AI on the WWW

Supply and Demand Agents

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AGENT-BASED SYSTEMS SIMPLIFY USER ACCESS TO THE MANY GLOBAL VIRTUAL ENTERPRISES NOW ARRIVING ON THE WORLD WIDE WEB. AFTER DISCUSSING THE ROLE SUPPLY AND DEMAND AGENTS PLAY IN THESE DEVELOPMENTS, THIS ARTICLE SUMMARIZES USEFUL AI INFORMATION RESOURCES THEY MAKE AVAILABLE.

WITH EACH PASSING MONTH, A number of new global virtual enterprises emerges on the World Wide Web. Relying on existing and rapidly developing commercial structures, they offer access to a wide range of information and services—from fashions to computer suppliers. Such virtual enterprises are built on a global information infrastructure, which relies upon the many new information resources on the WWW.

Many potential users, however, have not kept pace with this explosion of passive online information resources. Users are only slowly becoming aware of these databases—indeed, many are barely aware of the very existence of data on the WWW. Then, once they do become aware of these resources, most users need time, training, and upgraded equipment before they can take full advantage of them.

Web-available information sources provide heterogenous databases that can require expertise to use. In addition, the quantity of information sources has been growing exponentially, so that it is no longer feasible to be completely aware of all the universe of information sources. Accordingly, intelligent *agent-based systems*, employing intelligent and autonomous problem-solving agents, can greatly facilitate user access to these databases. These agents are computational processes that offer methods for achieving specific goals. Most current discussion of agent-based systems, however, revolves around their role in satisfying user demands for information. In such *information-gathering problems*, an agent takes on the task of gathering information to meet a variety of user needs.

A better, more comprehensive framework would include both demand *and* supply agents. After first exploring strategies employed in designing and implementing both of these kinds of intelligent agents, we show how they can provide access to valuable AI information on the WWW.

Supply and demand agents on the WWW

Supply agents provide information to demand agents. In particular, supply agents effectively configure information for information consumers. Supply agents may be either *originators* or *intermediaries*. Originators develop the information and place it on the WWW in its original form. Intermediaries take existing information or addresses to that information on the WWW and place it in a more accessible form and location. However, intermediaries may originate some information. Perhaps the most basic intermediary is the *list*, which is typically limited to a particular subject and provides references to a wide range of sources on that subject. Another type of intermediary is the search engine (keyword search tools).

Demand agents search for needed information. Also called information-gathering agents,[1] these typically are designed to search the WWW for information to meet user goals. Accordingly, one primary activity of the demand agent is the (effective) formulation of strategies for retrieval.

Other types of agents include *broker agents*, which match up supply agents' capabilities and demand agents' needs, and *librarian agents*. Minimal work has been done regarding these other agents, so we will focus here on supply and demand agents.

Need for supply agents. Previous research has focused on general-purpose demand

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agents that are designed to gather a wide range of information. Unfortunately, database searches typically require substantial domain-specific knowledge. Supply agents limit the extent to which demand agents must understand the world. Instead of knowing all aspects of the information or generating new information, demand agents can consult experts—the supply agents—that are responsible for supplying particular information.

Agent motives and objectives. Unlike much previous research in AI, we assume that agents operate in their own self interest. In this light, the motives of supply and demand agents can differ. The likely existence of different motives is probably more apparent when we consider the growth of electronic commerce on the WWW.

Consider the situation where supply agents are interested in selling information they have inventoried or summarized. In for-profit settings, the supply agent generates profits associated with use of the information or from making the information available. In that situation, supply agents want browsers to use their information, rather than information some competing source makes available.

Similarly, in a demand setting, because of cost constraints, agents must search for information as cheaply as possible. The search itself, the quality and completeness of information, and time can all entail costs. If there are multiple supply agents, the demand agent must choose among them, yet still complete its information-gathering goals.

Motives are particularly important in understanding the behavior of broker agents. Broker agents generate a return when they match up the supply and demand agents they represent. Thus, the broker would want to divert the demand agents to supply agents it represents, possibly in spite of the quality of the match.

Motives and storage location of information. Theoretically, information on the WWW need only be stored in one location, with other intermediary references to that information simply capturing the address. However, intermediaries have motives for maintaining locally available information on the WWW. First, in the current environment, where widespread use and understanding of the technology is limited, a certain amount of status accrues to the holder or originator of the information.

Second, and probably more important, the holder of the information controls what the viewer sees. Whenever an information consumer, or browser, views information, the information provider can present adjacent information and other addresses, thus shaping what information the demand agent or viewer accesses. Suppliers can more easily guide users to additional specific information if the information resides locally.

Information asymmetry and its impact. Demand and supply agents each experience asymmetries of information. Demand agents do not know the quality of the supply agent information. Supply agents can promise certain information, but may be unable to deliver. For example, until a search is made, the search agent cannot know if the search will yield the appropriate information.

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Similarly, supply agents may not know what information demand agents need. Though demand agents can be asked to provide information to help guide the search, such characterizations may be ambiguous or may change as new information arrives. Developing agent statements of information requirements presents a difficult issue, one subject to future research.

Broker agents may misrepresent the capabilities of the supply agents they represent. Unfortunately, unless they had multiple dealings with the particular broker and thus established the reputation of the agent, the ability of demand agents to determine if and when such misrepresentations had happened would be limited.

However, the Web itself could assist in mitigating the impact of brokers that aren't "truthful" regarding their clients. We could imagine agents that supply information about brokers or supply agents, regarding the fit between claims and actual available information.

Agent effectiveness and reputation. There are also effectiveness goals associated with supply, demand, and broker agents. Supply agents may supply too much or too little information, at too high a cost. Demand agents may not find the necessary information required to solve the information search problem they set out to do, or they may exceed budgets. Broker agents may be unable to direct demand agents to appropriate supply agents, or they may direct them only to very costly ones.

In multiperiod situations, the ability to meet objectives can affect reputations. If a supply agent promises that its information can meet certain goals, and if it does not do so, information demand agents may stop using that supply agent. By contrast, if the supply agent consistently provides the necessary information, it can anticipate enhancements to its reputation.

Distributed problem solving. Previous researchers[1] have discussed distributed problem solving for demand or gathering agents. Consider the case where a demand agent is asked to generate sufficient information for developing the financial ratio return on assets for a specific company. The problem might decompose into the search for the information that makes up that ratio. One agent could be responsible for searching available financial statement disclosures for average total assets, another for generating net income, and a third for generating interest expense net of income tax savings. Information from each of these agents could then be combined to generate the ratio of return on assets. This agent-based approach allows specialized knowledge about the generation of information, such as interest expense net of income tax savings, to be encapsulated into an autonomous agent. However, in spite of the need for and use of this specialized knowledge, the group of agents can still combine to solve the overall problem.

The introduction of supply and demand agents suggests that we need to develop a structure that allows distributed problem solving with supply and demand agents, and coordinated distributed problem solving between supply and demand agents. Many of the issues stay the same in both cases, but there are additional concerns.

Uncertainty increases[2] because of the information asymmetries between supply and demand agents, and from potentially heterogeneous supply agents. For example, supply

Originators

Much of the information about AI on the WWW is provided by the originators of the information. We have found a variety of originators of information, including those listed here:

Organizations: Both general computing and special interest AI organizations have home pages, with resources including pages for the journals they publish, upcoming meetings, awards, special interest groups, constitutional matters, subscription and membership information, and frequently asked questions (FAQs).

A few examples are

- American Association for Artificial Intelligence (AAAI) [http://www.aaai.org/]
- Association for Computing Machinery (ACM) [http://acm.org/] and ACM-Sigart [http://sigart.acm.org/]
- European Coordinating Committee for Artificial Intelligence (ECCAI) [http://wwwis.cs.utwente.nl:8080/mars/ECCAI.html]
- IEEE Computer Society [http://www.computer.org/]

Journals and newsletters: Journals of interest to the AI community have sites that include full text and/or abstracts of some or all of the articles published. Many journal sites include tables of contents of issues and information on where and how to submit papers. A few examples are

- *Artificial Intelligence: An International Journal*—general information, with no abstracts [http://www.elsevier.nl/catalogue/SA2/215/08670/08672/505601/505601.html]
- *IEEE Expert*—tables of contents and abstracts [gopher://info.computer.org:TablesofContents/Magazines/IEEE Expert]
- *AI Magazine*—editorial information, subscription information [http://www. aaai.org/Publications/ Magazine/magazine.html]

Bibliographies and article archives: A number of sites are available, including

- OFAI and IMKAI library information system [http://www.ai.univie.ac.at/biblio.html], provided by the Department of Medical Cybernetics and Artificial Intelligence at the University of Vienna (IMKAI) and the Austrian Research Institute for Artificial Intelligence (OFAI). It contains over 36,000 items (books, research papers, conference papers, journal articles) from many subareas of AI.
- HCI Bibliography Project [http://hyperg.tugraz.ac.at:80/D50FFDEC/CHCIbib] contain extended bibliographic information (abstract, key words, table of contents, section headings) for most issues of *Human-Computer Interaction* dating back to 1980 and selected publications before 1980.
- SEL-HPC Article Archive has sections for neural networks, distributed AI, theorem proving, and a variety of other computer science topics [http://www.lpac.qmw.ac.uk/SEL-HPC/Articles/ index.html].
- MLnet Machine Learning Archive at GMD includes papers, software, and data sets [ftp://ftp.gmd.de/ml-archive/README.html]
- Bibliographies on AI [ftp://ftp.cs.umanitoba.ca/pub/bibliographies/ai/index.html]

Grant information:

- National Science Foundation [http://www.nsf.gov/]
- European Commission [http://www.echo.lu/home.html]

Academic departments: Academic departments have pages of interest. Many of the departments include special sections for their AI activities.

Research labs and research groups: Several AI research labs and research groups have pages that include details of projects, publications, and software. A few examples of AI Labs are

- Robotics Research in Japan [http://hyp.jsk.t.u-tokyo.ac.jp/~tom/rsj.html]
- The Robotics and Vision Research Group at The University of Western Australia [http://www.cs.uwa.edu.au/robvis/index.html]
- The AI Lab at Hamburg University [http://lki-www.informatik.uni-hamburg.de/]
- University Catholique de Louvain Neural Net Group [http://www.dice.ucl.ac.be/neural-nets/NNgroup.html]

information may need to be coordinated between supply agents that originated from different sources. Information thus derived from these agents may not readily combine.

Generating problem solutions from groups of supply agents can require different types of coordination efforts, varying along a spectrum of supply-agent configurations. At one end of the spectrum is the case where the demand agent or broker agent would need to coordinate the solution of problems individually with a number of the supply agents. In the middle is the formation of federations of loosely connected supply agents. At the far end is a tightly knit set of agents with established roles of interaction for problem solution.

Information about agents on the WWW. The literature makes little, if any, actual reference to supply or broker agents, or to the corresponding issues surrounding the interaction of supply and demand agents. However, agents are an active area of research as represented by information on the WWW. For example: The Distributed Artificial Intelligence Laboratory at the University of Massachusetts has a Cooperative Information Gathering Project [http://dis.cs.umass.edu/research/cig.html].

The Carnot Research Group is working on the InfoSleuth project, exploring the application of semantic integration to the problems of publishing and advertising information in large-scale networks, as well as the problem of searching for information via intelligent agents [http://www.mcc.com:80/projects/infosleuth/].

Intelligent agent resources on the WWW include

- Intelligent Agents page from the University of Maryland, Baltimore County [http://www.cs.umbc.edu/agents/]
- Knowledge Systems Laboratory of the Canadian NRC's AI Resource List Agents page [http://ai.iit.nrc.ca/subjects/Agents.html]
- Intelligent Software Agents housed at the University of Cambridge Computer Laboratory [http://www.cl.cam.ac.uk/users/rwab1/agents.html]
- A comprehensive series of links to intelligent agent material [http://pelican.cl.cam.ac.uk/people/rwab1/ag-pages.html]
- WWW Robots, Wanderers, and Spiders information [http://web.nexor.co.uk/mak/doc/robots/robots.html] provided by Nexor includes a page [http://web.nexor.co.uk/mak/doc/robots/active.html] with references to descriptions of several Web wanderers.

Supply of AI information on the WWW

AI information supplies come from two primary sources: originator suppliers and intermediary suppliers. The Originators box and the Suppliers box present the results of

Originators (continued)

- Knowledge Systems Laboratory, National Research Council [http://ai.iit.nrc.ca/home_page.html]
- The Massachusetts Institute of Technology AI Laboratory [http://www.ai.mit.edu/]

Companies: Numerous companies with AI related products, services, and research labs also have Web pages. A few examples are:

- Inference Corp. [http://www.inference.com/] features information on ART*Enterprise and CBR2 (CBR Express and CasePoint) including product demonstrations and success stories from customers.
- Lockheed AI Center has information on Lockheed's Recon system and several other current research projects [http://hitchhiker.space.lockheed.com/aic/README.html]
- The Price-Waterhouse Technology Centre, USA—includes descriptions of their expert systems [http://www.pw.com/]
- Teknowledge Corporation has information on their Intelligent Systems Integration program, system successes, and other products and services [http://www.teknowledge.com]

Teaching resources: Teachers are beginning to provide course outlines, tutorials, teaching notes, and other teaching materials to students on the WWW. Many are willing to share these materials with others and post them on lists such as

- The World Lecture Hall [http://www.utexas.edu/world/lecture/]
- The Global Campus [http://www.calpoly.edu:80/~delta/]
- AI-related courses available on-line at the UK Open University [http://kmi.open.ac.uk/diploma-msc-info.html]
- Pedagogic Resources for Teaching and Learning Introductory AI [http://yoda.cis.temple.edu:8080/IIIA/ai.html]

Software: FTP sites offer the opportunity to download AI-related software including:

- Babylon [ftp://ftp.gmd.de/GMD/ai-research/Software/Babylon/]—a modular, configurable, hybrid environment for developing expert systems. The shell is implemented and embedded in Common Lisp.
- Clips [http://www.jsc.nasa.gov/~clips/CLIPS.html]—a productive development and delivery expert system tool that provides a complete environment for the construction of rule- or object-based expert systems.
- Winterp [http://www.eit.com/software/winterp/winterp.html]—a rapid prototyping environment for creating and delivering GUI-based applications.
- Various machine-learning programs at
  - University of Illinois [http://ilg.cs.uiuc.edu/pub/src],
  - University of Texas [http://net.cs.utexas.edu/users/ml/], and
  - University of California, Irvine [http://www.ics.uci.edu/AI/ML/MLPrograms.html]
- A wide range of software is available at the Carnegie Mellon University Artificial Intelligence Repository software site [http://www.cs.cmu.edu:8001/afs/cs.cmu.edu/project/ai-repository/ai/areas/0. html]

Contests: There is even information available about contests

- Loebner Prize Competition in Artificial Intelligence [http://www.csusm.edu/loebner_contest.html]
- 12th Maryland Theory Day, "Man vs. Machine Chess Match": Grandmaster Gennady Sagalchik vs.1800-node Intel Paragon Supercomputer Running Socrates [http://www.cs.umbc.edu/conferences/mtd95/mm_match/]

AI books can be ordered on-line from some publishers including:

- AAAI Press [http://www.aaai.org/Publications/Press/press.html]
- Cambridge University Press Complete On-line Catalog [http://www.cup.cam.ac.uk/Connections/BRS.html]
- Elsevier Science [http://www.elsevier.nl/]
- Reiter Books [http://www.awa.com/reiters/14.html]
- MIT Press [http://www-mitpress.mit.edu/mitp/recent-books/comp/comp-sci-toc.html]

an extensive survey we conducted of WWW-supplied information.

Analysis

With all the available databases, we may want to compare empirically the importance or influence of supply agents. There are a number of ways of gathering data about a WWW information source. First, the very existence of intermediary supply agents suggests that the information is important to some set of users.

Second, probably the most frequently used and easiest-to-capture measure is the number of "hits," or times a source is visited. However, only the owner of the address page generally has access to that information, and information generated based on number of visits, or hits, is easily distorted and manipulated.

Third, we can determine the number of times a particular address is mentioned by other supply agents; that is, to what extent intermediate sources find the originator information important. Since such a measure is probably constantly changing, in many cases it may be difficult to determine. One approach to approximate the number of references to a particular address is to limit the investigation to a particular set of intermediate sources. For example, the importance of a journal might be measured by the number of appearances of the journal's address in supply agents. Unfortunately, this measure may also be biased. Such lists depend on addresses available at a particular time, so the supply agent may not reflect any changes since that time. Further, getting information to be captured by a particular supply agent may be a political process. In some cases, lists may be specifically limited to information suppliers that meet a specified requirement—for example, only "http" format or willingness to pay a fee. Finally, the level of WWW awareness of the originator may also limit the extent to which information is made available by different intermediaries.

Originators. In our study, we did not find that originators were particularly effective in the way they configure information. Virtually all the original information was not designed for supplier intermediaries or demand agents. For example, seldom do originators provide key words or other information description data that might facilitate intermediate supply agents' presentation of information or demand agents' search for information. In addition, many originators of information on the WWW did not provide e-mail addresses for communication about the information they presented.

Information originators do seem to view the provision of information as a signal. Frequently, that signal is designed to bring additional attention to the information source. For example, originators of information on journals probably provide that information

Intermediary suppliers

Intermediaries of AI information occur in almost all of the same categories as originators. Intermediaries assist in the structuring of the information/knowledge on the Web. We found a number of intermediary sources of agents, including the following. (The address for "our list" is included with the authors' biographies.)

Organizations: Resources provided by organizations can be extremely detailed, including—for example, its magazines and journals and searchable abstracts from the proceedings of all conferences held under the auspices of the organization. There are some more extensive lists of AI organizations, including the following.

- Our list has links to over 20 organizations from around the world
- CMU's AI Associations and Journals FAQ, which has an extensive list of AI Associations, some with links to the association's home page. [http://www.cs.cmu.edu/Web/Groups/AI/html/faqs/ai/ai_general/ part3/faq.html]

Journals and newsletters: There are more extensive lists of journals available at

- AI Journals List [http://ai.iit.nrc.ca/ai_journals.html]
- Our list has links to approximately 50 sites.

Bibliographies and article archives on AI: A number of sites are available, including

- Bibliographies on Artificial Intelligence has links to several bibliographies for journals, including *AI Expert, IEEE Expert, AI Magazine,* and many more. [ftp://ftp.ira.uka.de/pub/bibliography/AI/index.html]
- List of AI Bibliography sites is available at [http://liinwww.ira.uka.de/bibliography/AI/others.html]

Grant information: Grant information is provided by a number of suppliers of information:

- University of Tennessee's Research Services page at [http://solar.rtd.utk.edu/]
- The Corporation for National Research Initiatives at [http://www.cnri.reston.va.us/]
- Possibly the best way to find this information is to use the Lycos Search Engine.[http://query1.lycos.cs.cmu.edu/lycos-form.html]

Academic departments: Although there are probably hundreds of academic departments with home pages, there are two primary lists of academic departments.

- Yahoo (probably the largest hierarchical database on WWW, with 33,512 entries as of March 1995) has a list of Computer Science departments [http://www.yahoo.com//Science/ Computer_Science/Institutes/]
- The WWW Virtual Library also has a page on University Computer Science Departments [http://src.doc.ic.ac.uk/bySubject/Computing/UniCompSciDepts.html]

Research labs/research groups: There are a number of lists of AI labs.

- Our list, with over 140 AI Labs, includes labs from four continents.
- Yahoo has a list of AI Institutes at [http://www.yahoo.com/Science/Computer_Science/Artificial_Intelligence/Institutes/]
- The WWW Virtual Library also has a section on computer science institutes at [http://src.doc.ic.ac.uk/bySubject/Computing/Overview.html#inst]

Companies: Our list has links to around 40 companies.
Teaching resources: Secondary supply of teaching resources has apparently received little attention.
Contests: There does not seem to be any secondary supplier of information on contests.
Software: The Virtual Library Logic Programming section has many links to down-loadable software.[http://gruffle.comlab.ox.ac.uk/archive/logic-prog.html]

Individuals' home pages: Many individuals include a list of their research publications on the WWW. If you find an article of interest, it is relatively easy to find subsequent publications and working papers on similar topics on lists of home pages. For example:

- Artificial Intelligence Personal Home Pages (a list of lists, including one for famous AI researchers) [http://ai.iit.nrc.ca/ai_people.html]
- Case-Based Reasoning Home Pages [http://mnemosyne.itc.it:1024/avesani/html/cbr.html]
- Graduate Students Who's Who in Robotics [http://www.sm.luth.se/csee/ra/sm-roa/Robotics/WhoSWho.html]

AI domain resource lists: There are a number of suppliers of lists of AI information:

- Yahoo includes a section on AI [http://www.yahoo.com//Science/Computer_Science/Artificial_Intelligence/]
- Sigart's resources list [http://sigart.acm.org/otherAI.html]
- Artificial Intelligence Resources [http://ai.iit.nrc.ca/ai_point.html]
- The Virtual Library's AI List at [http://www.comlab.ox.ac.uk/archive/comp/ai.html]
- The AI, Cognitive Science, and Robotics WWW Resource Page [http://www.cs.ucl.ac.uk:80/misc/ai/]
- Robotics [http://www.sm.luth.se/csee/er/sm-roa/Robotics/RoboJump.html]
- Machine Learning Resources [http://www.eecs.wsu.edu/~schlimme/ml.html] and [http://www.ics.uci.edu/AI/ML/Machine-Learning.html]
- Knowledge Discovery and Data Mining [http://info.gte.com/~kdd/]
- Network Cybernetics Corporation's AI Internet Resource list [http://www.ncc.com/ncc/ai/ai3_other.html]
- Artificial-Life Simulators and their applications resource guide, bibliography, and list of active research groups [http://alife.santafe.edu/alife/topics/simulators/dret/dret.html]

as a means of generating awareness about the journal, and originators of information about companies probably hope to generate awareness about the companies. The information disclosure thus becomes a form of publicity.

Not surprisingly, our analysis thus found that particular information originator sources seldom reference other sources of the same information: companies rarely reference other companies, and journals rarely reference other journals. If there are references, they are to other noncompeting types of sources of information. Journals, for example, might reference organizations.

Intermediaries. Demand agents probably use a number of criteria to evaluate the quality of information supplied by intermediaries. When comparing the quality of supply agent lists, completeness and correctness are two readily identifiable criteria. With completeness, if there is information available on one list, we can anticipate that the same knowledge will become available on future lists, a finding that journal lists substantiate. We generated a list of AI journals that subsumed a previous list. Both are given under Journals

and Newsletters in the Intermediary Suppliers box. We fully anticipate that our list will be subsumed by some other list or other type of intermediary agent. Subsequent versions of supply agents will likely adopt available knowledge. The knowledge in subsequent specialized supply agents then is likely to be highly correlated.

Further, the relationship between the information available in different intermediary supply agents will likely depend on if the intermediary supply agent requires an application for the new information to be added or if the agent takes all comers. If the agent requires an application, there will generally be a lower correlation in the knowledge than if the agent takes all comers. In the latter case, the different versions of supply agents—the lists—are likely to be highly correlated as information cascades from one supply agent to another, over time. Most lists for AI information are of the second type.

BROADENING THE FOCUS TO INclude both demand agents and supply agents and their intermediaries gives us a fuller insight into the recent rapid growth of intelligent agent-based systems. Such a fuller perspective can help introduce new information users to a wider range of resources more quickly.

Work remains to be done in a number of areas. First, in general, agent suppliers of information are not "demand-agent ready." There is no universal set of interfaces or language to indicate what supply agents can provide. Second, there is little research that relates to linking requests or requirements of demand agents to the ability of supply agents to provide information. Third, additional research in the brokering of information between intelligent agents on the WWW is needed. Issues such as reputation and asymmetries of information need to be explored as well.

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