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Report of the Expert Meeting on Virtual Laboratories

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James P. Vary, Editor

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PREFACE

Advances in high-speed digital communications are revolutionizing how businesses interact, information flows, where new jobs are created and even the nature of those jobs. In a similar way, scientific/technological activity is experiencing major changes and, in some cases, is leading these communication developments.

The motives, opportunities, mechanisms, and challenges presented by the development of "Virtual Laboratories" (VL) require critical analysis, especially if developing country participation is to be insured. To accomplish this analysis and arrive at findings and recommendations, UNESCO asked the International Institute of Theoretical and Applied Physics (IITAP) at Iowa State University to organize an Expert Meeting on Virtual Laboratories, 10-12 May, 1999 in Ames, Iowa. This report is intended to present the analysis, findings and recommendations of that meeting in order to disseminate this information as broadly as possible.

Major challenges exist in ensuring widespread sharing in the benefits of this emerging technology. Hence, the Terms of Reference of the Expert Meeting were to determine:

i. The definition of the Virtual Laboratory in terms of objectives, techniques and participating communities;

ii. The state-of-the-art and trends of Virtual Laboratories with respect particularly to geographical and institutional participation, subject coverage and technologies applied, paying special attention to low bandwidth and "small science" applications of Virtual Laboratory techniques;

iii. The potential relevance of Virtual Laboratory techniques in advancing and monitoring research and analysis bearing on problems of development, and the technical, organizational, social and psychological, and economic factors affecting the application of these techniques to these problems;

iv. Recommendations for action at the international, regional, national and professional levels, with particular reference to developing countries and the research and international communities.

This report begins with the Participants' Policy Statement which takes into account the background, findings and recommendations of the meeting. Then the report's first five chapters summarize the current situation as seen by the meeting's participants. The remaining chapter presents the consensus findings and recommendations.

The Participants' Policy Statement, as well as the findings and recommendations were presented at the World Conference on Science (WCS), Budapest, July 1999. As a result of this presentation and the vigorous discussion which followed, the World Conference on Science – Framework for Action states: "Research and education institutions should take account of the new information and communication technologies, assess their impact and promote their use, for example through the development of electronic publishing and the establishment of virtual research and teaching environments or digital libraries."

Readers having inquiries on the expert meeting are invited to send them to:

Mr James P. Vary
Director
International Institute of Theoretical and Applied Physics
Iowa State university
Ames, Iowa 50011 - 3022
USA
E.mail: jvary@iastate.edu

Suggestions for further actions should be addressed to:
Mr John Rose
Programme Specialist
Information and Informatics Division
UNESCO
1, rue Miollis
75732 Paris Cédex 15
E.mail: j.rose@unesco.org

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PARTICIPANTS' POLICY STATEMENT

The 20th century was a period of immense material progress—driven by the explosive growth of science and technology and characterized by the rapid internationalization of the world science and technology enterprise. However, the cultural, economic, and social benefits of science and technology have been unevenly shared. The burgeoning research engine of the northern hemisphere has attracted the world's intellectual talent and the benefits have largely accumulated to the industrialized nations without equitable benefit accruing to the vast majority of the world's population in the less-developed nations. We agree, in keeping with the ideals of UNESCO, that the world should work to integrate its talent, creativity, and cultural variety for the benefit of all. This can be achieved by promoting access to the global telecommunications regime.

The advent and growth of digital telecommunications has accelerated the globalization of science. With the evolution of cost-effective tools and processes to share both instruments and thought, scientific and technological programmes are being distributed increasingly among remote geographic facilities and organizations.

The participants of this expert meeting have attempted to characterize these trends, to develop recommendations and studies to exploit their potential for the advancement of science, and to assure that the benefits are widely shared among the human family in the 21st century. While science is our primary focus, we found that greater access to digital telecommunications will also benefit such diverse activities as collaborations among artists and other creative people.

We note that the emerging patterns of electronically mediated collaborations fall along a spectrum of evolving activities—from greatly enhanced interaction among scientists at distant sites to the development of new organizational structures for research. This will require tools featuring the most advanced techniques of instrument control, data sharing, collaboration in an "electronic commons," and the rapid dissemination of results to an international audience of scholars, economic actors, and the public via electronic publishing. Such incipient structures promise to become powerful assets to educate new generations of scholars. We define this enterprise as "the sustainable, effective use of telecommunications and informatics to organize facilities and intellectual talent to help generate, verify, and disseminate scientific and technological knowledge."

"Virtual laboratories" or "collaboratories" are emerging as the key embodiments of activities that include the vast international human genome collaboration, the association of astronomical facilities called "the whole-earth telescope," the planned construction of long-baseline interferometry laboratories, and global observation networks for the environmental and social sciences. The tools employed are increasingly adapted to health/medical applications and to creative activities in the social sciences and the humanities.

We adopt a broad perspective and define a virtual laboratory (VL) as "an electronic workspace for distance collaboration and experimentation in research or other creative activity, to generate and deliver results using distributed information and communication technologies."

The workshop participants recommend creation of an on-line catalog of those best practices that promise to promote and enhance the VL as a valued collaboration tool. We further recommend the organization of an international collective to share information on new developments in VLs, foster Internet access, identify existing resources, codify technological problems and their possible solutions, and initiate international VL programmes that promote and enhance the benefits of world science. We understand that such an effort must seek partners to provide connectivity and access to tools, programmes, and training. We recognize that, ultimately, a tapestry of connections among scientific institutions, industrial enterprises, governments, intergovernmental organizations, non-governmental organizations, and philanthropies will be needed for a new international framework to promote and extend scientific and technical knowledge in an equitable, balanced international regime.

It is essential that governments and intergovernmental organizations redouble their efforts to assure ample access to telecommunications and informatics for pure and applied research. We appreciate that investment in the scientific and technological infrastructure and capacity is a promising path to economic betterment and improvements in the quality of life. It is equally essential that the scientific and political communities work together to reduce the constraints limiting the beneficial development of science and technology in the information era. Such constraints include the legal impediments to sharing the benefits of scientific knowledge, the ethical challenges associated with widening scientific sponsorship, and the economic disparities that have arisen among nations.

1. INTRODUCTION

Advances in high-speed digital communications are beginning to revolutionize business practice, information flows, the creation of new jobs and even the nature of those jobs. In a similar way, scientific and technological activity is experiencing major changes and, in some cases, is leading these communication developments. The advent of high-speed digital communications, with declining cost for fixed functionality, has made feasible the rapid growth of "Virtual Laboratories" (VLs) to address forefront research issues with greater efficiency and less movement of personnel than previously required.

The present report reviews the motives, opportunities, mechanisms, and challenges presented by the development of VLs in support of co-operative research, and presents recommendations for future actions to ensure widespread sharing in the benefits of this emerging technology. This report examines issues relevant to the expansion of Virtual Laboratories to include specialists and research problems of developing countries.

The major considerations for the international community which are covered in this context are:

- definition and promotion of policies and best practices for VLs which ensure the widest possible access, equitable sharing of resources and benefits, and fairness in assigning responsibility and credit for contributions and results;
- promotion of the development, distribution and adoption of appropriate technologies that support those policies and best practices;
- provision of needed human resources development and other enabling facilities to permit researchers in developing countries to initiate and participate in VL activities.
- advancing the understanding of the economic, social and psychological dimensions of increased use of VL structures in the development of education, science and culture.

This report focuses primarily on examples from the physical sciences and engineering that are better known to the meeting participants. However, examples from the life sciences, such as the human genome project, could also serve as valuable prototypes. Additional examples from the social and political sciences exist, e.g. in demographic studies and opinion polling.

1. 1. Definition of a Virtual Laboratory

The meeting adopted a broad perspective and defined a virtual laboratory (VL) as “an electronic workspace for distance collaboration and experimentation in research or other creative activity, to generate and deliver results using distributed information and communication technologies.”

A VL is distinguished from a "Real Laboratory" (RL) or a "Traditional Laboratory". However, a VL is not viewed as a replacement for, or a competitor with, a RL. Instead, VLs are possible extensions to RLs and open new opportunities not realizable entirely within a RL at an affordable cost.

Alternative terms encompassing the concept of a VL include "Collaboratory", "Virtual Workgroup", “Virtual Enterprise”, “Cross-organizational Group” and "Distance Collaboration Group".

A collaboratory, as defined by computer scientist William Wulf, who coined the word in 1989, is a "centre without walls" in which users can "perform their research without regard to geographical location - interacting with colleagues, accessing instrumentation, sharing data and computational resources, [and] accessing information in digital libraries." Underpinning such a set-up is computer software that enables people at various sites to work collaboratively and simultaneously. Shared access to electronic notebooks and white-boards, videoconferencing capabilities, and other such technologies enhance the feeling of being "down the hall while across the country [or the world]", as James Myers, who leads a collaboratory project in environmental research, puts it.

In the broadest sense, a VL is a collaboration focused on achieving particular creative and/or decision support objectives. Hence, the VL may encompass almost all spheres of human intellectual endeavors.

1.2. General features of a Virtual Laboratory

The forces driving the formation and operation of a VL are seen to arise from three main directions. First, a particular project may actually require a VL structure. Second, specialists may need access to large-scale facilities to which access is actuated through a VL ("person to equipment" and "person to metamachine" media, see chapter 3). Third, more general interactions among members of a common specialist community may be facilitated by a VL for team building, joint project identification and joint fund-raising efforts.

A project driven VL has a well-defined goal and a fixed time scale. The project could be research to develop a major experimental device such as a detector for a high energy physics accelerator. Another example would be to solve a particular environmental problem such as designing a remediation plan for the cleanup of a lake contaminated by industrial pollutants. In a wider view, other intellectual or creative collaboration could be assimilated to VL "research", e.g. medical practitioners participating in "telemedicine" consultations and artists collaborating to create digital media.

In particular, large and complex projects involving expertise from many institutions and cross-disciplinary activity may require a VL approach. An example could be the analysis of impacts from predicted global and regional climate changes. Here, the overall analysis would involve the climate modelers who perform the climate simulations and provide the results with an analysis of the uncertainties. The impact assessors (economists, political scientists, epidemiologists, social scientists, public health specialists, government planners, etc.) review the simulations, request additional data, and analyze the consequences in their areas of expertise. Such a process is currently underway through the Intergovernmental Panel on Climate Change (IPCC). Future efforts may focus more on the regional and local versions of this process.

In some cases, a geographical distribution of participants is essential to the scientific and technical goals of a project. Examples range from astronomical observations requiring uninterrupted data collection from different parts of the earth to weather and environmental monitoring which may, for example, require regional data samples at precise times in order to measure the flow of atmospheric components and their interchange with the soil and bodies of water.

Multi-national collaborations also share knowledge in the area of human medicine. Spurred initially by the need to deliver medical services to rural locations in the U.S.A., telemedicine has become international and more collaborative in scope. The need to share expertise and best practices, especially for communicable diseases, has driven much of this expansion.

Political and social scientists are conducting collaborative studies, developing Web sites for sharing information, running listservers and chat groups, as well as conducting online surveys.

More generally, a VL involves a distributed creative effort. Members of the team may bring different cultural perspectives to the project. A "Collaborart" project between artists in the Russia and the U.S.A. is currently underway and could serve as an example of this new form of artistic activity.

1.3. Motivations for a Virtual Laboratory

There appear to be a number of motivating factors for a VL. We cite a number of these below, some drawing on the examples mentioned:

- Certain major scientific and technological challenges require a size and scale of effort beyond the capacity of a single laboratory or even a single nation.
- Human resources and expertise required for the scientific and technical goals may be distributed among two or more institutions.
- The subject matter may require participation of specialists from different regions due to needs for region-specific data (new or archival), field tests, or available human resources or training base.
- To carry out the research, it may be necessary or cost-effective to share access, via remote means, to scientific instruments that are unique, scarce or otherwise difficult to access. Examples of such equipment include accelerators, telescopes, deep-sea probes, planetary probes, electron microscopes, mass spectrometers or other high-end analytical equipment.
- The application of the research results for social and economic benefit may depend on regional participation in the project.

The last case could be important where the research results must be interpreted in light of the self-interest of the government with authority over the region or locality studied. Depletion of fresh water resources and fishing stocks are two prominent examples. Atmospheric, soil and water pollution represent additional examples where alternative courses of local action must be weighed in light of the local contexts.

The VL represents a potential for a <u>new paradigm – and a new culture - of science</u> that can produce unanticipated breakthroughs when there are shared cognitive functions. We cite some examples of research areas where VLs may be especially valuable:

- global and regional teamwork in data prospecting and mining,

- searches for new correlations in environmental or health data,
- new multi-disciplinary and multi-cultural approaches to problem solving,
- synergistic insights with added value from multi-national and multi-cultural collaborations,
- joint studies where scientific consensus is important for policy goals.

The VL may generate an enhanced ability to attract R&D contracts from the private sector due to flexibility of access to personnel, laboratory facilities, expertise, geographic presence, scale-up and scale-down capacity, etc.

Let us illustrate a motivation for a VL by a specific example. For security reasons, some National Laboratories of the U.S. Department of Energy have large facilities with restricted access. A standard but very expensive piece of equipment may be housed in a restricted area. Motivated by a forefront scientific and technological goal, that equipment may be made available to experts over an Internet hook-up for remote control of their experiment. Conceivably, experts from developing country institutions could ship their own samples to the experimental facility and have digital access from their own offices through their participation in a VL.

Consider another example. For industrial security reasons such as the protection of intellectual property and know-how, industrial labs often restrict physical access to their facilities. In such cases, public-private sector co-operation may be facilitated by resolving these issues of physical access to facilities via more tightly controlled digital links to specified instruments, experiments, intellectual property, or data sets.

Consider the actual VL example of the Human Genome Project with funding from the United States National Institutes of Health. Laboratories around the world agree to share their gene-sequencing data via central repositories in return for access to the collectively generated sets of data. The private sector provides contract services for the repositories and performs research on the data sets for specific purposes such as genetic engineering of new crops and development of new pharmaceuticals. Press coverage of this VL project is extensive, often focusing on the intellectual property issues and their variances from one country or region to another. The data generated via this VL are likely to represent a true "gold-mine" for data mining over the coming decades.

2. NEEDS AND CONTEXT OF RESEARCHERS IN DEVELOPING COUNTRIES

As circumstances vary widely, even within a single country, it would be difficult to present a comprehensive view of the situations in developing countries. In order to provide some insights, however, this section presents the situation in a few countries with a wide range of size and economic situation. This "snapshot in time" should generate an impression of the many difficulties faced by potential VL partners in developing countries.

The selection of countries and territories presented in this chapter was based on contributions by participants in advance of and during the meeting and information available to the editor. On this account, one will ascertain that the countries selected have a significant level of scientific and information technology infrastructure, and in particular are not representative of the least developed nations.

2.1. China

It is estimated that by the year 2000, there will be 28.5 million Asian families linked up with the Internet. In recent years, sales of computers in China increased rapidly. In 1997, PC sales was 3.4 million units; in 1998, it was 4.7 million with the PCs made in China taking up most of the market share. It is estimated that by 1999 the sales will reach 6 million and by 2000, 10 million. Sales of computers in the China market are expected to exceed Japan at the beginning of the 21st century. China has built up a telecommunications net centred around optical cable lines and accompanied by multiple means of communications like microwave, satellite, telephone, mobile phone, digital communications, multi-media communications etc. The networks cover cities and towns all over the nation and reach to telecommunications networks all over the world. The optical cable trunk line reaches all capital cities and 70% of the big cities. The capacity of the switchboards of telephone bureaus all over the nation reaches over 200 million. And the capacity of the switchboard for mobile phones reaches 60 million users. The digital data communications net reaches 90% of the cities and counties of the nation and the public computer network covers all cities and districts and most of the economically developed counties. The households with telephones take up 13% of the total households and over 40% of the city households.

Since China first linked up to the Internet in 1994, the network has developed rapidly. At present, there are four large networks in China: the Chinese Science and Technology Net (CSTNET), the Public Computer Network (CHINANET), the Chinese Education and Research Net (CERNET) and the China Gold Bridge Net (CHINAGBN). The number of network users has also been increasing rapidly, reaching 3 million people in 1999. It is estimated that by the end of the year 2000, the number of network users will be 10 million. Among the users, 79.2% are young people aged from 21 to 35. As far as the kind of information the current users wish to obtain from the net is concerned, 67.2% of the users wish to get scientific and technological information; 63.3% wish to get information on entertainment and sports; 45.1% economic and political news; 43.7% commercial information and consultation and 26.1% financial and stock information. At present, over 90% of the scientific information on line is in a language other than Chinese. China is trying to build up information resources in Chinese on the Internet. The development and construction of scientific information and databases together with the on-line scientific/technical services contributes to the promotion of the information industry.

Over the past twenty years the education and scientific research conditions in China have greatly improved. Today, scientists experience a more open and cooperative atmosphere compared to the relatively isolated research situation that dominated in the past. Now, especially, the use of the Internet is enabling scientists to share information and data with colleagues more effectively.

One example can serve as an illustration. In 1994, the Shanghai Research Centre for Applied Physics (SRCAP) was established to overcome the research barrier that existed between institutes and universities. SRCAP was supported mainly by the Chinese Academy of Science and the Ministry of Education. It links six research institutes and six universities, including several key laboratories and public laboratories in the Shanghai area.

SRCAP differs from the original “centre” structure and operates more like a "Virtual Centre". Outstanding professors and scientists from individual research groups use the centre's facilities to do collaborative research in physics and other cross disciplinary areas such as the life sciences, chemistry, information, material science, medicine, environment science etc. SRCAP provides these scientists with hardware and software resources from many different groups to produce successful results more effectively with less cost. Researchers communicate daily and discuss problems with each other heavily relying on the use of e-mail, telephone, fax and other modern communication tools through the telephone line and Internet system. The Internet system has a high speed backbone of 155M recently installed in Shanghai.

Scientists in developing countries like China still need to access large amounts of information originating mainly in developed countries. The cost of using Internet to transfer the high density data and information from overseas (like the rich image picture data) is much higher than that for local area usage due to politics, economics and technical reasons. Consequently the “Virtual Laboratory” at SRCAP is having difficulties fulfilling its goal to achieve a world-wide scale in the near future. At the moment some practical methods such as mirror servers can help address this problem. Therefore, scientists from different working groups can transfer the data and information to the local server at SRCAP by mirroring scientific web sites located in the USA or in other countries. Although the method is not perfect and needs much improvement, it can significantly reduce the overseas Internet cost and very much increase the data transfer speed.

2.2. Ghana

The Ghana Atomic Energy Commission (GAEC) has a 2 Mbps radio link to a private ISP, Network Computer Systems Ltd. (NCS) that provides 64 kbps connectivity. This is the same link that provides connectivity for the University at Legon to the Internet. The Technical University in Kumasi links to Internet via a different point-of-presence (POP). Ghana Telecom provides the leased line services required to bypass unreliable local connections.

It is clear that a combination of radio links and leased lines will be required to provide the needed academic and research connectivity in Ghana since the existing telephone net can only provide dial-up communications and this will not support real-time access to the Internet. To address these issues, training is a critical problem and the Ghana National Committee on Internet Connectivity (GNCIC) plans to build upon its advanced networking training programme inaugurated in 1997. Thus, training must include such subjects as radio propagation, radio spread spectrum, narrow band (HF, VHF and MW) and spread-spectrum (MW).

The library at the University of Ghana at Legon will be connected by fiber-optic link from the post office but it currently uses a radio link to NCS. Ultimately, plans call for the implementation of a national fiber-optic spine. The campus backbone has been supported by the Danish development agency, DANIDA. In the near future, plans call for a network of virtual POPs accessible at 64 kbps.

The general research programme of the Physics Department, University of Ghana, Legon, includes photo-voltaic and solar thermal investigations, materials research, remote sensing and radiation physics (x-ray fluorescence studies, reactor neutron scattering). Equipment and backup were the most intractable problems facing the faculty and their telecommunications was limited to store-and-forward dial-up email since the library link is not radiated to members of the physics faculty.

Ghana's telecommunication sector has been liberalized and the traditional public telecommunication operator, Ghana Telecom (GT), has been partially privated with considerable foreign investment (mostly Malaysian). In the near-term, a 7 gigaherz GT ‘mini-loop’ will interconnect Accra, Cape Coast and Kumasi. The longer-term plan is for a VSAT-fiber optic network to provide 64 kbps access, supplemented with an SDS microwave backbone. However, GT has not yet established rates for leased lines for either the ‘mini-loop’ nor the higher capacity network. Currently, GT does provide leased lines for interconnecting the ISPs. Thus, theoretically, short-line access to the national spine or ‘mini-loop’ could result in a considerable cost savings

The Internet retail sector in the country is private with three main ISP's serving about 10,000 clients including much of the academic and research community.

The central issue with respect to the University of Cape Coast (UCC) was the connection of the campus network, the development of which is being supported with a Carnegie Corporation grant. It has been recommended to link the campus net via a 128 kbps radio link to the area PTT (this would provide for the ability to rapidly upgrade when circumstances permitted). A leased line would connect to Accra from which radio would connect to NCS. If the connection was to function at 64 kbps, two 33 kbps aggregated segments would be required at a cost of US$ 5,000/year (US$ 2,500 per line). But the largest recurring operating cost will be the transit Internet access which is calculated as US$ 3,000/month (US$ 36,000/year). In addition, power space charges are estimated as US$ 4,000/year. Thus, these connectivity charges of US$ 45,000/year would have to be defrayed among UCC users.

While the transit Internet access is negotiable, much will depend on whether or not additional volume is given to NCS to provide connectivity for other academic and research users. Clearly a scheme involving all universities and research institutions would provide a basis for saving on operating costs. Such a pilot academic and research network including schools, libraries and other public service institutions is being implemented by GNCIC under the Ministry of Education with support through a UNESCO sponsored project financed by the World Bank's InfoDev Programme.

2.3. Republic of Kazakhstan

In 1997 the Institute of Atomic Energy, National Nuclear Centre of the Republic of Kazakhstan had a pilot project together with Los Alamos National Laboratory (LANL), USA, to establish a Virtual Laboratory on radio-ecological problems in Kazakhstan. Radio-ecological problems are very real for Kazakhstan because of the radioactive contamination in the country as a result of Former Soviet Union activity (uranium ore mining and processing, nuclear weapon tests etc.). This project was supported by UNESCO.

Currently the Institute of Atomic Energy is in close collaboration with LANL and continues to carry out joint investigations. The Virtual Laboratory is the most promising way of collaboration between the scientists involved.

However, security is a major problem in these virtual interactions. In this case, security does not mean the usual server security problem. As an example of the type of security implied, the Institute of Atomic Energy wanted to obtain remote access to a workstation of LANL from Kazakhstan to run some non-commercial software for the purpose of data processing. But it was not possible to get permission from the computer service of LANL to do this because of the "security" problem.

Kazakhstan shares the problem of low-bandwidth access to Internet. Indeed, in 1998 only a few scientists working in the Kazakhstan capital, Almaty, had e-mail. There are three main reasons that slow down the growth of access to Internet technologies in Kazakhstan:

- economical constraints
- lack of necessary information
- educational problems

2.4. Palestinian Authority

Academic Institutions

There are eight university-level institutions in the various towns of the West Bank and the Gaza strip. Two of these are in the city of Gaza and the other six are in the West Bank in the towns of Nablus, Birzeit, Bethlehem, Hebron (2) and one university in Jerusalem itself. Birzeit is the oldest and best known institution with about 4000 students and 200+ faculty members, while Al-Najah in Nablus is the largest with over 10,000 students. Bethlehem is a Catholic university funded by the Vatican, and the University of Jerusalem is comprised of several colleges scattered around the Jerusalem-Ramallah area. Hebron has a university college and a tiny polytechnic institute. There are also a few teacher training colleges.

Scientific Research

Research in the scientific fields is quite modest. Individual researchers benefit from external grants to do some research while the budget for research at the local institutions is quite insignificant.

The government has no funds allocated to supporting scientific research. Some externally funded equipment has been provided to some of the institutions but the situation for experimental research remains dire. Research in the applied fields like the environment and health sectors is much easier to fund than pure research in the physical sciences. Nevertheless, a handful of projects have been generously funded by the European Union and some of its members.

Communications Infrastructure

The current telephone network is being updated. Services are provided by one company (a monopoly with links to the government PalTel). An integrated services digital network (ISDN) is being established; this will improve the quality of traditional services (telephone, telex, etc.) and will enable new ones to be provided; high-speed facsimile, enhanced videotext, electronic mail, tele-shopping, data transmission, etc.

At present, PalTel is only capable of offering local or intra-city data communications to it's clients on a very limited scale. The service may be summarized as follows:

- The current infrastructure allows for point to point copper connections between two sites only. HDSL (high bit rate data subscriber line) equipment is normally used at each end.
- The local access network is very congested, and the number of readily available copper wires to potential clients is limited. In the future PalTel plans to use various access methods including wireless connections to address these limitations.
- PalTel does not have any policies for data networking services yet: pricing, services, support, etc.
- Local connections are being dealt with on a case by case basis.

Computers and the Internet

Computerization is widespread in the sense that more people have access to cheaper computers. Software piracy is widespread while very little local software is being developed.

More schools are equipped with computers but those are still used mainly for simple tasks like word processing and other office work. No money is being spent on educational software. Colleges and other institutions of higher learning provide more opportunity for students and faculty to have access to computers but most students still remain without basic services like email! Most universities and some schools are networked locally, but not all have gateways to the Internet.

There are at least two major fundamental flaws in the way technology is proliferating:

1) Even though a lot of money is spent on hardware, basically no money is spent on software. Content production is meager and the use of pirated software for routine tasks is prevalent.

2) In colleges and educational institutions the best equipment finds its way to administrative offices and basically for secretarial work whereas science and engineering departments are quite poorly equipped.

Computers outside the Educational Arena

Outside the educational stream, the computing and communications equipment seems to have found its way into the various endeavors of life but not without a similar set of problems. Two main branches of the society where the technology is finding acceptance are the government sector and the important sector of non-governmental organizations (NGOs). The former had no choice being established in an era where this new compelling technology is indispensable, while the latter has actually been pioneering in its own way. Some of these organizations have been associated with the early steps of introduction of the Internet to the area.

A short history of the Internet in the region

The first connection to the outside world was a UUCP connection by modem from Birzeit. A university alumni collaborated with a couple of faculty members to run this modem based service, partially using their home phones and computers. Immediately after that the system was adopted by the UNDP (United Nations Development Project) and NGOs were also connected. The Palestinian Academic Network (PLANET) was created in 1994 and meant to serve the faculty in the universities. Unable to generate funds and due to fierce competition from commercial ISPs it split into a commercial chunk (Palestine online) and the old PLANET is now part of Al-Quds University.

Public interest in the Internet has grown considerably. Commercial ISPs are utilizing the Israeli backbone and are basically reselling Israeli service in the Palestinian territories. The universities themselves are dependent on this service provided by ISPs to serve their needs.

Internet Backbone

Internet users in the Palestinian Authority areas are using the following media for communicating with their service providers:

- Telephone lines using modems.
- Satellite connections (down-link of 128 kbps (incoming traffic), and an up link of 38 kbps outgoing traffic).
- Wireless Technology (it is being used both by Internet service providers and customers that require larger on-line bandwidths (128 kbps -3 Mbps range).
- Leased lines and dedicated lines.

Content Creation

Content creation for the Internet originating in Palestine is quite limited and Internet access is basically one-way. This is especially so in the technical and scientific fields. Universities, NGOs, and some private companies have put up some information basically describing themselves. Some libraries are finally becoming partially accessible via the Internet. A major limitation on content production is the difficulty in producing content in Arabic. Another is insufficient or inappropriately applied resources.

2.5. Panama

The Internet backbone of Panama is now divided in two main streams: an academic network (which will soon be sub-divided) and a commercial backbone (Intered).

The academic network consisted at one time of four universities and several governmental institutions. That has changed and now only three universities, the ones that initiated the academic network (now known as PanNet, then known as ARAPESCI), are hooked to it: University of Panama (UP), Technological University of Panama (UTP) and the Catholic University (USMA). At one time the UTP network and PanNet were one and the same, since PanNet is currently administrated solely by UTP. Now these two networks are logically and partly physically different. PanNet is also the national NIC (*.pa node administrator). Soon UP and USMA will be hooked in a separate network with a direct satellite circuit to the Internet Backbone. This was the result of institutional differences and the interpretation of the recently adopted telecommunications law.

The current PanNet network has a 512 kbps circuit (confirmed 256 kbps recently) to a local commercial satellite circuit provider. From the PanNet site there is a high speed local line to the UTP network and a 2 Mbps circuit to Intered (see below). From PanNet there are two leased lines of 64 kbps , one to UP and one to USMA (these will soon be replaced). From the UTP network there are 64 kbps leased lines to the 5 UTP campuses in the country side. There are no leased lines from UP or USMA to their campuses in the country side, yet. The new Frame Relay topology (after disconnection from PanNet) managed by the local telecom will link all 6 UP campuses and all 3 USMA campuses, each with 128 kbps lines; the main router of this frame-relay links out to a 128 kbps (hopefully to be upgraded) satellite circuit to the USA. A local traffic circuit is under negotiation with the ISP belonging to the telecom. Besides these links, USMA has an alternate 256 kbps (soon to be upgraded to 512 kbps and later to 1.5 Mbps leased line to a commercial ISP which has cooperated with USMA in various projects. The rest (7) of the universities with Internet (mostly private) are connected via commercial ISPs (mostly 64 kbps leased lines).

The commercial backbone is a physical network of DSL 2 Mbps lines to the commercial ISPs (seven up to now), three of them have their own satellite circuits (ranging 1x1.5 Mbps to 4x1.5 Mbps), the others being linked to the only oldest licensed private satellite network provider with 2 Mbps and multiple 2 Mbps lines. This last provider is the one so far providing the hookup to PanNet.

At present negotiations are underway how to setup a local traffic circuit between framerelay routers and the ISP run by the Telecom company, and to upgrade the proposed bandwidth to acceptable limits. For use of IP Multicast (for which the majority of tools use UDP) RSVP + RTP/RTCP services will need to be implemented to have a better remote control of instrumentation, for example. In 1998 a small network was built to run IPv6 and tested various network tools, and at present negotiations are underway to create a tunnel to the 6Bone. IPv6 traffic has been sent through parts of the current network described above.

Examples of two universities in Panama

The Universidad Santa Maria La Antigua (USMA) in Panama, is a Catholic university and the first private one in the country. The Physics Department has established a small research centre called TeleSITE (Centro de Investigación en Telecomunicaciones, Sistemas de Información y Tecnologías Educativas or Centre for Research on Telecommunications, Information Systems and Educational Technology).

In 1988 a listserve group Panama-L was established that helped the people in Panama in the building of that Internet infrastructure which until recently linked the three major universities. A while later a CU-Seeme server was installed and in 1996 a few clients set things up to push the bandwidth of USMA to the limit. In mid '97 USMA was invited to participate in a national project (Enlace Multimedios) to setup a national MBone and to have a stable link to the global Mbone. This was done in early 1998, a first in Central America. Since then USMA has been able to do audio-conferencing between different universities and their regional campuses and with universities abroad (MBone participants mostly, MBone tools allow also for unicast links). USMA is about to initiate testing of IP Multicast and IPv6 (an offspring of the Enlace project) over the national telcom´s FrameRelay and ATM (the National Telemedicine Initiative).

At present one of USMA's goals is to retake the aspiration of setting up a base for a VL. This will be accomplished by working on the development of two small multicast applications:

1) A small whiteboard application, that will work with XML and regular document (word and scientific word) formats;
2) A small instrument application that will provide an active GUI to a physics lab instrument interface (either a National Instruments type or a more simple thing such as Pasco´s for something like a virtual physics teaching lab, to allow students in the country side to participate in a distance physics lab metaphor).

This will be done using Linux/GNUC++/Java/Perl/TclTk/StarOffice

The Technological University of Panama, is currently establishing a Science and Technology website called CICTA (Centro de Información Científica y Tecnologica de Azuero). The idea is to establish a centre that would provide Internet and related tools, space and a forum for teachers and researchers. The goals are to mirror some educational and scientific sites (upon agreement) and ultimately create a "Virtual Library" with "Virtual Laboratory" applications and capabilities. One of the major difficulties encountered so far is related to bandwidth limitations (a 512 kbps connection to the main, with 64 kbps link to the interior of the country) and the fact that "State Universities" do not have the financial means to improve the basic infrastructure during times of budget cutting. Most of the hardware (maybe 99%) is Intel-based running either Microsoft or Linux. Although e-mail access is easily available, Panama still lacks the important tools for video-audio Internet applications. In the past year the Tecnological University has been exploring the idea of setting up two or three development centres to be mirrored in all regional campuses. The hope is to achieve a better flow of information by having it come to the nearest centre. This is still far from an up-to-date "VL" environment. Instead, this case serves to illustrate how low the demand on bandwidth should be in order for the VL tool to reach those with similarly limited resources

3. TECHNOLOGY FOR VIRTUAL LABORATORIES

3.1. A Taxonomy of Virtual Laboratory Tools

Based on the definition of a VL (see previous section), it is clear that generic communication tools that can link heterogeneous computer and communication equipment in multiple, geographically distributed institutions are at the heart of such an undertaking. This chapter will attempt to categorize such tools, to discuss existing and pertinent technologies, and to describe areas where development opportunities exist. Detailed consideration of computational tools for VLs, which tend to be highly specific to the research functions of a VL, is beyond the scope of this document.

Virtual laboratories can have a range of organizational foci:

- a large-scale research facility composed of a network of laboratories
- a network of research tools with remote access
- a network of scientists, characterized by a clear membership to a given community

The fields of networking, multimedia communication tools, and distributed computing are a large and very active part of computer science and electrical engineering research and of related industrial effort. Among the several classifications and taxonomies of communication services and tools that have been developed, the International Organization for Standardization – Open Systems Interconnection (ISO/OSI) reference model is the most prominent. This model, however, deals with the transmission of data and not so much with the communication tools that build on these services.

Considering the above taxonomy of VL foci, one arrives at two major communication tool classes:

- person-to-person communication in a network of scientists
- person-to-equipment communication to control a network of tools

A third communication class should become increasingly relevant to VLs in the future: "person-to-metamachine," which involves access to an intelligent network of information and computing resources.

The following subsections are devoted to a more detailed analysis of these three classes of electronic communication.

<u>Person-to-Person</u>

The communication services in this class are typically modeled after conventional techniques of human interaction such as a conversation, a telephone call, a book, TV, or a letter. The computer-supported analogs are video conferences, Internet telephony, the WWW, and E-mail. The standard—almost classic—approach to their classification is a division along temporal relationships (synchronous versus asynchronous, see Table 1).

synchronous	*asynchronous*
chat, telephony	**E-mail, file exchange**
Internet audio	**CSCW, joint authoring**
video conference	**project management**
teleteaching	**WWW**
virtual awareness	
application sharing	

Table 1. Person-to-person communication.

The International Telecommunications Union (ITU) is using the interactivity of the service to build subclasses: interactive services and distribution services. Another option is to divide along roles such as producer and consumers leading to a consumptive class and a cooperative class [Froitzheim 1997]. A scale based on roles versus interactivity is the most appropriate approach (see Figure 1) to reflect the characteristics of the services.

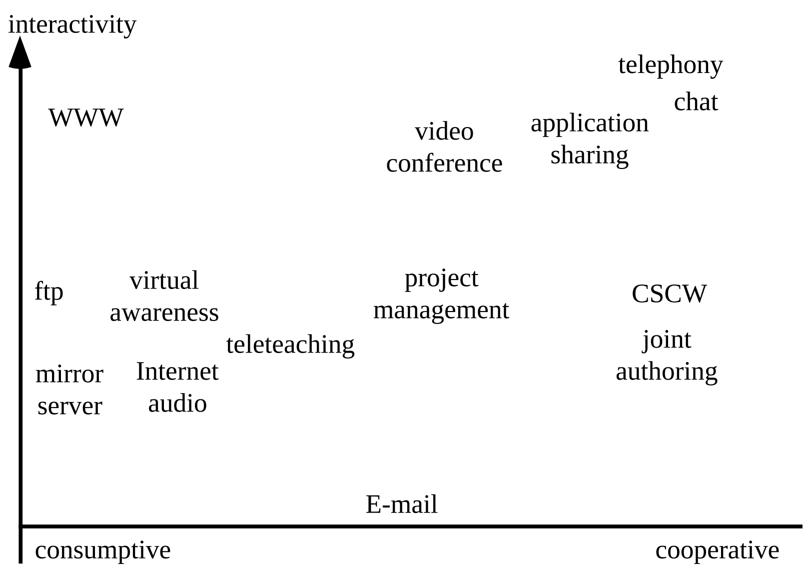

Figure 1. Person-to-Person Communication.

Person-to-Equipment (Person-to-Experiment)

An important part of many VLs is the experiments. They can be operated by certain manipulators and the results are collected by measuring equipment, which can again be controlled. In virtual laboratories this operation and control can be performed remotely.

The control of the equipment can either be performed interactively (typically called teleoperation) or asynchronously with a predefined procedure, script, or program (teleprogramming). Depending on the chosen method, synchronous feedback to the researcher may be necessary.

Teleoperation
In the teleoperation scenario, a scientist gives commands to remote equipment. The equipment is typically a measuring device (telescope, camera), a manipulator, or a probe. These commands may be of a strategic nature (move to position x, fill tank, explode, etc.), while fine control will often be performed by the equipment itself, which also prevents catastrophic behavior. In this case the feedback channel (mostly video or sample streams) is used to inform the remote scientist of the status of the system and whether a strategic goal has been achieved.

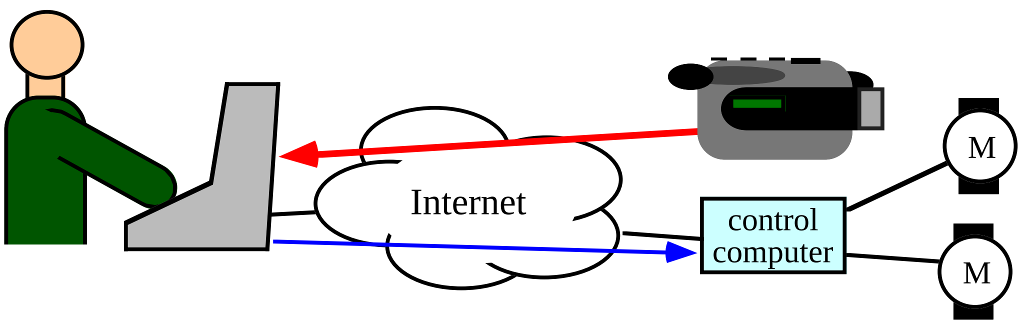

Figure 2. Operator-Controller-Equipment.

In the second mode, the commands are on a lower level (move right, pour fluid, stop). In this mode the feedback channel is of utmost importance, since very high interactivity is required. The critical nature of the feedback imposes high quality-of-service requirements on the communication channel with respect to delay and throughput.

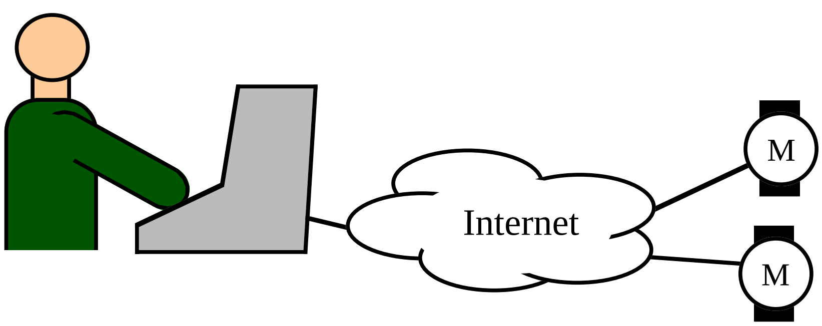

Figure 3. Operator-Motor-Equipment.

The result of the experiment—i.e., the data (media) stream obtained—can either be collected and stored at the equipment site for later transfer, or it can be transmitted live to the user site. The second is predominantly the case when the feedback channel also contains results.

Application sharing can be used as a tool for teleoperation. The local computer-based equipment control program to operate the experiment will be used remotely in this case. The application-sharing service transmits the user interface of this program to the remote site and the remote input is fed back into the program. Application-sharing systems include WTS (Windows Terminal Server, Microsoft/Citrix), Proshare, and Timbuktu.

WWW-based control interfaces are implemented with a WWW server and the CGI mechanism or by integrating a small WWW server into the instrument control software. The user interface is then based on simple or advanced html pages with certain embedded links pointing to the equipment control software complete with parameters.

Examples are:

- The eight remote access instrumentation facilities sponsored by the U.S. Department of Energy within the Materials Micro Characterization Collaboratory

    http://tpm.amc.anl.gov/mmc/

- The interactive model railroad at the University of Ulm, Germany; feedback is given through the WWW-based video, WebVideo

    http://rr-vs.informatik.uni-ulm.de

- A remote controlled robot at the University of Western Australia with a WWW-based user interface for all six degrees of freedom; feedback is again provided with WebCams (see http://www.rearden.com), several of them in this case [Sayers 1998]

  http://telerobot.mech.uwa.edu.au

Teleprogramming

Teleprogramming is an asynchronous approach to the operation of equipment in a virtual laboratory. The scientist creates a series of commands for the device that is then downloaded into the device and executed. The result stream is recorded and later sent back for evaluation by the scientist.

This command series is in many cases either a script or a program. Most programming languages can be used as long as the equipment manufacturer supports them. Today Java is certainly a good choice, as long as the programs created are not time critical. Two problems should be mentioned in this context:

- As everybody knows, programming is a task intimately associated with errors/bugs. Since the remote programming task is especially tedious in regards to turnaround times, local simulation of the programs is very important. Such a simulation environment helps reduce the time until the program works and it avoids catastrophic errors. However, simulation environments for experiments and equipment are not very common. They are a critical part of teleprogramming in a VL.
- In order to write a program for a given experiment, a formal description of the functionality of the equipment and of the controllable parameters is a prerequisite. This can be in the form of interface files or distributed programming interfaces (CORBA, RMI-objects, etc.). Again, not every equipment manufacturer supports this.

These two problems lead to the fundamental issue of abstract equipment description, which must be addressed in order to simplify remote experimentation.

Person-to-Metamachine

The concept of metamachines has been discussed in the November 1998 issue of *Communications of the ACM* [More 1998]. The idea is that scientific projects will be increasingly based on large, distributed data sets manipulated by transformation algorithms on supercomputers. Access to the data (digital library) and control of the computing power may therefore become part of a VL-communication infrastructure.

The second reference cited above [More 1998] gives two examples of such problems. The first is the digital sky project, where a huge multi-wavelength database of astronomy data is provided on-line, so that statistical analysis of this data in many different supercomputers will become possible. The second area presented is the 'mapping the brain' effort, where neuroscientists deal with multiple gigabytes of volumetric data.

The data sets are typically stored in huge databases. They are then filtered to extract pertinent data for certain questions, and finally transformed and analyzed by sophisticated algorithms in supercomputers or networks of distributed processors.

It should be stressed that person-to-metamachine communication need not necessarily involve supercomputers, but rather comes into play whenever computer-based information, calculation, and/or equipment resources are coordinated and exploited together through an intelligent interface or network.

Several techniques related to this communication class, which can be expected to become increasingly important, have been used in computing and networking for some time now:

- client-server computing (Corba, RMI, ODBC, JDBC, Java, etc.)
- remote database clients
- remote computer operation based on Telnet, X-Window, and application sharing (Windows Terminal Server, Timbuktu, QuiX)
- remote program preparation for the supercomputers
- agent technology as an interesting approach to the data-filtering task described above.

Problems exist in the areas of consistency and reliability of information and throughput (bandwidth and delay) between the data storage and the data processing resources. If equipment sharing is involved, the person-to-equipment quality-of-service constraints discussed above will also apply.

A systematic taxonomy of this class is not known to the authors. Further research is needed to explore this field in more depth to provide recommendations to the architects of VLs.

3.2. Transmission of Digital Media

The transmission of digital media—asynchronous as files and synchronous as streams—is a field of rapid development, intense commercial competition, and scientific research. This document cannot provide a full discussion of the technical and scientific implications, nor can it predict future developments. It will rather give an overview of media parameters and formats and the network quality-of-service constraints for various VL communication applications.

Although this section may sound very technical to those who are not in the business of communication tool design, it is important to understand that the transmission characteristics and media parameters are of utmost importance to the implementer of a VL. The triangle of desired services, media parameters and formats, and network capacity decisively frames the design rules for any VL.

Media Parameters

Media parameters describe the principal requirements from the viewpoint of data transmitted to the network. The selection of the media to be communicated results in a list of required network service qualities. This list then has to be compared to the available infrastructure quality.

The digitization of continuous media (sound, pictures, and movement) requires discrete sampling of the media in space and time. The resolution of the digitized medium is of course critical for the quality of the media stream presented to the human viewer. On the other hand, finer resolution increases the data volume and thus the data stream bandwidth requirement. It is furthermore very important for media processing algorithms used to evaluate the stream from scientific experiments. Most media streams have a very large size immediately after digitization. In order to transmit them economically, they are compressed.

Compression of the media streams is based on the removal of redundancy and discarding of 'unimportant' information. Lossless compression schemes (LZ-77, LZW, Huffman, Arithmetic Coding) are applied to measurement data, files, text and formatted text, and geometric data. Compression schemes for pictures, audio, and video rely typically on the introduction of small loss into the data, which is hopefully not noticeable by human senses (or the brain). MPEG-1, MPEG-2, MPEG-4, MP-3, GSM audio compression, and JPEG are examples.

Compression is sometimes of limited use in typical Internet small bandwidth scenarios. Audio is taken as an example in the following table:

audio quality (compression scheme)	*stream bitrate*	*500 byte*	*20 msec*
high (MP-3)	192 kbit/s	21 msec	500 byte
reasonable	32 kbit/s	125 msec	80 byte
low (GSM)	13 kbit/s	307 msec	32.5 byte
very low	4 kbit/s	1 sec	10 byte

Table 2. Compressed audio in Internet packets.

The effective data-rate is determined by three factors: compression rate, desired quality, and knowledge about the source. Speech can be compressed better—i.e., at a higher rate than music—because the compressor knows that it is working on speech. On top of that, speech need only be understandable while music should be indistinguishable from the original.

Aggravating factors are that sophisticated compression schemes like MP-3 may actually achieve a lower overall compression rate than lower quality schemes, and, in addition, that lossy compression cannot be used on media objects that are to be processed at the receiving end; losses will, for example, influence image processing and image enhancement algorithms.

Another problem lies in the small packet size—Internet routers do not process small packets efficiently (the computational load is the same regardless of the packet size) and the payload/overhead ratio is unfavorable.

Compression and Delay

Conversational (interactive) services such as telephony require short roundtrip times. Long delays from the sender to the receiver and back impede standard human interaction and lead to a serious loss in productivity. Delays do not only appear in transmission and compression, they can also result from assembling a reasonably sized IP packet. Table 2 shows unacceptable delays for the assembly of IP-frames from audio-codes such as GSM or CELP. Low bitrate audio formats are only useful for distribution services such as the RealAudio system or certain MBone-tool applications such as teleteaching.

Although low bitrates typically do not occur as the result of video compression, the compression delay that schemes like MPEG introduce are again only acceptable in distribution scenarios. Hardware accelerators improve the situation only marginally—they typically make heavy use of pipelining.

Service	*medium*	*recommended throughput*
file transfer	text	1 – 10 kbyte/s
	formatted text	2 – 10 kbyte/s
telephony	PCM-audio	64 kbit/s
video-telephony	MPEG-audio	64 kbit/s
	Video H.261 CIF	384 kbit/s
teleconference with n participants	2 channel MPEG-audio	participants · 192 kbit/s
	video M-JPEG (10 frames/s)	participants · 400 kbit/s
	graphics	1 kbit/s – 4 Mbit/s
TV-quality	MPEG-2 AV	4 Mbit/s
	HDTV	17 Mbit/s

Table 3. Recommended data rates for certain media streams.

Media and Document Formats

Design and efficient implementation of compression schemes, various media, and media streams are very active fields of research. This research has not led to surprising results however, as we are still bound by the Shannon's limit on the minimum amount of information needed to transmit a given signal.

Text—i.e., human language written on paper or any other display device—is built out of symbols for characters or syllabi. The coding of the symbols depends on the set of characters or syllabi used in the particular language. Code sets range from simple ASCII (for US-English), ISO 8859-X (for Roman, Slavic, Arabic, Hebrew, and Greek character-based languages), to Unicode (which includes representations for Chinese, Korean, and Japanese). The RFC 822 standard for Internet e-mail is, for example, built around the ASCII set. Other character sets are not easily transmitted with RFC 822.

Text is typically compact in terms of size with a high amount of information. It is furthermore simple to compress text. Transmission of uncompressed text is rather tolerant against bit errors. However, packet loss damages text severely.

Formatted text includes information on the rendition of the text for presentation. The importance of formatting such as boldface, italic, font type, size, and other attributes for the readability of text should not be underestimated. Most word processors come with their own document format. The commercial success of Microsoft Word has promoted the Word file format to a universal document format despite its shortcomings. MIF, the Framemaker file format, is another example of an application that has created a de facto document format standard. True standards such as X.420 have not been nearly as successful. In those communities of science that make extensive use of formulae in publications, the LaTeX format is very popular. It should be noted that it’s use is today limited to physics, mathematics, and theoretical computer science. Other areas of science such as biology, chemistry, or engineering do not profit from LaTeX.

Pixelmaps are typically rectangular areas with graphic information, pictures, and formatted text. Many formats and compression standards for this data type exist: simple schemes such as Fax G.3 (T.4), BMP, and TIFF; mixed mode formats such as Fax G.4 (T.6); and advanced formats such as GIF, JPEG, and JBIG. Many include compression algorithms with or without transformation-based loss introduction (DCT-JPEG, Wavelet, and Fractals).

Object graphics are an important means to convey conceptual information. The relation between object graphics and bitmap graphics can be compared to text and speech. Pixel graphics contain at least an order of magnitude more redundancy than object graphics. Furthermore, this redundancy is not easily identified and removed by compression algorithms.

Object graphics formats are today often defined by a computer graphics system such as X-Window, Windows-Metafile, or QuickDraw-Pict. They are either transmitted as streams of drawing commands or stored in files and transmitted asynchronously. Other standards are IGES, VRML, and many others.

The required quality of service (QoS) for graphics transmission is typically higher than text and comparable to formatted documents: medium data rates (64 kbit/s) and no errors.

Text and vector-graphics data types are compressed off-line, typically with compression and archiving utilities. Programs such as StuffIt store multiple files in one document and they use a variety of compression algorithms (LZW, LZ-77, ArithCoders, Huffman) to compress the files. They typically analyze the data and apply the code with the best results to the data. Some can even mix compression schemes to achieve optimal compression.

Audio compression schemes have reached high compression rates for specific sound types, taking into account the fact that the human hearing apparatus is able to identify very small elements of sound and it is very susceptible to errors. Table 4 shows typical standards and data-rates.

Name	*sound-type*	*bitrates [kbit/s]*	*quality*
ADPCM	voice	16, 32	reasonable
GSM	voice	7, 13	low
CELP	voice	2.4, 4	very low
MP-3	music	128, 192	superb

Table 4. Audio compression.

Video can be compressed with astounding factors as high as 1:100, and it is still useful for many purposes. Video quality is determined by two factors: spatial resolution (pixel count horizontally and vertically) and temporal resolution (frames). As an example, TV has a resolution of 720 * 486 pixels and 30 frames/second.

Simple techniques compress the individual frames for the video with pixelmap techniques. Reducing the resolution (pixels and frame rate) can be used to adapt the data rate or the size. More advanced and more effective compression is based on temporal correlations between the frames. All the standardized video compression schemes that exploit temporal redundancy are, however, not scalable in the network (network filtering); frames cannot be dropped in the network without seriously damaging the stream. Another aspect of temporal compression is a high degree of error susceptibility.

Although the application of JPEG to video streams has never been formally standardized, Motion-JPEG is widely used to transmit video over the Internet. The compression rates are not overwhelming (20:1), and the resulting stream is scaleable and error resilient. Another commonly used format is GIF-streams; GIF allows for updates in picture areas. The animated ad banners on almost every WWW page are living examples.

State of the art video compression schemes are MPEG-1, MPEG-2, and MPEG-4. They use JPEG and exploit temporal redundancy to achieve compression rates between 1:30 and 1:200 at good to acceptable quality. The ITU-standard H.261 and its variants are slightly less effective.

Compound documents are primarily file resp. transmission formats to combine several media types: Word, Framemaker, ODA (Office Document Architecture), MHEG, or Fax G.4 (T.6).

Computer programs can be considered as a special type of document and programming languages as the corresponding format. Many good and useful programming languages have been created over the years. Many of them are highly specialized for certain types of problems. Universal languages such as ANSI-C, C++, and Java seem to be the most useful to VLs, although process control languages may become relevant for the teleprogramming type of the person-to-equipment class. However, the main problem in this area is in the interfaces and Application Program Interfaces (APIs) that can be used: does the target system have the same set (functionality and versions) of the dynamic link libraries as the source? If not, data volumes or user effort will have to increase to ensure interoperability.

3.3. Quality of Service (QoS)—The Core Problem of Synchronous Communication Tools

Quality of service is a set of performance parameters associated with a certain service, especially with data transmission services. Typical parameters are

- throughput, the amount of data (packets, bits) transmitted per time unit (packets/sec)
- delay, the time a packet needs from entering the network to delivery (seconds)
- delay jitter (variations of the delay)
- error probability (lost packets, bit errors)
- error detection probability (effectiveness of checksums)
- error correction measures (retransmission, forward error correction)
- topology (unicast, anycast, multicast, broadcast)
- availability (probability of a successful connection set-up)

A given network may always provide certain values of these parameters (guaranteed QoS), achieve them on average over a given time (statistical QoS), or just strive to maintain the values (best-effort QoS). For example, guaranteed QoS is provided by the ISDN telephone system with respect to data rate, but not in all the other areas.

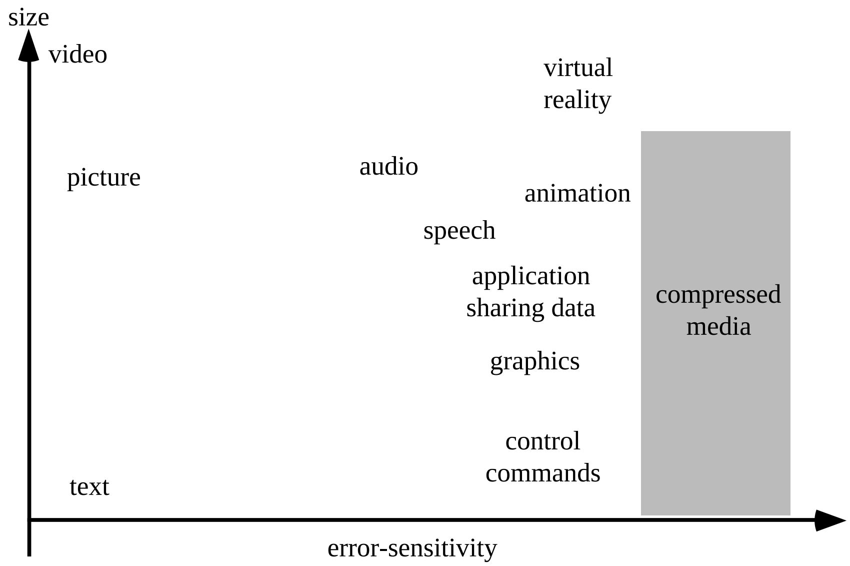

Figure 4. Media stream size versus error-tolerance.

The current publicly available Internet is based on the best-effort QoS paradigm. In reality, Internet-QoS is completely unpredictable. Although research and development is trying to add true QoS to the Internet (IntServ, DiffServ), reliable QoS in today's Internet is based on overdimensioning the system (links and routers).

Dramatic improvements in overall Internet bandwidth have taken place and will be achieved in the immediate future. However:

Internet performance for the individual user cannot increase as long as the user number growth remains in the double-digit range.

3.4. Tool Overview

We will now discuss the services together with their requirements relating to the infrastructure such as computers, network QoS, and document formats. We will only review person-to-person tools, because there is a large and stable supply of such tools. The other fields (person-to-equipment experiment, person-to-metamachine) are not as well developed—there is no palette of existing, well-known tools available.

E-mail

Electronic mail is the exchange of text or multimedia documents in electronic form. It is usually performed by a distributed system of servers, which store messages and/or forward the messages to other servers. Messages are composed and read by humans with personal computers.

Examples for electronic mail services are

- Internet mail based on the standards RFC 821 (SMTP protocol), RFC 822 (syntax and format), and RFC 1341 Multipurpose Internet Mail Extensions (MIME)
- X.400 based on the X.420 document format

As servers and end-systems are very simple, low performance computers suffice. QoS-requirements are very moderate: low bandwidth and reasonably reliable transmission.

Unfortunately common document formats for e-mail are either unsatisfactory (RFC822+MIME) or not widely used (ODA, etc.). Users typically resort to attaching native documents to mails, thus creating a major incompatibility problem.

ftp

File transfer, the client-controlled transmission of files of any type (unknown to the protocol, except for the distinction between text and binary files), is used to exchange data between users. The data is produced and later presented by specific applications, which are not part of the service. Examples are the Internet file transfer ftp or distributed files systems (nfs, Appleshare, Novell, …), which are usually associated with operating systems.

Computer requirements for the servers vary depending on the number and size of stored documents and service users. The requirement to the client computers is determined by the applications working with the files.

QoS requirements focus on a very reliable transmission without bit-errors and reasonable bandwidth. In low-bandwidth environments where multiple users need access to the same files, a caching/pre-fetching mechanism based on **mirror-servers** can be used.

WWW

The World Wide Web is a distributed hypertext system. Servers store documents linked with so-called hyperlinks to enable easy referencing and navigation. Multimedia content (such as pictures) is also embedded with the hyperlink mechanism. Client programs such as Netscape or Internet Explorer help users navigate the web and display media-rich documents.

Computer requirements for the servers vary with the number and size of stored web pages and service users. The browser software on the client computers is demanding in terms of memory and execution speed. This is especially true if Java applets are embedded in the pages.

The web uses a wide variety of data formats: simple formats such as text, html, or GIF to very sophisticated proprietary compression schemes for video (Real Networks, QuickTime).

Computer Supported Cooperative Work (CSCW)

Computer supported cooperative work (**CSCW**) tries to coordinate the work of many persons on one entity such as a document or a process. Workflow management falls in this area or the management of file collections associated with an object or an event. Newer systems feature a WWW-based front end.

The foundation of generic (horizontal) CSCW systems such as BSCW is basically a file server. The system then adds cooperation support—access management, revision control, a comment process, archiving, etc. Vertical CSCW systems are specific to the application. They usually model a business or administrative process—e.g., the design of a paperclip or the response to a customer complaint. Since vertical CSCW tools are mostly custom or heavily customized software, they are typically very expensive. Virtual laboratories in the scope of this report will therefore have to write their own vertical CSCW tools.

Generic CSCW tools such as BSCW need medium QoS, basically the combined bandwidth and interactivity requirements of ftp and WWW. The endsystems should be somewhat more powerful than ftp and WWW servers combined.

Joint authoring of documents is a special form of CSCW—the asynchronous editing of documents such as publications by multiple authors. Tools add a transactional semantic to file management based on version and access rights.

Another subset of the CSCW tools is made up of distributed **project management** tools such as calendars, delivery date planning, and milestone supervision. These are typically proprietary applications with very specific data formats and distribution characteristics. Standards employed in this area are CORBA, DCE, RMI, COM/DCOM, and RPCs.

For both joint authoring and project management, QoS requirements include reliable delivery of messages, multicast or broadcast topologies, and specific delivery semantics, which are provided by additional software layers. They can be very demanding with respect to network delay in order to provide reasonable interactivity.

Chat

This ancestor of Internet real-time communication tools is a text-based synchronous conversation. Early forms of chat are Telex or UNIX talk. It is basically the text equivalent of a telephone call. Today chat is very popular among young people. Internet Relay Chat (IRC), ICQ (an Internet community and chat service), and many chat servers that can be attached to a WWW site exist today.

The requirements on the end systems vary with the platform used. Special chat programs are not demanding; Java-based chat in browsers is more dependent on fast computers. Network QoS requirements are simple, too—low bandwidth is sufficient, but the delay should be reasonably low (< 500 msecs) to guarantee interactivity.

Whiteboard

These applications allow the exchange of visual information such as writing text and drawing sketches (or formulae as pixelmaps) on a board. The paradigm is that of a teacher and his students using the board in the classroom. The exchange of information is typically based on drawing operations or bitmaps. Telepointing is another important component of the service. Although these tools seem easy to program at first, they are actually challenging to implement in a manner that makes them useful and easy to use. Examples are the Mbone tool whiteboard (see below) and built-in components of video conferencing tools.

Both chat and whiteboard are very generic—they exchange simple text and simple graphics (pixelmaps and drawing primitives such as line, circle, rectangle, and a few more). More complex, application-oriented symbols are typically not supported. Chat and/or whiteboards with scientific symbol capabilities for collaboration events between physicists, mathematicians, engineers, students, etc., are not widely available. In a VL, these kinds of tools that allow sharing of equations, formulae, chemical symbols, etc., will play an important role. A multi-platform "ScientificTalk[1]" prototype is currently under development at the Abdus Salam International Centre of Theoretical Physics (ICTP) in Trieste, Italy. It is an example of a 'vertical' chat/whiteboard for the natural science community to help researchers work on 'unfinished' scientific material with remote peers.

Internet telephony

This variation of the classic telephone service is based on audio compression and transmission in IP packets. Although many prototypes exist, they are not very useful. The bright future that analysts predict for IP telephony will probably use specially built networks based on Internet technology (packet switching, soft-state, RSVP). These networks will be considerably overdimensioned in order to guarantee appropriate QoS. They will be carefully managed by the operators. There will be charges similar to the current telephony service. The only price advantage for the users will result from increased competition and lower cost to the operator.

IP-based telephony is also available on the general public Internet. However, the QoS provided here is unpredictable due to the best-effort nature of this part of the Internet. Problems include frequent pauses because of packet losses, jitter, and very noticeable roundtrip delays (in the order of seconds). One should not expect free telephony with ISDN-QoS in the foreseeable future. For examples, see below under video conferencing.

Video conferencing

Video conferencing on the public Internet has similar problems to IP telephony, because the audio part is based on the same tools. Although the throughput requirements for video itself are higher than audio, QoS problems such as dropped frames and jitter are a lot less disturbing for the viewer than similar problems with audio streams. The video component can therefore be

[1] Contact: canessae@ictp.trieste.it.

useful as an added media stream for Public Switched Telephone Network (PSTN)-telephony. Examples are Intel ProShare, PictureTel, Netscape Conferencing, Microsoft NetMeeting, CUSeeMe, VocalTec, and many others. Most of these tools include other functions such as whiteboards.

MBone tools

This collection of real-time media distribution programs is most suitable to producer-consumer scenarios. In a typical multicast session, a few stream sources generate video, audio, and whiteboard graphics, which are then viewed by many consumers in a geographic area or even around the globe. Tools include vat (visual audio tool), rat (robust audio tool), nv (network video), vic (video conferencing), wb (whiteboard), ivs (audio and video from Inria), nte (network text editor), sdr (session directory), and other tools such as session recorders.

The most important ingredient of this system is, however, the MBone itself—the Multicast Backbone network. That is a subnetwork of the Internet consisting of special multicast routers and packet transmission tunnels between them. It should be noted that a working MBone and tool infrastructure requires significant maintenance. A good example is computer science conferencing, where five to ten UNIX gurus frantically work for more than an hour before the actual session and during the whole event to enable the MBone session. In terms of QoS, all the rules for audio and video apply—high bandwidth, low delay, and configurable error recovery.

Application sharing

The remote use of computers over a network is an early concept of computing. The application to be shared executes normally on the host computer. The application sharing service intercepts all screen output of this program and transmits it (i.e., the user interface) to the remote site and the remote input is fed back into the program. Thus, the program can be used from the remote site. However, systems to use programs on a computer from another computer of the same or a different kind no longer operate simply in the 'terminals-to-host' mode. Application sharing can be very useful in conjunction with a videoconference, to work from home in the office environment, to control lab-equipment remotely, and in many other situations. Examples of application sharing systems include WTS (Windows Terminal Server, Microsoft/Citrix), Proshare, and Timbuktu. All of them require good network quality of service (throughput, delay, and error-resilience) to ensure functionality and interactivity.

Virtual awareness

A relatively new form of WWW-based communication is centred around the notion of virtual vicinity. The idea is to add typical human interaction patterns to WWW surfing. Virtual presence services allow Web users to see each other while they are present on a Web page or on a linked page. The users can then start synchronous communication such as chat, telephony, and conferencing (see above). The proximity of users—i.e., whether they are in a vicinity—is measured with metrics such as time, link distance, document similarity, etc.

CoBrow is such a service. It uses a client server model, where the server is typically co-located with a Web-server. The client component can either be a Java-applet, a standalone program, or an html-based user interface page. QoS requirements are less than the requirements of WWW surfing. This does not, however, count the synchronous communication once it is started.

4. MODELS, EXAMPLES AND TRAINING ISSUES

During the past two decades, the increasing size and complexity of experiments in physics have forced governments to concentrate resources on a very few, but very large, experimental facilities. These facilities and their experimental programs are often epitomized by the term "megascience." At the same time, the size of the teams of scientists working together to accomplish a common objective has increased dramatically and the number of institutions involved in a particular collaboration has expanded greatly. The fields of elementary particle physics, nuclear physics, astronomy and condensed matter physics have all experienced this trend.

While physics experiments are conducted and data is taken at the major facility, analyses are often performed at the participating scientists' home institutions. This has led to the development of significant "user-groups" at universities and national laboratories that use remote facilities for their experiments. These user groups are often formed around collaborating teams that design and build large detector facilities housed at large accelerators that produce selected beams of particles for the experiment. A detector design, construction and installation project itself may cost hundreds of millions of dollars and take 5-10 years from initial concept to first data acquisition.

Increasingly, other areas of science are following this same trend. For example, the life sciences are adopting accelerator-based tools for analysis (e.g. x-ray synchrotron light sources controlled over digital networks) and for cancer research and therapy (e.g. neutron, proton, pion and heavy-ion beams). As another example, archeologists use large-scale centralized facilities for detailed chemical and physical experiments on samples for such studies as composition and dating.

In Telemedicine, teams of experts at various facilities review test results and perform diagnoses for patients at remote locations assisted by a local medical practitioner. Increasingly, medical research teams share data and conduct research using these same networking tools.

For such projects to be successful and cost-effective, a great deal of co-ordination is needed and efficient use of resources is required. Travel costs, especially for international travel, can be a significant factor and teams work to minimize these costs. As these scientists are often specialists in the use of computers and digital communications, they aggressively utilize these new tools and even push the frontier of their development. It is not surprising that the World Wide Web (WWW) grew out of the physics community's efforts to reduce the costs of travel and communications while facilitating a distributed network of data analysts in these megascience projects.

While these examples serve as useful prototypes of highly functioning VL enterprises, they may not be typical of the VL activities accessible for developing country researchers for two related reasons: they tend to depend on major amounts of funding available only from the developed countries and tend to restrict participation to those countries that can provide significant financial support. Exceptions exist where participating institutions from developing countries contribute "in-kind" support in the form of special expensive materials (iron for magnets, lead glass for detectors, boron, etc.) or significant personnel services for modeling and data analysis.

4.1. Administrative foundation for Virtual Laboratories

Because VLs are conceived to draw and complement "Real Laboratories" (RLs), the various models of organization of RL collaboration should be examined carefully in designing the appropriate VL support.

In the U.S.A., a consortium of research institutions may form to address large-scale research and advising functions usually in service to a major agency of the United States government such as United States Agency for International Development (USAID). A central consortium office is established with seed funding from the member institutions. The consortium then bids on large government contracts and subdivides the work effort among the participating institutions. The Midwestern University Consortium for International Agriculture (MUCIA), an example of this model, is active in the acquisition of large-scale contracts for agriculture research and infrastructure improvements in developing countries.

Other consortia have been formed to run large national facilities for the Department of Energy and for the National Science Foundation of the United States. Again, a central coordinating office is formed which becomes self-supporting through the contracts it obtains from the supporting agency. Most US National Laboratories run in this mode – that is, they are managed by the consortium holding the contract. Another feature of this model is that the staff of the National Laboratory are employed by the consortium and are not US Government employees. This gives the funding agency additional options to terminate all or parts of these laboratories on short notice as government funding priorities shift. Typical consortia may hold government contracts ranging from several hundred million dollars to more than a billion dollars per year.

Another model favored by large United States government agencies is the contractor - subcontractor model. The primary contractor, typically in the private sector, provides the core administrative functions and negotiates subcontracts with the subcontractors providing personnel and services. This model is used, for example, by at least one of the National Laboratories of the United States Department of Energy, by the United States Agency for International Development (USAID) and by the United States Information Agency (USIA). This approach appears favored for two main reasons: (1) flexibility to acquire or dismiss staff as projects and available funding require; (2) reduction in bureaucracy by having fewer government contracts in favor of the contractors' having more subcontractors. The private sector entity undergoes an extensive process of scrutiny and certifications to gain and maintain the status of a qualified government contractor. The subcontractors have relatively little paperwork to handle in comparison to the administrative responsibilities of the contractor.

In this model, the subcontractors report directly to the contractor and provide the "deliverables" via the contractor to the government. Thus, this model is more of a "top-down" or "hub and spokes" model rather than the VL involving dynamic collaborations. It is more concerned with "distributed procurement of the results" rather than with co-operative effort involving a high degree of interactivity and iterative discovery processes.

A third model of interest is that of the international research centre, typified by the following examples in the area of physics:

- International Centre for Theoretical Physics (ICTP), Trieste, Italy,
- Center for Theoretical Physics, Santa Barbara, California,
- National Center for Nuclear Physics, Seattle, Washington,
- International Centre for Theory (ICT), Trento, Italy.

At these centres, teams of experts from around the world are assembled for a fixed period of time, usually three months to one year, to address forefront research areas. In a typical case, a topic is identified, often on the interface between two sub-areas of physics, and a group of 20-40 experts are identified and invited to the centre for a fixed period of time. Partial support for their visit is provided by the centre itself.

These centres also have a permanent scientific staff forming the nucleus of some of these programs. Outside experts are called upon to organize programs as well. In a virtual laboratory context, teams formed through initial intensive periods spent at one location could be supported to continue their collaborations through the digitally-enabled forms of VLs. Special training activities could be developed to enable team members to continue productive collaborations once they return to their home institutions.

International research centres with similar overall orientations can be found in other areas, notably, for example, the network of international agricultural research centres under the sponsorship of the Consultative Group on International Agricultural Research (CGIAR).

Whatever underlying administrative model is chosen, certain core administrative functions are necessary for co-ordination and management of a VL and, possibly, fund raising as well. For example, a sponsor of a project requiring a VL approach may wish to work with a primary contractor due to practical limitations on the sponsor's staff (number and/or expertise). On the other hand, for purposes of having a robust and responsive VL, it may be advantageous for the central coordinating office of a VL to move among the participating institutions at fixed time intervals.

In the near term, as the technology in support of VL activities is rapidly evolving, VLs will require considerable infrastructure support from RLs to form, establish technical and personnel protocols, train VL participants and address many of the policy issues such as those presented in chapter 7 of this report.

Given the fixed time scale for a VL, it is reasonable that the VL would not have a permanent research staff. Instead, these personnel could be under contract through a RL, seconded by a RL to the VL, or under some other full or partial "buy-out" arrangement from a RL.

A VL typically produces publications as one of its "deliverables" to meet its contractual obligations. The VL may thus work with a well-defined "Chain of Command" or "Authority Structure" in order to:

- determine content and timing for release of information by a VL in conference proceedings,
- determine list of authors for a VL publication.

In one model of such a "Chain of Command", a Central Coordinating Group (CCG) with a chairperson (usually the lead Principal Investigator on a contract with a primary supporter) sets the overall policies on how information will be released publicly on the project. The policies will include production and circulation of draft documents (papers, press releases, reports, etc.), consensus-building and review before submission and release, authorship determination, and other related issues.

The CCG is a representative body so that all participants in the VL are represented in the policy process. Typically, each location participating in a VL has a senior member representing it on the CCG. The chairperson leads the discussions and the CCG works for consensus views. For example, the CCG may determine that it should review all documents from the VL which are to be released to the public such as scientific or technical publications, press releases, VL reports, etc. Furthermore, the CCG may determine that first drafts will be completed by teams within the VL which are designated by the CCG or by the chairperson acting on behalf of the CCG. The breadth of authorship may be similarly determined.

It is typical in large-scale experiments in particle physics at major facilities, for example, that a collaboration will have 10-20 institutions participating, or more. Such a collaboration can be viewed as a leading example of a VL. As one experiment may produce 5-25 Ph.D. thesis projects and many more journal articles, central co-ordination is very important to avoid duplication and to insure maximum productivity of the collaboration. As publications are a primary product of these collaborations, the process leading to the submission of a publication or to the presentation of results at a conference is highly formalized. The final decision is made by the "spokesperson" of the experiment (who serves like a "chairperson" in the model presented above).

It is interesting to note that in these particle physics experiments, the data is taken at the major experimental facility in great volumes. Typically, analyses are conducted by various teams looking for specific phenomena and these teams are responsible for producing the draft publications. The entire collaboration participates in the review process leading to a paper submitted for publication that is authored by all participants in the collaboration. This has led to journal articles in recent years with more than 500 authors in some cases. Such large-scale efforts may produce a long publication list for team members, but also leads to challenging issues of credit assignment and evaluation criteria for youthful participants facing promotion and tenure decisions.

4.2. Some examples of Virtual Laboratories

Whole Earth Telescope (WET)

WET is a VL which has been operating for about 10 years and has produced 15 Ph.D.'s. About 20 telescopes, many in developing countries, are linked together to co-ordinate observations of variable stars, link their data sets, share the analysis and write joint publications. WET was recently featured in an article in *Science* and covered in the popular press (see Bibliography).

WET makes two "runs" per year, each lasting about two weeks. During a run, all the participating telescopes measure the light output of a particular star as a function of time. Together, the telescopes amass an uninterrupted time sequence of varying light output from the stars over many days. This uninterrupted data set is subject to Fourier analysis to obtain the oscillating modes and, via computer models, the collaboration can then apply "stellar seismology" to determine the makeup of the star's interior.

Central coordination for WET had been at the University of Texas but, in 1998, moved to the International Institute of Theoretical and Applied Physics (IITAP). The annual budget is modest at US$ 200,000, not counting contributions from the home institutions of the participants in the VL.

WET has at least one annual meeting where 40-60 participants gather to discuss results, iron out difficulties and set new research goals.

Increasingly, WET is using collaborative software for real-time analysis of the data collected at remote sites to evaluate whether the scientific goals are being achieved with a given "target" star. Real-time evaluations provide options for changing the "target" star to take maximum advantage of scheduled observing time on the global telescope network.

The WET Director and Assistant Director are located at Iowa State University/IITAP. Major scientific and policy decisions are approved by a Council of the Wise ("COW"). WET's infrastructure support is via IITAP (computing and communications). WET has enjoyed continuous funding from the United States National Science Foundation and more recently from UNESCO via IITAP.

WET proves that large-scale science is not necessarily large budget science. Data archiving, data mining and standardized software accessible over Internet are current areas under intense development. A major scale-up (WET-II) with a new type of advanced photon detector is planned. WET-II involves distributed design, fabrication and testing of detectors which will cost about US$ 50,000 each. The plan is to build 10-20 of these advanced detectors in order to increase by an order of magnitude the range of variable stars that can be observed. WET-II will extend the limit of the VL in many directions, particularly as it involves critical participation by developing country scientists and technicians in all of its phases.

Space Physics and Aeronomy Research Collaboratory (SPARC)

SPARC brings together researchers in upper atmospheric and space physics from around the world, providing them a set of on-line collaboration tools and workspaces that link together scientific instruments and models. The collaboratory is itself a subject of study by computer and behavioral scientists who are developing and refining the tools and organizational structures that will make such real-time, on-line collaborative research commonplace. SPARC specializes in software developments in support of distributed groups working collaboratively with very limited bandwidth communications.

Argonne National Laboratory – Micro Characterization Laboratory

Under a program of the US Department of Energy called DOE2000, a consortium of leading institutions (Argonne Lab, Lawrence Berkely Lab, Oak Ridge Lab, Univ. of Illinois, and National Institute of Science and Technology) have developed a collaboratory for materials characterization. The Materials MicroCharacterization Collaboratory focuses on the scientists as users in an interactive electronic laboratory. The project is developing an electronic virtual environment equipped with state-of-the-art research capabilities, (consisting of both scientists as well as instrumentation) which revolves around a common theme of microcharacterization and materials research.

Project to Intercompare Regional Climate Simulations (PIRCS)

PIRCS is a VL recently started at IITAP with initial funding from the Electric Power Research Institute (EPRI) of about US$350,000 per year. When fully operational, PIRCS will link research teams in different regions of the world for cross-comparisons of regional climate simulators.

PIRCS' goal is to discover the strengths and weaknesses of the different regional climate simulation models by addressing a wide range of data sets (region specific) and then to move to a phase of making improvements in the regional climate models based on the results of the cross-comparisons. Workshops are currently held about every six months to assemble the participants in order to map out the basis on which the cross comparisons will be made and to identify the models and teams that will participate.

At present, since the start-up is heavily based on existing model-development teams, industrialized countries are primarily involved. However, some labs in developing countries have indicating their intention to join.

Central coordination for PIRCS is at ISU/IITAP with a three-scientist team leading the efforts. Infrastructure support is via IITAP (computing and communications), and UNESCO is fully involved via IITAP. UNESCO's Director General opened the first PIRCS workshop in 1994.

More so than the other models presented here, PIRCS illustrates how the VL concept can link the public and private sector in mutually beneficial ways. The private sector invests in a non-exclusive research project and welcomes investment from other sources. In this case, federal agencies of the U.S.A., Iowa State University and UNESCO all support the VL project. Proposals have been submitted to additional international sources of support including the Inter American Institute which manages funding for the Global Environmental Facility under the World Bank.

National Virtual Laboratory (NVL)

NVL is a well-known VL driven by needs of defense-related research. NVL is funded by various U.S. Department of Defense entities. NVL has run 3-4 projects ("experiments") and the lessons learned have been published in conference proceedings.

NVL works entirely with large-scale RLs in the U.S.A. so some of the lessons learned may be less relevant to the contexts of developing countries. Some of the lessons, e.g. importance of adopting cross-platform software and database management tools, and the need for central co-ordination, would appear to be general. Sandia National Laboratory has provided central coordination of the initial projects and assessed the outcomes (see Bibliography).

An Ecology VL

This project example is a one-year assessment project, recently reported in *Science* (see Bibliography), in which eight institutions, twenty faculty and one hundred graduate students participated. The purpose of the project was to evaluate the quality of the science used in preparing 44 Habitat Conservation Plans filed by various corporations. Central coordination was provided by the National Center for Ecological Analysis and Synthesis (NCEAS), Santa Barbara, California. A team leader and twelve other ecologists provided the scientific leadership. One might refer to this group as a "Core Team" of administrating scientists.

4.3. General training support

As VL projects often require introduction to specialized equipment and software, it is anticipated that intensive workshops offering "hands-on" experience may be required. Such workshops should be planned well in advance.

Attempts should be made to have some redundancy in personnel trained on elements critical to the success of the VL. This redundancy is necessary as the specialized training received often has a significant value in the private sector and some turnover of personnel is anticipated. Whenever possible, those receiving this specialized training should be under contract (in view of the support received for the training) with their sponsoring institution to remain at their home institution for a sufficient time to train others in the critical skills they have acquired.

As one example of a training programme in the core technologies applicable to a VL, IITAP operates an 8-week intensive programme called Networks for Use in Mathematics and Physical Sciences (NUMAPS – www.iitap.iastate.edu/numaps). NUMAPS offers hands-on experience to managers of computer networks and leaders in content development on forefront advances in networking and tools for content generation and presentation. Participation is by an application process and UNESCO provides partial support for participants from developing countries, for which NUMAPS is especially intended.

NUMAPS participants learn how to take computers from their shipping boxes and build a network-based on TCP/IP protocol and to link that network to the Internet. From there, they learn how to establish and maintain network servers and to install software that facilitates network access and usage by other members of their institutions. Previous participants have graduated to set up similar training programmes in developing countries.

The International Women in Science and Engineering (IWISE) Programme at IITAP, with support from UNESCO and Iowa State University, consists of (1) a training programme for leadership and network building, and (2) an opportunity to advance professional development through collaborative research at a facility in the United States. Components of the training programme address communications and networking. Collaborations have emerged from this training activity when, for example, Ukrainian and African participants found they had mutually beneficial and complementary experiences to share. Similarly, Russian and El Salvadoran participants have teamed together and are writing a joint research proposal.

UNESCO, working with a number of international partners has supported training programs on the Internet in Africa, including national courses in Ghana supported with the International Telecommunication Union, the United Nations Development Programme and the Physics Action Council of UNESCO and a series of sub-regional courses in African centres of excellence sponsored with the UN Economic Commission for Africa and other international partners. These courses have produced a core of trained personnel to establish and maintain local networks connected to Internet in service to research and educational institutions. Similar training activities could be organized for developing countries specifically for VL support, and would benefit from the experiences gained through this programme.

Additional training programmes exist and may be investigated over Internet. Care must be exercised in checking the quality of the programme before enrolling and investing significant resources. Costs and charging structures are found to vary widely – sometimes by as much as a factor of three for similar types of training activities. However, other training programmes that specifically aim to serve participants from developing countries have not been identified.

It is also feasible to deliver training modules in a distance education mode, increasingly so over the Internet. Although it takes considerable effort to develop effective educational packages with interactive exercises utilizing the Internet, as newer and more developer-friendly tools become available, the process of developing these modules is becoming simpler.

4.4. Training within VL projects

It may be desirable, due to scheduling issues and cost factors, for the central coordinating body of the VL to set up and operate the specialized schools as needed.

Several examples can be cited of VL pilot projects which accomplish training activities as a component of the VL project itself.

The Whole Earth Telescope (WET), presented above, conducts periodic workshops for its collaborating members to present papers, review scientific results, and to develop its plans for future runs. Overview presentations at the workshops are designed to introduce potential and new collaborators to the science and technology of WET. With additional consultations and access to the available literature, it is possible for a trained astronomer to become an active participant in WET within a relatively short period of time. The continued productivity of WET depends on this growth and replacement mode as some members of the WET collaboration move on to other interests over time.

The Project to Intercompare Regional Climate Simulations (PIRCS), also presented above, is relatively new and has been growing primarily through accretion of established regional climate simulation groups who decide to join the project. Periodic workshops are held for members to present their latest developments and simulation results for cross comparison with the other members' results. Some developing country scientists have participated in the first few workshops as observers.

More recently, PIRCS has initiated a program to host atmospheric scientists who are committed to developing research groups that will join PIRCS. Two scientists from China were in residence for an extended period during 1998 for this purpose. Scientists from Latin America and Africa have expressed an interest in joining. Members of the PIRCS collaboration have visited with these scientists, and additional visits are planned to further map out a programme of training that could lead to full participation in PIRCS. Funding in partial support of the Latin American training activities at PIRCS appears to be imminent.

5. BROADER IMPLICATIONS OF VIRTUAL LABORATORIES

A number of additional considerations should be addressed for the successful formation of VLs involving participation from specialists in developing countries. These questions include how the developing country partners can

- get meaningful shares of (and credit for) the research assignments
- benefit and perceive their benefits
- become integrated into the world-wide research enterprise
- acquire the training, experience, and infrastructure support (e.g., equipment and software for this new work environment)
- build up their infrastructures
- become acquainted with the standards of the contracting or coordinating body
- acquire expertise in technology transfer and management of intellectual property rights
- prevent brain drain, which might actually be stimulated by the VL through awareness building of a specialist's "market potential."

The answers to these issues are not clear at the present time, and appropriate plans and safeguards may have to be developed initially on a case-by-case basis. Such plans would be improved as experience with VLs expands. Fortunately, in many areas of intellectual endeavor, there is considerable experience with international collaborations that will form a starting point for these arrangements. In a real sense, the goals for international collaborations have not changed radically, whereas the means to accomplish those goals has been revolutionized.

Arrangements should be made on a mutually beneficial basis, and, in particular, any type of exploitative behavior should be avoided. For a VL to be sustainable, all parties must perceive fair value received for their contributions. Since customs concerning payment schedules, interpretation of deadlines, meanings of key words, and value of verbal/written agreements can often differ from one culture to another, an international VL places additional requirements on extensive use of channels of communication in order to avoid misunderstandings. Thus, it is best to arrange all details via a written contract or a memorandum of understanding before expecting participants to commit significant resources into the VL project.

When practical, it is advisable to subdivide a large project into smaller projects and to stage them with frequent conferences between partners, at least initially, to discuss all phases of the cooperative project.

In some cases, awareness-building activity at the participating institutions—for example, seminars in cross-cultural perception—may be sufficient to foreshadow difficulties for the VL. Simply understanding the different reference frames from which the collaborators originate may help partners interpret motives underlying each other's points of view.

Prototypes for addressing these issues could lead to better formulation of agreements for establishing the VL and to a more robust VL itself. For example, vigorous discussion of these issues among the participating groups and institutions, mutual decision making, and a high level of transparency of policies and procedures should work to minimize downstream complications from these issues. Some of the major considerations that should be included in such discussions are presented in the following subsections.

The participants in this meeting feel that they do not have a clear-cut set of answers to the questions presented below. Instead, we feel that the issues outlined in this section are worthy, in their own right, of vigorous investigation by multidisciplinary teams. From such research, one may hope to better identify what the best practices in each area are and that complete models for successful VLs will emerge.

5.1. Economic Considerations

Potentially, some of the most sensitive issues relate to economic considerations. Concerns about exploitative behavior and undemocratic policies and procedures may be rooted here. Key questions include:

- Costs and benefits—how to distribute equitably?
- Which market value determines compensation?
- How to manage funds and to transfer funds—local rights and responsibilities in a VL?

As VLs will generally operate in the context of real laboratories (RLs) serving as hosts of the local participants, considerable attention should focus on the latters' roles in resolving these issues. It seems reasonable that local salary structures serve as the reference frame while premiums may be added as inducements to generate additional VL activity for the RL.

Innovative financial instruments such as net cash or cyber checks may be introduced and provide additional mechanisms for remuneration. The extent to which such a resource is convertible to other goods and services will determine the utility and value of such financial instruments. This area remains to be fully investigated.

Real laboratories may wish to consider adopting their own policies and procedures so as to make their institutions attractive sites for participation in VL projects.

5.2. Legal Considerations

Scientists and technologists often prefer to ignore the complexities of legal issues tied with their activities. However, too frequently, failure to anticipate these issues leads to major misunderstandings, damaged relationships, and lost opportunities. Here we list several issues for which adequate advance consideration is recommended:

- intellectual property rights—how to balance the distribution of benefits in accordance with the rules of each participating country
- multi-institution contracts—responsibilities, sharing in rights and privileges
- liability—workers' safety, warrantees on products and services
- non-performance clauses—allowance for institutional emergencies
- fees, methods of payment—transfer and conversion of funds
- duties, taxes, transportation fees—assignment of responsibility

- insurance—medical, liability

The general rule is that the institution providing the salary support for the VL participant attends to the above issues. When multiple institutions are involved, they will generally meet to develop agreements, such as memoranda of understanding (MOU's), which cover the inter-institutional issues and international issues. Ultimately, the adoption of the VL format will benefit by greater homogeneity of intellectual property rights among countries.

5.3. Organizational Considerations

Clearly, a VL must have an organizational structure that is both responsible and flexible. Transparency will be essential so that key decisions will be made and accepted in a timely fashion. Arguably, the most successful organizational structure is likely to be one that is self-determined (self-organized) and adjusted as needs warrant—one in which all participants have a voice.

Here we list several key issues to be aware of in determining the organizational structure of the VL:

- Who sets policies and determines what is fair, ethical, "normal"? Who oversees that compensation is fair to the participants?
- How to establish and manage efficiently? Organic growth vs. monolithic growth?
- What is fair feedback of VL benefits to the local environments? What share of the burden for sustaining/improving local infrastructure should a VL bear? How does the VL engage the local institutions as "stakeholders"?
- How to distribute work, motivate VL employees, deliver training, recognize and reward excellence while discouraging non-performance (develop the "carrots and the sticks")?
- Models for structures—examples of "chain of command" in decision making (central leadership -> site leadership -> group leadership)?
- How is authorship of joint publications to be determined? How will decisions on the release of research results in conference proceedings, press releases, and reports to sponsors be made?

In some cases, it has been easier for the participating institutions to join in creating a new entity with legal status in the respective countries of the participating institutions. This new entity, held in common by the partners, has its own articles of incorporation and provides the organization under which the major economic and legal issues of this section are addressed. Clearly, the VL effort must be of sufficient magnitude and importance to warrant such an administrative burden. Note that there is also the burden on the VL participants of reporting to more than one administrative unit at the same time. Indeed, most experts see a major virtue of the VL concept is that it minimizes such additional administrative units.

5.4. Social and Psychological Considerations

Social and psychological issues are often not considered until after the VL becomes operational, when problems become more apparent. Some forethought and preparations on specific issues may help avoid disruptive influences from VL projects that are not necessary:

- relocations for training that may disrupt family or professional activities at home
- effects on collegiality—VL participants may be viewed as having left the RL and become treated like “outsiders”; similarly, VL participants may tend to consider themselves as a privileged class
- splintering into subgroups of “haves” and “have-nots” in regards, for example, to access to digital workgroup environments, external support
- cross-cultural perceptions in a digital workgroup
- cognitive difficulties in working virtually—e.g., understanding meanings and intentions of co-workers without face-to-face meetings; maintaining perspectives and thought trains while working asynchronously with collaborators
- cognitive disassociation when working in working virtual environments where sensory feedback is lacking (e.g., tele-robotics without feedback).

While diversity is a potential strength of the VL approach, diversity motivates significant effort for good interpersonal communications. Many experts feel that a suitable level of communication can only be acquired initially through face-to-face meetings. They feel that, even before a VL is launched, there should be significant in-person interactions so that the participants become familiar with each other’s frames of reference.

5.5. Ethical Considerations

One area in science that has received relatively little attention is the issue of professional ethics—particularly in the physical sciences. This issue is much more thoroughly investigated in the social and life sciences, which have seen a rapid increase of efforts to define and refine the notions of professional ethics.

A good example of advancing discussions is bioethics, where entire institutes are now established to bring together philosophers, life scientists, and social scientists to discuss challenging issues of professional ethics. Issues ranging from ownership of information, rights to profit from genetic knowledge, and cloning of humans represent but a sample of the areas of vigorous investigation.

We enumerate below some broad categories of issues that deserve special consideration with the advent of the VL:

- How is the research agenda determined? Are the resource-rich participants exploiting those less endowed with resources? Are the relationships patronizing or peer-based?
- How are the benefits distributed (monetary, credit, technology transfer, advantages for industrial or economic stimuli)?
- There should be guidelines for eligibility for participation.

- Equal pay for equal work—should global, regional, or local market conditions prevail?
- Fair credit for authorship—should postgraduate students and technical staff be included?
- The brain-drain issue—with advances in telematics, is physical location an essential element or only incidental?
- Who controls the resultant data and for how long (once shared, it may depreciate in value)?
- Idea-drain issues—where do ideas fit in the global knowledge industry? As consumables? Are new definitions needed?

6. FINDINGS AND RECOMMENDATIONS

In this section, we outline the consensus views of the participants of the workshop held May 10-12, 1999.

6.1. Promotion of Policies and Strategies for Application at the Institutional, Professional, and Governmental Levels

The meeting defined a VL as "an electronic workspace for distance collaboration and experimentation in research or other creative activity, to generate and deliver results using distributed information and communication technologies."

We recommend specific actions to foster the widest possible access to the benefits of virtual laboratories. In some areas, more information is needed and we recommend studies to resolve critical issues.

1. New communications technologies should enhance freedom in the conduct of science, facilitate the self-governance of scientific communities, and promote open exchange among all participants. At the same time, such enhanced capabilities impose ethical obligations. Freedom without scientific responsibility greatly reduces the value of science to the world. This has led the discussants to respectfully recommend the following actions:
   - Organize an international roundtable on the interface between community self-governance, law, ethics, and responsibility. Two appropriate bodies to refer this proposal to are the American Association for the Advancement of Science (AAAS) Committee on Scientific Freedom and Responsibility, and the UNESCO World Commission on the Ethics of Scientific Knowledge and Technology, which have mandates in science and human rights, responsibility of science, and science and law.
   - Examine the implications for scientific freedom of the emerging technologies with the possibility of developing information and advice for the International Council for Science (ICSU) and the scientific unions. An appropriate body is the ICSU Standing Committee on Freedom in the Conduct of Science.

2. The value of science and technology for society is in economic, social, and cultural improvement. Thus, science and technology must be exploited to ensure that all countries benefit. We are obligated, therefore, to secure equal access to the new communications media in order that scientists and engineers around the world may participate freely in the world science and technology enterprise. For this reason, the discussants expect individual scientists and their learned societies to actively work to educate the public and government officials for the need to provide connectivity for their scientific communities.

3. We find several issues requiring the attention of governments: technology transfer in VL work (e.g., intellectual property rights) and tools (e.g., encryption technology not permitted to be transferred by the U.S. government); assuring or enabling adequate connectivity (provide affordable options such as discounts or exceptions for the scientific

and educational community); and promotion of VLs to examine global issues and problems. Our specific recommendations follow.

- Ask the International Telecommunication Union (ITU), the Internet Society (ISOC), and other organizations to explore the problems and make recommendations to approach governments.
- Develop/provide sensitization seminars to acquaint government officials with the capabilities of telecommunications technology.
- Develop a series of national and regional policy conferences.

4. The public itself must participate and benefit; the VL medium permits public access and outreach. Such outreach must be considered integral to all projects to emphasize the public stake in research and technology.
   - Develop interactive forums to inform the general public on the outcomes of programs and provide channels for explanation and exchange of information.
   - Develop educational interfaces at all levels—K–12 and higher education.
   - Provide access for those seeking specific project-related information on science and technology issues and references for those interested in seeking additional sources of information.
   - Provide forums for exchanges at the interface of science, technology, and public policy.

6.2. Virtual Laboratory Pilot Projects

To promote rapid development and support for VLs, we suggest that the world's scientific and development support communities cooperate in organizing as soon as possible a range of pilot projects to test the potential of VLs for achieving shared objectives of researchers in developing and developed countries. To this end, we present nine areas of criteria for evaluating proposals for VL pilot projects. In an appendix to this report, we list 12 pilot projects developed by the discussants as candidates for support. Since the purpose is to stimulate actions and to indicate the breadth of opportunity, this report does not evaluate the pilot projects but presents them as illustrative examples.

<u>Measures of Quality and Success</u>

The quality of the project can be estimated in terms of the qualifications of the principal investigators and team member(s) as well as the subject of the investigation, the objectives, the infrastructure or environment in which the work is conducted, the proposed methodology, and the deliverables.

The measure of the success will depend upon the quality of the deliverables. Quantitative information often includes the number of refereed publications and technical reports and their impact. The ability to leverage resources from a variety of sponsors will be an indirect measure of success, as will be the professional advancement (e.g., promotions) of the VL participants. The resulting improvement in local infrastructure (human and physical resources) will be another indirect measure of success. The less tangible measures of success include increased access to critical information resources and increased training levels of the participants and their local colleagues.

Scalability and Openness to Participation

The project scalability can be considered in three dimensions: time, space, and size. A scalable time frame allows for extension of the deadline in order to address unanticipated aspects of the project. Alternatively, as a result of initial successes, it may become necessary to extend the timeline in order to widen the scope of the project. A scalable spatial feature addresses the possibility of repeating or duplicating the project in other geographical areas of the world. For the VL pilot project to be size-scalable, it should provide for maximum openness of information and promote the free flow of contributions, etc. In other words, limiting data availability and/or access to analytical tools must be viewed with circumspection.

Goals

The goals of the project should be clearly stated and related to a specific need and to the potential of the VL technology. When possible, there should be evidence of previous experience of the collaborators. Clear evidence of a group and institutional commitment is highly desired.

Sources of Funding

The financial sources could be institutional, governmental, or from the private sector, international funding agencies, and foundations. All forms of support such as financial, in-kind, knowledge, information, voluntary contributions, and so forth are acceptable and should be stated.

Flexibility/Adaptability

By definition, VL pilot projects are highly dynamic. Therefore, project flexibility and adaptability become very important to the survival of the project. In addition, a provision for necessary adjustments to address unforeseen circumstances or difficulties will be an advantage. Therefore, it is recommended that projects should have open designs and that developments within the project follow standardized methodologies, frameworks for development, tools, and techniques. Recommendations below for a "toolbox" and on-line documentation should facilitate VLs in these technical issues.

Project Sustainability

For the sustainability of the project, there should be an indication of the availability and adequacy of the required resources throughout the life cycle of the project. Mechanisms for utilizing the outcomes of the project should be outlined.

Sustainable Development

To help promote sustainable development, the project should be related to the needs and development plans of the countries involved.

Originality/Uniqueness

Unique and original projects that capitalize on the VL approach and lead to the advancement of knowledge should be encouraged. There is also a need for projects that help to promote and disseminate experience gained from successful VL projects and possible variations in different applications and localities.

Dimensions/Time Length/Diversity

The nature of a VL project may be characterized by its goals and outcomes. For example:

- collaborative scientific research for the advancement of knowledge
- collaborative effort for the enhancement of scientific and technical capabilities of the groups involved through resource and talent sharing (multi-directional training)
- other conceptual, intellectual, or creative collaboration for human development based on knowledge integration and dissemination

To avoid excessive overlap and duplication of efforts, it is important to monitor the diversity of the portfolio project mix. Adopting a modular form of project outcome production could reduce the potential for project overlap and duplication. To help categorize projects to be evaluated for inclusion into the VL project portfolio, we recommend a three-dimensional matrix. The three dimensions are (1) the basic nature of the VL project, (2) its size and time span, and (3) its geographical and disciplinary scope.

In terms of project size, a VL project can be labeled with such descriptors as mini, midi (medium), or maxi (large), which would typically be applied to the aggregate of resources to be committed to the project. The scope of a project can be generally categorized, based on its personnel involvement and/or potential impact of its outcome, such as local, regional, or global. Additionally, the scope would include its disciplinary or multidisciplinary character.

6.3. Implementing and Sustaining a Virtual Laboratory Collaboration with Effective Tools, Support for Training and Operation

We recommend establishing a long-term project, involving a distributed team of specialists, to develop and maintain an on-line site that contains a toolbox, documentation, and training/support information. This project itself would operate in the VL mode and test the products offered through the site. This would require that actions be taken to establish facilities/capabilities in the following areas:

Toolbox

We recommend establishing an on-line toolbox consisting of software for the creation and distribution of information and services to support VL collaborative research efforts. These tools exist both in open and commercial form. A well-documented on-line directory with evaluations for effectiveness in VL environments must be created with an appropriate review process. The toolbox will consist of a collection of software and references/abstracts/reviews of software. Special concern should be given to regional operational issues such as bandwidth, administrative restrictions, costs, etc. Consistency in the selection of software and the review process will be important for the utility of the toolbox.

A profile matrix for collaborative systems will be established with suggested categories—quality of service (QoS), content, and taxonomy. Taxonomy is identified as the following types of interaction: person to person (both asynchronous and synchronous), person to equipment (teleoperation or teleprogramming), or person to metamachine ("intelligent" computer and equipment complex).

Distribution of these resources would be conducted using common network methods such as ftp and http. Special consideration would be taken to support those regions that are not able to transfer large data archives. Thus, CD-ROM distributions and/or e-mail access to the toolbox will be provided.

Documentation

We recommend creating an on-line site for information on the process of establishing a VL environment and its continued operation. This documentation should include the organizational and social dimensions, technology framework, and underlying infrastructure. Documentation will be created with the intent of its utilization as a training tool. Information on training and support opportunities as well as VL conferences/workshops should be included.

Documentation on the organizational and social issues will include:

- intellectual property rights and other legal issues
- planning and management aspects
- team building

- sociological issues such as working with remote collaborators (including such topics as tele-awareness and issues of cross-cultural perceptions)

Documentation for technological and infrastructure issues will include:

- network infrastructure building and operation
- client/server network operation and support
- media, file, and executable standards
- content creation methods

A collaborative creating, editing, and feedback process will provide a basis for dynamic updating and evaluation of the documentation project to maintain currency. Collecting, reviewing, and annotating existing documentation will be integral in this effort.

In support of the technology section, a trouble-shooting section covering common issues of operation in all previously mentioned areas will be created, thus providing a first step for the resolution of operational issues in a VL environment.

Training Support

An effort such as a VL requires a support network to enhance sustainability. Training, both on-site and at established training facilities, will be required. This support and training must address not only information technology staff but also administrative structures affecting a collaborative effort. As such, this training will help increase the local human resource capital in the area of information workers.

Training will be tailored to the audience, such as trainers versus practitioners or technologists versus administrators. Evaluation of the effectiveness of the training on the various audience types will be important in the process of managing instructional resources.

Training in scheduled, well-structured settings as well as on-demand and on-site training will be required. Training modules, such as on-line tutorials, will be created to facilitate independent training by groups or individuals in various settings. Virtual laboratories themselves should create on-line, openly available modular tutorials that facilitate the growth of VL activity, especially in developing countries.

Both synchronous and asynchronous mechanisms should be addressed. To support running VLs, a procedure for addressing, in near real time, questions regarding operation and VL software systems should be established.

Coordination among existing groups and their training efforts will be required to maximize both effectiveness and efficiency.

REFERENCES AND BIBLIOGRAPHY

References

More, R., T. A. Prince, and M. Ellisman. “Data-intensive computing and digital libraries,” *Communications of the ACM* 41 (11): 56–62, 1998 (other more specific articles follow)

Froitzheim, K. *Multimedia-Kommunikation*. University of Heidelberg. 1997.

Sayers, C. *Remote Control Robotics*. University of Heidelberg. 1998.

Canessa, E., F. Postogna, and S. Radicella. “Enhancing electronic collaboration in the South,” *Nature* 398:744, 1999; and http://helix.nature.com/wcs/c12.html.

Additional Reports, Books and Journal Articles

Chadwick, S. , “Modeling trust as part of organizations,” Iowa State University, 1999.

Kopka, H., and P. W. Daly, *A Guide to LaTeX 2e.* 2d ed. Harlow, England: Addison-Wesley, 1995.
LaTeX is a system that supports cross-platform sharing of publication-quality and camera-ready documents.

Mann, C. and M. Plummer, “Qualified thumbs up for habitat plan science, ”*Science* 278:2052. 1997. Contact: Mr. Peter Kareiva, University of Washington.

Matey, J. R. “ A world without barriers,” Editor’s report from NIWEEK ’97. *Computers in Physics* 11, 570 (1997).
NIWEEK is National Instrument Corp’s conference on virtual instrumentation. “A virtual instrument is a layer of software and/or hardware added to a general-purpose computer in such a fashion that users can interact with the computer as though it were a traditional electronic instrument.” The computer screen presents a rendition of the control panel of the instrument with controls. The user manipulates the controls with a mouse and cursors. The instrument displays readings from signals acquired through a hardware interface to the external world. This article also discusses telepresence—digital control of experiments at a distance—and cites Mars Pathfinder/Sojourner, a Swiss mechanical experiment, and Oak Ridge Laboratory’s toxic-gas-testing system.

Vary, J.P., “IITAP as a ‘Hub of Network Science’” Director’s column from the March 1997 issue of IITAP’s newsletter, *SPECTRUM*. Available on-line at http://www.iitap.iastate.edu.

Wulf, W., The national collaboratory--A white paper. In *Towards a National Collaboratory: Report of an Invitational Workshop* . Ed. J. Lederberg, and Uncapher, K. USA: Rockefeller University, 1989.
Definition of collaboratory by computer scientist William Wulf, President of the National Academy of Engineering: “A centre without walls, in which users can perform their research without regard to geographical location—interacting with colleagues, accessing

instrumentation, sharing data and computational resources, and accessing information in digital libraries."

____, "Cyber astronomy," *Science* 283 (January): 139, 1999.
This article describes on-line 0.9 meter telescope outside Cleveland, Ohio, as "the country's first robotic telescope accessible to the public." http://astrwww.cwru.edu/nassau/nassau.html.

____, International Virtual Research and Development Laboratory (IVRDC) description contained in the white paper from the IITAP Planning Workshop for Regional and International Cooperation in Science and Technology, October 1995.
Available on-line at http://www.iitap.iastate.edu//reports/

____, "Large projects in graphical programming environments," *Computers in Physics* 11:573, 1997.

____, "Microscopy across an ocean," *Science* 281:303, 1998.
Biologists use world's most powerful electron microscope in Osaka University (Japan)—while sitting 6,000 kilometres away in San Diego, California. Contact: Mr. Mark Ellisman, neurologist, University of California at San Diego.

____, *National Collaboratories—Applying Information Technology for Scientific Research*, Committee on a National Collaboratory, National Research Council, 1993 (National Academy Press, 1993).

____,Unicode Consortium. Unicode Standard, Version 2.0. Addison-Wesley, ISBN 0-201-48345-9. http://unicode.org.

____, "Webculture," *UNISIST Newsletter* 25 (2), 1997.
This article provides an overview of SIGGRAPH 97, the world's largest computer graphics and interactive techniques conference (Los Angeles, 3-8 August, 1997), including several technologies presented that provide multi-user communication infrastructure for complex virtual worlds.

Web Sites

A visit to any of the major web search engines with a request on "virtual laboratory" will provide thousands of citations. Most deal with the physical sciences and engineering. An attempt is made here to provide a selection of sites representative of different VL themes and approaches.

<u>IITAP's Web Site for the Virtual Laboratory</u>
http://www3.iitap.iastate.edu/numaps98/vl/
This site is basically a central reference site to many related sites, categorized and annotated.

<u>The Virtual Laboratory: Using Networks to Enable Widely Distributed Collaboratory Science</u>
http://www-itg.lbl.gov/~johnston/VirtualLab.short.fm.html
http://www-itg.lbl.gov/~johnston/Virtual.Labs.html

This site focuses on electronic access/use of large scale experimental facilities.

An Examination of User Interaction Paradigms in Synthetic Environments
http://www.public.iastate.edu/~bperles/Research/UserInteraction.html

DOE2000 Collaboratory Research
http://www.mcs.anl.gov/DOE2000/collabs.html
To make existing resources truly effective, scientists and engineers must be able to interact as if they were physically co-located—sharing data, high-performance computing systems, and instrumentation independent of location. To this end, the DOE2000 Collaboratory Research activity is exploring several new areas. Site contains many links to subareas under this major project.

Basic Support for Cooperative Work (BSCW) Home Page
http://bscw.gmd.de/
BSCW is a groupware system developed by GMD—German Research Centre for Information Technology—which is completely based on Internet and web technology. End users of the system only need a normal web browser such as Netscape Communicator or MS Internet Explorer to use the full functionality of the system. It is particularly useful for collaboration in locally dispersed groups with heterogeneous system platforms.

Knowledge and Distributed Intelligence (KDI)
General: http://www.ehr.nsf.gov/kdi
1998 awards: http://www.ehr.nsf.gov/kdi/award98/default.htm
This is a funding programme of the U.S. National Science Foundation.

Medical Collaboratory
http://www.si.umich.edu/medcollab/
See especially:
http://www.eecs.umich.edu/~nelsonr/medcollab/report95.html
For a description of “Record and Replay Paradigm for Computer-Supported Collaborative Work,” where medical diagnostics materials (such as x-rays) can be shared, analyzed, and reviewed over networks. The site contains presentations and tutorials and deals with capturing intra-task content (audio, visual, computer-generated).

Kaiser Permanente, Division of Research
http://www-itg.lbl.gov/Kaiser/home-page.html
Site is an on-line cardio-angiography laboratory (Bay Area ATM Network [BAGNet] tested; telemedicine as a contribution to the National Information Infrastructure).

The CoVis Project
http://www.covis.nwu.edu/
This site explores issues of scaling, diversity, and sustainability as they relate to the use of networking technologies to enable high school students to work in collaboration with remote students, teachers, and scientists. An important outcome of this work will be the construction of distributed electronic communities dedicated to science learning. Participating students study

atmospheric and environmental sciences through inquiry-based activities. Using state-of-the-art scientific visualization software, specially modified to be appropriate to a learning environment, students have access to the same research tools and data sets used by leading-edge scientists in the field.
See also their software suite (only available for Macs):
www.covis.nwu.edu/info/CoVis_Software.html.

Human Genome Project
http://www.ncbi.nlm.nih.gov/HUGO/
The Human Genome Sequencing Index (HGSI) provides a service to members of the international consortium to support coordination and tracking of the Human Genome Project (HGP). Sequence and mapping target data from centres participating in the international consortium are submitted via the HGSI web site (a "target" is a chromosomal region delimited by Framework Markers). This web site also presents an overview of HGP progress to the research community in tabular and graphic displays of the target data. Both the password-protected data submission pages and the publicly available data overview pages are accessible from this page.

Political Scientists Researching Use of New Technologies for Distance Learning
http://www.public.iastate.edu/~sws/distance_learning_survey.htm
This is the first phase of a project to develop a network of political science researchers and educators that will share their experiences on effective use of new communication technologies in their discipline. An online survey is the primary instrument for identifying motivated individuals who will participate in the network. A subsequent phase will survey the effectiveness of these technologies in achieving educational objectives. So far, the network is primarily aimed at researching educational issues.

The CyberInstitute for Teaching Government and Politics
http://www.iastate.edu/~polsci/sws/professors/
This site is a clearing house for ideas for students to use the World Wide Web as a component of their political science course. Sample assignments and learning objectives are given.

Humanities-Net (H-Net) Discussion Networks
http://www.h-net.msu.edu/lists/
An extensive list of listservers and chat rooms for students, educators, and researchers in the humanities. Researchers often use listservers to obtain information and lead to sources of information. For example, clicking on "H-Mideast-Medieval" takes one to an extensive web site and discussion network devoted to The Islamic Lands of the Medieval Period.

The Virtual Laboratory: The Distributed Collection and Analysis of Binding Sites on Cell Membranes Using 3D Digital Microscopy and the Sharp3D Software
http://www.njc.org/Research/Labs/Monk/SC95.html

SkyView—Virtual Observatory/Telescope
http://skyview.gsfc.nasa.gov
This site allows astronomers to specify targets, obtain observations, and access use of facilities.

Intelink Management Office (IMO) Collaboration Working Group Activities
http://www.dtic.mil/ieb_cctwg/index.html
Site of Collaborative Computing Tools Working Group (CCTWG).

National Technology Virtual Laboratory
http://www.dtic.mil/ieb_cctwg/contrib-docs/Fall-Conf-96/4-NIMA/index.html
Site is a PowerPoint presentation of lessons learned from several projects conducted.

Synthetic Environment Lab
http://www.cs.sandia.gov/SEL/
This site concentrates on integrating different data sets referencing the same system in order to visualize the data with multiple user options. This is more a virtual reality example (data visualization) than a virtual laboratory (electronic collaboration) example.

Space Physics and Aeronomy Research Collaboratory (SPARC) {Formerly: Upper Atmosphere Research Collaboration (UARC)}
http://www.crew.umich.edu/UARC/

Whole Earth Telescope (WET)
http://wet.iitap.iastate.edu/

Virtual Environment Technology Laboratory (NASA/University of Houston collaboration)
http://www.vetl.uh.edu/
This is more a virtual reality example (data visualization) than a virtual laboratory (electronic collaboration). However, the Shared Virtual Environments for Testing at http://www.vetl.uh.edu/sharedvir/shared.html is more relevant. It features training at a distance using virtual reality (high-end simulators).

Virtues (and Vices) of Virtual Colleagues (an article by Nancy Ross-Flanigan)
http://www.techreview.com/articles/ma98/ross-flanigan.html
“When researchers work with their colleagues on the Net, they may generate more ideas. But some aspects of collaboration—such as trust—are hard to develop electronically.”
Underpinning such a setup is computer software—some designed specifically for the collaboratory and some borrowed from other applications—that enables people at various sites to work on experiments simultaneously. Shared access to electronic notebooks and whiteboards, videoconferencing capabilities, and other such technologies enhance the feeling of being “down the hall while across the country,” as James Myers, who leads a collaboratory project in environmental research, puts it.

CollaborArt
http://bailiwick.lib.uiowa.edu/global_connections/maps/index.html
CollaborArt uses the Internet and computer technology to connect Iowa students and educators with students, teachers, and artists in Central and Eastern Europe and the New Independent States (NIS) through visual arts and written text.

NCSA Internet and WWW Software
http://www.ncsa.uiuc.edu/Indices/Software/Research.html
Site has links to homepages for Habanero, Joule, ISAAC, POS, and more.

The Spectro-Microscopy Collaboratory At The Advanced Light Source
http://www-itg.lbl.gov/BL7Collab/
The University of Wisconsin-Milwaukee will remotely operate a sophisticated synchrotron-radiation beamline in the Spectro-Microscopy Facility at the Advanced Light Source. This collaboratory will provide remote access to three analytical tools at Lawrence Berkeley Laboratory's ALS that provide spatially resolved chemical information at length scales ranging (depending on the tool and the technique) from one micron down to atomic scale. The collaboration that uses these instruments is fairly large and geographically distributed, with investigators from nine institutions, so the potential for savings in time, expense of training, staffing, and travel is considerable. The ongoing growth trend of synchrotron-radiation applications will provide a large and welcoming audience for the results, in terms of both opening the Spectro-Microscopy Facility to a broader user community and applying the concepts and technologies at other facilities. One particularly interesting target audience for remote usage of this and similar facilities is the semiconductor industry, which has a critical need for sample inspection and would perform essentially identical measurements on a large number of samples.
The Spectro-Microscopy Collaboratory is one of four projects funded by the U.S. Department of Energy to build distributed, collaboratory experiment environments. The project goal is to apply current network and videoconferencing technology and provide remote access to the advanced light source (ALS).

Distributed Collaboratories and Collaboratory Interoperability
Framework Project Publications, Presentations, and Demonstrations
http://www-itg.lbl.gov/~deba/ALS.DCEE/project.publications.html
This site contains an estimated 200 references to publications, etc., with on-line references via URL's.

The William R. Wiley Environmental Molecular Sciences Laboratory (EMSL)
http://www.emsl.pnl.gov:2080/
The EMSL, located at Pacific Northwest National Laboratory (PNNL) in Richland, Washington, is the Department of Energy's newest national scientific user facility. The EMSL is operated by PNNL for the DOE Office of Biological and Environmental Research.

Abdus Salam International Centre for Theoretical Physics (ICTP)
http://helix.nature.com/wcs/c12.html
Site contains notes for enhancing electronic collaboration in the South.

Virtual Neutrino Network
http://neutrino.pc.helsinki.fi/neutrino//virtual.html
The Virtual Neutrino Network (ViNNet) is an international collaboration based on computer networks developing internet-based tools for scientists and publishing original and compiled scientific data or simu different observable phenomena for the World Wide Web. Presently the work is focused on neutrino ph which is the hottest research field in elementary particle physics.

The purpose of the project is to develop new ways for distributing actual scientific information. Particular aim to build tools that allow the scientists to do real research work via computer networks. We ar developing educational multimedia that helps to visualize the phenomena in the universe.

Argonne National Laboratory—VLs Based on Person-to-Person Collaboration
http://www-unix.mcs.anl.gov/~minkoff/Collabtools.html
Contact Mike Minkoff (minkoff@mcs.anl.gov), who operates a mud/moo, which is a text-based virtual reality environment. This supports a community of researchers in the U.S. and Europe using this environment to complement telephone, Mbone video (with archiving), and e-mail.

Argonne National Laboratory – Micro Characterization Laboratory
http://tpm.amc.anl.gov/mmc

Includes remote controlled microscopy laboratory with less technical interfaces for schools – contact nestor j. zaluzec" <zaluzec@aaem.amc.anl.gov
http://tpm.amc.anl.gov
http://tpm.amc.anl.gov/MMC/Pubs/AnalyChem98/AnalyChem98.html

Merit Review, Digital Library Design and Cooperative Cognition
http://www.info.unicaen.fr/bnum/jelec/Solaris/d03/3turner.html
W. A.Turner, P. de Guchteneire, K. van Meter, Paris, 1995.

APPENDIX A: EXAMPLES OF POTENTIAL PILOT PROJECTS

PROJECT 1
Title: Laser Science in Africa
Submitted by: Ahmadou Wague
Project Summary: Laser science and applications in agriculture and medicine, environment and communications. Participating institutions/networks include the Abdus Salam International Centre for Theoretical Physics (ICTP), African Laser Atomic Molecular and Optical Sciences Network (LAM), and U.S. and European centres.
Working Groups:

Atomic, Molecular and Optical (AMOP)
applications in agriculture
applications in medicine
applications in environment
applications in monitoring
applications in communications

Topics Addressed

- exchanges
- problems
- cross referencing
- developing resources

PROJECT 2
Title: The Information and Communication Technologies (ICT) Decision Modelling Collaboratory
Submitted by: Joseph Potvin
Project Summary: The ICT Decision Modelling Collaboratory is a project concept for the development of an operations research model consisting of an objective function and a set of several linear algebraic and/or ordinary differential equations, each representing factors that affect ICT infrastructure decisions (e.g., bandwidth needs, scalability, population of participating researchers, financial costs, types of uses, administrative constraints, geographical constraints, etc.). Experts participating in the collaboratory would take responsibility to first prepare, and then maintain (as technology and experience evolve), each equation to be used in the model. The model would be made available to ICT system developers for remote access as a VL, offering both web and structured e-mail access for queries to help investigate appropriate ICT investment alternatives.

PROJECT 3
Title: Remote Material Characterization and Environmental Monitoring in Central America
Submitted by: Abdoulaye Diallo
Stakeholders: Countries in the region, ICTP, UNESCO, Organization of American States (OAS), and others
Project Summary: Tele-experiment to set up a remote study arrangement to characterize the behavior and properties of different materials under extremely corrosive conditions and to monitor the environmental conditions in the Panama Canal Zone. The Internet infrastructure

used to extract and process the data would also be used to provide connectivity to adjacent rural communities for telemedicine, tele-education, and sustainable development programmes.

PROJECT 4
Title: Virtual Computer Lab (or Open Computing Environment)
Submitted by: J. P. Vary
Project Summary: Provide a computational environment available by Internet for scientists to perform their calculations, model studies, data analyses, and store/retrieve their results; also, a place to create web pages, make data accessible to collaborators, lurkers, etc.

PROJECT 5
Title: CollaborArt: Cultural Environment Exchange
Submitted by: Barbara Bianchi (under the guidance of IITAP, ICTP, and Alexei Gvishiani of Earth Data Network for Education and Scientific Exchange [EDNES])
Participants: Suggested, but not limited to, the following: Ile-Ife, Nigeria, Africa, Trieste, Italy, Uzbekistan, Egypt, Russia, and Iowa, U.S.A.
Project Summary: As an interactive art collaboratory, CollaborArt will use computer technology to connect students and teachers in Iowa's rural school districts with students and teachers in other countries. Its purpose is to use the arts to help students deepen their understanding of the world and their place in it. Participants will use e-mail and the Internet to share their stories and collaborate with artist Barbara Bianchi and each other through the universal language of the visual arts.

PROJECT 6
Title: Network of Asynchronous Learning Nodes for Science Education
Submitted by: Liangyao Chen, Yunsheng Ma, David Tehyu Kao, Doug Fils
Project Summary: An effective, efficient, and economical approach to resource sharing and popularizing science and technical education in China.

PROJECT 7
Title: International Condensed Matter Physics and Engineering Laboratory
Submitted by: Anatoli Frishman
Project Summary: Create an international condensed matter physics and engineering laboratory with a specific mission—to serve as a bridge between Ukrainian and American scientists that will achieve the very best scientific and technological results.

PROJECT 8
Title: Real-Time Experimentation within the Virtual Laboratory Environment
Submitted by: Najeh Jisrawi
Region: Middle East
Project Summary: It has been recognized that an important part of the VL is remote instrument control or remote experimentation. For some years now, we have been teaching an instrumentation course that demonstrates the concepts of 'virtual instruments' and teaches students how to automate instruments for scientific experiments. I propose to expand that course and make it usable within the framework of a VL with web-enabled control of instruments and

sharing of data and resources both within and outside the lab. We also would like to use the VL framework to co-teach the course in several regional institutions.

PROJECT 9

Title: Development of a Network to Link the Participants in a Multinational Collaboration Focused on Sustainable Development in Henan, China

Submitted by: Joel A. Snow, Bing-Lin Young

Project Summary: The International Institute of Theoretical and Applied Physics (IITAP) and the Chinese Academy of Sciences' Research Centre for Eco-Environmental Sciences have been developing a programme on sustainable development in China that focuses on the sustainable development in a single province, Henan. Powerful technology will be needed to provide the connectivity and the resources to carry out collaborative research and technology transfer. We propose the establishment of a VL administrative umbrella to link the participants with each other and provide for rapid dissemination of research results. This will provide a straightforward application of the principles developed in this workshop to a major research programme urgently needed by China for which almost all the preliminary analysis and negotiation has already been completed.

PROJECT 10

Title: Use of Central Laboratories, Central Computing Facilities, and VL Concepts for Post-Graduate and Post-Doctoral Research in Developing Countries with Africa as a Case Study

Submitted by: G. O. Ajayi

Project Summary: A few well-furnished central laboratories in some disciplines (e.g., physical sciences laboratories and central computing facilities) will be established in developing countries. Several VLs in the sub-region will have access to the central research facilities using the Internet and other information network facilities. Facilities will also be provided to access appropriate physical laboratory facilities in the north.

PROJECT 11

Title: ICTP-VSAT-based VL for scientific collaboration—Pilot Project

Submitted by: S. M. Radicella, F. Postogna, A. Nobile, E. Canessa, G. O. Ajayi, ICTP, Trieste, Italy, Atef Sherif, Egypt

Project Summary: The use of VSAT (very small aperture terminal) technology is likely to explode due to declining costs and the launch of new satellites covering most continents on Ku band, requiring small equipment. The use of this technology could became a valuable option to support VL in the south because it provides reasonable speed.

Objectives:

(1) To link a number of scientific institutions in developing countries to allow scientists to collaborate in a modern scientific environment.

(2) To overcome scientific isolation while filling the need to transfer knowledge to the south in an unprecedented way.

Under this project, the scientific institutions in developing countries will have access to the following VL services:

- computational facilities
- Internet facilities of scientific relevance (e-mail, WWW)
- interactive sharing of documents (whiteboard, scientific talk)

- scientific and engineering data visualization

At the same time, the system will also serve more general purposes such as access to library resources, broadcast of selected lectures, and voice over IP (Internet Protocol).

The participating institutions will be able to use the VL facilities to engage in specific scientific projects that could be south-south and/or south-north based and/or open to partnership.

PROJECT 12

Title: Simulation Games for Peace and Conflict Resolution

Submitted by: Alfredo Rojas, Galileo Violini

Project Summary: Since 1994, the UNESCO Santiago office has been developing simulation games (SG) to train decision makers from the Ministries of Education in the region, as well as curriculum designers and school directors. A compiled CD ROM, "*Heuristica Educativa*" (Educational Heuristic), with six of these programmes has been distributed since 1998. SG and VL tools together will provide a powerful approach to address social problems like the weakness of the presence of women scientists in Latin America and the weakness of the actual possibilities of training in modern technologies in Latin American universities. A VL supporting the development of SGs for peace and conflict resolution would fit particularly well with the action of UNESCO to diffuse the culture of peace.

APPENDIX B: LIST OF PARTICIPANTS

Gabriel Ajayi, Professor, Obafemi Awolowo University, Department of Electronic and Electrical Engineering, NIGERIA

Wolfgang Appelt, German National Research Centre on Information Technology, Institute for Applied Information Technology, GERMANY

Barbara Bianchi, Artist, University of Iowa, U.S.A.

Enrique Canessa, Scientific Computer Section, Abdus Salam International Centre for Theoretical Physics (ICTP), ITALY

Dongsheng Chen, Director, Department of Science and Technology, Ministry of Education of PR China, CHINA

Liang Yao Chen, Executive Director, Fudan University, Shanghai Research Centre for Applied Physics, CHINA

Guy de Teramond, Director, Computer Centre University of Costa Rica, COSTA RICA

Abdoulaye F. Diallo, Research Professor, Technological University of Panama, PANAMA

Douglas Fils, System Support Specialist, International Institute of Theoretical and Applied Physics (IITAP), Iowa State University, U.S.A.

David Flory, Department of Agronomy, Iowa State University, U.S.A.

Anatoli Frishman, Scientist, Center for Advanced Technology Development (CATD), Iowa State University, U.S.A.

Konrad Froitzheim, University of Ulm, Distributed Systems Department, GERMANY

Alexei Gvishiani, Director, Centre of Geophysical Computer Data Studies, RUSSIA

Joseph Hardin, Director of Systems Development and Operations, University of Michigan, U.S.A.

Najeh Jisrawi, Professor of Physics, Birziet University, West Bank, PALESTINE

David Kao, Professor of Engineering, Iowa State University, U.S.A.

Steven Kawaler, Director of the Whole Earth Telescope (WET), Professor of Physics and Astronomy, Iowa State University, U.S.A.

Igor Khromushin, Head of the Laboratory, Almaty Department of the Institute of Atomic Energy, KAZAKHSTAN

Yong Lee, Professor of Political Science, Iowa State University, U.S.A.

Irving Lerch, Director of International Affairs, The American Physical Society, and Chair of the UNESCO/Physics Action Council Working Group on Telecommunications Networks for Science, U.S.A.

Tihamer Margitay, Vice Dean, Faculty of Social and Economic Sciences, Technical University of Budapest, HUNGARY

Gerard van Oortmerssen, Director, CWI Centre for Mathematics and Computer Science, THE NETHERLANDS

Fulvio Postogna, Networking and Radiocommunications, Abdus Salam International Centre for Theoretical Physics (ICTP), ITALY

Joseph Potvin, Senior Programme Officer, Bellanet International Secretariat, CANADA

Sandro Radicella, Head, Aeronomy and Radiopropagation Lab, Abdus Salam International Centre for Theoretical Physics (ICTP), ITALY

John Rose, Information and Informatics Division, UNESCO, FRANCE

James Sheats, Technology for Sustainability, Hewlett-Packard Laboratories, U.S.A.

Mack Shelley, Professor of Statistics, Iowa State University, U.S.A.

Atef Sherif, Professor of Aerospace Engineering, Cairo University, EGYPT

Peter Siegel, Director, Academic Instructional Technology, Iowa State University, U.S.A.

Joel Snow, Executive Associate Director, International Institute of Theoretical and Applied Physics (IITAP), Iowa State University, U.S.A.

James P. Vary, Director, International Institute of Theoretical and Applied Physics (IITAP), Iowa State University, U.S.A.

Mr. Ahmadou Wague, Departement de Physique Faculte des Sciences et Thecniques, Universite Cheikh Anta Diop, SENEGAL

Bing Lin Young, Assistant Director, International Institute of Theoretical and Applied Physics (IITAP), and Professor of Physics and Astronomy, Iowa State University, U.S.A.

Y. D. Zhang, Director of Science Infrastructure Construction, Ministry of Science and Technology, CHINA