PERVASIVE, HUMAN-CENTERED COMPUTING

MIT PROJECT OXYGEN

OXYGEN

MIT LABORATORY FOR COMPUTER SCIENCE   MIT ARTIFICIAL INTELLIGENCE LABORATORY

TABLE OF CONTENTS

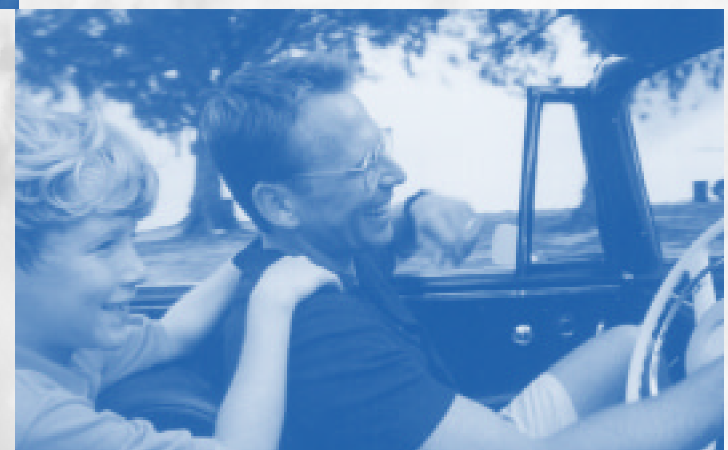
PERVASIVE, HUMAN-CENTERED COMPUTING

For forty years, computer systems have catered to machines. Purporting to serve people, they actually have forced people to serve them. They have been difficult to use. They have required us to interact with them on their terms, speaking their languages and manipulating their parts. They have not been aware of our needs or even of whether we were in the room with them.

In the future, computation will be human-centered: it will enter the human world, handling our goals and needs and helping us to do more by doing less. Computation will be pervasive, like batteries, power sockets, and the oxygen in the air we breathe. Configurable generic devices, either handheld or embedded in the environment, will bring computation to us, whenever we need it and wherever we might be. As we interact with these “anonymous” devices, they will adopt our information personalities. They will respect our desires for privacy and security. We won’t have to type, click, or learn new computer jargon. Instead, we’ll communicate naturally, using speech and gestures that describe our intent (“send this to Hari” or “print that picture on the nearest uncongested printer”), and leave it to the computer to carry out our will.

New systems will boost our productivity. They will help us automate repetitive human tasks, control a wealth of physical devices in our environment, find the information we need (when we need it, without forcing our eyes to examine thousands of search-engine hits), and enable us to work together with other people through space and time. To support highly dynamic and varied human activities, the Oxygen system must master a number of technical challenges.

It must be accessible anywhere. It must adapt to change, both in user requirements and in operating conditions. It must never shut down or reboot – components may come and go in response to demand, errors, and upgrades, but Oxygen as a whole must be available all the time.



THE APPROACH

INTEGRATED TECHNOLOGIES THAT ADDRESS HUMAN NEEDS

Oxygen enables pervasive, human-centered computing through a combination of specific user and system technologies.

Oxygen's user technologies directly address human needs. Speech and vision technologies enable us to communicate with Oxygen as if we're interacting with another person, saving much time and effort. Automation, individualized knowledge access, and collaboration technologies help us perform a wide variety of tasks that we want to do in the ways we like to do them.

Oxygen's system technologies dramatically extend our range by delivering user technologies to us at home, at work, or on the go. Computational devices, called Enviro21s (E21s), embedded in our homes, offices, and cars sense and affect our immediate environment. Hand-held devices, called Handy21s (H21s), empower us to communicate and compute no matter where we are. Dynamic networks (N21s) help our machines locate each other as well as the people, services, and resources we want to reach.

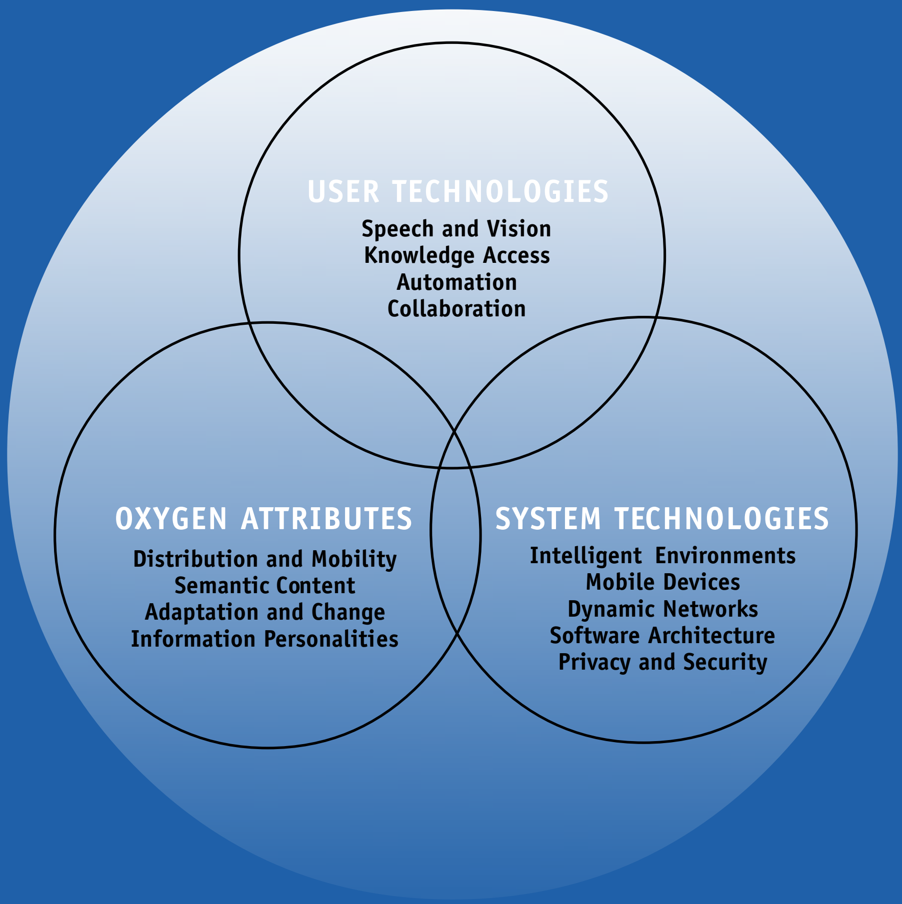
Oxygen's user technologies include:

Speech and Vision
Modes of interaction appropriate to the task at hand.

Knowledge Access
Finding the information you want by remembering what you've looked at before.

Automation
Offloading repetitive tasks from your brain to the computer.

Collaboration
Tracking and documenting a working group's discussions and interactions.



The Oxygen technologies work together and pay attention to several important themes:

- Distribution and mobility – for people, resources, and services.
- Semantic content – what we mean, not just what we say.
- Adaptation and change – essential features of an increasingly dynamic world.
- Information personalities – the privacy, security, and form of our individual interactions with Oxygen.

Oxygen is an integrated software system that will reside in the public domain. Its development is sponsored by DARPA and the Oxygen Alliance of industrial partners, who share its goal of pervasive, human-centered computing. Realizing that goal will require a great deal of creativity and innovation, which will come from researchers, students, and others who use Oxygen technologies for their daily work during the course of the project. The lessons they derive from this experience will enable Oxygen to better serve human needs.

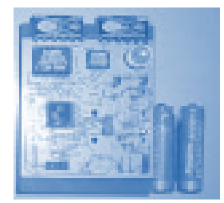
SYSTEM TECHNOLOGIES

DEVICES AND NETWORKS

People access Oxygen through stationary devices (E21s) embedded in the environment or via portable hand-held devices (H21s). These universally accessible devices supply power for computation, communication, and perception in much the same way that wall outlets and batteries deliver power to electrical appliances. Although not customized to any particular user, they can adapt automatically or be modified explicitly to address specific user preferences. Like power outlets and batteries, these devices differ mainly in how much energy they can supply.

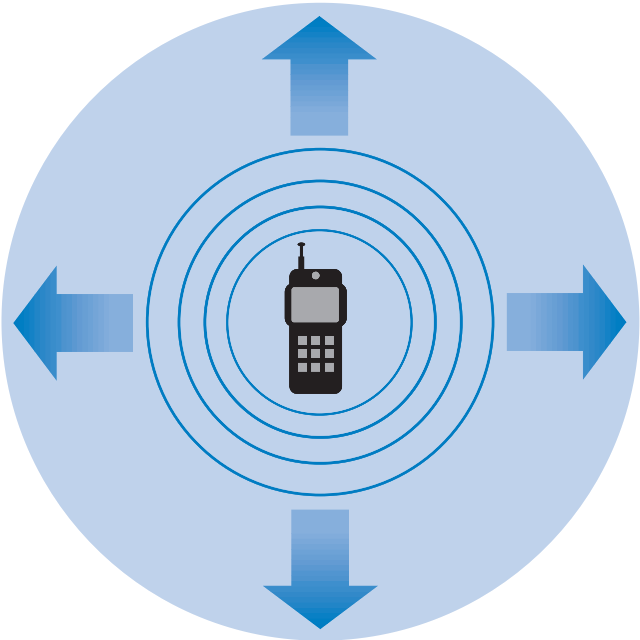
E21 STATIONARY DEVICES

Embedded in offices, buildings, homes, and vehicles, E21s enable us to create situated entities, often linked to local sensors and actuators, that perform various functions on our behalf, even in our absence. For example, we can create entities and situate them to monitor and change the temperature of a room, close a garage door, or redirect email to colleagues, even when we are thousands of miles away. E21s provide large amounts of embedded computation, as well as interfaces to camera and microphone arrays, thereby enabling us to communicate naturally, using speech and gesture, in the spaces they define.



H21 HAND-HELD DEVICES

Users can select hand-held devices, called H21s, appropriate to the tasks they wish to perform. These devices accept speech and visual input, can reconfigure themselves to perform a variety of useful functions, and support a range of communication protocols. Among other things, H21s can serve as cellular phones, beepers, radios, televisions, geographical positioning systems, cameras, or personal digital assistants, thereby reducing the number of special-purpose gadgets we must carry. To conserve power, they may offload communication and computation onto nearby E21s.



Hand-held devices, or H21s, provide mobile access to Oxygen for users both within and beyond E21-controlled environments. Each H21 contains a powerful computer and supports multiple modes of communication. H21s can reconfigure themselves to support a range of communication protocols or to perform a wide variety of useful functions.

NETWORK AND SOFTWARE INFRASTRUCTURE

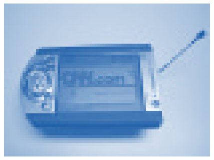
People use Oxygen to accomplish tasks that are part of their daily lives. Universally available network connectivity and computational power enable decentralized Oxygen components to perform these tasks by communicating and cooperating much as humans do in organizations. Components can be delegated to find resources, to link them together in useful ways, to monitor their progress, and to respond to change.

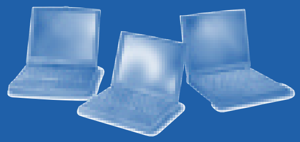
N21 NETWORKS

N21s support dynamically changing configurations of self-identifying mobile and stationary devices. They allow us to identify devices and services by how we intend to use them, not just by where they are located. They enable us to access the information and services we need, securely and privately, so that we are comfortable integrating Oxygen into our personal lives. N21s support multiple communication protocols for low-power local, building-wide, and campus-wide communication, enabling us to form collaborative regions that arise, adapt, and collapse as needed.

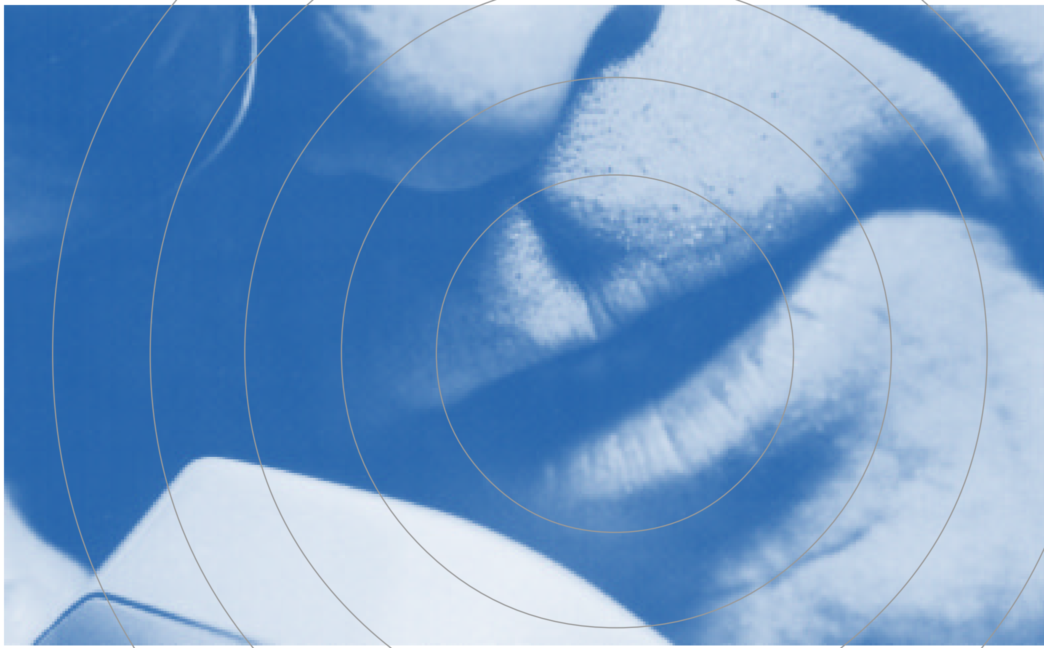
SOFTWARE ARCHITECTURE

Oxygen's software architecture supports change above the device and network levels. The software architecture matches current user goals with currently available software services, configuring those services to achieve the desired goals. When necessary, it adapts the resulting configurations to changes in goals, available services, or operating conditions. Thereby, it relieves users of the burden of directing and monitoring the operation of the system as it accomplishes their goals.





Several important technologies harness Oxygen's pervasive computational, communication, and perceptual resources to advance the human-centered goal of enabling people to accomplish more with less effort:



SPOKEN LANGUAGE, SKETCHING AND VISUAL CUES

Spoken language and visual cues, rather than keyboards and mice, define the main modes of interaction with Oxygen. By integrating these two technologies, Oxygen can better discern our intentions, for example, by using vision to augment speech understanding through the recognition of facial expressions, gestures, lip movements, and gaze. These perceptual technologies are part of the core of Oxygen, not just afterthoughts or interfaces to separate applications. They can be customized quickly in Oxygen applications to make selected human-machine interactions easy and natural. Graceful switching between different domains (e.g., from a conversation about the weather in Rome to one about airline reservations) supports seamless integration of applications.

KNOWLEDGE ACCESS

Individualized knowledge access technologies offer greatly improved access to information — customized to the needs of people, applications, and software systems. Universal access to information is facilitated through annotations that allow content-based comparisons and manipulations of data represented in different formats and using different terminologies. Users may access their own knowledge bases, those of friends and associates, and other information publicly available on the Web.

Visual recognition enables computers to discern our intent from visual cues. It allows us to use gestures or simply to go about our business, confident that the computer will notice us and respond in ways we have directed in advance.

Speech understanding makes computing more accessible. It allows us to give simple instructions like "Book the next flight to New York" or ask simple questions like "What is the weather like there?" without having to type or punch buttons.

AUTOMATION

Automation technologies provide natural, easy-to-use, customizable, and adaptive mechanisms for automating and tuning repetitive information and control tasks. For example, they allow users to create scripts that control devices such as doors or heating systems according to their tastes. In a hospital operating room, a physician-supplied script could automate equipment set-up, monitor its use during an operation, and fine-tune the script to improve the set-up procedures.

COLLABORATION

Collaboration technologies help people engage in group activities by allowing them to interact in secure collaborative regions, even though they may be participating at different times and in different locations. They trace group interactions, keeping an accessible, annotated trail of issues, decisions, documents, and important fragments of conversations. They link these elements in a semantic web, which enables group members to find the information they need.

These user technologies can be combined to serve more complex human needs. For example, using Oxygen, you can give the verbal instruction, "If the discount rate goes over 5%, convene our watchdog group." This simple-looking instruction exercises all user technologies – speech, because it was spoken; automation, because it creates an automated procedure to monitor the discount rate; individual information access, because the system accesses the information it needs from the right places; and collaboration, because the system will alert the watchdog group members and interconnect them.

HOW OXYGEN WILL WORK

FIELD TRIP

1
Leave Boston
On a field trip from Boston to New York, students use H21s to converse with friends on another bus, listen to music, play games, and identify the fancy cars they see out the window.

2
Museum Treasure Hunt
Teams use H21s to collaborate, get directions to exhibits from the museum's E21, and communicate with teachers to get new clues.

3
Check in at Hotel
Students use their H21s to locate their rooms, unlock their doors, and find their friends to go swimming.

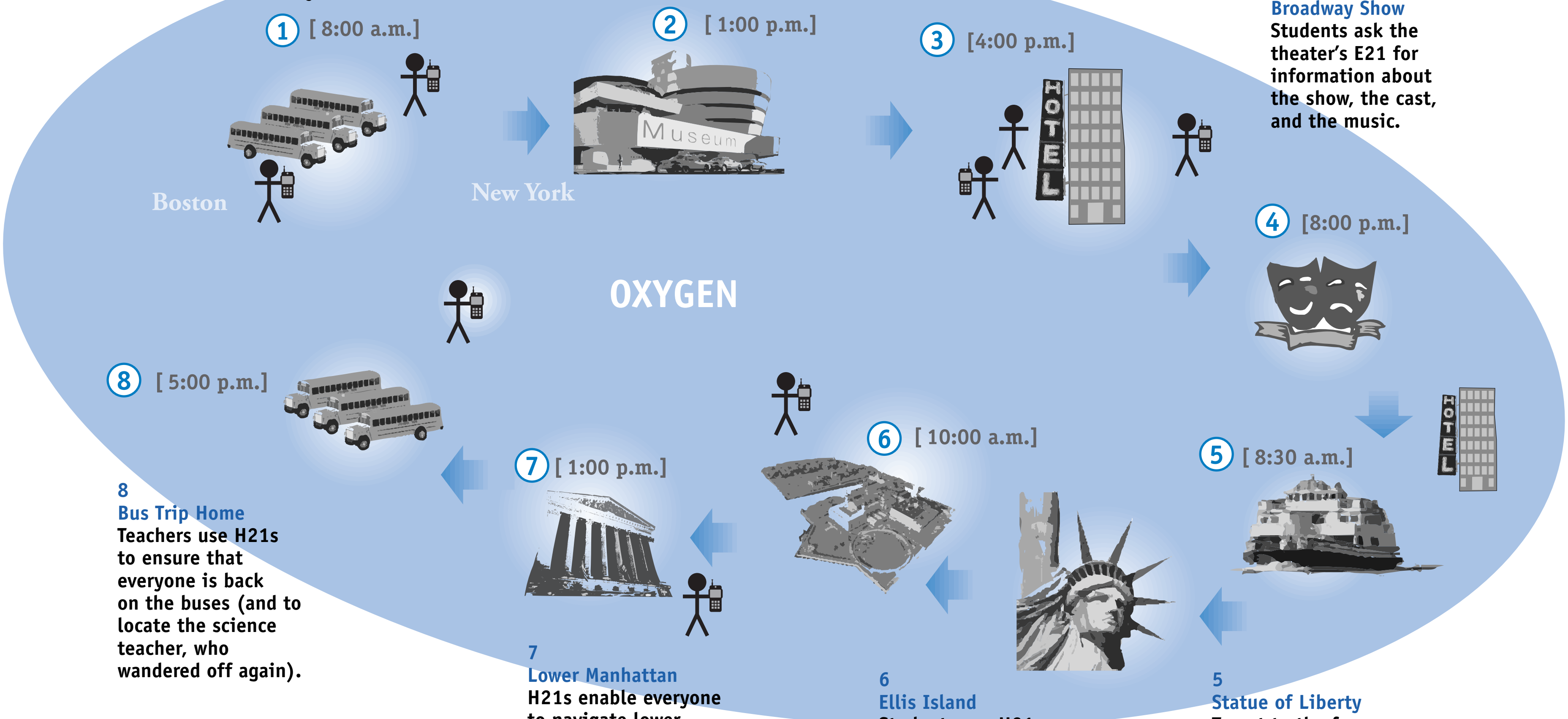
4
Broadway Show
Students ask the theater's E21 for information about the show, the cast, and the music.

5
Statue of Liberty
To get to the ferry on time despite unusually heavy traffic, H21s get students up and onto buses earlier than planned.

6
Ellis Island
Students use H21s to gather material for writing assign-ment about their family's immigration experience.

7
Lower Manhattan
H21s enable everyone to navigate lower Manhattan, find where to eat, tour the Stock Exchange, and enjoy free time in Chinatown.

8
Bus Trip Home
Teachers use H21s to ensure that everyone is back on the buses (and to locate the science teacher, who wandered off again).



Two further scenarios illustrate how Oxygen's integrated technologies make it easier for people to do more by doing less, wherever they may be.

BUSINESS CONFERENCE

Hélène calls Ralph in New York from their company's headquarters in Paris. Ralph's E21, connected to his phone, recognizes Hélène's telephone number; it answers in her native French, reports that Ralph is away on vacation, and asks if her call is urgent. The E21's multi-lingual speech and automation systems, which Ralph has scripted to handle urgent calls from people such as Hélène, recognize the word "decisif" in Hélène's reply and transfer the call to Ralph's H21 in his hotel. When Ralph speaks with Hélène, he decides to bring George, now at home in London, into the conversation.

All three decide to meet next week in Paris. Conversing with their E21s, they ask their automated calendars to compare their schedules and check the availability of flights from New York and London to Paris. Next Tuesday at 11am looks good. All colleagues say, "OK," and their automation systems make the necessary reservations.

Ralph and George arrive at Paris headquarters. At the front desk, they pick up H21s, which recognize their faces and connect to their E21s in New York and London. Ralph asks his H21 where they can find Hélène. It tells them she's across the street, and it provides an indoor/outdoor navigation system to guide them to her. George asks his H21 for "last week's technical drawings," which he forgot to bring. The H21 finds and fetches the drawings just as they meet Hélène.

GUARDIAN ANGEL

Jane and her husband Tom live in suburban Boston and cherish their independence. As they have advanced in age, they have acquired a growing number of devices and appliances, which they have connected to their E21. They no longer miss calls or visitors because they cannot reach the telephone or door in time; microphones and speakers in the walls enable them to answer either at any time. Sensors and actuators in the bathroom make sure that the bathtub does not overflow and that the water temperature is neither too hot nor too cold. Their automated knowledge system keeps track of which television programs they have enjoyed and alerts them when similar programs will be shown.

Just before their children moved away from the area, Jane and Tom enhanced their E21 to provide them with more help. Tom uses the system now to jog his memory by asking simple questions, such as "Did I take my medicine today?" or "Where did I put my glasses?" The E21's vision system, using cameras in the walls, recognizes and records patterns in Tom's motion. When Tom visits his doctor, he can bring along the vision system's records to see if there are changes in his gait that might indicate the onset of medical problems. Jane and Tom can also set up the vision system to contact medical personnel in case one of them falls down while alone. By delivering these ongoing services, the E21 affords peace of mind to both parents and children.

OXYGEN TODAY

Oxygen technologies are entering our everyday lives. Here are some of the technologies being tested at MIT and by the Oxygen industry partners:

Distribution and mobility. The *Cricket* location support system provides an indoor analog of GPS. The Intentional Naming System (*INS*) provides resource discovery based on what services do, rather than where they are located. The Self-Certifying (*SFS*) and Cooperative (*CFS*) File Systems provide secure access to data over untrusted networks without requiring centralized control.

Perceptual interfaces. *Multimodal* systems enhance recognition of both speech and vision. *Multilingual* systems support dialogs among participants speaking different languages. The *SpeechBuilder* utility supports development of spoken interfaces. Person tracking, face, gaze, and gesture recognition utilities support development of visual interfaces. Systems that understand sketching on white boards provide more natural interfaces to traditional software packages.

Semantic content. *Haystack* and the *Semantic Web* support personalized information management and collaboration through metadata management and manipulation. *ASSIST* helps extract design rationales from simple sketches.

Security and privacy. *Trusted software proxies* provide secure, private, and efficient access to networked and mobile devices and people. Decentralization in Oxygen aids privacy: users can locate what they need without having to reveal their own location.

Software and hardware architectures. *MetaGlue* is a robust architecture for software agents. The *GOALS* ystem integrates software services to accomplish user-defined goals. *RAW* and *Scale* expose hardware to compilers, which optimize the use of circuitry and power. *StreamIt* provides a language and optimizing compiler for streaming applications.

AN INVITATION

Widespread use of Oxygen and its advanced technologies will yield a profound leap in human productivity – one even more revolutionary than the move from mainframes to desktops. By enabling people to use spoken and visual cues to automate routine tasks, access knowledge, and collaborate with others anywhere, anytime, Oxygen stands to significantly amplify human capabilities throughout the world.

To realize our vision of all-pervasive, human-centered computing, researchers at the Laboratory for Computer Science and Artificial Intelligence Laboratory are engaged in an Industry Alliance to advance and integrate all Oxygen technologies. We expect the first Oxygen prototype in 2005. There will be many technical challenges to overcome, but we're confident that we can achieve our goals through ongoing and future collaborations with researchers and corporate sponsors. In that spirit, we invite you to consider joining us in this exciting endeavor.

ORGANIZATION

Victor Zue, Director, Laboratory for Computer Science
Rodney Brooks, Director, Artificial Intelligence Laboratory
Anant Agarwal, Associate Director, Laboratory for Computer Science

Please direct all inquiries to oxygen@lcs.mit.edu.

Project Oxygen Partners
The Acer Group
Delta Electronics
Hewlett-Packard
NTT
Nokia
Philips

Oxygen is also sponsored by the Information Processing and Technology Office (IPTO) of the Defense Advanced Research Projects Agency (DARPA) of the U.S. Department of Defense.

LCS

MIT LABORATORY FOR COMPUTER SCIENCE

Since its inception in 1974, under the leadership of Michael Dertouzos, its founding director, the MIT Laboratory for Computer Science (LCS) has been at the forefront of computer science. The hallmark of its research is a balanced blend between forefront technology and human utility. LCS members and alumni have been instrumental in the development of the ARPANET, the Internet, Ethernet, the World Wide Web, time-shared computers, RSA encryption, and dozens of other technologies. Anyone who makes decisions using a spreadsheet, sends and receives email, communicates with colleagues through a LAN, or surfs the Web is benefiting from the creative output of a present or former member of LCS.

LCS research has spawned over three dozen companies, including 3Com Corporation, Cirrus Logic, Inc., Lotus Development Corporation, Open Market, Inc., RSA Data Security, Inc., and Akamai Technologies, Inc. The Laboratory currently runs the World Wide Web Consortium, an open forum of companies and organizations, which strives to lead the Web to its full potential.

Currently, LCS is focusing its research on the architectures of tomorrow's information infrastructures. In the interest of making computers more efficient and easier to use, LCS researchers are putting great effort into human-machine communication via speech understanding; into designing new computers, operating systems, and communications architectures for a networked world; and into automating information gathering and organization. LCS researchers are also exploring the boundaries between computer science, biology, and medicine, as they continue to probe the theoretical underpinnings of computer science.

The Laboratory is committed to leading the computer revolution, expanding the boundaries of today's information technology, and redefining how computers may be used to help people lead better lives.

AI

MIT ARTIFICIAL INTELLIGENCE LABORATORY

Since Marvin Minsky and John McCarthy formed the Lab in 1959, it has always been a place where significant new tools and applications have been developed. The great strength of the AI Lab is its willingness to put together large-scale systems in ways that others have either not dared or for which they have not been able to marshal the required resources. The AI Lab has great strengths in connecting computation to the physical and social world through vision, robotics, and natural language.

These traditions are all alive and well, and the last few years have seen significant applications built on our robotics, vision, language, and circuit design technology. Over recent years we have pioneered new methods for image guided surgery, new remote presence surgical robots, intelligent prosthetics legs for people, natural language based methods for Web queries, and changed the way NASA explores planets. Twenty active companies have spun off from the Lab in just the last few years.

This activity will not abate any time soon. There are dozens of new applications currently being developed at the Lab helping surgeons, assisting the disabled, replacing precision mechanical components with computation, building new classes of human computer interfaces, providing new capabilities in image understanding, producing compilers that output DNA sequences to gain digital control over the biochemistry of living cells, and putting new learning algorithms to work. Our work in exploring intelligence feeds these applications. Our work on applications gives us new tools to explore intelligence. It is a symbiosis that has worked for us for a long time, and it appears that it will continue to work for the foreseeable future.

Published by the
MIT Laboratory for Computer Science
Design: Metcalf Design
Photography: Digital Vision, Getty Images, Masterfile
Printing: Arlington Lithograph

First Printing June, 2000
Second Printing, May, 2002

MIT PROJECT OXYGEN

MIT LABORATORY FOR COMPUTER SCIENCE
MIT ARTIFICIAL INTELLIGENCE LABORATORY

www.oxygen.lcs.mit.edu

MIT Laboratory for Computer Science
200 Technology Square
Cambridge, Massachusetts 02139
USA

MIT Artificial Intelligence Laboratory
200 Technology Square
Cambridge, Massachusetts 02139
USA

phone: 1.617.253.5851
fax: 1.617.258.8682
email: oxygen@lcs.mit.edu