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EXERCISE/EXERCICE NEW HORIZONS

**ARTIFICIAL INTELLIGENCE:
THE FUTURE OF COMMAND AND CONTROL?**

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ABSTRACT

Despite the unlimited imagination of Hollywood and the unbridled enthusiasm of a young computer science field, the level of optimism that Artificial Intelligence (AI) enjoyed in the late 1970's and early 1980's could not be supported by scientific advancement. The resulting failure to achieve anything close to their ultimate goal of human-like intelligence in machines was a huge disappointment to AI visionaries, but it did force them to redirect AI efforts in other directions. The subsequent advances in the development of expert systems and other specialised areas have found widespread application, including within military operations. At the same time, continuing research into truly intelligent machines has expanded AI into a multidisciplinary field and rekindled much of its early optimism.

With the growing complexity of military command and control (C^2) systems in the future battlespace, the study of AI in the context of C^2 is particularly relevant. But to appreciate fully the potential impact of AI, C^2 must be split into its two components of "command" and "control" with each considered separately. The application of AI technology to the control side of C^2 is already a reality and will become increasingly important in the future, but recent AI developments highlight significant potential for the development of machines with human-like intelligence that can be applied to the more controversial command, or human, side of C^2 .

Looking ahead, future technology seems indistinguishable from magic.
But as technology advances, it creates magic.
This will be the case with AI.¹

Arthur C. Clarke
Author of *2001: A Space Odyssey*

INTRODUCTION

The arrival of year 2001 holds a special significance in the eyes of Artificial Intelligence (AI) enthusiasts. This, of course, was the year that author Arthur C. Clarke chose as the futuristic setting for his popular book, *2001: A Space Odyssey*. One of the central characters of the story is a super-intelligent computer named "HAL" that displays many human-like qualities, such as language, common sense and emotion. Reaching this special year now provides an appropriate opportunity to reflect on the progress of AI in the real world.

The decision to choose the year 2001 for the book was probably based more on the fact that it represented a relatively distant year at the start of a new century rather than on any careful calculation of the potential advances of computer science. However, the optimism surrounding this relatively new field of AI in the late 1970's and early 1980's was such that the notion of creating a HAL-like computer by 2001 was considered not only feasible, but very probable. Unfortunately, the reality of AI development has been very different, as its progress in "all human-type problems has fallen far, far short."²

The many setbacks experienced while trying to meet the challenge of developing computers as smart as humans have had, in many ways, a positive impact on the field. These

failures have resulted in the development of new and innovative approaches to AI, whose results have rekindled some of the past optimism. Concurrently, less grandiose versions of AI have resulted in many capabilities that today have widespread applications, including within military operations.

Both in Hollywood and in real life, AI's long-standing appeal rests in the romance of combining the creative problem-solving methods of human thought with the presumably flawless logic of computer circuits, creating essentially intellectual workhorses.³ In a general sense, AI is really about understanding and creating human faculties that are regarded as intelligence. Military command and control (C^2) is about the application of human intelligence to the management of resources in a dynamic environment. The link between the two is intuitively obvious and makes the study of AI in the context of C^2 particularly relevant,⁴ especially today with the growing complexities and challenges of the modern battlespace.

To fully appreciate the potential impact of AI, C^2 must be split into its two components of "command" and "control" with each considered separately. The application of AI technology on the control side of C^2 is already a reality and will become increasingly important in the future, but recent AI developments highlight significant potential for the development of machines with human-like intelligence that can be applied to the more controversial command, or human, side of C^2 .

AI - BACKGROUND

The birth of modern AI is commonly traced back to the landmark Dartmouth Conference of 1956.⁵ However, clearly defining AI has always been a challenge, particularly since its definition seemed to change with each new advance in computer science. The frustration surrounding this challenge was expressed by a long time researcher in the AI field when he concluded that "[advances] are considered AI before you [make] them, and after you do it, they're considered engineering."⁶ An early definition from 1968 described AI as "the science of making machines do things that would require intelligence if done by men."⁷ Later definitions were more specific, describing AI as "an interdisciplinary subfield of computer science that seeks to recreate in computer software the processes by which humans solve problems."⁸ Perhaps the more cynical observer would choose to describe AI as the attempt to get real machines to behave like the ones in the movies.⁹

Part of the confusion surrounding AI is the lack of a clear understanding of what really constitutes "intelligence." The mainstay of AI research for over thirty years was the development of what are referred to as "rule-based systems," which were considered to exhibit symptoms of intelligence by having the behaviour of human experts programmed in, thus allowing for highly optimised performance. Probably the most celebrated example of this type of system was IBM's Deep Blue computer that defeated world chess champion Garry Kasparov in 1997. Upon closer reflection, however, most people regarded this feat as simply a demonstration that the game could be reduced to a mass of complex calculations and therefore

considered Deep Blue's victory more as a triumph of raw processing power than a clear example of machine intelligence.¹⁰

When considering examples such as Deep Blue, it becomes clearer that there is an essential connection between randomness and intelligence. Any device that follows a simple unending repetitious pattern of behaviour does not deserve to be described as intelligent.¹¹ From first principles, for any organism to be intelligent it must make decisions. Therefore, intelligence can be defined in terms of the "capability of a system to adapt its behaviour to make appropriate decisions in achieving desired goals in a range of environments. [Thus], any computer program that is not adaptive is not intelligent."¹² One of the enduring standards of determining if a computer is truly intelligent is referred to as the Turing Test, named after British mathematician Alan Turing.¹³ In 1950, Turing wrote a paper in which he proclaimed that a truly intelligent computer would be able to carry on a dialogue in which it convincingly passed as a human.¹⁴ Even fifty years later, this challenge has not been met.

Marvin Minsky, the head of the AI laboratory at the Massachusetts Institute of Technology (MIT), proclaimed in 1967 that "within a generation the problem of creating 'artificial intelligence' will be substantially solved." By 1982, the reality of the situation forced Minsky to retract this prediction and admit that the "AI problem is one of the hardest science has ever undertaken."¹⁵ Despite the clear failure of the early attempts at developing systems that demonstrated the capabilities of traditionally-defined AI, these setbacks have resulted in refocused efforts in different directions, leading to an impressive array of AI applications and a renewed enthusiasm for the ultimate goal of truly intelligent machines.

AI - INNOVATIVE APPROACHES

The early setbacks forced the AI community to acknowledge finally that advancement would be a relatively slow and iterative process. To maintain interest and funding in AI, researchers turned their attention to narrower fields that were better suited to shorter-term, commercial applications. By far, the most successful product of this work has been the "expert system." Expert systems are a form of knowledge-based system that are considered intelligent because they use expert knowledge in a specific domain to resolve complex problems. Because they are designed to work in a specialised field, as opposed to the complex and unpredictable real world, they are able to assist users who are generally not experts in the domain of concern in exercising judgement in semi-structured or unstructured decision situations.¹⁶ These systems can make inferences, implement rules of thumb, and solve problems in much the same way humans routinely make decisions.¹⁷

AI researchers have also broken down the intimidating challenge of building a machine with human-like intelligence by concentrating their efforts on particular human traits. Examples of this reduction of scope include work in the discipline of natural language understanding, where the goal is for computers to combine an understanding of natural language and appreciation of general principles governing a user's cognitive behaviour to understand his goals and actions.¹⁸ Spin-off applications include reading machines for the blind and speech-recognition devices. A second area of considerable interest involves vision systems, which includes work ranging from the short range sensing of robotics to the remote sensing performed by satellites and military platforms. Another example of marketable research includes work in

the area of game playing, which has been expanded to include advances in training and simulation.

Despite the recent focus of AI efforts on more short-term, commercially viable projects, work aimed at emulating the functioning of the brain still goes on in pure research. These efforts are mainly split into two camps, one approaching the problem from the top down and the other from the bottom up. The top down camp is attempting to replicate the results of human thought. It has become clear that although logic-based reasoning can solve many problems in computer programming, most real-world problems need methods that better represent how humans actually think. A large part of human thinking requires the application of common sense knowledge.¹⁹ This common sense thinking involves a huge collection of hard-earned ideas, including masses of factual knowledge about the problems that need to be solved. But it also requires effective ways to retrieve and apply the relevant knowledge. Many processes must be engaged when humans imagine, plan, predict, and decide using multitudes of exceptions and rules. Doing this requires knowledge about how to think, or how to organise and control those processes.²⁰ In addition, without this common sense knowledge, a system will never have enough judgement to select changes that will lead to self-improvement, another essential part of the adaptation required for intelligent behaviour.²¹

Therefore, researchers are trying to find ways to represent and build-up vast reserves of common sense knowledge. Once the required reserves are compiled, a computer's memory will be able to easily outperform a human because the average human memory has rather modest bounds.²² In addition, the knowledge can be easily transferred from one system to another

without having to be "relearned" from the beginning, the way every child has to learn. However, the challenge facing researchers is not only how to represent all this knowledge in computer terms, but also the sheer magnitude of the task. Even the mental networks of knowledge in children are enormous. Language alone consists of millions of units of knowledge, but represents only one of our large-scale abilities. There is also vision, hearing, touch, physical manipulations, and social knowledge, to name only a few. Therefore, although progress is being made on this important step towards achieving human-like intelligence in machines, many challenges remain.

The other camp of pure research, adopting a bottom up approach, is attempting to replicate human learning. Of course, one of the primary goals in developing machine intelligence is to build systems that acquire knowledge with time and adapt their reasoning to improve their performance at specific tasks or to acquire new skills. This is a fundamental requirement for any intelligent system expected to operate in a changing environment. In the bottom up approach, researchers are developing what are referred to as "neural networks," which are computer versions of the basic biological connections in the human brain, and attempting to make them grow and learn. This process is referred to as "evolutionary computation" and is now a mainstream method of machine learning. An example of this research involved the development of an evolutionary algorithm to evolve artificial neural networks that taught themselves to play checkers at a near-expert level. It developed by simply playing the game against itself, receiving feedback on the results, then retained the better neural networks to be parents at each generation. Of course, this is many orders of magnitude away from creating machine intelligence that could adapt to real world conditions, but it is a very important step

along the way because it demonstrates that computers can solve problems without relying on human expertise. In this regard, evolutionary algorithms offer significant potential for the future.²³

One of the other positive developments in AI since the setbacks of the 1980's involves the long-running controversy of whether computers should attempt to model how things were done by humans, known as the cognitive science approach, or whether they should follow methods that humans do not use but that have the potential to improve on human performance, known as the engineering approach.²⁴ AI researchers realised that the model of reasoning used in AI was very different from what happens inside a human head. But it was decided that such differences do not invalidate the non-human approaches.²⁵ A common analogy used to justify this rationale involves the development of the airplane. An airplane is a good example of a very useful machine despite the fact that it flies in a manner that is very different than the way real birds fly. Therefore, it was agreed that AI methods should use human techniques only when they are necessary or offer a distinct advantage. Modelling of the human mind is not necessarily the objective. Only the strengths of the human mind are desired, not the weaknesses.²⁶ This change of mentality opened AI up to a whole new way of approaching problems and significantly increased the potential of finding the path necessary to successfully develop human-like intelligence in machines.

The new directions that AI is taking are exciting because they change the pursuit of AI from a software activity to an interdisciplinary pursuit. AI experts realised that they could no longer work in isolation, but must collaborate with bordering knowledge areas to increase their

relevance and applicability. Such disciplines as cognitive science, psychology, electronics, mathematics, neurophysiology, and nanotechnology²⁷ must join forces with the computer science field to expand the possibilities and opportunities that AI has to offer. It has been recognised that "this [increased] breadth adds much to the neo-traditional AI perspective".²⁸

These new directions being pursued in the field of AI bode well for military C², where creative thinking is the crucial weapon. Although expert systems have some applications in C², the incorporation of common sense knowledge and the development of systems that can adapt and learn in a changing environment, like neural networks, signal the real breakthroughs necessary to create intelligent machines that will eventually be useful in the challenging and dynamic environment typical of military command and control.

COMMAND AND CONTROL

Military command and control systems are among the most complex and large scale real-time resource management systems known to man and it is clear that these systems will only grow in size and complexity with the impending challenges of the single integrated battlespace of the future.²⁹ Because of the all-encompassing nature of C² systems, it is easy to forget that the elements of "command" and "control" are separate entities with very distinct connotations and roles. This distinction, however, is important when trying to understand the potential impact that advances in AI may have on C².

Today, command is generally expressed as a uniquely human behaviour that is manifested through the structures and processes of control. Command is distinct from control in that it is considered a creative act that allows for the realisation of human potential through which military power and effectiveness are derived. Dr. Ross Pigeau and Carol McCann, in their paper "Clarifying the Concepts of Command and of Control," emphasise these human and creative dimensions when they define command as "the creative expression of human will necessary to accomplish the mission."³⁰ In their writings, Pigeau and McCann consistently associate command with humans because they have made the assumption that AI will not develop to the point where a non-human system could exercise command.³¹

Unlike command, control is more closely associated with equipment, structures and processes, rather than humans. The control function is really just a tool of command and has been defined by Pigeau and McCann as "those structures and processes devised by command to manage risk." The key tenet of this definition is that control must ultimately depend on command and, moreover, is incomplete without command.³² Control mechanisms seek to invoke and control action aimed at reducing uncertainty and increasing the speed of response to events. These actions assist command in making decisions, carrying out orders, and ensuring mission accomplishment.

When command and control are combined to form C^2 , the interesting dynamic between these two elem

course, is to find the right balance between promoting creativity on the one hand and using control mechanisms to effectively manage risk on the other. This balance will necessarily be situation-dependent, but command creativity should always be given primacy.

An interesting parallel can be drawn between the relationship linking command with control, and the one linking the cognitive approach to AI with the engineering approach. Just as command represents the defining element of C^2 , the cognitive, or human approach, represents the foundation of AI. Ironically, both have been overshadowed in recent years by their trusty counterparts. In AI, the original quest for true human-like machine intelligence has been overtaken by the emphasis on the more marketable and short-term technology of expert systems. Likewise, in C^2 , command is being overshadowed by the current push to develop and acquire the latest technology used to support the element of control.³⁵ This is just one of the many dimensions that forms a link between AI and control.

AI IN "CONTROL"

Throughout history, man has developed more and more control mechanisms to support his ability to command. He has amplified his muscle power by using mechanical systems, his senses by using electromagnetic and acoustic devices, his ability to communicate over long distances by using radio, and his calculating capability by using computers. It is therefore only logical that he would also take advantage of the support capabilities offered by AI systems.

Expert system technology has enjoyed the most commercial success of any AI product to date and it has certainly found a place within military applications. Generally, the C² environment is not the ideal place for expert systems, as these systems function best in applications that are deductive, well bounded, and enjoy a host of human experts.³⁶ There are, however, specific applications that fall within the bounds of control mechanisms that meet these prerequisites. These expert systems are normally embedded into real-time military applications, typically as part of a weapon or weapons platform, and perform such military specific functions as battle management, threat assessment, and weapons control.³⁷ As the battlespace becomes more complex and the requirement for faster decisions and reactions increases, there will be a growing need for automated expert systems for such functions as sensor interpretation and automatic target recognition and tracking.

Other AI systems, known as "decision support systems," have broader applications in the C² environment. This is because they assist in the organisation of knowledge about ill-structured issues. The emphasis is on effectiveness of decision-making, as this involves formulation of alternatives, analysis of their impacts, and interpretation and selection of appropriate options for implementation.³⁸ These systems aid humans in mission planning, information management, situation assessment, and decision-making. A particularly relevant application is in the area of data fusion, where AI advancements in the fields of natural language, knowledge discovery and data mining are assisting in the analysis and interpretation of the vast quantities of data being collected by the ever-increasing number of intelligence, surveillance, and reconnaissance assets.³⁹ In addition, AI contributions to game playing and simulation are also leading to better training for personnel who must perform within the demands of the C² environment.

Not surprisingly, as computers and automated systems occupy a more prominent place within C^2 , one of the continuing challenges involves the human/machine interface. It has been observed that "human initiative and creativity are best used when the user of a knowledge support system is able to self-direct the system..., rather than having to respond to the dictates of a behaviourally insensitive and inflexible paradigm used as the basis for support system development."⁴⁰ If these considerations are ignored, it is unlikely that the system will be utilised to its full potential, or worse, these automated decision aids designed to reduce human errors may actually make people prone to new types of errors.⁴¹ Consequently human/machine interface considerations must be given the appropriate attention in the development of design principles for these support systems.

In an effort to improve the human/machine interface and to make computers more user-friendly, much work is being done on ways to make communication with computers easier and more natural. Significant progress in this area will be essential if AI hopes to achieve its ultimate goal of creating machines with human-like intelligence. Previously mentioned advances in natural language understanding and vision systems will feature prominently in these developments. Other advancements involve computers with the capability to read facial expressions, to react to gestures and touch, and to translate language automatically. In addition, researchers have developed a method for detecting the brain's weak electric signals in a busy environment filled with electronic noise. It is believed that this research will lead to a simple, slip-on head cap that lets people command machines by thoughts alone.⁴² Conversely, progress is also being made to improve the feedback that humans get from machines. An example is

electronic speech with digital human-image animation that produces a photo-realistic image of any human face that appears to be speaking naturally.⁴³

Although some of these technologies are far from being perfected, they clearly represent the future of the human/machine interface. It can be expected that in this future, instead of inputting instructions into a computer through a keyboard or a graphical user interface, users will be able to transmit information just as they would to another human. This will involve using inputs as natural as voice, as subtle as facial expressions and hand gestures, or as inconceivable as just their thoughts.

It is clear that AI has found a permanent home within the control element of the C^2 equation. The prominence of this technology will continue to increase with the demands that will be imposed on commanders and their C^2 architectures in the complex and unpredictable battlespace of the future. AI advances in human/machine interface capabilities will also help to close the gap between humans and the machines that support them. The still controversial questions lies in whether AI technology can advance to the point where this gap no longer exists, effectively allowing machines to replace humans and perform with human-like intelligence. It is at this stage that AI will enter the realm of "command."

AI IN 'COMMAND'

The notion that a machine could exhibit intelligence comparable to a human is preposterous to most people and downright frightening to others. Even visionaries like Sun

Microsystems co-founder and futurist Bill Joy have warned that "this is one genie that shouldn't be let out of the bottle".⁴⁴ Others are less concerned because they simply do not believe that it is possible. The most common and pertinent argument that refutes the plausibility of a thinking machine is the "Lady Lovelace" objection, which asserts that "a computer can only do what it is programmed to do and therefore will never be capable of generating anything new."⁴⁵ If this assertion were true, it would also follow that a machine could then never think, make a decision, or take a human by surprise. Obviously, only time will ultimately determine if machines with human-like intelligence are possible, but recent advances in technology have already silenced many of the critics and are offering a glimpse into the possibilities of the future.

Some of the believers, like inventor Ray Kurzweil, who wrote the popular book *The Age of Spiritual Machines*, predict that in the next twenty to thirty years computers will be as smart as humans because computing power will by then far exceed the hardware capacity of the human brain.⁴⁶ Of course, even if computing power does continue to increase exponentially, which is questionable, the simple feat of generating bigger and faster machines does not by consequence imply that anything resembling intelligence will emerge from those machines.⁴⁷ When referring to command, it is this intelligence that is key because, by nature, command scenarios will involve situations where it is necessary to deal with inexact or incomplete knowledge about a problem. The solution process for these problems is commonly called decision-making and it is fundamental to command.⁴⁸

This aspect of command is what has compelled Pigeau and McCann to refer to it as a uniquely human behaviour. This is to demonstrate the fact that command is primarily an

intellectual exercise and to emphasise the fundamental importance of those qualities that are traditionally associated only with human intelligence. Included here are such things as creativity, which denotes inventiveness and imagination, the capacity to learn and adapt, the ability to initiate and surprise, the facility for contemplation and reasoning, the capacity for thought, and the most human of all qualities, consciousness.⁴⁹ These generally represent the intellectual qualities that are considered necessary to exercise command.

AI creativity is an area of growing importance. Until AI systems can be fruitfully, although not infallibly, creative, their ability to model, and even to aid, human thinking will be strictly limited.⁵⁰ But creativity is only part of the issue. A thinking machine should also be a learning machine, capable of altering its own configuration through a series of rewards and punishments, in order to filter out wrong ideas and retain useful ones.⁵¹ In fact, machines with some intelligence have already been developed. These intelligent machines can adapt their behaviour to meet goals in a range of environments by using random variation of their behaviour followed by iterative selection in a manner akin to natural evolution. Evidence of this type of machine learning was previously cited in relation to the development of neural networks. In this way, these systems exhibit creativity, not to mention the ability to offer continual surprise, thus refuting the "Lady Lovelace" objection.

Igor Aleksander of the Imperial College London, in his book *How to Build a Mind*, has taken the next step in the evolution of intelligent systems. He has developed a neural computer, referred to as the Neural Representation Modeller, that has demonstrated internal contemplative activity. It has the ability to visualise internally and to imagine. For example, if it is told to

imagine a blue banana with red spots, even though it has never seen one, it puts features together through the use of adjectival phrases to "imagine" this object. Aleksander thus makes the link between imagination, contemplation and consciousness, and sees imagination at the core of conscious experiences. Although he admits that they have not yet achieved the other aspects of consciousness that go with imagination, like intention, the ability to plan, and the capacity to understand cause and effect, he argues that even hardened philosophers will accept that it is possible to see those capabilities happening in a neural machine.⁵²

Critics will downplay the importance of some of these developments because they occurred in the virtual world of computers. Many argue that it is impossible to have intelligent behaviour unless there is interaction with the surrounding environment.⁵³ This is why the real potential in machine intelligence development lies in combining the work of people like Aleksander on the contemplative nature of systems with the progressive work currently being done in robotics.

Researchers at MIT's AI lab are exploring and creating complex robots that are programmed to learn as they go and react "emotionally" to outside stimuli.⁵⁴ They are also incorporating some of the advances in the area of human/machine interface, like the ability to read human facial expressions, intelligent vision,⁵⁵ and language. Interactive robots are being developed with what is referred to as "embodied intelligence," which allows every joint to act as an independent "thinking" machine that is designed to interact in simple ways with the joints around it and to take cues either directly from its environment or from its central computer. This approach more closely resembles the way humans interact with their environment.⁵⁶ Robots are

also employing the evolutionary computation capabilities of neural networks, which allows them to be programmed with a limited amount of information and then demonstrate the ability to learn modestly. The resulting robots are being referred to as "intelligent agents" and are capable of processing information, limited reasoning and decision-making.⁵⁷

As a result of these advances, robots now learn to solve problems in ways that humans can scarcely understand. In fact, one side effect of these learning methods is systems that are anything but explainable. Careful design no longer suppresses emergent behaviour but encourages it. With the realisation that the designer does not need to conceive solutions beforehand, hope for building intelligent, human-like robots has been rekindled.⁵⁸ Moreover, the goal is no longer for robots to merely learn but also to develop; that is, to enrich their cognitive ability to learn and extend their physical ability to apply learning. Although robots will always require an initial program, just as humans begin with a program encoded in their DNA, this does not preclude them from wilfully and creatively building on it. By exploiting their ability to interact with humans, robots can learn diverse behaviours and eventually, to use the context of military operations, commanders who might not know beforehand what tasks the robot will need to accomplish will be able to naturally and quickly task it.⁵⁹

While it is easy at this stage to criticise these early breakthroughs in machine intelligence as being relatively primitive compared to the abilities of humans, similar criticism can be directed at the human brain in other areas. For example, the communication ability of the human brain is limited by fairly low bandwidth input and output and the thinking power of the brain, while impressive, is rather slow. In the C^2 context, the amount of time required to train and

develop human commanders is significant and yet they are still severely affected by such prevalent factors as stress and data saturation. In these areas, as well as in more recognised areas involving human physical and emotional vulnerabilities, machines will offer significant advantages.

Although many sceptics remain, the on-going advances in creating machine intelligence should not be ignored or dismissed as insignificant. Many of the recent accomplishments in AI have broken through barriers that were previously considered impenetrable. Although still at a relatively basic level, these breakthroughs include the progress being made on the development of human intellectual qualities in machines, particularly when these are being successfully transferred out of the virtual world and combined with the impressive advances in robotics. Since command, by nature, is an intellectual activity that requires decision-making in a dynamic environment, these developments bode well for the eventual incorporation of AI technology within the command element of C².

THE FUTURE

In contrast to its earliest years, when AI was often considered a luxury, a novelty, or a science fiction fantasy, it is now recognised as a central part of computer science.⁶⁰ The reckless optimism of the early years has given way to a more deliberate, realistic, and multi-disciplined approach to AI that is already reaping impressive benefits.

AI technology is already firmly entrenched on the control side of C^2 and with the anticipated challenges of the future battlespace, the demand for specialised expert systems and automation technology will only increase. The gap between the human and technology dimensions of C^2 will continue to close with the incorporation of impressive human/machine interface technologies. But most exciting of all is the potential for AI application within the command element of C^2 .

Although still at a relatively primitive level, intelligence in machines is nonetheless a reality. Machines have clearly demonstrated human-like intellectual qualities, such as creativity and the ability to learn and adapt to their environment. They have demonstrated the capacity for thought, reason, and decision-making. Further, they have made progress in the areas of contemplation, imagination, and, according to some, have even shown signs of consciousness. As these advances are combined with the impressive work being done in other areas, such as robotics, common sense knowledge, and related disciplines, the future for intelligent machines looks very bright indeed.

Although the progress to date is still a far cry from machines being able to exercise command in a complex and dynamic battlespace, it must be remembered that the science of AI is very young. Achieving the ultimate goal of AI will require time, vision, and persistence. After all, "short-sightedness and high technology are incompatible."⁶¹ The recent developments in machine intelligence are a clear indication that it is now more a question of "when", not "if," AI will find its place on the command, or human, side of C^2 .

CONCLUSION

With the help of the unlimited imagination of Hollywood and the unbridled enthusiasm of a young computer science field, Artificial Intelligence enjoyed a level of optimism in the late 1970's and early 1980's that could not be supported by scientific advancement. The resulting failure to achieve anything close to human-like intelligence was a huge disappointment to AI visionaries, but it did force them to refocus AI efforts in new directions. The subsequent advances in the development of expert systems and other specialised areas have found widespread application. At the same time, research involving common sense thinking and neural networks has expanded AI into a multidisciplinary field and renewed much of the early optimism for eventually creating human-like intelligence in machines.

With the growing complexity of military C^2 systems, particularly in view of the upcoming challenges of the future battlespace, the study of AI in the context of C^2 is particularly relevant. To fully appreciate the potential impact of AI, C^2 must be considered with its two components of "command" and "control" as separate and distinct elements. Whereas control deals more with structures and processes in support of command, command is a uniquely human behaviour that is characterised by the intellectual exercise of decision making in a dynamic environment.

The application of AI technology on the control side of C^2 is already a reality with the existence of expert systems and decision support systems. In addition, impressive advances in the area of the human/machine interface will help close the gap between humans and the

machines that support them. It is clear that with the growing demand for command and control systems and automation technology, AI will play an increasingly important role within the control dimension of C^2 .

The role of AI technology on the command side of C^2 is a much more controversial issue because of command's natural connection with qualities that are traditionally associated only with human intelligence. AI is already a reality and many of the human intellectual qualities associated with command have been successfully demonstrated. Although these advances are still at a relatively primitive level, they clearly signal significant potentialia

END NOTES

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- ¹ Gary Stix, "2001: A Scorecard," Scientific American (Jan 2001): 37.
- ² Stix, 36.
- ³ Robert Strohmeier, "Total Autonomy," Smart Business Magazine (Aug 2000): 73.
- ⁴ C.J. Harris, ed., Application of Artificial Intelligence to Command & Control Systems (London: Peregrinus, 1988): 1.
- ⁵ Marti A. Hearst and Hayrn Hirsh, "AI's Greatest Trends and Controversies," IEEE Intelligent Systems (Jan/Feb 2000): 8.
- ⁶ Katie Hafner, "Still a Long Way from Checkmate," New York Times 28 Dec. 2000: G1.
- ⁷ Stephen J. Andriole and Gerald W. Hoppole, ed., Defense Applications of Artificial Intelligence (Lexington: Toronto: 1984): 341.
- ⁸ Andriole, 18.
- ⁹ Frederick E. Allen, "The Myth of Artificial Intelligence," American Heritage (Feb/Mar 2001): 30.
- ¹⁰ Allen, 28.
- ¹¹ David B. Fogel, "Imagining Machines with Imagination," Proceedings of the IEEE, Vol. 88, No. 2 (Feb 2000): 284. Fogel uses the example of a simple calculator. Although it can add a lot faster than a human, it exhibits no creativity, inventiveness, or imagination.
- ¹² Fogel, 287.
- ¹³ Of interest, Dr. Turing is better known for his role in breaking the German Enigma code system during WW II.
- ¹⁴ Allen, 28.
- ¹⁵ Allen, 28.
- ¹⁶ Andriole, xiv.
- ¹⁷ Andriole, 19.
- ¹⁸ C. Apte, L. Morgenstern, et al, "AI at IBM Research," IEEE Intelligent Systems (Nov/Dec 2000): 52.
- ¹⁹ Hearst, 11.
- ²⁰ Marvin Minsky, "Commonsense-based Interfaces," Association for Computing Machinery (Aug 2000): 69.
- ²¹ Minsky, 67.
- ²² Minsky, 68.
- ²³ Fogel, 285.
- ²⁴ Hearst, 15.
- ²⁵ Hearst, 13.
- ²⁶ Andriole, 6.
- ²⁷ Nanotechnology refers to the next level of technology miniaturization beyond microtechnology, as the prefix "nano" refers to 10^{-9} . Some experts feel that this technology will be the key that unlocks the mystery of creating human-like intelligence in machines, Stix, 37.
- ²⁸ Andriole, 145.
- ²⁹ This view of the future battlespace is detailed in DND, Shaping the Future of the CF: A Strategy for 2020 (Ottawa, Jun 1999) and is consistent with the vision of the future battlespace shared by most Western nations.
- ³⁰ Ross Pigeau and Carol McCann, "Clarifying the Concepts of Control and of Command," Command and Control Research and Technology Symposium, Newport, RI, 29 Jun-1 Jul 1999: 4.
- ³¹ This assumption is clearly stated in Pigeau and McCann, "Putting 'Command' Back into Command and Control: The Human Perspective," Command and Control Conference, Ottawa, 25 Sep 1995: 12, but applies throughout their writings.
- ³² Pigeau & McCann, "Clarifying...", 3-4.
- ³³ Pigeau & McCann, "Clarifying...", 1.
- ³⁴ Pigeau and McCann, "A Conceptual Framework for Discussing Command and Control," DCDS Retreat, Ottawa, Feb 2001: 4.
- ³⁵ This theme of command being overshadowed by control is the main subject of Pigeau & McCann, "Putting..."
- ³⁶ Andriole, 25.
- ³⁷ Andriole, 326.
- ³⁸ Andriole, xvii.
- ³⁹ Apte, 54.
- ⁴⁰ Andriole, xi.

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- ⁴¹ Richard J. Babyak, "Cheek to Cheek with Machines," Appliance Manufacturer (Oct 2000): 8.
- ⁴² Babyak, 8.
- ⁴³ Babyak, 9.
- ⁴⁴ Frederic Golden, "A Robot out of Cyberspace," Time (Sep 11, 2000): 47.
- ⁴⁵ Fogel, 285.
- ⁴⁶ Ray Kurzweil, "Spiritual Machines: The Merging of Man and Machine," The Futurist (Nov 1999): 22.
- ⁴⁷ Fogel, 286.
- ⁴⁸ Decision-making can be defined as "finding an optimum value of the three independent parameters of time, risk/uncertainty and reward," Liao, Shu-hsien, "Case-based Decision Support System: Architecture for Simulating Military Command and Control," European Journal of Operational Research 123 (2000): 562.
- ⁴⁹ Obviously, to be an actual "commander," these intellectual qualities must be complemented with experience, as well as being given the responsibility and accountability to fill a commander's position. This paper will only address the intellectual aspects of command.
- ⁵⁰ Hearst, 14.
- ⁵¹ Fogel, 285.
- ⁵² Jeremy Webb, "Imagine That," New Scientist (19 Aug 2000): 42-44.
- ⁵³ Webb, 45.
- ⁵⁴ Roy Simpson, "The New Machine - Move Over Data!" Health Management Technology (Jan 2000): 16.
- ⁵⁵ Intelligent vision refers to the ability to understand the image that a camera or other sensory device produces.
- ⁵⁶ Simpson, 17.
- ⁵⁷ Apte, 52.
- ⁵⁸ Mark Swinson and David Bruemmer, "Expanding Frontiers of Humanoid Robotics," IEEE Intelligent Systems (Jul/Aug 2000): 14.
- ⁵⁹ Swinson, 14-15.
- ⁶⁰ Apte, 55.
- ⁶¹ Andriole, 363.

BIBLIOGRAPHY

- Allen, Frederick E. "The Myth of Artificial Intelligence." American Heritage (Feb/Mar 2001): 28-30.
- Andriole, Stephen, Hopple, Gerald, ed. Defence Applications of Artificial Intelligence. Toronto: Lexington Books, 1988.
- Apte, C., Morgenstern, L., et al. "AI at IBM Research." IEEE Intelligent Systems (Nov/Dec 2000): 51-57.
- Babyak, Richard J. "Cheek to Cheek with Machines." Appliance Manufacturer (Oct 2000): 8-9.
- Boehle, Sarah, Dobbs, Kevin, et al. "The Return of Artificial Intelligence." Training (Nov 2000): 26-27.
- DND. Shaping the Future of the CF: A Strategy for 2020. Ottawa, Jun 1999.
- Fogel, David B. "Imagining Machines with Imagination." Proceedings of the IEEE, Vol. 88, No 2 (February 2000): 284-288.
- Golden, Frederic. "A Robot out of Cyberspace." Time (Sep 11, 2000): 47-48.
- Hafner, Katie. "Still a Long Way from Checkmate." New York Times 28 Dec. 2000: G1-G4.
- Harris, C.J. Application of Artificial Intelligence to Command & Control Systems. London: Peregrinus Ltd, 1988.
- Harvey, Inman. "Brainy Bots." New Scientist (April 2000): 54.
- Hearst, Marti A., Hirsh, H. "AI's Greatest Trends and Controversies." IEEE Intelligent Systems (Jan/Feb 2000): 8-17.
- Killingsworth, M. Jimmie. "When Things Start to Think." Journal of Business and Technical Communication (Jul 2000): 374-378.
- Kurzweil, Ray. "Spiritual Machines: The Merging of Man and Machine." The Futurist (Nov 1999): 16-21.
- Liao, Shu-hsien. "Case-based Decision Support System: Architecture for Simulating Military Command and Control." European Journal of Operational Research 123 (2000): 558-567.
- Minsky, Marvin. "Commonsense-based Interfaces." Association for Computing Machinery (Aug 2000): 66-73.

Pigeau R., and McCann C. "Clarifying the Concepts of Control and of Command." Command and Control Research and Technology Symposium. Newport, RI, 29 Jun - 1 Jul 1999.

Pigeau and McCann. "Putting 'Command' Back into Command and Control: The Human Perspective." Command and Control Conference. Ottawa, 25 Sep 1995.

Pigeau and McCann. "A Conceptual Framework for Discussing Command and Control." DCDS Retreat. Ottawa, Feb 2001.

Sample, Ian. "Wired Like a Human." New Scientist (June 2000): 11.

Simpson, Roy. "The New Machine - Move Over Data!" Health Management Technology. (Jan 2000): 16-17.

Stamps, David. "The Return of Artificial Intelligence." Training (November 2000): 26-27.

Stix, Gary. "2001: A Scorecard." Scientific American (Jan 2001): 36-37.

Strohmeier, Robert. "Total Autonomy." Smart Business Magazine (Aug 2000): 73.

Swinson, Mark L., Bruemmer, David J. "Expanding Frontiers of Humanoid Robotics." IEEE Intelligent Systems (Jul/Aug 2000): 12-17.

Webb, Jeremy. "Imagine That." New Scientist (19 Aug 2000): 42-45.