Computer Modelling and Simulation

Lectures 1 and 2

Introduction to Modelling and Simulation

- Modeling and Simulation (M&S) is a separate discipline with it’s own body of knowledge, theory and research methodology.
- M&S is founded on the following concepts:
  - Modeling: Models are approximations for the real - world .
  - Simulation: Repeated observation of the model.
  - Analysis: Aids in the ability to draw conclusions and make recommendations based on various iterations or simulations of the model.
  - Visualization: The ability to represent data as a way to interface with the model
  - Verification and Validation

Modelling and Simulation

- Modelling and simulation (M&S) is the use of **models** as a basis for **simulations** to develop data utilized for managerial or technical **decision making.**

What you'll be able to do after this course?

- Make simulations of different types of systems used in real world with the help of a simulation software i.e. **AnyLogic.**
- Create mathematical and graphical models of natural phenomena like population growth, predator-prey relationships, drug-dosage model, fall under gravity, spread of SARS etc
- Study numerical solutions for the mathematical models of the systems
- Study different types of modeling techniques (like Petri Nets, Cellular Automata etc) to represent systems.
- Understand the role of randomness in real-world systems and model that randomness.

Mathematical Model of different systems

- Predator Prey Relationship

$$ds/dt = ks\ s - khshs$$

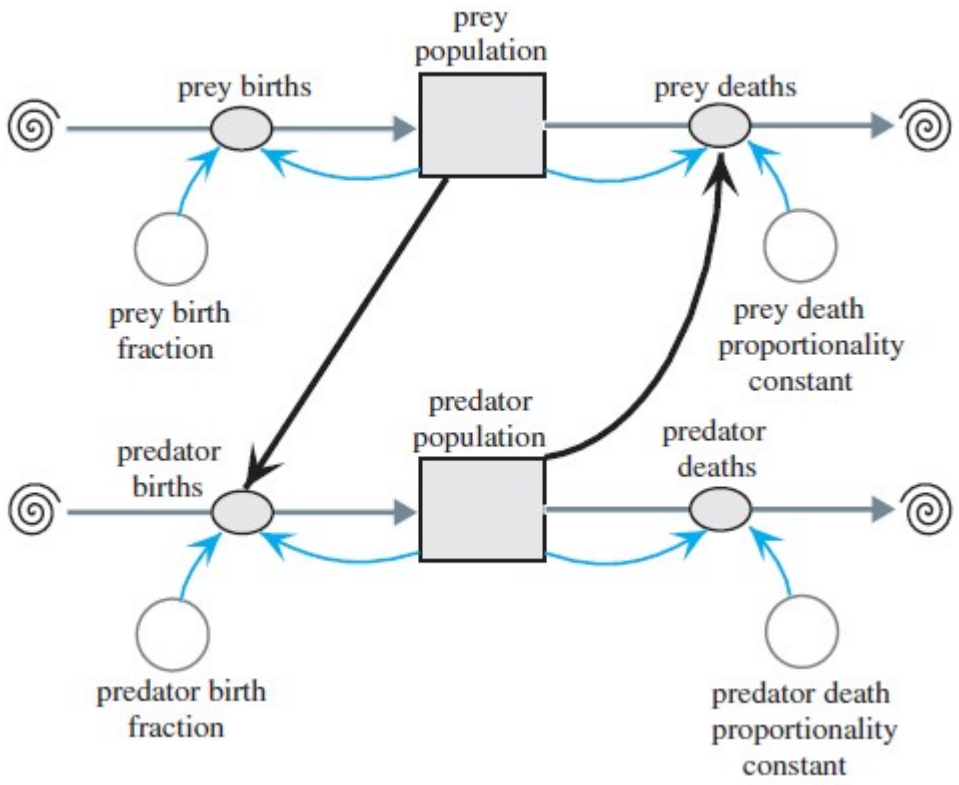
$$dh/dt = ksh\ sh - kh\ h$$

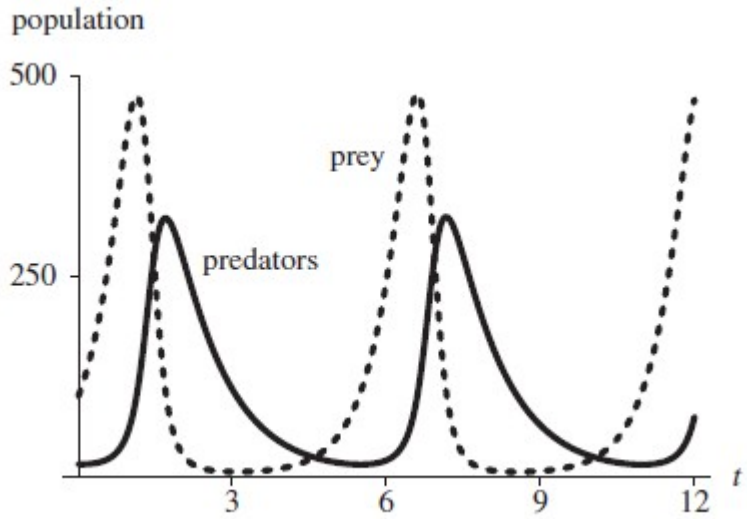
- Drug dosage Model

elimination = elimination_constant * aspirin_in_plasma

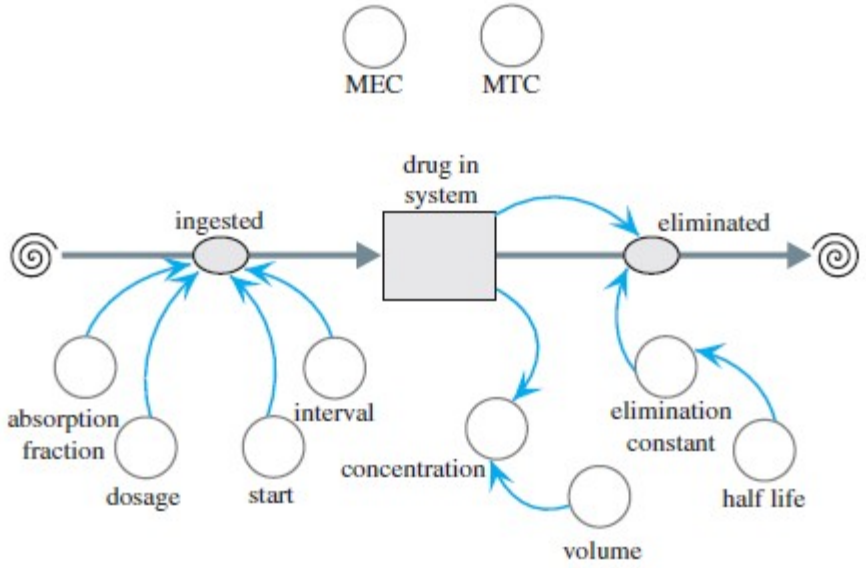
plasma_concentration = aspirin_in_plasma/plasma_volume

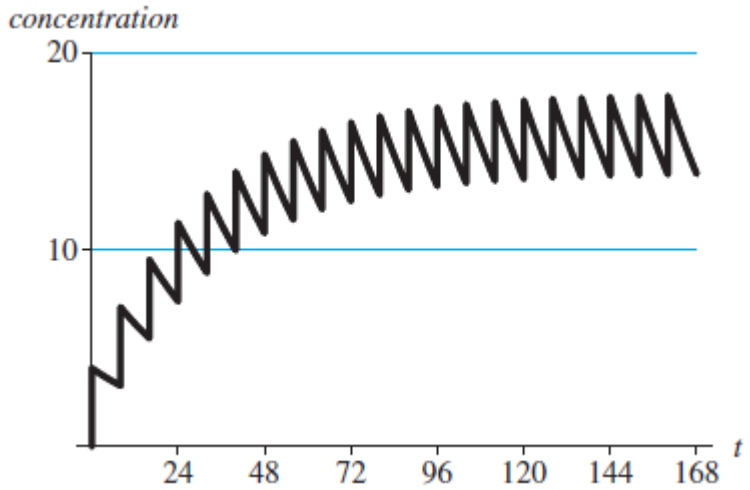
Graphical Representation of Predator-Prey Relationship and It’s analysis





Graphical Representation of Drug Dosage Model and It’s analysis





Applications of M & S

- *Training* — goal is to provide real - world experience/opportunities in a controlled environment e.g. flight simulator
- *Decision Support* — to provide a descriptive, explanatory, predictive tool
- *Understanding* — this type of modeling and simulation facilitates testing a hypothesis relative to the structure and function of a complex system e.g. modeling spread of covid or other infectious diseases
- *Education and Learning* — used for teaching and learning systems with dynamic behavior and with serious gaming (this is also called game – based learning) e.g SuperBetter (a motivational game), FoldIt (puzzle solving game for the benefit of scientific research)
- *Entertainment* — simulation provides a realistic representation for elements possessing dynamic behavior e.g. modern video games

How learning M&S will help you?

- Job opportunities
- https://www.glassdoor.com/Job/simulation-and-modeling-jobs-SRCH_KO0,23.htm
- https://www.ziprecruiter.com/Jobs/Modeling-and-Simulation-Analyst

Pre-Requisites

- Knowledge of Basic Mathematics
- Knowledge of Programming Language
- Willingness to work on many assignments and class activities

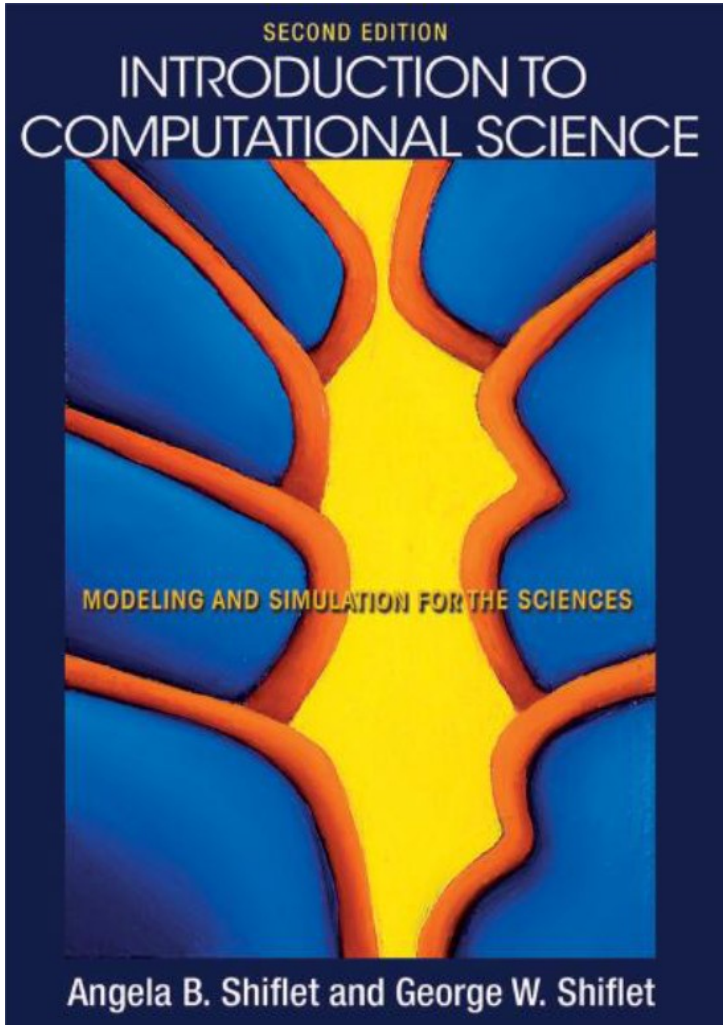
Course Policies

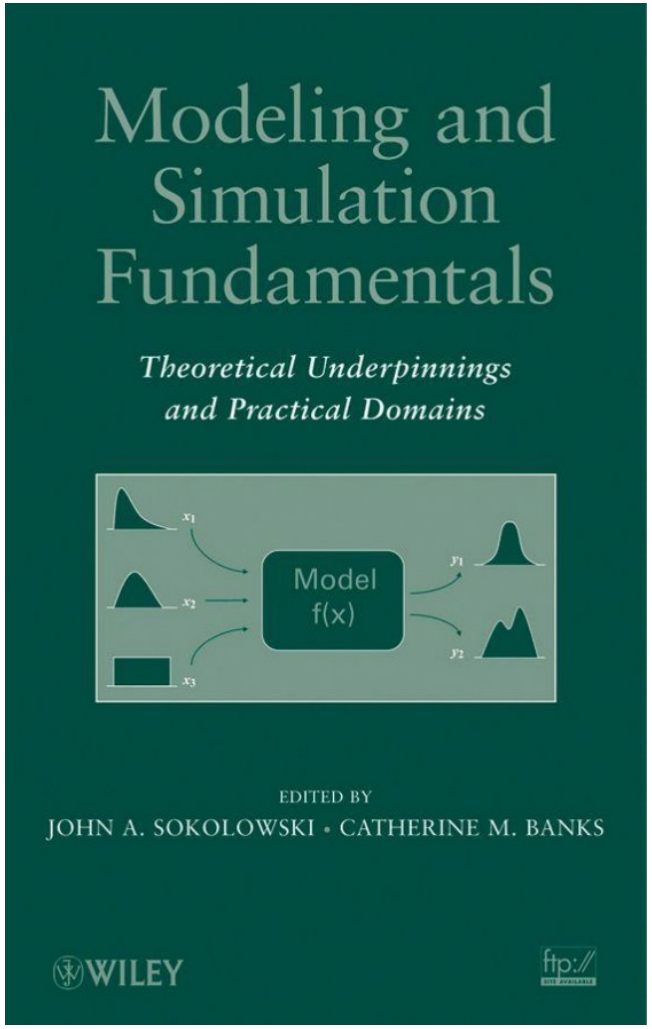
- Attendance (strict 80% attendance - no compromise on attendance)
- Zero Tolerance Policy for Plagiarism in assignments -(again no compromise)
- Grading Policy:
  - Relative

Evaluations in the course

- Quizzes - 5%-10%
- Assignments - 15%
- Sessionals (1&2) - 30% each
- Final Exam - 45%-50%

Recommended Books





Learning Resources

- AnyLogic Video Tutorials
- AnyLogic Youtube Channel

What is this?

- This is not an apple.
- It’s a representation of an apple
  - Sufficient for those who want to know what an apple looks like but not for those who want to know how it tastes like

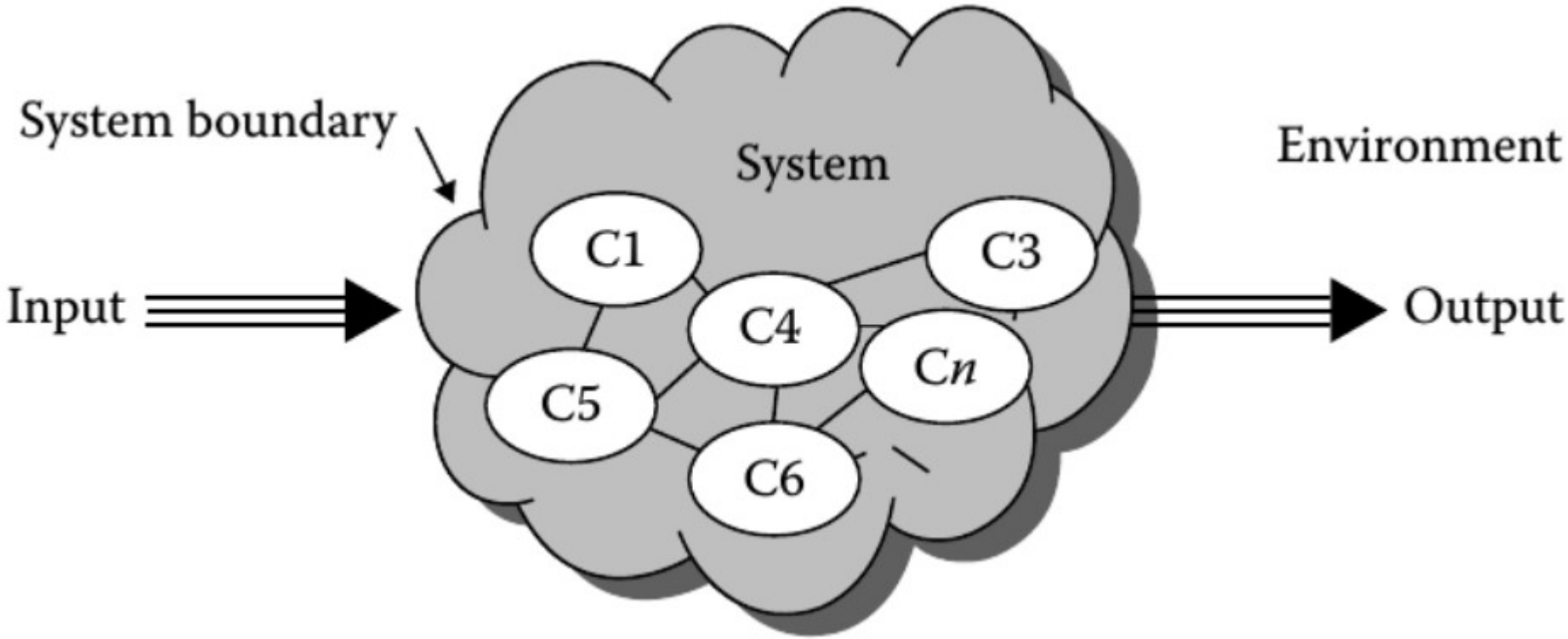
What is a model?

- A model is an abstract representation of a system.
- An abstraction in which only the essential ingredients are retained according to the questions we ask about the system.
- Level of details?
  - “Everything should be made as simple as possible but not simpler.” Albert Einstein.
- The same system can be described at different scales.
  - Cells, tissues, organs, living beings
  - Mechanical parts, cars, traffic

System

- The term "system" comes from the Latin word *systēma*, "whole concept made of several parts or members”
- An entity or group of entities that exist and operate in time and space.
- International Council of Systems Engineering INCOSE suggests that a *system* is a construct or collection of different elements that together produces results not obtainable by the elements alone.
- System refers to the subject of model development; that is, it is the subject or thing that will be investigated or studied using M & S.

System


System boundary
System
Environment
C1
C3
Input
C4
Output
Cn
C5
C6

System

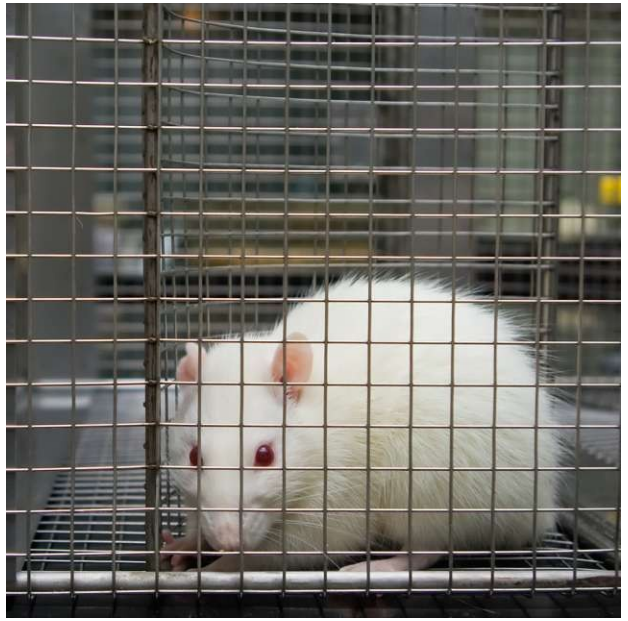
- **Examples**
  - Planetary system in the universe (gravitation bound objects in orbit around a star)
  - Banking system in finance industry (payment, loan, deposit, investment processes)
  - Software system in a computer (processes, threads, IPC, etc.)
  - Other examples are in medicine, biology, socio-economic, political, communications, environment, transportation, electrical, mechanical, etc

Types of Models

- Physical
- Notional

Types of Models

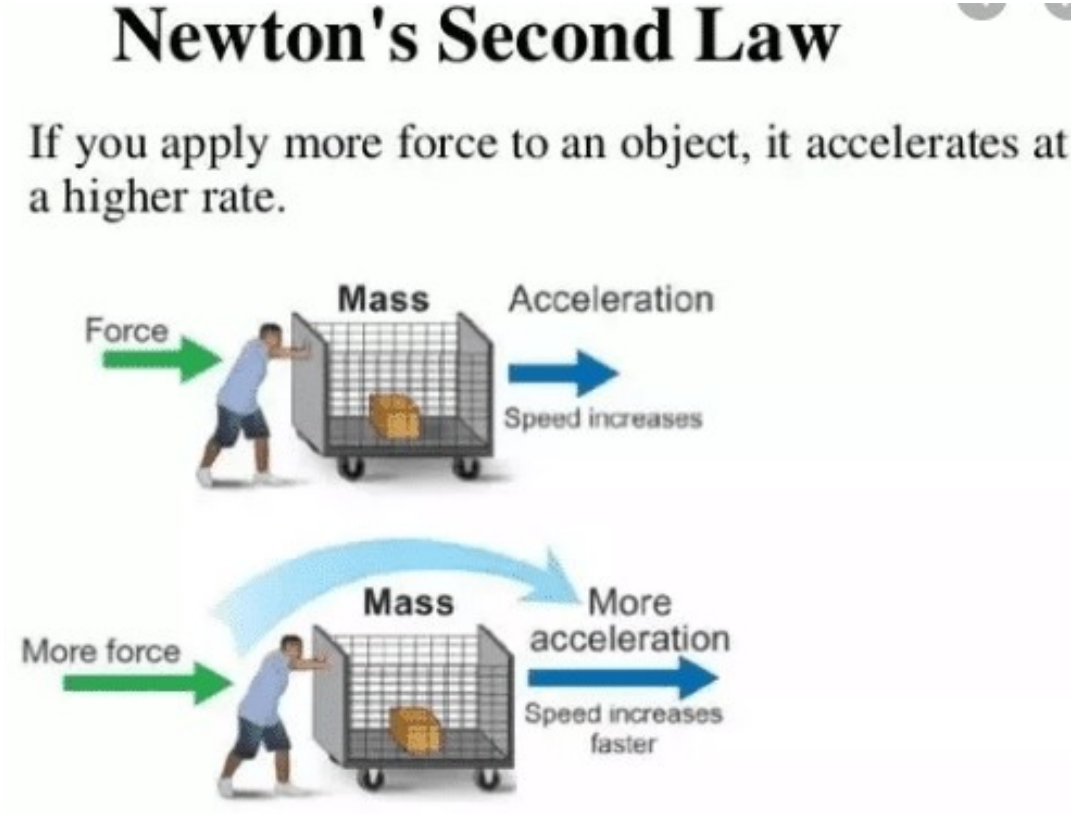
- A model can be **physical** , such as a scale model of an airplane to study aerodynamic behavior.



Types of Models

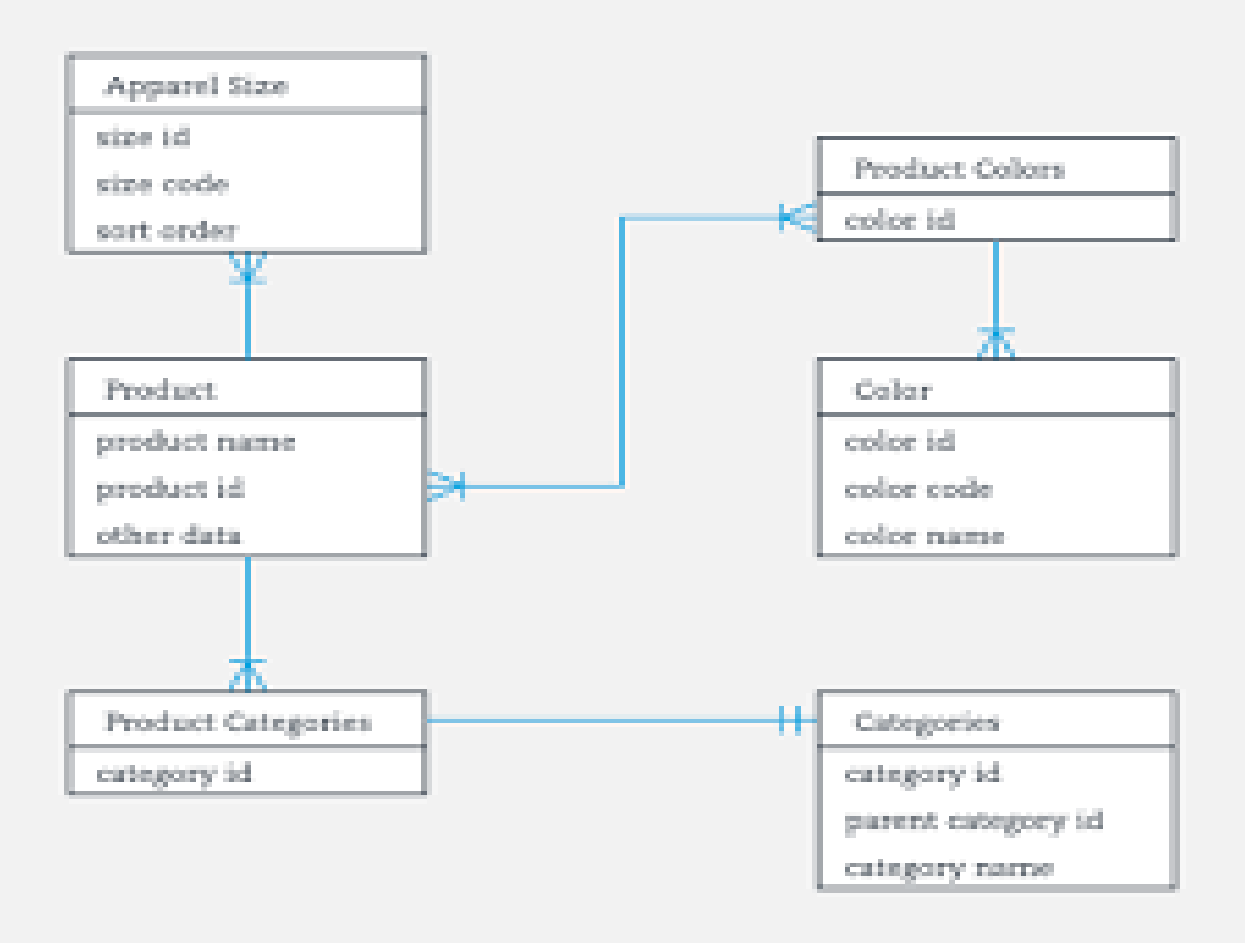
- A model can be **notional** i.e. a model consists of a set of mathematical equations or logic statements that describes the behavior of the system.
  - Mathematical model
    - Simple equations often result in analytic solutions that has mathematical proofs.
    - Some mathematical models require numerical solutions
  - Logical model
    - Software analysis/design models, computer programs.

Example of Mathematical model



F = ma

Example of a Logical model



An example Class Diagram

Mathematical Model of a free falling body

Consider a model that represents the vertical height of an object moving in one dimension under the influence of gravity.

The mathematical model takes the form of an equation

$$h = 1/2\ at^2 + vt + s$$

where

h = height (feet),

t = time in motion (seconds),

v = initial velocity (feet per second, + is up),

s = initial height (feet),

a = acceleration (feet per second per second).

Simulation

Multiple definitions:

- a nontechnical meaning not real, imitation
- A method for implementing a model over time.
- a technique for testing, analysis, or training in which real - world systems are used
- an unobtrusive scientific method of inquiry involving experiments with a model rather than with the portion of reality that the model represents
- a methodology for extracting information from a model by observing the behavior of the model as it is executed

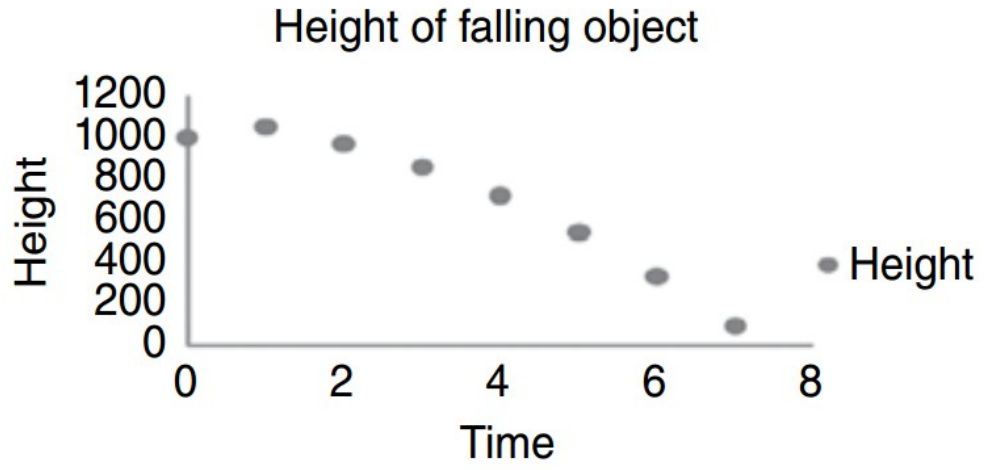
Simulation of a free falling body

Simulation Example 1

```
/* Height of an object moving under gravity. */
/* Initial height v and velocity s constants. */
main()
{
float h, v = 100.0, s = 1000.0;
int t;
for (t = 0, h = s; h >= 0.0; t++)
{
h = ( -16.0 * t * t) + (v * t) + s;
printf("Height at time %d = %f\n ", t, h);
}
}
```

Simulation of a free falling body

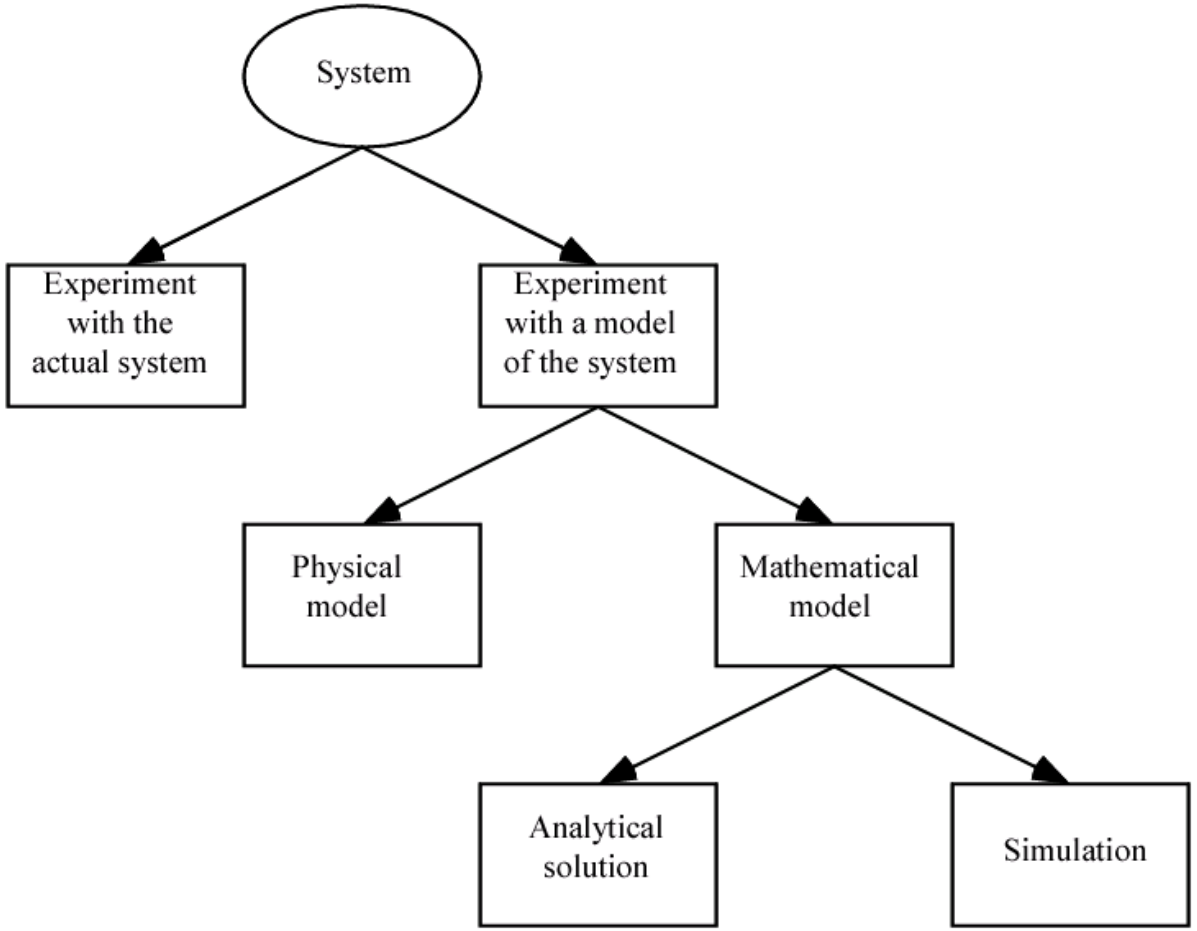
t	*v*	*h*
0	100	1000
1	68	1052
2	36	972
3	4	860
4	–28	719
5	–60	540
6	–92	332
7	–124	92



Another definition of Simulation

- Sometimes the mathematical model is sufficiently complex that the only way to solve the equations is numerically. This process is referred to as computer simulation .
- Essentially, a system is modeled using mathematical equations; then, these equations are solved numerically using a digital computer to indicate likely system behavior.
- Analytic solutions are precise mathematical proofs, and as such, they cannot be conducted for all classes of models.
- The alternative is to solve numerically with the understanding that an amount of error may be present in the numerical solution.

Another definition of Simulation



Types of Simulation

- Live Simulation
- Virtual Simulation
- Constructive simulation

Types of Simulation

- A *live simulation* involves real people operating real systems.
- Example: War games
- The purpose of live simulation training is to provide a meaningful and useful experience for the trainee.

Types of Simulation

- A ***virtual simulation*** is different from live simulation in that it involves real people operating in simulated systems.
- These systems are recreated with simulators, and they are designed to immerse the user in a realistic environment.
- Example: Cockpit simulator

Types of Simulation

- ***Constructive simulation***
- This simulation involves real people making inputs into a simulation that carry out those inputs by simulated people operating in simulated systems.
- The expected result of constructive simulation is that it will provide a useful result.
- Example: SimCity

Advantages of M&S

- The ability to *choose correctly* by testing every aspect of a proposed change without committing additional resources.
- *Compress and expand time* to allow the user to speed up or slow - down behavior or phenomena to facilitate in - depth research
- *Understand why* by reconstructing the scenario and examining the scenario closely by controlling the system
- *Explore possibilities* in the context of policies, operating procedures, methods without disrupting the actual or real system
- *Diagnose problems* by understanding the interaction among variables that make up complex systems
- *Develop understanding* by observing how a system operates rather than predictions about how it will operate
- *Visualize the plan* with the use of animation to observe the system or organization actually operating
- *Better training* can be done less expensively and with less disruption than on - the - job training

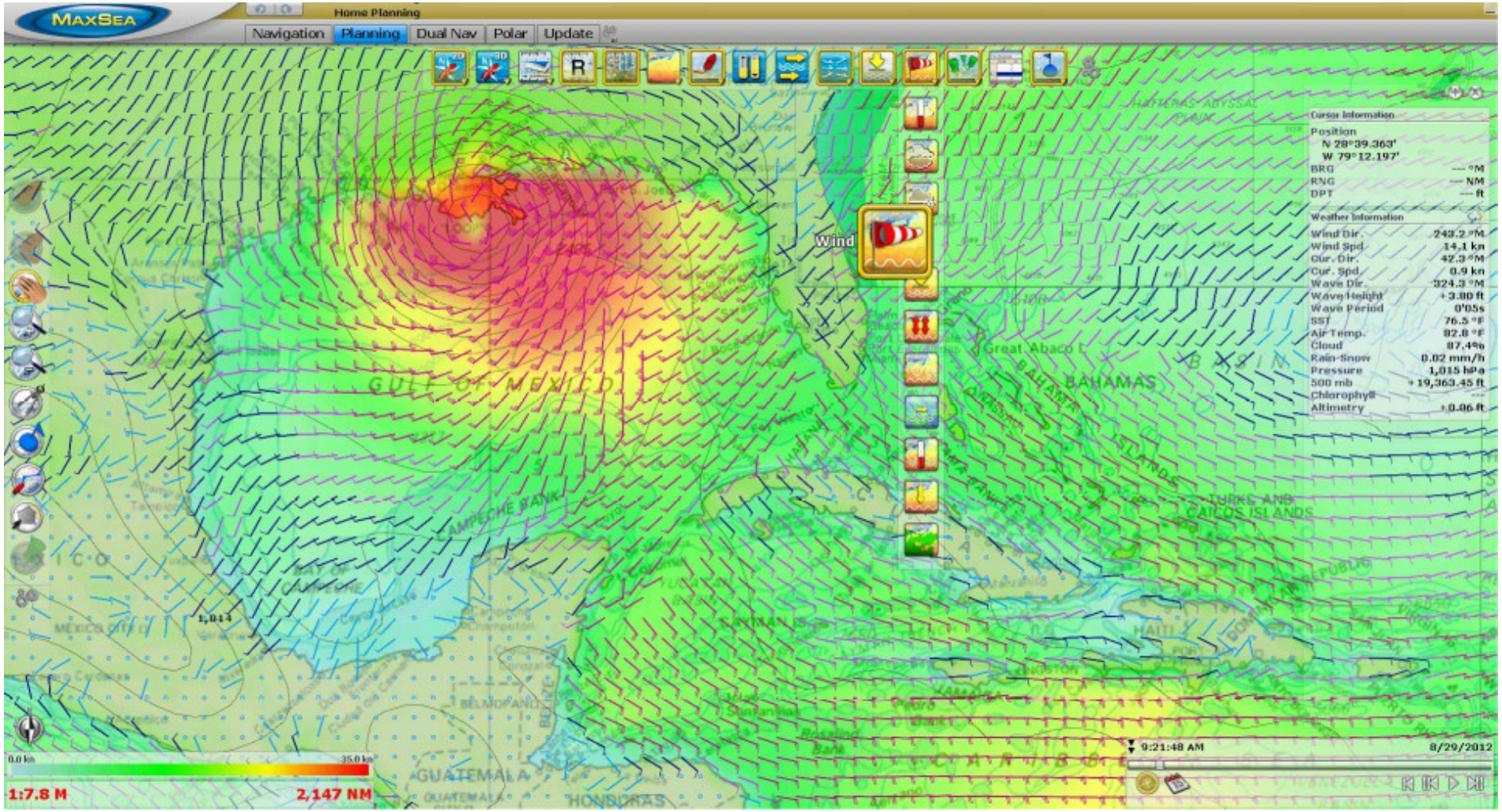
Disadvantages of M & S

- Simulation results may be difficult to interpret
- Some simulations may take months to complete
- Some simulations may require expensive hardware
- Some simulations may be run when they are not needed. For example,when analytical solutions are available.

Domains

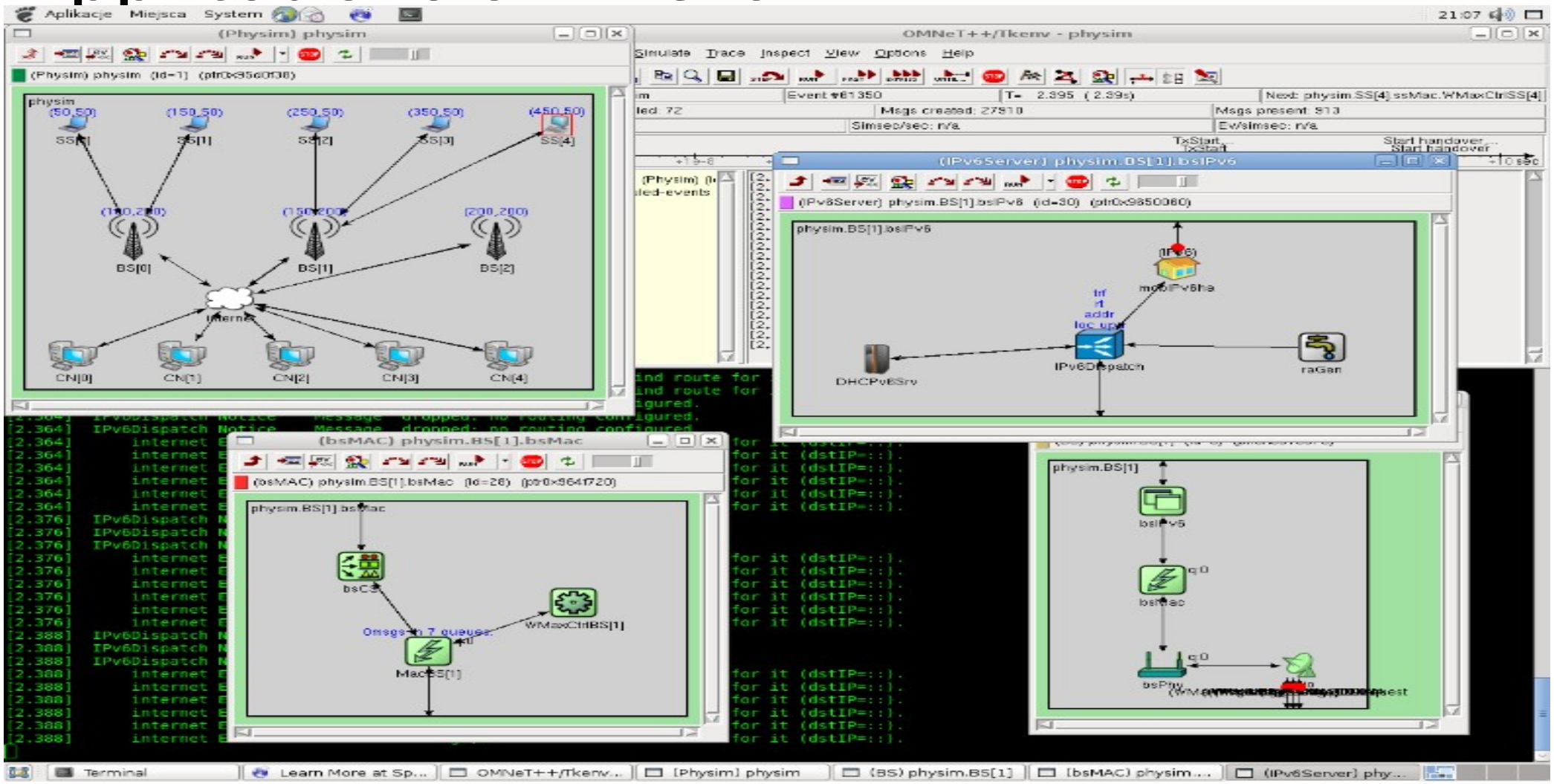
- **Transportation M & S**
- **Business M & S**
- **Medical M & S**
- **Social Science M & S**

Applications of M & S



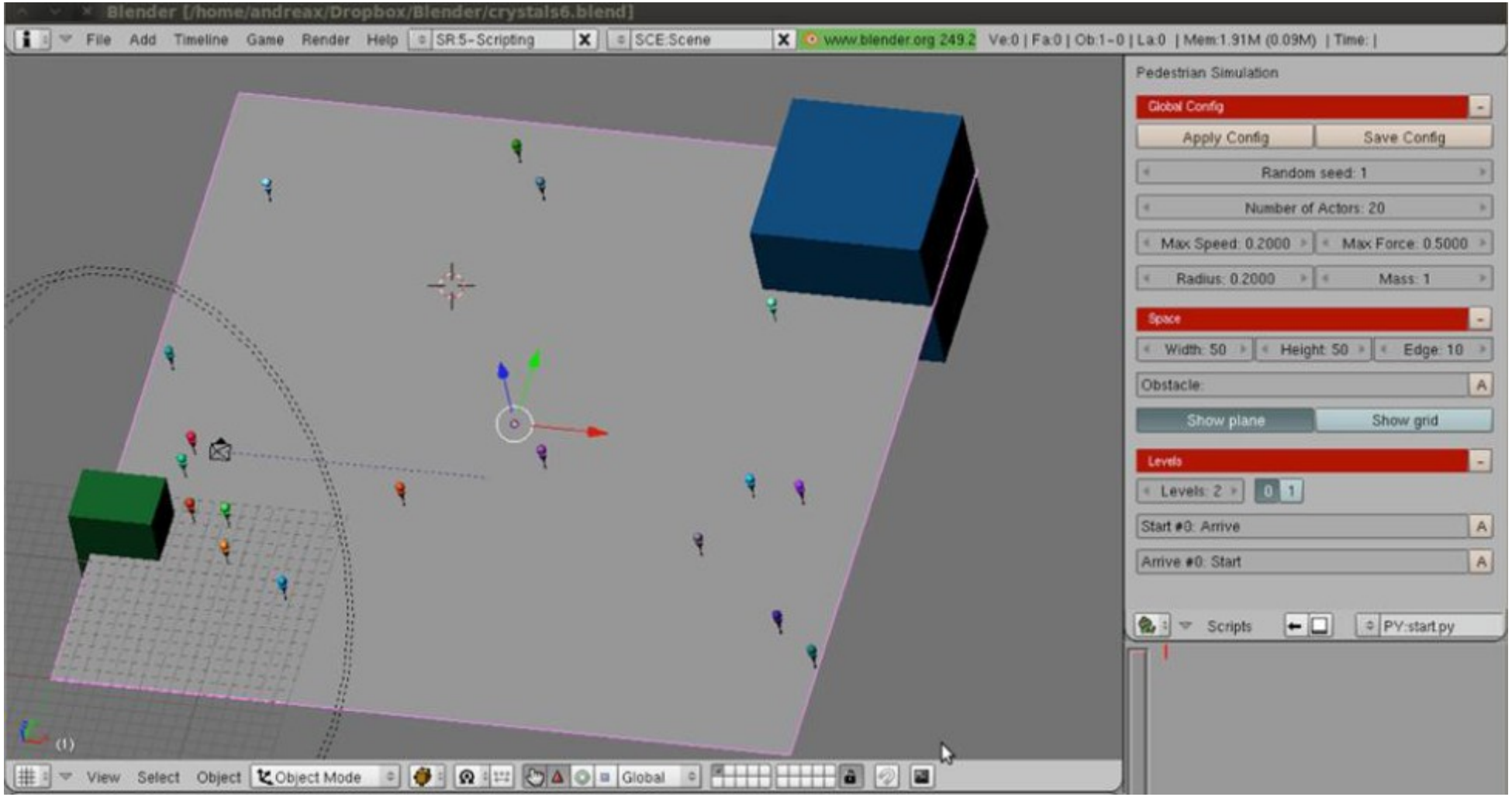
Weather Forecasting

Applications of M & S



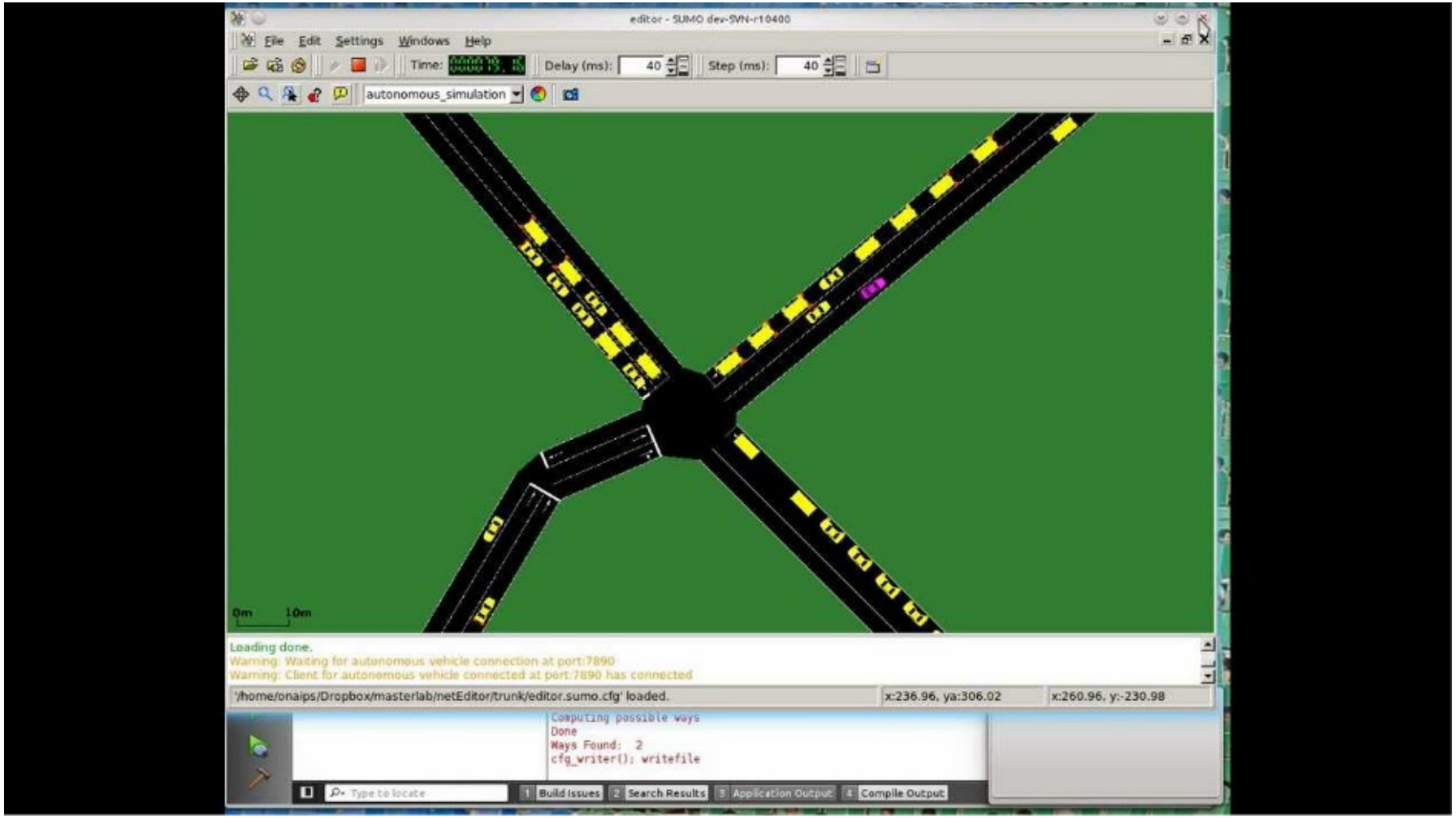
Examples of Network Simulations in Omnet++ (IMG: omnetplusplus.blogspot.com)

Applications of M & S



Crowd Modelling during Tawaf IMG: L. Manenti et. al., MAKKSim: Dealing with Pedestrian Groups in MAS-based Crowd Simulation

Applications of M & S



Simulation of Urban Mobility (SUMO)