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Market Simulations for Evaluation of Regulatory Strategies

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Market Complexity

- Markets are complex, chaotic systems
  - May 6 “Flash Crash”
- How do we design and test new regulations?
  - Law of unintended consequences
- Transaction volume
  - CBOT ~10^7 contracts daily
  - NYSE ~2×10^7 transactions daily

Why Agent-Based Modeling (ABM)?

- ABM is intuitively appealing when describing complex systems in which
  - System dynamics are a function of heterogeneous interacting agents
  - Dynamics occur over multiple, possibly long-range time scales
  - Actions and decisions are made locally, with local information

- ABMs capture full distributional information
  - Facilitates identification of extreme or “tail” events

- ABMs capture explicit *and* implicit feedback effects

- In market modeling, ABM provides a natural and easily understood association between simulation elements and market participants

Sandia and Agent-Based Simulation

- Sandia has extensive experience developing agent-based simulations
  - N-ABLE [NISAC: Eidson, Mackey, Ehlen, et al.]
  - CoreSim [1410: Watson, Strip, Mitchell]
  - EMPaSE [1430: Siirola]
  - Loki [6320: Glass, Beyeler, Quach, Detry, Bynum, et al.]
- Experience includes
  - Modeling expertise required to capture “fuzzy” agent behaviors
  - Development of frameworks to support rapid deployment
  - High-speed simulation to support national-scale analysis
- Two specific examples
  - Policy assessment for diabetes management in Brownsville, Texas
  - Spare parts logistics chain analysis for the Joint Strike Fighter

Diabetes Mellitus: A Prototypical Policy Scenario

- Focus on Diabetes Mellitus (DM) progression in the US/Mexico border population
  - Politically "hot" at both state and national levels
  - DM is epidemic in Mexican-American populations, huge public costs
  - Extensive data set for individuals from Brownsville, TX

- Baseline case
  - Initialize agents based on Brownsville survey statistics
  - Execute simulation over 20 years, track number of agents in each of the various DM states (non-DM, diagnosed-DM, DM-with-complications, etc.)

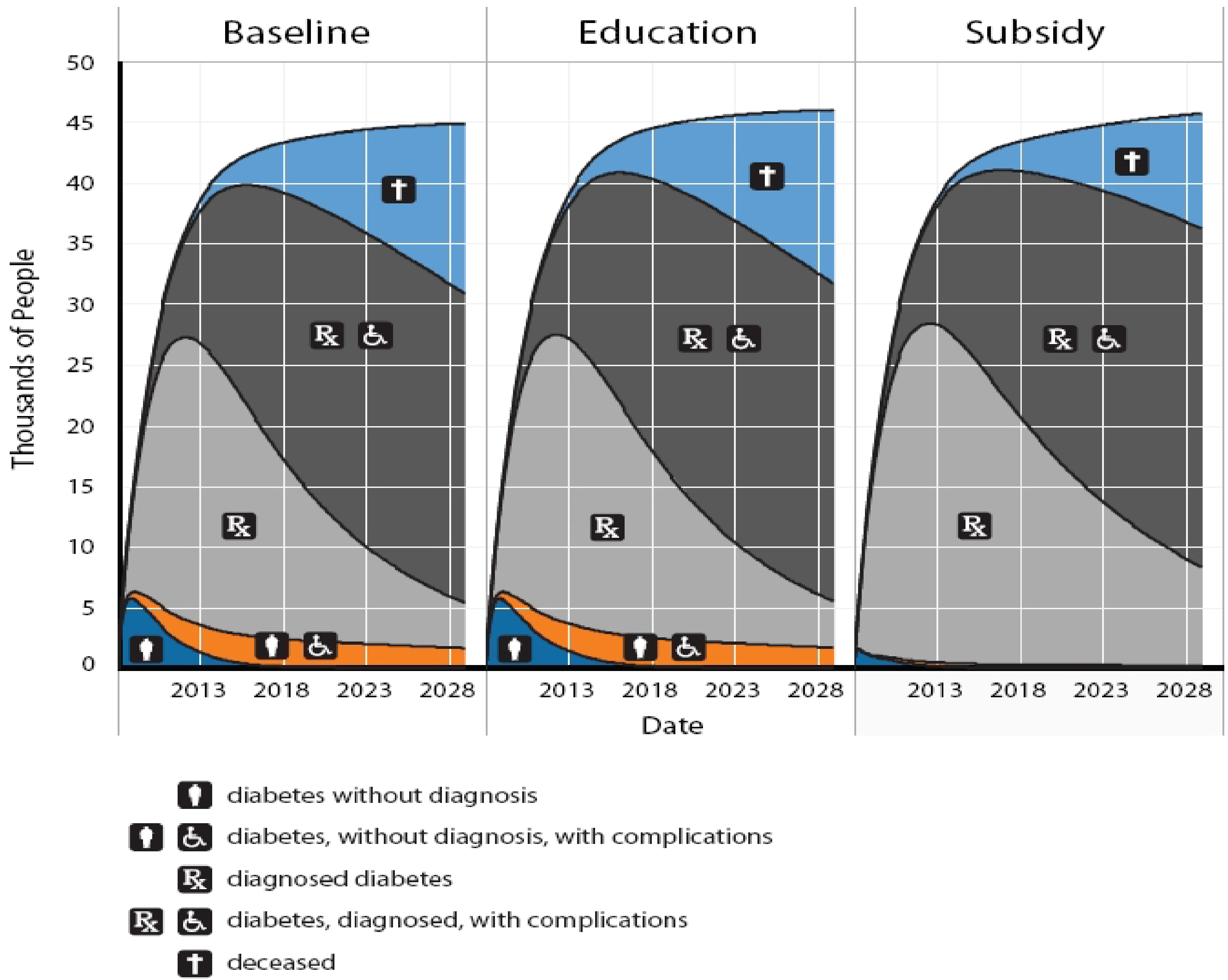
- A policy of interest: "The Medical Home"
  - Around-the-clock, comprehensive, coordinated, and on-going medical care
  - No agreement over how to best *implement* the medical home concept
  - Some incremental alternatives
    - Subsidies to reduce the cost of doctor visits
    - General access to dieticians and other lifestyle influencers

Agent-Based Model Highlights

- Individuals
  - (Pseudo-)static attributes such as height, sex, income, etc.
  - Evolve physiological attributes over time, including weight/BMI, HbA1c, based on factors including activity level and caloric intake
  - Track DM-related state changes through time
  - Initiate and track doctor visits

- Populations
  - Individuals are linked through physical and virtual social networks
    - “Small-world” distributional characteristics
  - Weight gain/loss is influenced by the BMI distribution of friends
    - “Fattiness” as a social phenomenon (JAMA)
  - Medical adherence is influenced by friends and your support network

Evaluating Alternate "Medical Home" Policies



The Lockheed Martin Joint Strike Fighter (JSF)

- Scale of sustainability support system for JSF
  - Thousands of distinct line-replaceable parts (LRUs) per aircraft
  - 3,000+ aircraft over 20 years at 60+ bases on 4 continents
  - 50+ OEMs, 10+ supply depots, 10+ repair depots
  - 50+ year operational lifetime

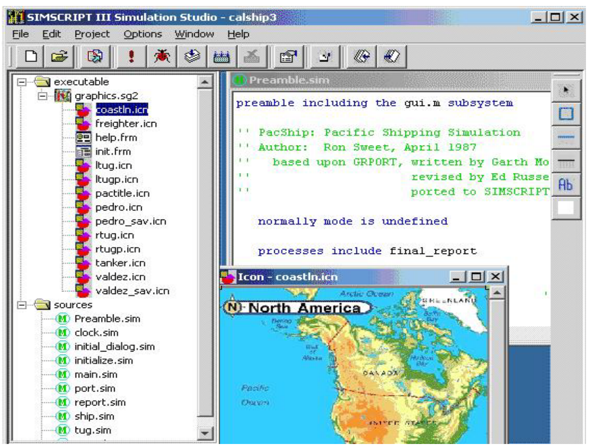
- The primary use of any weapon systems is peacetime operations

- The primary peacetime objective is to perform a pre-determined schedule of training and operational readiness missions

Accelerating Logistics Simulation Through Domain-Specific Discrete-Event Software Libraries

Commercial, General-Purpose Library +
High-Level Programming Language

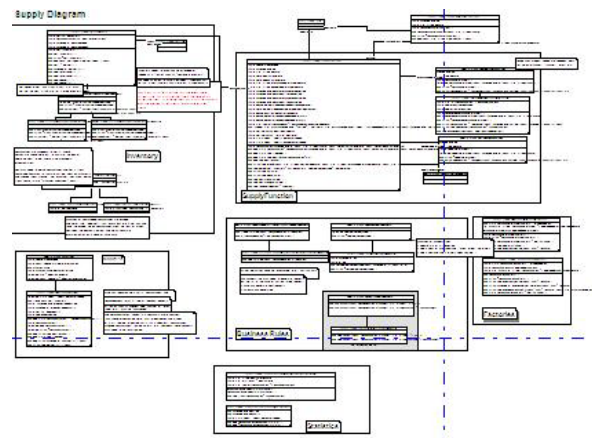
MODSIM



Faster development, low SE expertise,
slow run-times

Domain-Specific C++ Library +
Careful Algorithmics and Profiling

CoreSim



Slower development, high SE expertise,
fast run-times

Real-world performance: 35 seconds to 70ms (test data set)
> 12 hours to 15 seconds (JSF data set)

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Assessment of Regulatory Strategies via Simulation

- A primary simulation use case for CFTC is the identification of system conditions that can yield anomalous or extreme behaviors
  - The May 6 Flash Crash
  - Unexpected instabilities induced by automated trading algorithms

- First-order approaches
  - Systematic exploration of parameter space (LHS / Importance Sampling)
  - Coupling with black-box optimization to reproduce specific behaviors

- Second-order approach
  - Optimization to design specific trading agents that yield extreme events
    - Automated “interdiction”

Market Reconstruction

- By using historical data to drive the simulation, the ABM can be used to reconstruct the state of the market and it's participants

- Allows *post facto* analysis of events

- Allows detailed view of portfolio positions over time, as well as the evolution of other aspects of participants state.

Risk Assessment for Complex Financial Instruments

- CDO, CDS, synthetic CDO, etc., all can have complex structures with hard-to-model correlations, cascading effects, etc.

- Inadequate modeling of complex instruments played a significant role in the financial crisis

- Opportunities
  - Independent assessment of underlying risk
  - Better evaluation of "tail" risk
  - Modeling cascading effects among multiple instruments
  - Targeted modeling of extreme cases
    - Parameter space search
    - Optimization

What we are *not* proposing

- Forecasting or predicting market movements

- Creating tools for investors to "beat the market"

Research and Implementation Challenges (1)

- Modeling trader behavior
  - Electronic trading algorithms
    - Are analytic representations available?
    - Existing rules limiting range of trading behaviors?
    - How sensitive is the market to the exact algorithm?
  - Human traders
    - How to construct parameterized families of agent models

- Technical approaches
  - Data mining and machine learning
  - Literature and subject matter experts

Research and Implementation Challenges (2)

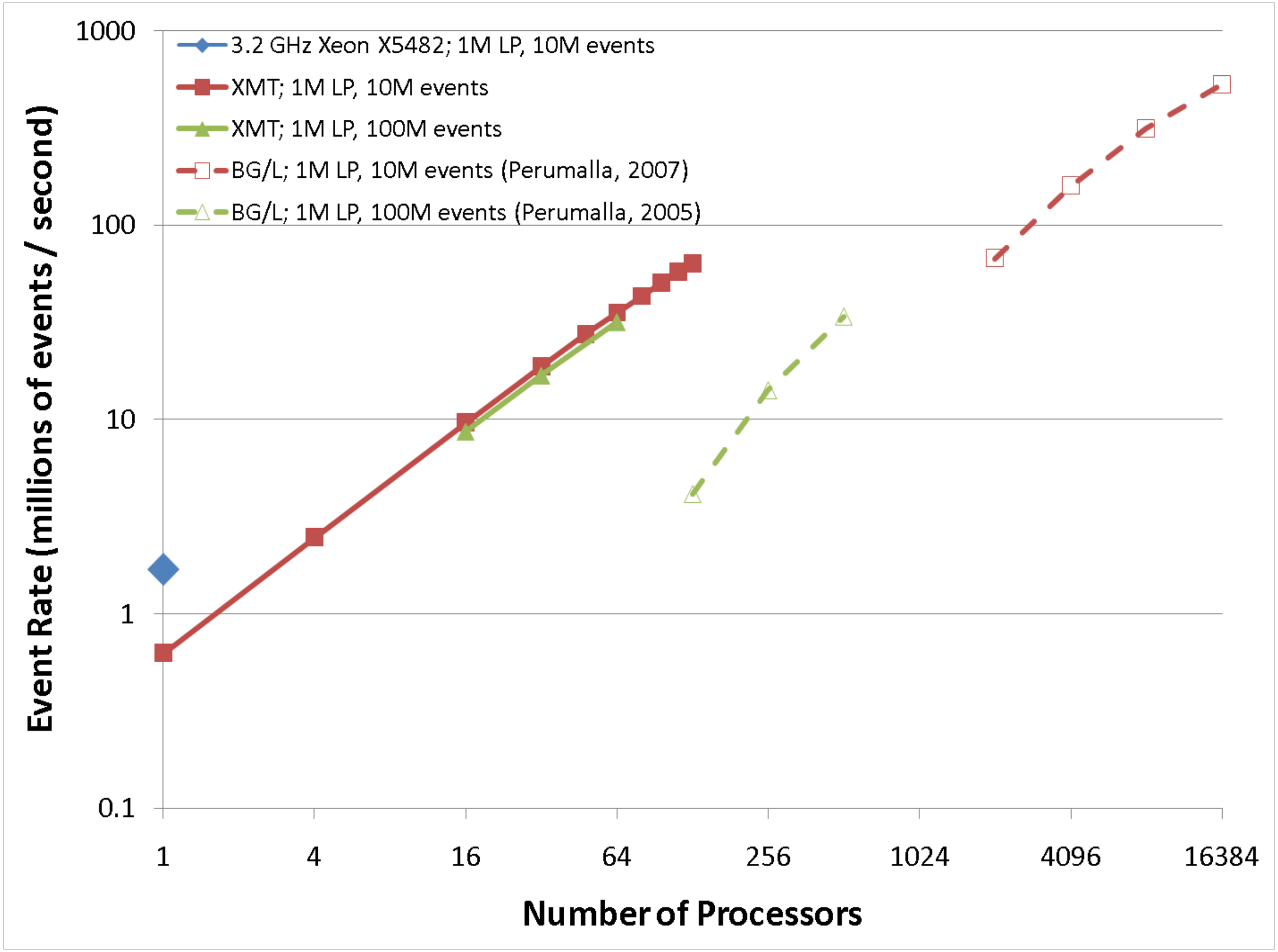
- Interactions among multiple markets
- Key practical issues
  - Model maintenance
  - User interface
  - Execution platform(s)
    - Client-server?
    - HPC?
- Validation and Verification

Parallel Agent-Based Simulation (PDES)

- Why?
  - Size & Speed

- Notoriously difficult, despite >30-year history
  - "Thin events" (low computation-to-communication ratio)
  - Unstructured communication pattern
  - Fine-grained synchronization requirements: global time
  - *Huge* memory requirements
    - e.g. 300M individuals in a national disease propagation model
      - 1.2 – 14.4 GB just for a directory mapping (individual -> node)

Efficient, scalable PDES engines



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Conclusions

- Modeling and Simulation provide powerful tools for analyzing the impact of
  - Existing and alternative regulatory strategies
  - Existing and alternative trading strategies
  - Existing and future investment instruments

- Modeling and simulating markets regulated by the CFTC is challenging but within the scope of other problems we have addressed

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Conclusions

- The scale of a realistic commodities market model *may* require advanced computing to make the simulation tractable. Alternatives we have utilized include:
  - efficient single-processor engines (CoreSim)
  - off-the-shelf parallel engines (from RPI, ORNL, WarpIV) on commodity clusters
  - bleeding edge research on specialized hardware (XMT)