Carnegie Mellon

A Multi-core High Performance Computing Framework for Probabilistic Solutions of Distribution Systems

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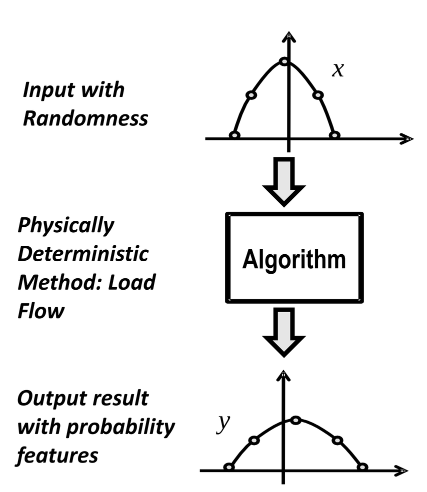
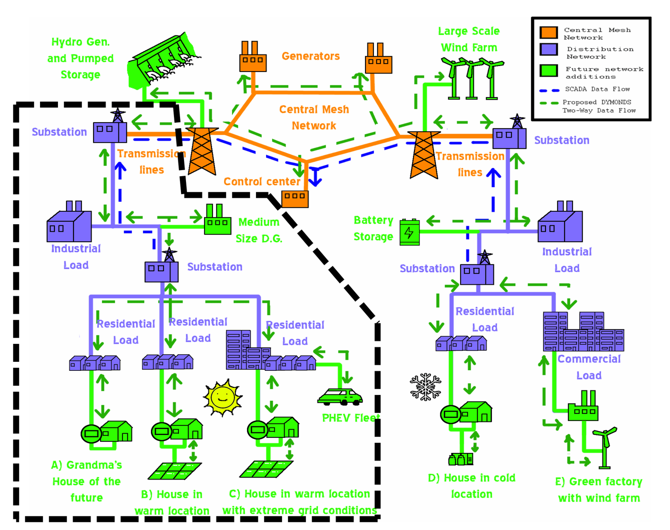
Motivation and Background

❖ Problems from Power System

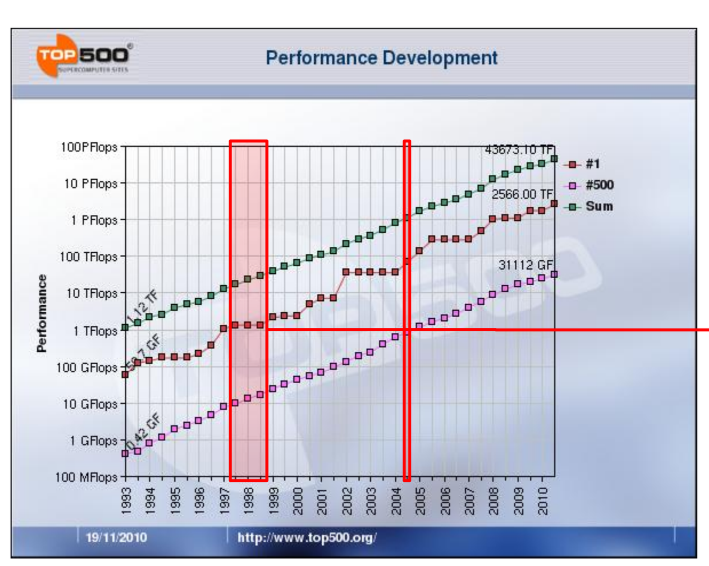
- Uncertainties in electric power distribution system:
  - Wind power, DG, PHEV, responsive load, etc.
- Lack of real time measurements:
  - AMI, Smart metering may help, but still in preliminary stage.
- Probabilistic Model for Uncertainties:
  - Wind forecast model, EV pattern, Load profile.
- A Probabilistic Solution of Distribution System

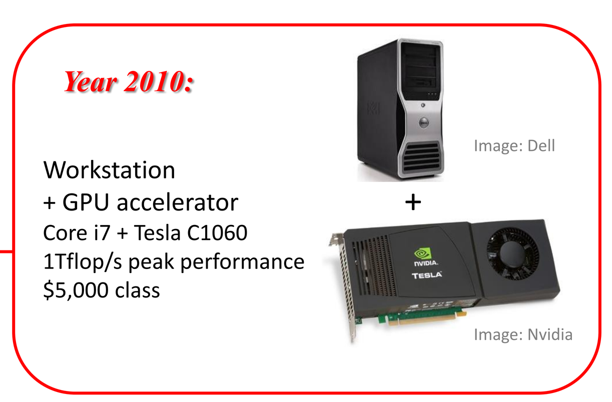




Active Role of Distribution System in Smart Grid
*Original figure by Andrew Hsu (EESG)

❖ Advances in High Performance Computing





- Fully utilizing the computing power is a difficult problem
  - **NO** free speedup, parallelism, memory , special instructions
  - Require knowledge in specific domain & computer architecture
- Potential Benefit: Moore's law!

❖ High Performance Computing Enabled Power System Solution

- Monte Carlo based Probabilistic Solution of Distribution System:
  - "Golden standard" for probabilistic power flow
  - Well fitted problem on modern computing platform
  - Extensible to contingency analysis, steady state time-series…

An Affordable Supercomputing Center for Distribution Substation

Methods & System

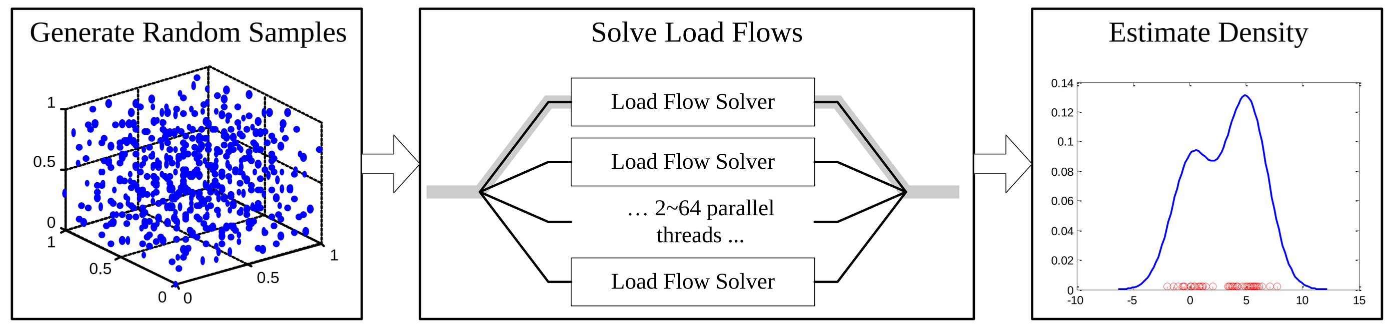
❖ Distribution Power Flow Model

- Forward / Backward Sweep
- Small complex ***Matrix-Vector Mult***

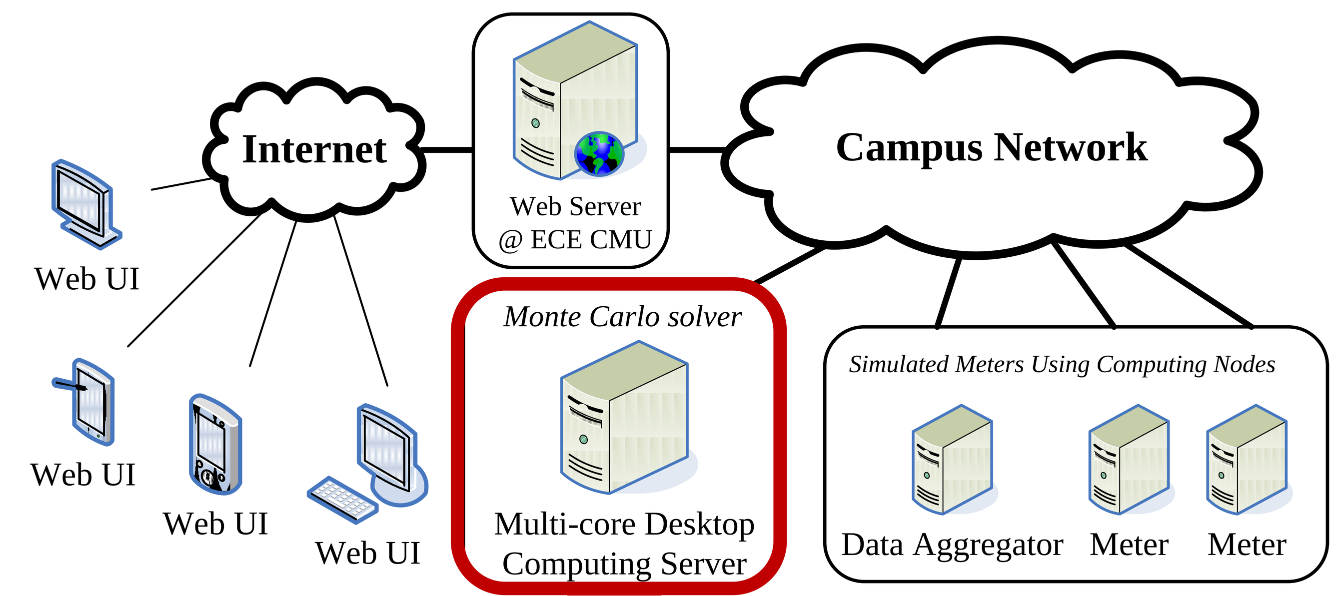
$$[I_{abc}]_n = [c]\cdot[V_{abc}]_m + [d]\cdot[I_{abc}]_m$$

$$[V_{abc}]_m = [A]\cdot[V_{abc}]_n - [B]\cdot[I_{abc}]_m$$

❖ Monte Carlo Simulation:

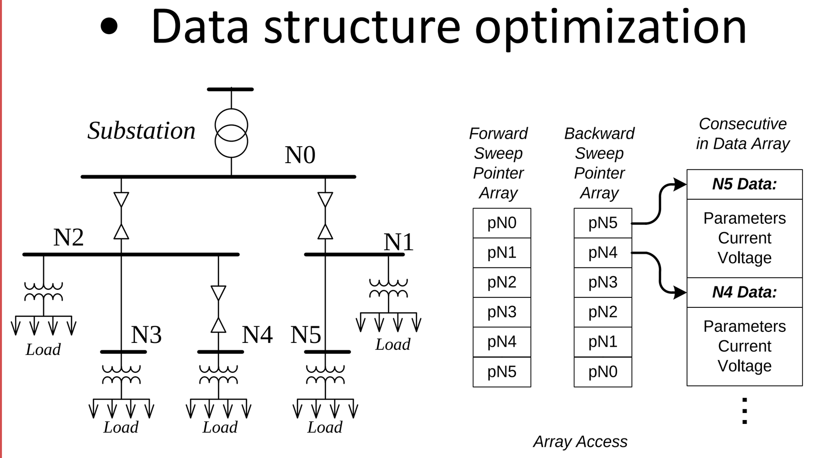


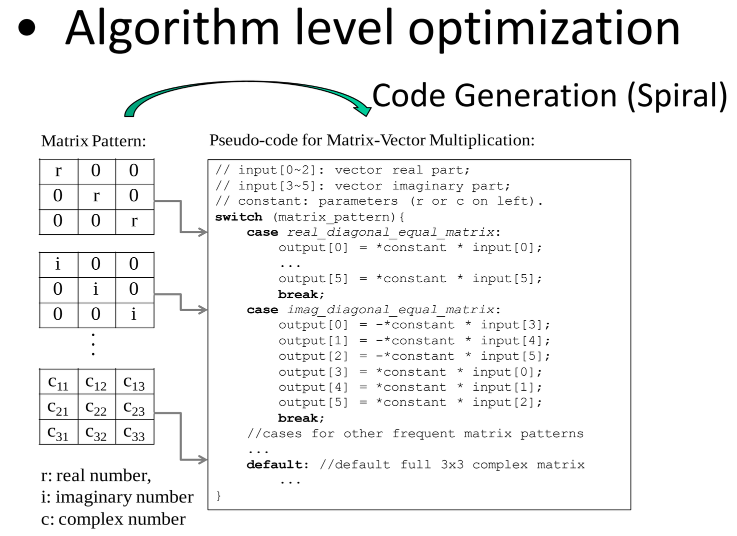
❖ Distribution System Probabilistic Monitoring System



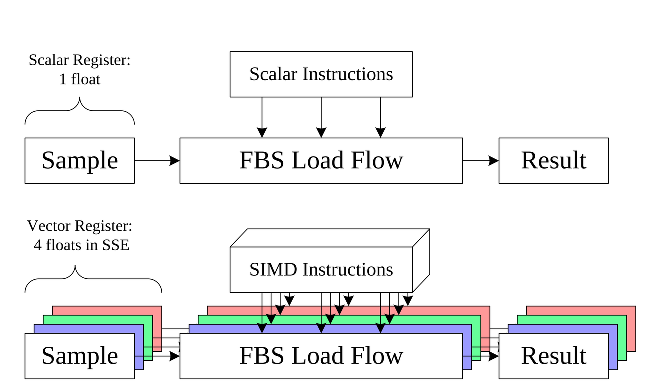
❖ Aggressive Code Optimizations on Monte Carlo Solver

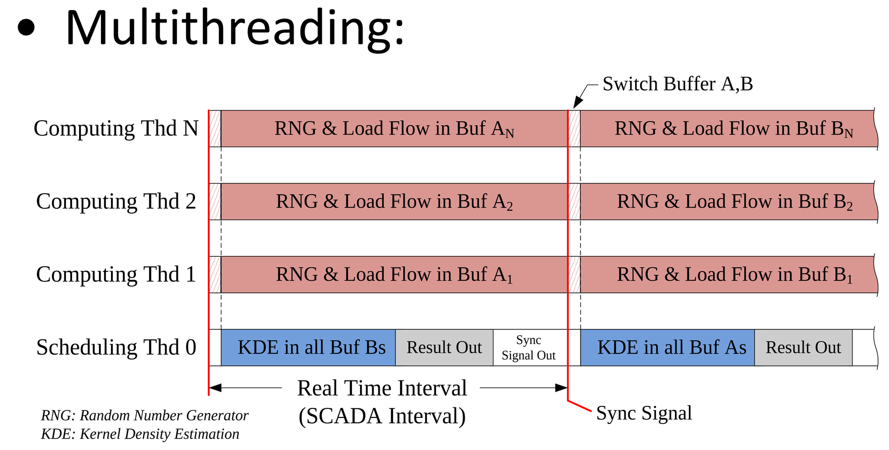
- Data structure optimization
- Algorithm level optimization





- SIMD vectorization
- Multithreading:

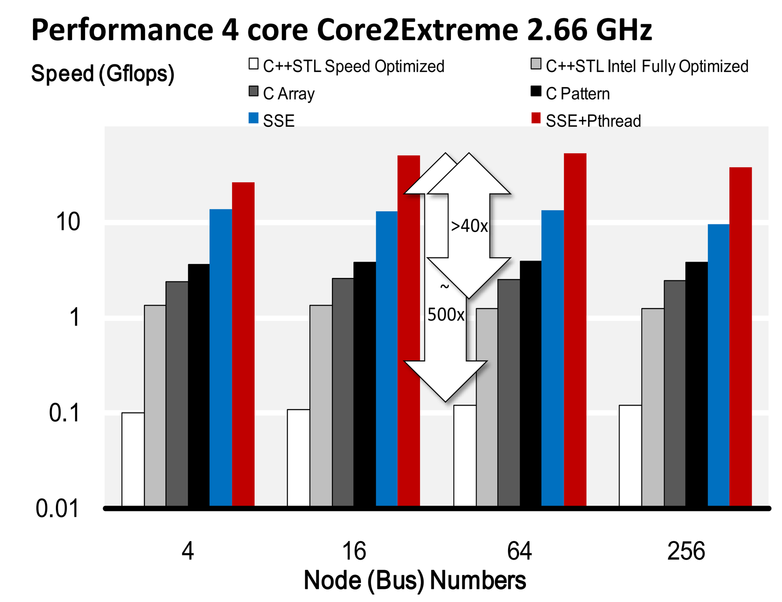


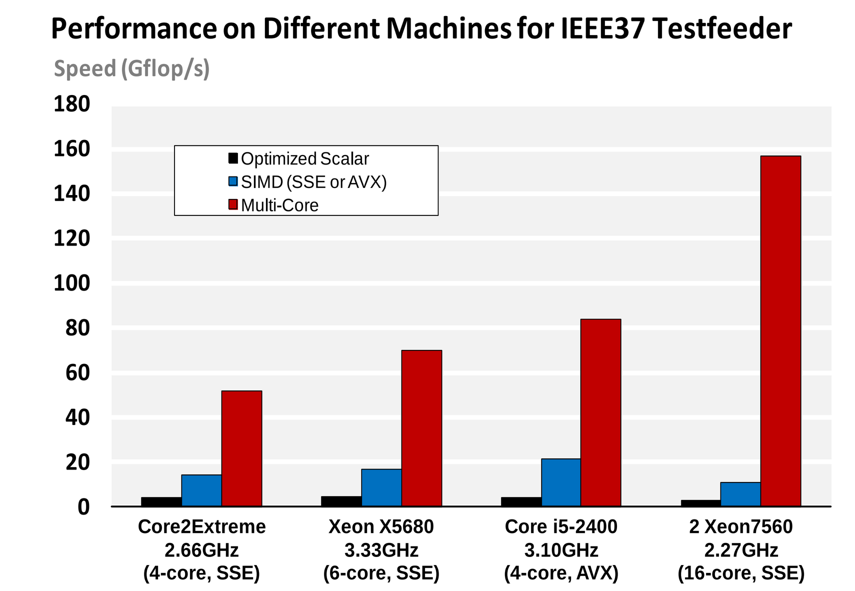


Squeezing Computation Power out of the Computer Architecture.
Push Performance to the Hardware Peak.

Latest Results

❖ Performance Result: High Performance Computing Engine

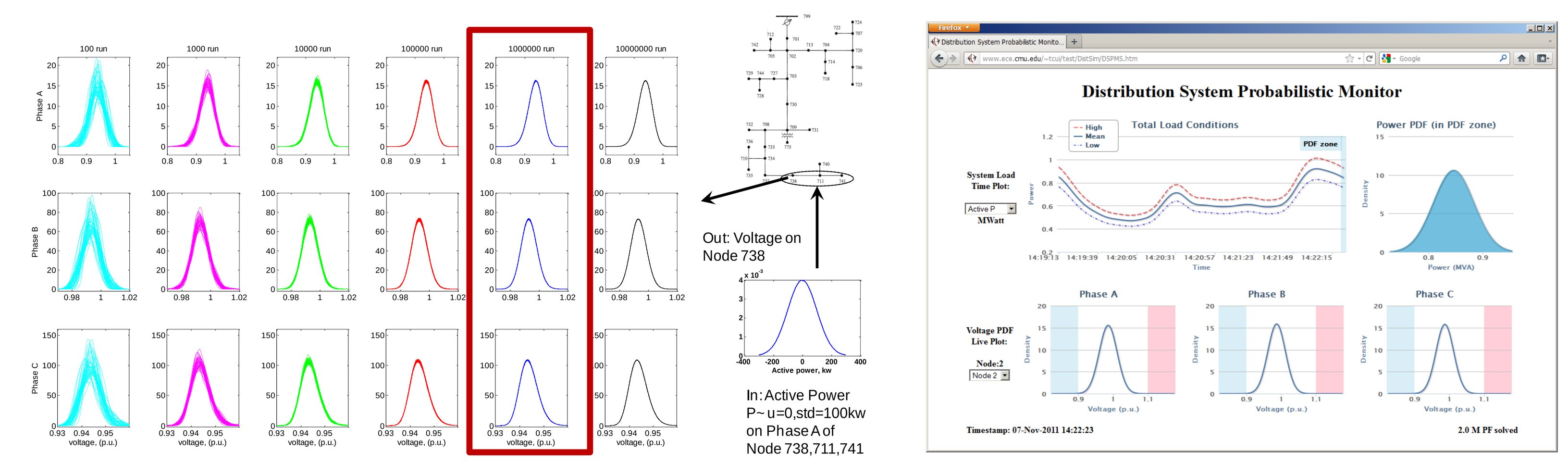




Translate speed (Gflop/s) into run time:

Problem Size (IEEE Test Feeders)	Approx. flops	Approx. Time / Core2 Extreme	Approx. Time / Core i5	Baseline. C++ ICC –o3 (~300x faster then Matlab)	Comments
IEEE37: one iteration	12 K	~ 0.3 us	~ 0.3 us		
IEEE37: one load flow (5 Iter)	60 K	~ 1.5 us	~ 1.5 us		0.01 kVA error
IEEE37: 1 million load flow	60 G	~ < 2 s	~ < 1 s	~ 60 s (>5 hrs Matlab)	SCADA Interval: 4 seconds
IEEE123: 1 million load flow	200 G	~ < 10 s	~ < 3.5 s	~ 200 s (>15 hrs Matlab)	

❖ Monte Carlo Results and Web User Interface



Conclusions & Future Work

❖ Program optimization / parallelization:

- Enable fast computation of large amount of power flow.

❖ Performance can be further increased on new platform:

- Tracking new development in CPU micro-architecture.
- GPU: small, less powerful but many more cores.

❖ Applications of fast distribution power flow solver:

- Probabilistic monitor of distribution system
- Fast time series solution; statistical analysis…

Acknowledgement & Publications

- This work is supported by NSF through awards 0931978 and 0702386.

- Related Publications:

1. T. Cui, F. Franchetti, "A Multi-Core High Performance Computing Framework for Distribution Power Flow," The 43rd North American Power Symposium (NAPS), Boston, USA, Aug 2011.
2. T. Cui, F. Franchetti, "A Multi-Core High Performance Computing Framework for Probabilistic Solutions of Distribution Systems," IEEE PES General Meeting 2012, San Diego, CA, USA.

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