Behavioral Elements in Simulation Models

Ahti Salo
Systems Analysis Laboratory
Helsinki University of Technology
P.O. Box 1100, 02015 HUT

Background

- Systems analysis laboratory
  - Operations research, decision analysis, risk management, investment science
    - » about 15-20 MSc theses and 2-3 dissertations a year
    - » graduate school in systems analysis, decision making and risk management
  - Decision models and analysis, evaluation methods, technology foresight
    - » financial engineering, investment science, risk analysis
    - » energy markets, telecommuncations sector, theory

- Example of Theses Work
  - Teemu Nyholm: Optimization Algorithm for Securities Settlement (OMHEX Oyj)
  - Taras Beletski: Forecasting the Term Structure of Interest Rates with Stochastic Models (Research Center CAESAR)
  - Tomas Lågland: Stochastic Optimization in Dynamic Asset and Liability Management (Moneybell Ab)
  - Nuutti Kuosa: Market valuation of employee stock options. (HSE)
  - Kai Arte: Bandwidth Derivatives under Network Arbitrage (EigenValue Ltd)

Outline

- Simulation models
- Agents and systems
- Behavioral modelling
- Analogies
  - energy markets
  - military games
- Possible challenges

Why simulation?

- Rationales
  - Experimentation with the real system impossible or too costly/risky
  - System is so complex that ’good’ decisions cannot be taken e.g. by intuition
  - Changes in the system environment are envisaged

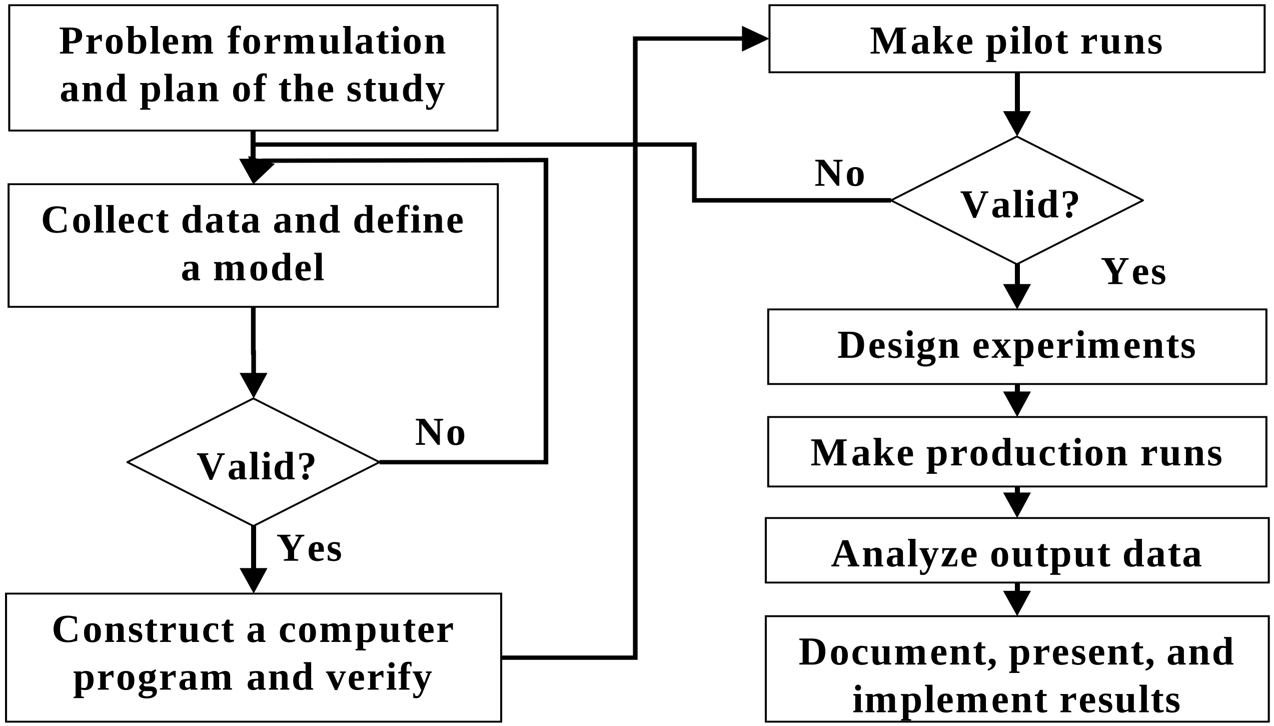
- Approach
  - Build a model which captures the salient features of the system under study
    - » often leads to a learning exercise as such
  - Modelling issues
    - » system scope - what are the salient features? time horizon?
    - » validation - does the system really capture these featues? (cf. errors of omission)
    - » verification - does the system produce correct results?

- Uses
  - Gain insights into possibilities for enhanced performance or robustness
  - No ’optimal model’ - a purposeful model is better than a comprehensive one

System concept

- ”A collection of entities that act together toward the accomplishment of some logical end” [Schmidt&Taylor 1970].
- Simulation model
  - A (computer) program describing the system under study
  - The interaction between entities is well defined
  - System environment = external factors which can cause a change in the system
  - System state = collection of variables necessary to describe a system at a particular time
- Typologies
  - Static - Dynamic (e.g., does the system evolve over time?)
  - Continuous - Discrete (e.g., is the system event-driven?)
  - Stochastic - Deterministic (e.g., are the inputs and outputs uncertain?)

Steps in simulation



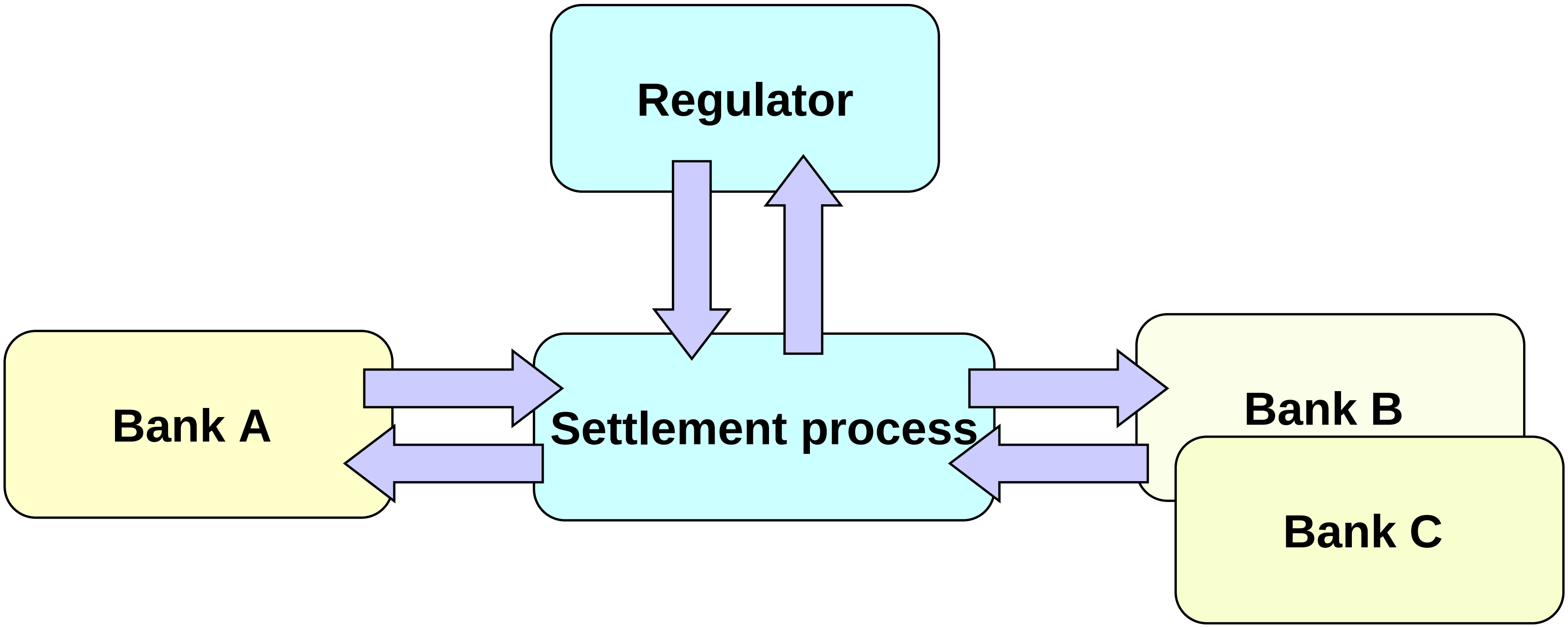
As viewed by Law & Kelton

Advantages and concerns in simulation models

- Benefits
  - Control over experimental conditions
  - Possibility to study even non-existent
    - Compression or expansion of time
    - Few limitations on problem type or model structure
  - Comparisons with other decision support techniques
  - Observation and development of diverse performance indicators
  - Sensitivity analysis (cf. risk management)
  - Dynamic visualisations, educational uses

- Remaining questions
  - Model *validity* - do the results apply to the actual system, too?
  - Sufficiency of data (augmented by jugdementa)l
  - Cost of data collection, model construction, experimentation
  - Usability and usefulness of results - strategies to improve system behavior?

Trading as a system



Agents

- Characteristics of agents
  – Possess independent decision making capabilities (e.g., actions, trades)
  – Pursue their own objectives (e.g., preferences over alternative system states)
  – Exert an influence on the system state through their actions

- Issues in agent modelling
  – What is the scope of actions that the agents take?
  – What do the agents know when taking their decisions?
  – How do the agents map this information onto decisions?
  – How does the system state evolve through these decisions and other determinants? ('rules of the game')

- Possible simplifications
  – agents are 'similar' or represents pre-defined cohorts
    » permits the modelling of large networks
    what characteristics are resilient as the size of the network changes?

Concerns in behavioral modelling

- Game theory and mainstream economic modelling
  - Assumptions
    - Agents are rational and have similar expectations ('theory of rational expectations')
    - Well-defined objectives captured by von Neumann-Morgenstern utility functions
  - These are partly unrealistic
    - 'bounded rationality' (Herbert Simon)
    - empirical evidence on the use of 'rules of thumb'

- Agent modelling
  - Develop simple mapping which convert observations into actions
    - e.g., technical trading rules ('sell if the price falls below 10€')
  - Applications in literatures on
    - (distributed) artificial intelligence - emergence in the late 1980's
    - decentralized automation and control (robust systems)
    - regulatory design and performance assessment
  - Learning often a key challenge

Possibilities in behavioural modelling

- Data-based pattern matching
  - Behavioural patterns are assumed to be reflected in available data
  - These patterns stable enough and can be discovered with suitable techniques
  - Agents exhibit similar behavioural patterns in the future, too

- Validation
  - Selection of sample data for estimation purposes
  - Validation through application to out-of-sample test data
    - » To what extent are agents forward-looking?
    - » Impact of delays (observation, reflection upon information, execution of actions?)

- Examples of methodological approaches
  - Neural networks
  - Linear judgemental models
  - Rule-based simulation
  - Parametric fitting

Methodological approaches (1/3)

- Neural networks
  - Non-linear multi-layered models which map input onto outputs
  - Features
    - are able to capture non-linear and complex behavior
    - not easy to see ’why’ the agents behave as they do - a ’black box’ approach
    - require a (very) large set of training data
    - may exhibit unstable behaviour under extreme conditions - did not replace traders

- Linear judgemental models
  - Simple linear regressors where current, past and predicted informational cues combined as a weighted sum into a real-valued variable
    - cf. predictive control
  - Features
    - conceptual validity can be readily assessed
    - do not usually pose significant computational problems (apart from multicollinearity)
    - do not capture interactions arising from interactions among variables

Methodological approaches (2/3)

- Rule-based simulation
  - Short conditional statements about characteristic behaviour
    - » may be qualitative (e.g, ’take an umbrella if it is raining’)
    - » widely employed in the field of artificial intelligence
  - Features
    - » the logic of rules may be difficult to elicit and/or justify
      - ’what rules do I apply when playing Chess?’
    - » combinations of multiple rules may be difficult to foresee - stability is not guaranteed

- Variable parametric fitting
  - Behaviour assumed to obey parametric structures some patterns
    - » e.g., trades arrive according to an exponential process
  - Features
    - » parameters estimated and revised based on past data
    - » incremental learning can be modeled (within the confines of model structure)
    - » vulnerable to the selection of an inadequate structural model

Methodological approaches (3/3)

- Bayesian variable selection
  - Incorporate several models simultaneously
    - » associate probabilities with each model (its ’correctness’)
    - » revised these probabilities upon the arrival of new evidence
    - » generate outputs from each model
    - » revise model probabilisties accordingly
  - Features
    - » little ex ante guidance on the selection of models
    - » may involve an inordinate computational effort
- Combinations of all the above & yet others
  - most of the above do not even seek to model agent’s objectives
    - » implicitly contained in the data
  - cf. conjoint modelling in marketing research
    - » products exhibit characteristics, customers respond to these

Similation models in regulatory risk management

- Systemic risk
  - The possibility of system ’collapse’ is a major concern
  - Although extremely unlikely, it cannot be excluded from consideration
  - Analogies to the assessment of high-impact low-probability risks
    - » cf. nuclear accidents, catastrophic consequences due to natural phenomena (e.g., dam breakdowns due to floods)
    - » meticulous examination of past accidents, subsequent adaptation of regulatory measures

- Concerns
  - If past data is based on ’normal conditions’, how much information will it convey about how the agents would behave under ’abnormal conditions’?
  - How to imagine the ’unimagineable’?
    - » creative backcasting - start from the ’worst case scenario’ - infer what would have had to have happened before such a scenario?
    - » deliberate stratification in the simulation studies - focus on unfavourable drives etc.

Analogies

- Energy markets
  - energy is being traded at an exchange in the Nordic energy market
  - modelling issues
    - » energy utilities modelled as profit maximizers with known production capacities
    - » their actions consists of bids and offers for the delivery of electricity
    - » prices influenced by a host of factors (demand, rainfall, temperature)
    - » results of interest to regulators, too
- Military games
  - long tradition in the application of game theory in the military sector
    - » e.g., pursuit-evasion games between missiles and fighter planes
    - » team theory - agents share same objectives but act upon different information
  - formulations tend to become intractable in multi-agent multi-period settings
  - currently a ’hot’ topic

Concluding remarks

- Behavioral modelling must be driven by objectives
  - Do we wish to
    - » explain 'normal' behavior?
    - » explore the limits of the system?
    - » identify extreme risks?

- Challenges in robust regulation
  - Analogies to the assessment of high-impact low-probability risks
    - » cf. nuclear risks; judgemental complements to data-driven modelling
    - » cautious and defensible use of expert judgements

- Scoping of behavioral modelling
  - Parametric modelling of past data & extended variability of inputs?
  - Identification of context-sensitive behavioural patterns?
  - Impact of structural changes in the system? (e.g., larger networks)