installation maintenance and system evolution. Greater expenditures on specification, documentation, and system structuring early in the life cycle can greatly reduce costs later in the life cycle. The total capital cost of such systems can be billions of dollars (the DoD command and control system, WIS, is budgeted at over $30 billion over 15 years). Our current technology for such systems is inadequate and results in gross inefficiencies in their construction, use, and maintenance. The programming language Ada was an attempt to develop a capital-intensive technology base for large evolving systems and has served to focus attention on this problem. But Ada has not yet demonstrated that it can significantly reduce the cost or improve the reliability of such systems.

The impact of cheaper computer hardware is similar to that of cheaper energy sources. It has made computers affordable in every home and appliance, but has also increased our appetite for building complex capital-intensive systems. Distributed systems with greater hardware complexity, as well as very complex software systems, are becoming technologically and economically feasible. It is precisely because hardware has become so cheap that software has become the limiting bottleneck. Cheaper hardware provides an incentive and economic justification for capital-intensive software technology in much the same sense the cheaper energy provides an incentive for capital-intensive industrial technology.

When I started thinking about capital-intensive software technology in the late 1970's, I viewed the analogy between the computer and industrial revolutions as a convenient peg on which to hang some philosophically suggestive verbiage. But the analogy is more than superficial. Energy and engines for transforming energy in the industrial revolution have deep analogies with information and engines for transforming information in the computer revolution. The roles of tools and reusable components, of factories that facilitate the manual and automatic application of sequences of tools, and of an integrated product development technology, are strikingly similar in both industrial and computer contexts.

The further analogy between capital-intensive industrial and software technology appears at first to be less compelling, not only to Lewis, but also to traditional engineers. The myth that software is an add-on requiring less professional expertise than engineering design is widely held by upper and middle management in engineering companies responsible for constructing large hardware-software systems. This is illustrated by a middle manager of a large defense system who, when asked by the author whether software was a primary bottleneck, said that the system was built so that all the software were thrown overboard, system performance would not be affected.

The failure to realize that software technology is as capital-intensive as hardware technology is in fact one of the causes of the present software crisis. Software structures are not as visible as hardware structures, and the effort needed to complete them cannot be estimated as easily as that needed to complete a partially constructed building. The effectiveness of software tools cannot be judged by their visible effects, as can the effectiveness of cranes and steam hammers. Information structures are more subtle than physical structures but are just as real. Their construction, maintenance, and distribution require careful capital-intensive preparation by highly-trained "construction engineers."

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INNOVATIVE SOFTWARE APPLICATIONS

Software A&E, a rapidly growing company in Washington, DC, specializes in the development of advanced products and systems which integrate software engineering and artificial intelligence technologies. Current projects include intelligent workstations, expert system development tools, extensions to Ada for AI applications, and more. These projects involve the use of Ada, C, and LISP on VAX, M68000, and LISP-oriented machines.

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MULTIPROCESSING ENGINEERS—PROGRAMMERS

The new Center for Supercomputing Research and Development (CSRD) of the University of Illinois at Urbana-Champaign seeks experienced technical staff for the development of high-speed multiprocessor systems. With support from the U.S. Government and the State of Illinois, CSRD is initiating an effort to design and construct a multiprocessor that will deliver high performance over a wide range of computations. This effort is based on over ten years of research in software, architecture, and algorithm development performed by a nucleus of an experienced research staff. In addition, this project will enjoy the cooperation of some of this country's leading industrial groups. The project will begin October 1, 1984.

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To take part in a group of research engineers in gate array design and systems integration. Minimum qualifications include a Master's degree in Computer Science (C.S.) or Electrical Engineering (E.E.) or Ph.D. is desirable, and four years of experience.

SENIOR RESEARCH PROGRAMMER
To take part in research and development of the above hardware activity. Minimum qualifications include B.S. degree in C.S. or E.E. (Ph.D. is desirable), and four years of experience.

Research Engineer
To take part in research and development of the above software activity. Minimum qualifications include a Master's degree in Computer Science (C.S.) or Electrical Engineering (E.E.) and two years experience.

SENIOR RESEARCH PROGRAMMER
To provide programming expertise and technical leadership in development of compilers, operating systems. Minimum qualifications include a Master's degree in Computer Science (C.S.) or Electrical Engineering (E.E.) and two years experience.

SENIOR RESEARCH SCIENTIST
To provide programming expertise and technical leadership in development of multiprocessor numerical and non-numerical algorithms in a variety of applications. Minimum qualifications include a Ph.D. degree in C.S., E.E., or any computer-related field.

TECHNICAL SCIENTIST
To take part in research and development of the above numerical and non-numerical algorithms. Minimum qualifications include a B.S. degree in a computer-related field.

The Center for Supercomputing Research and Development will offer industrial-scale salaries, in addition to providing University benefits. Please send resume, including educational background, recent professional experience, and salary requirements to:

D. J. Kuck, Director
Center for Supercomputing Research and Development
University of Illinois
1304 W. Springfield Avenue, Urbana, Illinois 61801
Telephone (217) 333-1650

Applicants should clearly specify the position or positions for which they are applying. To expedite the filling of all positions, qualified applicants will be interviewed during the advertising period. All applications submitted by December 3, 1984, will receive full consideration. Some positions may begin immediately.

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