IE630: Simulation Modelling & Analysis
Fundamentals of Simulation

Saurabh Jain

Assistant Professor

Department of Industrial Engineering and Operations Research

IIT Bombay

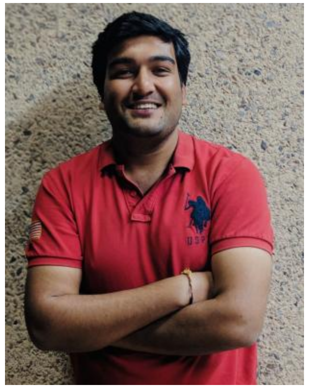
Know the team!

Instructors:

Prof. Jayendran Venkateswaran

Professor & Department Head

IEOR, IIT Bombay



Prof. Saurabh Jain

Assistant Professor

IEOR, IIT Bombay

Teaching Assistants:

Gurkirat Wadhwa

Sachin Bodke

Monu Pathak

Deepesh Saini

Bhavya Gupta

Jishnu N

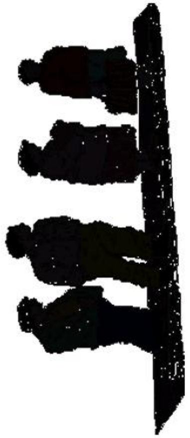
Topics to be covered in the course

- Introduction (definitions and types of simulations)
- Mechanism of discrete event simulation
- Review of probability and statistics
- Random number/variate generation
- Input data analysis (input distribution modeling)
- Simulation modeling using Anylogic
- Simulation output analysis
- Monte Carlo simulation
- Modeling continuous processes
- Verification and validation of simulation models
- Advanced Modeling techniques – ABMS, SD etc.

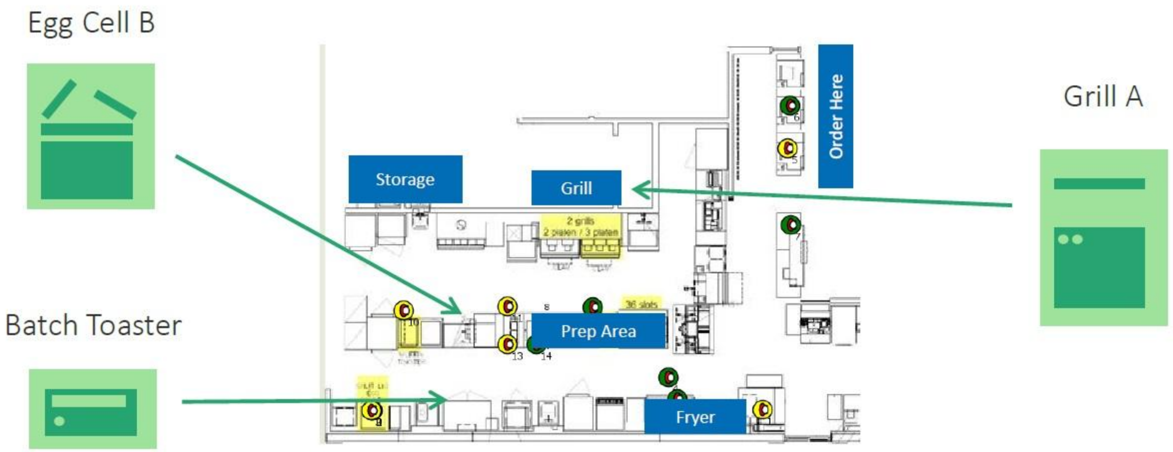
Systems

- Owner of a McDonalds
- What is your goal?

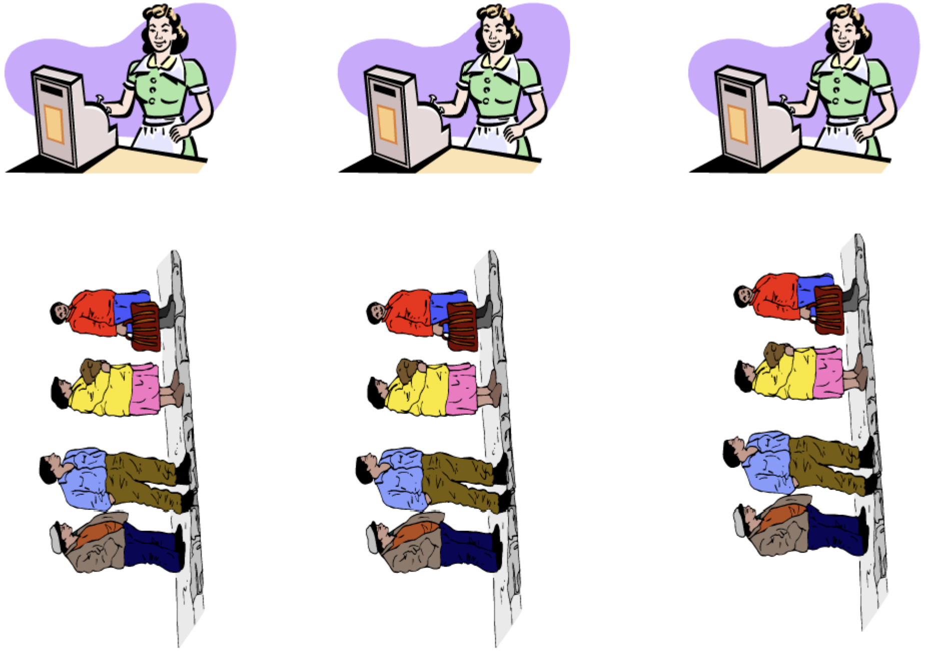
- How?
  - Better business, Service Quality Improvement



Arriving Customer



Systems



Just arrived customer:
He/she can choose the shortest line or something

Carl's Jr Strategy

Just arrived customer:
No choice=> stand at the end of the line

Airport Strategy

Examples - Systems

Abstraction - Consider something theoretically or separately from something else

High Abstraction
Less Details
Macro Level
Strategic Level

More generalization

Aggregates, Global Causal Dependencies, Feedback Dynamics, …

- Marketplace & Competition
- Population Dynamics
- Manpower & Personnel
- Health Economics
- Ecosystem
- R&D Project Management

Middle
Abstraction
Medium Details
Meso Level
Tactical Level

- Traffic Macro Models
- Waste Management
- Supply Chain
- Transportation
- Asset Management
- Call Center
- Electrical Power Grid
- Emergency Department

Low Abstraction
More Details
Micro Level
Operational
Level

- Factory Floor
- Warehouse
- Traffic Micro Models
- Pedestrian Movement
- Computer Hardware
- Automotive Control System

Individual objects, exact sizes, distances, velocities, timings, …

Applications:

IEOR
Mechanical
Electrical Engg.
Civil Engg.
Materials
Science
Economics
Business

Whenever given a subset of a process, try to get to corresponding micro, meso and macro analogues of the same process. Then divide them into the three categories.

Examples - Systems

- Manufacturing Applications (Mechanical, IEOR)
  - Analysis of electronics assembly operations
  - Design and evaluation of a selective assembly station for high-precision scroll compressor shells
  - Comparison of dispatching rules for semiconductor manufacturing using large-facility models
  - Evaluation of cluster tool throughput for thin-film head production
  - Determining optimal lot size for a semiconductor back-end factory
  - Optimization of cycle time and utilization in semiconductor test manufacturing
  - Analysis of storage and retrieval strategies in a warehouse
  - Investigation of dynamics in a service-oriented supply chain
  - Model for an Army chemical munitions disposal facility
- Semiconductor Manufacturing (MEMS, Mechanical Engg., IEOR)
  - Comparison of dispatching rules using large-facility models
  - The corrupting influence of variability
  - A new lot-release rule for wafer fabs

Examples - Systems

- Assessment of potential gains in productivity due to proactive reticle management
- Comparison of a 200-mm and 300-mm X-ray lithography cell
- Capacity planning with time constraints between operations
- 300-mm logistic system risk reduction

- Construction Engineering (Civil, Hydrology)
  - Construction of a dam embankment
  - Trenchless renewal of underground urban infrastructures
  - Activity scheduling in a dynamic, multiproject setting
  - Investigation of the structural steel erection process
  - Special-purpose template for utility tunnel construction
- Military Application
  - Modeling leadership effects and recruit type in an Army recruiting station
  - Design and test of an intelligent controller for autonomous underwater vehicles
  - Modeling military requirements for nonwarfighting operations
  - Multitrajectory performance for varying scenario sizes
  - Using adaptive agent in U.S Air Force pilot retention

Examples - Systems

- Logistics, Transportation, and Distribution Applications (Business, ECE)
  - Evaluating the potential benefits of a rail-traffic planning algorithm
  - Evaluating strategies to improve railroad performance
  - Parametric modeling in rail-capacity planning
  - Analysis of passenger flows in an airport terminal
  - Proactive flight-schedule evaluation
  - Logistics issues in autonomous food production systems for extended-duration space exploration
  - Sizing industrial rail-car fleets
  - Product distribution in the newspaper industry
  - Design of a toll plaza
  - Choosing between rental-car locations
  - Quick-response replenishment

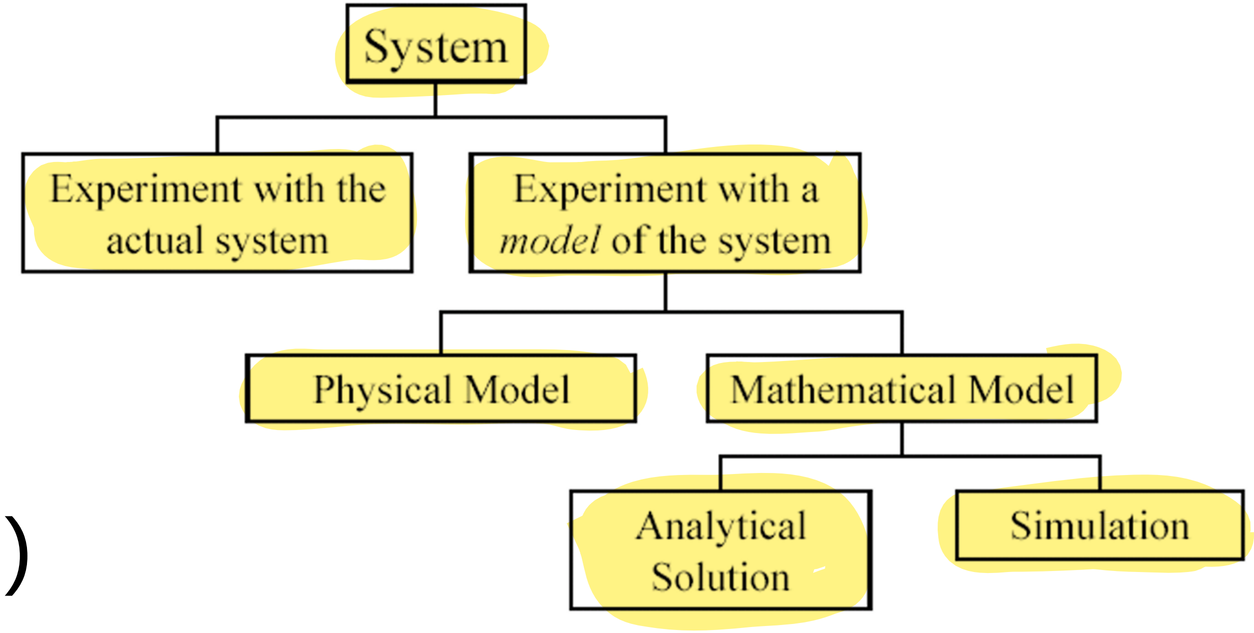
Modelling of Complex Systems

- Method to study (analyze) a system (why modeling?)
- Trade-off between system and model
- Note: For a system, there can be models with different level of details

(   )

System → Model

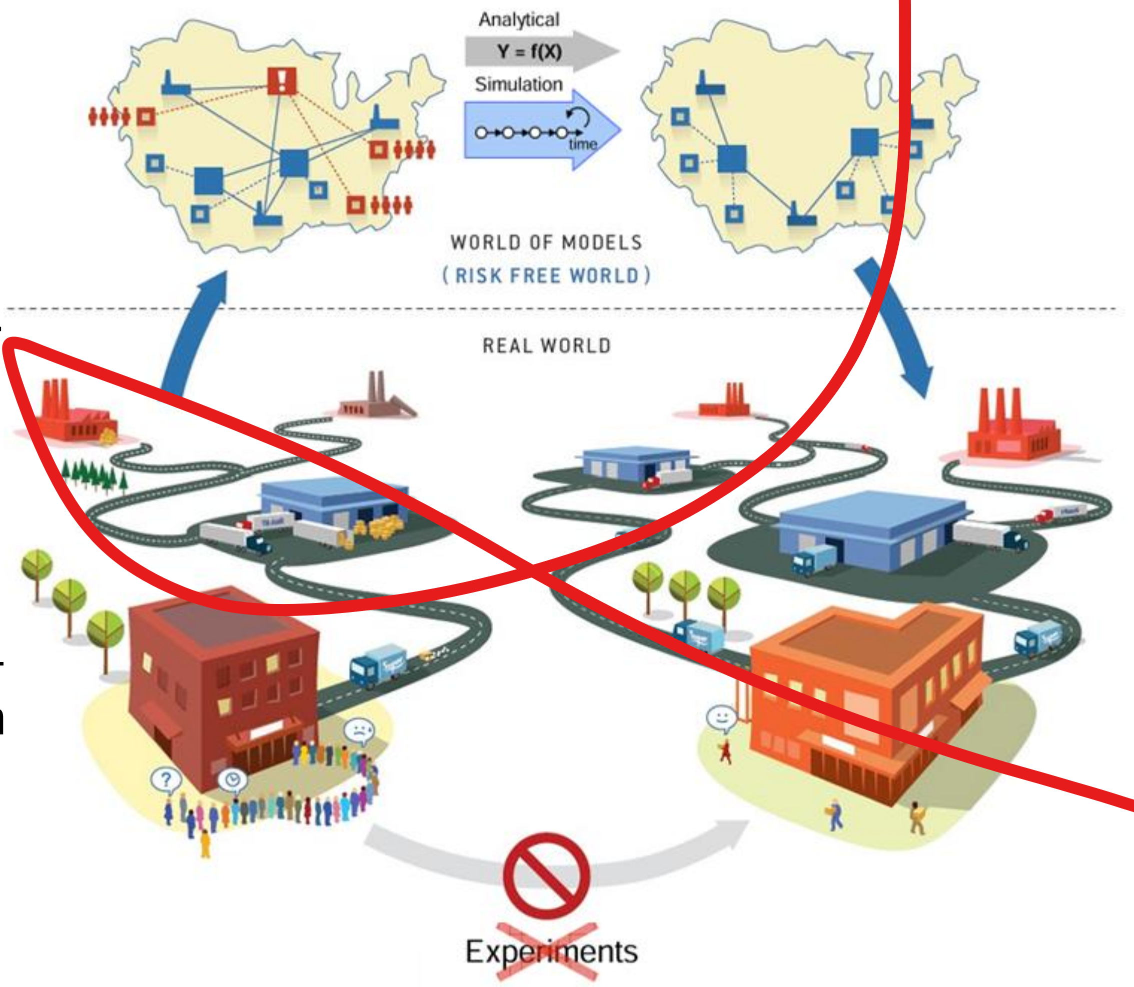
System ← Model



Law and Kelton, 1991

Modelling of Complex Systems

- Solving complex problems for large scale systems
- Used for ________________ and ________________ with the real system when the system is ___________________ or ___________________
- Involved 3 major steps:
  - The process of ________________
  - Model _____________ and _____________
  - Mapping the _________ back to real system
- Computer Modelling –
  - Analytical
  - Simulation



Modelling of Complex Systems

- Physical Models
  - Physical replica or scale model of the system
  - Tabletop models of material handling systems with exactly same mechanism but different scale
  - A full scale McDonald for experiment
  - Physical flight simulators: combination of physical and computer simulation models
- Analytical Models
  - Measures of performance (e.g. mean time in system) are expressed as mathematical functions of input parameters (e.g., arrival rates of customers, service rates)
  - One example? ( )
  - Where expected values of inter-arrival time and service-time (assuming μA > μS)

$$\text{Average Delay in Queue: } \frac{\mu_s^2}{\mu_A - \mu_s}$$

Fidelity - The degree of exactness with which something is copied or reproduced

Modelling of Complex Systems

- Simulation Models
  - Simulation is THE modeling tool with highest fidelity
  - It can model very complicated systems
  - Costly than analytical models since we need to run the models in the computer for a certain amount of time
  - If systems to be studied have the following characteristics, we need simulation

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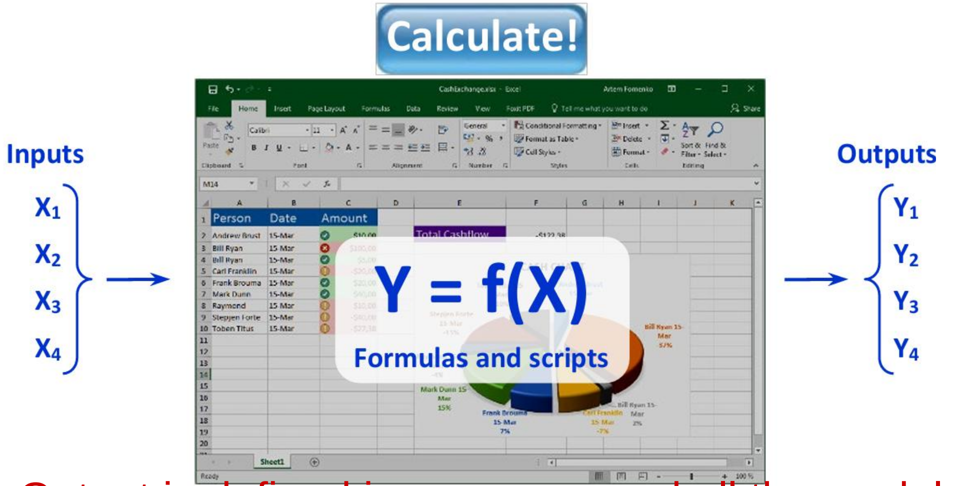
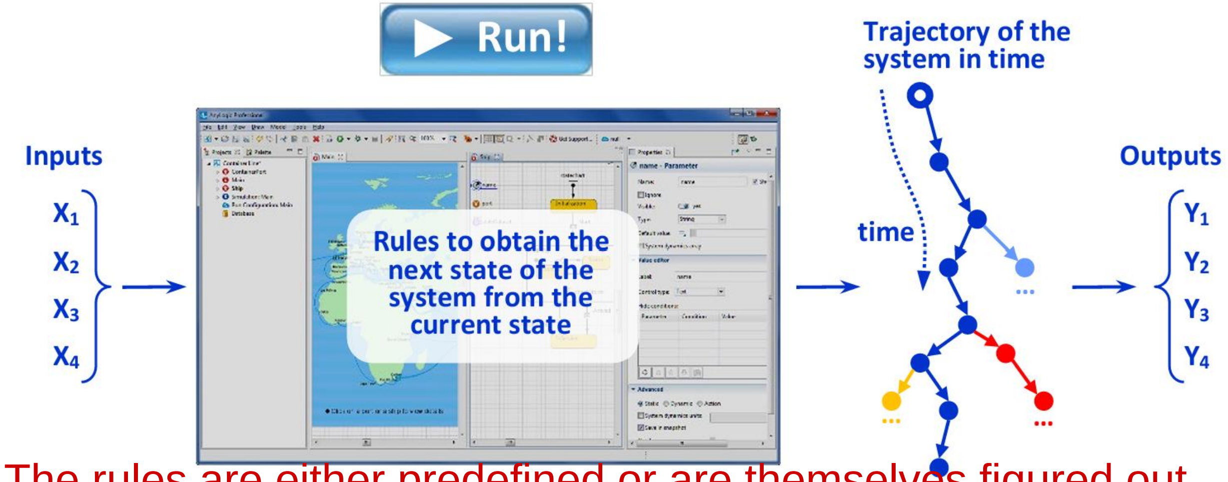


Output is defined in a manner and all the model does is either it calculates the output values, or it applies some mathematical model to analyze the variables to get a particular output (trading)



The rules are either predefined or are themselves figured out during the runtime and then the input is associated to some output

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Further Characterization : Modeling

- Discrete vs. Continuous
  - Continuous: The state of the system can change continuously over time. Examples include boiling water, level of reservoir, chemical processes, etc.
  - Discrete: The change can occur only at separated points in time such as part arrival, part finishing, machine break-down, etc.
  - Can we use continuous model for discrete system (nature)?
  - Can we use discrete model for continuous system (nature)?

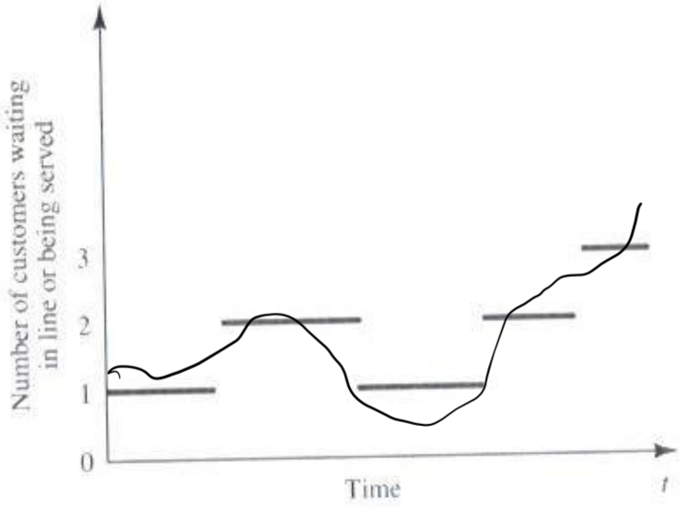

Figure 1.1. Discrete-system state variable.

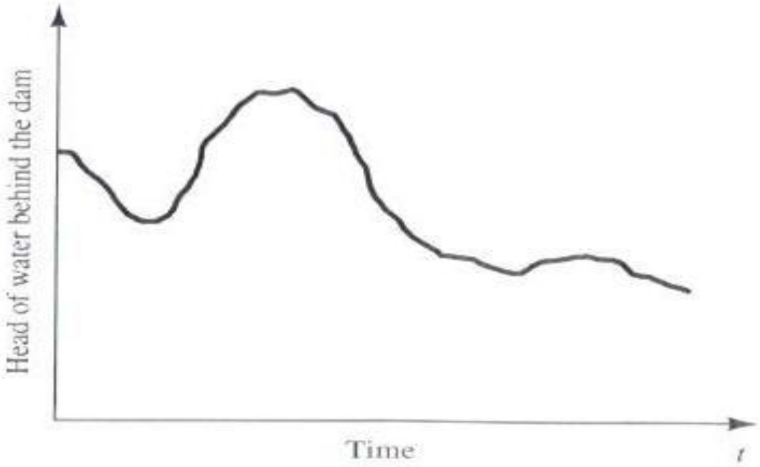

Figure 1.2. Continuous-system state variable.

Exercise Time

Inventory Management Model
Optimize inventory by ordering a fixed quantity of products whenever the stock level reaches a reorder point.

A

Stock Price Prediction
A stock price is need to be predicted based on historical data

Traffic Flow at an Intersection
A traffic flow of vehicles at an intersection

Projectile Motion
A ball is thrown far away

A

Exercise Time

Reliability Analysis of a Machine System
A system of machines is analyzed to calculate the failure probability using known distributions for component lifetimes.

Weather Forecasting Using Historical Data
Using a model that takes historical weather data into account, future weather conditions are predicted, considering randomness in temperature and precipitation.

Queuing Model (M/M/1) for Customer Service
A customer service desk is modeled

Disease Spread (Epidemic Model)
A disease spreads in a population with individuals transitioning between different states (e.g., susceptible, infected, recovered)

Fixed Growth Population Model (Exponential Growth)
A population grows at a constant rate over time, with the number of individuals at any time calculated using the exponential growth formula.

Simulation

Real-world process ( ) → Modeling & Analysis

- Simulation
  - the replication of the operation of a real-world process or system over time
  - to develop a set of assumptions of mathematical, logical, and symbolic relationship between the entities of interest, of the system.
  - to estimate the measures of performance of the system with the simulation-generated data
  - Understanding the behavior of the systems under different strategies
- Simulation modeling can be used
  - as an ( ) for predicting the effect of changes to existing systems
  - as a ( ) to predict the performance of new systems

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History: Simulation

1940
'Monte Carlo' method developed

1960
First special purpose simulation language developed

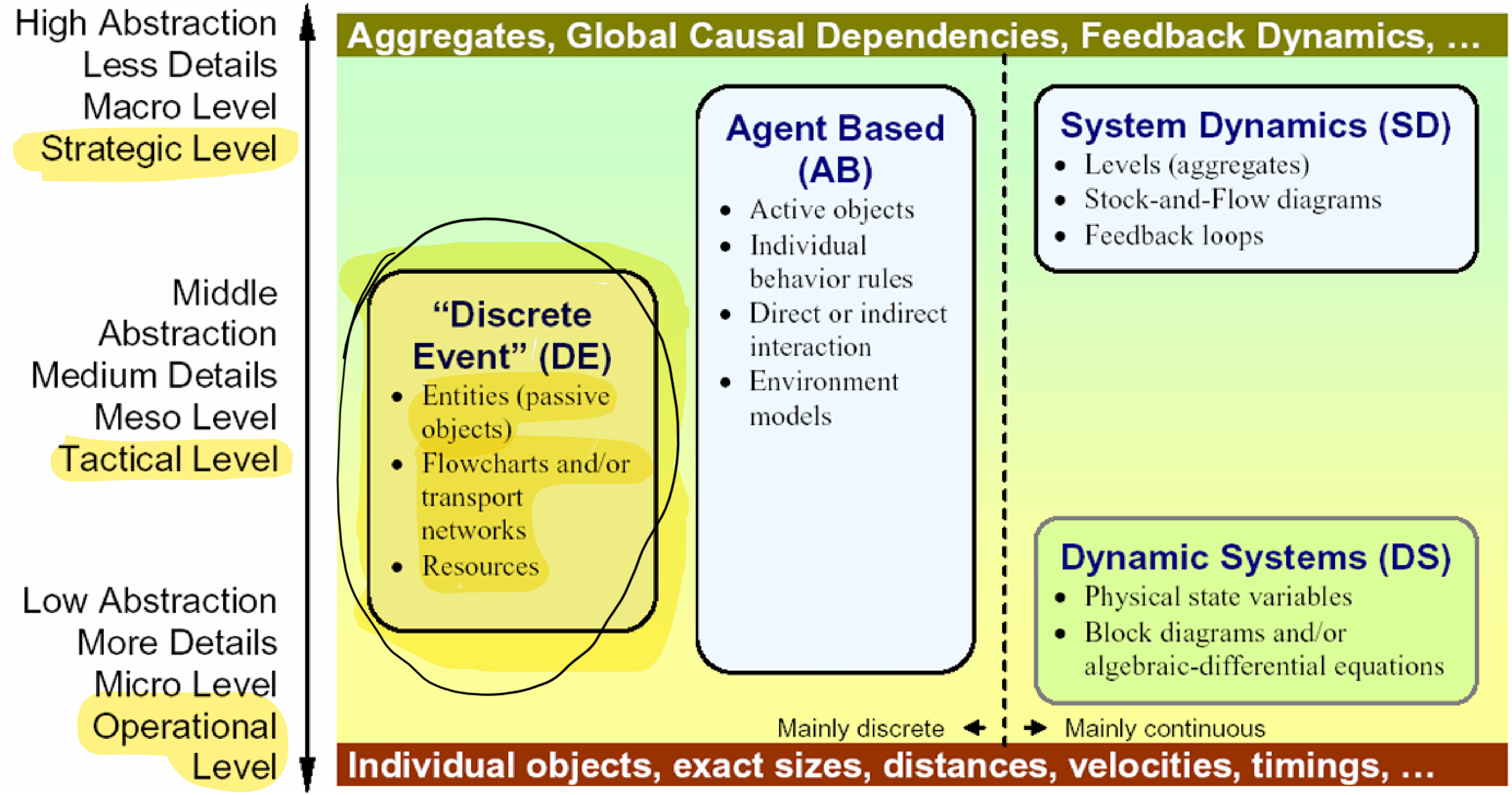
1970
Research initiated on mathematical foundations of Simulation

1980
PC-based simulation software, GUIs, OOPs were developed

1990
Web-based simulations evolved, Animation graphics, Simulation based optimization

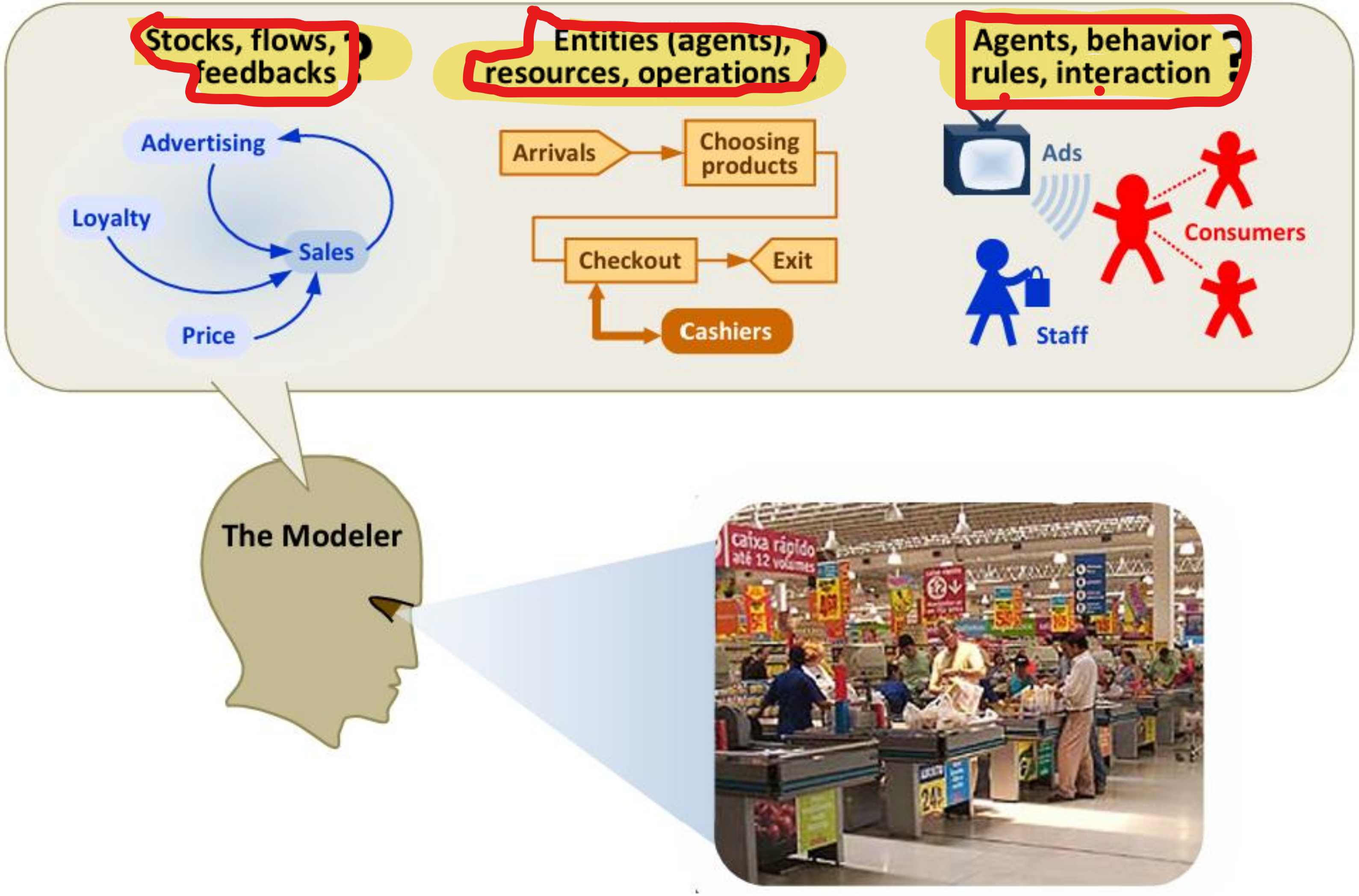
2000s
Additional Simulation paradigms
More computing

Types of Simulation



Types of Simulation

- System Dynamic
- Agent-based Modeling
- Discrete Event Simulation



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Application Systems: Simulation

- How the simulation can be used for different purposes?

Training and Skill Development
Use Cases:
- Industrial process training.
- Healthcare system simulations.
- Emergency response planning.

Key Benefit: Practice without risks or resource waste.

Decision Support Systems
Use Cases:
Policy testing and optimization.
Resource planning and allocation.
Supply chain dynamics.
Key Benefit: Informed, data-driven decisions.

Understanding Complex Systems
Use Cases:
- Population dynamics using agent-based models.
- Epidemic spread via system dynamics.
- Traffic flow analysis in urban areas.

Key Benefit: Deeper insights into interconnected systems.

Education and Research
Use Cases:
Modeling ecosystems or economies.
Exploring theoretical systems dynamics.
Teaching complex systems interactively.
Key Benefit: Engaging, practical learning for better retention.
Visuals: Simple examples of simulation graphs or timelines.

Entertainment and Beyond
Use Cases:
- Simulations in game mechanics.
- Story-based simulations for research outreach.
- Systems-based storytelling for engagement.

Key Benefit: Simplifying complex ideas for broad audiences.

Simulation : Appropriate Tool ?

- Simulation helps study and experiment with complex systems or their subsystems
- It allows testing how changes in information, organization, or environment impact system behavior
- Changing inputs and analyzing outputs reveals key variables and their interactions
- Test new designs or policies before implementation to anticipate outcomes
- Use simulation to confirm analytic solutions
- Train without disrupting operations or incurring costs using simulation models
- Visualize plans with animation showing simulated operations
- Handle complex systems effectively through simulation

Simulation : Not so Appropriate Tool ?

- When the problem can be solved using common sense.
- When the problem can be solved analytically.
- When it is easier to perform direct experiments.
- When the simulation costs exceed the savings.
- When the resources or time are not available.
- When system behavior is too complex or can't be defined.
- When there isn't the ability to verify and validate the model.

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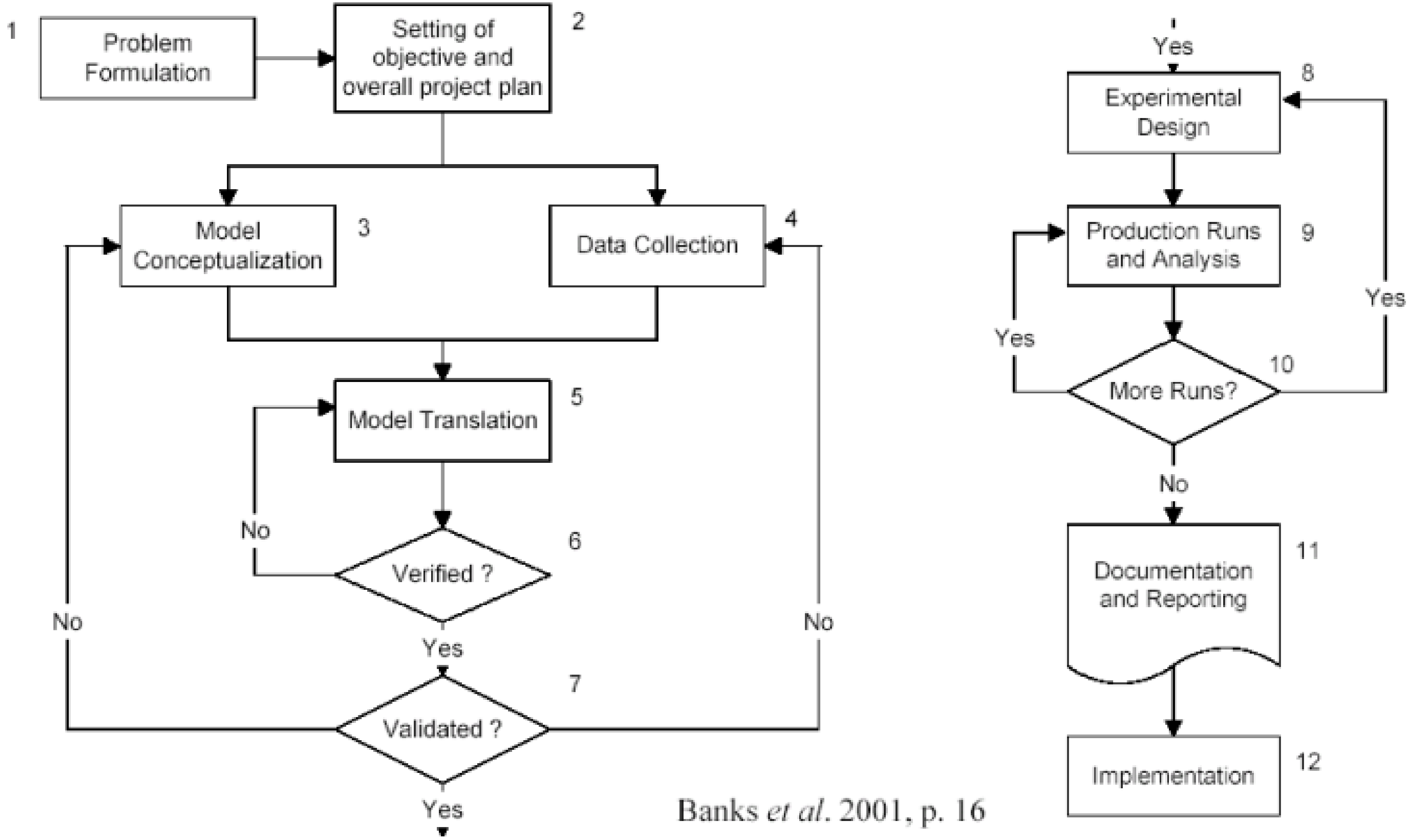
Advantages: Simulation

- New polices, operating procedures, decision rules, information flows, organizational procedures, and so on can be explored without disrupting ongoing operations of the real system.
- New hardware designs, physical layouts, transportation systems, and so on, can be tested without committing resources for their acquisition.
- Hypotheses about how or why certain phenomena occur can be tested for feasibility.
- Insight can be obtained about the interaction and importance of variables to the performance of the system.
- Bottleneck analysis can be performed indicating where work-in-process, information, materials, and so on are being excessively delayed.
- "What-if" analysis can be performed. This is particularly useful in the design of new system.

Disadvantages: Simulation

- Special Training: While building simulation models requires expertise, the learning curve is manageable, and modern tools make it easier for practitioners to develop effective models.
- Interpretation Challenges: Simulation results reflect randomness, but statistical analysis techniques make it possible to extract meaningful insights and account for variability.
- Time and Cost: Though simulations can be resource-intensive, they often save significant costs by avoiding expensive real-world experiments
- Analytical Alternatives: While analytical solutions exist for some problems, simulations provide more flexibility and can model complex, real-world scenarios that analytical methods cannot handle.
- Accuracy of Results: Simulations are sometimes perceived as inaccurate due to their dependence on assumptions, but their accuracy depends on the quality of input data and validation, which can be rigorously ensured.

Steps in Simulation Study



Banks *et al*. 2001, p. 16

Steps in Simulation Study

- Problem formulation
  - Policy maker/Analyst understand and agree with the formulation.
- Setting of objectives and overall project plan
- Model conceptualization
  - Systems thinking!!
- Data collection
  - Data – Fidelity!
  - Abstraction Level
- Model translation
  - Identification of mode of simulation
- Verification
  - Is the computer program performing properly?
  - Debugging for correct input parameters and logical structure
- Validation
  - The determination that a model is an accurate representation of the real system.
  - Validation is achieved through the calibration of the model
- Experimental design
  - length of the initialization period
  - length of simulation runs
  - number of replications to be made of each run
- Production runs and analysis
  - To estimate measures of performances

Steps in Simulation Study

- More runs?
- Documentation and reporting
    - Program documentation : for the relationships between input parameters and output measures of performance, and for a modification
    - Progress documentation : the history of a simulation, a chronology of work done and decision made.
- Implementation
- Bank Demo

Sample Path and Sample Path Analysis

- Sample path – a record (an instance realization) of the behavior of the system
- Sample path analysis – Extract system performances from SP

- Input data + Logic => ( )
- What kinds of input data?
- What kinds of logic? Recursive equations for a simple system (spreadsheet based simulation) or event mechanism (to be covered)

Sample Path and Sample Path Analysis

- Goals of the study
  - The total production during 20 min
  - The average waiting time in Queue
  - The maximum waiting time in Queue
  - The Average number of parts waiting in Queue
  - The maximum number of parts waiting in Queue
  - The average time in system
  - The maximum time in system
  - The Utilization of the drill machine

Part #	Arrival Time (A_i)	Inter-arrival Time (B_i)	Service Time (C_i)	Time_in_Q (D_i)	Time_in_Sys (E_i)	Depart Time (F_i)
1	0.00	1.73	2.90			
2		1.35	1.76			
3		0.71	3.39			
4		0.62	4.52			
5		14.28	4.46			
6		0.70	4.36			
7		15.52	2.07			
8		3.15	3.36			
9		1.76	2.37			
10		1.00	5.38			
11		.	.			
…		.	.			
…		.	.			