# A CLASSIFICATION OF MODELLING AND SIMULATION APPROACHES BASED ON THE ARGESIM BENCHMARKS

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**Abstract**

The paper presents a classification of modelling and simulation problems and approaches with emphasis on and exemplified with the ARGESIM Comparisons. The change of modelling and simulation over the years, the rapid developments in the field as well as the new approaches made it necessary to create a framework to classify and bring order into the multitude of approaches in modelling and simulation. The problems in the creation, the final result as well as the benefits of such a classification are presented. In the end a multi-dimensional landscape emerges where the different approaches to modelling and simulation, how the problems are posed and the different ways of solving them are mapped. In the end what can be seen and deduced from that new classification and what the future might bring will also be discussed. The ARGESIM Comparisons are of great use in teaching modelling and simulation to students as well as to people who are already advanced in the subject and with the new classification even more can be learned. Finally they have been and are also excessively used to test new simulation software and are therefore also of interest to simulation software designers.

**Keywords: classification, education, ARGESIM comparisons, modelling approaches.**

## Presenting Author's biography

Stefan Pawlik is a student of applied mathematics at the Vienna University of Technology. Having spent the last few years in various fields of simulation with the aim to acquire the knowledge to do a comparison of the approaches, methods and possibilities as well as passing that knowledge on to others he is now approaching the end of his master studies. He has done work in the field of System Dynamics as well as classical modelling and claims to know bits and pieces of nearly all other modelling and simulation approaches.

## 1 Introduction

In this paper it has been tried to find a suitable classification for modelling and simulation problems. By now there are so many different modelling and simulation approaches, so many methods, that it is hard to keep an overview. With a way to group and classify them better it would be easier to find ones way through the jungle of modelling and simulation.

## 2 The ARGESIM Benchmarks

The ARGESIM Benchmarks, also called ARGESIM Comparisons, first made their appearance in the early 1990ies. To be precise the first one of them made its appearance in November 1990 when it was published in the first issue of Simulation News Europe (SNE 0). Currently there are 20 published Comparisons with around 300 different solutions [1]. Also see Tab. 1 for further information.

So what are they?

The ARGESIM Comparisons are standardised modelling and simulation problems that challenge the software used to solve them as well as the user who is modelling the problem. They aren't incredibly difficult but they all have their tricky parts. Designed to test how well certain programs handle certain simulation problems and how well certain simulation problems can be handled with a specific modelling approach their purpose is to give new insights and to challenge. They are a chimaera of standard feature tables and classical benchmarks (for speed) and are therefore much more versatile and can cover a wider range of information.

This project soon grew into a veritable well of information and in 1995 a database was built to not loose track of all the solutions and to give them structure and a classification. However, as the amount of comparisons and solutions grew the classification was not appropriate any more, especially as new developments in simulation could not be taken into account appropriately.

At the moment it is hard to maintain a good overview over all the solutions present, and as this info is not wanted to be wasted the ARGESIM staff decided to edit this material in a new database and under a new and more appropriate classification. With the seemingly endless amount of solutions it's hard to keep an overview but with all the "data" that gets provided by the variety of solutions it might just be possible to see a structure in the whole system, to see relations between certain aspects that aren't visible with only one solution of a problem.

The ARGESIM Comparisons are also used extensively in teaching as well as in testing new software. They are a valuable tool in education as they can show the learner where the problems lie and why [1].

Now we give a short overview over the non-discrete ARGESIM Comparisons with a few words of what their purpose is and what the special problems (SP) are.

**C1 Lithium-Cluster Dynamics [2,3]**

checks integration of stiff systems, parameter variation, steady state calculation

SP: loops with logarithmic increments, correct double – logarithmic plots, steady state calculation

**C3 Generalised Class-E Amplifier [4]**

simulation of electronic circuits, table functions, eigenvalue analysis and complex experiments

SP: use of same model for analytical and numerical analysis, up to now accuracy, table function evaluation vs. piecewise functions

**C5 Two State Model [5]**

checks high- accuracy features and state event handling

SP: analytical approach possible but ill-conditioned, fully discrete approach possible, accuracy of state event handling

**C7 Constrained Pendulum [6]**

checks features for hybrid modelling, comparison of models, state events, boundary value problems

SP: choice of states, different levels of hybrid approaches

**C9 Fuzzy Control of a Two Tank System [7]**

asks for approaches and implementations of modules for fuzzy control

SP: support for fuzzy control, two-dimensional calculations for control surface, pure discrete approach possible

**C11 SCARA Robot [8]**

deals with implicit and hybrid systems with state events

SP: implicit model, different approaches for collision event and action

**C12 Collision of Spheres [9]**

allows numerical or analytical analysis as well as continuous or discrete approaches

SP: broad variety of approaches (numerical - continuous, numerical – discrete, numerical – analytical, analytical – symbolic), collision limit

**C13 Crane Crab with Embedded Control [10], revised [11]**

checks techniques and features for embedded digital control with sensors and with observer systems

 

SP: discrete control coupled with sensor diagnosis and observers, complex experiments

**C15 Clearance Identification [12]**

checks identification features (based on measured data) and influences of noise

SP: identification algorithms, short-term input functions (Dirac-like), support of statistics

**C17 Spatial Dynamics of Epidemic [13]**

analyses temporal and spatial behaviour of the process by cellular automata models

SP: proper features for cellular automata in simulation systems, comparison of spatial/temporal results with pure temporal results

**C18 Neural Networks vs. Transfer Functions [14]**

compares transfer function modelling and neural net modelling for given data of a nonlinear process

SP: proper features for neural net modelling in the simulation system, combination of transfer functions with neural nets for parameter tuning

**C19 Ground Water Flow [15]**

studies the flow of contamination in the ground water in 2D-space and time, allowing different modelling approaches for the spatial behaviour (numerical PDE solution, discretisation to ODEs, cellular automata, etc.)

SP: features for description of spatial dynamics, combination of spatial/temporal behaviour with temporal behaviour of control inputs

### 2.1 C7 - Constrained Pendulum – Complete Definition [6,16]

This comparison tests features of simulation languages regarding state events, comparison of models, and parameter variation. The system under investigation is a constrained pendulum as can be seen in Fig. 1.

The motion of the pendulum is given by the equation

$$ml\ddot{\varphi} = -mg\sin\varphi - dl\dot{\varphi},$$

where $\varphi$ denotes the angle measured in radian counter-clockwise from the vertical position. The parameters *m* and *l* characterize the pendulum with mass *m* and length *l*, *d* is a damping factor.

If the pendulum is swinging, it may hit a pin positioned at angle $\varphi_p$ with distance $l_p$ from the point of suspension. In this case the pendulum swings on with the position of the pin as the point of rotation and the shortened length $l_s = l - l_p$.

Note that the angular velocity $\dot{\varphi}$ is defined now with respect to the new point of rotation; therefore the angular velocity $\dot{\varphi}$ is changed at position $\varphi_p$ from $\dot{\varphi}$ to $\dot{\varphi}\frac{l}{l_s}$.

The above equations remain valid.

If the pendulum swings back and passes $\varphi_p$, the pendulum behaves as before with length *l*, and the angular velocity $\dot{\varphi}$ is changed at position $\varphi_p$ from $\dot{\varphi}$ to $\dot{\varphi}\frac{l_s}{l}$, and so on as seen in Fig. 2.

General parameters for the following tasks are

$m = 1.02$, $l = 1$, $l_p = 0.7$ ($l_s = 0.3$), $g = 9.81$.

**Task a)** Simulate the motion of the pendulum with the following initial conditions and plot $\varphi$ over *t*.

(i)

$$\varphi_0 = \frac{\pi}{6}, \dot{\varphi}_0 = 0, d = 0.2,\ \varphi_p = -\frac{\pi}{12}, t \in [0,10]$$

(ii) $\varphi_0 = -\frac{\pi}{6}, \dot{\varphi}_0 = 0, d = 0.1,$

$$\varphi_p = -\frac{\pi}{12}, t \in [0,10]$$

(the pin is left of the pendulum)

**Task b)** The equations can be linearised giving the linear model

$$ml\ddot{\varphi}_L = -mg\varphi_L - dl\dot{\varphi}_L.$$

Implement the linear model and compare the results of non-linear and linear model by plotting $\varphi$ and $\varphi_L$ together and the deviation over *t* for

$$\varphi_0 = \varphi_{L_0} = \frac{\pi}{12}, \dot{\varphi}_0 = \dot{\varphi}_{L_0} = 0,$$

$$\varphi_p = -\frac{\pi}{24}, d = 0.2, t \in [0,10].$$

Indicate whether the language permits comparison of sequential simulation runs of the different models, or whether the two models must be run simultaneously as a single simulation.

Task c): For

$$\varphi_0 = \frac{\pi}{6}, \varphi_p = -\frac{\pi}{12}, d = 0.2$$

determine the initial angular velocity $\dot{\varphi}_0$ so that the maximum angle of the shortened pendulum phi reaches exactly $-\frac{\pi}{2}$ . Indicate experimentation commands or model changes for automatic or manual variation of initial angular velocity $\dot{\varphi}_0$ .

## 3 Classification

Now that it is relatively clear what we are talking about, let's get down to business.

### 3.1 About Classifications

Since the beginning of humankind we tried to put a structure to things, to classify them and to put similar things into the same category, animals, plants, people, everything basically. It is in the nature of men that we want to classify and group things. Why do we do that you might ask. There are several reasons for that, one of them being that it makes things easier to understand and to remember and lets us comprehend and understand new things better and faster.

That brings up the obvious problem of how to classify things.

### 3.2 What is a Classification?

A classification is a defined grouping of things where objects that are related in a predefined way are in the same class and, if you want to expand on that thought, classes that are similar are close to each other.

Classification always leads to equivalence classes of some sort. With that in mind there are ultimately two extremes, neither of them being of much help to us.

1) All the elements of our set are in one equivalence class.

$$| M \setminus \sim | = 1 \qquad (1)$$

2) Every element of our set has an equivalence class of its own.

$$| M \setminus \sim | = | M | \qquad (2)$$

Those two would be easy to achieve, obviously, but they would help us as much as if we wouldn't have bothered to tackle the problem at all. What we want is to find an equivalence relation that gives us several classes with more than one element in them.

After studying the data it soon became obvious that this will be a herculean task.

In the end we had to settle on a quite rough classification with not too many equivalence classes and rather general conditions for them. Furthermore we had to adapt the idea of equivalence classes to our needs.

Furthermore we only take the continuous ARGESIM Comparisons into account. As it can easily be seen that one very rough classification is simply to classify a simulation problem into

continuous – hybrid – discrete

Where hybrid can be furthermore broken down into

continuous with discrete parts – truly hybrid – discrete with continuous parts

We leave the discrete half of the simulation world outside here and only try to classify the continuous ones.

The general idea is to

1) use a permutation to change the order of the tasks and subtasks to make them more uniform.

2) find an overlaying structure, a grid, for the tasks and subtasks and apply it to our comparisons.

3) map the actual solutions of the comparisons on that structure.

Let's have a look.

### 3.3 Permutation of the Tasks and Subtasks

A permutation is the arrangement of objects into a certain order. If you change the order of the objects to get another order without removing or adding any object it's called permuting.

The permutation is necessary as, at the time most of the comparisons were defined, it wasn't taken into account to make them easily classifiable and therefore we have to adjust them first.

Luckily most of the ARGESIM comparisons already follow a kind of rough structure so there were only a few comparisons that had to be redefined by permuting its tasks and subtasks and smaller parts of those. As in every permutation the content won't be changed, only the order.

### 3.4 Creating the Grid

After the permutation the comparisons are thus structured that the model criteria are all covered in the first task and the experiments with the model are done in task 2 and 3.

Let *P* be a solution to one of the comparisons. We decompose the solution into several aspects A. An aspect is a characteristic of a given solution, for example implementation. Each aspect is disjoint from any other aspect but they aren't classes because the union of all the aspects doesn't necessarily create the whole space.

Now let us divide each aspect into classes, with all the mathematical characteristics of classes. This leads to a space that is the union of all possible aspects which each aspect being the union of all possible classes in it.

$$\sum_{i=1}^{n}\sum_{j=1}^{m} A_{ij} \qquad (3)$$

With $A_{ij}$ being the *j*-th class of the *i*-th aspect.

 

Now we define the aspects and classes for the first task.

The first task is all about model criteria and the following are all aspects of the first task with their classes.

**Model Description**

This aspect consists of the classes that describe the possible ways models can be described, it consists of several sub-aspects. The sub-aspects are as follows.

**Block Diagrams:** Block diagrams are a graphical way of representing models by way of building a model with pre-constructed functional blocks provided by the simulation software, a simple yet efficient way of modelling is possible. This sub-aspect consists of the following classes.

Block Diagrams, implicit, structured

Block Diagrams, explicit, structured

Block Diagrams, implicit, unstructured

Block Diagrams, explicit, unstructured

**Equations:** the classical way of describing models

Differential Equations, explicit

Differential Equations, implicit

Differential Algebraic Equations, explicit

Differential Algebraic Equations, implicit

**"Alternative" Approaches:** This includes all the other approaches that came into existence over time.

Cellular Automata, deterministic

Cellular Automata, stochastic

Agent Based

System Dynamics, block diagrams

System Dynamics, equations

Bond Graphs

Implementation

implement [17]

Function: *transitive verb*
**1) carry out, accomplish**; *especially* **:** to give practical effect to and ensure of actual fulfillment by concrete measures
**2)** to provide instruments or means of expression for

So the implementation is the actual realisation of the task by converting it into a for the computer understandable and solvable problem.

numerical, explicit

numerical, implicit

analytical, explicit

analytical, implicit

mixed numerical analytical, explicit

mixed numerical analytical, implicit

**Implementation, control:** The way the control is implemented in certain comparisons.

classical

fuzzy

**Simulation method:** the general approach

continuous

continuous with discrete parts

true hybrid

discrete with continuous parts

discrete

For the tasks and subtasks this is done similarly.

### 3.5 Spatial Arrangement of the Aspects with regard to their Relation to each other

Once all the "classification" is done we rearrange the aspects so that related aspects are spatially close.

Imagine a 3-dimensional space where every aspect is a cuboid or similar structure. Now you arrange them in your 3-dimensional space so that the aspects which are similar boarder each other or are close to each other, for example, all the block diagrams and all the explicit approaches and so on, Fig. 3.

Once this is done you'll have more or less clearly visible clusters of related aspects. Now a first structure is visible.

The next step is to decompose the available solutions into their aspects and map them onto this classification. With some solutions that might be harder than with others. The problems that occur are because we made compromises when we created the classification, otherwise we wouldn't have gotten to any useful classification as was mentioned in the beginning. Sometimes you will need to use your intuition to choose to which aspect it should be linked. Nevertheless it gives a pretty good picture of the whole scenario.

With that done we can now see where most of the solutions to our simulation problem lie and we should be able to see what approach would be suited best or at least better than most others.

## 4 Figures

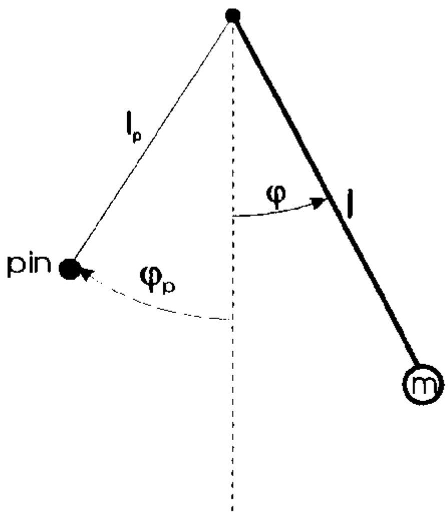


Fig. 1 Constrained pendulum

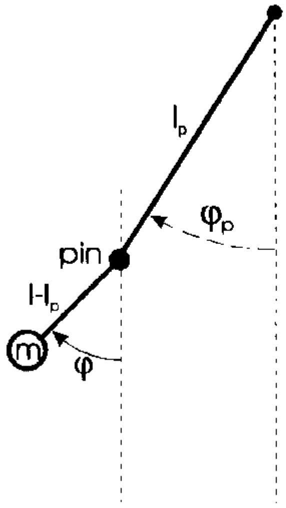


Fig. 2 Constrained pendulum hitting the pin

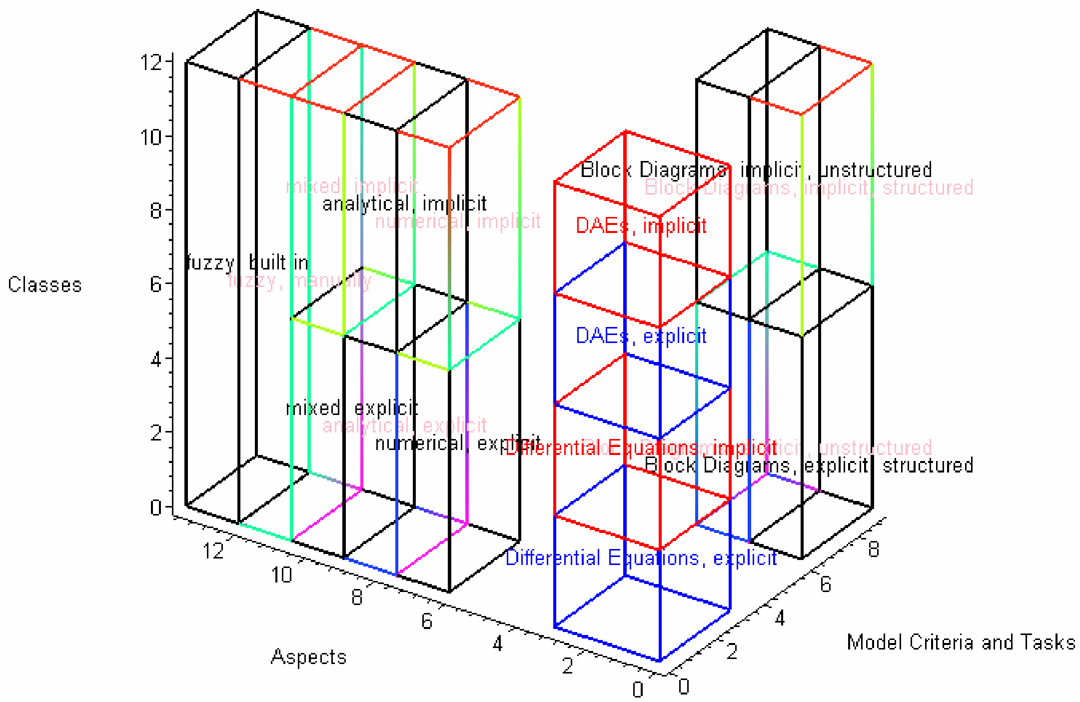


Fig. 3 A part of the grid

## 5 Tables

Tab. 1 Definitions and solutions of ARGESIM Comparisons in SNE

| **SNE** | **COMPARISON** | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Sum** | **C1** | **C2** | **C3** | **C4** | **C5** | **C6** | **C7** | **CP** | **C8** | **C9** | **C10** | **C11** | **C12** | **C13** | **C14** | **C15** | **C16** | **C17** | **C18** | **C19** |
| **0** | | Def | | | | | | | | | | | | | | | | | | | |
| **1** | 5 | 5 | Def | | | | | | | | | | | | | | | | | | |
| **2** | 8 | 4 | 4 | Def | | | | | | | | | | | | | | | | | |
| **3** | 10 | 4 | 3 | 3 | Def | | | | | | | | | | | | | | | | |
| **4** | 13 | 1 | 5 | 5 | 2 | Def | | | | | | | | | | | | | | | |
| **5** | 8 | 4 | - | 1 | 1 | 2 | | | | | | | | | | | | | | | |
| **6** | 5 | - | 2 | - | 2 | 1 | Def | | | | | | | | | | | | | | |
| **7** | 7 | 1 | 2 | 1 | 2 | - | 1 | Def | | | | | | | | | | | | | |
| **8** | 5 | - | 1 | - | - | - | 1 | 3 | | | | | | | | | | | | | |
| **9** | 5 | - | - | - | - | - | 2 | 3 | | | | | | | | | | | | | |
| **10** | 7 | 1 | 2 | - | - | - | 1 | 2 | D/1 | | | | | | | | | | | | |
| **11** | 8 | 2 | 2 | 1 | - | 1 | - | - | 2 | | | | | | | | | | | | |
| **12** | 7 | 1 | - | 1 | - | - | - | 2 | 3 | | | | | | | | | | | | |
| **13** | 4 | - | - | - | - | - | - | 3 | 1 | | | | | | | | | | | | |
| **14** | 6 | 3 | - | 1 | - | - | - | 2 | - | | | | | | | | | | | | |
| **15** | 2 | - | - | 1 | - | 1 | - | - | - | | | | | | | | | | | | |
| **16** | 3 | 1 | - | - | - | - | - | 1 | - | D/1 | | | | | | | | | | | |
| **17** | 6 | - | - | 1 | - | 1 | - | 1 | 1 | 1 | D/1 | | | | | | | | | | |
| **18** | 5 | - | - | - | - | - | - | 2 | 2 | - | - | D/1 | | | | | | | | | |
| **19** | 6 | - | - | - | - | - | - | - | 1 | 1 | 1 | 3 | | | | | | | | | |
| **20** | 5 | - | - | - | - | - | - | 1 | - | 1 | 1 | 2 | | | | | | | | | |
| **21** | 10 | - | 1 | - | 1 | - | 1 | 5 | - | - | - | 2 | | | | | | | | | |
| **22** | 10 | 1 | - | 1 | - | 1 | - | 5 | - | 1 | - | - | D/1 | | | | | | | | |
| **23** | 5 | - | 2 | - | - | - | - | - | - | - | 2 | - | 1 | | | | | | | | |
| **24** | 7 | 1 | - | - | 1 | - | - | 2 | - | - | - | 1 | 2 | | | | | | | | |
| **25** | 7 | - | 1 | - | - | 1 | - | - | - | - | 3 | 1 | 1 | | | | | | | | |
| **26** | 11 | 2 | 1 | 2 | 1 | 1 | - | 1 | - | - | 1 | 1 | 1 | | | | | | | | |
| **27** | 5 | - | - | 1 | - | - | - | - | - | - | 2 | 1 | - | D/1 | | | | | | | |
| **28** | 7 | - | - | 2 | - | 1 | - | - | - | - | 2 | - | - | 2 | | | | | | | |
| **29/30** | 11 | 1 | 1 | 1 | 1 | - | 3 | - | - | - | - | 1 | - | 3 | | | | | | | |
| **31** | 6 | - | - | - | - | - | - | 1 | - | - | - | - | 1 | 3 | D/1 | | | | | | |
| **32/33** | 10 | - | 1 | - | - | - | - | 1 | - | - | 2 | 1 | - | 4 | - | D/1 | | | | | |
| **34** | 5 | 1 | 1 | - | - | - | 1 | - | - | - | - | 1 | - | 1 | - | - | | | | | |
| **35/36** | 13 | 2 | - | - | 1 | 2 | - | 3 | - | - | - | 1 | - | - | 2 | 1 | D/1 | | | | |
| **37** | 11 | - | 1 | - | - | 1 | - | 2 | - | - | | 2 | - | - | 2 | 2 | 1 | | | | |
| **38/39** | 14 | 1 | 2 | 1 | 1 | 1 | 3 | - | 1 | - | - | 1 | 1 | - | 1 | - | 1 | | | | |
| **40** | 9 | - | 1 | 2 | - | 1 | 1 | - | - | - | - | - | 1 | - | - | 1 | 1 | D/1 | | | |
| **41/42** | 9 | 1 | - | - | - | - | - | - | - | 1 | - | 1 | - | 1 | - | 1 | 1 | 2 | D/1 | | |
| **43** | 8 | - | - | - | 1 | - | - | 1 | - | 1 | | 1 | - | - | 1 | - | 1 | 1 | - | D/1 | |
| **44/45** | 8 | 1 | - | - | - | 1 | 1 | - | - | - | - | - | - | 1 | - | - | - | 2 | - | 1 | D/1 |
| **Total** | **291** | **38** | **33** | **25** | **14** | **16** | **15** | **41** | **12** | **7** | **15** | **21** | **9** | **16** | **7** | **6** | **6** | **6** | **1** | **2** | **1** |
| | **Sum** | **C1** | **C2** | **C3** | **C4** | **C5** | **C6** | **C7** | **CP** | **C8** | **C9** | **C10** | **C11** | **C12** | **C13** | **C14** | **C15** | **C16** | **C17** | **C18** | **C19** |

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