



Is There an Intelligent Agent in Your Future?

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"The White House said the increased technology spending - mentioned briefly by President Clinton during last week's State of the Union address - could be used, for example, to create "intelligent agents" that roam the Internet collecting information" ... (AP News Service, January 24, 1999)

Imagine that you are lucky enough to find some free time in your schedule, and you decide to take a trip. What do you do? If you're like most people, you contact a travel agent to arrange the details. You describe your needs (where you want to go and when), the constraints that you need to impose (how much you are willing to spend, the hotel must provide child care) and some personal preferences (your preferred airline, you'd like to sit in an aisle seat). The travel agent, using a combination of information sources (flight schedules, hotel guides) and guidance from past experiences, recommends where you might go. Once you confirm your choice, the agent generates the itinerary, books the flights and generally does all the things that you don't want to bother with.

Now think about your voyages on the internet. Wouldn't it be nice to have an agent to help you in these travels? You could specify your needs (to find journal articles describing experiments in a particular field), your constraints (that a certain experimental system or a particular reagent was involved), and your preferences (that articles are written by research groups at major universities). An internet travel agent, would then find you some possibilities and ask you to choose one of its choices. Upon your agreement, the agent would download the articles and provide in any registration details needed for the web sites, arranging credit card payment to those that need it, any number of mundane things that you don't want to bother with.

The vision of such *intelligent agents* is quite compelling and many people now believe they will be necessary if we are ever to tame the increasing complexity caused by the accelerating and virtually uncontrolled growth of the World Wide Web. The present situation can only get worse as new web technologies (for example new mark-up languages such as [XML](#)) permit the further integration of more complex data sources (for example database searches, real-time simulation of complex systems, multimedia presentations, *etc.*).

If you are unconvinced of the need for help try searching the Web using a few scientific keywords in your favourite search engine. Look at the ten or twenty items found. Now imagine the web was a hundred times its current size (which is the predicted growth in the next 2-3 years). That item might be number 1,000 or 2,000, buried under the avalanche of false hits, misused terms, misinformation and all those other problems that already cause many of us to consider the Web a 'necessary evil' rather than a true boon to our scientific endeavours.

At this moment such agents do not exist, despite the great need for their services. There are technical reasons why developing such agents is hard, but considerable work is under way to improve the current state of the art.

What makes a good "agent"?

Returning to the travel agent analogy, what makes a travel agent good as opposed to one you wouldn't want to use?

First, you must be able to communicate with the travel agent. Both you and your agent must speak the same language. Any agent that cannot understand where you want to go or what you want to do there will be of little help to you.

Second, the agent must be able to act as well as suggest. This is the difference between some sort of travel advisor and a real travel agent. An advisor might let you decide where to go, but when you needed to book flights and hotels, rent a car, and all the other minutia that is involved in a trip, you have to do that yourself. A real travel agent on the other hand can actually do these things for you.

Third, an agent can do things without supervision. Imagine trying to book a very complex trip, through a travel agent which required you to be on the phone with them until all details were planned and finalized. You'd need to wait while they looked up flights and contacted hotels and airlines, checked with previous travellers whether they had enjoyed their trips to the same places, searched through price lists and day/destination lists, checked with the hotel to see if it was open that day, *etc.* Forget it! Good travel agents collect some information from you, go off on their own to find options, call you back to suggest and discuss possibilities, take the itinerary you prefer and then go book it.

Finally, a key ability of good travel agents is that they use their experience to help you. They don't send you to hotels which other customers have told them were awful. Similarly, if you travel a lot your travel agent should learn about your preferences: which airlines you like, what times you like to fly, what sort of car you prefer to rent, all those little things that can make the difference between a good and a bad trip. But further, the best travel agents learn how much, or how little, you want them to do: some people like to micromanage their entire itinerary, some prefer to let the agents make all the choices, and others like something in the middle.

The ideal internet agent

A good internet agent needs these same capabilities. It must be *communicative*; able to understand your goals, preferences and constraints. It must be *capable*; able to take options rather than simply provide advice. It must be *autonomous*; able to act without the user being in control the whole time. And it should be *adaptive*; able to learn from experience about both its tasks and about its user's preferences.

Let's look at each of these in turn, reviewing current research in these areas.

- **Communicative**

What does it mean to be able to communicate with someone (or something in the computational case)? Greatly simplifying an issue which has been a cornerstone of intellectual thought for many years, useful communication requires shared knowledge. While this includes knowledge of a language – the words and syntactic structures – it is even more focused on know-

about the problem being solved. To deal with a travel agent, you need able to talk about travelling, to interact with a florist you need some knowledge of flowers, and to deal with an internet agent you must have vocabulary about the area of concern.

A key problem with current search engines is that although based in language, they have no knowledge of the domains of interest. Searching physics papers would be enhanced if the search engine actually 'knew' something about physics (how experiments are performed, which words are ambiguous, whether papers are theoretical or empirical, etc.), rather than simply looking for the appearance of key words. Not all squids are superconducting quantum interference devices!

Solutions to this problem usually involve 'ontologies'. While this term is part of the technical jargon of artificial intelligence researchers, the basic concept is simple – an ontology is a formal definition of a body of knowledge. The most typical type of ontology used in building agents involves a structural component. Essentially a taxonomy of class and subclass relations coupled with definitions of the relationships between these things.

In addition, the ontologies contain some kinds of 'inference' rules – they can be explicit rules about an item, or they can be 'structural' inference provided by a system. An example of the former might be a rule like "if X is a car, then X has four tires." An example of the latter might be a rule like "if one thing is part of something else, and that latter thing is itself a component of an assembly, then the first item is a part of the assembly." (that is, if a hubcap is part of a tire, a tire is part of a car, therefore the hubcap is part of a car).

As an example of an ontology, consider the one shown at <http://www.cs.umd.edu/projects/plus/SHOE/tse/tseont.html>. This ontology was developed at the University of Maryland in a joint effort of computer scientists and FDA and veterinary biologists to help in the development of new tools to interact with information about transmissible spongiform encephalopathies (the most famous being BSE or 'mad-cow disease'). This ontology links a number of concepts such as diseases to diseased animals, symptoms to diseases, *etc.* It is worth noting that this ontology is far from complete. It doesn't get down to prions or other deep molecular concepts but it does provide key concepts that are being developed for an internet agent that will help users find internet-based information to aid in making risk-assessment decisions.

If an ontology can be made machine readable, it allows a computer to manipulate the terms used in the ontology, terms that make sense to us but which we do not understand. The computer doesn't understand this information, in any deep sense of the term, but it manipulates terms that the user understands. This allows for a form of communication between us and the computer, which in turn enables the creation of software products, the agents we've been discussing, which can represent the needs, preferences, and constraints of the user.¹

- **Capable**

For an agent to be capable, it must be able to take action in some sort of

world. As mentioned before, the difference between an agent and an advisor, is that the agent not only provides advice, but also provides a service, the ability to do things on the Web without you needing to know details. Unfortunately, the current state of the art is limited by the need to know much about the specifics of the internet sources the agent will interact with. For example, suppose you want a paper from some particular physics journal, but the journal charges for it. If you want an internet agent to be able to download this paper for you, it would need to know where on the web page the price is, where it communicates your credit card number, in what formats the various pieces of information about you need to be put, *etc*. In fact, this is exactly the information that you would need to use the page yourself, and the variations from site to site is one of the reasons the current web is so hard to use.

This is a difficult problem, and many current internet communities are worrying about how to overcome the syntactic issues involved in finding appropriate items on web pages (for example [XML](#)). While agreement is starting to emerge, a lot of engineering is still to be done to encode information about internet sources and about how to manipulate them. Intelligent agent researchers are watching these developments closely, as the web becomes increasingly 'agent-friendly' more capable agents are being developed.

- **Autonomous**

One of the more contentious issues in the design of human-computer interfaces arises from the contrast between 'direct manipulation' interfaces and autonomous agent-based systems (see <http://www.acm.org/sigchi/chi97/proceedings/panel/jrm.htm>). The proponents of direct manipulation argue that a human should always be in control - steering an agent should be like steering a car - you're there the whole time. However, if the software simply provides an interface to, for example, an airlines booking facility, the user must keep his or her needs, constraints and preferences in his or her own head.

Software that can help make wiser decisions, but is not capable of doing anything for you or needs constant steering to be effective, may be a useful advisor, but falls short of the time saving tool that a true agent would be. A truly effective internet agent needs to be able to work for the user when the user isn't directly in control. Of course, if the software were too autonomous this could cause problems. Thus, the key to autonomy is finding the right level for the task at hand.

Enabling autonomy is a difficult programming task, particularly because it is very dependent on features of the area in which a program is operating. A travel agent must have very different levels of autonomy than a real estate agent. For human agents the level of autonomy is clearly defined, sometimes by law, sometimes by customs that have grown up over many years. For internet agents it is much less clear (hence the debate described above). It is even unclear whether the variation among tasks will be high or low for internet agents. It seems unlikely that an agent helping find, or download physics papers would be much different from one in biology. However, the agent helping find biological papers might have very different constraints than one that visits protein databases to download data. The paper agent might check with you about costs, but might be given automatic authority to do all the downloading. The database agent might check with you about

downloading (which could fill my entire disk if queried carelessly), but be concerned about costs for public or low-cost databases. Unfortunately, with a technology this new, the agents' rules are not established by precedent.

One realm being explored is the so-called *mixed-initiative* approach. In these systems the internet agent varies its autonomy based on factors like cost of the resources needed, or other variables the user might wish to control. Sometimes, the system is in charge, pre-authorized to make decisions and suggest alternatives. Other times, the user is in charge, taking control and steering the decision making.

In another sort of mixed-initiative system the agent essentially 'looks over the user's shoulder'. Such a system might make suggestions as to which pages to look at next, predict downloads to pre-process so that by the time the user wants to see a particular page it has already been downloaded, or otherwise take actions directly based on the actions the user is taking while interacting with a browser or other network aware system. Mixed-initiative systems could also have the potential to learn a user's preferences over time and customize its actions accordingly.

- **Adaptive**

The best way for a system to find the appropriate level between aiding the user and overstepping the bounds of what the user would prefer, is for the system to learn the user's preferences. Similarly, the internet agent with predetermined pages to visit is quite limited. Thus, a truly useful agent should be able to adapt its behaviour based on a combination of user feedback and environmental factors. For example, if the agent visits a web site that no longer works, it should learn to stop going there. If the site has changed features, the agent should learn the new ones or should ask the user for help in reorganizing.

Such adaptive behaviour can be achieved in a number of ways. The simplest way is to group users based on some set of features, and then to assume similarity between them. This can work fairly easily. A new user can fill out a questionnaire that allows the system (using a statistical clustering algorithm) to figure out to which cluster of other users this user belongs. Preferences associated with that group are then assumed to work for the user.

As an example, a now defunct movie finder site used to ask the user to rate on a scale of 1-10 each of ten movies. The users' results were then clustered with others who answered the questions in a similar way. That information was then used for new movie recommendations. Members would enter their preferences on other movies, and that would be used to provide 'advice' on movie choices to others in the same group. A similar technique has been used at a number of sites that sell various commercial productsⁱⁱ.

Other forms of machine learning techniques are also being explored for Internet use. One particularly clever application attempts to learn to recognize web advertisements and to strip them from sites (<http://www.cs.ucd.ie/staff/nick/research/ae/> for more information and relevant literature citations). Other applications range over a wide variety of learning techniques and web behaviours, far too many to review here. Several interesting examples of learning agents have been developed to

Carnegie-Mellon University's Text Learning Group

(<http://www.cs.cmu.edu/afs/cs/project/theo-4/text-learning/www/index.html>); other pointers to research in this area can be

found at a number of the "agents resource sites" linked to this article).

What is the state of the art in agent design?

To build agents with the desired capabilities is a challenge the computer science research community is now attacking – but what is the state of the art today? The bad news is that the sort of internet agents I've been describing so far are few and far between – usually running in research labs and not robust enough for general use. The good news is that many of the components to build such agents are beginning to move beyond research exercises and it is not hard to imagine such agents coming into common use in the next few years. However, there are still a number of limiting factors that must be overcome before scientists will be routinely using internet agents to augment their search, downloading and other research needs.

Building autonomy into web agents is not the limiting factor. This capability is even particularly difficult given that modern web-based computer languages like Java™ now provide numerous 'class libraries' aimed at providing such applications. In fact, in my undergraduate computer science classes I often have students write such agents as a final project. Using simple tool sets, the students are able to build agents that wander the web looking for particular concepts and suggesting to the user some web sites to look at. While nice demonstrations, however, these systems are still too limited for use by scientists in commercial applications.

The key limiting factor at present is the difficulty of building and maintaining ontologies for web use. The most basic need in interacting with an agent is a language in which to communicate. While it is possible to 'fake' these semantics (with the program reacting appropriately to keywords, for example), an agent that is truly useful must have a lot of knowledge about the problem being solved. A travel agent doesn't know about geography (Where is the Caribbean?), transportation (What airlines go there?), lodging (Is that a good hotel?), economics (Can I afford to stay there?), *etc.* then we cannot easily communicate our needs. The internet agent doesn't understand the area in which it must work (molecular biology, particle physics, *etc.*), it is not able to find appropriate resources any better than current keyword based approachesⁱⁱⁱ.

Organizing ontologies

Unfortunately, building these ontologies is a daunting task, especially as extremely detailed knowledge is needed to provide truly useful searches. Even when produced such ontologies must be brought to the web in a machine readable form. A further problem arises in a trade-off between the depth of the ontology and the difficulty in encoding the knowledge. Thus, the SHOE system described above (<http://www.cs.umd.edu/projects/plus/SHOE>), is aimed at being written and edited by scientific experts without specialized computer science training; but currently provides a relatively shallow ontology. Other research groups, for example the Knowledge Sharing Laboratory at Stanford University (<http://www.ksl.stanford.edu/currentproj.html>), are developing more complex ontologies that encode deeper knowledge. However, these approaches require knowledge of artificial intelligence knowledge representation techniques, something that isn't in the typical training of the average scientist.

It is worth noting that major efforts are underway to overcome these problems to develop new tools for creating ontologies and/or bringing them to the web. High Performance Knowledge Base Initiative, sponsored by the US Defense Advanced Research Projects Agency is one example (see <http://www.teknowledge.com:80/HPKB/> for more info). Thus, there is reason to believe that as the current set of web tools (like SHOE) get more capable, and the high end tools (like those at KSL) become more accessible, the bottleneck in developing ontologies will be overcome.

Improvement is also being seen in the effort to make agents more capable. Market forces are now driving online journals and other scientific content providers to explore the greater use of agent-based systems. Current search engines, using keyword based techniques, are inadequate for providing the detailed sort of searches needed by the scientific community. Further, XML and other advanced web languages are being used to organize scientific material, making it easier for web agents to find key aspects of scientific documents (these can be as simple as author names and affiliations or as complex as identifying components in sequences described in figures). These languages also make it easier for agents to become 'capable' as they can more clearly identify what information is needed for downloads, *etc.*

The area of agent-based systems is a hot one. We have the technology to build software agents that are communicative, capable, autonomous and adaptive. The key behaviours needed to help make our internet journeys more fruitful. The limiting factors in building such systems are being overcome, and new approaches are emerging from information technology research laboratories around the world. In short, if you're not now using agent-based technology, don't worry, you soon will be.

Agent research sites

As with most hot topics on the web, there are many sites which describe work on agent-based systems. The following are some links that may be useful in learning more about research in this area:

- The UMBC Agent Web - <http://www.cs.umbc.edu/agents/>
- The National Research Council of Canada Agent resource list - <http://ai.iit.nrc.ca/subjects/Agents.html>
- The French "@agency" Frontpage - <http://hoegaarden.iut3.unicaen.fr/bin/pywiki>
- The European Community Agentlink project - <http://www.agentlink.org>
- In addition, a number of web sites also describe interesting research in agent-based systems. As well as those directly cited in above, some others that are usually up to date and include demonstrations are
- The University of Washington "Softbots" Project - <http://www.cs.washington.edu/research/projects/softbots/www/softbot>
- The MIT Media Laboratory Agents Research group - <http://agents.www.media.mit.edu/groups/agents/>
- The Ariadne Project at the Information Sciences Institute - www.isi.edu/ariadne

(Please note, as with all other web pages, the quality of the pages above is variable and characterizes the state of the art. The above are starting pages that point to many useful web sites, but no endorsement of the content.)

pages or the information thereon is intended.)

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ⁱThe ontology shown previously is actually represented in a formal machine readable language called SHOE. The web-literate reader might wish to look at the document source for the `tseont.html` page, and see both the HTML form, which is displayed, and the SHOE form, with a set of HTML extensions that allow ontology use on the World Wide Web. See <http://www.cs.umd.edu/projects/plus/SHOE> for more details.

ⁱⁱ This technique is currently being explored by several popular and large e-commerce sites, however I will not provide links to commercial sites from this article.

ⁱⁱⁱ At the time of this writing, a common internet search engine given the string "Can you find papers discussing the instability of retroviral proviruses in chromosomes" returned more than 1,000,000 hits, with no recent research papers in the top 100 – surely we can do better than



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Artificial intelligence is defined as a study of rational agents. A rational agent could be anything which makes decisions, as a person, firm, machine, or software. It carries out an action with the best outcome after considering past and current percepts (agent's perceptual inputs at a given instance). An AI system is composed of an agent and its environment. The agents act in their environment. The environment may contain other agents. An agent is anything that can be viewed as : perceiving its environment through sensors and acting upon that environment through actuators. Note : Every agent can perceive its own actions (but not always the effects) To understand the structure of ... Intelligent Agents is an automated email notification feature that can assist instructors, administrators, when defined activity occurs in a course or when there is a lack of login or course entry. This article compiles a list of useful Intelligent Agents and how to set them up for a course. We advise you to check out our other guides, Intelligent Agents " Getting started and Intelligent Agents " effective practices and pitfalls, especially the first one if you haven't been introduced to Intelligent Agents. Intelligent Use 1: No Brightspace Login. Why: To see which students are not "attending" Intelligent Agents can be any entity or object like human beings, software, machines. These agents are capable of making decisions based on the inputs it receives from the environment using its sensors and acts on the environment using actuators. AI-Enabled agents collect input from the environment by making use of sensors like cameras, microphone or other sensing devices. The agents perform some real-time computation on the input and deliver output using actuators like screen or speaker. These agents have abilities like Real-Time problem solving, Error or Success rate analysis and information Intelligent agents are one of the most promising future emerging fields. The more intelligent they become the more useful they are ! However, intelligent agents without ethical behaviours may turn out to dramatic consequences. How can we define (unformally and formally) an "unethical intelligent agent" in a cooperative multi agent environment ? Relevant answer. Peter Goldschmidt. Good afternoon Alberto: - There is a lot of information out on the WWW, Intelligent Tutor Systems, Adaptive Educational Hypermedia, Adaptive Information Retrieval Techniques. If you want to drop me a e-mail i can send you (academics names in the research field/area). Dr. Robert Costello.