HIGH-PERFORMANCE ARTIFICIAL INTELLIGENCE SYSTEMS

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The High-Performance Artificial Intelligence Systems research group specializes in artificial intelligence research – investigating new technologies for creating "intelligent" behaviour in a computer. Although our research spans many areas of artificial intelligence – including search, machine learning, and heuristic knowledge – historically we have used games to demonstrate the ideas. Fundamental problems in artificial intelligence are being investigated in the context of computer programs that play chess, checkers, Go, and poker. Many of our game-playing programs have achieved a high level of performance and have challenged the best human players in the world.

EXECUTIVE SUMMARY

Although our group's reputation was initially made by applying our work to classic board and card games, since 1999 the group has been moving more towards addressing the challenges of the commercial games industry. Interactive entertainment (the "saleable" name for computer games) is a maturing industry that had over $15 billion in sales in North America last year. In the past year we strengthened our ties with Electronic Arts (Vancouver – the largest games company in the world) and BioWare (Edmonton – the world leader in role-playing games), and formed a new partnership with Relic Entertainment (real-time strategy games, in Vancouver). Our new technology has been well received, and the prospects of it being integrated into commercial products are very good.

Another thrust of this project is the development of parallel programming environments. For over 15 years, we have been building tools to simplify the task of parallel programming. Our third generation tool, CO^2P^3S, has reached a mature stage of software development and has been made available on the web.

RESEARCH GOALS AND OBJECTIVES

Our project is progressing extremely well and along the lines outlined in the original iCORE proposal. Our group has built an international reputation based on our artificial intelligence (AI) research, using games as an experimental test-bed for this work. However, the research challenges from the classic board and card games are limited (the games of poker and Go being a notable exceptions). Since 1999, we have been slowly moving our research efforts

towards addressing the challenges of the commercial games industry. This represents a golden opportunity for us, since the use of artificial intelligence in this industry is still in its infancy.

In the past year we have made major strides forward in engaging the commercial games industry and making significant progress in doing industry-based research. Three major games companies have made big commitments to support our group's research. We have become the largest research group in this area and are recognized academically as being leading edge. However, as we are learning, there is a large gap between academic research and industry expectations. The commercial games industry in particular is heavily performance oriented. They need real-time solutions that use little CPU and memory. Few AI efforts address real-time constraints – an area which is one of our group's strengths. We are not developing industrial strength solutions for our partners, but we are building proof-of-concept demonstrations that show that our technology can meet the stringent industry demands.

Our group continues to build on its past success in artificial intelligence. Most notable is the poker project, which is addressing the hard AI problems of reasoning with imperfect and incomplete information. We have made great strides forward in the past year, developing new technology that has resulted in a quantum improvement in the state of the art. Our poker-playing program became the first such program to be competitive with a top human player (January 2003). This milestone was recognized by our winning the prestigious best paper prize at the biennial International Joint Conference on Artificial Intelligence (from over 900 submissions). The program has subsequently been commercialized. In the upcoming year, we hope to challenge the best players in the world. (see http://www.poki-poker.com)

The long-term objective of our work is to enhance our understanding of search, knowledge and their interactions. We have one of the strongest groups in the world working on developing high-performance search algorithms. Unlike most research groups, we build complete AI systems, addressing all the issues needed to achieve high performance. It always starts with search (which we understand very well), integrating application-dependent knowledge (which no one understands well) only on an as-needed basis. Discovering new ways to lessen our dependence on knowledge is critical to AI success; human knowledge is fraught with error and difficult to obtain. Our hope is to automate this process as much as possible.

Part of the project funding supports research into parallel computing – something that was not discussed in the original iCORE proposal. For over 15 years we have been developing new parallel algorithms and tools to simplify the difficult task of writing a correct parallel application. While this research area is not artificial intelligence, it is considered "high performance." These activities have always hovered around 30 percent of the Chair's research time. However, because we have successfully engaged the commercial games industry, have made a decision to scale back this research with the intent of ending it by the end of 2004.

Of interest is that the technology we built to develop parallel applications (our CO^2P^3S parallel programming environment) is directly applicable to our artificial intelligence scripting project. CO^2P^3S builds on the (sequential) software idea of design patterns – exploiting commonly occurring software designs. CO^2P^3S uses parallel design patterns. We have copied this technology for AI scripting. Character behaviour also follows patterns. If one describes a character as a "guard" then that conveys a lot of information about that character's behaviour. The guard notion becomes a behavioural pattern that can be customized to give the specific behaviour that is desired. It is surprising (at least to us) that the technology we developed for parallel computing would be relevant in artificial intelligence.

RESEARCH PROJECTS

Our research group has many research projects under way. In this section, the major efforts are highlighted. More details can be found at http://www.cs.ualberta.ca/~games.

Commercial Games Research

In the past, computer graphics were the major technological differentiator between competing games products. The realism of the graphics has increased consumer demand for realism in the game characters. The commercial games industry now recognizes that artificial intelligence has become a major consumer consideration in assessing the quality of a product. Unfortunately, the games industry has few AI experts and almost no resources are devoted to research. This gives university researchers an opportunity to have a major impact in new technology development. In academia, the University of Alberta has the world's largest (and best) research group working in this area.

The first major thrust is in AI scripting. Character behaviours in games are usually defined using scripts. However, the result is complex software that is hard to maintain. Further, the resulting performance of the characters is disappointing because the characters will

only precisely do what has been scripted, and typically this is a very small (usually one) set of behaviours. We have been developing a tool that allows for the rapid construction of complex character behaviours. The tool, called ScriptEase, is based on having a rich set of pre-defined behaviours (for character behaviours, conversations, situations, and plot) that the user can select and then customize to their needs. This work is novel and, because of our extensive experience with patterns (see the CO^2P^3S section below) gives us a competitive edge for developing the next generation of scripting technology. Our tool has been used to build complex stories in a very short time, as evidenced by experiments performed with high school and novice game players. Creating realistic characters has many industrial applications, including training programs, web interfaces, and other forms of interactive entertainment.

ScriptEase has been demonstrated to BioWare and been very well received (they called it "the answer to our non-programming dreams"). ScriptEase was made publicly available in November, 2003; being downloaded over 6,000 times. (http://www.ualberta.ca/~scripting)

The second major thrust is pathfinding. For many computer games, the "simple" task of having a character find a path from their current position to a goal is a time-critical, CPU-intensive function. This is an instance of a problem domain called single-agent search, but in this case is restricted to a two-dimensional grid (with the intent of moving to three dimensions). This technology is applicable to a wider domain of applications, including robot planning. We developed new algorithms for grid-based pathfinding that are being used by BioWare and by Relic Entertainment. New technology for coordinated pathfinding (having multiple agents attempt to catch a moving target) received the Best Poster Prize at the International Joint Conference on Artificial Intelligence (from over 200 submission).

The third major thrust is applying machine learning to games. Game companies are reluctant to ship games that learn in response to the user's interactions. The reason for this is that it is difficult to control the learning, and a player can contrive to have a program learn poor behaviour. Also, conventional learning algorithms are either too slow, or learn too slowly. For example, in Electronic Arts' successful FIFA soccer game, the computerized soccer players are incapable of adjusting their play to match that of their human opponents. We have developed new technology that allows computer soccer players to dynamically modify their behaviour in a controlled way, allowing the program to recognize when it has made a mistake and adjust its play so that the mistake is not repeated. This technology has been endorsed by Electronic Arts.

Another commercial games-related research initiative is Michael Buro's work on real-time strategy games. He has developed a test-bed for exploring issues in real-time strategy games including client-server architectures, managing limited CPU resources, and complex group behaviours.

Jonathan Schaeffer and some research team members in Edmonton, 2004

Classic Games

Traditional games research has concentrated on two-player games of perfect information (the opponents are not hiding anything). Poker is very challenging because of hidden information (you do not know the opponent's cards), multiple players (typically 10 in a game), and deception (bluffing is critical to successful play). These dimensions significantly complicate the problem domain, making it an application domain that better represents the complexities of intelligence in real life. For example, poker is a model for economic game theory as well as business negotiations and Internet auctions.

For over a decade we have been developing new technologies for dealing with imperfect information. We have applied the notion of Nash equilibriums to build a pseudo-optimal two-player poker program (an optimal program is too computationally expensive to build right now). This program achieved international success by narrowly losing a match to a world-class player in January 2003. We working to line up a sponsor for a real-money match against one of the best players in the world in 2004.

The poker program has been commercialized and it selling very well. (http://www.poki-poker.com)

Other efforts in classic games include

- Martin Müller has built up a team of six people working on computer Go. Unlike games like chess, search is ineffective here. Success in the game depends on using complex interacting knowledge.
- For almost a decade we have been working on solving the game of checkers. That is we will have a program that will never lose (assuming checkers is a draw with perfect play, as seems likely). The game has a search space of $O(10^{20})$ – a daunting number. Although the final result – solving checkers – is not particularly exciting from the scientific point of view, the technology and tools developed to solve such a large computational problem are relevant to a wide audience. We have a major unannounced result: we have proven that one popular opening is a draw.
- We continue to improve our world-championship programs for the games of Lines of Action, shogi (Japanese chess), hex and 9x9 Go.

Jonathan Schaeffer

Other Artificial Intelligence Initiatives

- Planning: Many of our search-based research contributions are applicable to the field of artificial intelligence planning systems. For the past year we have been developing new technologies for planning systems. Out technology takes a planning problem domain (for example a robot having to plan how to restock inventory) and decomposes it into a global problem (what has to be done) and a series of local problems (stocking individual items). The result is a system that can come up with workable plans considerably faster than conventional approaches. This has been tested on a variety of real-world domains including pathfinding, aircraft landing schedules, pipeline layouts, and transportation schedules. Our planner has been entered into the International Planning Competition – results will be announced in June.
- Civil engineering: A new project has us using AI search algorithms to automate the layout of sanitary and storm sewers in housing subdivisions. We are working closely with Simaan Abou-Rizaak (Civil Engineering, University of Alberta) and civil engineering companies.

CO^2P^3S

The CO^2P^3S project attempts to use modern software technology to simplify the complexities of developing parallel applications. CO^2P^3S stands for Correct Object-Oriented Pattern-based Parallel Programming System. As the name suggests, the package uses objected-oriented technologies, design patterns and frameworks to facilitate code development. A user selects a parallel design pattern that best matches their application needs, selects some options to customize it to their application, and then fills in CO^2P^3S-generated sequential code stubs with application-dependent code to generate a complete, functional parallel application. The software is available for download. (http://www.cs.ualberta.ca/~systems/cops)

The state of the art in parallel programming tools remains primitive, and we face a difficult task to demonstrate the value of our tool set. Despite being well received in academia (for example, reflected by a best paper prize), we have not yet been able to build up a strong user community.

WestGrid

Although this is not a direct research contribution, in many ways the WestGrid project may have the most long-term impact. WestGrid is a partnership of seven Alberta and British Columbia institutions to bring world-class high-performance computing resources to Western Canada. The partners are the University of Alberta, University of British Columbia, University of Calgary, University of Lethbridge, Simon Fraser University, TRIUMF, and The Banff Centre. This project was successful at achieving roughly $50 million of funding from the Canada Foundation for Innovation, the province of Alberta, the province of British Columbia, computer vendors, and the member institutions. The five co-principal investigators for the project are Jonathan Borwein (Simon Fraser University), Grenfell Patey (University of British Columbia), Jonathan Schaeffer (University of Alberta), Brian Unger (University of Calgary), and Michel Vetterli (TRIUMF). Although my research will benefit in only small ways from this infrastructure, the impact on the research productivity of Alberta and British Columbia researchers will be immense. There will be major benefits to researchers in areas diverse as biology, chemistry, physics, engineering, medicine, and the social sciences.

OBJECTIVES FOR THE NEXT YEAR

It is difficult to identify key milestones in the next year. Research will progress towards the vision outlined above. A wish list for key objectives to strive for in 2004-2005 include:

- A man-machine match in poker against one of the best players in the world. Win, lose or draw, this would be a major historic milestone.
- ScriptEase has been tested with novice users. We want to take that one step further: we have been given permission to use it in a Grade 11 course as a for-credit assignment. This experiment will allow us to get quantitative data on how effectively our tool can be used for interactive story telling.
- We expect that our sewer layout program will be as good as if not better than what human experts can do. If this is achieved, we have a company that has committed to using our technology.
- We continue to strengthen our ties with the commercial games industry. Electronic Arts, BioWare and Relic Entertainment have all made big commitments to our research. If these all come to fruition, then all of our research projects in this area will make major advances.
- We expect to see some of our commercial games technology appearing in a commercial product.

RESEARCH TEAM

Faculty Team Members

The table below lists the faculty members involved in this research group and the percentage of their time committed to the project.

NAME	TITLE	PERCENT
Michael Bowling	Assistant Professor	25
Michael Buro	Associate Professor	100
Russ Greiner	Professor	10
Ryan Hayward	Professor	25
Rob Holte	Professor	50
Paul Lu	Assistant Professor	10
Martin Mueller	Associate Professor	100
Jonathan Schaeffer	Professor	100
Duane Szafron	Professor	50

Faculty involved in co-supervising these students include Michael Buro, Rob Holte, Martin Mueller, Duane Szafron, and Ben Watson (Northwestern University).

Postdoctoral Fellows, Programmer/Analysts and Support staff

NAME	POSITION	PERCENTAGE
Yngvi Björnsson (now a professor at the University of Iceland)	Postdoctoral Fellow	100
Neil Burch	Programmer/Analyst	100
Aaron Davidson	Programmer/Analyst	10
Markus Enzenberger	Programmer/Analyst	100
Valerie Drostle	Administrative Support	50
Matthew McNaughton	Programmer/Analyst	100
Nathan Sturtevant (UCLA graduate)	Postdoctoral Fellow	100
Kai Tan	Programmer/Analyst	10

PhD Students

NAME	TOPIC	AWARDS
Ehud Sharlin	Tangible user interfaces	
Darse Billings	Handling imperfect information in poker	NSERC (past), Killam (past), Steinhauer (past)
Adi Botea	Planning	UofA
Markian Hlynka	Learning search control	NSERC (past)
Akihiro Kishimoto	Solving graph-based search anomalies	
David O'Connell	AI applied to civil engineering	NSERC
Jack van Rijswijck	Learning in sports games	UofA
Peter Yap	Pathfinding	
Ling Zhao	Satisfiability	Alberta Ingenuity

MSc Students

NAME	TOPIC	AWARDS
Mark Goldenberg	Meta-scheduling	
Dave Gomboc	Learning in ames	
Zhung Guo	CO^2P^3S	
Thomas Hauk	Search in stochastic domains	
Dominique Parker	Visual programming	
James Redford	ScriptEase	
Xiaomeng Wu	Learning errors in sports games	
Jianjun Zhou	Search trees as graphs	
Michael Chung	Planning as search in real-time strategy games	NSERC, Alberta Ingenuity
Patrick Earl	CO^2P^3S	

NAME	TOPIC	AWARDS
Bret Hoehn	Game theory	NSERC
Alex Kovarksy	Pathfinding in real-time strategy games	NSERC
Jonathan Newton	Learning in commercial games	
Xiaochen Niu	Heuristic knowledge and search	
Terence Schauenberg	Opponent modelling in poker	NSERC (past)
Gang Xiao	Learning for testability	
Haizhi Zhang	Search algorithms	
Jonathan Yip	Scripting in RTS	NSERC

COLLABORATIONS

Our group is actively working with several partners:

ELECTRONIC ARTS (COMMERCIAL GAMES RESEARCH)
Electronic Arts has funded us in the past with cash and graduate student internships. In the past year, they made a (small) software donation to our group. They have committed to give us access to their most valuable asset: the source code to their FIFA 2004 product (valued at $1,350,000).
BIOWARE (COMMERCIAL GAMES RESEARCH)
BioWare sponsors our research with $10,000 per year. They have committed to continue this financial arrangement for another three years, and give us access to the source code for Neverwinter Nights (valued at $2,000,000).
RELIC (COMMERCIAL GAMES RESEARCH)
In the past year they gave us a six-month graduate internship.
JOERG DENZINGER, UNIVERSITY OF CALGARY
Joerg is working with us as part of our Intelligent Robotics and Intelligent Systems (IRIS) NCE funding.
IKAT AT THE UNIVERSITY OF MAASTRICHT (THE NETHERLANDS) AND THE COMPUTER GAMES LABORATORY AT SHIZOUKA UNIVERSITY (JAPAN)
We have strong research ties with IKAT at the University of Maastricht (The Netherlands) and the Computer Games Laboratory at Shizouka University (Japan). This includes annual visits and graduate student exchanges.
WESTGRID
This is a multi-institutional initiative (University of Alberta, University of British Columbia, University of Calgary, University of Lethbridge, Simon Fraser University, TRIUMF, and The Banff Centre) and multi-disciplinary initiative. Our industrial partners include Hewlett Packard, IBM, and Silicon Graphics.
ALBERTA INGENUITY CENTRE FOR MACHINE LEARNING (AICML)
This research centre was formed two years ago, with Jonathan Schaeffer as one of the co-principal investigators. AICML is starting to work with a number of industrial partners.

INTELLECTUAL PROPERTY

Schaeffer is the co-founder of BioTools Inc. (http://www.biotools.com), a bioinformatics company. BioTools has three successful commercial products: PepTool (protein analysis), GeneTool (DNA analysis), and ChromaTool (DNA/protein assembly). These products are used in over 1,000 research laboratories around the world. Our success with these products led to the opportunity to do contract work with some of the biggest players in the human genome efforts. BioTools has commercialized the poker program (http://www.poki-poker.com), and is investigating working with us on other technologies.

Chenomx is a spin-off from BioTools (http://www.chenomx.com). Chenomx has developed revolutionary software technology to do fluid analysis. From a spectrogram produced by a NMR machine, our programs can analyze the data to a level of detail not easily possible in a laboratory. Our first application is to analyze urine. Conventional urine analysis (as prescribed by a doctor) returns the analysis of six (of over 250) compounds in the urine. Our software accurately returns an analysis of over 100 compounds, faster and at less cost. We have partnered with Varian and Breuker, the two largest NMR manufacturers in the world. Our product, Eclipse, is currently under evaluation by major pharmaceutical companies.

BioTools and Chenomx are successes, but both have been hampered by a lack of venture capital. Together they employ over 20 people and have combined revenues of roughly $1 million.

AWARDS

The following awards have been won by members of our group in the past year:

- Darse Billings, Neil Burch, Aaron Davidson, Rob Holte, Jonathan Schaeffer, Terence Schauenberg, and Duane Szafron. “Approximating Game-Theoretic Optimal Strategies for Full-Scale Poker”, International Joint Conference on Artificial Intelligence (IJCAI), Morgan-Kaufman, pp. 661-668, 2003. Distinguished Paper prize.
- Mark Goldenberg, Alexander Kovarsky, Jonathan Schaeffer and Xiaomeng Wu. “Multiple Agent Moving Target Search”, International Joint Conference on Artificial Intelligence (IJCAI), Morgan-Kaufman, pp. 1538-1540, 2003. Best poster prize.
- Brian Sheppard: Ph.D. thesis “Towards Perfect Play in Scrabble” wins Best Publication Award for the Year 2003-2004 from the International Computer Games Association (ICGA). Jonathan Schaeffer was Brian’s co-supervisor.
- Yngvi Björnsson, Ryan Hayward, Mike Johanson, Morgan Kan, and Nathan Po: Silver medal at the Seventh Computer Olympiad for the game of Hex.
- Markus Enzenberger: Silver medal at the Seventh Computer Olympiad for the game of 9x9 Go.
- Darse Billings, Neil Burch, Aaron Davidson, Rob Holte, Jonathan Schaeffer, Terence Schauenberg, and Duane Szafron: Gold medal at the Seventh Computer Olympiad for the game of poker.
- Akihiro Kishimoto (with Yashushi Tanase): Silver medal at the Seventh Computer Olympiad for the game of Shogi.
- Akihiro Kishimoto (with Yashushi Tanase): First place at the World Computer Shogi Championship.

FUNDING

Jonathan Schaeffer is a leader of the Alberta-British Columbia high-performance computing initiative, WestGrid. WestGrid is funded by CFI (~$12M), ASRA (~$6M), BCKDF (~$6M), and industry contributions worth ~$20M. Schaeffer and his team also participate in the Alberta Ingenuity Centre for Machine Learning ($1.4M/year) and the IRIS ($155/year) and PENCE ($125K/year) National Centres of Excellence. Dr Schaeffer holds a Tier 1 Canada Research Chair worth $200K per year. He was also a co-applicant on a NSERC major facilities grant for $600K this year and and received industry cash contributions from Silicon Graphics ($100K) and BioWare ($10K/year).

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M. Müller, M. Enzenberger, and J. Schaeffer, "Temperature discovery search," in American Association for Artificial Intelligence National Conference (AAAI), 2004, to appear.

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