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EDUCATIONAL ASPECTS OF DEVELOPMENT AND APPLICATION OF A SUBPROGRAM-PACKAGE FOR CONTROL

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AUTLIB (AUTomatic control LIBrary) is a FORTRAN coded subroutine package developed at the Institute for Automatic Control in Zurich. Each of the subprograms included is intended to solve a well defined basic problem in analysis and synthesis of control systems. The subprograms are written and documented according to a prescribed scheme. A good deal of the subroutines has been programmed by students as part of research and diploma projects and afterwards been implemented into the library. These students also form a major part of the users of the program library. The paper first discusses the experiences with the development of the subprograms by students. Educational aspects as well as aspects of program efficiency are considered. Furthermore reporting is given upon experiences with the application of the subprogram package in connection with student projects, research projects of graduate students and assistents and with an interactive program system.

I. INTRODUCTION

At the Institute for Automatic Control of the Swiss Federal Institute of Technology in Zurich a subprogram library called AUTLIB has been developed A great deal of the subprograms has been coded by electrical engineering students during their "semester" and "diploma" projects. These students also form a major part of the users of this program library. It is the aim of this paper to discuss the experiences made with the development (chapter III) and application (chapter IV) of the program package AUTLIB.

According to the topic of this symposium the accent of this paper is put to the educational aspects. It, therefore, is necessary to review shortly how the education of an electrical engineer is organized at the Swiss Federal Institute of Technology. Each student has to carry out two "semester projects" during the seventh and the eighth term respectively. In these projects he treats a specific problem for the period of one term (12 to 16 weeks) on which he works approximately 20 hours per week, and for which ha also elaborates a written report. In addition to these two projects he has to carry out a "diploma project" during six (soon eight) weeks of full time work. All these projects are carried out under the supervision of two professors or assistents. The student is free to select a project of one of the eleven institutes at the Department of Electrical Engineering. About 30 % of the students accomplish one or two of their projects at the Institute for Automatic Control.

The development of the program package AUTLIB has been motivated by the following situation: About 10 years ago our students started to use the digital computer as a tool for the analysis and synthesis of control systems in their project works. This rapidly growing trend resulted in a tremendous amount of different computer programs. In most cases their documentation was in an unsuitable form, hard to find or not present at all. After a short time no one could overlook all the programs developed so far at the institute. Therefore, every student had to write by himself all programs required for the computations in his problem. Programs written beforehand for similar or same purposes were of no use at all, because:

-- one did not know about them
-- one could not find them
-- one could not understand them
-- they did not fit properly.

Unsatisfied with this situation a group of assistents and researchers of the institute started in 1972 to build up systematically a library of programs which were likely to be reused in future. The group formulated the objectives to be reached with this program library and determined a set of directives how subprograms are to be coded and documented. This working group meets periodically to discuss and coordinate the documentation, the maintenance, the extension and the application of the program package AUTLIB.

II. ORGANIZATION OF THE PROGRAM PACKAGE

In order to guarantee for a most efficient use of the program package the working group stated the following objectives:

1. AUTLIB should be an assistance to the programmer. He should be released from writing program parts for standard tasks, as for example transformations of systems' representations, simulation of dynamic systems, data input, numerical and graphical representation of results.

2. Subprograms which have been written during a student project or research work on analysis or synthesis of control systems should be available for future projects. This to allow existing algorithms to be applied to other applications or to be compared to new algorithms with little effort.

To reach these aims programming directives have been elaborated. They can be summarized as follows:

1. In order to allow an easy application within other programs, only subprograms are accepted. Each subprogram should fulfil a well and most generally defined task.

2. The programs are to be coded in FORTRAN. A subset of ANSI-FORTRAN-IV has been defined which allows implementation on different computers (e.g. CDC 6000 series installation, IBM 370/155 and PDP 11/45). Particularly matrices used as formal parameters are to be stored in vector form.

3. Input and output statements should only be used within specific input/output routines as far as possible.

4. Documentation directives: All information needed for proper use of a subprogram must be given as comment cards at the beginning of the source program. The information includes the purpose of the subprogram, the directives how to use it, indication of the method and references to more detailed documentation. Forthermore the name of the programmer and the date of the last revision should be mentioned. The form of documentation is similar to the one of the IBM Scientific Subroutine Package (SSP), with the main exception that the parameters are subdivided into input-, output- and auxiliary-parameters. This modification has proved to be a great help for the students.

For the practical use of AUTLIB a collection of all source listings (including the program documentation) is periodically updated and distributed at the institute. The subprograms are classified as follows (in parentheses the actual number of subprograms is indicated):

M-	MATHEMATICS	
MM	MATRICES	(8)
MO	OPTIMIZATION	(5)
MD	INTEGRATION OF DIFFERENTIAL EQUATIONS	(4)
MF	FUNCTIONS	(1)
MS	STATISTICS	(0)
MX	MISCELLANEOUS	(3)
L-	LINEAR DYNAMIC SYSTEMS	
LI	IDENTIFICATION	(2)
LR	TRANSFORMATION OF SYST. REPRESENTATION	(11)
LA	ANALYSIS (E.G. STABILITY)	(6)
LS	SYNTHESIS	(10)
LX	MISCELLANEOUS	(0)
N-	NONLINEAR DYNAMIC SYSTEMS	
NI	IDENTIFICATION	(1)
NR	TRANSFORMATION OF SYST. REPRESENTATION	(0)
NA	ANALYSIS	(0)
NS	SYNTHESIS	(1)
NX	MISCELLANEOUS	(0)
S-	SIMULATION MODELS	
SR	RANDOM NUMBER GENERATION	(1)
SP	PLANTS	(2)
SC	CONTROLLERS, OBSERVERS AND FILTERS	(9)
SX	MISCELLANEOUS	(5)
I-	INPUT/OUTPUT	
II	INPUT	(5)
IO	OUTPUT	(5)
IX	MISCELLANEOUS	(0)
XX	MISCELLANEOUS	(1)

A detailed description of AUTLIB and some application examples illustrating the use of the subprograms is in preparation for being published.

III. EXPERIENCES WITH THE DEVELOPMENT OF THE SUBPROGRAMS

Two different types of experiences with the *development* of subprograms by students may be quoted:

-- experiences concerning the learning effect of a student (educational aspect)

-- experiences concerning the computational efficiency of a program developed by a student (aspect of program efficiency).

1. THE EDUCATIONAL ASPECT

In this respect our experiences are mostly positive. The following points may be stated:

a) The student is forced to structure his problem into well defined subproblems. He learns to think in terms of black boxes rather than in terms of elementary components. After having decomposed a complex system or problem into a combination of several black boxes or subproblems, most of them can independently be coded as computer subprograms. This partitioning seems to be very important for the education in control engineering, because the students get trained in analysing more carefully and systematically the problems to be solved. The student learns to decompose his problem into subproblems which already have been solved and into subproblems he has to solve. For solved subproblems the student refers to the existing subprogram package. For solving subproblems of general interest which are not yet coded in the program library the student has to give a most general and precise description of the problem and its solution (Pflichtenheft). Then he has to develop and code the appropriate algorithm.

b) By writing a part of a library the student exercises a team-work. He has to occupy himself intensively with the interfaces to other parts of the library.

c) The student learns to properly document his intellectual products. This is an absolute prerequisite for a subprogram to be added to the library and is most important for the examination of his work. By using programs coded by other students he will easily learn to distinguish between sufficient and insufficient documentation of a program.

d) Most students are satisfied with their projects since they feel that the results of their efforts will be of use afterwards to other people and not only decorate a bookshelf -- a motivation which is missing in many university projects.

2. THE ASPECT OF PROGRAM EFFICIENCY

In this respect our experiences are merely negative. The following points may be mentioned:

a) Programs coded by students are rarely faultless. They often turn out to work only under certain conditions and within certain restrictions which the student was unable to recognize due to his limited overview and experience in control theory. Most students tend to be happy if they obtain results at all. Their credulity reduces sometimes the credibility of their products. We now tend to add a new program to the library only when one or several independent users have applied it successfully under different environmental conditions. Most programs need several updates until their test status is believed to be satisfactory.

b) All students are satisfied as soon as their programs work correctly.

They do not care very much about efficiency considerations of a program. Due to their lack of programming experience their programs often show a remarkable amount of overhead. It sometimes is easier for the supervisor to recode the subprogram entirely than to ameliorate the existing version.

c) Normally our students do not have a very good background in numerical mathematics. (An additional lecture on this subject has for this reason been added recently to the compulsory classes for all students in electrical engineering. However, those students attending this new lecture are not yet in their seventh term, therefore, we are unable to measure any results of this provision yet.) Thus the numerical behavior of programs coded by students is sometimes doubtful.

However, most of the subprograms are called intensively by many programs of many different users. Therefore, in most cases deficiencies do not remain unnoticed for a long period of time.

IV. EXPERIENCES WITH THE APPLICATION OF THE SUBPROGRAM PACKAGE

The experiences with the use of the subprogram package AUTLIB will be discussed by considering three different types of applications:

-- Student projects

-- Research projects of graduate students and assistents

-- Application as part of an interactive program system.

1. THE APPLICATION OF AUTLIB IN CONNECTION WITH STUDENT PROJECTS

In the last few years we had at our institute the opportunity to use this software package during student projects and exercises. The software package has for example been applied to control problems in the following fields: Solar heating, inverted pendulum, aircraft landing, cement mill, power generator, precision weight measuring, pH-analysing.

The advantages and disadvantages of the application of the library may be stated as follows:

a) The student or diploma projects are normally realized by groups of two students. Each student may apply different methods, out of which the results can then be compared and discussed. By using the subroutine package the student is in a position to programme very sophisticated algorithms in a very short time. Through this, the work performed gets more interesting for him and most of the problems are more precisely analysed. The students invest less of their time for the computer programming and, therefore, more of their time for studying the theory.

b) Very often a student project is a part of a larger research project. In this case the supervising professor or assistent has a better guarantee of receiving correct numerical results, because each subprogram has independently been tested beforehand by different other scientists. Furthermore, by using the output subroutines of the library, the results are generally presented in a clear and perceptual form.

c) By forcing the student to integrate already programmed subroutines into his own program he is trained to think in terms of black boxes. The subprograms become a system of black boxes, for which only the interconnections have to be programmed. As mentioned already in chapter III it is an important fact, that the student learns to use existing subprograms and, therefore, to structure his given problem into well defined subproblems (this is one of the fundamental laws in problem solving). But on the other hand we have noticed that in some cases it is hard to motivate the student to analyse and to understand what really happens in the different black boxes. This can be an important educational disadvantage, because fundamental knowledges may be missing during the project. If for instance his program fails he often is unable to locate the error and, therefore, needs the help of his supervisor. It is then sometimes difficult to judge the personal initiative of the student.

d) It is possible to solve rather complex problems of analysis and synthesis of control systems by use of AUTLIB. Therefore, also the student projects proposed by the assistents of the institute are becoming more and more complex. For this reason the knowledge of the students is not always compatible with the requirements of the projects. The software package is a very powerful tool, but only, if the user is aware of the fundamental laws, limitations and assumptions in each algorithm. Concerning these difficulties the assistants must carefully try to formulate the student projects in such a way that they are separable into different subproblems which are easier to understand. Furthermore the team-work between student and assistent is of major importance.

2. THE APPLICATION OF AUTLIB IN CONNECTION WITH RESEARCH PROJECTS OF GRADUATE STUDENTS AND ASSISTENTS

Due to their deeper knowledge in control theory and their better founded background in numerical mathematics the assistents and researchers can apply the subroutine package much more efficiently than the students. No negative experiences as they were mentioned at the end of the last section have been made in connection with research projects.

Unlike some students most assistents and researchers do not have programming difficulties when using the AUTLIB package. The programming part of their work is reduced to a minimum. The researcher may thus concentrate on the theoretical, numerical and practical aspects of his problem. Nevertheless, with increasing complexity of the programs it is getting more and more difficult to overlook in detail each numerical operation and, therefore, the obtained results must be considered with the necessary scepticism.

Assistents and researchers have successfully applied the program package to control problems in the following fields: Spacecraft rendezvous manoeuvres, road traffic control, digital autopilot, power electronic circuits, power distribution systems, modeling of ferro-magnetic phenomena, railway systems.

3. THE USE OF AUTLIB IN CONNECTION WITH AN INTERACTIVE PROGRAM SYSTEM

Some of the subprograms of AUTLIB have been integrated into an interactive conversational computer program, performing the analysis and synthesis of linear dynamic systems. This conversation type program allows the user to communicate with the computer by means of english written statements. This interactive package has the advantage that no programming experience is required. Only good knowledges in control and system theory are needed for efficient use of the program. The application of the AUTLIB routines in this form is more restricted, but the educational effect is more specifically directed towards control engineering: All problems concerning computer and programming remain in the background and the students may concentrate on the problems to be solved.

V. CONCLUSIONS

Concerning our experiences with the *development* of library subprograms by students we conclude:

1. If a student has to programme a certain subproblem of his work as a generally usable subproblem, he may benefit from the necessary problem decomposition, team-work and program documentation. The educational advantage is important, because the student is well motivated to create a part of an often used program library.

2. The relative inexperience of students in numerical methods and computer programming often reduces the efficiency of the resulting subprograms. This must be compensated by good supervision of the project and excessive testing of the subprograms.

Summarizing the experiences with the *applications* of AUTLIB three points can be stated:

1. The use of the subprograms for student exercises to be solved within one or two hours is only efficient if they are integrated into a ready to run program, for example into an interactive program system. Otherwise the programming part is so time consuming that the students have no time left to analyse and understand the given problems.

2. The use of AUTLIB as programming help during student projects has many positive educational effects, but only if the project is carefully prepared and supervised by the responsible professors or assistents. The project should be divided into subproblems which are not too complex.

The students' knowledge level must be taken into consideration.

3. For more comprehensive research projects which are performed by graduate students and researchers the program package allows to work very efficiently. The use of the program package results in better structured software solutions, in less programming effort and reduced error probability.