Mechatronics – the Evolution of an Academic Discipline in Engineering Education

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ABSTRACT

In a Didactic approach to Mechatronics the subject of Mechatronics can be described in a dialectic fashion where the identity of Mechatronics is viewed as thematic in contrast to disciplinary, the legitimacy is functional in contrast to formal, the selection is a vertical exemplarity in contrast to a horizontal exemplification and where the communication is interactive in contrast to active.

Following this lead with a thematic view of the subject of Mechatronics a model to describe the evolution of Mechatronics is proposed. In unison with the didactic approach to Mechatronics the evolution-model describes the move from a disciplinary view to a thematic. For the purpose of illumination this move is divided into six stages, each represented by a characteristic view and practise of the subject of Mechatronics.

To further illustrate this evolutional process examples from various universities and institutes in North Europe are given. The purpose is not to assess or criticize, only to illustrate. The universities and institutes borrowed for this purpose acts as examples for stages three to five in the model; stages represented by a change in courses (stage three), a change in curricula (stage four) and by a change in organization (stage five).

Examples from the Mechatronics Lab at KTH are also given as examples of attempts to implement the thematic view of the subject, at first by implementing the 'Mechatronic Learning Concept', and secondly by planning for the implementation of a full undergraduate and graduate program in Mechatronics.

1. INTRODUCTION

The aim of this paper is to describe the ongoing process of establishing Mechatronics as an Academic Discipline with examples from North Europe. A theoretical model illustrating this process has for the purpose of this paper been developed, and will be applied to the examples under study in this paper as a means of illustration and classification.

1.1 A Didactical Definition of Mechatronics

An attempt to define the identity and legitimacy of Mechatronics [7] has been presented in an earlier study by Grimheden and Hanson [10], as well as the implications on the subjects' selectivity and communication. In short this definition is based on the notion of regarding the identity of Mechatronics as the "synergistic combination of precision mechanical engineering, electronic control and systems thinking in the design of products and manufacturing processes" [4] rather than the earlier descriptions of Mechatronics solely as an interdisciplinary subject, as the union between mechanical- and electrical engineering, control theory and computer science or other combinations of traditional disciplines within an engineering sphere.

The choice of defining the identity of Mechatronics as thematic (the theme is related to the concept of synergy) according to the above is in unison with the legitimacy of the subject. In a choice between a formal or a functional legitimacy Mechatronics is mostly regarded from a functional point of view; the demands from the society and/or the industry is rarely formal but mostly functional, i.e. the demands from the industry is rather functional skills than formal knowledge, which is also reflected in the selection and communication of the subject. (What is taught and How it’s taught.)

1.2 The history of Mechatronics at KTH

In 1976 the professor of Machine Elements returned to KTH from a visiting professorship at Stanford University bringing back a microcontroller, an Intel 8008. The professor declared that the microcontroller was indeed a machine element, to compare with gears, bearings etc, and should therefore be thoroughly analyzed for its possibilities and functionality in a Mechanical Engineering product and process perspective.

Today the development continues at the Department of Machine Design, KTH, where the Mechatronics Lab constitutes the largest research team. The research is mainly focused on the areas of control of complex mechanical systems and real-time control systems [21].

In perspective of the tradition of Mechatronics at KTH the identity of Mechatronics is strongly related to the history of the department of Machine Elements, which later came to be a part of the department of Machine Design. Here the microcontroller was enrolled in the designs to enable better functionality; better behavior and physical structure in what came to be known as mechatronic embedded systems. An example of this is a student- and research project undertaken between 1980 and 1985 in Machine Design [13]. The aim of the project was to develop a new design of a shock absorber for the car industry. The students soon discovered the need for a flexible solution, a shock absorber that could “sense” the conditions like the actual load, and compensate for this automatically. Therefore, the students created a mechatronic design with an active shock absorber that automatically compensated for variations in load [13]. The purpose was not to build a complex computer-based system, neither to design an unnecessarily advanced system for the racing-industry. The purpose was to solve a complex mechanical problem introducing computers to perform intelligent control algorithms.

1.3 The “New” Approach to Engineering Education

The implications of defining the identity of Mechatronics as thematic and the legitimacy as functional, is that the preferred selection of the subject is rather a vertical exemplarity than a horizontal representation, and that the preferred communication of the subject is rather interactive than active [7], [10].

In relation to education this approach cannot be described as new; the ideas that the student and the teacher are, or might be, learners together was developed, amongst others, by John Dewey in 1897 [8] together with ideas about the view of education as primarily a social function. Further on the “method of shaping” (shaping of complex behavior) as a means of giving proper motivation in contrast to the earlier traditional methods of trial and error in learning was developed primarily by the behaviorist B. F. Skinner [19]. Finally the observations that the development of intelligence in children have implications for the teaching situation; that the teacher should appreciate the limits and capabilities for each individual child and focus on gaining a greater understanding for the ways in which the child operates was developed by the child-psychologist Jean Piaget [16].

Much like the “Emperors New Clothes” these ideas has been brought forward over the years under new names and in combination with “new” educational approaches or proposals. Even though the reason behind the “new approaches” certainly in most cases is most commendable, it’s important to point out that many ideas has been thought and discussed before.

In the case of Mechatronics, in relation to the didactical analysis, the resulting choice of a vertical exemplarity as selection and an interactive communication can be regarded as “well in line” with these learning theories.

Concluding these remarks regarding the title of the paper, what’s new in the approach is the subject; Mechatronics, and therefore the need to find the appropriate educational approach is apparent.

2. THE EVOLUTION OF MECHATRONICS – FROM CROSS-DISCIPLINARY TO THEMATIC

As a basis for our description of the evolution of Mechatronics we use a model showing the stages of the evolution.

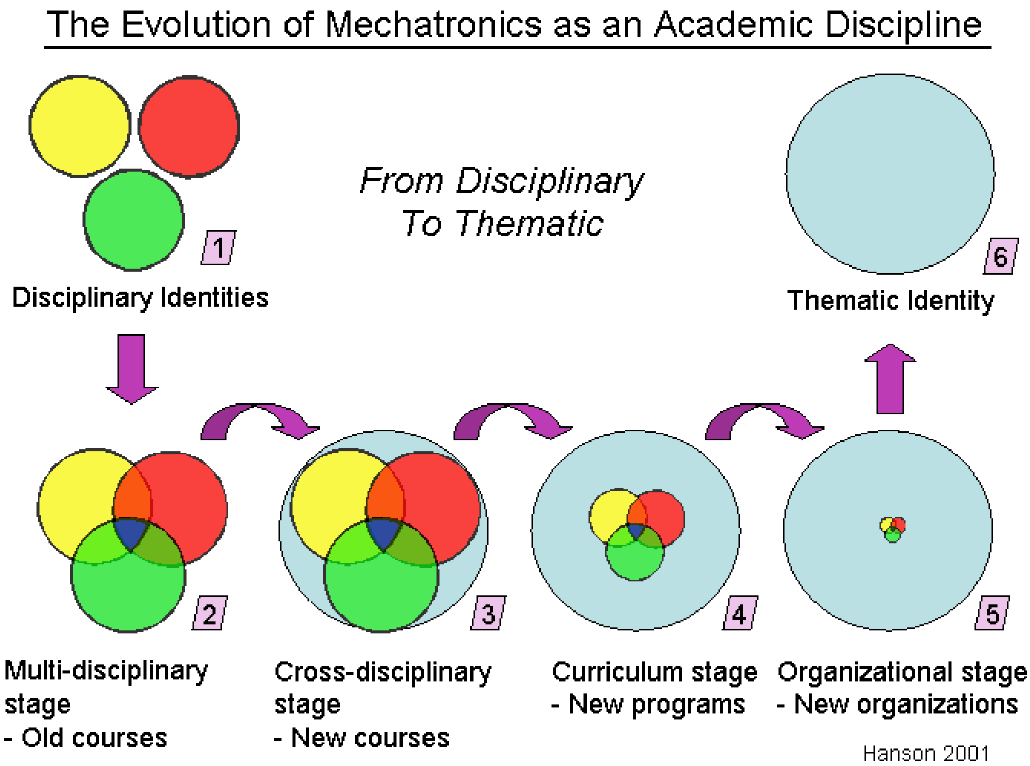

Figure 1: The Evolution of Mechatronics as an Academic Discipline. In the following the boxed numbers are used as references to the different stages.

As shown in the model in Figure 1 the transition from disciplinary identities to a thematic identity is divided into steps where the major changes are symbolized by moves between six stages. From the first stage (1) where no interaction between the original disciplines exists the move to the second stage (2) represent a situation where students combine courses from different disciplines to broaden their knowledge, which can be described as a multi-disciplinary stage where the entire educational system still is organized and functioning in disciplines. The third stage (3) represent the situation where the main effort is put into the creation of cross-disciplinary courses, efforts at, for example, consciously giving courses in electrical engineering to mechanical engineering students and labeling this as education in mechatronics. The fourth stage (4) is represented mainly by efforts at creating new curricula suitable for the cross-disciplinary thinking as well as for the different identity of the subject. Here the disciplinary identity is diminishing in advantage for the thematic identity. In the fifth stage (5) the original disciplines are almost diminishing entirely, which is possible due to a complete change in organization, for example by moving towards mechatronic departments lead by faculty with a background in the mechatronic discipline, a situation which of course requires quite some time to realize. The sixth stage (6) is therefore equivalent with treating Mechatronics in full as a thematic identity.

The move from a disciplinary view to a thematic view is discussed by Wikander, Törngren and Hanson [22] and compared to the trade of products and systems engineering. Wikander, Törngren and Hanson define the traditional Mechatronics Approach as subsystem based – meaning a development strategy where integrated systems are built from technology homogenous subsystems, which might be mechanics-, electronics-, control- or software subsystems. In the traditional Mechatronics Approach these subsystems are developed concurrently with a main focus on interfaces. A didactical implication to this approach is that the education should focus on team building to facilitate the multidisciplinary understanding between the different actors.

This approach, therefore, tend to lead towards a strong disciplinary activity. The interactions between the disciplines are limited to the interfaces, and there will rarely be a demand on development of a certain technology as a result of its close integration with other technologies [22]. The synergistic effects regarding the development of mechatronic technology are rare if existing, and the need for a new approach where the subject is no longer seen as a multi-disciplinary subject is obvious. As we will point out in this paper, many courses and curricula have this traditional Mechatronics approach, an approach which we will compare to the third and fourth stage in the model of the evolution, third or fourth stage depending on the status of the subject within the curriculum.

2.1 The Origin and the Multi-disciplinary Stage (Stage 1 – 2)

Many new mechatronic programs and courses have been developed during the last decade. The most common pattern is that mechatronic programs, courses and departments have their origin in either mechanical engineering or electrical engineering, with the absolute majority in mechanical engineering [20], [22]. The most usual approach is to add courses in electrical engineering, computer science and control theory to the existing mechanical engineering curriculum, or for example to let electrical engineering students take courses in mechanical engineering and let them major in mechatronics. We define this stage as the Multi-disciplinary stage (Stage 2).

In comparison between these two approaches a pattern has been noticed where the educations with an origin in mechanical engineering tend to lean towards a more functional aspect of mechatronics, where the educations with an origin in electrical engineering tend to focus slightly more on formal aspects [6]. Due to the nature, or the identity, of the subjects of electrical engineering and mechanical engineering, the former tend to play a more theoretical role versus the more applied science of mechanical engineering which might be a possible explanation to this pattern.

2.2 The Cross-Disciplinary Stage (Stage 3)

As described earlier this second stage is commonly observed at traditional universities wishing to add new courses into existing programs or curricula. A few brief examples will be given to illustrate this stage.

The most commonly found courses in mechatronics are project based and have strong connections to laboratory exercises. The concept that the students will create, program and run a mechatronic product where the mechatronic product consists of mechanical parts, electrical parts and the ubiquitous microcontroller seems to be dominant. The students are primarily mechanical engineering students with basic knowledge in electrical engineering and computer science, and the faculty in many cases consists of a single faculty member or a handful of members with a special interest in expanding the scope of mechanical engineering into mechatronics.

Even though most of the universities or institutes teaching mechatronics have moved from this cross-disciplinary way of giving single courses in mechatronics towards changing entire curricula to accommodate an education in mechatronics it seems that many universities and institutions have a history of giving these project-organized mechatronic courses.

A characteristic element of this stage is the commonly found project organized and problem based courses where the aspects of team building and multidisciplinary understanding are stressed. As described earlier, one explanation to this phenomenon is the notion of subsystems engineering, or a more traditional approach.

2.3 Examples of the Cross-Disciplinary Stage

2.3.1 University of Applied Sciences, Münster, Germany

The department of physical engineering has given courses since 1999 in physical engineering aiming at designing mechatronic systems mainly consisting of one or several sensors and a microcontroller. Even though the scale is quite small the courses has gained high interest from local media and the rest of the university. The course is elective, and possible to take for students in their final three semesters. The students have limited prior basic knowledge in sensors, actuators, robotics and microprocessors from their first two years of studies, and the Mechatronics course can be seen as a course where the students apply this knowledge in a sharp project [18].

The laboratory parts constitute the major part of these courses. Examples of projects are:

- Optical rotary speed measurement on radio controlled airplane propeller
- Micromechanical sensor system to measure loudspeaker cabinet vibration
- Breathing air alcohol measurement device

2.3.2 Friedrich-Alexander-University, Erlangen-Nürnberg, Germany

In the second semester of 2001 the Friedrich-Alexander-University started a new course in mechatronics. The aim of the course is to offer a knowledge base from various domains of engineering science, and to describe the integrative character of mechatronics. The course is given by the department of engineering design, and the lectures given consist of a series called "Mechatronical Systems" and a revised version of a course called "Mechanical Component" [15].

This Mechatronics course is unique in the sense that it is not project-organized, problem-based or has a focus on laboratory work. The course focuses on the Mechatronical engineer; the need for a broad knowledgebase, integration aspects, synergistic effects and systems-thinking. In the wake of the development of this course there has sprung forward discussions regarding the need to change the entire curricula to facilitate the education of this new Mechatronical engineer.

2.3.3 University of Waikato, Hamilton, New Zealand

The history of mechatronics started in the early nineties in New Zealand with emphasis on a practical, "hands-on" approach, where the students were encouraged to design a mechatronic system from inception to completion. In several cases a high enthusiasm was created by the adding of competition to the projects, for example by competing in classic contests like the Micromouse competition [3]. The department of Physics and Electronic Engineering has since starting teaching mechatronics seen "a huge growth in mechatronic interest" [2], particularly "despite funding difficulties and lack of staffing".

The laboratory parts constitute the major part of the course. The hardware in the projects has evolved from mechanical parts entirely designed by the students with an ordinary microcontroller to the currently used LEGO-bricks with a Hitachi H8-microcontroller marketed as the LEGO DACTA-system. The software is the LabView-based RoboLab. The resulting programming-environment for the student is entirely icon-based and no further programming skills is required.

Even though this example hardly can be viewed as a North-European example it received a note here since this example is typical for several universities; the development of a first mechatronics course, which in this case was introduced by the students themselves.

2.4 Summarizing the Cross-Disciplinary Stage

To characterize this stage a typical education in mechatronics is offered as one or several courses in mechatronics mainly for students in a mechanical engineering program containing mainly basic electrical engineering and computer science. In two of the three cases described above the scale of the courses are small and in the hands of one or two enthusiastic teacher(s) [12]. In several cases these courses rely heavily on laboratory exercises, and are in most cases project-organized and problem-driven. In several cases the course-design is quite different from traditional courses, and many courses therefore have gained attention at the respective universities and in local media.

More examples used for comparison in this study are gathered from the University of Applied Science in Kiel, Germany [20], Tallin Technical University, Estonia [1], Technical University of Denmark [5].

2.5 The Curriculum Stage (Stage 4)

The Curriculum Stage is a natural continuity of the Cross-Disciplinary stage. The single courses in mechatronics are dependant of basic knowledge in the areas of mechanical engineering, electrical engineering, control theory and computer science, and therefore the need to further investigate the necessary components of basic subjects necessary to study the applied science of mechatronics has in many cases led to the situation where the faculty responsible for the courses in mechatronics also has taken responsibility for the part of the curriculum leading up to the mechatronics courses. Other examples of this stage are represented by universities that recently have created entire curricula in mechatronics based mainly on existing courses and organizations.

2.6 Examples of the Curriculum Stage

2.6.1 Universities of Applied Sciences in Germany; Bochum, Kiel, Brandenburg, Augsburg

In Germany the history of Mechatronics is said to have started in Bochum in the early nineties [20]. The university started an entire study program in Mechatronics in 1993. In 1996 the program grew larger than the mechanical engineering program (Maschinenbau), and in 1998 the program was larger than the program of electrical engineering (Elektrotechnik & Informatik) [20], [9]. Recent developments has seen a increasing number of students attending the electrical engineering program, the number of students has more than doubled between 1998 and 2000, so even if the mechatronics program also has increased it is not the largest program today.

Since the start of the mechatronics program in Bochum, Germany, several other German universities has followed. Among them are the University of Applied Sciences, Kiel (started 1996) [20], University of Applied Sciences, Brandenburg (started 1999) [14], University of Applied Sciences, Augsburg (started 2000) [17]. Currently there are intensive discussions in Germany regarding curriculum design, and there is a strong tendency at the moment to unify the universities into creating and accepting a common curriculum. One important reason behind this work is the idea of an international program in mechatronics to facilitate for example student exchange programs and prepare students for a global market [20].

The German higher technical educational system is basically divided into two parts; the technical universities (Technische Universität) and the universities of applied sciences (Fachhochschule). The technical universities have ten mandatory semesters, including thesis work and excluding at least one semester of mandatory practical work. The universities of applied sciences have eight mandatory semesters including one semester of thesis work and one semester of practical work which means six semesters of courses in reality.

Quite some effort at the moment is spent on discussing the optimal curriculum, in most cases for use in these six semesters at the universities of applied sciences, and a focus should be aimed at the development of the relative new mechatronic programs and the respective fall-outs.

In several cases examples can be found of the courses described earlier in these programs, particularly in the latter two semesters, and these are often connected in some way to the final thesis work. An example from Brandenburg will illustrate this.

2.6.2 University of Applied Sciences, Brandenburg, Germany

The University of Applied Sciences, Brandenburg, Germany gives a program in Mechatronics of six semesters. In 1999 an educational project started – to build a walking robot. One team of students where set to deal with kinematic principles of legs and structures of walking mechanisms, and other teams of students continued with the development of control-algorithms, with the development of force-sensors and with the development of more advanced motion control systems. Spin-offs from the educational project are a Robot-building Lab with resources to give courses in mechatronics with various scopes, for example with exercises like robot-designing with commercial LEGO-bricks and pre-manufactured control-unit [14].

2.6.3 Tallin Technical University, Estonia

The concept of Mechatronics has gained a considerably wide recognition and use in Estonian industry and education in recent years. Compared to other European countries Estonia started teaching Mechatronics early, in the eighties, and today several universities gives a full Mechatronic program.

In Estonia of today the industry and economy as a whole is developing fast, and one effect of this is the resulting demand for qualification systems and certifications. The Estonian Chamber of Commerce has therefore composed a five level standard of Mechatronics profession, where the highest level is equal to the Master level. The resulting Mechatronics programs are given mainly by the already existing departments and faculties like Mechanical engineering, Automation and Electrical engineering.

2.7 The Organizational Stage (Stage 5)

Besides aiming at modeling and describing the evolution of Mechatronics as an academic subject and discipline, we would also like to argue for our notion of viewing the fifth and the sixth stages as final stages and a necessity for the creation of the subject and discipline of Mechatronics. Therefore, in this section of the paper, we will focus more on the conclusions of our research, and implications on education. When describing this stage it's important to point out that it is actually two stages in focus, or rather a continuum between these two. The fifth stage, the organizational stage represents a situation where the entire organization is modified according to the characteristics of Mechatronics, and the sixth stage represents the final move towards a thematic view. The organizational stage can therefore be seen also as a continuum stretching towards the thematic view, due to the notion of defining the subject of Mechatronics with a thematic identity.

First we will give an example of an organization, the Mechatronics Lab at KTH, moving towards a Mechatronic organization, and thereafter briefly describe our plans for the future education in Mechatronics, based on the research described here.

Even though we have identified many successful courses in mechatronics and entire curricula, there is one common factor in these courses that makes further evolution difficult; the notion of viewing the subject of Mechatronics as a combination of any kind of any subjects. In our survey we still haven't seen one department or course that focuses on the synergy and synergistic effects in such a scale that the original subjects have diminished. We believe that this is due to the fact that faculty and even entire departments regard themselves as part of an electrical engineering faculty, a mechanical engineering faculty, with expertise in control theory, with a background in computer science and so on. Our hypothesis is that, to develop into this organizational stage, the department ought to be a mechatronic department, with a faculty with a background in mechatronics, and with expertise in mechatronics.

However, since it might take quite some time to reach this stage, an interim solution would be one where the mechatronic faculty is composed of people with various backgrounds, i.e. with backgrounds in the various subjects described earlier. The need to make this a separate organization to disregard from earlier affiliations is though necessary in this case.

2.7.1 The Mechatronics Lab at KTH

As described earlier, the history of the Mechatronics Lab at KTH started as early as in 1976. Since then several hundred engineers with a degree of Master of Science with a major in Mechatronics has graduated. Today approximately 40 master students per year graduate and several continue as PhD-students. The faculty as of today consists mainly of professors with a Master of Science and a PhD in Mechatronics, and also of professors with a background in electrical engineering or mechanical engineering. PhD-students are recruited from the former students in Mechatronics, but also from other disciplines; primarily control theory and computer science. All PhD-students with a background other than mechatronics follow most of the Master courses in Mechatronics to familiarize themselves with the perspective of Mechatronics [11], [22].

Since the majority of the faculty de facto has their background primarily in Mechatronics, the traditional approach with cross-disciplinary thinking and disciplinary backgrounds has almost diminished entirely.

2.7.2 The Mechatronics Learning Concept (MLC)

The Mechatronics Learning Concept started in 1998 at KTH as a major project aimed at the renewal of the Mechatronics education at the Mechatronics Lab as well as at other interested parties in industry or other universities. The idea was to create a platform for learning in Mechatronics with focus on the aspects put forward in this paper, i.e. to emphasize the thematic view.

The Mechatronics Lab at KTH gives courses in Mechatronics, but also in Motion control, Real-time computer control, and the need for an experimental platform suitable for several subjects and courses where obvious.

In 1999 a first version of what came to be called the Mechatronic Learning Concept was introduced in the first course. The idea behind the concept is a modularised, portable and affordable experimental system suitable for experiments not in a single particular subject, but rather a set of courses, or a theme.

The equipment consists of compatible modules; for example CPU-modules with different kinds of microcontrollers, of application-modules like a Motion control-module with actuators and sensors appropriate for physical motion control-experiments.

Even though the actual experiments in most cases are not unique, the uniqueness behind the Mechatronic Learning Concept in those cases is the portability and affordability; each student can have his or her own kit, for the entire period of the course or education, and do the experiments anytime and anywhere. We strongly believe that this can be viewed as a change in organization, and a change in line with the ideas described in this paper. Even though the basic idea by organizing the laboratory work in this fashion is to enable constant access and constant exposure an underlying factor is also the uncertainty and inability to foresee the needs of tomorrow's students – and in preparation for this we put a focus on access instead of form.

3. CONCLUSIONS

Following the notion of defining the identity of Mechatronics as Thematic a model has been developed that illustrates the evolution of Mechatronics from a Disciplinary identity to a Thematic identity; an evolution divided into six stages characterized by certain milestones like the creation of new courses in Mechatronics (stage 3), creation of new programs in Mechatronics (stage 4) and the creation of entire Mechatronic organizations (stage 5).

This model has further been illustrated by examples from various universities and institutes; examples with the purpose of illustrating certain aspects like the move from a situation where the Mechatronics education is mainly seen as one or several courses where basic knowledge can be applied in a hands-on approach to situations where the Mechatronics education is seen as an entire educational program comparable to Mechanical engineering and Electrical engineering, but still unique from day one.

To fully appreciate the concept of Mechatronics in an engineering education, for example in relation to the earlier described subsystems-based perspective, we argue for the full implementation of the final step in the evolution-model; the move from the organizational stage toward the thematic stage.

4. ACKNOWLEDGEMENTS

This work has been made possible thanks to a grant from KTH Learning Lab. The examples from the various universities are primarily gathered from two conferences on Education in Mechatronics; the 1st International Workshop on Education in Mechatronics, Bochum, Germany and the 1st Baltic Sea Workshop on Education in Mechatronics, Kiel, Germany. The Mechatronic Learning Concept (MLC) was initiated in 1998 as a student-project, and has since then been run and financed by the Mechatronics Lab at KTH.

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