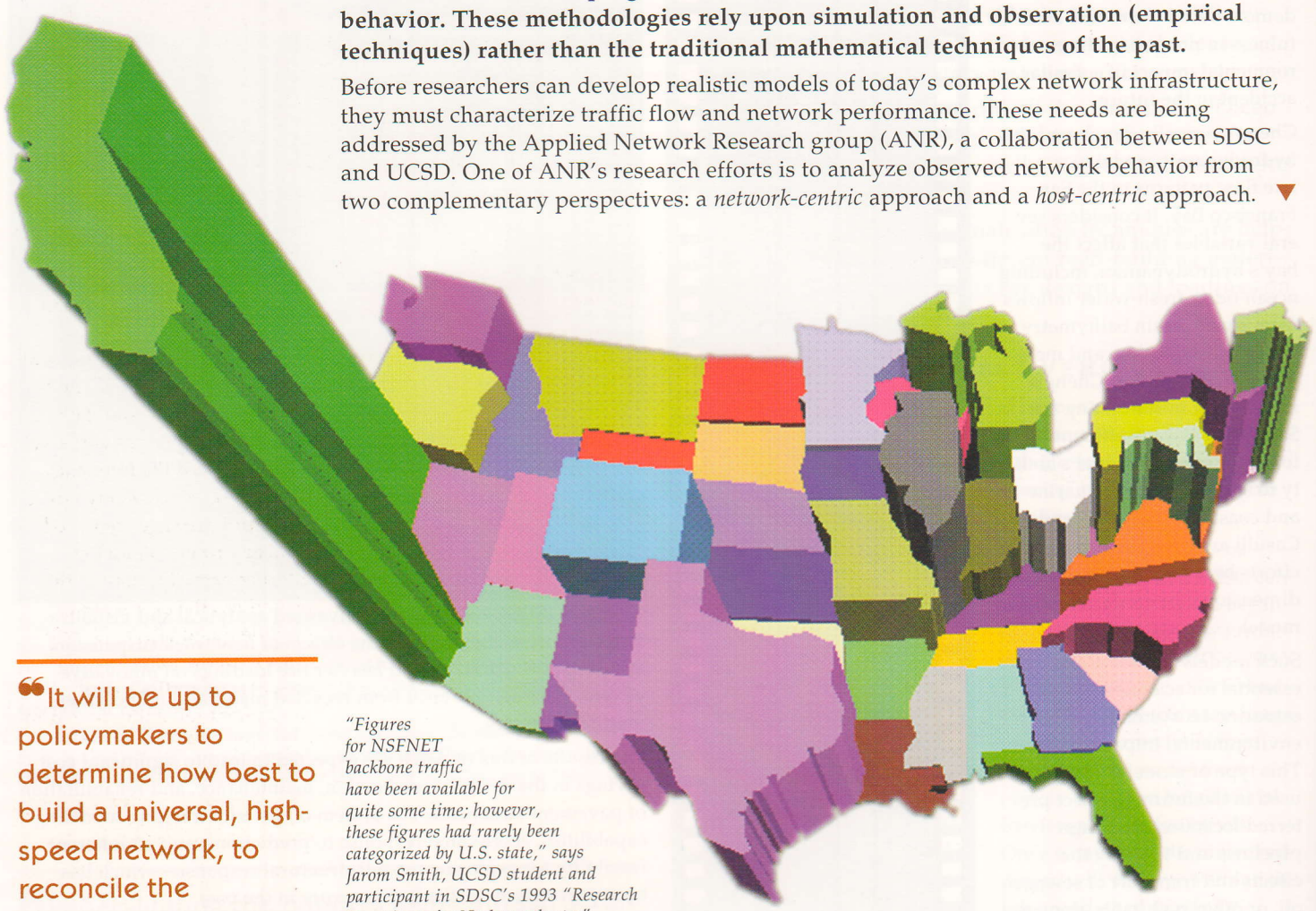
NETWORK BEHAVIOR

APPLIED NETWORK RESEARCH

Networking technology has advanced much faster than has our understanding of network behavior. Traditional mathematical models have met with little success in today's networking environments, yet network analysis is essential for the network to evolve to gigabit-per-second speeds and beyond. Therefore, researchers are developing more realistic methodologies to understand network behavior. These methodologies rely upon simulation and observation (empirical techniques) rather than the traditional mathematical techniques of the past.

Before researchers can develop realistic models of today's complex network infrastructure, they must characterize traffic flow and network performance. These needs are being addressed by the Applied Network Research group (ANR), a collaboration between SDSC and UCSD. One of ANR's research efforts is to analyze observed network behavior from two complementary perspectives: a *network-centric* approach and a *host-centric* approach. ▼



"Figures for NSFNET backbone traffic have been available for quite some time; however, these figures had rarely been categorized by U.S. state," says Jarom Smith, UCSD student and participant in SDSC's 1993 "Research Experience for Undergraduates" (REU) program. One portion of his REU project involved associating each U.S. network with its respective state, and visualizing the data for easy comprehension. This image, generated by Smith, illustrates the volume of data packets entering the NSFNET backbone, per state, during June 1993. He obtained the network data from Merit, Inc. (the organization responsible for maintaining and monitoring the NSFNET backbone service), and used demography software on a Silicon Graphics workstation to visualize his results.

"It will be up to policymakers to determine how best to build a universal, high-speed network, to reconcile the competing corporate interests, and to create a network that maximizes the benefits enjoyed by all Americans."

–Vice-President Albert Gore, while senator

WORLD FOCUS

Establishing a policy foundation for the information and communications infrastructure of the future is an important issue to the High-Performance Computing and Communications (HPCC) program. The Federal Networking Council has already formed a policy committee to address critical network issues.

Cognizant of the need for information on which to build such a policy, the Applied Network Research group has been evaluating international network traffic routing that uses the NSFNET backbone to receive local traffic. This information is expected to help the committee develop a policy on international network access. □

by Marsha Jovanovic and Kimberly Claffy

EXPLORING AGGREGATE NETWORK BEHAVIOR

A network-centric approach allows researchers to explore the aggregate behavior of the network with de-emphasized concern for the impact of individual end users. This perspective helps ANR picture the aggregate workload on various components of a wide-area network. In their efforts to characterize network traffic, they are studying operational data collected on the NSFNET. Such efforts must rely generally on operationally collected statistics, which focus more on maintaining the infrastructure's operability rather than addressing performance issues or producing fine-grain traffic models. One of ANR's goals, therefore, is to define more refined data sets that can produce more realistic models of traffic on the NSFNET and the Internet. Ultimately, ANR hopes to apply its findings to other components of the Internet as well as to environments like the national ATM networks *(see box)* and the CASA gigabit testbed project.

As part of the CASA project, SDSC is developing wide-area gigabit networks to support the distribution of grand-challenge applications across heterogeneous computing environments. Recently, SDSC researchers made notable progress in this area. *(See the CASA article on page 20.)*

EXPLORING END-TO-END PERFORMANCE

A host-centric approach allows researchers to explore end-to-end performance issues without concern for the intervening network "cloud." Several ANR end-to-end studies have used this approach. These studies quantify delay, path availability, and quality of service between end sites. Among other developments, ANR has devised a scheme to measure, calibrate, and grade end-to-end service based on the variance in packet delays throughout the life of a connection. Any given path between two hosts may traverse many different networks at various bandwidths and loads. ANR has modified software to compute the gap associated with each pair of packets and then graphically examine the delay variances through time—for example, between a source host at SDSC and a host in Japan. ANR researchers plan to refine and calibrate the measurements to reflect congestion windows accurately.

In another host-centric project, ANR is investigating the dynamics of routing information flow. The NSFNET backbone network provides transit services to a large part of the global Internet and maintains connectivity information in routing tables. Analysis of routing fluctuations has revealed how backbone changes affect the connective stability of the attached networks. This study is an initial step in quantifying Internet-wide routing stability and has potential use for policy development.

ANR also began a host-centric study to identify parameters related to reliability of end-to-end Internet connections. The Internet's heterogeneous nature makes definitions and studies of end-to-end reliability complex and difficult. ANR researchers have observed various causes of instability and are gathering statistics about them to build realistic models. One experiment involves transmitting one packet per defined time window to each of several destination hosts distributed around the world, simulating active ongoing conversations. ANR analyzed the frequency, cause, and source of any error or control messages returned from any router along the Internet path. By refining this procedure, the group hopes to provide quantitative information about the longevity of Internet connections and the consequent reliability of end-to-end paths. ■

MULTI-AGENCY FAST PACKET NETWORK GRANT

SDSC's ANR was awarded a $1.5-million grant from the NSF to participate in multi-agency collaborations to develop networking technologies. The evolving asynchronous transfer mode (ATM) can switch cells—short packets of data with address and control information—at extremely fast speeds. An ATM network is deemed by the industry to be a significant advance in high-speed networking technology. ATM networks often use Synchronous Optical Network (SONET) technology, which allows data streams of varying transmission speeds to be combined without breaking down each stream. This project is considered an important part of NSF's long-term investment in high-speed networks and the evolving National Information Infrastructure. □

NETWORK ANALYSIS GRANT

The Applied Network Research (ANR) group is conducting a collaborative, three-year research project funded by the NSF to analyze high-speed network environments. The co-principal investigators are Hans-Werner Braun, SDSC principal scientist, and George Polyzos, UCSD assistant professor of computer science and engineering. This research effort has significant application for the NSF's informational and educational network (NSFNET), components of the Internet, the evolving National Research and Education Network (NREN), and the broader National Information Infrastructure (NII). □

ANR RESEARCHERS

HANS-WERNER BRAUN formed the ANR in 1992 and is well-known in the Internet arena for his expertise in network design, operational infrastructure, and network research.

GEORGE POLYZOS and graduate students from the department of computer science and engineering at UCSD participate in the network research projects.

KIMBERLY C. CLAFFY, a doctoral student in computer science and engineering, is using the network modeling and analysis project for her thesis research.

BILAL CHINOY, an SDSC network researcher, leads the SDSC portion of both the CASA gigabit network project and the National MetaCenter networking project.

CARL SCARBNICK, SDSC scientist, and GARY HANYZEWSKI, SDSC programmer/analyst, are working with UCLA researchers to parallelize an oceanic component of the GASA global climate model.

KEVIN FALL, a UCSD doctoral student, is assisting with the CASA project.