# Distributed Reinforcement Learning for Electricity Market Bidding with Spark

Vishnu Nanduri, Ph.D.
Vijay Srinivas Agneeswaran, Ph.D.

IMPETUS

Impetus Technologies Inc.

2014 Spark Summit (June 30th-July 2nd), San Francisco, CA





IMPETUS
Innovation Architected.

# Speaker Bios

- Vishnu is a Senior Data Scientist with experience in Reinforcement Learning, Supervised Machine Learning, Stochastic Optimization, and Statistical Analysis. He was a faculty member at the University of Wisconsin-Milwaukee before joining Impetus.

- Vijay is the Director for BigData Labs at Impetus, with experience in cloud, grid, peer-to-peer computing, and machine learning for Big-Data. He is the author of the recently published book "Big Data Analytics Beyond Hadoop."

# Agenda

- What is an electricity market?
- Why does it need to be modeled?
- Are there other markets that need/or could use such modeling?
- Why reinforcement learning?
  - Background and basics
- Why Spark? What other options exist?
- Solution strategy over spark
- Ongoing and future work

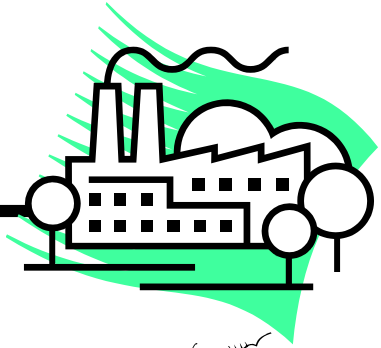



IMPETUS
Innovation Architected.

# What is an Electricity Market


ISO balances supply and demand and decides the price-quantity allocations

Independent System Operator (ISO)



Multiple Competing Suppliers submit Price-Quantity bids

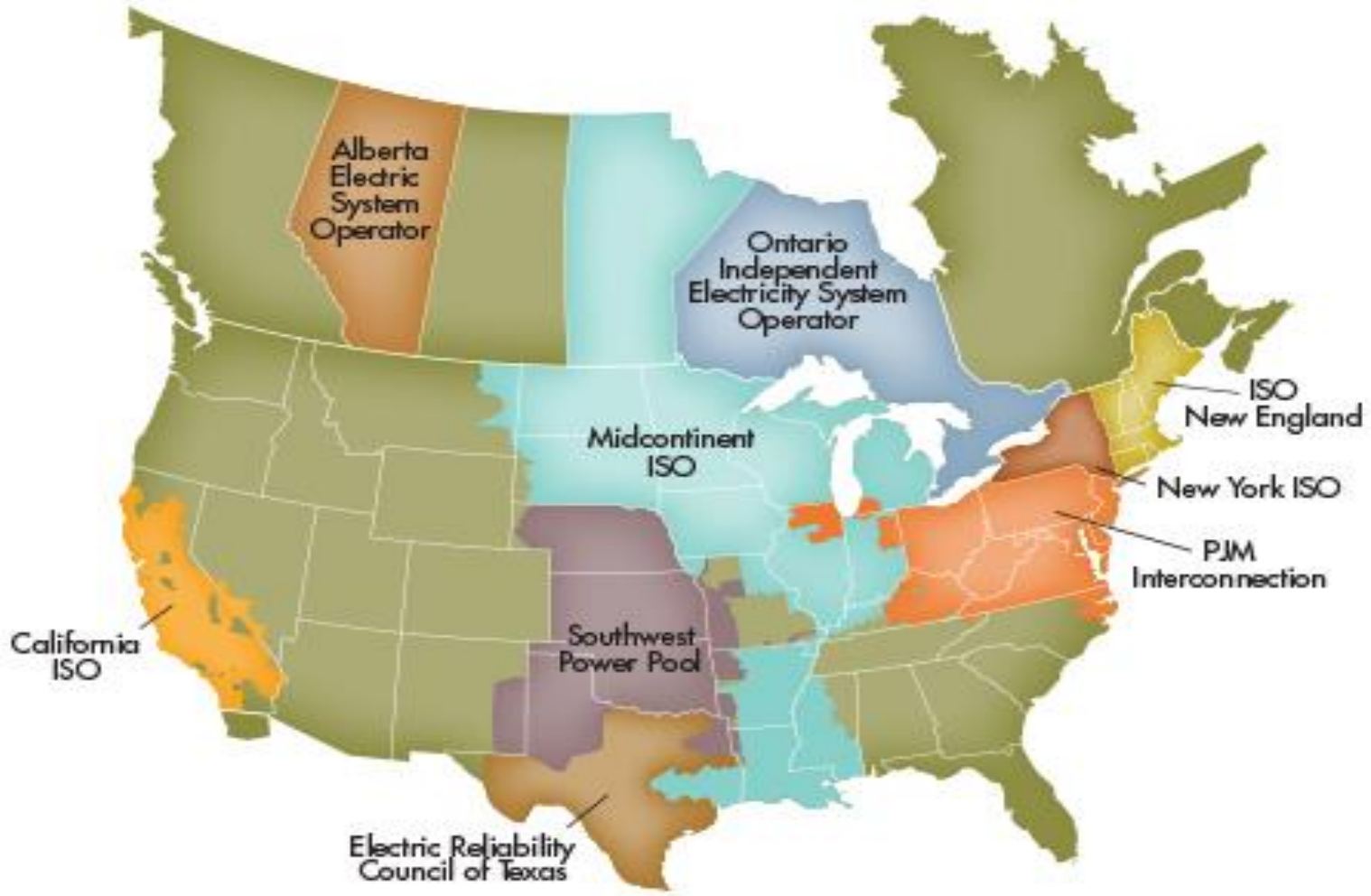
Load Serving Entities (LSEs) submit demand bids

IMPETUS
Innovation Architected.




Images from clipart and freefoto.com

# Electricity Markets in North America




Source:
http://www.caiso.com/about/Pages/OurBusiness/UnderstandingtheISO/Opening-access.aspx




IMPETUS
Innovation Architected.

# Why does it need to be modeled?

- To understand long-term behavior of market
- Equilibrium behavior
- Assessment of market power
- Investigate policy prescriptions




IMPETUS
Innovation Architected.

# Modeling Approach

- Bid each day (each hour) for supplying power the following day
- Stochastic processes underlying the day ahead energy market operations are modeled as a Markov chain
- Decisions embedded on a Markov chain are modeled as Markov decision processes
- Multiple generators competing in a market is modeled as a competitive Markov decision process (a.k.a., stochastic game)




IMPETUS
Innovation Architected.

# CMDP Model

- Let $B$ = Set of Supply/Load Buses in the Network

  $M$ = # of loads

  $N$ = # of suppliers

- $X^t = (q^t, p^t)$, is the system state at any day 't'

where,

- $q^t = (q_1^t, q_2^t, , q_3^t, , \ldots\ldots\ldots\ q^t_{|B|})$-forecast load vector
- $p^t = (p_1^t, p_2^t, , p_3^t, , \ldots\ldots\ldots\ p^t_{|B|})$- anticipated bus price vector
- $D^t = ( D_l^t : l \in \{ 1,2,3,\ldots\ldots N\})$

where,

- $D_l^t$ = $l^{th}$ generator's bid




IMPETUS
Innovation Architected.

# CMDP Model

- $X = \{X^t : t \in N\}$- System State process
- $D = \{D^t : t \in N\}$- Decision process
- The joint process $(X, D)$ is a Competitive Markov Decision Process
- Average reward criterion and non-zero sum nature of the game make solution more challenging
- Hence, simulation based optimization called Reinforcement Learning (RL)




IMPETUS
Innovation Architected.

# RL Basics

- The theory of RL is founded on two important principles:
- Bellman's equation and the theory of stochastic approximation.
- Any reinforcement learning model contains four basic elements:
  1. System environment (simulation model)
  2. Learning agents (market participants)
  3. Set of actions for each agent (action spaces)
  4. System response (participant rewards)

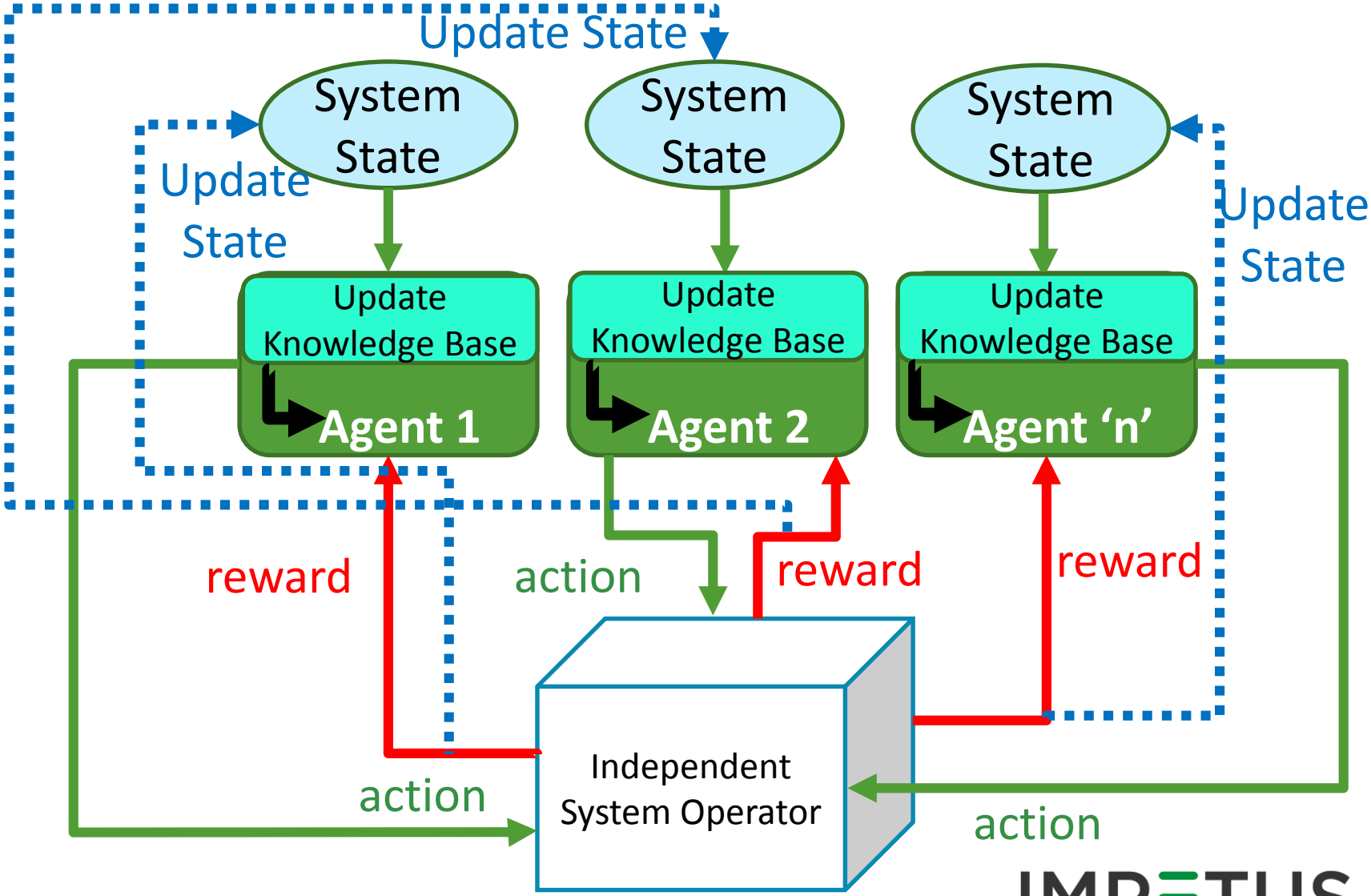
# Are there other applications?

- Generation capacity expansion planning
- Carbon allowance markets




IMPETUS
Innovation Architected.

# Reinforcement Learning: A Schematic







IMPETUS
Innovation Architected.

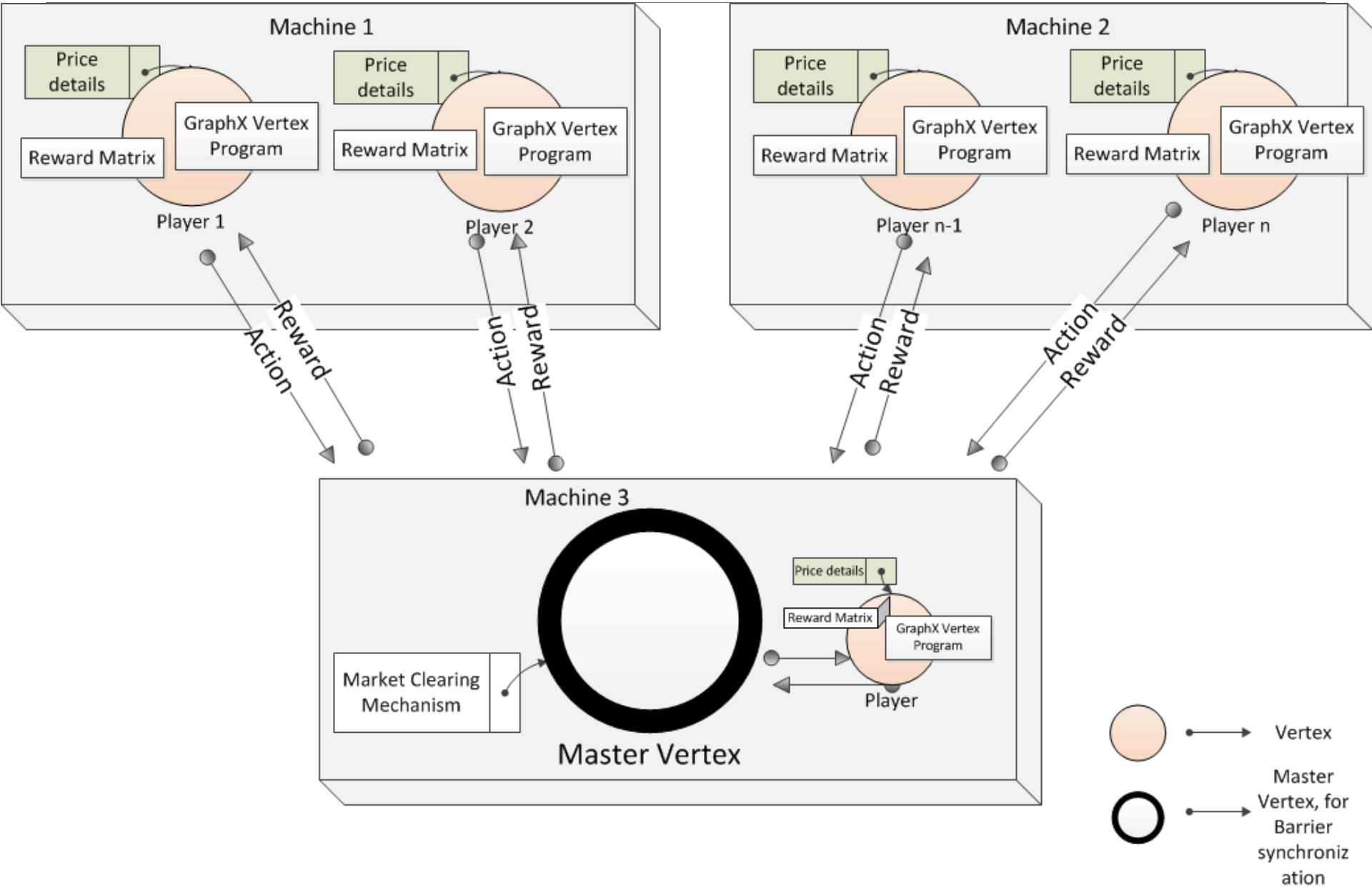
# Why Spark?

- Hadoop Map-Reduce is not well suited for iterative machine learning algorithms
- Twister/HaLoop/Apache Hama
  - Fault-tolerance is questionable,
  - Enterprise readiness is not clear
- GraphLab
  - Can only take distributed snapshots – no automatic recovery.
- Possible application to the spot market – real-time electricity bidding.




IMPETUS
Innovation Architected.

# RL Implementation over Spark



# Work-in-progress

- Giraph like APIs for GraphX
  - Allow user to specify master code VS slave code
  - Explicit barrier synchronization
- Reinforcement learning over Spark
  - Can be used by independent system operator or by individual generators
  - Can be used in other competitive bidding-based markets such as carbon allowance markets, which is a multi-million dollar industry in U.S. and Europe.
- RL over Hadoop/Stratosphere
  - Comparison with Spark/GraphX




IMPETUS
Innovation Architected.

Thank you!




IMPETUS
Innovation Architected.