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THE DESIGN RESEARCH CENTER AT CARNEGIE-MELLON UNIVERSITY

by

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THE DESIGN RESEARCH CENTER AT CARNEGIE-MELLON UNIVERSITY

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SUMMARY

The Design Research Center at Carnegie-Mellon University is an informal organization of 25 members drawn from engineering and allied fields. Members' research activities range over a great variety of concepts and design aids for all phases of engineering design. The center's main function is to facilitate the interchange of ideas and to foster interdisciplinary research on design issues.

INTRODUCTION

The Design Research Center (DRC) is an interdisciplinary center housed in Carnegie Institute of Technology, the college of engineering of Carnegie-Mellon University. It is dedicated to the improvement of the quality and diversity of computer aids for all phases of engineering design and across all engineering and allied design disciplines. Particular attention is given to computer aids applicable in the early, conceptual stages of design where the most important global design decisions can be made. Similar emphasis is given to general support functions, including computer graphics, design databases and high-level user interaction facilities, applicable to the broadest range of design activities. The interdisciplinary nature of the center's membership is exploited by stressing multi-level and multi-disciplinary design problems. As a natural outgrowth of this broad interest in computer aids, the center is also taking an increasingly active role in introducing a variety of computer aids, Computer-Aided Design and Engineering techniques and personal computers into the college's undergraduate and graduate programs.

The paper is organized in two parts. The first part presents factual information on the Design Research Center, discussing its history, organization, functions and funding. The second presents the rationale for the Center's mode of operation and illustrates it through brief descriptions of a number of current research projects of DRC members.

OVERVIEW OF THE DESIGN RESEARCH CENTER

BACKGROUND

The philosophy of DRC is deeply rooted in the Carnegie Plan, initiated in the 1940's and designed to introduce students to the analysis, synthesis and evaluation phases of engineering design[1]. While analysis - the thorough understanding of the behavior of engineering systems - is a significant portion of all educational and research programs in the college, much of the research on synthesis and evaluation tends to be performed by DRC members.

The more immediate impetus for the establishment of DRC was the influence of Herbert A. Simon, Richard King Mellon Professor of Computer Science and Psychology, one of the founders of the field of Artificial Intelligence. In his 1969 book, The Sciences of the Artificial,[2] Simon argued forcefully that the time was ripe for changing the design of man-made systems - artifacts - from an art to a science. Simon provided a detailed description of the tools and concepts which would constitute such as science.

In the early seventies, there were only a few faculty members at Carnegie-Mellon active in the areas described by Simon, notably John Grason in Electrical Engineering and Charles Eastman in Architecture and Computer Science. In

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relatively short order, a number of faculty members interested in design research joined the University, among them Arthur Westerberg and Gary Powers in Chemical Engineering, Steven Director in Electrical Engineering, and the author in Civil Engineering. With this "critical mass" achieved, DRC was established in 1974, with Gary Powers as the first director. Westerberg replaced Powers in 1976, and upon Westerberg's promotion to Department Head of Chemical Engineering, the author became director in 1979.

ORGANIZATION. STAFF AND FACILITIES

The Design Research Center operates as an informal federation of 25 members from the college's Departments of Chemical, Civil and Electrical Engineering and from Architecture, Computer Science, Design, Mathematics and the graduate schools of Industrial Administration and Urban and Public Affairs. Overall direction is provided by a Steering Committee of four members.

The DRC staff consists of an Administrative Assistant/Computer Programmer, a Research Engineer responsible for hardware and software and for assisting members in software development efforts, and a Research Scientist specializing in expert systems on a joint appointment with the Robotics Institute.

The DRC physical facilities include offices for staff and visiting faculty, a research laboratory for graduate student use, and a CAD Laboratory to be equipped with 12 to 15 personal computers for class, recitation and student practice use.

DRC has long ago decided that operating and maintaining its own computer would be counterproductive in the Carnegie-Mellon environment which consists of a large network of computers centrally managed by the Computation Center and the Department of Computer Science DRC therefore concentrates primarily on providing the best terminal and support software facilities for its members. DRC provides probably the broadest software library at Carnegie-Mellon outside the Department of Computer Science, and its staff is available to search for, acquire, install, modify and "customize" software for its members.

GOALS AND FUNCTIONS

The Design Research Center is not a degree-granting program, nor is it - on Carnegie-Mellon University's scale - a major entrepreneurial center for conducting sponsored research Its prime goals and functions are to provide DRC members and their graduate student an opportunity to pursue shared research and educational interests, to maintain a software/hardware environment in which to develop and share new concepts and design aids, and to serve as an active forum for the exchange of ideas.

The major formal activities in support of these goals are the following.

- Biweekly meetings are the major forum for presentations by DRC members, graduate students and visitors to discuss research in progress.

- Distinguished Lecturer Series provide an opportunity to bring to the University leading researchers and practitioners in a variety of areas.

- Annual meetings bring the members and their students together for a focused discussion of a central subject of interest

- Visiting Professorships serve to bring outstanding researchers to Carnegie-Mellon University for extended periods of consultation and intimate interaction.

- The Research Report Series, published twice a year, provide an organized way of "broadcasting" the full scope of the members' research activities.

In addition, there is a large number of informal activities. DRC regularly distributes lists of courses of interest to members and their students, and a number of departmental courses taught by members are arranged so that students from other departments can take all or portions of such courses. External members of thesis committees of members' students frequently are other DRC members.

The broad goal and informal organizational structure of DRC have served it well, and have permitted it to change with the times. For example, many of the early activities, seminars and lectures dealt with computer representation and processing of very large-scale engineering analysis problems (e.g., partitioning of large sets of equations, sparse matrix techniques. These issues have by now been so thoroughly "internalized" by the disciplines represented in DRC that we now seldom, if ever, have seminars on these topics. On the other hand, the shared interests in computer graphics, expert systems and new educational uses of computers form the basis of many of our current activities. Similarly, through the interest of its members DRC is becoming the leader in the introduction of personal computers in the college and the broader University community.

FUNDING

Support for DRC comes from three sources. The college provides a modest operating budget for the basic functions of the Center. The bulk of the Center's operations is supported by institutional grants. The largest of these is a four-year grant from the Sloan Foundation. Continuation of this type of support is expected from the Sun Oil Corporation, and minor grants have also been received from ICI industries and other donors. This funding supports the activities described above, as well as providing "seed money" to support a number of graduate students on exploratory projects. In awarding graduate student support the Steering Committee emphasizes interdisciplinary work, requiring academic supervision by two DRC members, preferably from different departments.

DRC is available as an "umbrella" for conducting interdisciplinary sponsored research, proposed and executed by its members. This mechanism is particularly attractive to members on multi-departmental projects where DRC can supply a simplified administrative structure.

OVERVIEW OF RESEARCH ACTIVITIES

RATIONALE

The preceding factual description of DRCs organization and activities can be used to review the rationale for DRCs function and mode of operation

All branches of engineering are evidencing a severe "design gap": new engineering systems (e.g, electronic chips, process plants, mega-projects) are becoming so complex that the ability to build them is advancing significantly faster than the ability to design them New materials and components potentially usable in such systems are appearing on the marketplace much faster than the designers' capacity to understand and evaluate them New requirements, objectives and constraints (e.g, energy efficiency, environmental concerns) are being superimposed on old design objectives at an increasing rate. New markets for products and services are opening up, while existing products and services have to be provided in drastically changing economic, labor and international environments. The time scale of development and the magnitudes of investments are such that significant redesigns are continually required

The computer has already become a major factor in the acceleration of design pace and the increase in design complexity; one can no longer conceive of a large-scale design effort in any branch of engineering without

extensive computer support The computer is even more significant as the principal tool for redressing the design gap. Computer-aided design in its broadest sense, and its natural extension into CAD/CAM, are seen in all branches of engineering as the mechanisms for coping with and controlling the design explosion. Every aspect of CAD/CAM in every engineering discipline merits and requires a significant research effort The present Conference vividly illustrates the range of CAD/CAM research centers at many universities.

Instead of a sharp focus on specific engineering disciplines, DRC has chosen to operate *as* an informal federation emphasizing an interdisciplinary flavor and has set as its goal to address, to the maximum extent possible, the conceptual stages of design.

The interdisciplinary attitude responds to several factors. First, internal to Carnegie-Mellon, it is predicated on the University's organizational structure, with an essentially complete absence of internal barriers and an environment that encourages the formation of interdisciplinary groups. This environment, together with the broad approach to design, has enabled DRC to assemble 25 active members. It is hard to conceive of a focused effort that could draw together such a broad "constituency." Second, externally, it is widely recognized that the interesting research and design issues are those at the interfaces of traditional disciplines. There is the equally wide recognition that design tools are common to many disciplines. Finally, sharing of tools and concepts across disciplines provides a synergistic effect allowing disciplines to adapt methods from leaders and thereby "leapfrog" over other researchers in their respective fields.

The emphasis on conceptual stages of design is a result of similar considerations. Optimization and synthesis are the two areas of CAD in the broadest sense where the most critical design decisions can be made, and where the major design research issues remain to be solved By keeping up with the ambition to affect design research in this crucial area, DRC has been able to adjust to new developments. The most significant of these is the impact of Artificial Intelligence on engineering design DRC rapidly capitalized on the field of expert systems (or knowledge-based systems) and there are now research efforts in expert systems in all three participating engineering departments, as well as in Architecture. *p*

REPRESENTATIVE RESEARCH PROJECTS

The following selection of capsule summaries of DRC research projects is no means exhaustive. Emphasis is given to projects that most vividly illustrate the synergistic effect of DRC. A complete listing of research reports is available from DRC A good sampling of DRC members' work may be found in the October 1981 Special Issue on Computer-Aided Design of the IEEE Proceedings[3].

Synthesis. Research in automated synthesis, that is, the generation of design alternatives, has been the focus of activity in several DRC projects. Work in chemical engineering has led to prototype programs that create entire configurations for chemical process systems[4]. The CMU-DA project in electrical engineering aims to develop automated synthesis aids for complete digital systems[5]. Successful synthesis tools have been developed for subproblems, such as heat exchanger networks and separation systems in chemical engineering[6] and alternative logical structures in digital systems[7].

Optimization. A wide range of projects deals with optimization techniques and their application to engineering design Among the significant ones are design centering as a means of maximizing yield of electronic components[8,9] approximation methods[10], and quasi-Newton methods for large chemical process systems[11]. The latter is illustrative of the "transference" afforded by DRC: the method has been successfully applied to optimal dispatch of electric power systems[12,13] and optimal structural design[14].

.xtensions of optimization to mixed integer problems[15] and to set covering problems[16] bring optimization close to synthesis.

Evaluation. The evaluation of designs for conformance with external standards and regulations is a particularly severe problem in civil engineering The techniques of representation and processing developed in that field[17,18] are being applied by DRC members in other fields, notably Architecture.

Design Databases. Design databases are emerging as the pivotal mechanism for large-scale computer-aided engineering and design Research issues addressed include: applications of design databases in specific design disciplines[19,20], the dynamic treatment of semantic integrity constraints[21], and the processing of consistency constraints[22,23].

Expert Systems. Knowledge-based expert systems promise to have a major impact on computer-aided design, by providing a mechanism to "encapsulate" experts' heuristic problem-solving rules and make them available to less experienced users[24]. Research in the development and application of expert systems is progressing in areas as diverse as architecture (window performance evaluation), chemical engineering (selection of physical properties), electrical engineering (VLSI design) and civil engineering (automated transit operations, automated tunneling).

CONCLUSIONS

The function and mode of operation of Design Research Center evolved in response to the specific circumstances of Carnegie-Mellon University, namely: a) the presence of a number of faculty members doing research on a broad range of problems affecting design; and b) the tradition of the University to support and foster interdisciplinary cooperation. DRC continues to serve its members and their respective disciplines by providing an informal forum for cooperation and mutual assistance in an environment free of the pressure of potentially competitive enterprises. DRC will continue to adjust its functions and research emphases in response to changes in its members interests and needs for support and cooperation

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