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ARTIFICIAL INTELLIGENCE — RESEARCH AND APPLICATIONS

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Submitted by

NILS J. NILSSON
Project Leader
(415) 326-6200, Ext. 2311

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Approved by:

BERTRAM RAPHAEL, *Director*
Artificial Intelligence Center

BONNAR COX, *Executive Director*
Information Science and Engineering Division

Copy No. ....90.........

I INTRODUCTION

Artificial Intelligence has existed as a research enterprise for approximately 15 years, during which time the scope and power of its techniques have steadily increased. In harmony with this, there is a growing conviction that artificial intelligence can be applied to solve a large number of specific user-oriented tasks.

We consider here a number of such tasks that represent potential applications of artificial intelligence. For each application, we shall present a brief description of the task and offer a preliminary assessment of its significance and difficulty. Where possible, we also note the agency of the federal government that has an interest in or has provided us with information about a particular task. Because we have not investigated all the tasks equally thoroughly, we also indicate a "confidence factor" that reflects the depth to which we have considered the task and, consequently, have confidence in the statements and opinions set forth.

The results of our study are summarized in Table 1. The first column lists, in alphabetical order, the various potential application tasks. Columns 2 and 3 contain our assessment, on a scale of 1 to 10, of the potential significance of the task to both the Department of Defense and to our society at large. A task was judged to have high significance (near 10) if it effected large

Table 1

POTENTIAL APPLICATIONS OF ARTIFICIAL INTELLIGENCE

Row	Task	Significance		Difficulty		Program Requirements		Confidence
		DoD	Non-DoD	Ill Defined	Technical Risk	Time Scale	Level of Effort	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
A	Aircraft records analysis	5	6	7	7	7	5	4
B	Economic/political models	4	8	2	4	3	4	10
C	Interactive scene analysis for cartography	7	3	2	2	2	3	8
D	Maintenance aids (near term)	8	7	4	3	4	4	8
E	Maintenance sensor-requirements analysis	7	5	7	5	6	5	4
F	Manipulators for dangerous tasks	3	6	3	2	2	4	8
G	Mapping and modeling of geographic areas	7	5	5	6	7	4	7
H	Missile range picture analysis	4	2	1	6	4	5	7
I	Political modeling	7	5	7	9	9	6	8
J	Remotely piloted vehicles	6	5	7	8	9	9	5
K	Resource exploration	7	9	2	3	5	5	9
L	Ship recognition	3	1	4	7	6	3	3
M	Tactical commander's management aide	9	9	5	4	5	8	3

savings or influenced a broad spectrum of users. It was judged to have low significance if it were narrow in scope and highly specialized.

Columns 4 and 5 contain our assessment, on a scale of 1 to 10, of two aspects of the technical difficulty of performing the task. (Great difficulty is rated at 10.) The two aspects reflect the degree to which the task is ill defined, and the degree of technical risk that one assumes in attempting to reach a useful level of performance.

Columns 6 and 7 set forth our estimates of time and money needed to achieve a laboratory prototype system. We have again used a relative scale of 1 to 10 because we have not investigated each task in sufficient depth to estimate the time and manpower requirements accurately. Informally, we think of the maximum rating of 10 as representing (say) a five to seven year research program, and a minimum rating of 1 as representing an immediate application for which a prototype exists today.

The final column contains the confidence factor (on a scale of 1 to 10) that represents a self-evaluation of our ability to make statements about the application task.

Before proceeding with the specific task descriptions, we should emphasize that these applications are merely a small selection from the very large class of potential applications of artificial intelligence. They were selected on the basis of such factors as interest to the defense community, availability of information, and interests of individual SRI staff members.

II CANDIDATE APPLICATIONS

A. Aircraft Records Analysis

1. Problem Statement

The military maintains a vast number of records about the history and status of its aircraft. These files include (1) a configuration file describing the precise configuration of each aircraft, together with ancillary information such as the manufacturers of the various components, (2) a failure file that records every failed part for every plane, (3) a maintenance file that records all repairs and preventive maintenance on each plane, and (4) a "red book" that contains past and forecast flight schedules. Similarly, a pilot file is kept on each pilot to record his training, flights, pilot errors, and so forth.

One use of this data is for the analysis of airplane crashes. In general, the purpose of analysis is to discover any common theme that links several crashes together. For example, a common theme might be a failed 1/2 horsepower motor manufactured by the same firm and installed on three different types of aircraft that have been involved in crashes. A common theme might also entail human error: for example, different maintenance mechanics, all of whom were trained by the same instructor, may have made the same error that has resulted in several crashes.

The artificial intelligence application would be to devise a program capable of accessing the various files and analyzing them to find links among a set of aircraft crashes.

2. Problem Assessment

This problem appears to be rather difficult because it is only moderately well-defined, and because apparently no close analogy to the required program already exists. In fieldable form, it also requires an ability to manipulate very large data bases, a problem only now beginning to receive serious attention. However, a small version of the required system could probably be developed in the medium-term future.

Interested agencies: all of the armed services, as well as the civilian aviation industry and regulatory bodies.

B. Economic/Political Models

1. Problem Statement

Econometric models of a great many varieties are in common use today. In contrast to this, useful political models are virtually nonexistent. It would be desirable to overcome at least part of the deficiency by merging an existing econometric model with at least a rudimentary political model that dealt only with those political consequences that affect the econometric model. In particular, the political model would deal with those events that alter the assumptions or data upon which the (typically analytic) econometric model is based.

2. Problem Assessment

The widespread interest in modeling "soft" processes of a political, economic, or sociological nature make this problem as important for its long-term implications as for its immediate utility.

Although superficially a difficult problem, recent work has indicated that useful levels of performance may be available in the near term.

Interested agencies: The intelligence community would be an immediate and direct beneficiary. However, if the technology were developed it would be likely to diffuse to a much larger set of users.

C. Interactive Scene Analysis for Cartography

1. Problem Statement

Both the military and civilian communities devote a considerable amount of effort to processing aerial photographs; the advent of satellites has increased this tendency. The purpose of the processing may be purely cartographic--i.e., to make maps--or it may be to obtain intelligence information about anything from troop movements to the suitability of a site for locating a new factory.

One particularly time consuming step in the cartographic process is the tracing or outlining of cartographic features and land-use categories on an orthographic photograph. For example, an operator must today laboriously trace out roads, rivers, lakes, forested areas, and so forth on an orthophoto displayed on a console. It would be far more preferable if he needed to indicate a given feature only by pointing at it with his cursor rather than by outlining it. A computer system could then abstract the distinctive characteristics of the particular feature, and would extrapolate from the single point to the entire feature. Thus, for example, the computer could outline a lake given a single point, thereby reducing operator time dramatically. The computer would display its results before finalizing them, thereby giving the operator an opportunity to correct any errors.

2. Problem Assessment

The enormous amount of pictorial data currently being collected and analyzed makes this problem an important one. Moreover, initial success on the cartographic problem would be likely to lead into more difficult areas of interactive photo-interpretation. The technical difficulty of the particular problem we cited seems remarkably low. The technical tools needed, insofar as we can determine, exist today in several laboratories.

Interested agencies: Army Engineering Topographic Agency, U.S. Geological Survey, other cartographic and photo-interpretation agencies.

D. Maintenance Aids (Near Term)

1. Problem Statement

There is already a welldeveloped technology of applying computer systems to troubleshooting mechanical equipment. Notable examples include the ATE/ICE system for diagnosing malfunctions in Jeep engines [1]* and the DEPOT/MAIDS system for depot-level maintenance of diesel truck and tank engines [2]. These systems use straightforward methods that do not require any AI technology.

We think that the use of AI techniques could make substantial contributions to the performance and efficiency of these kinds of systems. In particular, achieving the following improvements would seem worthy and could be added using existing AI technology:

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*References are listed at the end of this report.

a) More flexible man-machine communication, entailing a greater use of natural language, spoken word recognition, and voice output.

b) Ability for the technician to volunteer information he believes relevant before the program asks for it.

c) Greater ease of modifying existing programs to incorporate new troubleshooting procedures.

d) Addition of programs that can give advice about repair procedures and advice about how to assemble and disassemble the equipment.

2. Problem Assessment

The importance of the equipment maintenance problem faced by DoD is sometimes underestimated merely because maintenance is not a "glamorous" problem. Nevertheless, substantial savings as well as improved performance will occur from increased maintenance efficiency. While some progress has been made toward using computers to help automate the process, much more can be done, and the AI technology for doing so exists.

Interested agencies: U.S. Army Tank and Automative Command (TACOM), U.S. Army Frankford Arsenal.

E. Analysis of Maintenance Sensor Requirements

1. Problem Statement

Skyrocketing maintenance costs throughout our society are motivating an increasing interest in finding ways to automate the maintenance process. One easily discernible trend has been to build sensors into a particular device or system and to use the sensory information they provide to direct the maintenance process. For example, the aids mentioned in the previous section use sensors to assist in vehicular maintenance. As these methods gain acceptance, there will be an increasing need to identify, for a particular piece of equipment or for a class of equipment, the combination of sensors that are most cost-effective.

One approach to this problem would be to make use of the emerging family of artificial intelligence systems for diagnosis and troubleshooting (for example, the SOPHIE system [3], MYCIN system [4], and our own CBC system). Such programs could be used to evaluate the utility of a candidate set of sensors by running in a simulation mode. A large number of different faults could be simulated, and the program would note the difficulty in pinpointing each fault using the candidate sensor set. A large number of different candidate sets could be evaluated in this manner.

2. Problem Assessment

DoD's 60-billion dollar operations and material budget is one measure of the importance of this problem. The successes of the existing artificial intelligence diagnosis systems suggest that the problem can be approached using current technology as a base. As it stands, however, the problem is not very well defined, leading to a corresponding difficulty in assessing technical risk and resource requirements.

Interested agencies: Throughout DoD, as, for example, in the Navy Materiel Command. Successful technology development would also have a broad impact in the automotive industry.

F. Manipulators for Dangerous Tasks

1. Problem Statement

Many modern processes require handling radioactive or toxic substances. In order to handle such substances safely, remote handling devices, or teleoperators, have been developed. Although the history of such devices goes back at least to the 1940s, the current generation of in-service manipulators does not incorporate the sophisticated control techniques that have been developed in several of the leading artificial intelligence laboratories. One possible application would be to merge a fully automatic manipulator, as developed in these laboratories, with a supervisory level of human control in order to produce a teleoperator with extended capabilities. A laboratory prototype system of this sort has been demonstrated by SRI; its purpose is to help dismantle highly toxic devices whose use has been proscribed by Congress.

2. Problem Assessment

The near-term technical feasibility of extended capability teleoperators does not appear to be in question. Similarly, the ultimate need for such teleoperators by various agencies and by contractors of the federal government appears obvious. There is, however, a question as to how widespread the need is for these devices strictly within DoD.

Interested agencies: Edgewood Arsenal, Energy Research and Development Agency.

G. Mapping and Modeling of Geographic Areas

1. Problem Statement

Computer modeling of geographic regions has been an active enterprise for many years. In 1967, World Data Bank I was assembled, consisting of approximately 100,000 points specifying basic cartographic data (coastlines, international boundaries, and the like). In 1973, World Data Bank II came into existence, comprising over one million points specifying coastlines, international boundaries, major drainages, and so forth. (World Data Bank I is available to the public; II will be available in the not too distant future.)

Current software can access a world data bank in several different ways under user control. For example, it can "window" the data, and display it under any of several standard cartographic projections. In addition, various other data (like thematic overlays delineating, for example, land use) and software (like conventional correlation algorithms) can in principle be used in conjunction with the basic cartographic data. It would be of further interest to add symbolic models and procedures to this conventional software. For example, the economic/political models discussed previously could be expanded to make explicit use of basic cartographic and thematic data--to compute, say, the vulnerability of certain supply routes to geopolitical changes.

2. Problem Assessment

A major feature of interest in this problem is the demand it makes on combining several disparate sources of data and knowledge. It is a member of a class of such problems whose hallmark, when approached "manually", is the segregation of knowledge into specialties that often do not communicate freely with one another. Consequently, an artificial intelligence program able to deal with these disparate knowledge sources has the potential of achieving better performance than a single human expert could; moreover, it is likely to result in increased communication among the human experts in the various specialties. In the short term, the latter property is likely to be the more important one.

As the situation currently stands, the problem is ill defined.

Interested agencies: the intelligence community would be an initial user of a system aimed at the stated problem. If the technology were developed, however, it would almost certainly diffuse to a much wider set of users.

H. Missile Range Picture Analysis

1. Problem Statement

The White Sands Missile Range employs a large number of cinetheodolites (high accuracy, telephoto motion picture cameras) to provide vehicle tracking data whose accuracy far exceeds that available from radars. Currently, the data is extracted from film by operators who use cursors to define selected points on the target vehicle. Subsequently, the coordinates extracted from several separate films are combined numerically to yield the trajectory information that constitutes an important part of the vehicle test results. The problem is to develop fast picture processing algorithms that would automatically perform the tracking function now being done manually. These algorithms, possibly implemented on special purpose digital hardware, would be used with a video-based system that would supercede the film-based system now in use. If the whole process could be made to operate fast enough, real-time trajectory data could be obtained.

Any proposed solution to this problem would need to address squarely the following two major requirements. First, an average processing rate of 200 msec/frame, with a maximum processing time of about 400 msec for any single frame, is needed to effect the real-time control that is desired. Second, any proposed method would have to be general enough to deal with an appreciable fraction of the many types of airborne vehicles that are tested at the range each year.

2. Problem Assessment

The technical difficulty of this problem obviously stems from both the high processing speed and the generality desired. The generality issue may to some extent be bypassed through the use of an interactive system that allows an operator to define visual characteristics of the target vehicle. The high speed requirement may not be intractable in view of the present willingness of White Sands to consider special digital hardware. Viewed in broader perspective, the problem is one of a family of tracking problems now receiving attention from the artificial intelligence community.

Interested agency: White Sands Missile Range

I. Political Modeling

1. Problem Statement

Computer based political models of national scope do not, to our knowledge, currently exist. The intelligence community employs political analysts who "model", in poorly understood ways, a geographical area. It would be of interest first to understand the form of model(s) used by the analyst, and then to encode the model(s) for computer implementation. Models of this sort could serve as an interactive aide for an analyst, could provide backup, and could serve as a training aide for new analysts.

2. Problem Assessment

This problem represents an extremely interesting research project for artificial intelligence, but is both ill defined and likely to involve considerable technical risk. If successful, however, the technology developed would be likely to have broad implications for a variety of applications areas.

Interested agencies: Initially, the intelligence community.

J. Remotely Piloted Vehicles

1. Problem Statement

There are a number of existing or potential uses for remotely piloted vehicles (RPVs) within both the defense and nondefense spheres of interest. The most prominent existing application of RPVs is for airborne vehicles of several varieties. Perhaps less obvious is the potential use of RPVs in such underwater applications as undersea recovery or deep sea drilling. The hallmark of these applications is the requirement to maneuver and perform tasks under the local control of a combination of visual, sonic, or other sensors. Because artificial intelligence has been concerned with problems of this sort, it appears plausible that it may have techniques to contribute to the control of RPVs.

2. Problem Assessment

The problem as it stands is ill defined. Most airborne applications are highly classified, while undersea applications have not, to our knowledge, been seriously discussed. Accordingly, it is difficult to predict the extent to which relatively straightforward extensions and applications of artificial intelligence techniques can make a contribution.

K. Resource Exploration

1. Problem Statement

The process of exploring for mineral resources is a lengthy and involved one whose success depends critically on the knowledge of the field geologist actually surveying a geological province. If he has close familiarity with all the varieties of ore bodies that may be encountered in the province, he is far more likely both to observe relevant characteristics and to interpret correctly the characteristics that are noted. This, in turn, dramatically increases the likelihood of discovering significant ore bodies.

Unfortunately, it is unrealistic to expect one geologist, or even a small group of geologists, to possess this breadth and depth of knowledge. Instead, as in other professions, a geologist specializes much more narrowly. As a result, there are many documented cases of ore bodies that remained undiscovered after "thorough" exploration, only to be discovered subsequently by a geologist whose specialization happily matched the physical situation. Of course, there is no way of accurately estimating the number of ore bodies that have been missed by exploration programs and that remain undiscovered, but it is commonly agreed that the number of such ore bodies is significant.

The methodology for discovering ore bodies is closely analogous to the process of diagnosing diseases. In each case, there is an underlying state of physical reality whose identity the practitioner seeks to establish through a series of indirect observations and tests. Typically, none of the tests are definitive, so the practitioner must in principle consider several alternative models for the underlying state and then seek to confirm at least one of them. The success of the MYCIN [4] system for medical diagnosis, and the emergence of roughly analogous newer programs for diagnosing equipment malfunctions, suggests that a geological consultant to aid in the exploration process is feasible.

2. Problem Assessment

The fundamental significance of the problem, measured against the background of a world in which many mineral resources are in short supply, is unquestionably very high. DoD's preoccupation with this situation is reflected in the number of current studies dealing with present and projected shortages of critical materials.

The problem appears to be readily approachable from the current base of artificial intelligence technology.

Interested agencies: Department of Defense, Bureau of Mines, U.S. Geological Survey.

L. Ship Recognition

1. Problem Statement

A recurring task for crew members on submarines is to identify the class of a surface ship from its image in the periscope. Remarkably, the variety of ship classes is so great that even experienced sailors can identify by sight only a small fraction of them. Current procedure calls for two cooperating sailors to do the job. One views the surface ship through the periscope and calls out features (e.g., "two stacks"), while the other searches through a mass of pictorial data (perhaps silhouettes) in an effort to match the description with a particular picture. It may be possible to automate at least part of this procedure through the application of artificial intelligence techniques.

2. Problem Assessment

The problem is a very specialized one whose technical success will depend heavily on a judicious task specification. For example, a fully automatic procedure, working directly from (say) a video image of the periscope scene, is almost certainly too difficult for a near-term application project.

Interested agency: U.S. Navy

M. Tactical Commander's Management Aide

1. Problem Statement

The tactical commander of, say, an aircraft squadron, performs many typical management functions in the course of his daily operations. He is concerned with such items as degree of combat readiness of his aircraft; supply of fuel, spares, and other materiel; the state of readiness of his personnel; past and projected flight schedules; and so forth. The artificial intelligence community has, within the past year or so, shown an increasing interest in developing methods for helping management personnel deal with issues of this sort. The suggested methods typically deal with functions like file management aids, automatic alerting mechanisms, and message routing mechanisms, all driven by models of both the individual and his organizational environment. In this climate, it should be possible to develop management aids specifically aimed at the needs of the tactical commander.

2. Problem Assessment

The problem is of broad significance, with potential impact on many levels of management throughout DoD. It seems very likely that some useful functional aids could be supplied (on a laboratory demonstration basis) in the near term. Indeed, technical uncertainties center more on how much can be achieved how fast, rather than on the question of whether anything useful can be achieved.

Of much greater uncertainty is the degree of organizational problems that would attend any attempt to introduce this technology on a wide scale.

Interested agencies: Initially, agencies and services throughout DoD. Ultimately, agencies and organizations throughout both the public and private sector.

III CONCLUSIONS

We have undertaken here to provide some suggestions and evaluations of potential applications for artificial intelligence. Although, to reiterate, the applications we have considered are only a small sampling from the set of all possible applications, they probably represent a fair cross section nonetheless. Some of the systems considered emphasize what has been called "pure thinking." They accept input only from a conventional computer terminal, perform some deductions or other "intellectual" activity, and output the results to a conventional terminal. Other systems involve "doing" as much as "thinking." They may accept input from a variety of sensors as well as from a conventional terminal, and their output may control real-time devices. Some of the systems are aimed at providing highly interactive aids to a user; others may be envisioned as operating in a more nearly stand-alone mode.

If we assume that our assessments, as summarized in Table 1, are accurate enough to form a basis for discussion, then several of the tasks stand out as being ripe for early development. We can say with some confidence that interactive scene analysis for cartography (Row C) has considerable significance for DoD, has low technical difficulty, and can be pursued with a quite modest program. An application of artificial intelligence to maintenance problems (as exemplified by Rows D and E) also offers the possibility of significant payoff for moderate levels of risk and resource. Finally, we can say with considerable confidence that a program aimed at resource exploration (Row K) has the potential of being of very great relevance, but entails somewhat greater difficulty and would incur a higher cost.

Certain other program areas appear to be clearly unsuitable for current exploitation, either because the potential payoff is too small or because the risk is too great. Missile range instrumentation (Row H) and ship recognition (Row L) both have only a small potential payoff, especially when measured against their difficulty. Remotely piloted vehicle control (Row J) has a moderately high potential payoff, but appears to entail high levels of both difficulty and cost.

The tactical commander's management aid (Row M) is an interesting possibility presenting the strongest contrasts. It has very great potential significance, is of medium technical difficulty, but is likely to be costly to undertake and may have significant organizational problems associated with it.

An analysis of the set of tasks suggests several interesting taxonomies for application tasks generally and for these applications in particular. One taxonomy would be based on the underlying technology needed to support a class of applications. To illustrate this, let us consider four general areas of current artificial intelligence research or interest: Symbolic Models, Large Files, Perception, and Common-Sense (or Plausible) Reasoning. Techniques emerging from these areas of research are needed to support the various tasks as follows:

- Symbolic Models
  - Aircraft Records Analysis
  - Economic/Political Models
  - Maintenance Aids (near term)
  - Mapping and Modeling of Geographic Areas
  - Political Modeling
  - Remotely Piloted Vehicles
  - Resource Exploration
  - Seismic Analysis
  - Tactical Commander's Management Aide
- Large Files
  - Aircraft Records Analysis
  - Economic/Political Models
  - Mapping and Modeling of Geographic Areas
  - Political Modeling
  - Ship Recognition
  - Tactical Commander's Management Aide

Commonsense Reasoning

- Aircraft Records Analysis
- Economic/Political Models
- Mapping and Modeling of Geographic Areas
- Political Modeling
- Resource Exploration
- Seismic Analysis
- Ship Recognition
- Tactical Commander's Management Aide

Perception

- Interactive Scene Analysis for Cartography
- Maintenance Sensor-Requirement Analysis
- Resource Exploration
- Ship Recognition

A second useful organization for the set of tasks is one that groups tasks together according to their "synergistic possibilities", that is, according to the likelihood that a successful implementation of one application task could be incorporated in another application task to improve performance and/or capability. Here we have many possibilities, and cite only two for illustrative purposes:

Maintenance

Near Term Maintenance Aide

Maintenance Sensor Requirement Study

Interactive Computer Geography

Interactive Scene Analysis for Cartography

Mapping and Modeling of Geographic Areas

If we consider interactive computer geography as a new "application task," then we would include this task itself in a new group:

Plausible Deduction from (Partial) Geographic Data

Interactive Computer Geography

Resource Exploration

Seismic Analysis

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