Department of
Telecommunications

Agent-based Modeling of Electricity Markets in a Smart Grid Environment

Ph.D. Qualifying Examination

Candidate: Jurica Babić
Faculty of Electrical Engineering and Computing

Supervisor: Assistant Professor Vedran Podobnik

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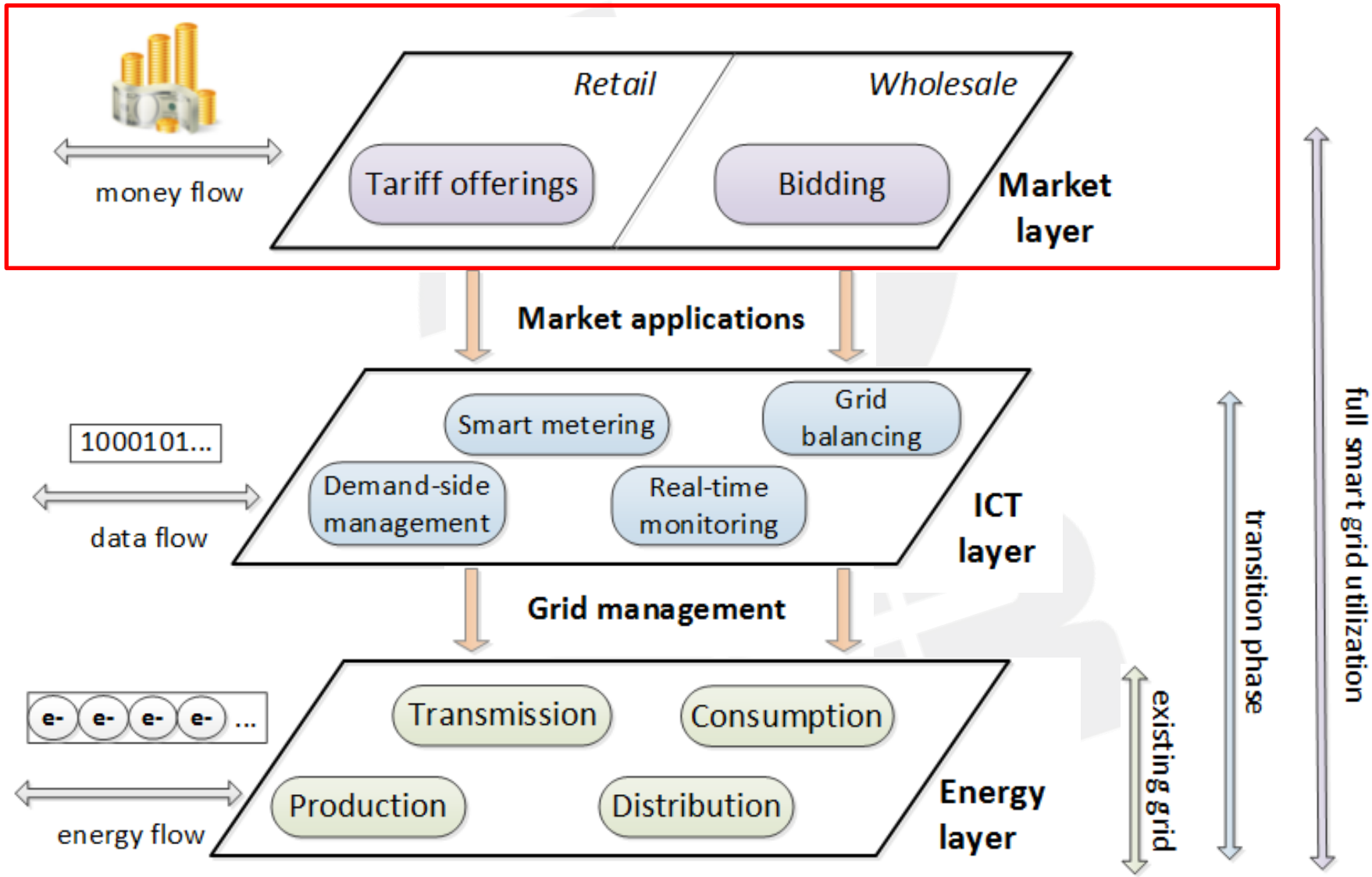
Outline

- Introduction – drivers of the smart grid
- Smart grid
- Electricity markets
- Electricity market modeling
- Agent-based computational economics
- Conclusions & future work

Introduction – drivers of the smart grid

- Modernization of the existing grid
  - Secure, reliable, efficient, sustainable electricity system
- European Union (EU)
  - Europe 2020
  - Different grid implementations
  - Main drivers: **environmental** and **diversity of grids**
- United States (US)
  - Northeast blackouts (2003, 50 million people without electricity for 2 days, 11 deaths, $6 billion cost)
  - Energy Policy Act (2005), Energy Independence and Security Act of 2007
  - Main drivers: **grid reliability** and **security of supply**

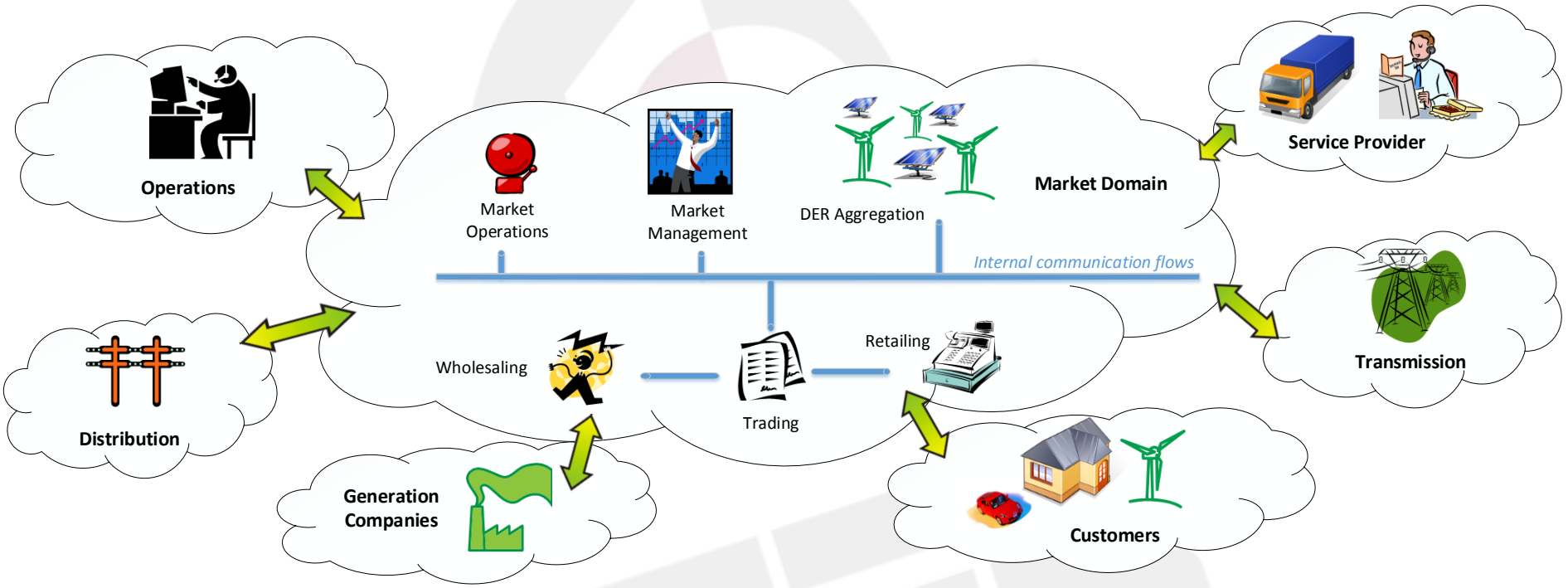
Multi-layered conceptual model of a smart grid



Economic benefits of the smart grid

- Prediction: smart grid has economic benefits
  - Great Britain (Ernst & Young report, 2012)
    - Benefits for other industries, boost in growth, jobs and exports
    - Investment strategies by 2050: smart grid could safe as much as **$30 billion NPV** over conventional technologies
  - US (Electric Power Research Institute report, 2011)
    - Net benefits (next 20 years) (e.g., productivity, quality of life, security and reliability) estimated at **$2028 billion**
  - Oman (Malik and Bouzguenda, 2013)
    - Net benefits (next 20 years): between **$2.3 billion** and **$4.2 billion**
- Potential savings on reliability costs
  - Power shortage (brownouts and blackouts)
  - US (Lacommare and Eto, 2006) – 1/3 total revenue from retail sales of electricity
  - Spain (Linares and Rey, 2008) – **Value of the lost load (VoLL) [kWh] $8** vs **retail price $0.25** (2013)

Market entities and interactions in smart grid market layer

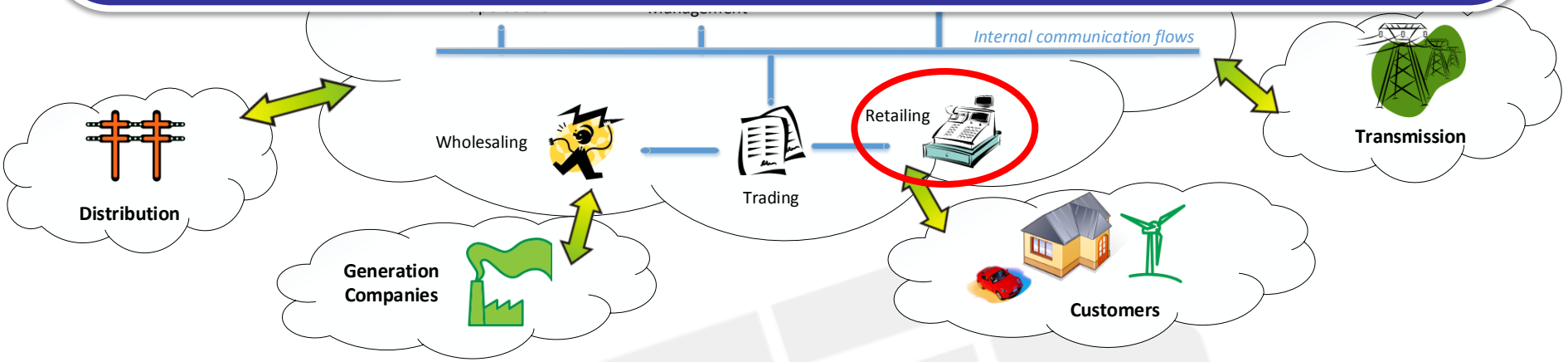


- Electricity
  - a produced good which can be bought or sold on an electricity market
  - storage expensive - instant consumption required

Market entities and interactions in smart grid market layer

Retail markets = sales of electricity to consumers by retailers

„energy choice" for end-customers, i.e., the ability to choose their supplier from competing retailers



- Electricity
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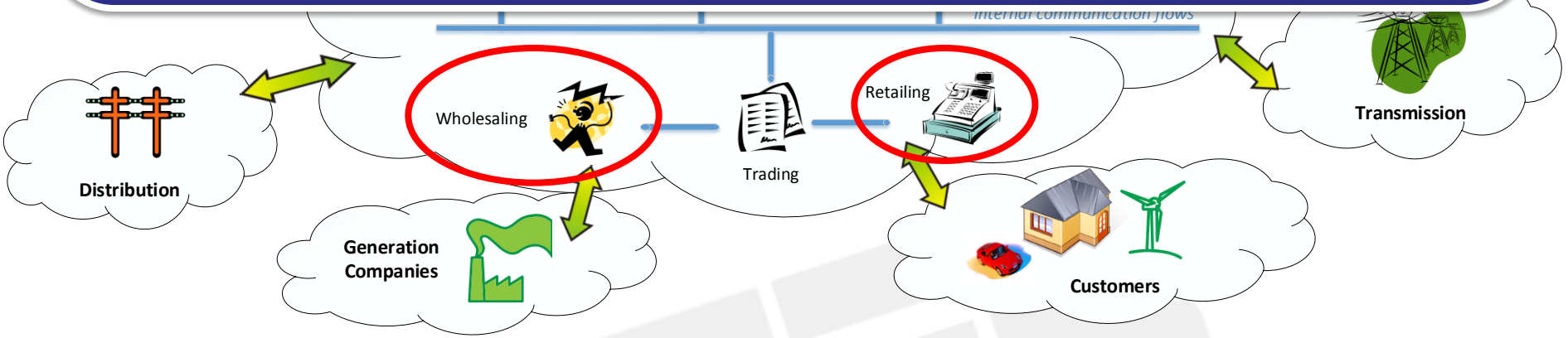
Market entities and interactions in smart grid market layer

Wholesale markets = sales of electricity among electric utilities and electricity traders before it is eventually sold to consumers

Types: Day-ahead spot market, Bilateral trading or over the counter (OTC) trading, Intraday market, Balancing market



- Electricity
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Considerations regarding electricity markets

- Before:
  - Little or no competition
  - Vertically itegrated monopoly structures (production, transmission, distribution)
- Nowadays:
  - Unbundling of a power system
  - More competition
  - Infrastructures kept under a natural monopoly
- Electricity deregulation & liberalization
  - Removing or reducing state regulations
  - Promoting the efficient operation of markets
  - **Pros**: high productivity, efficiency, lower prices
  - **Cons**: complicated process, complex market design = gaming, price volatility

Motivation For Market Modeling

- Market deregulation & market liberalization
- Retail market
  - Highly competitive
  - Efficient price signals => choice and & simplicity for end-customers
  - Customers role in balancing process
- Market design deployment without serious testing is dangerous (e.g., California energy crisis 2001)
  - complex
  - time consuming
  - risky
- Better approach
  - Test and evaluate all possiblities to prove market design robustness
  - **Test bed** needed
  - Prerequsite for a test bed is a **good electricity market model**

Electricity Market Modeling (1)

- Roots
  - early 1990s
    - Genetic algorithms (e.g., Marks, 1992, and Arifovic, 1994)
  - mid 1990s
    - Object-oriented paradigm (e.g., Räsänen, 1994)
    - Agent-based framework (e.g., Hämälainen and Paratainen, 1995)
  - 1998 onwards
    - James Hoecker (US Federal Energy Regulatory Comission Chairman, FERC) on computer-based electricity market models:
      - Economic interactions among suppliers and loads, transmission flows
      - Needed: time, education and consistent refinement
  - Nowadays: expansion of researches in electricity market modeling

Electricity Market Modeling (2)

- Electricity Market is a Complex Adaptive System (CAS) (James Holland, Santa Fe Institute)
  - Complex – a lot of entities and interactions among them
  - Adaptive – entities are able to learn and act on their own
  - Emergent behaviour – interactions cause a system to evolve which leads to emergent properties
- Market design guidelines
  - Wholesale design guidelines given by FERC (2003):
    - Reliable service, access to transmission grid, price signals, market power mitigation
  - General prerequisites (Crampton, 2003):
    - Finding the objective of a market
    - Understand the preferences and constraints of market participants

Common market modeling approaches

- Equilibrium models
  - Consist of equations for describing model variables and a database
  - Lack of strategic behaviour modeling
- Game theory
  - Mathematical models of conflict and cooperation between decission-makers
  - Constrained model on a few factors => unrealistic behaviour of participants
- Human-subject research
  - Use of human subjects for a systematic research
  - Expensive, time-consuming and highly complex process
- **Agent-based modeling**
  - Market entity encapsulated within a software agent
  - Rich modeling capabilities => more realism

Agent-based Computational Economics (ACE)

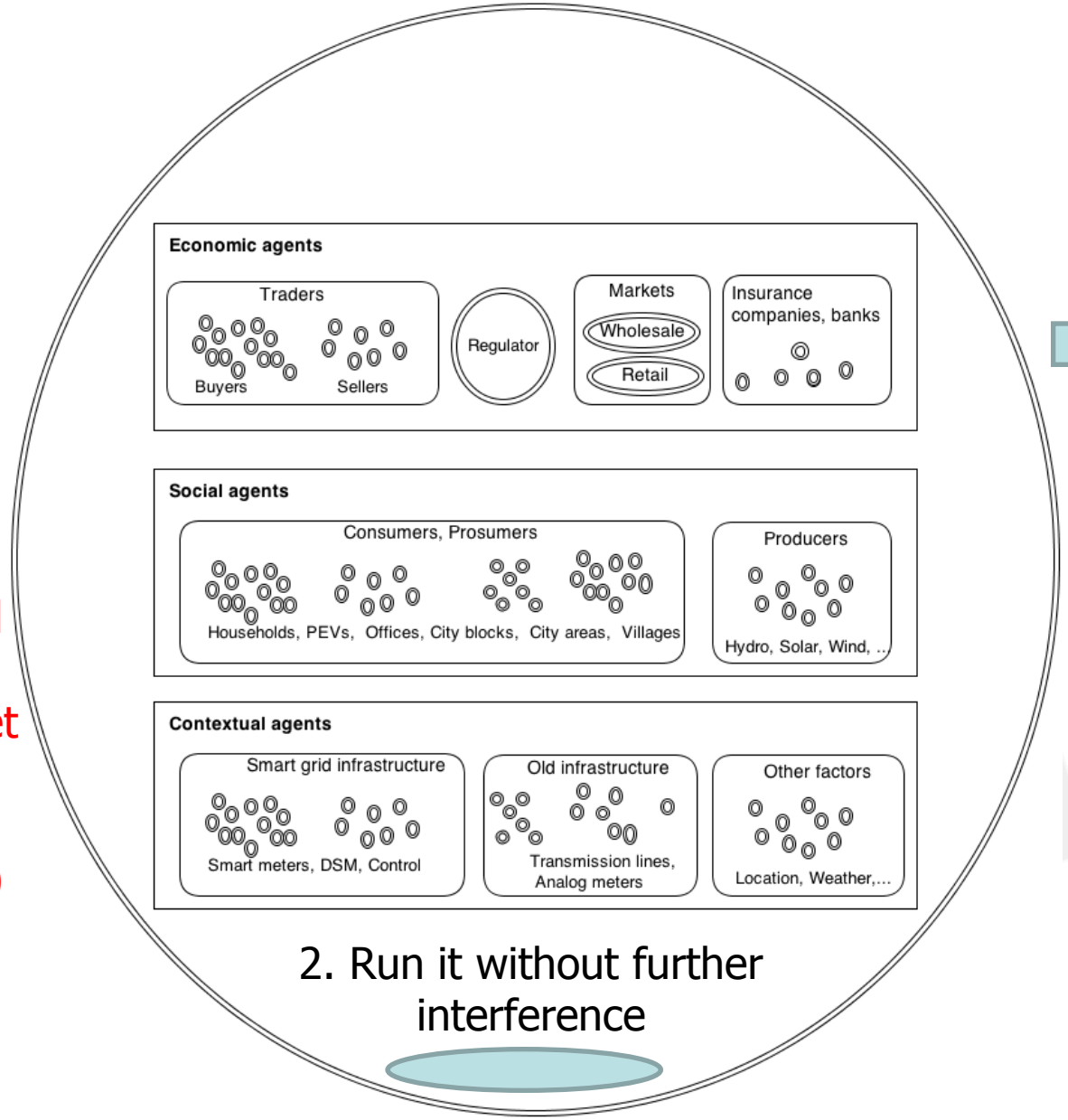
- „Computational study of economies modeled as evolving systems of autonomous interacting agents" (Tesfatsion, 2002)

- (A lot of) adaptive agents + local interactions = CAS
  - Microstructure = decisions and actions by agents
  - Macrostructure = emergent market conditions
  - Captures the „two-way feedback loop"
- ACE utilizes *bottom-up* approach to model a culture dish of three sets of agents:
  - Economic agents
  - Social agents
  - Contextual agents

ACE culture dish of an electricity market

1. Set up an experiment

Input: initial conditions (e.g., market protocols, agents paramaters)



2. Run it without further interference

Output: raw data

3. Answer

Why the behaviour emerged and persisted? (e.g., wholesale price patterns)

How did agent X influence the experiment? (e.g. destructive buyer caused high price volatility)

Smart grid market modeling with ACE

- Understanding and evaluating the market design
- Exploring the regulatory framework for markets
- Assesing interactions between automated markets and trading agents
- Development of rich environment for economic decision-making
- Proposing business policy based on expected market behavior

Important Agent-based Electricity Market Simulators (1)

- Electricity Market Complex Adaptive Systems Model
  - 2002, US, maintained by Aragonne National Laboratory
  - Results on economic consequences for companies and consumer groups in different scenario
  - Two/three weeks of training required
- Multi Agent Intelligent Simulator (Sueyoshi, 2008)
  - Used to study dynamic changes in prices in US wholesale market before and during the energy crisis in California
  - Agents can adapt trading strategies based on previous experiences
- Multiagent Simulation System for Competitive Electricity Markets (Vale, Pinto and Praça 2011)
  - Reinforcement learning
  - (Day-ahead, forward and balancing) markets and bilateral contracting
  - Used to evaluate a proposed method for trading in the electricity market

Important Agent-based Electricity Market Simulators (2)

- Power Trading Agent Competition (Power TAC)
  - Ketter, Collins, Block, 2010
  - **Open, competitive** market simulation platform
  - Extends the existing TAC scenarios (e.g., TAC SCM for supply chain management), simulations for testing policies for complex systems
  - Research results used to derive market rules for future retail-level electricity markets
  - Modeled: retail and wholesale market, balancing process, generation companies, retail customers, competitors
  - Competitors = brokers = energy companies
    - Tariff offerings for retail customers
    - Load management on the wholesale market
  - Different market scenarios (from oligopolies to highly competitive markets)
  - Research teams prepare intelligent software agents (competitive brokers) for the annual competition

Conclusions & Future Work (1)

- Electric power systems undergo major modernization process
- Smart grid is an important technical foundation for new emerging services (e.g., new tariff types on the retail market) in the market layer
- Electricity markets are highly complex
  - Many heterogeneous entities and interactions
  - Before real-life deployment, a good market model is required
  - Test bed needed

Conclusions & Future Work (2)

- Agent-based computational economics
  - Suitable for electricity markets since they are CAS
  - Electricity market entities are modeled as intelligent and interactive agents
  - Bottom-up approach, removes design barriers
  - Agent-based simulators can be used as a test bed for electricity markets
- Future work
  - Croatian retail-level electricity market:
    - Entrance of new retailers (currently happening)
    - Aging infrastrucutre (e.g., analog metering)
  - Technical and regulatory foundations for the evolution of future energy business in Croatia
  - Croatian electricity market as a use case for proving a general solution
  - Power TAC seems as a suitable tool for such research

References

- For full list please consult the supporting article