Working Together Online: The Challenge and Promise of Collaborative Internet Computing

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Professor Chengzheng Sun
Chair of Internet Computing

School of Computing and Information Technology
Faculty of Engineering and Information Technology
Griffith University
Brisbane, Queensland 4111, Australia

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Abstract

Internet computing is at the core of information revolution which changes the way we communicate, work, learn, do business, and play. A major trend in Internet computing is to use the Internet to enhance human-to-human interaction, communication, and collaboration. Collaborative computing represents a shift in emphasis from using computers to support individual users' work to using computers to support group users' interaction and collaboration. The integration of Internet computing and collaborative computing has led to the emerging and rapidly expanding area of collaborative Internet computing, which studies computing technologies and applications for supporting geographically dispersed people to work and play together over the Internet. Common examples of collaborative Internet computing applications are email systems, online chatting/messaging tools, collaborative editors, networked multi-player games, and distributed virtual environments.

High bandwidth networking and applications, such as tele-medicine, video-conferencing, and video-on-demand, have gained great publicity and been a major focus of industry and business. For a range of Internet supported interactive and collaborative applications, however, it is the communication latency, rather than the bandwidth, that presents a major technical challenge to the researchers and designer of such applications. To create a quality interactive experience to human users, such systems' response delay should be less than 100 milliseconds. However, the communication latency in the Internet is much longer than this. To overcome this problem, a variety of latency-hiding techniques have been invented, including replication, mobile code, asynchronous communication, state prediction, and optimistic concurrency control. Replication has been a widely used latency-hiding technique, which replicates the shared data/environment among multiple user sites so that each user's actions in the shared environment can be performed locally and responded to quickly by the replicated or mobile code, thus avoiding synchronous communication with remote sites and hiding the delay of remote responses. However, computing responses locally may result in incorrect response and/or inconsistent states among multiple replicas, particularly in the face of concurrent actions initiated by multiple users. A significant challenge in building such kinds of systems is maintaining system consistency while ensuring interactivity.

Consistency maintenance is a fundamental and challenging issue in many areas of computing, such as computer architecture, operating systems, and database systems. Collaborative Internet computing systems are quite different from these traditional computing systems because of the involvement of human users and the Internet environment. Consequently, consistency maintenance for collaborative Internet computing systems requires significant new research. This has attracted significant research and development effort from both academia and industry in the past decade.

My research team has been working in this area since 1994, under the umbrella of the REDUCE (REal-time Distributed Unconstrained Collaborative Environment) project, which aims to investigate the underlying principles and techniques for supporting human-

to-human interaction and collaboration over the Internet, and to design and implement collaborative Internet computing systems for evaluating and demonstrating the research results. Real-time collaborative editing systems allow multiple geographically dispersed users to view and edit shared text/graphics/image/multimedia documents at the same time over the Internet. They are not only useful tools in their own right, but also serve excellent vehicles for exploring a range of fundamental and challenging issues in collaborative Internet computing applications. One such issue is consistency maintenance under the constraints of high interactivity, high concurrency, and high communication latency.

The first challenge is to define suitable criteria for consistency. We have contributed to the area with a consistency model consisting of three properties: (1) The *convergence* property ensures that all users have an identical document at the end of a session. (2) The *intention preservation* property ensures the execution of an operation always produces the effect originally intended by the user at the time of issuing the operation even though the document's state may have been changed by concurrent operations issued by other users. (3) The *causality preservation* ensures that all users observe their operations' effects in the right cause-effect order. These properties are very important not only for achieving consistent final results but also for providing users with a logical and consistent mental model about what is actually going on during a collaborative editing session. This consistency model has been widely accepted as a theoretical framework for systematically addressing consistency problems in this area.

The second challenge is to devise innovative concurrency control techniques that are capable of achieving the required consistency properties. A well-known technological innovation in collaborative computing research is the invention of the operational transformation (OT) technique, which is able to achieve convergence and intention preservation without imposing any restriction on users' activities. This work was pioneered by a US team led by C.A. Ellis in 1989 and was widely adopted as the basis for constructing collaborative editors. Our contribution to the OT technique is the discovery of a major puzzle (flaw) in the original core OT algorithm and a systematical solution to this extremely challenging puzzle. Moreover, we have made major extensions to the OT technique and developed an integrated package of collaborative editing techniques to solve a range of challenging technical problems, including group undo, optional and responsive locking, vector logical clock compression, operation compression, flexible notification, and collaborative editing of SGML/XML/HTML documents. These results have been published by major international conferences and journals and well-received by the international research community.

The third challenge is to build a working collaborative editor prototype based on the theoretical research results. We have contributed to the area with the first publicly accessible collaborative editor, which demonstrates the feasibility and usability of the state-of-the-art collaborative editing technology. This prototype system has been demonstrated at the flagship ACM conference on Computer Supported Cooperative Work and at ACM

SIGGROUP and IEEE CS web sites.

The fourth challenge is to build useful collaborative editing systems for ordinary people. For collaborative editors to gain user acceptance, they must be compatible with single-user editors in functionality and interface features, as well as be able to support multi-user editing. Toward this end, we are investigating various strategies to integrate the REDUCE technology into existing popular single-user editors. We are currently building a collaborative XML editor and a collaborative word processor, which are fully compatible with the corresponding single-user editors. The outcomes of this effort are expected to make a major impact on public acceptance of collaborative editors, as well as on the advancement of the state-of-the-art in collaborative editing technology.

The REDUCE project has spawned a number of new research projects and evolved into a comprehensive and coherent research program, which covers both real-time and non-real-time collaboration, collaborative editing on a variety of media (text, graphics, and hypermedia), collaborative visualization, Internet-based collaborative programming and software system design, Internet-based multi-player games, and collaborative e-commerce environments.

Collaborative Internet computing is a challenging, competitive, and rewarding area of research. Through the REDUCE program, we have established our international reputation in this important area. To maintain our momentum and international competitiveness, it is essential that we are equipped with the necessary resources, including advanced computing and networking infrastructure, adequate funding for RHD scholarships and research assistance, and sufficient time to do research.