Columbia University Department of Computer Science NSF CISE Research Infrastructure Grant Scalable Multimedia Information Processing Year One Progress Report

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Abstract

The National Science Foundation's CISE Research Infrastructure Grant to the Computer Science Department at Columbia University is providing a networking and computational infrastructure for leading edge research projects in scalable multimedia information processing and active networks. This report describes the objectives and goals of the overall research program enabled by this award. In the first year of this award, we have implemented an innovative data networking infrastructure that has improved our networking capacity by two orders of magnitude. We summarize the projects aided by this award and the impact this award is having on our department, school, and university.

1 Introduction to Columbia University and its Computer Science Department

Columbia University is the oldest institution of higher education in the state of New York and the fifth oldest in the United States. It was established under a royal charter from George II in 1754 as Kings College. Among the University's early students were Alexander Hamilton, John Jay, Robert Livingston, and Gouverneur Morris, who were destined to play prominent roles in the founding of the United States.

The Computer Science Department at Columbia University was founded in 1979, and has grown to 21 faculty members who teach over 3000 students enrolled in the department's courses, and who supervise the research of 75 doctoral students. The new NSF Infrastructure grant is being used by the department to modernize its research infrastructure created with an NSF Institutional Infrastructure award beginning in 1991. These awards have helped make the Computer Science Department at Columbia University one of the top twenty computer science departments in the United States.

2 The Scalable Multimedia Information Processing Research Infrastructure Project

The overall technical goal of this project is to help create the scientific and technological infrastructure for building intelligent, scalable networks that enable any user anywhere to efficiently and effectively access and present desired information in any format and modality. The research program is driven by four key thrust areas: integrated multimedia information systems; visual information processing; mobile multimedia user interfaces; and scalable, adaptive multimedia networked systems.

In keeping with the University's traditions of excellence in education and research, this award is already having significant impact in both these endeavors. This is the first year of this award, and a distinctive feature of this year's work has been upgrading the capacity of the network of the department by two orders of magnitude, enabling significant new research initiatives in the four key thrust areas. This report describes the new networking infrastructure in detail.

3 Goals and Objectives

In the last few years, data networks have become not only a research topic, but also a vital infrastructure for conducting computer-science research in general. For most researchers, web and email access is far more important than, say, the postal system or the telephone. Computer networks play a central role in instruction, with course content, coordination and delivery of lectures depending on a high-speed networking infrastructure. In many cases, these new demands feed on each other, with remote interaction for instruction and collaboration providing motivation and problems for networking research, for example.

The Columbia University Department of Computer Science has embarked on an ambitious project of upgrading the departmental networking infrastructure to accommodate these new demands and allow deployment of advanced applications and protocols across all of its research activities.

Many of the recent issues concern the scalability of applications, say, for multicast delivery of multimedia content. Here, an advanced departmental network infrastructure can turn the department into a test and measurement facility under conditions much closer to reality than a small lab network. For example, there are about 500 networked devices such as workstations and PCs in the Department, far beyond the scale of any networking laboratory. Through high-speed connectivity to the campus at large, new applications such as high-quality audio and video delivery or Internet telephony can reach close to 20,000 users. The departmental infrastructure also provides the connectivity to enable the department to participate actively in the Internet 2 efforts, fostering interaction with sister institutions, the local laboratories engaged in networking research such as

Bell Laboratories, AT&T Research, Bellcore, NYNEX and NEC as well as the city's media and networking companies.

The new infrastructure described below allows faculty and students to pursue research into all thrust areas encompassed by this award. In designing the infrastructure, the research needs of senior undergraduate, master's and PhD students as well as the faculty were taking into account, as these often collaborate on research projects.

4 Components and Materials

Like many computer science departments, our network consisted of shared-media 10 Mb/s Ethernet subnets interconnected by routers, with a 100 Mb/s FDDI ring interconnecting the file servers. While in the past, most computation and program development was performed on central compute servers, so that data did not leave the FDDI ring, most compute applications are now performed on workstations in the individual labs or in the researchers' offices, severely taxing the network infrastructure. The existing infrastructure also could not support delivery of audio and video, as it lacked bandwidth and multicast capability. The problems with the existing infrastructure could not be remedied by replacing isolated components, as this would have simply moved the bottleneck elsewhere within the network.

Based on extensive discussions of future research and general infrastructure needs, we decided that a network based on a switched Ethernet would offer the best performance for the given budget, while opening avenues to higher-speed connectivity such as Gigabit Ethernet in the near future. Ethernet switches have low delays, making it possible to use the network for distributed computation, e.g., building a "virtual" parallel computer out of distributed workstations. Almost all of the department's traffic uses the Internet protocol suite, simplifying network design. Unlike ATM, 100 Mb/s Ethernet cards have become standard equipment for new workstations and PCs, making upgrading the network to either shared or switched 100 Mb/s easy without replacing the switching infrastructure.

The new networking infrastructure is based on the premise that current and projected applications require the delivery of 10 Mb/s to every desktop, with servers being connected at a speed of 100 Mb/s. This bandwidth corresponds to that recommended by the Internet 2 project.

Since the Department is distributed across two buildings, on two floors each, the network consists of five high-speed switches with a capacity of about 1 Gb/s each. Due to distance and concerns about electrical noise, the switches are interconnected by multi-mode fiber. All other wiring is being upgraded to category-5, enabling 100 Mb/s to the desktop.

The switches are designed to support link-layer Ethernet frame switching as well as routing, so that we can isolate, at the network layer, segments of the network. This is particularly useful for experiments that simulate larger networks. The switches support multicast filtering, so that only those parts of the network that want to receive, say, a video stream will be affected.

We are currently building gateways to the public switched telephone system. This allows us to experiment with wide-scale use of the new network for day-to-day audio and video communications, eventually replacing the standard telephone.

The high-speed network connectivity is also a central component of the new Student Research Lab being put in place. The new lab will consist of 20 workstations, each capable to capture and render audio and video. The lab will serve as an enabler for advanced student research projects in a wide variety of classes, ranging from computer networks to multimedia systems, operating systems, computer graphics, robotics and software engineering. Beyond individual projects, the lab also makes it possible for on-campus students to collaborate with others off-campus. Thirdly, the lab can serve as a fully interactive class room, which greatly improves the integration of off-campus students into the classroom experience compared to the traditional video-taped or narrow-band video-conferencing lectures. Students and instructors at locations off-campus can see and hear each other clearly and jointly control and display shared software applications. This is particularly important for Columbia University as we educate a large number of Master's students from New York City and the larger metropolitan area, such as the New York and New Jersey research labs mentioned earlier.

5 Indications and Degree of Success

This first year of this project has been immensely successful as measured by research collaborations with United States industry, interactions with other schools and departments within Columbia University, and student involvement in our new courses and research programs. The University and School of Engineering and Applied Science have already committed $700,000 in matching funds to expand and enhance the impact of the new NSF CISE Research Infrastructure grant.

Several dozen new research projects have been launched in the four key thrust areas because of the upgraded networking and computational infrastructure enabled by this grant. These projects have engaged 14 faculty members and more than 60 graduate students. These projects involve a number of U.S. companies, as well as the Columbia-Presbyterian Medical Center, the School of Architecture, the Graduate School of Journalism, Teachers College, as well as other departments in the Engineering School. Here are some examples of representative projects.

In collaboration with Microsoft, Netscape and Progressive Networks (RealAudio), we are developing a new media server control protocol (RTSP) [1, 2], which will allow flexible delivery of audio and video to individuals and large and small groups. A signaling protocol for Internet telephony and multimedia services is designed to fundamentally change the way that "intelligent" communication services and mobility are provided in the network [2]. Protocol enhancements and new protocols for scalable resource reservation are being designed in collaboration with IBM [3].

While the network infrastructure is being put in place, we have already introduced two new network courses, with emphasis on advanced Internet services and network security. The new networking courses have attracted more than 60 students each, with about 30 projects in each course. In addition, about half a dozen undergraduate and master's projects have emerged from these classes. In the advanced Internet services class, for example, students have completed semester projects including an Internet telephony manager, a Java-based mail composition tool, a Java shared whiteboard, a real-time quality-of-service measurement tool for the Internet, synchronization recovery in a MPEG-2 video-on-demand system, bandwidth estimation and a shared network calendar.

The strengthening of our research efforts in data and multimedia networking, facilitated by the research infrastructure grant, has already yielded intense new collaborations with AT&T, Lucent, Microsoft, IBM, Progressive Networks and Netscape and facilitated garnering two large new research efforts in network survivability and active networks [4]. The number of PhD students involved in networking-related research has more than doubled in the past year.

Given the prospect of high-speed network connectivity, the School of Engineering has contributed $200,000 in matching funds to the new student research lab; the department has become a focal point of the Internet 2 efforts within the University, with the promise of supporting large-scale distance learning efforts.

Other representative projects enabled by this grant include new algorithms for fraud detection for the financial community, a system called MAGIC for generating coordinated multimedia briefings for surgeons at Columbia-Presbyterian Medical Center's intensive care units, effective techniques for generating summaries of multiple news articles coming from several online sources, the development of an omnidirectional video camera with no moving parts, new algorithms for automatically recovering 3D CAD models from multiple range images, the development of video-on-demand storage servers for analysis and testing, and information management techniques for multimedia hyperlinked collaboration environments.

6 Outcome and Impact

This infrastructure project is having a profound influence on the effectiveness and impact of the Computer Science Department at Columbia University. The new infrastructure has helped the department's faculty to obtain 16 new research grants with funding in excess of $7M in the past year. Our faculty and students are increasingly involved in research collaborations with American industry in key technology areas. Our educational and research programs are attracting record numbers of new students. The computational and networking needs of sixty graduate students were supported by this infrastructure, ten of whom graduated with PhDs in the past twelve months. Dr. Pascale Fung, our most recent graduate, is a woman.

References

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