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JANUARY 27, 1982

The Honorable Jack Brooks
Chairman, Committee on Government
Operations
House of Representatives

RELEASED

Dear Mr. Chairman:

Subject: DOD Instruction 5000.5X, Standard Instruction Set Architectures For Embedded Computers (MASAD-82-16)

On July 30, 1981, you requested that we review the Department of Defense (DOD) plans to implement proposed DOD Instruction 5000.5X. Your request raised a number of questions about the potential impact of implementing the proposed instruction. We have responded to your five specific questions in enclosure I.

As we understand it, the primary objective of Instruction 5000.5X is curtailment of high costs resulting from hardware and software proliferation, and in particular, logistics support costs in the field. To accomplish this, DOD has chosen to limit the number of architectures that could be used for the design and development of computer hardware and software for the tactical environment. Moreover, DOD would require ownership of standard architectures for military-embedded computers. Although this proposed instruction has merit when considered in context of the hardware/software environment that existed during the mid-1970s, our evaluation raises some serious issues that challenge its validity in the time frame of the 1980s. Some of the more salient points for consideration are:

--Dramatic advances have been made in software technology. DOD has recognized that a lack of a standard programming language is a major contributor to the high cost of developing and maintaining software for military applications. DOD is to be commended for its initiative to fill that void by developing a common high-order programming language called Ada. Ada very specifically aims to readily adapt a very wide variety of DOD applications to most present (and future) computer architectures. Ada can potentially encompass the particularly useful aspects of future architectural advances and make their gains available to users, without their having to learn and worry about how the gains were

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realized. In other words, aggressive pursuit of a standard high-order language, such as Ada, could alleviate the software proliferation problem and at the same time permit the Government to fully capitalize on architectural advances.

--Likewise there have been many advances in computer technology. These advances are the result of demands made by the civilian sector for more reliable and rugged computers. And indeed, the civilian sector is starting to impose much stiffer reliability requirements on integrated circuits. These advances will be realized probably at little or no cost penalty because all integrated circuits will be made to the same high standards. There are computer companies already marketing highly reliable computers through the use of innovative architectures. These modern computers have substantially fewer parts and in many cases are a computer on a single board thereby reducing the need for extensive logistics support.

--Improved competition using militarized versions of commercial computers will open up competition to many firms that would not bid on specifications with DOD-owned architectures. The resulting unit prices will be less because DOD will not pay for duplicating hardware development and control and utility software development as it proposed to do under Instruction 5000.5X. Lower hardware unit costs and high hardware quality are in fact available in the commercial market because of the technology and broader market base.

--DOD ownership of architectures would seriously inhibit competition by a significant portion of the computer industry, and therefore DOD would not have the flexibility to capitalize on advances in computer architectural technology in a timely fashion. The ultimate impact would result in DOD very likely running the risk of getting locked into obsolete architectures.

--DOD would not be able to efficiently utilize the new DOD programming language Ada and will not be able to fully capitalize on the anticipated software cost savings Ada was designed to yield.

--The three services have initiated efforts commensurate with Instruction 5000.5X; for example, the Army's Military Computer Family, the Navy's AN/UYK-43 and 44, and the Air Force's 1750 programs. In a previous report entitled "The Department of Defense's Standardization Program for Military Computers--a More Unified Effort Is Needed" (LCD-80-69, June 18, 1980), we were critical of both the Army and Navy efforts. We made the following statements in that earlier report and believe they are even more valid today:

"* * * some computer manufacturers are already designing computers with modern architectures that will have Ada compilers available. These or other manufacturers will probably offer follow-on computers that will directly carry out Ada instructions and substantially improve performance reliability. Because these changes provide better support options, such as building more redundancy into systems, they should compel the Department to further evaluate the level of standardization to be achieved before allowing the Army and Navy to commit themselves * * * for the long term. (Emphasis added.)

"We view the need for architecture standardization as a function, in part, of the availability of Ada as the standard computer programming language. Because Ada is being developed to be a machine-transportable language with a relatively low life cycle maintenance cost, the need for standard architectures may be diminished when it is available * * *." (Emphasis added.)

CONCLUSIONS

We believe that DOD can accomplish its objectives more effectively through exploitation of advances made with high-order language standardization and related hardware technology. Further, we believe implementation of Instruction 5000.5X would preclude DOD's ability to make use of current and anticipated advances in software and related hardware technology.

RECOMMENDATIONS

We recommend that the Secretary of Defense not implement Instruction 5000.5X.

We also recommend that the Secretary of Defense direct the services to reevaluate their ongoing efforts and demonstrate why they are more cost effective than standardizing on a high-order language such as Ada and relying on the computer industry to provide the stimulus for computer architectural innovations.

SCOPE AND METHODOLOGY

During our review, we contacted officials representing 16 computer manufacturers, 3 system contractors who incorporate embedded computers in the systems they develop, and 4 industry associations representing manufacturers of computers and electronic equipment. We reviewed position statements and correspondence regarding Instruction 5000.5X. We also contacted program officials and reviewed program documentation regarding Ada, the Army's Military Computer Family, the Air Force's 1750, and the Navy's AN/UYK-43 and 44 efforts.

Our review was performed in accordance with our standards for audits of governmental organizations, programs, activities, and functions.

As arranged with your office, we did not obtain official agency comments on this report and we plan no further distribution of this report until 30 days from the date of the report, unless you publicly announce its contents earlier. Then, we will send copies to interested parties and make copies available to others upon request.

Sincerely yours,

Milton J. Socolar

Acting Comptroller General
of the United States

Enclosure

RESPONSES TO SPECIFIC QUESTIONS

REGARDING INSTRUCTION 5000.5X

WHAT EFFECT WOULD INSTRUCTION 5000.5X HAVE ON THE USE OF COMPETITION IN THE DEPARTMENT OF DEFENSE?

Instruction 5000.5X would effectively preclude any commercial architecture from the Department of Defense (DOD)-approved list because DOD must have full and clear data rights to all architectures listed. Currently, only DOD developed and funded architectures have been approved. The Army's unsuccessful attempt to use a commercial architecture in its Military Computer Family program is an example of how this policy will inhibit commercial architectures from competing for embedded computer systems.

The Army's unsuccessful attempt was caused by (1) the reluctance of the commercial firm to accept Army assurance that its proprietary architecture would not be remarketed commercially and (2) the lack of industry interest in providing hardware based on a competitor's design. It is fortunate that this attempt was unsuccessful because the commercial firm involved is now marketing a new architecture due to the prior one's limitations.

A majority of the industry officials interviewed assured us that they would not compete on DOD-embedded computer procurements if they had to use DOD-approved architectures. These officials were concerned that their key personnel would be diverted from current work to meet the production needs of the DOD-embedded computers, which have obsolete architectures. Therefore, the key personnel would lose their current technological expertise. A smaller number of industry officials felt that Instruction 5000.5X would encourage competition in DOD procurements. However, these officials generally represented companies currently under DOD contracts implementing approved architectures.

WHAT EFFECT WOULD INSTRUCTION 5000.5X HAVE ON THE CURRENT COMPUTER INDUSTRY?

Most industry officials and some military officials stated that Instruction 5000.5X would effectively eliminate many competent computer companies from the militarized embedded computer market. Very few companies are willing to compete on procurements mandating obsolete architectures. Under the current Navy program for the development of the AN/UYK-43 and 44 computers only two companies responded.

WOULD INSTRUCTION 5000.5X LOCK DOD INTO OBSOLETE TECHNOLOGY?

Instruction 5000.5X will minimize DOD's opportunities to capitalize on new architecture developments in the commercial marketplace. Computer architecture is a rapidly evolving technology and has a profound effect on the application of computer technology. As the computer industry improves the application of high-order languages, such as Ada, it also needs improvements and innovations in computer architectures to better support the use of high-order languages.

Most of the industry officials stated that DOD would definitely have obsolete equipment due primarily to the fact that the approved architectures in Instruction 5000.5X are or will be obsolete by the time they are implemented. We were also told that these architectures do not lend themselves to efficiently utilize the new DOD programming language Ada and will not be able to fully capitalize on the anticipated software cost savings Ada was designed to yield.

The architectures listed in Instruction 5000.5X do not include many modern concepts such as stack-oriented architectures, memory-to-memory architectures, efficient multiprocessing support, multiple concurrent tasking support, pipelined architectures, signal processing architectures, image processing, and array computers. Therefore, technological advances in computer architectures will be ruled out because of Instruction 5000.5X.

ARE COMMERCIAL OFF-THE-SHELF COMPUTERS CURRENTLY AVAILABLE THAT COULD SATISFY DOD'S MAJOR NEEDS FOR EMBEDDED COMPUTERS?

Militarized versions of off-the-shelf commercial computers are available, work very effectively with modern software, and can offer current computer technology at reasonable costs. Commercial computers have the advantage of giving program managers the latest technology and the most effective and efficient architecture for the particular job. Commercial computers also (1) have lower life-cycle costs, (2) can be militarized to the point where they are rugged enough for combat, (3) can help ease the logistics support burden, and (4) provide more competition.

Today, nearly all of the research and development in electronics is funded by the commercial sector (particularly in computer technology) and is available to DOD through the purchase of militarized commercial products. Military use of commercial technology would significantly reduce applications development and software life-cycle costs. For example, if DOD utilized commercial architectures, most of the associated research and development costs of the architecture and systems software would be borne by the manufacturer and not DOD. Although DOD is spending hundreds of millions of dollars for customized architectures, it has not offered adequate justifications for its dominant reliance on noncommercial architectures.

The market for embedded computers represents about 5 percent of the total computer market. This means that all embedded computer activities must compete for technical resources with a market that is about 20 times larger. We believe that DOD would do better by utilizing the resources of the entire market by opening the procurements to all the computer industry. Industry could then offer its best architectures, technology, and software support on a system-by-system basis.

Militarized versions of commercial computers already exist. For example, militarized versions of Data General Corporation and Digital Equipment Corporation computers are used in a variety of weapons, communications, and electronic warfare projects within all three services. Ruggedized IBM minicomputers are used extensively in the Marine Corps' Source Data Automation Program. Ruggedized, shock mounted, and straight commercial versions of other vendors' hardware are widely used in command and control and intelligence applications through the AN/GYQ-21(V) program.

Commercial hardware itself is becoming more and more rugged because ruggedness is being required in laboratory, manufacturing, control, vehicle, airborne, and shipboard environments. More dense circuitry and improved packaging have contributed to this trend. As a result, today's computers operate successfully under more adverse conditions than yesterday's and will perform even better in the future.

It is also argued that commercial technology will help solve DOD's problem of logistical support and wartime survivability. Because computers are using less circuit cards than before, the problem of maintenance or logistic support is diminishing. Past computers, in the 1970s, had up to 200 circuit cards compared to today's equivalent that uses only 13 circuit cards and is smaller and faster. Today's AN/UYK-19 (a military version of a commercial computer) uses only 13 circuit cards and the new "B" model only 7 circuit cards.

Adherents of commercial technology argue that it is less expensive and more practical to stock entire computer spares in the field (as the field replaceable unit) than to have more maintenance people in the field to diagnose and swap out an individual problem. Their logistics remedy is to place whole units in the field and ship them back to a central depot for repair. This reduces costs because an individual technician can service a greater number of machines. Also, as computers become smaller, it will be more cost effective to stock entire computer spares in the field.

It is easier to diagnose hardware problems due to advances in commerical technology. New hardware design allows relatively unskilled personnel to isolate problems. Field maintenance will consist of replacing the field unit. This will be facilitated by self-testing logic in the unit and fault-isolating diagnostics.

Throwaway computers are becoming possible because many field units will be a single circuit board, not several cabinets of electronics. Commercial industry is already at the point where several boards are throwaway units. With the high cost associated with maintaining equipment in the field, DOD could probably justify throwing away an even higher percentage of circuit boards. Units that can and should be repaired will be shipped back to a central depot where commercial vendors will repair the failed component. This will free critical military personnel from learning skills that are more readily available from private industry. While this service could be provided by the hardware manufacturer, it is also possible to compete this separately.

Survivability and the ability to maintain continuity of operations will be enhanced not only by simplified logistics but also by distributive processing. In the future, as computers become smaller and smaller, we will see individual computers designed to implement individual functions or to support an individual commander or operator in the field. These individual computers will then be connected together in a network, both locally within a building and more remotely over wider areas. When one of these computers is down, for whatever reason, it can be quickly disconnected from the network and a spare unit plugged into its place.

Lastly, opponents of standard architectures argue that using commercial hardware will increase competition. Instead of using standard architectures for all programs, there would be competitive selection of a computer system for each major new program. The competition would be based on technology as well as price. The pressure to win new programs would encourage the suppliers to introduce new technology without added cost to DOD.

SHOULD STANDARDIZATION OCCUR AT THE INSTRUCTION SET ARCHITECTURE LEVEL OR AT THE HIGHER LEVEL LANGUAGES, SUCH AS ADA?

Cost effective standardization for DOD-embedded computers requires standardization at the high-order language level, such as Ada. The proliferation of languages contributes significantly to the high cost and poor quality of software used in military computer applications. According to the DOD High-Order Language Working Group, none of the many programming languages used in the military is suitable as a standard language for military applications--including the Navy's CMS-2, the Air Force's JOVIAL, and the Army's TACPOL which have been established as interim standard languages. Four of the five architectures currently listed under Instruction 5000.5X are oriented to using these languages.

Studies made by the Defense Advanced Research Projects Agency and by Decisions and Designs, Inc., predicted that as the standard DOD language, Ada will result in substantial cost savings DOD-wide through common software, improved programmer productivity, and new technical features. According to these studies, DOD could save as much as $24 billion from 1983 to 1999.

Because DOD is implementing Ada as its standard programming language for military applications, computer manufacturers are currently developing Ada-oriented computers and Ada compilers using the latest technology with substantially improved performance and reliability. As a result, the need for standard computers and instruction set architectures has diminished.

The consensus of opinion from most of those we interviewed during this review was that DOD should standardize at a high-order language, such as Ada, and let the computer industry innovate at the architectural and hardware levels.

Department of Defense Instruction

USDRE

SUBJECT: Instruction Set Architecture (ISA) Standardization Policy for Embedded Computers.

References:
(a) DoD Directive 5000.1 "Major System Acquisitions", March 19, 1980

(b) DoD Directive 5100.40 "Responsibility for Administration of the DoD Automatic Data Processing Program", revision in coordination

(c) DoD Directive 5000.37 "Acquisition and Distribution of Commercial Products", September 29, 1978

(d) DoD Directive 4120.3 "Defense Standardization and Specification Program", February 10, 1979

(e) DoD Directive 5000.29 "Management of Computer Resurces in Major Defense Systems", revision in coordination

A. PURPOSE

This Instruction states policy and provides guidance for the standardization of Instruction Set Architectures (see definition in Attachment A) for embedded computer systems and applications. Such standardization is intended to improve the overall effectiveness of DoD computer resource utilization, including management of funds, manpower, time, and operational effectivess.

B. APPLICABILITY AND SCOPE

1. The provisions of this Instruction apply to the Office of the Secretary of Defense, the Military Departments, the Organization of the Joint Chiefs of Staff, and the Defense Agencies (hereafter referred to collectively as "DoD Components").

2. The provisions encompass acquistion programs of major defense systems, as designated by the Secretary of Defense (described in paragraph D.2.c of reference (a)). Additionally, the principles provided shall be applied in acquisition of Defense systems and subsystems which do not fall in the major acquisition category and in major modification (MOD) and conversion in lieu of procurement (CILOP) programs.

3. This Instruction covers all embedded digital computers and processors, regardless of implementation, technology, or size, unless they are specifically excluded by the paragraphs belc.:.

4. Excluded from the provisions of this Instruction are:

a. Nonmilitarized general purpose, commercially available, automatic data processing assets as defined and administered under reference (b).

b. Digital computers and processors used in hardware intensive (see definition in Enclosure 1) applications, as further specified in Component implementing instruction or regulation.

c. Digital computers and processors utilized as part of Automatic Test Equipment and Crew Training Devices (e.g., Flight Simulators, Maintenance Trainers), as further specified in Component implementing instruction or regulation.

d. Commercial products acquired under reference (c).

5. The provisions of this Instruction shall not apply retroactively to any defense system where a program decision relative to ISA was made, prior to the date hereof.

6. The provisions of this Instruction shall not preclude experimental use of unconventional or advanced technology ISAs in basic research and exploratory development. Such use, however, shall not be the basis for later waiver or proposal for addition to the approved list in lieu of the process of Enclosure 2.

C. POLICY

1. Only DoD-approved ISAs may be used in defense systems and subsystems unless it is demonstrated that none of the approved ISAs is technically practical or cost effective over the system life. Enclosure 3 lists the ISAs currently approved.

2. Each DoD-approved ISA is assigned to a DoD Component as listed in Enclosure 3 under the executive agent concept. The assigned executive agent will be responsible for assuring stability, specification, and configuration management of the ISA; certifying compliance of hardware implementations with the ISA; and for disseminating information to government and industry on the ISA and on associated existing software tools. ISA specifications shall be coordinated with affected DoD components in accordance with reference (d).

3. Approved ISAs shall be reviewed at least every two years by the Management Steering Committee for Embedded Computer Resources (MSC-ECR), established by reference (e) to determine if additions to or deletions from the list are appropriate.

a. An ISA will not be added to the DoD-approved list unless the DoD has full and clearly-defined rights to permit any vendor to implement the ISA in a system controlled by reference (a) or in less-than-major systems, or subsystems.

3. [illegible] criteria for adding or deleting an ISA to/from the DoD-approved list are set forth in Enclosure 2. These criteria shall be reviewed and updated, as appropriate, by the MSC-ECR at least every two years.

4. Each DoD Component shall institute procedures (acceptable to the MSC-ECR) to grant or reject exceptions (waivers) to this policy and shall publish procedures governing its waiver process in its implementing instruction or regulations. The designated waiver office in each DoD Component will maintain appropriate records to support periodic review by the MSC-ECR.

D. RESPONSIBILITIES

1. The MSC-ECR shall oversee and coordinate the accomplishment of the policies in this instruction and advise the Office of the Under Secretary of Defense for Research and Engineering on matters related to this policy. The MSC-ECR shall serve as the control point for adding/deleting ISAs to/from Enclosure 3.

2. The Assistant Secretary of the Army (Research, Development and Acquisition), the Assisstant Secretary of the Navy (Research, Engineering and Systems) and the Assistant Secretary of the Air Force (Research Development and Logistics) shall be responsible for implementation of this policy within their respective Departments. The Directors of the Defense Agencies shall be responsible for implementation of this policy within their respective Agencies.

[illegible] The DoD Component will assure that the U.S. Government has the rights defined in paragraph C.3. for its assigned ISAs.

4. The responsible DoD Component will designate a control agent for each assigned ISA.

5. Each DoD Component will designate a coordinating agent for each ISA which is assigned to a different DoD Component but which is of application interest.

E. EFFECTIVE DATES AND IMPLEMENTATION

This Instruction is effective immediately. The components shall provide five copies of implementing instructions or regulations to OUSD(R&E)SS not later than 90 days from the date of this Instruction.

Definitions

Instruction Set Architecture (ISA)

The attributes of a digital computer or processor as might be seen by a machine (assembly) language programmer, i.e., the conceptual structure and functional behavior as distinct from the organization of the data flow and controls, logic design, and physical implementation.

This definition includes the processor and input/output instruction sets, their formats, operation codes, and addressing modes; memory management and partitioning if accessible to the machine language programmer; the speed of accessible clocks; interrupt structure; and the manner of use and format of all registers and memory locations that may be directly manipulated or tested by a machine language program.

This definition excludes the time or speed of any operation, internal computer partitioning, electrical and physical organization, circuits and components of the computer, manufacturing technology, memory organization, memory cycle time, and memory bus widths.

Embedded Computers

Computers incorporated as integral parts of , dedicated to, or required for direct support of, or for the upgrading or modification of, major or less-than-major systems.

Those computer applications in which the function is fixed and hence, the computer program after development and test, is expected not to be changed for the lifetime of the physical component in which it is embedded.

Some of the factors which may be considered in determining whether an application program is likely to change are: Computer program size, the quantities associated with the application system in which a computer or processor is embedded; the practice of making changes only to newly-produced units rather than retrofit to fielded units; ratio of expected software life cycle cost to expected system life cycle cost; and implementation of programs in read-only memory.

Criteria for Adding and Deleting Instruction Set Architectures

General:

New ISAs will be added to or deleted from the approved list only if it is clearly shown to be in the best long-term interest of DoD in terms of life cycle cost and operational performance. Novelty or modest improvement in cost or performance is not sufficient justification for addition to the list. The following life cycle cost considerations and trade-offs should be weighed before requesting addition of an ISA:

1. Rights to use the ISA. DoD rights to use the ISA should be fully and clearly defined. The DoD should have the right to contract for implementation of the ISA via an open procurement that is truly competitive with regard to both technical and business considerations.

2. Ease of maintenance, both hardware and software.

3. Use of existing software. If a rich body of existing software is usable (technically and legally) with the new ISA, that ISA should be judged more acceptable than one that does not have such a software base.

4. Ability to automate heretofore impractical functions. A new ISA which would allow DoD to perform some function which was previously troublesome or impossible should be viewed positively.

E. Minimum new training or introduction of new skill requirements to force structure (impact). Should some new ISA be developed, its introduction and impact on support personnel should be examined.

Procedure:

A. The DoD Component nominating the new ISA will submit to the MSC-ECR a nomination document that:

1. Describes the new ISA,

2. Presents the rationale for adopting the new standard ISA,

3. Sets forth an economic analysis of impact of the ISA for its life cycle,

4. Gives a detailed plan for introduction of the ISA, and

5. Provides a detailed specification of the ISA.

B. After receipt of the nomination document, MSC-ECR will be briefed in detail on the proposal.

C. MSC-ECR will accept/reject the nomination within thirty (30) days after the briefing.

every two years," MSC-[illegible] will audit and analyze the [illegible] requests and waivers granted. This information may indicate a need to revise the list or the waiver process.

Approved Instruction Set Architectures and Executive Agents

The DoD-approved ISAs with the Executive Agent and defining document are:

ISA Title	Language	Executive Agent	Document
MIL-STD-1862 (NEBULA) (MCF)	Ada	USA	MIL-STD-1862
Navy Standard 16-bit ISA (AN/UYK-20)	CMS-2	USN	ELEX-P351
Navy Standard 32-bit ISA (AN/UYK-7)	CMS-2	USN	PD-PMS408-1
Navy Standard Signal Processor ISA (AN/UYK-14)	CMS-2	USN	MIL-A-85232
Air Force Standard 16-bit ISA	JOVIAL	USAF	MIL-STD-1750