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Mechatronics

Dynamical systems approach and theory of holors

**B T Fijalkowski**

# Chapter 3

# Dynamical systems approach

*Always strive to construct definitions, or at the least a rudimentary image of that which has arisen in your mind; strip it bare and focus on its true nature, considering its entirety through its elements and its elements through its entirety.*

Marcus Aurelius

*Less emphasis on analysis*
*More emphasis on synthesis.*

Anonymous

## 3.1 Introduction

The first advance of modern Western science occurred during the Renaissance, a cultural movement that spanned the period roughly from the 14th to the 17th century, beginning in Italy in the late Middle Ages and spreading to the rest of Europe. The prime attributes are 'analytical vision' and 'Cartesian reductionism'. The philosophy of Descartes was not only of prime importance for the advance of science, but it has also had an impressive impact on the Western 'universal' approach to thinking up to the present day. The Eastern 'universal systems thinking', derived from biology and medicine, is more holistic, based on the view that all things and events deduced by the senses are interrelated and connected, and cannot be divided during study; hence it focuses more on the relations between dynamical parts than on the essence of each dynamical part.

The modern universal systems approach or universal systems thinking was founded in the 20th century, but primitive versions emerged several thousand years before. In the ancient period, both Chinese and Greek philosophers created holistic visions of the Universe. At that time, science, philosophy and religion were not separated. These types of holistic visions are intuitive and from a contemporary

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viewpoint they are founded on primitive systems intuition. As for the science, as Einstein pointed out, 'The only valuable thing is intuition'.

Intuition can be considered as a mode of thinking and also as a kind of knowledge exploitation and creation. Intuition is an ability possessed by everybody. It is strictly related to tacit knowledge. Intuition is a preliminary step when scientists take a universal systems approach to a project. It has been suggested that this kind of intuition be called 'systems intuition' and it has more significance in systematics (systems engineering). Systems intuition or systems intuitive thinking is characterised by both holistic and intuitive vision. The scientific foundation of systems intuition is based on the noetic (cognitive) science initiated in the 20th century by the famous Chinese scientist, Xuesen Qian (Hsue-Shen Tsien), the father of space technology in China. He argued that the limitation of traditional cognitive science is that it focuses largely on analytical (logical) thinking and ignores imaginative thinking, which has the principal role in decisions and innovation. He is also the originator of 'systemology' and a science of thinking.

The neotenic features of systems intuition lie in the concept of the synthesis of imaginative thinking and creative thinking based on experience (Wang 2011).

An idea of the 'dynamical systems approach' in the methodology of the formulation of mathematical models of physical heterogeneous continuous dynamical hypersystems was originated by the author of this book under the influence of a book written by Weinberg (1975, 1979) entitled *An Introduction to General Systems Thinking*, which described different situations and methodological operations appearing in **research and development** (R&D) works step-by-step, showing them against a background of problems for a solution (Fijalkowski 1987).

The dynamical systems approach in the methodology for the formulation of mathematical models of physical heterogeneous continuous dynamical hypersystems facilitates the formation of mathematical models and offers a concept for their analytical study by computer, just using systems thinking, enabling skilful methodological progress.

General systems thinking is an approach to integration that is based on the belief that the dynamical parts of a dynamical hypersystem will act differently when isolated from the dynamical hypersystem's environment or other parts of the dynamical hypersystem. Standing in contrast to positivist and reductionist thinking, systems thinking sets out to view dynamical hypersystems in a holistic manner.

Consistent with systems philosophy, systems thinking concerns understanding a dynamical hypersystem by examining the linkages and interactions between the dynamical parts (dynamical systems, hyposystems and components, respectively) that comprise the whole of the dynamical hyposystem.

When scientists and engineers encounter situations that are complex and messy, systems thinking can help one to understand the situation systemically. This helps scientists and engineers to see the complex dynamical hypersystem—from which they may identify multiple leverage points that can be addressed to support constructive change. It also helps them see the connectivity between the dynamical parts (dynamical systems, hyposystems and components, respectively) in the situation, so as to support joined-up actions.

The never-enough-to-be-regretted Professor Bohdan Walentynowicz (past editor of the Polish *Electrotechnical Review*) in a preface to the first Polish edition of the book written by Weinberg (1979) wrote:

*Maybe what most accurately indicates the nature of the book written by Weinberg are the words printed on the book jacket of the original. One reads in them about how young workers in science can learn systems thinking in two ways. The first way—the specialist way—depends on mastering the detailed knowledge of a certain field, and then on crossing to generalisations, however at the comprehensible limitation of the field of sight because of the bending domain. The second way—the generalist way—involves learning about thinking, and then thinking in the categories of generalised systems, before the thinking domain, and sometimes it is concurrent with or also integrates specialist methods. This second way of thinking it is not limited to young workers in science, but also applies to mature scholars, engineers, organisers, students and different people.*

The author of this book gives up on defining the notion of the *system*, since this just deals with many authors of prominent books (Wilson 1969, Klir 1979, Weinberg 1979).

However, so the reader of this book can assimilate the notion of the dynamical hypersystem more easily, we will return to the words of Professor Bohdan Walentynowicz (Weinberg 1979), that this is a notion of 'some whole—entering into the composition of the larger wholes, created from parts (the smaller wholes), related in the way a certain structure is assigned, and distinguished with regards to some functions assigned to these wholes'.

The dynamical systems approach in the methodology of formatting mathematical models of physical heterogeneous continuous dynamical hypersystems concerns their analysis and also the projection of their relations, which because of the aim of dynamical systems are interesting.

In getting to know a physical heterogeneous continuous dynamical hypersystem, it is not desirable to examine the whole at once, one should decide on a limitation and investigate it step by step through its dynamical components, its functional and structural dynamical components. It is a matter of choosing what belongs to a given dynamical hypersystem and what does not, and in doing this, a matter of defining what that dynamical hypersystem is.

The physical heterogeneous continuous dynamical system is the thought construction created by the researcher, and so it is—Weinberg (1979) underlines this several times in his book—a certain 'way of seeing the world', for example, the 'physical universe' of the physical heterogeneous continuous complex and/or simple hypersystem.

When considering any functional physical heterogeneous continuous complex and/or simple dynamical hypersystem, encountered as a functional structure, there are a great number of diverse phenomena, which relate to various fields of theoretical and applied sciences.

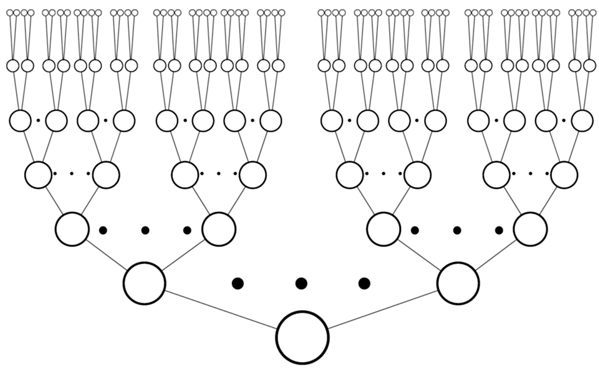


**Figure 3.1.** A hierarchical structure of a physical model of an abstract functional continuous complex dynamical hypersystem (Fijalkowski 1987).

From a definite point of view, one can perceive similar functional and structural dynamical components in these heterogeneous phenomena (e.g. physical phenomena), which sometimes seem various. To investigate these phenomena from the same point of view or with mutual correlations we introduce in this book an abstract notion that relates to all phenomena in the same degree. This is the notion of the 'abstract functional continuous complex and/or simple dynamical hypersystem' (figure 3.1). However, the principles established for these phenomena were termed the 'dynamical systems approach' in the formulation methodology of the mathematical models for abstract functional continuous complex and/or simple dynamical hypersystems. Thanks to this, in a methodology for the formulation of mathematical models of functional objects (e.g. machine aggregates and executive mechanisms), simplicity was found in the complexity.

Introducing the dynamical systems approach into the methodology for the formation of mathematical models for abstract functional continuous complex and/or simple dynamical hypersystems complies with the idealisation of this textbook—the 'continuous'—letting us describe a dynamical state of a considered complex and/or simple dynamical hypersystem through a finite number of certain physical quantities. The complex and/or simple dynamical hypersystems in which such an idealisation is admissible are termed 'continuous'.

As an example, the abstract functional continuous complex and/or simple dynamical hypersystem (figure 3.1) can be folded, respectively, with the finite number of continuous complex and/or simple dynamical systems, respectively, consisting of the finite number of continuous complex and/or simple dynamical hypersystems, folded with the finite number of continuous complex and/or dynamical hyposystems, or functional and structural dynamical elements, respectively.

The basic requirement of the dynamical systems approach in the methodology for the formation of mathematical models of physical heterogeneous continuous complex and/or simple dynamical hypersystems is the existence of: a researcher studying the functional object (e.g. a machine aggregate or an executive mechanism) and the solved problem, marking the point of the researcher's view of the studied functional object. So now, created by the researcher, the abstract functional continuous complex and/or simple dynamical hypersystem (figure 3.1) is the physical model of the original 'considered' by him from a definite point of view. What applicability does the described hierarchical structure of the physical model of the abstract functional continuous complex dynamical hypersystem have?

Firstly—it contains on every hierarchical level the full set, possible for this level, of the abstract functional continuous complex dynamical systems, complex dynamical hyposystems, simple dynamical hypersystems, simple dynamical systems, simple dynamical hyposystems and simple dynamical components. This means that it can be neither more nor less on the given level by even one abstract functional continuous complex dynamical system, complex dynamical hyposystem, simple dynamical hypersystem, simple dynamical system, simple dynamical hyposystem, or simple dynamical component, and that there can be such kinds that only this physical model simulates. This assures in practice the complexity of the analysis and synthesis, for example, of any functional continuous complex dynamical hypersystem.

Secondly—in the aim of a simulation of a concrete functional object, for example, a physical heterogeneous continuous complex dynamical hypersystem, one selects on every graph branch of the physical model (or one skips certain graph branches), the most distant from the basis of the graph tree (from a continuous complex dynamical hypersystem), such a continuous simple dynamical hypersystem which for researchers still has practical meaning in considerations, for example, of the physical heterogeneous continuous simple dynamical hypersystem. All the chosen (sorted) graph branches of the physical model end on a significant continuous simple dynamical hypersystem and still create the set of elementary functional continuous simple dynamical systems and relationships among them, serving to build, for example, the physical heterogeneous continuous simple dynamical hypersystem. One can build the physical model on this basis, simulating the concrete (e.g. physical) heterogeneous continuous simple dynamical hypersystem, considered from the definite point of vision.

Thirdly—it lets us compare among themselves various concrete (e.g. physical) functional heterogeneous continuous dynamical hypersystems (folded with elementary functional homogeneous continuous simple dynamical systems, simple dynamical hyposystems and simple dynamical components), of the same level by transformation to their functional objects. The aforementioned theses are not only valid for a received division and classification of the physical heterogeneous continuous simple dynamical hypersystems, but also for every different division under the condition that will be kept in the method of formation (introduced in this textbook) for the successive hierarchical levels. The hierarchical structure of the physical model of the abstract heterogeneous continuous simple dynamical hypersphere favours certain proprieties. Namely, when its level (beyond the level making up the complex dynamical hypersystem, that is the object, e.g. the aeroplane, helicopter, automobile, tractor, etc) contains the functional continuous complex dynamical systems as *subjects* acting on the things of their objects, they are on the level directly below and simultaneously the objects of the subjects, and acting

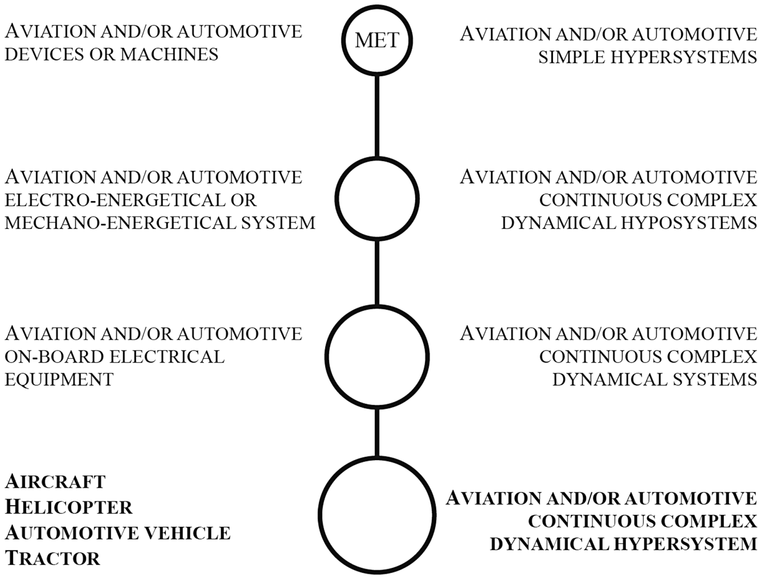


**Figure 3.2.** A hierarchical structure of a physical model of the aviation or automotive functional heterogeneous continuous complex dynamical hypersystem (Fijalkowski 1987).

of course directly on the higher level. A hierarchical structure on every level, moreover, contains the full set of possible abstract functional homogeneous continuous complex dynamical systems, complex dynamical hyposystems, simple dynamical hypersystems, simple dynamical systems, simple dynamical hyposystems and simple dynamical components created according to the previously described principles. Moreover, this hierarchical structure can at last be extended vertically in an unrestricted way. Therefore it has a theoretical character, because for practical aims the analysis incorporates the set of selected (by the author of this book) holonomic and unholonomic physical heterogeneous continuous complex dynamical hypersystems that are present in this structure (Fijalkowski 1987). It answers the requirements of these definitions for aircraft, helicopters, automobiles and tractor, and one can classify them to a class of phenomena called the physical universe, for instance, of aviation and automotive functional heterogeneous continuous complex dynamical hypersystems (figure 3.2).

In this physical universe, one distinguishes several functional classes of the physical heterogeneous continuous complex dynamical hypersystems, which may be presented in order of growing complexity, although in this book we are only interested in the three initial levels, namely:

- the level of static functional structures incorporating the ‘anatomy’ of aviation or automotive complex dynamical hypersystems (automobile, tractor, aeroplane and helicopter), i.e. the name of the functional continuous complex dynamical systems and settlement of their mutual positions, that is—among others—the aviation or automotive continuous complex dynamical system, i.e. aviation and automotive electrical equipment;

- the level of functional continuous complex dynamical hyposystems, that is—among others—the aviation or automotive continuous complex dynamical hyposystem, i.e. the aviation or automotive system electro- or mechano-energetic system incorporating the foreseen and repeated influence on itself of concrete simple dynamical hypersystems;
- the level of functional continuous simple dynamical hypersystems, that is—among others—aviation or automotive simple dynamical hypersystems, incorporating elementary continuous simple dynamical systems with definite basic dynamics, that is deterministic, continuous simple dynamical hypersystems, making up aviation or automotive devices and/or machines.

This classification of the complex and/or simple dynamical hypersystem of the level of the higher order contains, respectively, the complex and/or simple dynamical systems of the level of the lower order. Moreover, just this hierarchy of complex and/or simple dynamical hypersystems makes it possible to use the methods applied in the synthesis and analysis of simpler dynamical hypersystems for the formulation of the mathematical models, opinion, building and investigations of more complex and/or simple dynamical hypersystems.

To obtain the picture of the hierarchical function and structure of the concrete physically continuous complex dynamical hypersystem and its functional continuous simple dynamical systems and their functional continuous dynamical simple hypersystems its decomposition was executed. The physical model of the concrete physical heterogeneous (mechano-electro-thermal) continuous complex dynamical hypersystem whose hierarchical structure was built is shown in figure 3.3.

It should be noted that in the process of the successive decomposition of the concrete physical heterogeneous continuous complex dynamical hypersystem we distinguished its functional simple dynamical systems built up from its functional

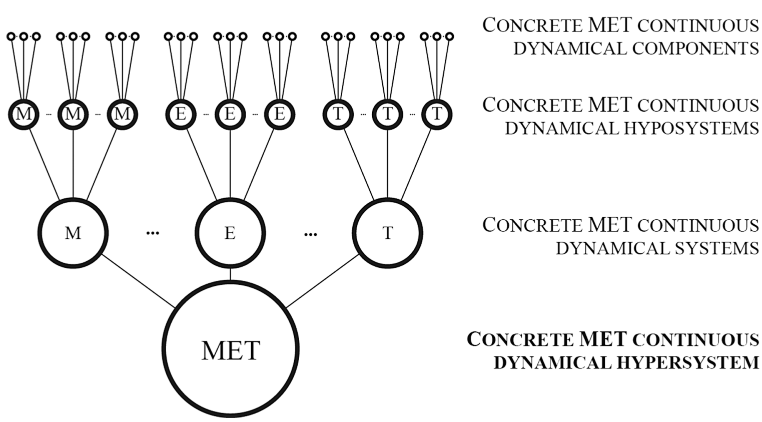


**Figure 3.3.** A hierarchical structure of the physical model of the physical heterogeneous (mechano-electro-thermal) continuous complex dynamical hypersystem (Fijalkowski 1987).

continuous simple dynamical hyposystems, built-up from its functional continuous simple dynamical components.

Functional heterogeneous continuous complex dynamical hypersystems, simple dynamical systems, simple dynamical hyposystems and simple dynamical component are thus exchangeable notions. Depending on the hierarchical level, prepare the road for the use of the dynamical systems approach in the formulation methodology of the mathematical models for computer analytical studies of both the dynamical and the static processes of the physical heterogeneous continuous complex dynamical hypersystem. A review should be carried out of the classic interpretation and behaviour during a continuous sequence of transformations of the abstract functional continuous simple dynamical hypersystem (figure 3.1).

Attention should be paid nearby to the principal result of the statement about unambiguous solutions of the differential equations of dynamics, because this defines a feature of the half-group called the 'right of causality'. It is shown below that the variation process is a generalisation of this concept.

To illustrate the use of the dynamical systems approach in the formation methodology of mathematical models of functional objects (e.g. machine aggregates and executive mechanisms) in its simplest generalised form, the ways that it leads to mathematical models for the case of selected physical homogeneous continuous simple dynamical hypersystems are shown in later chapters. Finally, to acquaint the reader with the dynamical systems approach in the formulation methodology of mathematical models we present the results of analytical studies of these selected physical heterogeneous continuous dynamical hypersystems.

## 3.2 The dynamical systems approach to physical heterogeneous continuous dynamical hypersystems

The dynamical systems approach is useful in the development of physical heterogeneous continuous complex and simple dynamical hypersystems.

The premise of the dynamical systems approach is that the development of a physical heterogeneous continuous complex or simple dynamical hypersystem should begin with a thorough understanding of what is intended, including the heterogeneous continuous dynamical hypersystem's dynamical behaviour. If such an understanding can be gained in the early stages of a project, it is possible to eliminate much of the uncertainty now inherent in the process, and to develop physical heterogeneous continuous dynamical hypersystems that are more successful yet less expensive. The understanding of a physical heterogeneous continuous dynamical hypersystem's dynamical behaviour in its environment over time is most often addressed in the design implementation and testing phases of a project, through iterative trial and error.

The dynamical systems approach provides an alternative to this costly process. It allows one to build a usable and comprehensive physical heterogeneous continuous dynamical hypersystem—a physical model that is accurate enough to be relied on and clear enough to be useful. The physical model addresses the usual functional and data flow issues, but also covers the dynamical and behavioural aspects of a physical heterogeneous continuous dynamical hypersystem. This physical model can then be tested with the mathematical model analysis and retrieval tools, which provide extensive mechanisms for inspecting and debugging the specification and retrieving information from it. By testing the physical model systems scientists and engineers can see how the physical heterogeneous continuous dynamical hypersystem as specified would behave if implemented. One can answer detailed 'what if?' questions, following specific scenarios, checking that certain desirable situations will occur in the lifetime of the physical heterogeneous continuous dynamical hypersystem and that other undesirable ones will not.

In this sense, systems scientists and engineers can be said to be playing the role of the eventual user of the physical heterogeneous continuous dynamical hypersystem as well as that of the environment. Moreover, one can also instruct the analytical tools themselves to play the role of the user and the environment. This kind of self-inspection capability has the advantage of testing scenarios that the systems scientists and engineers might not have thought of or might not want to check out individually. Often these scenarios represent unpredictable behaviour.

The physical model must be well structured, intuitive and comprehensive if it is to be useful to the variety of systems scientists and engineers involved, and it must be rigorous and formal if it is to serve as the basis for useful analysis and retrieval. This calls for representing as much of the physical model as possible in visual formalisms—diagrammatical languages with precise meaning.

The systems scientists and engineers model the physical heterogeneous continuous dynamical hypersystem using natural pictorial descriptions that can be understood by physicists, but which also have unambiguous underlying semantics that are meaningful to the computer and can thus be processed by the analytical tools.

The dynamical systems approach meets all of these requirements. It is consistent with existing structured methods, but is more powerful and more flexible.

This textbook explains the philosophy behind the dynamical systems approach. When one says 'approach', one has in mind an entire spectrum of concepts, methods, languages and tools.

The systems scientists and engineers work with a set of computerised tools that support a number of graphical physical commutation matrixers and non-graphical languages, including languages for both physical and mathematical modelling and the theory of holor analysis.

Many of the constituents in the dynamical systems approach are similar to those appearing in other approaches and methodologies for physical heterogeneous continuous dynamical hypersystem design, a fact that should be taken as evidence of their wide appeal. However, there are many aspects of the dynamical systems approach that go far beyond what is currently available elsewhere.

The author has discussed the dynamical systems approach as it applies to all phases of physical heterogeneous continuous dynamical hypersystem development, from physical and mathematical modelling through simulation and analysis to design and implementation.

The dynamical systems approach is based on the preparation and extension of a rigorous physical model, e.g. a physical commutation matrix that captures not only functionality but also dynamical behaviour. These models are constructed using visual formalisms that are clear and intuitive, but precise and rigorous, and thus amenable to computerised analysis.

The dynamical systems approach allows systems scientists and engineers to address the most crucial problem in the successful development of physical heterogeneous continuous dynamical hypersystems: the ability to gain an early understanding of a system's dynamical behaviour and to carry that understanding through the entire development cycle.

The dynamical systems approach will continue to develop as systems scientists and engineers gain the experience needed to advance the state of the art.

The **computer aided systems engineering** (CASE) environment will also continue to evolve: its ability to address future needs is the result of its being based on the firm foundation of comprehensive physical and mathematical modelling through simulation and analysis.

The principal heuristic innovation of the dynamical systems approach is what may be called 'reduction to dynamics' in contrast to 'reduction to dynamical components' as practised in the methodologies of classical science.

## 3.3 Summary

The dynamical systems approach:

- offers a holistic—from whole to local—approach for describing physical reality;
- produces a comprehensive picture of physical reality;
- produces accurate predictions with straightforward mathematics and clear logic.

The future of the dynamical systems approach is going to be very stimulating over the coming years. Science is developing, changing and expanding—and that is what maintains our enthusiasm.

## References

Fijalkowski B 1987 *Modele matematyczne wybranych lotniczych i motoryzacyjnych mechano-elektro-termicznych dyskretnych nadsystemów dynamicznych (Mathematical Models of Selected Aviation and Automotive Continuous Dynamical Hyperystems)*, Monografia 53 Politechnika Krakowska imienia Tadeusza Kościuszki, Krakow, 276 p. (In Polish)

Klir K 1972 *Trends in General System Theory* (New York: Wiley).

Wang Z 2011 Study of System Intuition from Noetic (cognitive) Science Founded by Xuesen Qian. *DUT Presentation,* 2011, In Memorandum of 100 Aniversary of Academician Xuesen Qian. Research Center of Knowledge Wane Sciences and Technology, Dalian University of Technology, 116085 Dalian, China, ss. 1-14

Weinberg G M 1975 *An Introduction to General Systems Thinking* (New York: Wiley) 1975

Weinberg G M 1979 Myslenie systemowe (Systems Thinking). *Wydawnictwo Naukowo-Techniczne*

Wilson W E 1969 *Projektowanie techniczne w ujeciu systemowym (Technical Design in the Systems Approach)*. Wydawnictwo Naukowo-Techniczne (In Polish)