AIspace: Interactive Tools for Learning Artificial Intelligence

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Abstract

AIspace is a project that has been providing interactive tools for teaching and learning basic concepts in Artificial Intelligence for several years. In this paper we give an overview of the history and current state of the project. We introduce new functionality which has been added to the tools and allows them to be customized for various applications such as presentations, online tutorials, or assignments. We also share our experience on how the AIspace tools have been successfully integrated into undergraduate AI courses at the University of British Columbia. Finally, we provide preliminary results of fielded evaluations of AIspace usage in these courses.

Introduction

AIspace (www.aispace.org) is a collection of Java applets that are designed as tools for learning and exploring concepts in Artificial Intelligence (AI). It has been an ongoing project developed at the Laboratory for Computational Intelligence at the University of British Columbia (UBC) under the direction of Alan Mackworth and David Poole. Each applet is designed to allow students to experiment with a particular AI method using techniques of algorithm animation to help them learn about principles that are otherwise hard to explain in static mediums such as lecture notes, white boards, or textbooks. The applets can also be used for in-class demonstrations, interactive online tutorials, or assignments. The tools are designed to facilitate easy usage in a variety of learning situations. The AIspace applets cover a wide range of AI concepts while using a consistent interface design. Different forms of help are also available to assist users.

In this paper we introduce new functionality that has been added to the tools and allows them be easily adapted for a variety of applications. We also share our experience on how the AIspace tools have been successfully integrated into undergraduate AI courses at UBC. AIspace has had formal laboratory studies conducted in the past which have been extensively described by Amershi et al. (2008). We provide results of the first comprehensive fielded evaluations that have been conducted for the AIspace project.

We start with background information about the AIspace project and its development history since its launch in 1999 and discuss the current state of the project with information about the tools and website. We then introduce the customizable applet functionality which has been recently added to AIspace. Next, we describe how we have used the tools in undergraduate courses at UBC and present the results of fielded evaluations. Finally, we summarize current work being performed on AIspace and ideas which may be incorporated into the project in the future.

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Background

AIspace was originally named CIspace, referring to the field of Computational Intelligence (CI). In January 2008, we relaunched CIspace as AIspace since AI is now a more accurate descriptor for the tools than CI. The AIspace project started in 1999 with the aim of developing a collection of tools which could be used to improve traditional approaches of teaching and learning concepts in AI. The tools were originally designed to accompany the textbook Computational Intelligence: A Logical Approach (Poole, Mackworth, and Goebel, 1998). We first introduced the AIspace project at a workshop at the International Joint Conference on Artificial Intelligence in 2001 (Poole and Mackworth, 2001). Since then, we have been actively developing and releasing new versions with bug fixes, interface improvements, and feature additions on a regular basis.

Formal laboratory studies on the AIspace tools have been conducted and found that: (i) studying with our interactive algorithm visualizations (AVs) is at least as effective at increasing student knowledge as studying with carefully designed paper-based materials; (ii) students like using our interactive AVs more than studying with the paper-based materials; (iii) students use both our interactive AVs and paper-based materials in practice although they are divided when forced to choose between them; and (iv) students find our interactive AVs generally easy to use and useful (Amershi et al., 2008).

Our approach to designing AIspace is to iterate through three stages. We first identify the pedagogical and usability goals of the tools. The second stage involves designing new applets or improving existing ones to achieve these goals. The final stage of development is evaluating the tools. The pedagogical goals have been identified as: (P1) increase student understanding of the target domain; (P2) support different learning abilities, learning styles and levels of knowl-

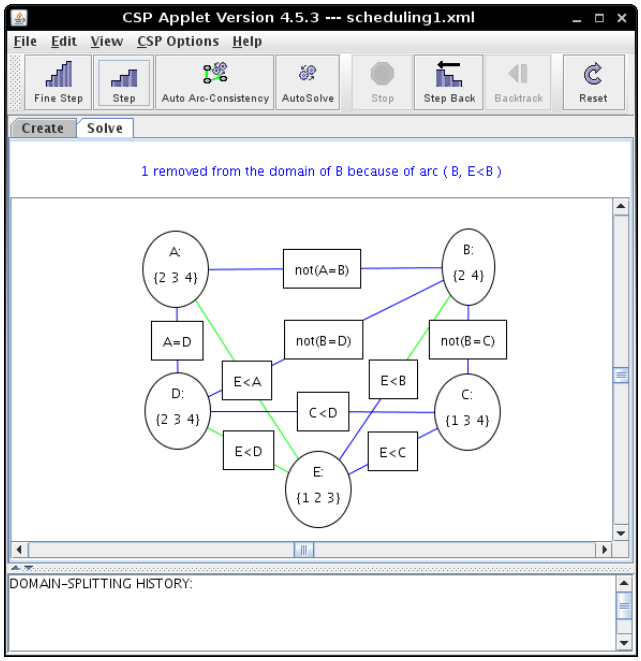

Figure 1: Consistency based CSP solver in solve mode

edge; (P3) motivate and generate interest in the subject matter; (P4) promote active engagement with the tools; and (P5) support various scenarios of learning, including in-class demonstrations, assignments and exploration (Amershi et al., 2005). The usability goals have been identified as: (U1) easy to learn; (U2) straightforward and efficient to use; and (U3) easy to integrate into a course (Amershi et al., 2005).

Several tools and resources[1] have been developed at other institutions with similar goals as the AIspace project. However, the majority of these efforts have either been abandoned or not developed beyond the prototype stage. The tools also tend to work only on predefined examples and do not allow problems to be created or modified[2].

Outside the field of AI there have been many interactive AV initiatives (e.g., Hundhausen, Douglas, and Stasko, 2002; Dionne and Mackworth, 1978; Tversky, Morrison, and Betrancourt, 2002). Despite the large number of AV tools created, widespread use within the academic community has yet to be achieved (Naps et al., 2002). The time and effort required to learn AV tools has been the the primary obstacle preventing instructors from incorporating them into courses (Naps et al., 2003). The usability and pedagogical goals of the AIspace project were developed specifically to overcome these problems.

AIspace Design

The Tools

There are currently seven AIspace tools, each focusing on a basic concept in AI. The tools cover graph searching, generalized arc consistency for constraint satisfaction problems (CSPs), stochastic local search for constraint satisfaction problems, definite clause deduction, belief networks and decision networks (also known as influence diagrams), decision trees, and neural networks. In addition, there are two prototype tools (robot control and planning) which are in earlier stages of development.

The tools were all designed to share similar interfaces to minimize the learning overhead required for using multiple tools. For example, all of the tools have a file menu, button toolbar, create and solve tabs, message panel, and graphing canvas as seen in Figure 1. The create mode allows users to create and modify problems, while the solve mode is used to apply an algorithm to solve a given problem. We have provided an analysis of the common interface elements used by the AIspace tools (Amershi et al., 2008; Amershi and Arksey, 2003).

Table 1: Summary of website usage by visitor location for 500 most recent page views (as of April 6, 2008)

Percent	Visitor Location
29.78%	Canada
15.65%	United States
7.61%	India
6.74%	Singapore
5.22%	Malaysia
4.78%	Morocco
3.91%	Belgium
3.70%	Sweden
3.70%	Netherlands
3.04%	Indonesia
2.61%	Japan
2.17%	Italy
11.09%	Other

Website

The AIspace website provides access to all of the tools as Java applets which can be run inside a web browser. The tools can also be downloaded as executable files so that they can be used in environments without Internet access. Online documentation provides information about how to use each applet. The help documentation for each applet is split into three sections; (i) a quick start guide, (ii) general information about all of the applet's features, and (iii) tutorials about how to perform common tasks in the applet. The tutorials are also accompanied by short instructional videos. Users can get support and provide feedback through email, an online forum, or by submitting a bug report using Bugzilla[3]. Table 3 shows the results of two class surveys regarding how students learned how to use the applets. The AIspace website has also received a substantial number of visitors from around the world (see Table 1, please note that the distribution presented in the table changes daily). In March 2008,

[1] See aima.cs.berkeley.edu/demos.html

[2] See www.ai.mit.edu/courses/6.034f/demonstrations.html

[3] An online bug tracking system; see www.bugzilla.org.

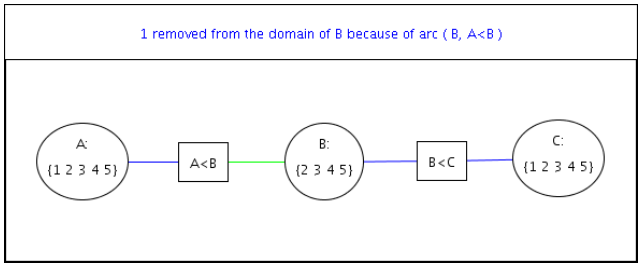

Figure 2: Customized consistency based CSP solver with toolbar buttons and bottom panel disabled

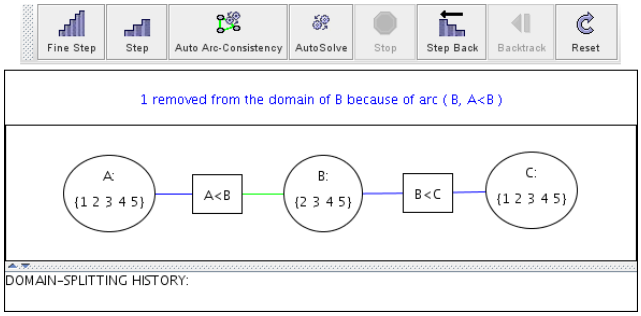

Figure 3: Customized consistency based CSP solver with toolbar buttons and bottom panel enabled

the AIspace website had 6,813 unique visitors who generated 22,754 page loads.

Customizable Applets

In October 2007, we introduced a new feature to the AIspace tools which allows their appearance and functionality to be customized. We developed the customizable applets after receiving user feedback which indicated that the number of features and options available in the original full-featured applets can be overwhelming for new users. Also, some of the features may not be suitable for certain applications. For example, the autosolve feature (which automatically solves a given problem) might be unwanted for an assignment since it allows students to solve problems without necessarily understanding the details of how the algorithms work. To deal with this issue, we have created a mechanism which allows instructors to easily remove unwanted features.

The customizable applets provide a wide variety of customization options. The appearance of an applet can be stylized by adjusting its size, borders, and internal panels. Specific examples can be loaded by specifying the location of an existing problem. The functionality of the applets can be modified by changing settings from their default values. Finally, unneeded options or features can be removed.

The interface of the customizable applets can be tailored for users with different levels of domain knowledge by providing default settings for beginner, intermediate, and expert users. The applets can be made significantly easier to use for beginner users by reducing the number of features and options available. For example, the applet in Figure 2 has had all of the standard toolbar buttons removed, the bottom panel hidden, and has been resized to match the aspect ratio of the graph that it initially loads. In comparison, the applet in Figure 3 has the bottom panel and the toolbar buttons enabled.

The customizable applets can be embedded within a webpage or a presentation[4]. The website contains instructions documenting how to customize an applet. Authors can specify parameters within an applet HTML tag to customize an applet's properties. HTML links within a webpage can also be used to control execution of an applet, giving users an alternative method of interaction. The customizable applets do not have the create mode which is available in the full-featured applets, so they can not be used to modify or create problems. Since they are always in the solve mode, they can only load problems which have already been created. This decision was made to simplify the process of creating a customized applet and also prevents users from modifying a problem, potentially changing the intended purpose of a customized applet.

The customizable applets are especially useful for online tutorials in order to demonstrate a particular AI concept. Using the applets as visualization tools to complement the textual explanation in a tutorial may increase pedagogical value according to the Dual-coding theory (Hundhausen, Douglas, and Stasko, 2002). HTML links in the text can also provide a convenient way for users to interact with an applet. In the applet shown in Figure 2, without buttons to interact with the applet directly users can be forced to interact using links in the text. This is useful for guiding users through tasks which need to be performed in a specific order. The customizable applets are currently being used within some of the AIspace tutorial pages to help guide users through common tasks.

Experience of Using AIspace at UBC

The AIspace applets have been used in undergraduate and graduate AI courses at UBC and elsewhere (e.g. Nanyang Technological University and Simon Fraser University) for several years. Although feedback from UBC students about the tools has been largely positive, it has become clear that since the integration between lectures and applets was done independently by each instructor for every new offering of the course, many opportunities for learning from past experience were missed. This situation has prompted us to study AIspace integration in a more systematic way. We hope that the outcome of this work will not only benefit our courses, but also facilitate any AI instructors who would like to integrate AIspace in their lectures. In this section we discuss the integration of the tools into the latest offering of two undergraduate AI courses at UBC: CS322 and CS422. CS322 provides an introduction to the basic approaches and techniques used for AI, while CS422 focuses on the more advanced principles underlying the design of intelligent computational systems. In both courses only the full-featured

[4]This can be accomplished using PowerPoint with the LiveWeb plugin (skp.mvps.org/liveweb.htm).

Table 2: Use of AIspace during CS322 course

Topic	AIspace Use
Search	11
Constraint Satisfaction Problems	4
Stochastic Local Search	1
Planning	0
Propositional Definite Clauses	3
Belief Networks	5
Decision Networks	8
Decision Processes	0

applets were used since the customizable applets were just released at the time the course material was being developed.

The instructor for CS322 systematically kept track of all the times in which an applet was used in a lecture to clarify a concept, to explain details of an algorithm, or in general to illustrate a point more clearly. This was done by explicitly marking the lecture slides with the AIspace logo whenever an applet was shown in the corresponding lecture. This allows not only to record the number of occurrences of applet use but also the specific context in which they were used to be recorded as well.

CS322 covers eight basic modules: search, constraint satisfaction problems, stochastic local search, planning, propositional definite clauses, belief networks, decision networks, and decision processes. Table 2 shows for each topic how many times an applet was used in lectures for that topic. First, notice that the distribution of applet usage in lectures between topics is rather unbalanced. We plan to investigate whether this is due to the different nature of the topics vs. the coverage of the topic provided by the corresponding applet. As an example of the latter case, the applet for planning was not used at all because of its limited coverage and because it is still in the early stages of development. In particular, it is clear that we need this applet to cover the mapping of planning problems into CSPs. This has become an important concept in planning as it leads to Graphplan and consequently has become a significant part of our lectures on planning.

On the other side of the distribution shown in Table 2, the usage of applets in lectures on search dominates usage in all other topics. A detailed analysis of the specific instances of use indicates that this is likely due to the nature of the topic. Search is presented as a collection of methods which can be compared on a small number of different criteria (e.g., completeness, optimality). It turns out that the graph searching applet is very effective in illustrating with examples how each method fares with respect to these criteria. So the eleven instances are mostly illustrations of the same properties (e.g., completeness, optimality) on the key search algorithms (e.g., breadth first, lowest cost first).

Moving back and forth between the lecture slides and the AIspace applets can be very time consuming, especially when this switch is needed multiple times in the same lecture. Customizable apples could help in this respect by being embedded within the presentation slides. Another issue related to time constraints is that sometime it is difficult to identify the right balance between what to show in class and what to leave as independent exploration. A few times the in-class demonstration of a complex example in AIspace had to be interrupted for the sake of time. Students were told to complete the study of the example independently outside the class.

Table 3: Student responses from CS322 class ($n = 21$) and CS422 class ($n = 17$) about how they learned to use the applets (multiple answers could be selected)

	CS322	CS422
Watching demonstrations in class	14	9
Looking through the AIspace help pages	11	3
Watching the video tutorials online	3	3
Asking others	5	3
Exploring the applet on their own	18	15

Table 4: Student responses about their use of AIspace applets in CS322 ($n = 21$)

	GS	CSP	SLS	DCD	BN & DN	Any
Seen in class	19	19	10	15	18	21
Used for assignment	4	4	0	16	14	21
Used for self-study	12	9	3	9	10	15

The AIspace tools are useful for assigned homework problems because they allow students to become exposed to AI concepts without being required to implement lower-level details in a programming language. Although assigning programming problems is effective for teaching certain algorithms, often the purpose of assignments is to focus on higher level concepts. For example, the neural network tool allows students to apply neural networks to a variety of interesting problems without requiring them to implement or understand details such as the backpropagation algorithm. AIspace gives instructors the flexibility of choosing the level of detail to expose to students. In CS322, two out of four assignments explicitly asked students to use the AIspace applets (for questions covering definite clause deduction and belief and decision networks). In CS422, two out of five assignments used the AIspace applets (for questions covering decision trees and neural networks).

Fielded Evaluation

AIspace has previously been formally tested in laboratory studies. These are extensively described by Amershi et al. (2008). Fielded evaluations were only performed for the consistency for CSP applet and belief networks and decision networks applet (Amershi et al., 2008).

Tables 3, 4, 5, and 6 show the results of questionnaires conducted in April 2008 in CS322 and CS422 courses. Note that this data is based exclusively upon the use of the full-

Table 6: Student evaluation of AIspace applets in CS322 and CS422

	CS322					CS422			
	GS	**CSP**	**SLS**	**DCD**	**BN & DN**	**BN & DN**	**DT**	**NN**	**Summary**
Effectiveness in class	$\mu = 4.3$	$\mu = 4.1$	$\mu = 4.0$	$\mu = 4.1$	$\mu = 3.9$		$\mu = 3.8$	$\mu = 3.8$	$\mu = \mathbf{4.0}$
1 = not at all effective	$\sigma = 0.9$	$\sigma = 0.8$	$\sigma = 1.1$	$\sigma = 0.8$	$\sigma = 0.9$	N/A	$\sigma = 0.9$	$\sigma = 1.0$	$\sigma = \mathbf{0.9}$
5 = very effective	$n = 19$	$n = 19$	$n = 8$	$n = 14$	$n = 18$		$n = 16$	$n = 13$	$n = \mathbf{107}$
Enjoyability in class	$\mu = 3.6$	$\mu = 3.6$	$\mu = 3.7$	$\mu = 3.4$	$\mu = 3.3$		$\mu = 3.6$	$\mu = 3.6$	$\mu = \mathbf{3.5}$
1 = not at all enjoyable	$\sigma = 0.9$	$\sigma = 0.9$	$\sigma = 1.0$	$\sigma = 0.9$	$\sigma = 1.1$	N/A	$\sigma = 1.0$	$\sigma = 1.0$	$\sigma = \mathbf{0.9}$
5 = very enjoyable	$n = 19$	$n = 18$	$n = 10$	$n = 16$	$n = 18$		$n = 16$	$n = 13$	$n = \mathbf{110}$
Usability outside of class	$\mu = 4.2$	$\mu = 4.0$	$\mu = 4.0$	$\mu = 3.7$	$\mu = 3.6$	$\mu = 3.8$	$\mu = 3.9$	$\mu = 3.8$	$\mu = \mathbf{3.8}$
1 = very difficult	$\sigma = 0.8$	$\sigma = 0.9$	$\sigma = 1.0$	$\sigma = 1.0$	$\sigma = 1.0$	$\sigma = 1.1$	$\sigma = 0.7$	$\sigma = 0.5$	$\sigma = \mathbf{0.9}$
5 = very easy	$n = 12$	$n = 10$	$n = 3$	$n = 16$	$n = 13$	$n = 12$	$n = 11$	$n = 8$	$n = \mathbf{85}$
Enjoyability outside of class	$\mu = 3.8$	$\mu = 3.7$	$\mu = 4.0$	$\mu = 3.7$	$\mu = 3.6$	$\mu = 3.8$	$\mu = 3.3$	$\mu = 3.7$	$\mu = \mathbf{3.7}$
1 = not at all enjoyable	$\sigma = 0.8$	$\sigma = 0.7$	$\sigma = 1.0$	$\sigma = 0.6$	$\sigma = 0.9$	$\sigma = 1.2$	$\sigma = 0.8$	$\sigma = 1.1$	$\sigma = \mathbf{0.9}$
5 = very enjoyable	$n = 10$	$n = 9$	$n = 3$	$n = 15$	$n = 13$	$n = 12$	$n = 12$	$n = 9$	$n = \mathbf{83}$
Usefulness outside of class	$\mu = 4.5$	$\mu = 4.4$	$\mu = 4.7$	$\mu = 3.9$	$\mu = 4.4$	$\mu = 4.1$	$\mu = 4.0$	$\mu = 4.0$	$\mu = \mathbf{4.2}$
1 = not at all useful	$\sigma = 0.9$	$\sigma = 0.5$	$\sigma = 0.6$	$\sigma = 1.0$	$\sigma = 0.6$	$\sigma = 0.9$	$\sigma = 0.7$	$\sigma = 0.7$	$\sigma = \mathbf{0.8}$
5 = very useful	$n = 12$	$n = 9$	$n = 3$	$n = 16$	$n = 15$	$n = 12$	$n = 12$	$n = 9$	$n = \mathbf{88}$
Summary	$\mu = \mathbf{4.0}$	$\mu = \mathbf{3.9}$	$\mu = \mathbf{3.9}$	$\mu = \mathbf{3.7}$	$\mu = \mathbf{3.8}$	$\mu = \mathbf{3.9}$	$\mu = \mathbf{3.7}$	$\mu = \mathbf{3.8}$	$\mu = \mathbf{3.8}$
	$\sigma = \mathbf{0.9}$	$\sigma = \mathbf{0.9}$	$\sigma = \mathbf{1.0}$	$\sigma = \mathbf{0.9}$	$\sigma = \mathbf{1.0}$	$\sigma = \mathbf{1.1}$	$\sigma = \mathbf{0.8}$	$\sigma = \mathbf{0.9}$	$\sigma = \mathbf{0.9}$
	$n = \mathbf{72}$	$n = \mathbf{65}$	$n = \mathbf{27}$	$n = \mathbf{77}$	$n = \mathbf{77}$	$n = \mathbf{36}$	$n = \mathbf{67}$	$n = \mathbf{52}$	$n = \mathbf{473}$

Table 5: Student responses about their use of AIspace applets in CS422 ($n = 17$)

	BN & DN	**DT**	**NN**	**Any**
Seen in class	N/A	16	13	16
Used for assignment	11	12	5	15
Used for self-study	9	7	7	12

featured applets since customizable applets were not used in these courses. CS322 had a total of 44 students and had 21 responses. CS422 had a total of 25 students and had 17 responses. In the tables we use the following and acronyms: GS - graph searching applet; CSP - consistency for CSP applet; SLS - stochastic local search for constraint satisfaction problems applet; DCD - definite clause deduction applet; BN & DN - belief networks and decision networks applet; DT - decision trees applet; NN - neural networks applet. Table 3 shows student responses about how they learned to use the AIspace applets. Tables 4 and 5 tally student use of the applets inside and outside of class throughout CS322 and CS422 respectively. The 'Any' columns in these tables show how many students used any of the applets under particular conditions. Students were also asked to evaluate the applets on different criteria using scales from 1 to 5. Table 6 summarizes their responses.

Here we provide some preliminary observations on the data we have collected. The feedback from students about the tools was generally positive. The overall average of the evaluations was 3.8 out of 5 (see Table 6 for more details). The scores for enjoyability of the applets during demonstrations in class were consistently lower than the scores for effectiveness with averages equal to 3.5 and 4.0 respectively (Table 6). Similarly, averages for enjoyability outside of class (3.7) and usability outside of class (3.8) were lower than average for usefulness outside of class (4.2). This indicates an important area for improvement, such as developing more engaging examples. The data also shows that 27 of the 38 students surveyed used the applets for self-study outside of class which may indicate that the in-class demonstrations of complex examples, even if just partial, were sufficient to motivate students to complete their study outside the class. In addition, 7 students enrolled in CS322 and 11 students enrolled in CS422 used applets for assignments when it was not explicitly stated as a requirement. Many of the students seemed to prefer learning how to use the applets by observing in class demonstrations and through self exploration of the tools (Table 3). In the future we will compare these results with previous partial fielded evaluations (Amershi et al., 2008). We also plan on performing additional fielded evaluations regularly and use the results for guiding future AIspace development.

Ongoing and Future Work

The results of the fielded evaluation show that there is room for improvement for future AIspace development. We plan on continuing our iterative development cycle to achieve this goal. In particular we want to advance development of the robot control applet and the planning applet. We plan on creating tutorial pages on the website focusing on teaching particular algorithms using the customizable applets. The AIspace project is also being closely integrated with the upcoming textbook Artificial Intelligence: Foundations of Computational Agents (Poole and Mackworth, 2009).

Another area of future work relates to the development

of adaptive interfaces to detect and adapt to the needs of a user in real time. Customized applets for different users require that the users know how to select the most suitable version of an interface, while adaptive applets can autonomously suggest how to best tailor the interface to their needs. They can generate these suggestions by dynamically building a user model. We have already started research on how to generate this model from interaction behaviors both using HMMs (Gorniak and Poole, 2000a,b) and unsupervised learning (Amershi and Conati, 2007).

Acknowledgments

Many other faculty and students have contributed to the development of AIspace including S. Amershi, N. Arksey, M. Cline, W. Coelho, P. Gorniak, H. Hoos, K. O'Neill, K. Leyton-Brown, M. Pavlin, K. Porter, J. Santos, S. Sueda, L. Tung, A. Yap, and R. Yuen. The AIspace project has been financially supported by the Natural Sciences and Engineering Research Council of Canada (NSERC) through their Undergraduate Student Research Awards (USRA), and by NSERC grants to A. Mackworth and D. Poole.

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