G54SOD (Spring 2018)

Lecture 01

Introduction (The Bigger Picture)

Peer-Olaf Siebers & Dario Landa-Silva

The University of Nottingham

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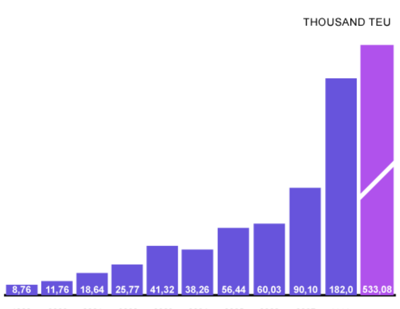
Container Terminal of Novorossiysk



Applet Viewer: novorossiysk_container_terminal/Simulation$Applet.class

Applet

x32 AnyLogic

Container Terminal of Novorossiysk

Simulation duration (weeks)	104
Trains arrivals per day (units)	2
Preparatory period before train arrival (hrs)	4
Parking service capacity (units)	16
Entry gate lanes (units)	3
Exit gates lanes (units)	3
Trailers per crane (units)	4
Maximum amount of trucks at terminal (units)	60
Transport speed outside terminal (km/hr)	20
Transport speed at terminal (km/hr)	12
Portal cranes speed (km/hr)	5
Portal cranes working rate (op/hr)	22
Jib cranes working rate (op/hr)	20
Gantry cranes working rate (op/hr)	24

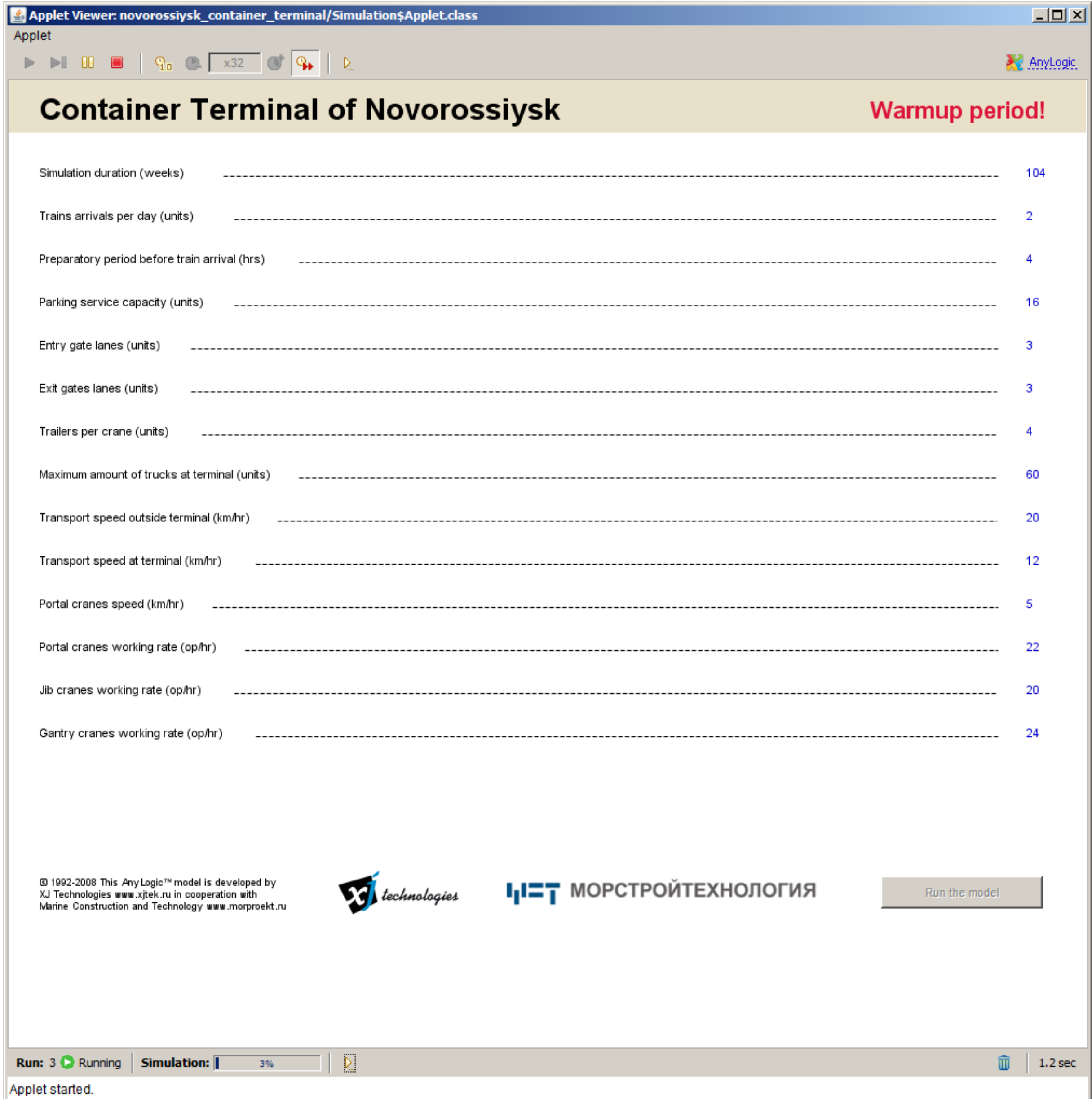
XJ technologies

МОРСТРОЙТЕХНОЛОГИЯ

Run the model

Run: 2 Idle **Simulation:** Stop time not set 478.7 sec

Applet started.


Applet Viewer: novorossiysk_container_terminal/Simulation$Applet.class
Applet
x32
AnyLogic
Container Terminal of Novorossiysk
Warmup period!
Simulation duration (weeks) 104
Trains arrivals per day (units) 2
Preparatory period before train arrival (hrs) 4
Parking service capacity (units) 16
Entry gate lanes (units) 3
Exit gates lanes (units) 3
Trailers per crane (units) 4
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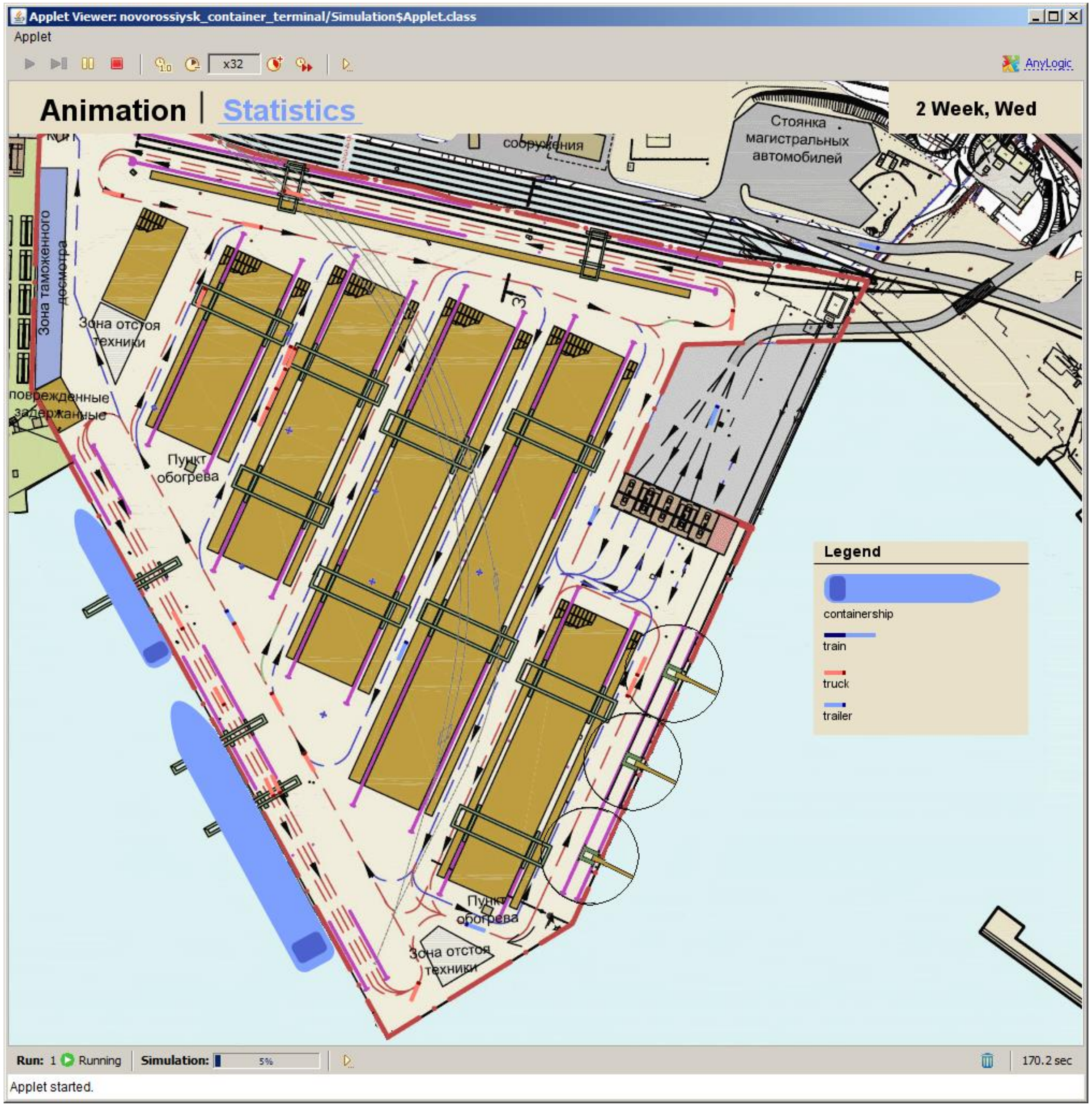
Portal cranes working rate (op/hr) 22
Jib cranes working rate (op/hr) 20
Gantry cranes working rate (op/hr) 24
© 1992-2008 This AnyLogic™ model is developed by XJ Technologies www.xjtek.ru in cooperation with Marine Construction and Technology www.morproekt.ru
technologies
МОРСТРОЙТЕХНОЛОГИЯ
Run the model
Run: 3 Running
Simulation: 3%
1.2 sec
Applet started.


Applet Viewer: novorossiysk_container_terminal/Simulation$Applet.class
Applet
x32
AnyLogic
Animation
Statistics
2 Week, Wed
Стоянка магистральных автомобилей
Зона таможенного досмотра
Зона отстоя техники
поврежденные задержанные
Пункт обогрева
Пункт обогрева
Зона отстоя техники
Legend
containership
train
truck
trailer
Run: 1 Running
Simulation: 5%
170.2 sec
Applet started.


Applet Viewer: novorossiysk_container_terminal/Simulation$Applet.class
Applet
x32
AnyLogic
Animation
Statistics
2 Week, Wed
Shipment volume, TEU
At storage
total
import
export
6,000
4,000
2,000
0
week
import: 2,122
export: 1,640
total: 3,762
Processed
0
5,000
10,000
import: 4,102
export: 4,787
total: 8,889
Storage level, tiers
Current
3
2
1
0
week
import: 1.257
export: 1.076
total: 1.167
Average
0
0.5
1
1.5
2
import: 1.619
export: 0.83
total: 1.224
Service time
100%
50%
0%
containerships (hrs): 31.532
trains (hrs): 4.042
trucks (hrs): 0.602
import containers (days): 5.107
export containers (days): 3.334
Utilization
Truck waiting time
Truck queue size
Trailer queue size
service on parking: 0.044
entry gates: 0.099
exit gates: 0.027
cranes at storage: 0.539
cranes at berth 39: 0.385
cranes at berth 40: 0.248
cranes at railway: 0.513
on parking (mins): 4.763
at entry gates (mins): 3.458
at exit gates (mins): 0.965
at storage (mins): 4.711
on parking: 3.073
at entry gates: 3.574
at exit gates: 1.187
at storage: 1.57
at railways: 1.722
at berth: 1.702
at storage: 2.041
Run: 1
Running
Simulation:
5%
62.2 sec
Applet started.

Motivation for this Lecture

- Clarify the module organisation
- Introduce the idea of "Would-Be-Worlds" [Casti 1998]
- Introduce relevant terminology
- Introduce standard simulation modelling paradigms
- Introduce the concept of simulation optimisation
- Introduce heuristic search and optimisation techniques

What is this module about?

- Module Catalogue
  - This module offers insight into the applications of selected methods of decision support. The foundations for applying these methods are derived from Operations Research Simulation, Social Simulation, Data Science, Automated Scheduling, and Decision Analysis.
  - Throughout the module, you will become more competent in choosing and implementing the appropriate method for the particular problem at hand.
  - This module requires some object oriented (Java) programming skills.

Module Convenors

- Peer-Olaf Siebers
  - Simulation
  - CompSci B35

- Dario Landa-Silva
  - Optimisation
  - CompSci C70

My Research Interests

- It's all about Agents and Agent-Based Modelling

My Research Interests

- Technical Aspects
  - Engineering Agent-Based Social Simulations
    - Using Software Engineering methods and tools to define social agents and their interactions

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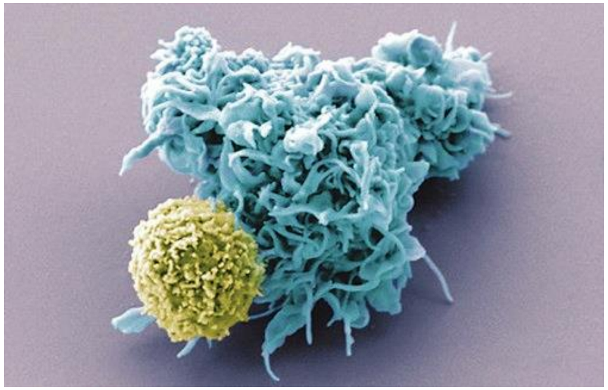
My Research Interests

- Applications
  - My Mission: Applying OO-ABM to as many fields as possible
    - Business studies (Risk Assessment; CBA; MCDA)
    - Economics (Game Theory; Agent Based Computational Economics)
    - Social Sciences (Political Science; Social Simulation)
    - Engineering (Manufacturing; Urban Modelling; Energy; Transportation)
    - Computer Science (Robotics; Game Development)
    - Operations Research (Healthcare)
    - Systems Biology (Immunology)



Module Organisation

- Lectures
  - Monday, 9:00-11:00
    - JC-BSSOUTH-A06
- Labs
  - Wednesday, 11:00-13:00
    - JC-COMPSCI-C11
- Workshops
  - Thursday, 12:00-13:00
    - JC-BSSOUTH-A06

Module Organisation

- Credits: 20 = 200 hours of work

Activity	Description	Per Week	Hours
Lectures	-	3	33
Labs	-	2	22
Self Study	Revision	3	33
Self Study	Tutorials (3x2h)		6
Group Activity	Conceptual Modelling (supported by 2 labs)		6
Individual Coursework	Reflection + Modelling + Analysis + Report (supported by 2 labs)		80
Exam Preparation	-		20
		Total	200

Introduction
Lecture 01: Introduction to simulation and optimisation (the bigger picture)
Lab: Discussion of case studies + first contact with AnyLogic
Workshop: Introduction to AnyLogic

Developing Models and Algorithms
Lecture 02: Conceptual Modelling
Lab: AnyLogic Tutorials
Workshop: Simulation study life cycle
Lecture 03: Discrete Event Simulation
Lab: Introduction to focus groups + group activity (initial brainstorm)
Workshop: Input modelling and linking AnyLogic/Optimiser
Lecture 04: Agent-Based Simulation
Lab: Group activity (focus groups)
Workshop: Peer's research - Engineering agent-based social simulations
Lecture 05: System Dynamics Simulation + Hybrids
Lab: Group activity (presentations)
Workshop: Model verification and validation
Lecture 06: Heuristic optimisation: Local search
Lab: Implementing local search
Workshop: Multi-objective optimisation
Lecture 07: Heuristic optimisation: Evolutionary algorithms
Lab: Implementing evolutionary search
Workshop: Evaluating heuristic methods

Peer and Dario will be out of office. Please use the time to work on your coursework.

Easter Break :)

Application
Lecture 08: Design of experiment + experiment + output analysis
Lab: Running experiments in AnyLogic + capturing data
Workshop: Guest speaker
Lecture 09: Optimisation in theory and practice
Lab: Implementing optimisation solution
Lecture: Dario's research - Optimisation case study

Decision Support in Practice
Lecture 10: Cost-Benefit Analysis (CBA) and Multi-Criteria Decision Analysis (MCDA)
Lab: Coursework clinic
Workshop: Guest speaker
Lecture 11: Client engagement + PhD student presentations
Lab: Coursework clinic
Workshop: TBA

Oral Assessment (if required) THIS SESSION IS COMPULSORY FOR SELECTED CANDIDATES

Module Organisation

- Resources
  - Module Website: Moodle
    - Slides (two versions) + reading list + announcements

- Assessment:
  - 75% Coursework
    - Group Activity Reflection (individual work)
    - Simulation Study (individual work)
  - 25% Exam

Module Organisation

- Software:
  - AnyLogic Free PLE 8 (hopefully available in C1 on Wednesday :)

http://www.anylogic.com/downloads

Module Organisation

Resources

We will use AnyLogic Free PLE 8 for this module. There is a free introductory book for version 7 available from the AnyLogic website. This is still useful for learning AnyLogic. There is also a interesting blog with the latest news about AnyLogic

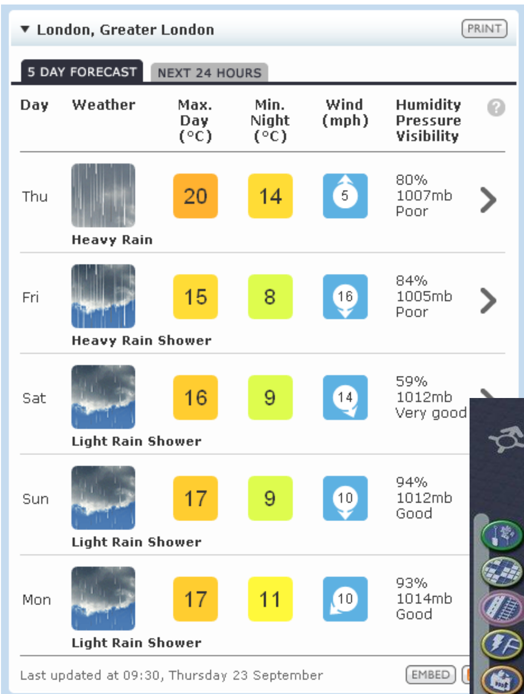
Below you find a collection of books that I would recommend for self-study. Most of the module's teaching is based on Stewart Robinson's book. Borshchev's book (although a bit outdated) is useful if you want to learn more about the technical aspects, i.e. how to implement simulation models in AnyLogic. More up-to-date information is available in the AnyLogic Help.

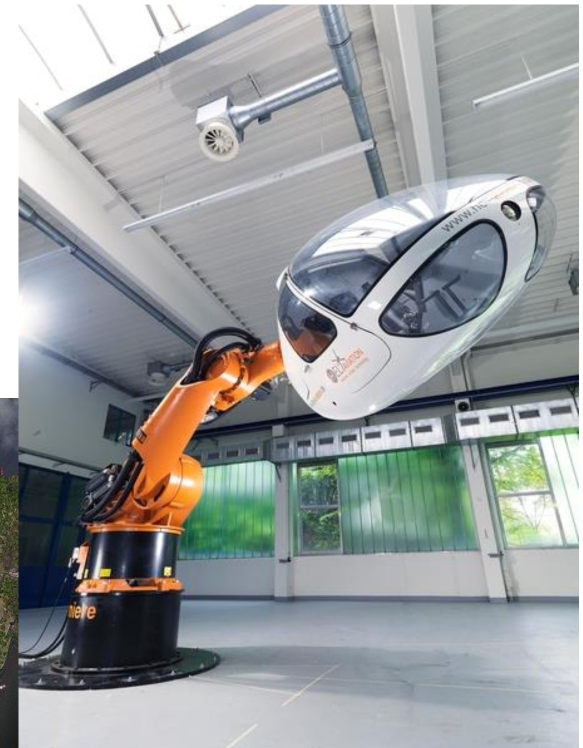
- **Simulation in General**:
  - Borshchev (2013) The Big Book of Simulation Modeling - Multimethod Modeling with AnyLogic 6 (with a focus on model implementation in AnyLogic 6 (please note that in the lab we use AnyLogic 8); also provides an introduction to the required Java)
  - Kelton et al (2014) Simio and Simulation: Modelling, Analysis, Applications - 3e (with a focus on model implementation in Simio)

- **Discrete Event Simulation**:
  - Robinson (2014) Simulation: The Practice of Model Development and Use - 2e
- **Agent-Based Simulation**:
  - Gilbert and Troitzsch (2005) Simulation for the Social Scientist - 2e
- **System Dynamics Simulation**:
  - Morecroft (2007) Strategic Modelling and Business Dynamics: A Feedback Systems Approach
- **Java Programming**:
  - Sierra and Bates (2005) Head First Java (explains object oriented programming in Java from scratch)
- **Heuristic Optimisation**:
  - Siarry (2016) Metaheuristics, Springer
  - Rothlauf (2011) Design of Modern Heuristics - Principles and Applications
  - Talbi (2009) Metaheuristics from Design to Implementation

Furthermore, the WSC Proceedings are also a valuable source of information, in particular the introductory tutorials are very useful. [url] (you can download all papers directly from this website for free). Another good resource for scientific papers is Google Scholar [url]. You will also find more about my research in Google Scholar [url].

Simulation Examples





Systems

- System:
  - Collection of parts organised for some purpose (weather system: parts: sun, water, land, etc.; purpose: maintaining life)
  - Defining a system requires setting boundaries

- Different categories of systems:
  - Natural systems (weather system, galactic system)
  - Designed physical systems (house, car, production system)
  - Designed abstract systems (mathematics, literature)
  - Human activity systems (family, city, political system)

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Systems

- Operations system:
  - Configuration of resources combined for the provision of goods and services (functions: manufacture, transport, supply, service).
- Social system:
  - Entities or groups in definite relation to each other which create enduring patterns of behavior and relationship within social systems.
- Economic system:
  - Particular set of social institutions which deals with the production, distribution, and consumption of goods and services.

Systems

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Models

- Model:
  - Some form of abstract representation of a real system intended to promote understanding of the system it represents.
  - A model is a static representation of the system
  - Models can have many forms
    - mathematical equations, diagrams, physical mock-ups

- Why model?
  - Models give us a comprehensible representations of a systems
    - Something to think about
    - Something to communicate about

Simulation

- Simulation:
  - The process of designing a model of a real system and conducting experiments with this model for the purpose of understanding the behaviour of the system and /or evaluating various strategies for the operation of the system [Shannon 1975]
  - Uses a model to emulate the dynamic characteristics of a system

- Why simulate?
  - Predict the performance of a system under a specific set of inputs
  - Experimental approach to modelling (what-if analysis tool)

Nature of Operations and Social Systems

- Such systems are subject to variability
  - Predictable variability
    - E.g. staff rota, planned maintenance of machines
  - Unpredictable variability
    - E.g. customer arrivals, machine breakdowns

- Such systems are interconnected
  - Components of a system affect one another
    - E.g. customers in a three stage service process

[Robinson 2014]

Nature of Operations and Social Systems

- Such systems are (highly) complex
  - Combinatorial complexity
    - Number of components and number of combinations of components
      - E.g. travelling salesman problem
  - Dynamic complexity
    - Mainly systems that are highly interconnected (feedback systems)
      - Where an action has a different effect in short/long run
      - Where an action has a different consequences in one part of the system compared to another part of the system
      - Where an action has non-obvious consequences

In simulation studies we are able to explicitly represent the variability, interconnectedness, and complexity of operations systems

[Robinson 2014]

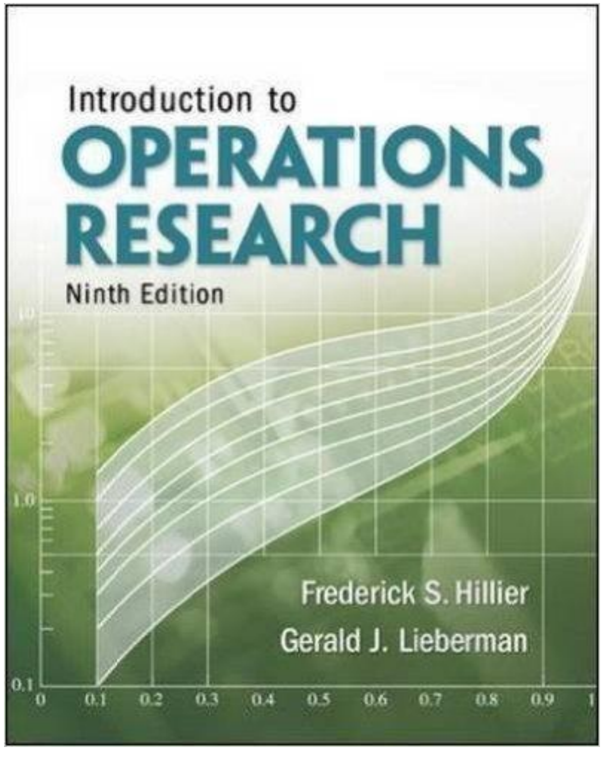
Why Simulate?

- It is possible with a simulation:
  - To predict system performance
  - To compare alternative system designs
  - To determine the effects of alternative policies on system performance

- Advantages: Simulation vs. Experimentation
  - Cost
  - Time (real time vs. virtual time)
  - Control of experimental conditions
  - Real system might not exist

Why Simulate?

- Advantages: Simulation vs. other modelling approaches
  - Other modelling approaches
    - Linear Programming
    - Network Analysis
    - Dynamic Programming
    - Meta Heuristics
    - Game Theory
    - Markov Chains
    - Queuing Theory
    - Simulation



Why Simulate?

- Advantages: Simulation vs. other modelling approaches
  - Modelling variability
    - Some other approaches could be adapted to account for variability but it often increases their complexity
  - Restrictive assumptions
    - Most of the other approaches require assumptions, e.g. queuing theory assumes particular distributions for arrival and service times, for many processes these distributions are not appropriate

Why Simulate?

- Advantages: Simulation vs. other modelling approaches
  - Transparency
    - More intuitive than a set of equations, an animated display of the system can be created, giving a non-expert grater understanding of, and confidence in, the model
  - Creating knowledge and understanding
    - Sometimes just building the model is enough
  - Visualisation, communication, interaction

Why Simulate?

- Disadvantages: Simulation vs. other modelling approaches
  - Expensive + time consuming + data hungry
  - Requires expertise
    - It is an art rather than a science
  - Overconfidence
    - When interpreting the results from a simulation, consideration must be given to the validity of the underlying model and the assumption and simplifications that have been made!

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Classification of Simulation

- Static vs. Dynamic:
  - Static: No attempts to model a time sequence of changes.
  - Dynamic: Updating each entity at each occurring event.
- Deterministic vs. Stochastic:
  - Deterministic: Rule based.
  - Stochastic: Based on conditional probabilities.
- Discrete vs. Continuous:
  - Discrete: Changes in the state of the system occur instantaneously at random points in time as a result of the occurrence of discrete events.
  - Continuous: Changes of the state of the system occur continuously over time.

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Level of Abstraction

- Simulation can be applied at different stages:
  - Strategic
    - high abstraction, less detailed, macro level
  - Tactical
    - middle abstraction, medium details, meso level
  - Operational
    - low abstraction, more details, micro level

Level of Abstraction

Aggregate, global causal dependencies, feedback dynamics

Strategic

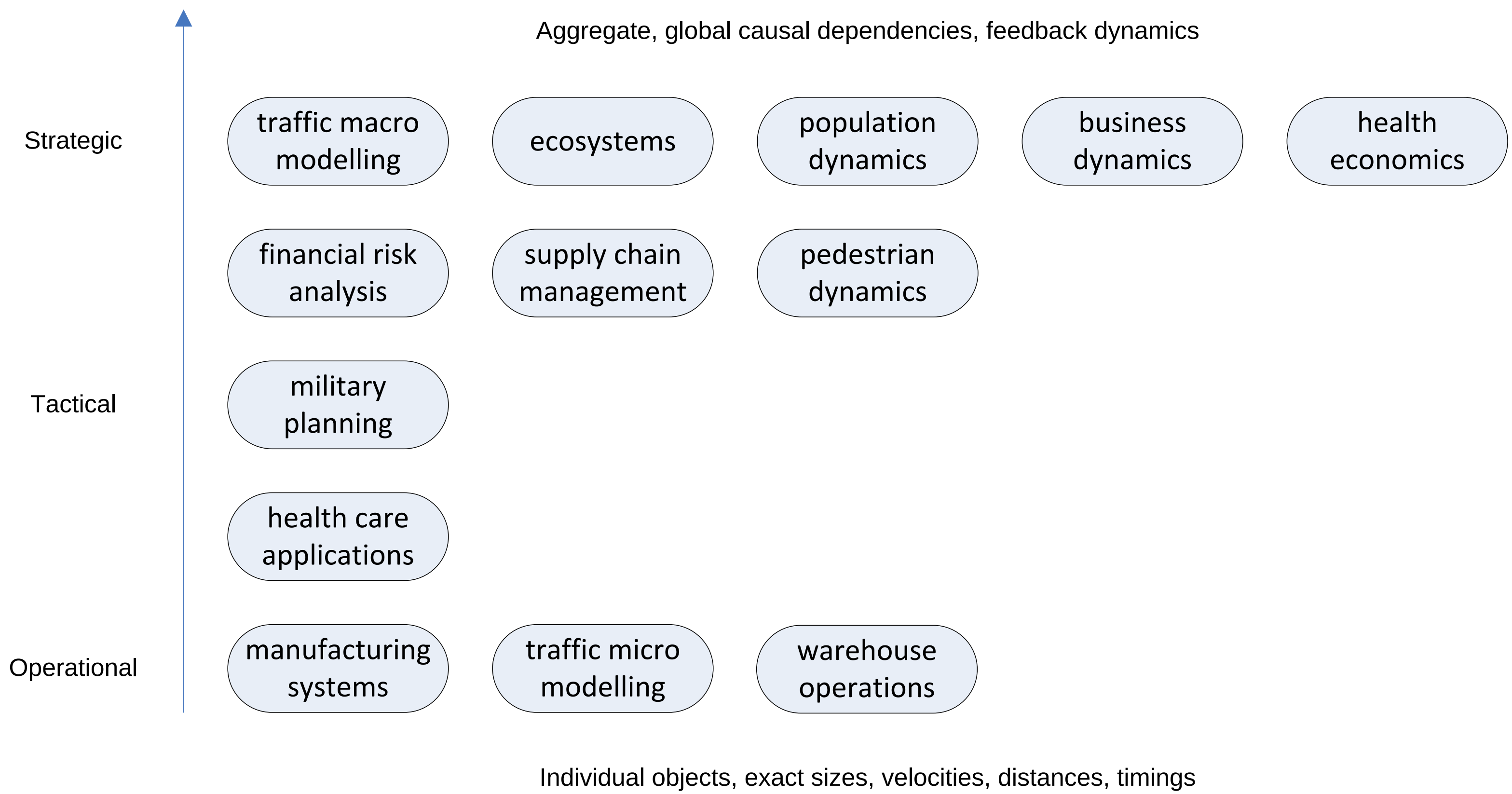
Tactical

Operational

traffic macro modelling, traffic micro modelling, supply chain management, population dynamics, financial risk analysis, manufacturing systems, ecosystems, pedestrian dynamics, health care applications, health economics, military planning, business dynamics, warehouse operations

Individual objects, exact sizes, velocities, distances, timings

Level of Abstraction

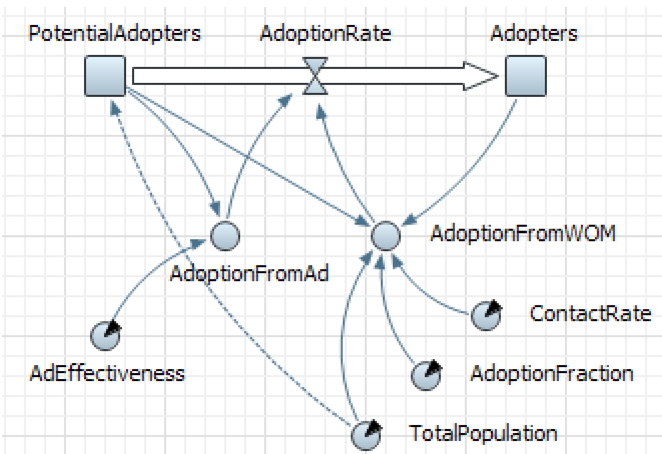


Simulation Modelling Paradigms

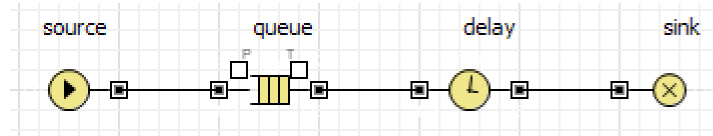
- System Dynamics Modelling (SDM) and Simulation (SDS)
  – Modelling: Causal Loop Diagrams + Stock and Flow Diagrams
  – Simulation: Deterministic continuous (differential equations)
- Discrete Event Modelling (DEM) and Simulation (DES)
  – Modelling: Activity Cycle Diagrams (deprecated) + Flow Charts
  – Simulation: Stochastic discrete (process oriented approach)
- Agent Based Modelling (ABM) and Simulation (ABS)
  – Modelling: Equations or UML
  – Simulation: Stochastic discrete (object oriented approach)
- Hybrid Modelling (HM) and Simulation (HS)

Paradigms

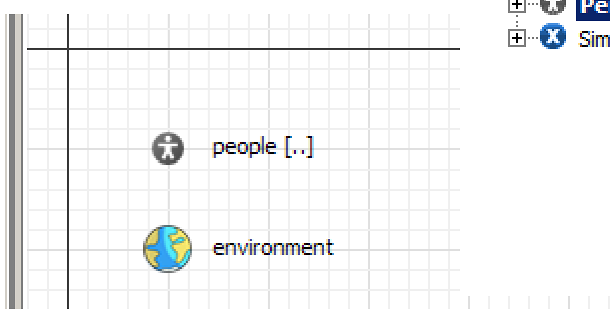
- SDM

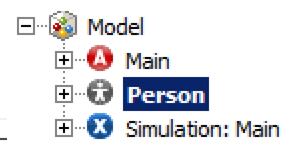


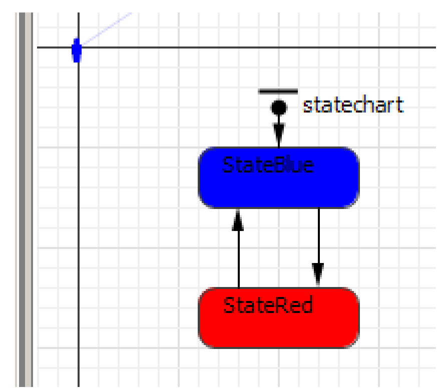
- DEM



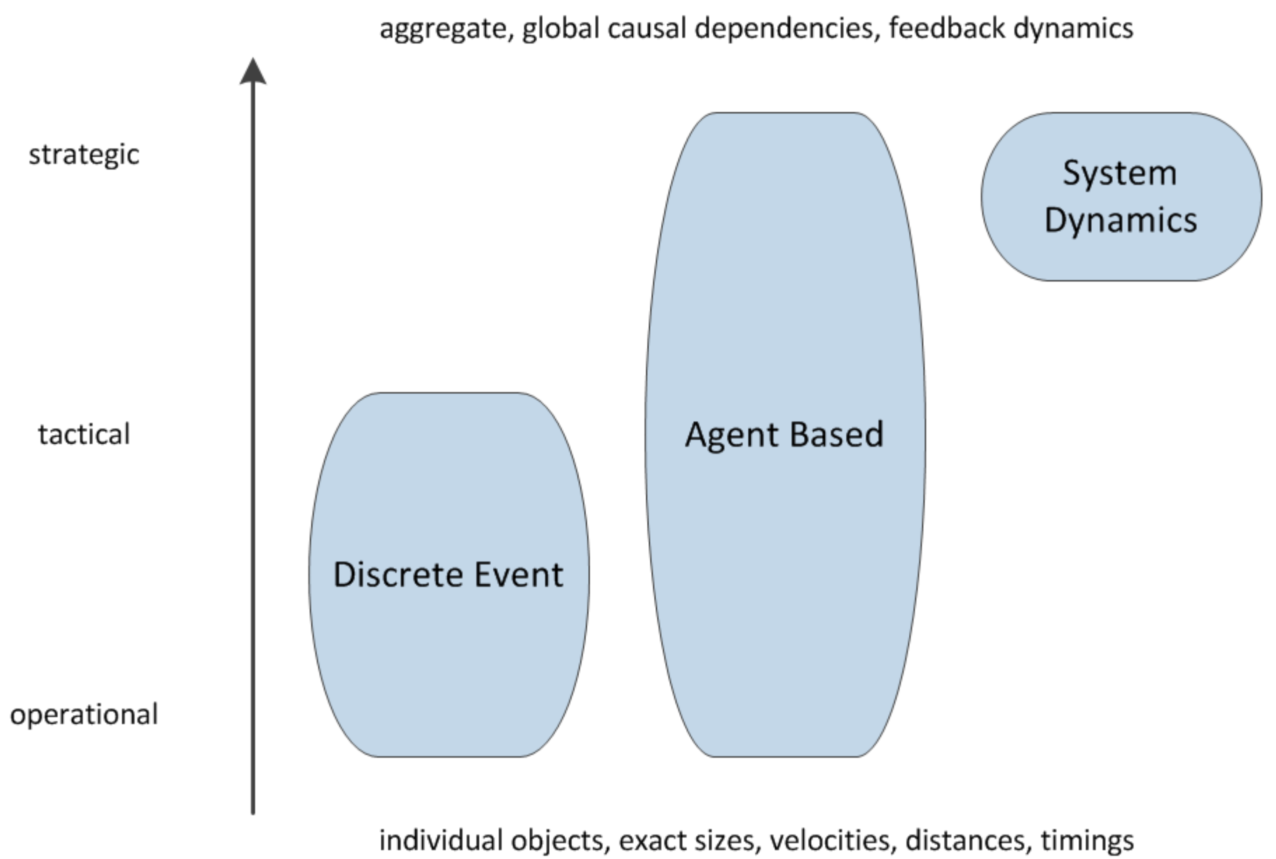
- ABM







Paradigms



aggregate, global causal dependencies, feedback dynamics
strategic
tactical
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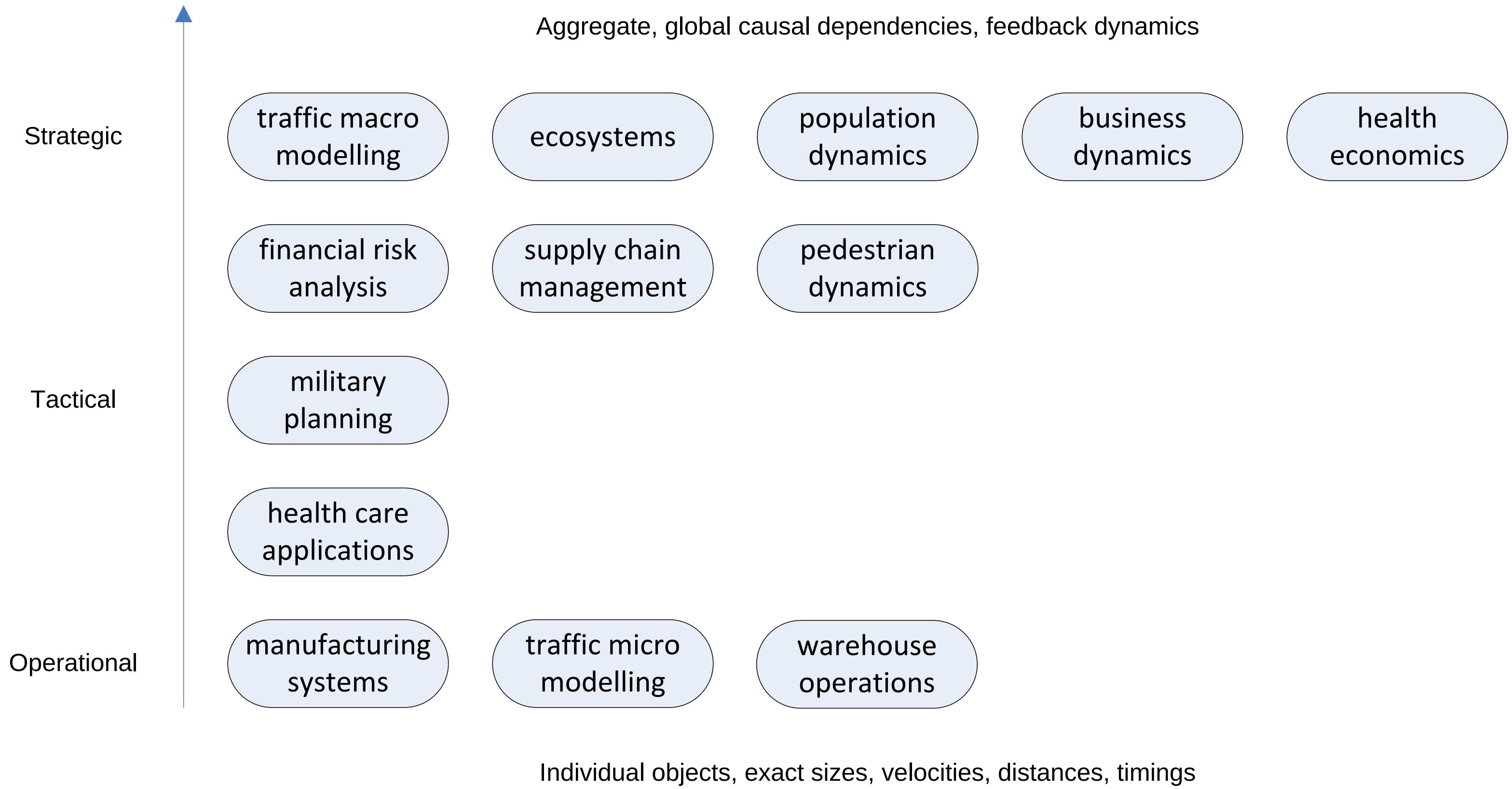
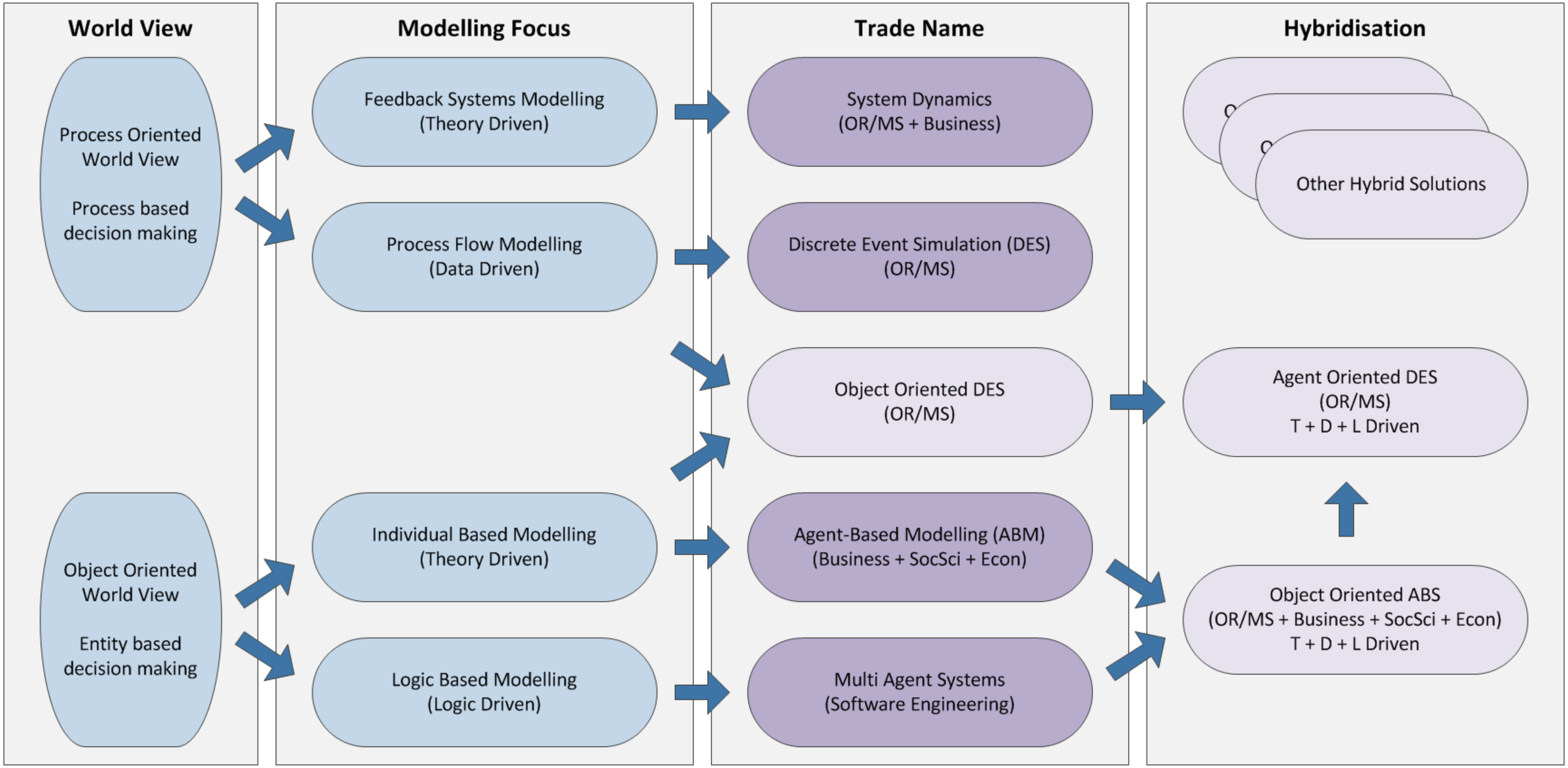
System Dynamics
Agent Based
Discrete Event
individual objects, exact sizes, velocities, distances, timings

Level of Abstraction



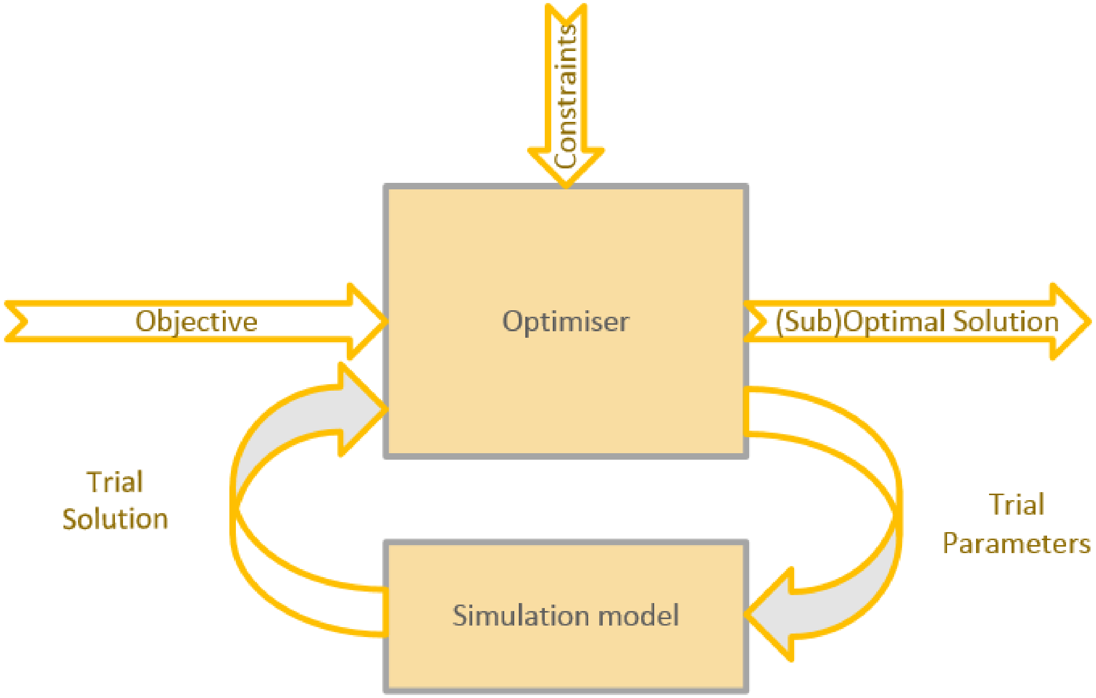
Simulation Modelling Framework



Theory Driven: Theories for model formulation; data for model validation
Data Driven: Data for model formulation (can be quantitative and qualitative); data for model validation
Logic Driven: Logic for model formulation; data for model validation

Simulation Optimisation

- How does it work?
  – The optimiser runs as a master application that controls the simulation model



Overview of the Optimisation Part

Achieve an understanding of modern heuristic search techniques with emphasis in tackling search and optimisation problems.

Heuristic Search and Optimisation refers to a set of computational techniques that aim to find good quality solutions to very difficult problems in search, optimisation, design, etc. while consuming a reasonable amount of computational resources.

Heuristic methods are AI inspired approaches and are related both to computer science and operations research.

Heuristic methods have been successfully applied to many problems in different areas including: engineering, management, finance, planning and scheduling, medicine, biology, automated navigation, image processing, robotics, art design, etc.

Describing Heuristics

A heuristic search method is a technique that seeks good quality (i.e. near optimal) solutions at a reasonable computation time but that is not able to guarantee either feasibility or optimality.

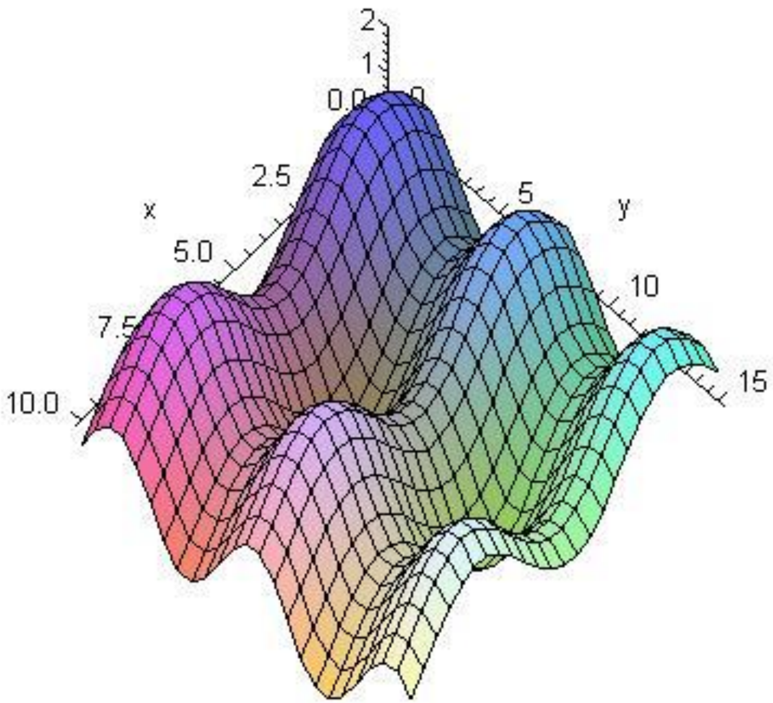
There is a range of heuristic methods including: simple constructive heuristics, local search, meta-heuristics, hyper-heuristics, hybrids, evolutionary methods, etc.

Societies and Publications

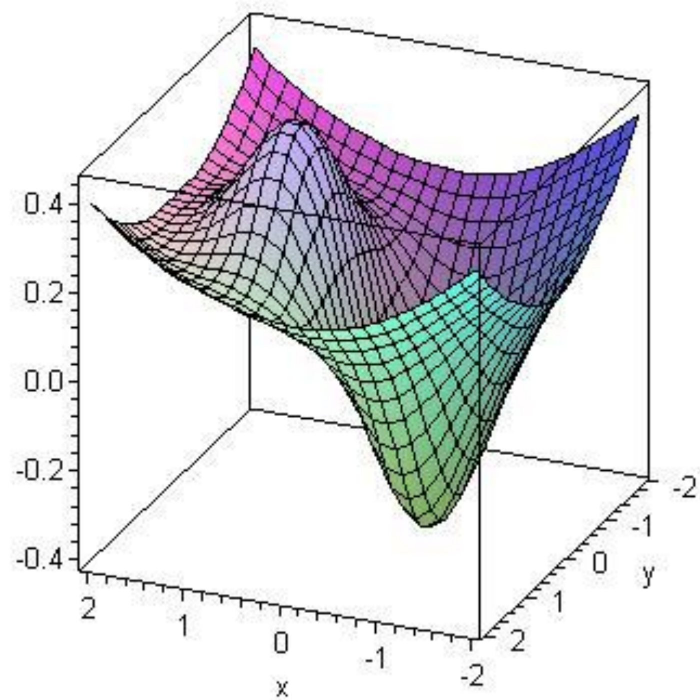
- Related conferences include: CEC, GECCO, HM, MIC, PPSN, SLS
- Related journals include: Applied soft computing, Evolutionary computation, Evolutionary intelligence, IEEE Trans. on EC, Intl. journal of meta-heuristics, Journal of heuristics, Memetic computing, Swarm intelligence and others.

Examples of (nonlinear) continuous search problems:

$$f(x,y) = x \cdot exp^{\left(-(x^2+y^2)+\frac{x^2+y^2}{20}\right)}$$
$$\text{s.t.} \quad 0 < x < 10 \text{ and } 0 < y < 15$$



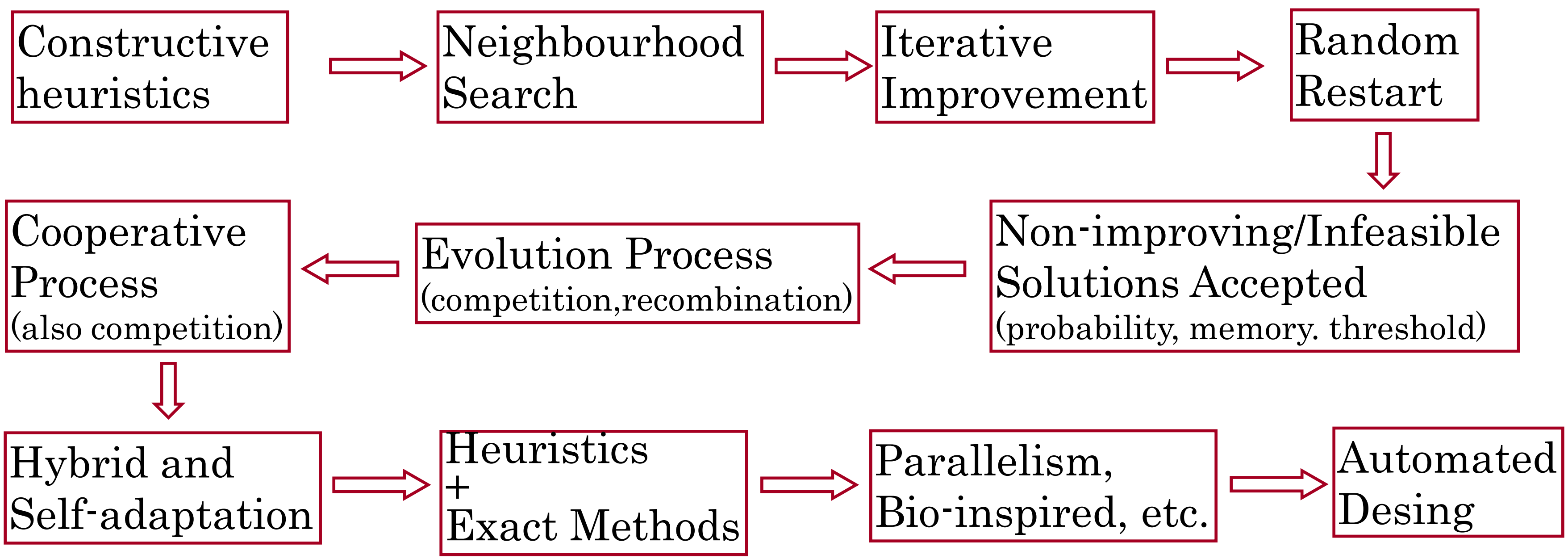
$$f(x,y) = Sin(x) + Sin(y)$$
$$\text{s.t.} \quad -2 \le x, y \le 2$$



Progress on Heuristic Search

A heuristic is a 'rule of thumb' based on domain knowledge from a particular application, that gives guidance in the solution of a problem (Oxford Dictionary of Computing).

A meta-heuristic is a iterative master process that guides and modifies the operations of subordinate heuristics to efficiently produce high-quality solutions (Voss et al. 1999).



And finally ...

- Questions and comments ...

References

- Casti (1998) Would-Be Worlds: How Simulation is Changing the Frontiers of Science
- Robinson (2014) Simulation: The Practice of Model Development and Use
- Shannon (1975) Systems Simulation: The Art and Science
- Voss et al (1999) Meta-heuristics: Advances and Trends in Local Search Paradigms for Optimization