State-of-the-Art Survey

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Yang Cai (Ed.)

Ambient Intelligence for Scientific Discovery

Foundations, Theories, and Systems

Springer

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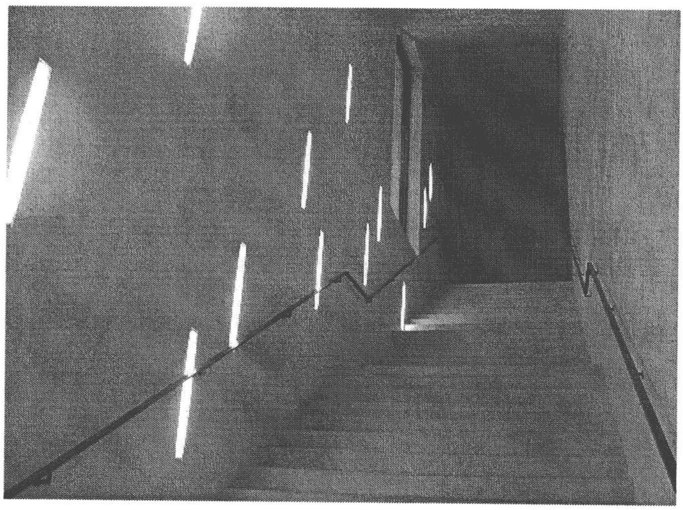

The Museum of Modern Art is perhaps one of the most interesting landmarks in Vienna, where SIGCHI 2004 Workshop of "Ambient Intelligence for Scientific Discovery" was held. The building is covered by walls and ceiling composed of thick slabs of dark basalt stone cut at intervals by narrow vertical slits, accentuating the monolithic effect of the entire volume.

Preface

For half a century, computer scientists have been working on systems for discovering lawful patterns in letters, numbers, words and images. The research has expanded into the computational study of the process of scientific discovery, producing such well-known AI programs as BACON and DENDRAL. However, *autonomous* discovery systems have been rarely used in the real world. While many factors have contributed to this, the most chronic difficulties seem always to fall into two categories: (1) the representation of the prior knowledge that people bring to their tasks, and (2) the awareness of new context.

Many difficult scientific discovery tasks can only be solved in *interactive* ways, by combining intelligent computing techniques with intuitive and adaptive user interfaces. It is inevitable that human intelligence is used in scientific discovery systems. For example, the human eyes can capture complex patterns and relationships, along with detecting the exceptional cases in a data set. The human brain can easily manipulate perceptions (shape, color, balance, time, distance, direction, speed, force, similarity, likelihood, intent and well-being) to make decisions. This process consists of *perception* and *communication* and it is often ubiquitous and autonomous. We refer to this kind of intelligence as ambient intelligence (AmI).

Ambient intelligence is about human interaction with information in a way that permits humans to spot interesting signs in massive data sources – building tools that capitalize on human strengths and compensate for human weaknesses to enhance and extend discovery capabilities. For example, people are much better than machines at detecting patterns in a visual scene, while machines are better at manipulating streams of numbers.

Scientific discovery is a process of creative perception and communication. With growing data streams and the complexity of discovery tasks, we see a demand for integrating novel digital media and communications (e.g., body media, capsule cameras, WiFi, etc.) and opportunities for ambient intelligence to use interaction methods that are usually taken for granted, such as perception, insight and analogy. We want to search for solutions to interesting questions such as: How do we significantly reduce information while maintaining meaning? How do we extract patterns from massive and growing data resources?

This volume represents the outcome of the SIGCHI Workshop on "Ambient Intelligence for Scientific Discovery," held in Vienna, on April 25, 2004. The chapters in this volume were selected from the revised papers submitted to the workshop and contributions from leading researchers in this area. The objective of this volume is to present a state-of-the-art survey of studies in ambient intelligence for scientific discovery, including novel ideas, insightful findings and ambient intelligence systems across multiple disciplines and applications. The volume is published for graduate students, senior undergraduate students, researchers and professionals. Therefore, extended references are provided in each chapter.

The contents in this volume are organized into three tracks: Part I, New Paradigms in Scientific Discovery; Part II, Ambient Cognition; and Part III, Ambient Intelligence Systems. Many chapters share common features such as interaction, vision, language, and biomedicine, which reflect the interdisciplinary nature of this volume.

I. New Paradigms in Scientific Discovery. Processing massive data has been a bottleneck to modern sciences. In Chap. 1, "Science at the Speed of Thought," Devaney et al. describe a virtual laboratory that is designed to accelerate scientific exploration and discovery by minimizing the time between the generation of a scientific hypothesis and the test of that idea, and thereby enabling science at the speed of thought. In Chap. 2, "Computational Biology and Language," Ganapathiraju et al. present a breakthrough approach that enables exploitation of an analogy between natural language and speech processing techniques in computational biology. In Chap. 3, "Interactive Comprehensible Data Mining," Pryke and Beale present their interactive data mining system that helps users gain insight from the dynamically created virtual data space. In Chap. 4, "Scientific Discovery Within Data Streams," Cowell et al. present the architecture of a next-generation analytical environment for scientific discovery within continuous, time-varying data streams.

II. Ambient Cognition. Understanding how people sense, understand and use images and words in everyday work and life can eventually help us design more effective discovery systems. In Chap. 5, Leyton reviews his theory of "Shape as Memory Storage", addressing shape description over time. Leyton's theory has been used in more than 40 fields, such as radiology, metrology, computer vision, chemical engineering, geology, computer-aided design, anatomy, botany, forensic science, software engineering, architecture, linguistics, mechanical engineering, computer graphics, art, semiotics, archaeology, and anthropology, etc. In Chap. 6, Hubona and Shirah investigate how various spatial depth cues, such as motion, stereoscopic vision, shadows and scene background, are utilized to promote the perceptual discovery and interpretation of the presented imagery in 3D scientific visualization. In Chap. 7, "Textual Genre Analysis and Identification," Kaufer et al. present a knowledge-based approach for encoding a large library of English strings used to capture textual impressions and report on a study of a popular textual genre – the technology review. The expert system incorporates contextual information, e.g., culture, emotion, context, and purpose, etc., which is different from many prevailing methods such as machine learning or statistics. In Chap. 8, "Cognitive Artifacts in Complex Work," Jones and Nemeth use acute care and scientific ethnographic field studies to show how cognitive artifacts can be used to grasp the nature of cognitive work in uncertain, complex, technical work settings. This front-end research is aimed at optimizing the distributed cognitive work.

III. Ambient Intelligence Systems. Ubiquitous sensors and communication technologies not only can assist scientific discovery, but can also catalyze new sciences. In Chap. 9, "Multi-modal Interaction in Biomedicine," Zudilova and Sloot investigate the practical deployment of virtual reality systems in the medical environment. They explore the multi-modal interaction of virtual reality and desktop computers in Virtual Radiology Explorer. In Chap. 10, "Continuous Body Monitoring," Farringdon and Nashold describe a personal and continuous body monitor that is one of the few examples of ambient intelligence devices commercially available today. This also brings challenges to sciences: for example, how do we extract the interesting patterns from a continuous body monitor? From this example we can see how the research scope has been extended from laboratories to homes and in vivo. In Chap. 11, "Ambient Diagnosis," Cai et al. explore *Ambient Diagnosis* that is based on traditional Chinese medicine (TCM). The case study shows how to map the visual features on the tongue into a vector of numbers. In Chap. 12, Tanz et al. describe methods for location mapping in a wireless local area network (WLAN) and applications in social sciences. The system cmuSKY developed by the authors has become a public online resource for scientific discovery. In Chap. 13, "Behavior-Based Indoor Navigation," Abascal et al. present a method for motor fusion using ambient information from the environment. Indoor robotic navigation has been an active subject because of applications in assisted-living, such as smart wheelchair control, guidance for the visually impaired, or indoor assistance of the elderly. Finally, in Chap. 14, "Ambient Intelligence Through Agile Agents," O'Hare et al. explore agile agents as a key enabler for the realization of the ambient intelligence vision.

We are deeply indebted to all the authors who contributed papers to this volume; without this depth of support and commitment there would have been no meaningful product at all. We acknowledge the members of the program committee, all those involved in the refereeing process, the workshop organizers, and all those in the community who helped to convene a successful workshop. Special thanks go to Judith Klein-Seetharaman, Peter Jones, William Eddy, David Kaufer, Yongxiang Hu, Bin Lin, and Vijayalaxmi Manoharan for their contributions to the workshop and this volume. Thanks to the external reviewers Howard Choset, Lori Levin, Susan Fussell, and Tony Adriaansen for their comments on the manuscripts. Thanks to Teri Mick for assisting the volume editing and Sarah Nashold for assisting the book design. This project is in part sponsored by NASA grant NAG-1-03024 and National Academy of Sciences (NAS) grant T-37.

Pittsburgh, October 2004

Yang Cai

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Science at the Speed of Thought

Judith E. Devaney[1], S.G. Satterfield[1], J.G. Hagedorn[1], J.T. Kelso[1], A.P. Peskin[1], W.L. George[1], T.J. Griffin[1], H.K. Hung[1], and R.D. Kriz[2]

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1 Introduction

Scientific discoveries occur with iterations of theory, experiment, and analysis. But the methods that scientists use to go about their work are changing [1].

Experiment types are changing. Increasingly, experiment means computational experiment [2], as computers increase in speed, memory, and parallel processing capability. Laboratory experiments are becoming parallel as combinatorial experiments become more common.

Acquired datasets are changing. Both computer and laboratory experiments can produce large quantities of data where the time to analyze data can exceed the time to generate it. Data from experiments can come in surges where the analysis of each set determines the direction of the next experiments. The data generated by experiments may also be non-intuitive. For example, nanoscience is the study of materials whose properties may change greatly as their size is reduced [3]. Thus analyses may benefit from new ways to examine and interact with data.

Two factors will accelerate these trends and result in increasing volumes of data:

- CPU speedup: as companies strive to keep Moore's law [4,5] in effect
- Computer architecture speedup: as all computers benefit from architecture advances in high end computers.

Figure 1 gives an overview of how these impact problems [6]. These factors make computers ever more capable and increase the move to computational experiments and automation.

But a third factor offers a partial solution: graphics speedup. Computer game enthusiasts are funding a fast pace of development of graphics processing units (GPUs) [7,8]. The use of these GPUs in the support of science makes the future world increasingly computational, visual, and interactive.

We believe that representation and interaction drive discovery, and that bringing the experiments (computer and laboratory) of science into an interactive, immersive, and collaborative environment provides opportunities for speed and synergy. Adding traditional data analysis, machine learning, and data mining tools, with multiple representations and interactions can speed up the rate

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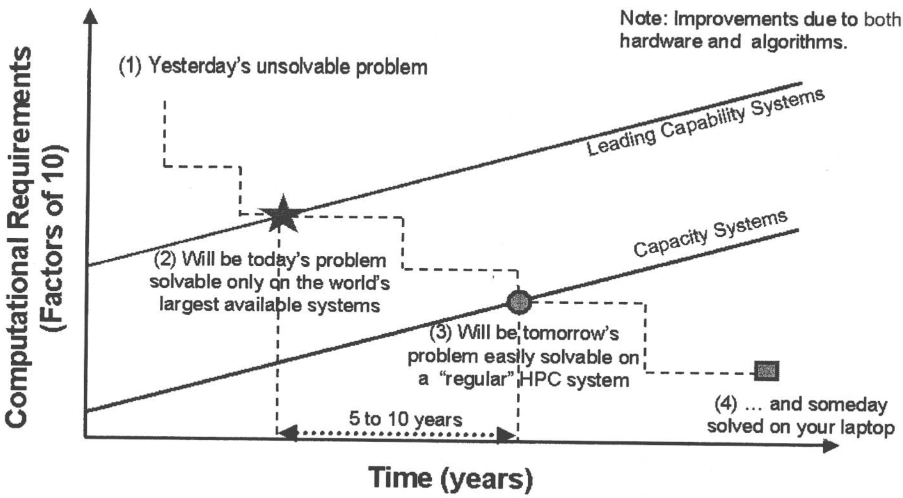

Fig. 1. Transition of solving important problems from unsolvable to solvable on your laptop.

of exploration and lead to new insights and discovery. Creating an environment that is efficient, general and flexible enough to work well across a wide variety of scientific applications is at the heart of our Virtual Laboratory (VL) design.

In section 2, we describe the VL we are building at NIST to address these issues. In section 3, we describe some applications. We present conclusions and future work in section 4.

2 The Virtual Laboratory

The VL needs to be efficient, general, and flexible, but it also needs to be able to get applications into it quickly in order to speed up the process of science and not burden it. Representations and interactions of many types need to be available and easily accessed. To accomplish this, our design consists of the following components:

- A distributed computing environment that provides the communication fabric of the VL,
- An immersive visualization environment that provides representation, interaction, and collaboration capability in the VL,
- A suite of tools for machine learning and analysis.

We will discuss each of these in turn.

2.1 Distributed Computing Environment

An important part of the VL is the capability of users to interact with their data sources, analysis programs, and their experiments, either computer experiments or laboratory experiments, from any of the supported VL access points (see Fig. 2

for a schematic). Examples of access points are the immersive visualization system or a remotely connected workstation. For the purposes of this discussion, data sources and analysis programs will be subsumed under computer experiment. The interactions range from viewing the status of their currently running experiment, or the results of a prior experiment, to providing feedback to the experiment in order to alter or restart the experiment. To provide this range of access requires a framework that enables communication between the user, the experiment, the visualization, and possibly with other collaborators actively interacting with the experiment.

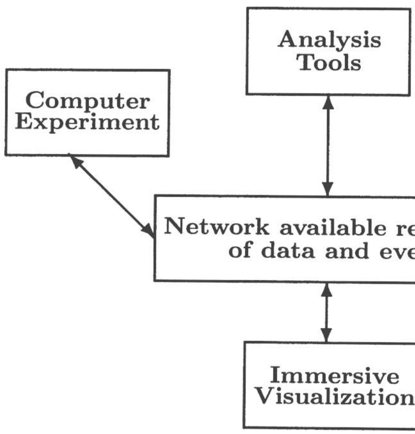

Fig. 2. Schematic of Distributed Computing Environment. Each component may also access other data sources.

The VL uses what is generically referred to as a coordination framework to provide a loose coupling between all participating entities of an experiment. The coupling is loose in that participants, that is, laboratory experiment equipment, computer simulations, visualization systems, user interfaces, and any other connection to the VL, can choose whether or not to utilize this coupling and can connect and disconnect from it at any time without disrupting the system. The VL distributed computing framework is implemented using the Java technology of Jini and JavaSpaces [9] [10]. Both of these packages, Jini and JavaSpaces, are available as pure Java implementations and so are portable to any system that supports a Java virtual machine, which includes systems running Linux, Microsoft Windows, and most Unix based operating systems.

Jini provides support for a form of distributed computing that explicitly handles common issues that arise in a distributed (networked) system, such as intermittent network outages and server crashes. Support includes automatic discovery of services available on the network, active leasing of services to help maintain current service information and to purge services that no longer exist, and distribution of events to remote applications to allow applications to communicate asynchronously and to react to expected or unexpected developments.

JavaSpaces is a specification for a Jini service that provides a coordination framework in the form of a tuple space. The concept of a tuple space was first introduced in the early 1980s by computer scientists David Gelernter and Nick Carriero, within the context of the programming language Linda [11] [12]. This is referred to as a coordination framework since it allows a loose collection of applications, linked over a common network, to communicate asynchronously. This communication is so loosely coupled that the applications do not need to be running, or even exist, at the same time. To take the possibilities to an extreme, application A can send a message that is ultimately to be read by application B (and possibly others) which has not yet been written and will run on a machine that has not yet been built. When application B receives the message, application A, and the machine it ran on, may no longer exist.

There are many ways to describe the purpose and use of a JavaSpace. The concept of a coordination framework is a good high-level description. At a lower level, a JavaSpace can be thought of simply as a shared memory space, accessible from any machine on the network and addressed using an associative lookup rather than by memory address. Objects stored in a JavaSpace are instances of classes in Java that have a few special characteristics needed to support storage and retrieval from the JavaSpace. So the associative lookup uses the Java class type system to identify objects to be written or read from the JavaSpace. This is a very robust addressing scheme, compared to using raw memory addressing or simple string matching, since it ensures that you receive an object of the correct type when you read from the space. These objects can store any type of information that might be needed by the applications. It is also possible to maintain structures of objects in a JavaSpace, such as a linked list of objects, a tree of objects, or an array of objects. Objects can also simply be markers, holding absolutely no data, but giving information simply by their existence or non-existence in the JavaSpace.

In the VL, a JavaSpace is maintained to allow for the coordination of experiments, visualizations, and interacting collaborators accessing the VL through their workstation or other supported interface device. Typical information stored in the VL JavaSpace includes experiment parameters, current status of an experiment such at the latest time-step of a computer simulation, or latest result from a laboratory experiment.

Of course, applications need not be written in Java to participate in the VL. In fact, it is expected that most computer simulations will likely be written in Fortran or C/C++, and most participating laboratory devices will likely not have direct network access. In Jini, applications and devices that are not capable of participating directly, either because of insufficient resources to run a Java virtual machine, or because they are closed systems, can still participate through the use of a surrogate [13]. These surrogates allow the application or device to participate by performing as a communications gateway to the Jini/JavaSpace network and also performing any computation needed in the process. The communication between the surrogate and the Jini/JavaSpace network uses the standard Jini/JavaSpaces protocols. The communication between the surrogate and