Modelling and Simulation

Decision Support for Management

Unit 2: Learning Outcomes

1. To understand the definitions of complex system; open and closed systems; hierarchical systems
2. To understand the systems approach
3. To be able to explain the differences between Hard problems and Soft problems
4. To describe the characteristics of Hard Systems approach and Soft Systems approach
5. To understand the differences between static and dynamic systems; discrete and continuous systems; deterministic and stochastic models; normative and descriptive models
6. To understand the various types of models, e.g. physical models, symbolic models, mental models, mathematical models
7. To understand the definitions of incomplete, inconsistent and ambiguous models
8. To understand the definition of simulation
9. To be able to explain the relationship between modelling and simulation
10. To describe the key steps of a simulation process
11. To be able to explain the limitations of simulation

Introduction

As business becomes more complex, the decision faced by management become more difficult to solve. Decisions can no longer be taken as a result of a “hunch” or what was once called experience. Instead, managers and people who are paid to make decisions need to use decision making techniques to help them.

Most of these techniques are quantitative in nature and so the decision maker needs to be numerate.

Being numerate does not necessarily mean being a mathematician, but it does mean being comfortable with figures and appreciating that there are a number of numerate techniques that can be applied to management problems.

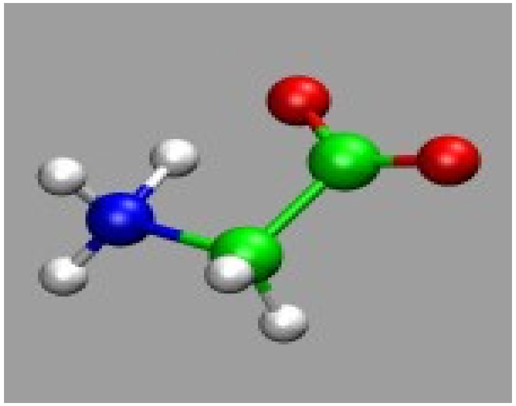
What is a Complex System? (1)

"A system is a collection of parts which interact with each other to function as a whole. Therefore, systems have a purpose as a whole and the whole is not the pure sum of the parts of the system. From systems we have also the concept of **synergy**, that is the mutual interaction of the parts is more worth than the sum of the individual parts."

"A system is an entity that maintains its existence through the mutual interaction of its parts"

"A system is any set (group) of interdependent or temporally interacting parts. Parts are generally systems themselves and are composed of other parts, just as systems are generally parts or components of other systems."

An example of systems can be the educational delivery of a university course, where the components would be the tutor, the students, the resource facilities.

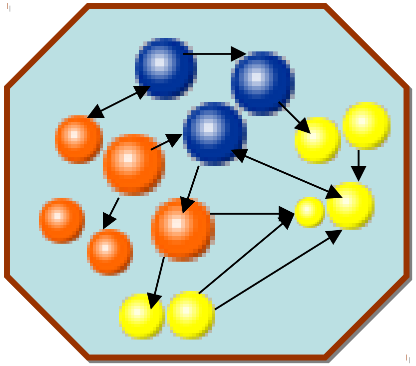


Systems theory focuses on organisation and interdependence of relationships within a system.

What is a Complex System? (2)

"The systems approach considers two basic components: elements and processes. Elements are measurable things that can be linked together. They are also called objects, events, patterns, or structures. Processes change elements from one form to another. They may also be called activities, relations, or functions. In a system the elements or processes are grouped in order to reduce the complexity of the system for conceptual or applied purposes."

"Depending on the system's design, groups and the interfaces between groups can be either elements or processes. Because elements or processes are grouped, there is variation within each group. Understanding the nature of this variation is central to the application of systems theory to problem-solving."



Systems Approach (1)

“The systems approach distinguishes itself from the more traditional analytic approach by emphasizing the interactions and connectedness of the different components of a system.”

The systems approach emerged as scientists and philosophers identified common themes in the approach to managing and organising complex systems.

Systems Approach (2)

Four major concepts underlie the systems approach:

Specialization: A system is divided into smaller components allowing more specialized concentration on each component.

Grouping: To avoid generating greater complexity with increasing specialization, it becomes necessary to group related disciplines or sub-disciplines.

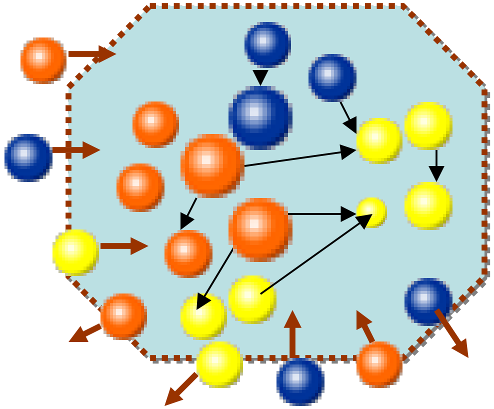
Coordination: As the components and subcomponents of a system are grouped, it is necessary to coordinate the interactions among groups.

Emergent properties: Dividing a system into subsystems (groups of component parts within the system), requires recognizing and understanding the "emergent properties" of a system; that is, recognizing why the system as a whole is greater than the sum of its parts.

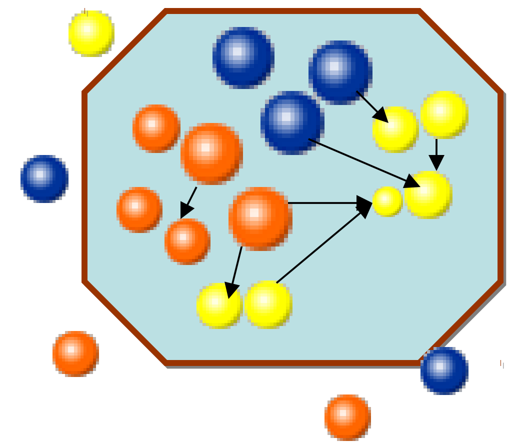
> For example, two forest stands may contain the same tree species, but the spatial arrangement and size structure of the individual trees will create different habitats for wildlife species. In this case, an emergent property of each stand is the wildlife habitat.

Open *vs.* Closed Systems

Systems could be open with respect to certain elements or processes. The elements or processes can flow into or out of the system. For example, an automobile engine is "open" with respect to gasoline - gasoline flows in and exhaust (oxidized gasoline) flows out.



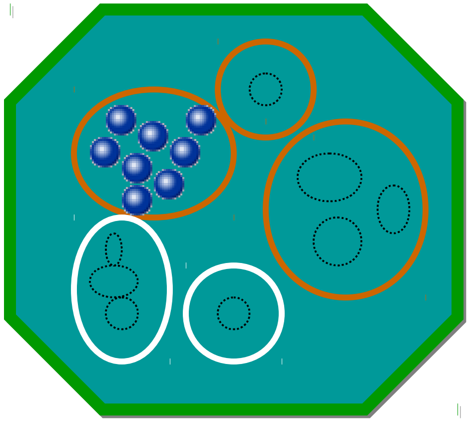
Systems could be closed with respect to certain elements or processes. The elements or processes do not leave the system. For example, an automobile engine is largely "closed" with respect to lubricating oil - the oil does not leave the engine.



Hierarchies

Most systems contain nested systems; that is, subsystems within the system. Similarly, many systems are subsystems of larger systems.

Nested systems can be considered as a hierarchy of systems. Hierarchical (nested) systems contain both parallel components (polygons of the same colour) and sequential components (polygons of different colours).



"At the higher levels, you get a more abstract, encompassing view of the whole emerges, without attention to the details of the components or parts. At the lower level, you see a multitude of interacting parts but without understanding how they are organized to form a whole (Principia Cybernetica, 1999)."

Hard Problems and Soft Problems

Soft Systems methodology was developed by Peter Checkland for the express purpose of dealing with problems of this type.

Problems

Hard Problems

Soft Problems

Hard problems are problems characterized by the fact that they can be well defined. You assume that there is a definite solution and you can define a number of specific goals that must be accomplished. In essence, with a hard problem you can define what success will look like prior to embarking on implementing the solution. The "WHAT" and the "HOW" of a hard problem can be determined early on in the methodology.

Soft problems are difficult to define. They will have a large social and political component. When we think of soft problems, we don't think of problems but of problem situations. We know that things are not working the way we want them to and we want to find out why and see if there is anything we can do about it. It is the classic situation of it not being a "problem" but an "opportunity".

Hard Systems and Soft Systems (1)

Since the 1970s, the systems concept has been further refined into two distinct and complementary approaches, namely the hard systems and soft systems approach (Checkland and Scholes, 1990).

Walker (1996) presents a detailed account of the contrasting philosophical concepts, problem conceptualisations and general methodologies of the two approaches.

Hard Systems approach and Soft Systems approach are two approaches to system development.

Hard systems approach is based on systems engineering and systems analysis. The people are treated as passive observers of the system development process. However, this approach is not suitable in organisational environment that involves political, social, or human activities. Development of such systems require an active involvement of every stakeholder. The approach that encompasses all the stakeholders of the system is soft system approach.

Hard Systems and Soft Systems: Characteristics of the Approaches (2)

Systems Approach

Hard Systems Approach	Soft systems Approach
✓ Well-defined boundaries and simple linkages with other problems ✓ Goals, alternatives and consequences are well-defined ✓ The standard management technique is to collect and analyse data, unilaterally decide on a best course of action, and implement accordingly.	✓ Ambiguous boundaries and complex linkages with other problems ✓ Goals, alternatives, and consequences which are not well-defined or well-understood ✓ Pervasive uncertainty which may not be quantifiable ✓ Iterative management which involves conflict and negotiation among multiple stakeholders with divergent interests and values.

Attributes of a Complex System

1. "Frequently, complexity takes the form of a hierarchy, whereby a complex system is composed of interrelated subsystems that have in turn their own subsystems, and so on, until some lowest level of elementary components is reached."

2. "The choice of what components in a system are primitive is relatively arbitrary and is largely up to the discretion of the observer of the system."

3. "Intra-component linkages are generally stronger than inter-component linkages. This fact has the effect of separating the high-frequency dynamics of the components – involving the internal structure of the components – from the low-frequency dynamics – involving interaction among components."

4. "Hierarchic systems are usually composed of only a few different kinds of subsystems in various combinations and arrangements."

5. " A complex system that works is invariably found to have evolved from a simple system that worked. … A complex system designed from scratch never works and cannot be patched up to make it work. You have to start over, beginning with a working simple system."

(G. Booch)

State of a System

The state of a system at a moment of time is the set of relevant properties which that system has at that moment.

Any system has an unlimited number of properties. Only some of these are relevant to any particular research. Hence those which are relevant may change with changes in the purpose of the research.

The values of the relevant properties constitute the state of the system. In some cases we may be interested in only two possible states (e.g. off and on; or awake or asleep). In other cases we may be interested in a large or unlimited number of possible states (e.g. a system's velocity or weight).

System Classification: Static *vs*. Dynamic Systems/Models

Systems are either static or dynamic.

A static system (one-state) is either where time does not play any significant role or where we are only interested in the system at one particular instance in time. A static system is one to which no events occur.

A system that is changing over time is usually said to be a dynamic (multi-state) system. A dynamic system is one to which events occur, whose state changes over time.

Static models are those models which do not explicitly take the variable time into account.

Mathematical models that deal with time-varying interactions are said to be dynamic models.

Dynamical System

A dynamical system is a concept in mathematics where a fixed rule describes the time dependence of a point in a geometrical space.

The mathematical models used to describe the swinging of a clock pendulum, the flow of water in a pipe, or the number of fish each spring in a lake are examples of dynamical systems.

A dynamical system has a state determined by a collection of real numbers. Small changes in the state of the system correspond to small changes in the numbers. The numbers are also the coordinates of a geometrical space - a manifold.

The evolution rule of the dynamical system is a fixed rule that describes what future states follow from the current state. The rule is deterministic: for a given time interval only one future state follows from the current state.

System Classification: Discrete *vs.* Continuous Systems

Systems can also be discrete or continuous.

A discrete system is where the sate of the system changes at discrete time intervals while a continuous system changes smoothly (i.e. system changes continuously with respect to time).

Deterministic & Stochastic Models

Models of systems are either deterministic or stochastic.

The word “stochastic” derives from the Greek (to aim, to guess) and means “random” or “chance”. The antonym is “sure”, “deterministic“, or “certain”.

In a Deterministic Model, the functional relationships, that is, the models parameters, are known with certainty.

In a Stochastic Model there are some uncertain relationships/parameters. We would develop a stochastic model to incorporate the uncertainty. A stochastic model may have some functional relationships that are both deterministic and stochastic or all relationships may be stochastic. Such models, if they are structured in the form of a normative model, are such that solutions can be derived that provide the best expected results, that is, for example, the objective function is optimised for maximum or minimum expected results.

Deterministic & Stochastic Models

In deterministic models variable are not permitted to be random variables and characteristics are assumed to be exact relationships rather that probability density functions. Deterministic models can frequently be solved analytically by such techniques as the calculus of maxima and minima.

Those models in which at least one of the characteristics is given by a probability function are said to be stochastic models.

Normative & Descriptive Models

A descriptive model is one that represent a relationship but does not indicate any course of action.

A normative model (e.g. optimisation model) is prescriptive in that it prescribes the course of action that the decision maker should take to achieve a defined objective.

Descriptive models are useful in predicting the behaviour of system but have no capability to identify the "best" course of action that should be taken.

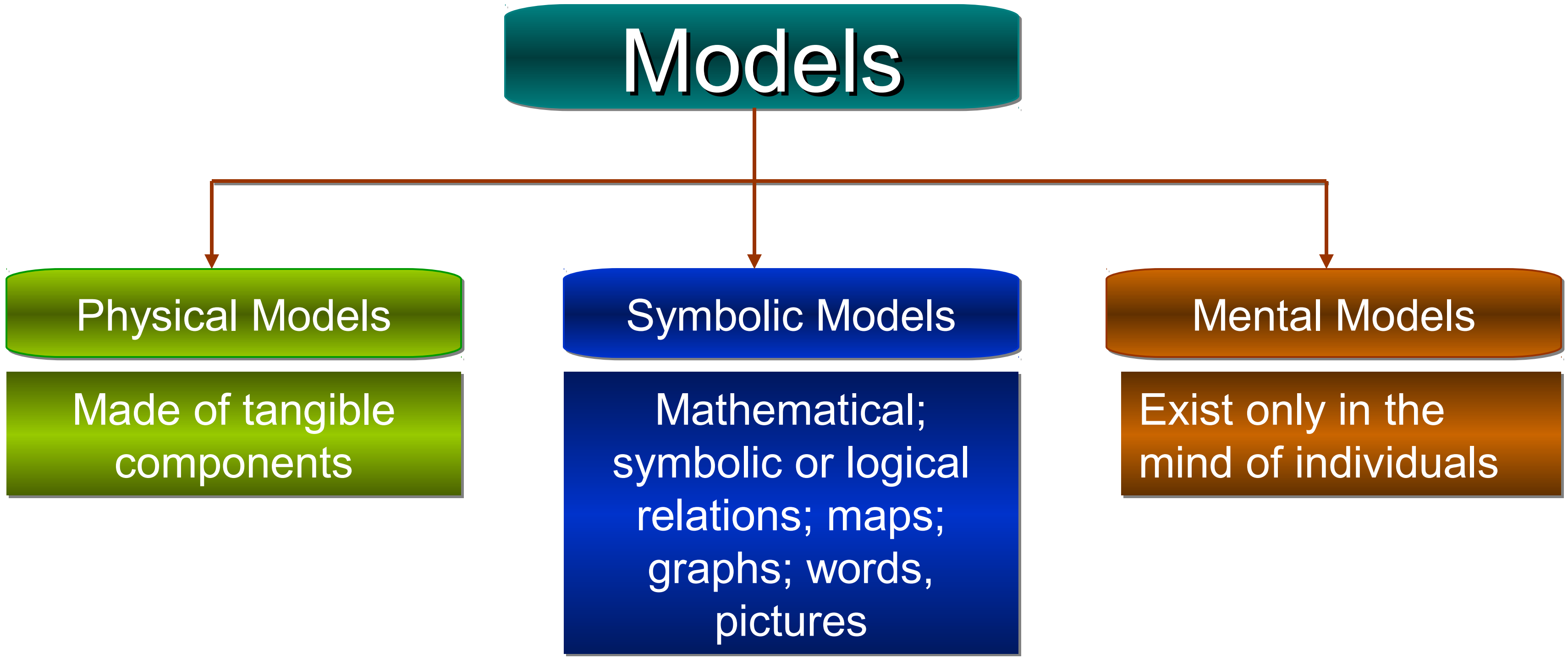
Many statistical models are descriptive.

A normative model may contain descriptive sub-models, but it differs from the descriptive model in that it is possible to determine an optimal or best course of action.

Many management science models fall under the classification of normative models.

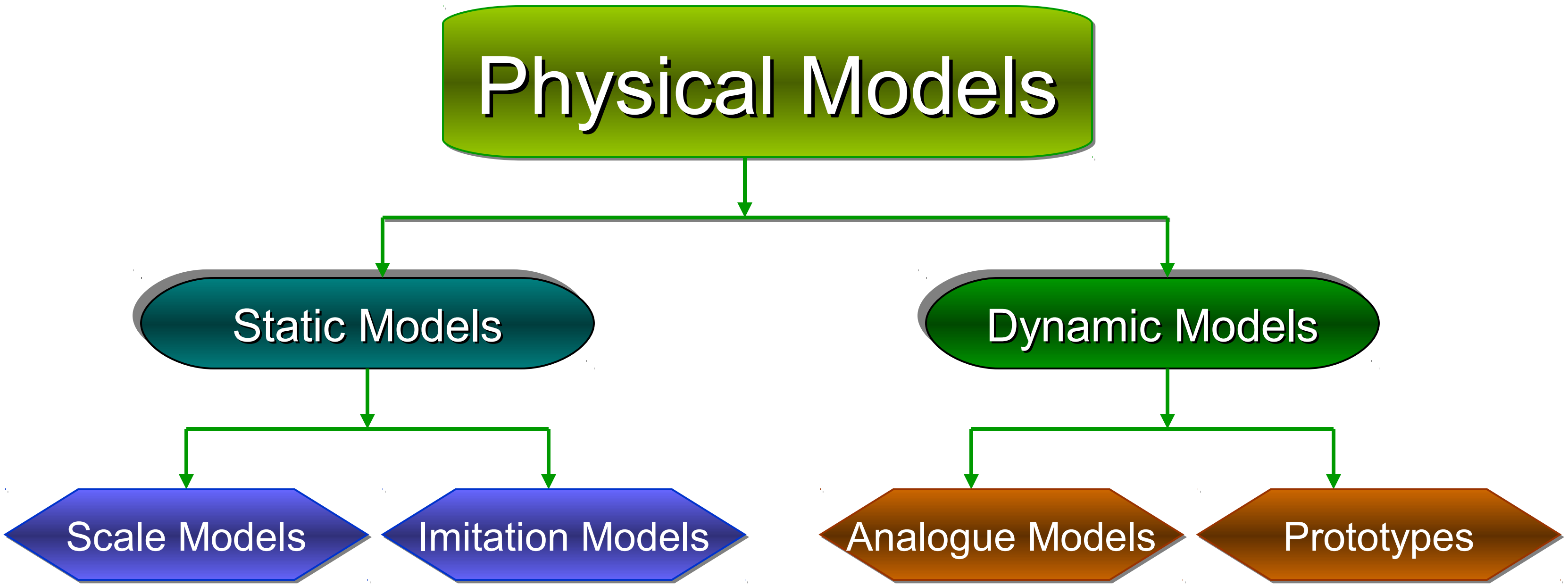
Types of Models

Models can be classified in many ways, e.g.



From F. Neelamkavil, Computer Simulation and Modelling, 1987

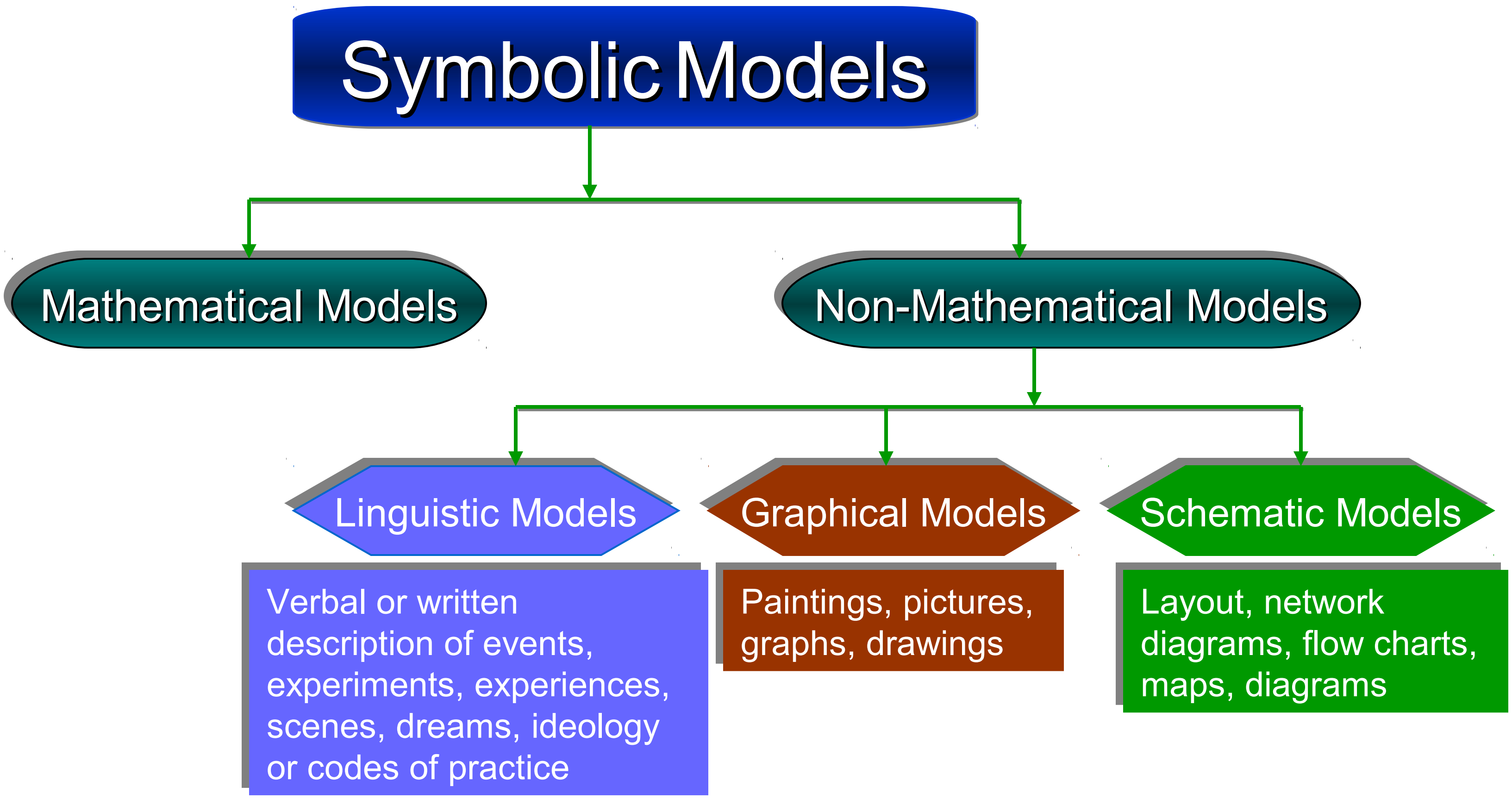
Physical Models



….

From F. Neelamkavil, Computer Simulation and Modelling, 1987

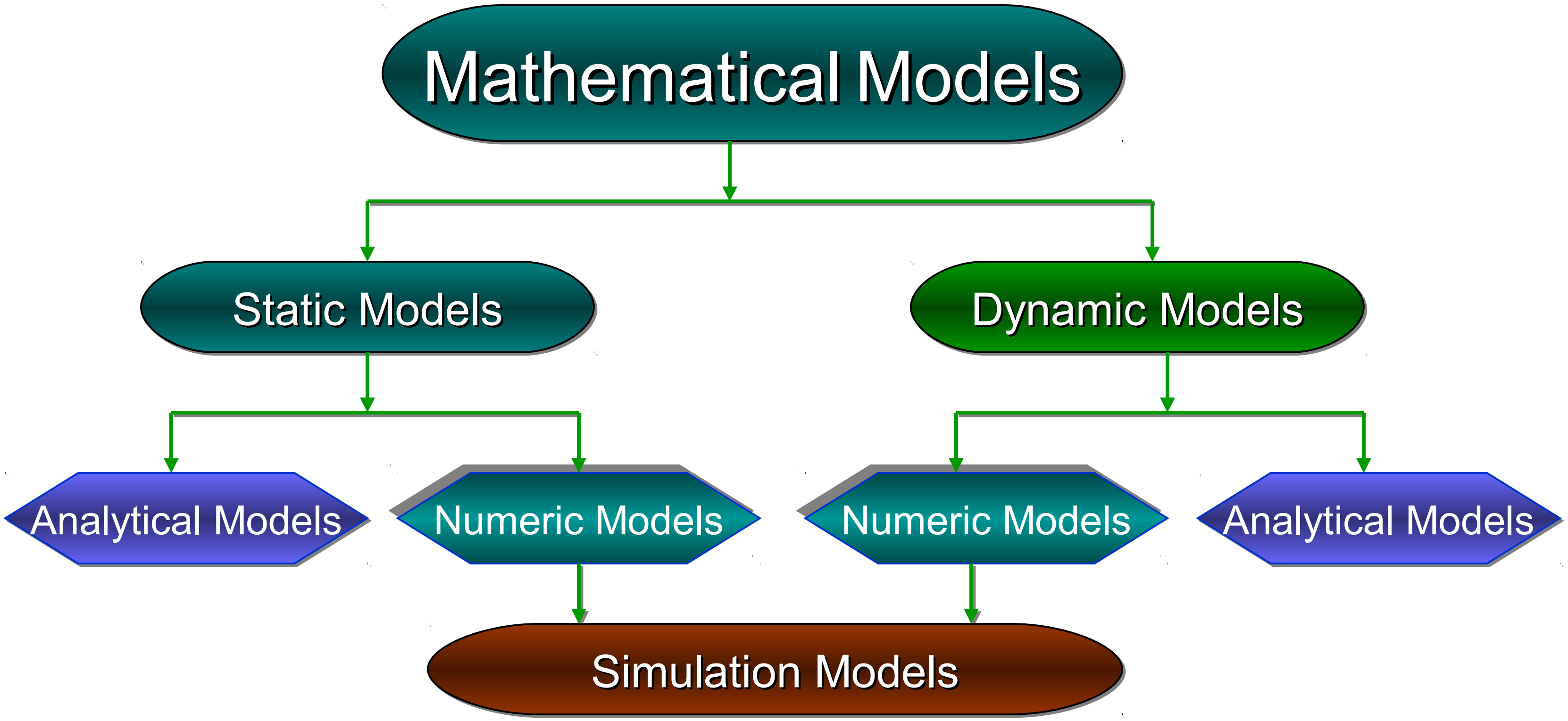
Symbolic Models



....

From F. Neelamkavil, Computer Simulation and Modelling, 1987

Mathematical Models



From F. Neelamkavil, Computer Simulation and Modelling, 1987

Mathematical Models (1)

Most management science analyses are constructed by using mathematical models. Not all mathematical models are complex.

For example: we can develop a mathematical model to determine the pay of a salesperson who received a commission of £20 on each sale. More specifically, assume we are given the following data that describe the relationship between the salesperson's commission and the number of sale.

Number of sales	**0**	**1**	**2**	**3**	**4**	**5 …**
Commission income in £	**0**	**20**	**40**	**60**	**80**	**100 …**

If we let x represent the number of sales and y represent the pounds of income, then the mathematical function between sales and income is expressed:

$$y = 20x$$

Mathematical Models (2)

This functional relationship can be viewed mentally as representing a processing operation, much in the same manner as we would visualize a data processing operation. The various values of x (0,1,2,3,4,5,..) can be thought of as inputs, with the corresponding values of y (0,20,40, 60,…) being outputs. The inputs and outputs are commonly called variables.

Using conventional mathematical terminology, the input variable is referred to as the independent variable and the output variable as the dependent variable. The numerical value is referred to by several labels: constant, coefficient, and parameter.

Incomplete, Inconsistent & Ambiguous Models

A model may be incomplete because the modeller did not think of all the relevant situations that might arise and did not provide a complete description.

If the modeller did consider all possibilities, he/she may have intended that the rules should apply to distinct sets of situations, whereas in fact one or more rules apply to the same situation. If they prescribe contradictory actions, the model is rendered inconsistent, since no action is actually possible in this situation.

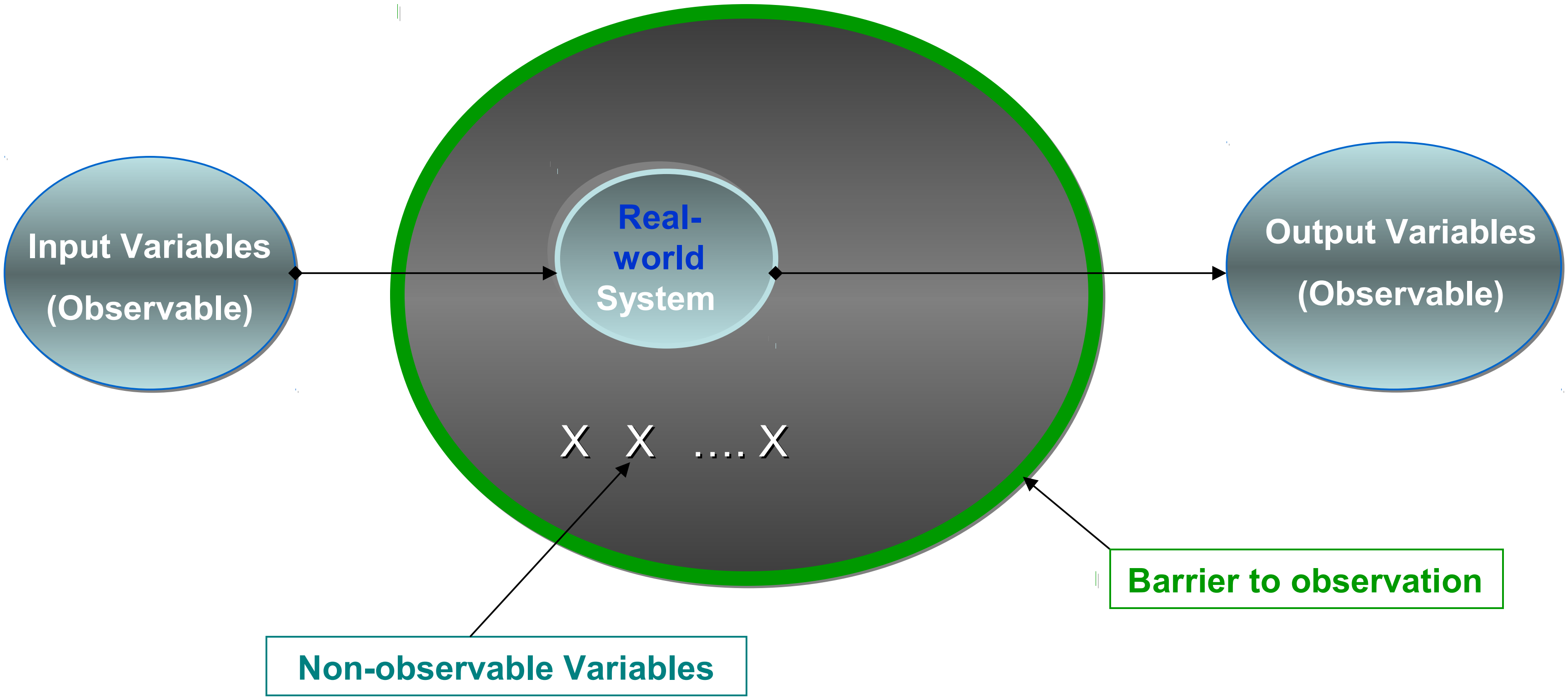
Finally, a model may be ambiguous because two or more possibilities are suggested in a particular situation, but it is not clear which one the modeller intended.

Components of Scientific Modelling

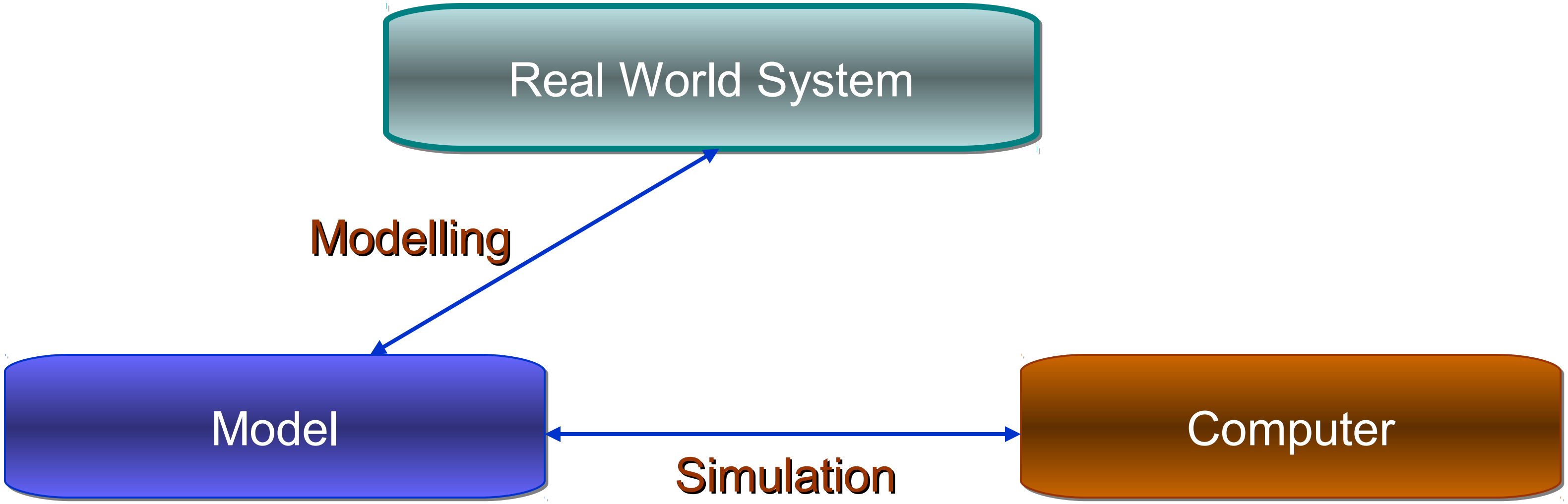
Scientific modelling has three components:

- ✓A natural phenomenon under study
- ✓A logical system for deducing implications about the phenomenon
- ✓A connection linking the elements of the natural system under study to the logical system used to model it.

Variables of the Real System



Modelling and Simulation:
Elements and Relations



Simulation: Definition

Simulation is emulation of reality using mathematical model.

Simulation is the process of designing a model of a real system and conducting experiments with this model for the purpose wither of understanding the behaviour if the system of of evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system.

Thus we understand the process of simulation to include both the construction of the model and the analytical use of the model for studying a problem.

Simulation: Definition

Do not restrict definition of simulation to experiments conducted on electronic computer models.

Man useful simulations can be and are run with only paper and pen or with the aid of a desk calculator.

Simulation modelling is an experimental and applied methodology which seeks to:

- ✓Describe the behaviour of systems
- ✓Conduct theories or hypotheses that account for the observed behaviour
- ✓Use these theories to predict future behaviour, that is, the effects that will be produced by changes in the system or in its method of operation.

Simulation: Definition

All simulation models are so-called input-output models.

That is, they yield the output of the system given the input to its interacting subsystems.

Simulation models are “run” rather that “solved” in order to obtain the desired information or results.

They are incapable of generating a solution on their own in the sense of analytical models; they can only serve as a tool for the analysis of the behaviour of a system under conditions specified by the experimenter.

Thus, simulation is not a theory but a methodology of problem solving.

Simulation Models

Simulation models can be classified according to the time at which state transitions occur. This way there is differentiation between continuous and discrete simulation models.

In a continuous simulation, the state of the model changes continuously with the times.

In a discrete simulation, the state transition occurs at intervals, i. e. at discrete times.

Discrete simulation models are further differentiated into time-controlled, event-driven, activity-oriented, process-oriented and transaction-oriented simulation models.

Simulation: Steps

In case a simulation model is developed, the following steps must usually be taken:

- ✓ analysis of the simulation requirements
- ✓ generation and specification of the simulation concept
- ✓ assessment of the simulation concept
- ✓ generation of test scenarios
- ✓ development of the simulation model
- ✓ testing the simulation model
- ✓ making available the scenario test data and performing the simulation runs
- ✓ analysis and evaluation of the simulation results
- ✓ testing the simulation model
- ✓ possible upgrade or modification of the simulation model

When to use simulation

Simulation is a slow, iterative, experimental problem-solving technique. Sometimes it is referred to as the method of last resort. One should contemplate problem-solving by simulation only when:

- ✓The real system does not exist and it is expensive, time-consuming, hazardous, or impossible to build and experiment with prototypes (new design of a computer, solar system, nuclear reactor)
- ✓Experimentation with the real system is expensive, dangerous, or likely to cause serious disruptions (transport systems, nuclear reactor, manufacturing system)
- ✓There is a need to study the past, present, or future behaviour of the system in real time, expanded time or compressed time (real-time control systems, slow-motion studies, population growth, side-effects of new drugs)
- ✓Mathematical modelling of system is impossible (oil exploration, meteorology, world economy, international conflicts, computer networks)
- ✓Mathematical models have no simple and practical analytical or numerical solutions (non-liner differential equations, stochastic problems)
- ✓Satisfactory validation of simulation models and results is possible
- ✓Expected accuracy of simulation results is consistent with the requirements of the particular problem

(Francis Neelamkavil)

Limitations of Simulation

- ✓Neither a science nor an art, but a combination of both
- ✓Method of last resort
- ✓Iterative, experimental problem-solving technique
- ✓Expensive in terms of manpower and computer time
- ✓Generally yields suboptimum solutions
- ✓Validation difficult
- ✓Collection, analysis, and interpretation of results require a good knowledge of probability and statistics
- ✓Results can be easily misinterpreted and difficult to trace sources of errors
- ✓Difficult to convince others

(Francis Neelamkavil)

Research Question

- Read and write short notes on the following categories /models of the model base (and what they support):
    - Strategic models
    - Tactical models
    - Operational models
    - Analytical models.

References

- University of Sunderland - School of Computing and Technology

- Efraim, T., Jay, E.A., & Ting-Peng, L. (2005). *Decision Support Systems and Intelligent systems, 7th ed. Pearson Education inc.*