Stochastic Modeling and Supercomputing for Smart Grids

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Smart Grids and Supercomputing

- Smart grids will generate large amounts of sensor measurements whose timely processing and utilization will be used to improve efficiency and reliability
- Intermittent energy sources (wind, solar) increase supply uncertainties
- Parallel computing provides natural tools for data processing, optimal decision making and uncertainty modeling

Advantages of HPC

- High performance compilers
- Parallelism: doing many things at the same time
  - Instruction-level parallelism: doing multiple operations at the same time within a single processor (e.g., add, multiply, load and store simultaneously)
  - Multiprocessing: multiple CPUs working on different parts of a problem at the same time
    - Shared Memory Multithreading
    - Distributed Multiprocessing
- Powerful storage hierarchy

What is High Performance Computing?

- ***High Performance Computing* (HPC)**, also called supercomputing, is the biggest, fastest computing right this minute. Likewise, a ***supercomputer*** is one of the biggest, fastest computers right this minute. So the definition of supercomputing is constantly changing.
- New York Blue:
  - Consists 18 racks IBM Blue Gene
  - Each rack consists of 1024 compute nodes (a total of 18432 nodes)
  - each node consists two 700 MHz PowerPC 440 core processors and 1 GB of memory (a total of 36864 processors and 18.4 TB of memory)
  - Website: http://www.bnl.gov/newyorkblue/
  - Top 500 Supercomputer ranking: 67 as of 06/2010 (17 as of 06/2008)

Some Applications of HPC

- State Estimation
  - Estimate the steady states condition of EPS using online measured values
  - The measurement system consists of active and reactive line power flow and bus injection real and reactive power measurement and bus voltage magnitude measurement
- Forecasting
  - Weather forecasting
  - Load, price, capacity, equipment states, rating and reliability, etc.
- Control and Planning
  - Unit Commitment Problem, Economic Dispatch
- Power Flow Control

State Estimation

- Provide reliable estimates of the quantities required for monitoring and control of the EPS
- A set of measurements obtained is centrally processed by a static state estimator
  - Higher frequency -- shorten the time interval between consecutive state estimations to allow a closer monitoring of the system evolution particularly in emergency situations in which the system state changes rapidly
  - Larger size -- enlarge the supervised network by extending state estimation to low voltage sub networks

State Estimation

- Challenges:
  - Higher frequency requires the development of faster state estimation algorithms
  - Larger size increase the demand on the numerical stability of the algorithms
- Solutions:
  - Parallel and distributed implementations of the state estimation function

State Estimation

- State Estimation model:

$$\mathbf{z} = \mathbf{h}(\mathbf{x}) + \mathbf{w}$$

z – (mx1) measurement vector

x – (2nx1) true state vector

h(.) – (mx1) vector of nonlinear functions

w – (mx1) measurement error vector

m – number of measurements

n – number of buses

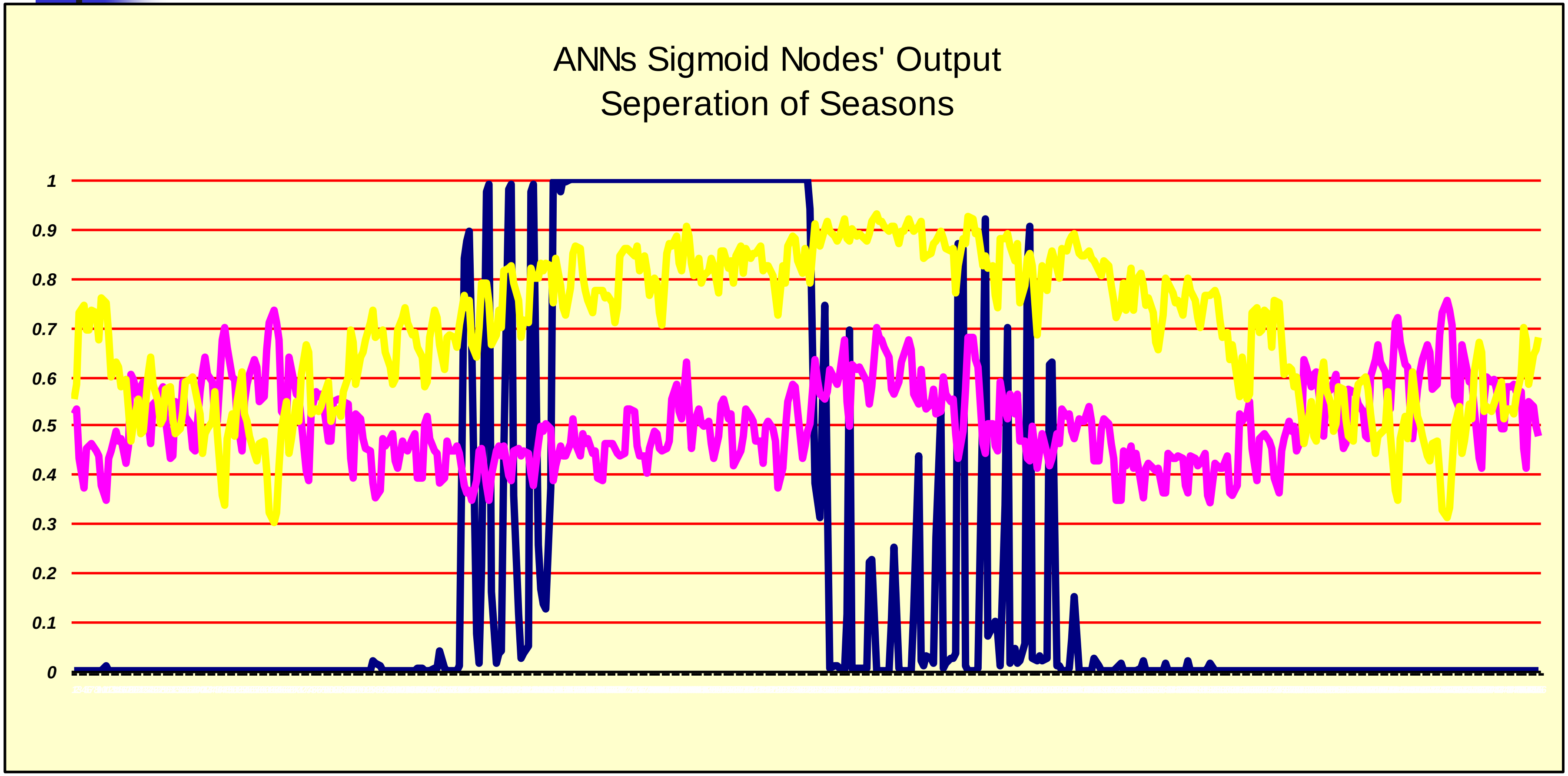
Load Forecasting

- Accurate forecast of future demand required by all entities involved in the energy markets
  - Electric Utilities
  - Independent System Operators
  - Power Marketers
- Different forecast horizons
  - Long Term: Several years out – required for planning purposes
  - Mid Term: Several weeks to months – scheduling maintenance, planning fuel supply, transactions
  - Short Term: Next hour to next week – daily operation, energy transactions, reliability studies

Regression Models: Example

- $L(t) = F(d(t),h(t))*f(w(t))+R(t)$
  - L(t) – Actual load at time t
  - d(t) – day of the week
  - H(t) – hour of the day
  - F(d,h) – daily and hourly component
  - w(t) – weather data that include the temperature and humidity
  - f(w) – weather factor
  - R(t) – random error

Forecasting using ANNs: Example



Predict = ∑Sigmoid Node Output + Error

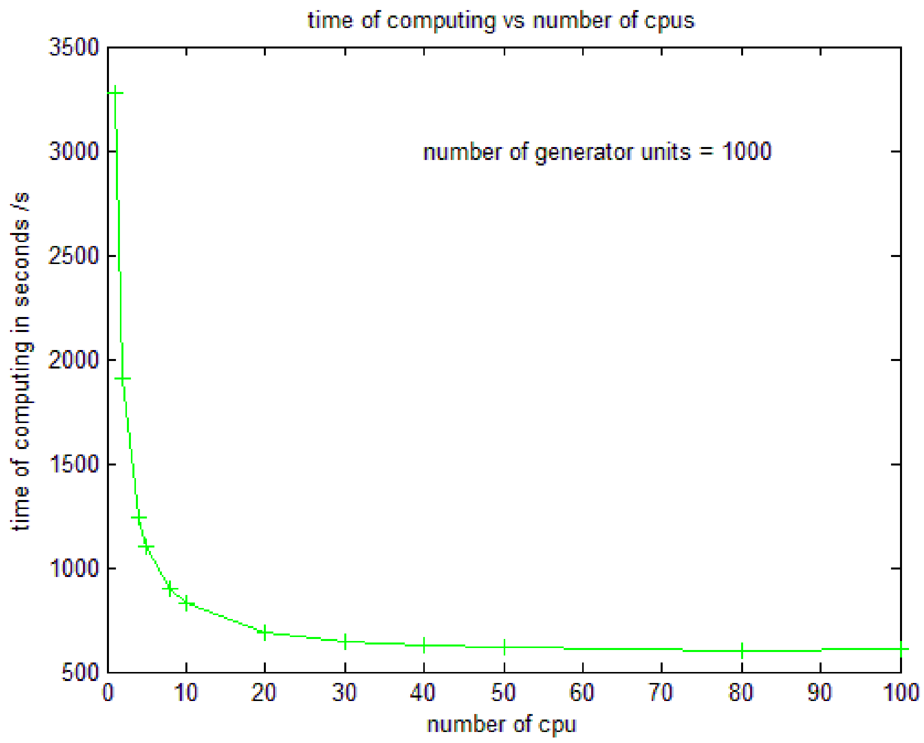
Unit Commitment Problem

- Optimal generator assignment problem for electric grid
- Schedule the power generator units over a short time period, in order to:
  - Minimize the operation cost
  - Satisfy the electricity demand
  - Maintain system reliability
- Formulation: Mixed Integer Programming Problem

Unit Commitment Problem

- Challenges
  - Large scale mixed integer programming: thousands of integer and continuous variables, numerous security constraints
  - Uncertainty in electricity loads
  - Volatile energy sources: wind energy, solar energy
- Solutions
  - Parallel implementation of UCP solver to boost computational speed
  - Stochastic modeling of uncertainty

Effectiveness of Parallel Computing



Computational time (in seconds) *vs.* Number of CPU's
Number of power generators: 1000