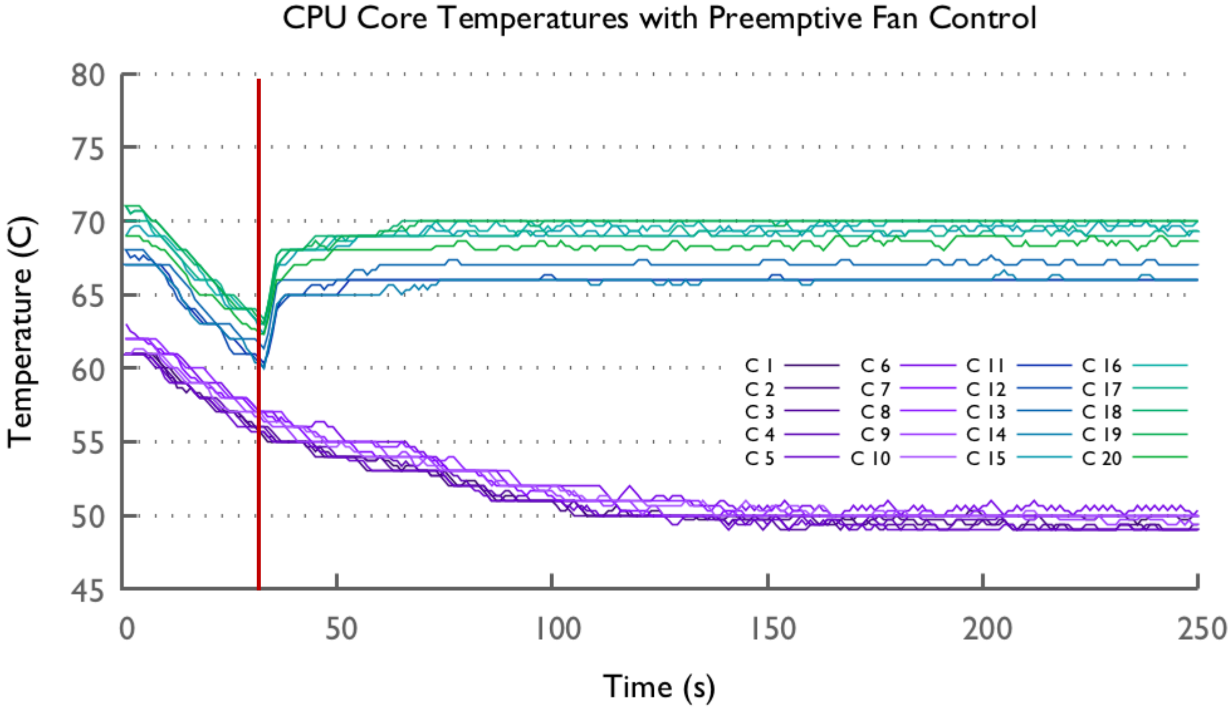
- In summary, we propose:
  - A neural-network based temperature prediction model
  - Proactive cooling mechanisms:
    - Fan control
    - Load balancing
- Our results shows:
  - We can accurately predict core temperatures
  - Peak fan power can be reduced by 53%
  - Air cooling systems can be made more efficient

Thank you!

Comparison of Reactive vs Preemptive Fan Control

- The key idea is cool the processor proactively, for example, before the application starts.





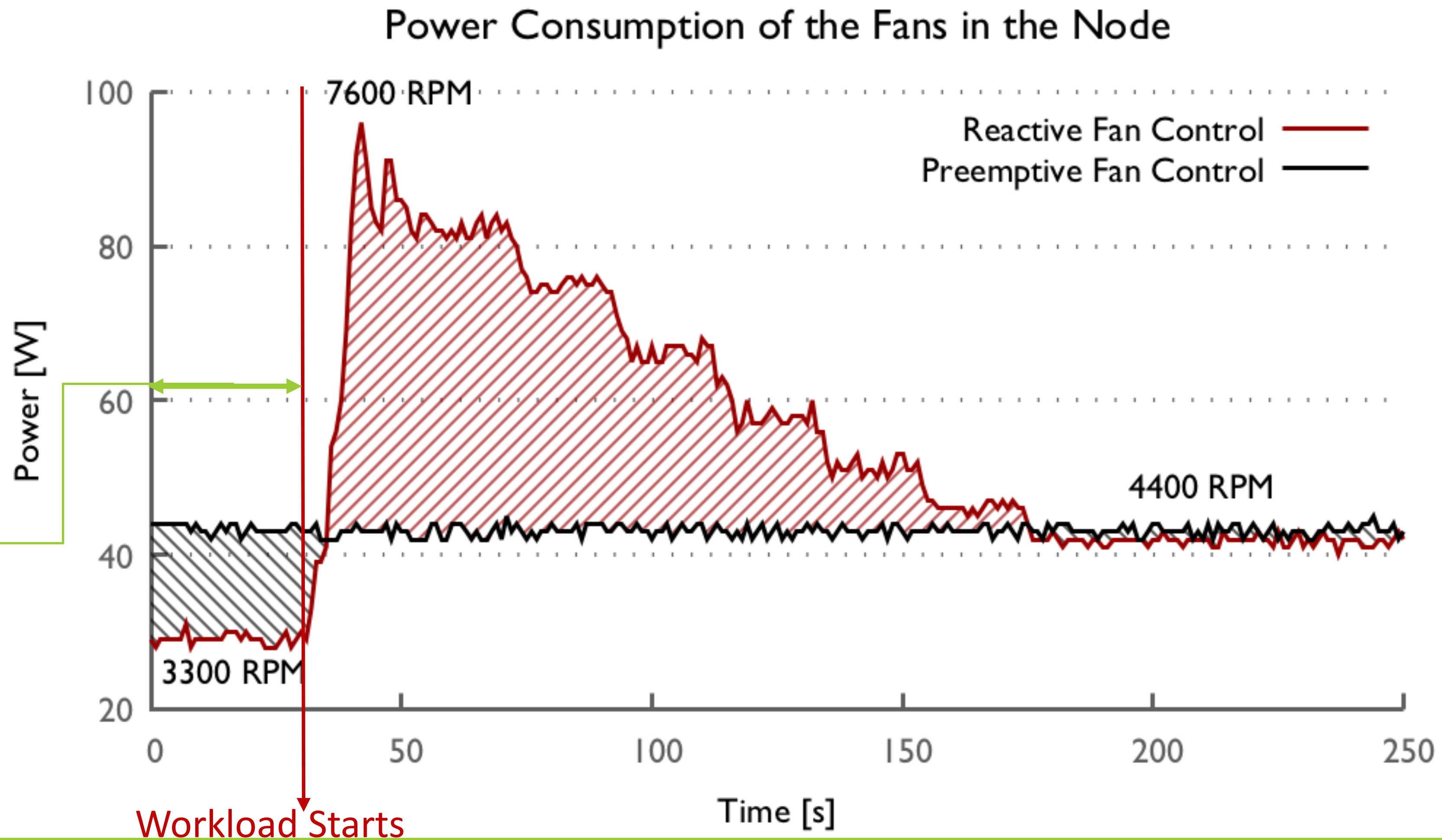
- Preemptive fan-control removes temperature peaks, and is able to keep the temperature as the same level as reactive fan control.

- It can be done via job scheduler, and/or runtime without taking over the total control of the fan.

Power Reductions in Preemptive Fan Control

- Peak fan power can be reduced by 54 Watts = 58% reduction in cooling power.
- 2790 Joules of energy is saved = Red area – black area

How early to set the cooling speed?



Workload Starts