Perspectives on
Emerging/Novel Computing Paradigms and Future Aerospace Workforce Environments

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INTRODUCTION

The accelerating pace of the computing technology development shows no signs of abating. Computing power reaching 100 Tflop/s is likely to be reached by 2004 and Pflop/s (10^{15} Flop/s) by 2007. The fundamental physical limits of computation, including information storage limits, communication limits and computation rate limits will likely be reached by the middle of the present millennium. To overcome these limits, novel technologies and new computing paradigms will be developed.

An attempt is made in this overview to put the diverse activities related to new computing-paradigms in perspective and to set the stage for the succeeding presentations. The presentation is divided into five parts (Figure 1). In the first part, a brief historical account is given of development of computer and networking technologies. The second part provides brief overviews of the three emerging computing paradigms – grid, ubiquitous and autonomic computing. The third part lists future computing alternatives and the characteristics of future computing environment. The fourth part describes future aerospace workforce research, learning and design environments. The fifth part lists the objectives of the workshop and some of the sources of information on future computing paradigms.
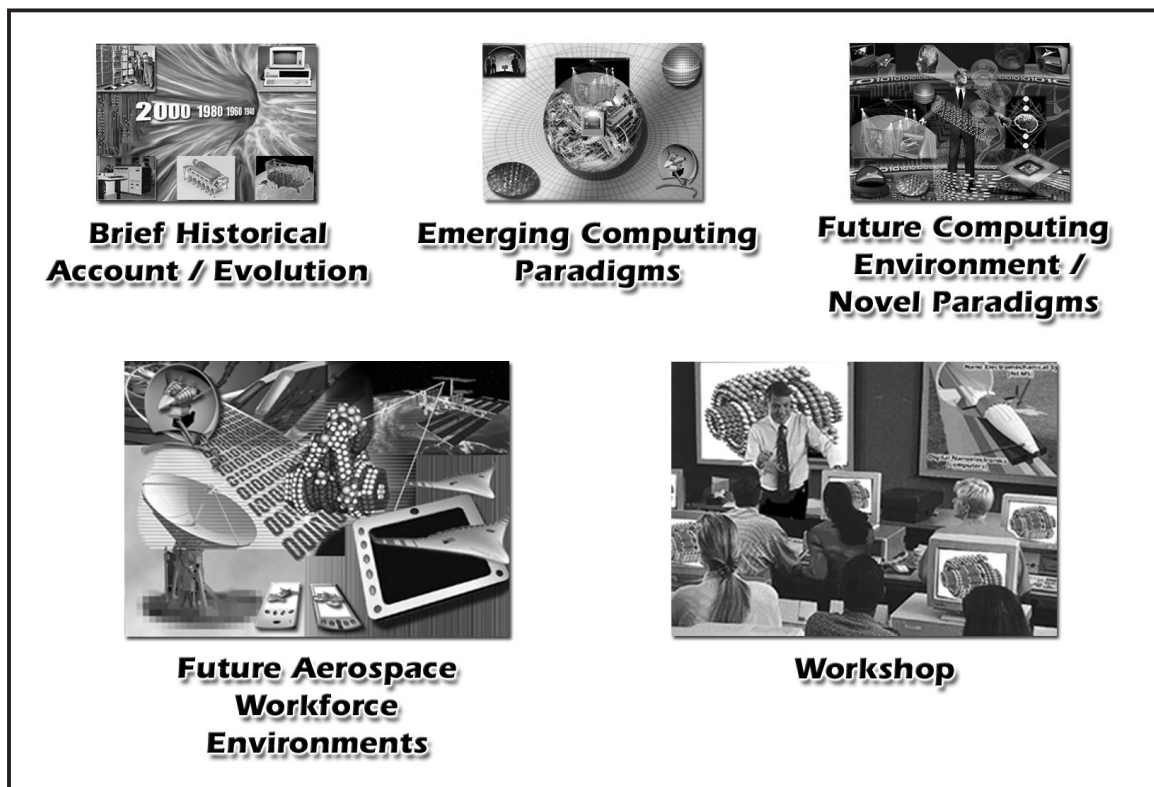

Figure 1

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BRIEF HISTORICAL ACCOUNT OF THE DEVELOPMENT OF COMPUTER AND NETWORKING TECHNOLOGIES

The field of computing is less than sixty years old. The first electronic computers were built in the 1940s as part of the war effort. The first transistor was invented in 1947. By 1950s, IBM and Univac built business computers, intended for scientific and mathematical calculations to determine ballistic trajectories and break ciphers. Soon other companies joined the effort – names like RCA, Burroughs, ICL and General Electric – most of whom disappeared or left the computer business. The first programming languages – Algol, FORTRAN, Cobol, and Lisp – were designed in the late 1950s, and the first operating system in the early 1960s. The first computer chip appeared in the late 1970s, the personal computer around the same time, and the IBM PC in 1981. Ethernet was invented in 1973 and did not appear in the market until 1980. It operated at 10 megabits per second (10 Mb/s) and increased to 1 Gb/s (10^9 bits/s) in 1997. The internet descended from the ARPANET in 1970s, and the World Wide Web was created in 1989 (see Figure 2).
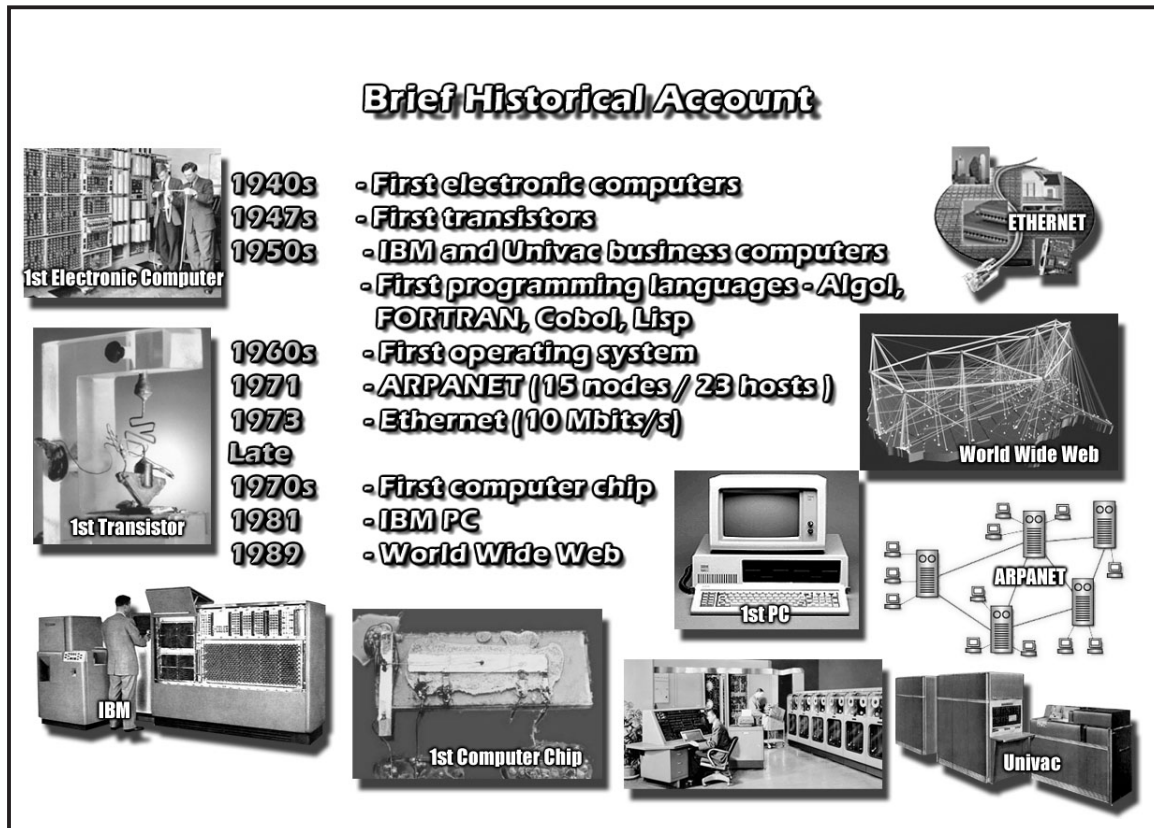

Figure 2

EVOLUTION OF MICROPROCESSORS

Although the first computers used relays and vacuum tubes for the switching elements, the age of digital electronics is usually said to have begun in 1947, when a research team at Bell Laboratories designed the first transistor. The transistor soon displaced the vacuum tube as the basic switching element in digital design. The nerve center for a computer, or a computing device, is its integrated circuit (IC or chip), the small electronic device made out of a semiconductor material. Integrated circuits, which appeared in the mid-1960's and allowed mass fabrication of transistors on silicon substrates are often classified by the number of transistors and other electronic components they contain. The ever-increasing number of devices packaged on a chip has given rise to the acronyms SSI, MSI, LSI, VLSI, ULSI, and GSI, which stand for small scale (1960s – with up to 20 gates per chip), medium-scale (late 1960's – 20-200 gates), large-scale (1970s – 200-5000 gates per chip), very large-scale (1980s – over 5000 gates per chip), ultra large-scale (1990s – over million transistors per chip), and giga-scale integration (over billion transistors per chip), respectively (Figure 3).

In 1965, Gordon Moore hypothesized that processing power (number of transistors and computing speed) of computer chips was doubling every 18-24 months or so. For nearly four decades the chip industry has marched in lock step to this pattern or rule of thumb, which is referred to as Moore's law (see Figure 3).
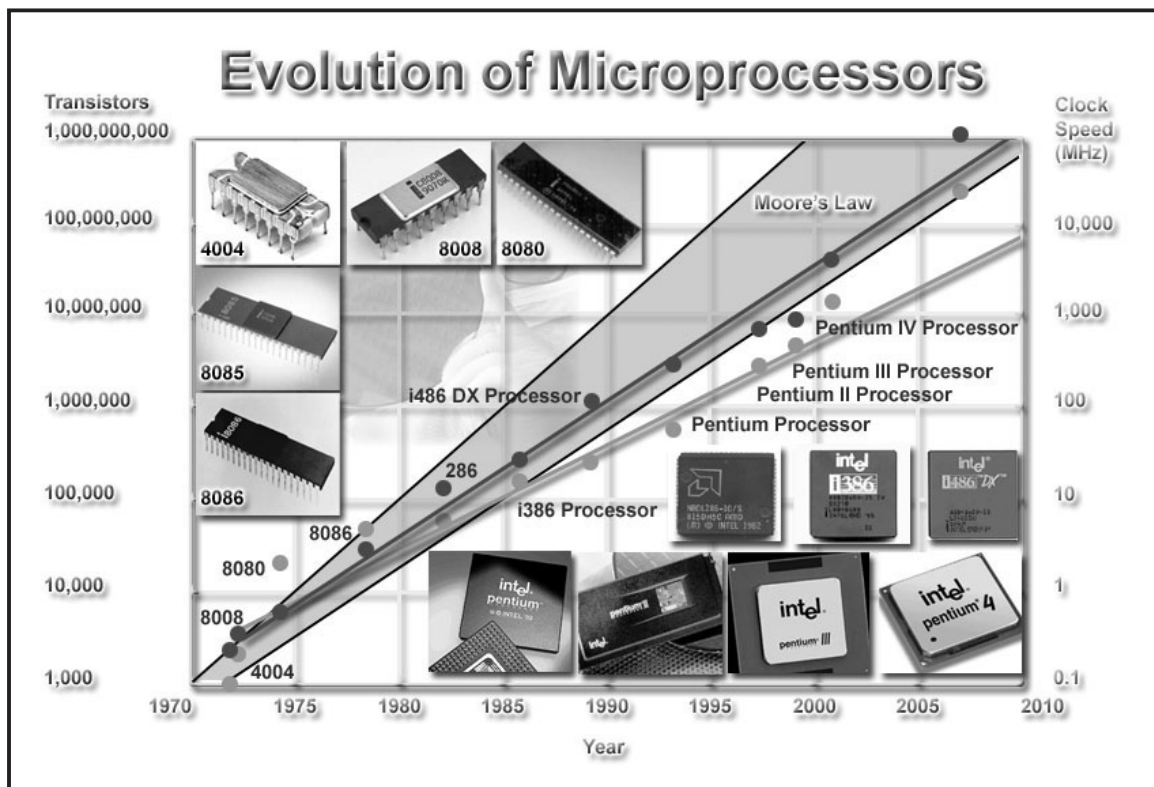

Figure 3

GROWTH IN COMPUTER SPEED AND SHIFT IN HARDWARE TECHNOLOGY

Advances in microprocessor technology resulted in increasing the speed of computers by more than trillion times during the last five decades, while dramatically reducing the cost (Figure 4).

A number of technologies have been used to achieve ultra fast logic circuits. These include use of: new material systems such as gallium arsenide (Ga As); multichip modules (MCM); monolithic and hybrid wafer-scale integration (WSI); new transistor structures such as the quantum-coupled devices using hetero-junction-based super lattices; and optical interconnections and integrated optical circuits. More recently, the use of carbon nanotubes as transistors in chips; clockless (asynchronous) chips and; hyper-threading, which makes a single CPU act in some ways like two chips, have been demonstrated.

The incessant demand for computing power to enable accurate simulation of complex phenomena in science and engineering has resulted in the development of a class of general-purpose supersystems designed for extremely high-performance throughput, and new paradigms for achieving the high-performance. These include:

- Vector/pipeline processing
- Parallel processing on multiple (hundreds or thousands) CPUs, and
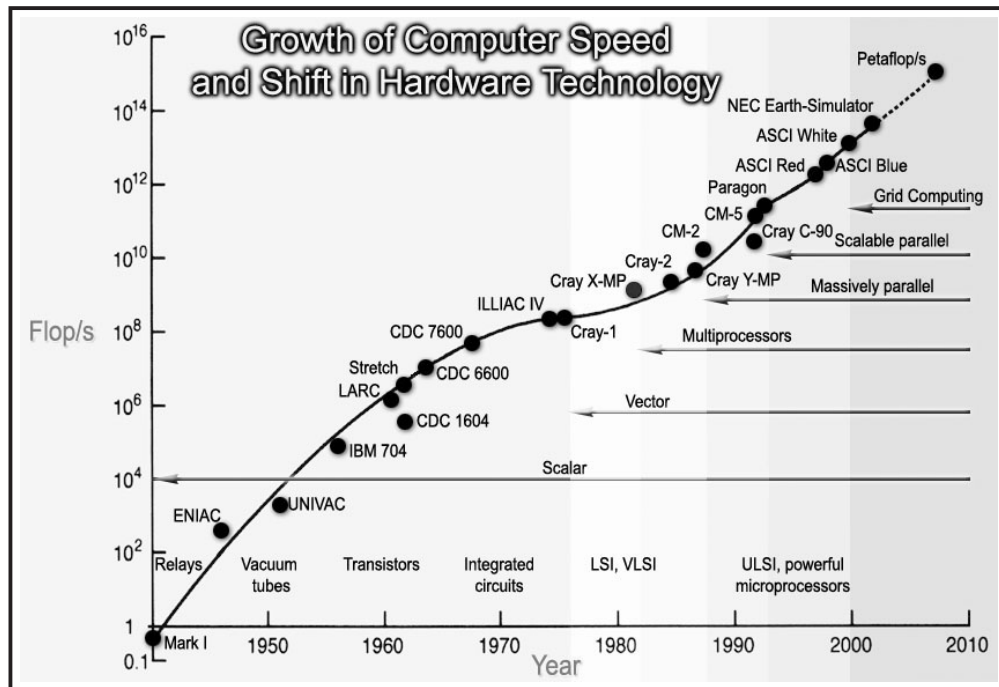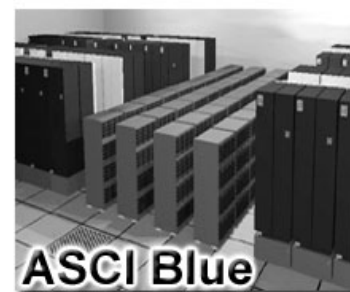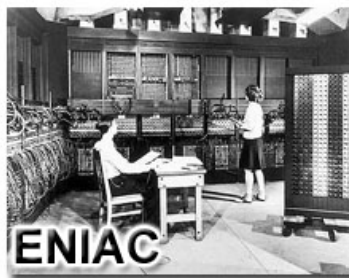- Multitasking with cache memory microprocessors

Figure 4

Figure 4 (continued)

TOP FIVE SUPERCOMPUTER SITES

Although the peak performance of the first generation supersystems was less than 100 Mflop/s, the gigaflop barrier (1 Gflop/s) was passed in 1988/89, and the teraflop barrier (1 Tflop/s) in 1996/7. In 1995, the US Department of Energy supported the development of three terascale machines through its Accelerated Strategic Computing Initiative (ASCI). The three machines are: ASCI Red, with 9,472 Intel Pentium II Xeon processors – 2.379 Tflop/s at Sandia National Labs; ASCI Blue Mountain with 5,856 IBM PowerPC 604E processors – 1.608 Tflop/s at Los Alamos National Labs; and ASCI White with 8,192 IBM Power 3-II processors – 7.226 Tflop/s at Lawrence Livermore National Lab.

To date, there are over 17 terascale machines worldwide. The maximum performance reported today is 35.86 Tflop/s of the Earth Simulator at Kanazawa, Japan, which consists of 5,104 vector processors (with peak performance of 40 Tflop/s).

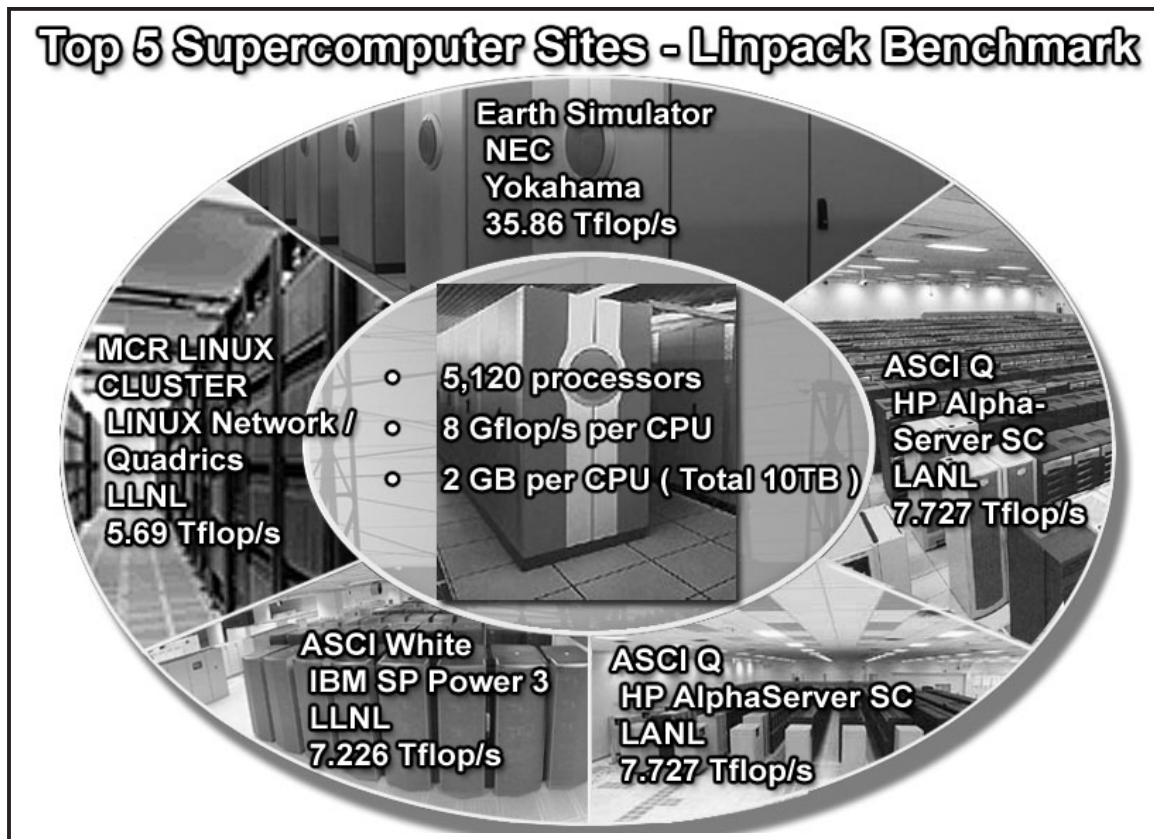The top five supercomputer sites, based on the Linpack benchmark are shown in Figure 5.

Figure 5

PETAFLOP SUPERSYSTEM

In December 1999, IBM announced a five year effort to build a petaflop (10^{15} Flop/s) supersystem – The Blue Gene Project. The project has the two primary goals of advancing the state of the art of biomolecular simulation, and computer design of extremely large-scale systems. Two systems are planned: Blue Gene/L, in collaboration with Lawrence Livermore National Lab, which leverages high speed interconnect and system-on-a-chip technologies and has a peak performance of 200 Tflop/s; and Blue Gene/P, the petaflop-scale system. The system will consist of more than one million processors, each capable of one billion operations per second. Thirty-two of these ultra-fast processors will be placed on single chip (32 Gflop/s). A compact two-foot by two-foot board containing 64 of these chips will be capable of 2 Tflop/s. Eight of the boards will be placed in 6-foot high racks (16 Tflop/s) and the final system will consist of 64 racks linked together to achieve the one Pflop/s performance (Figure 6).
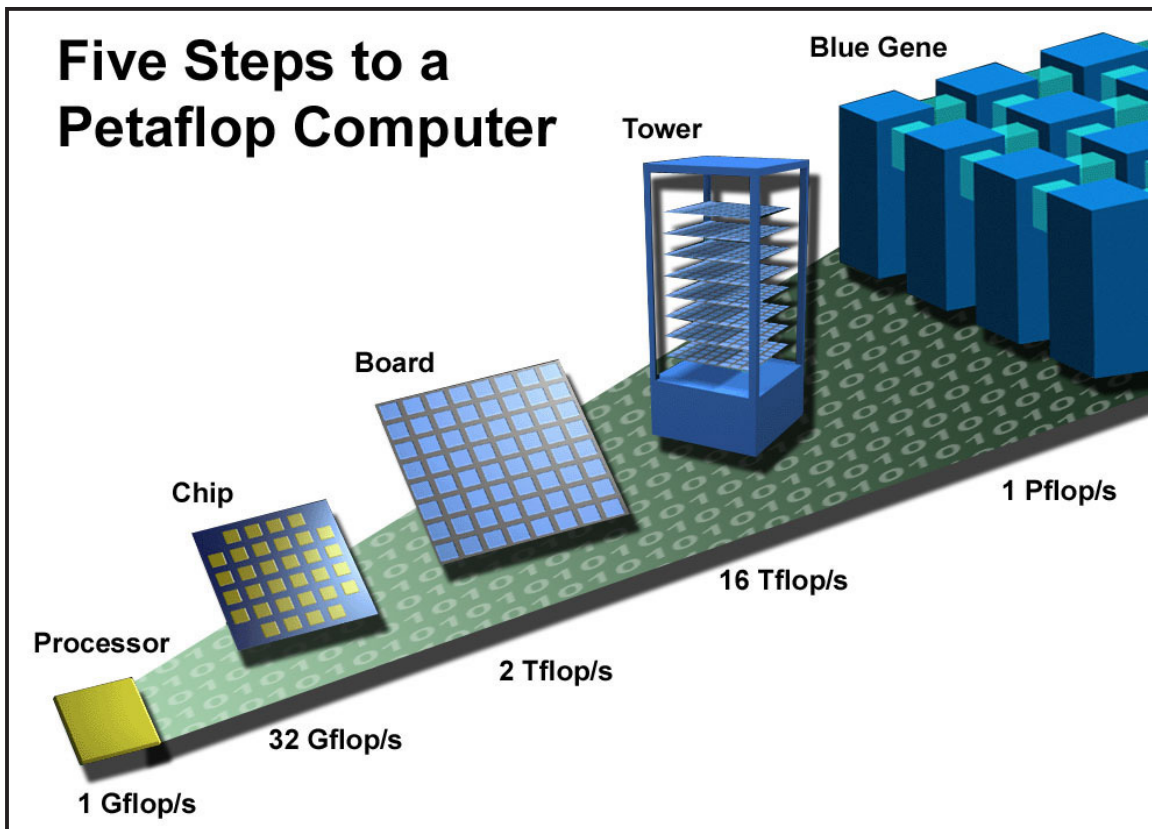

Figure 6

EVOLUTION OF HUMAN-COMPUTER INTERFACES

Figure 7 shoes the evolution of human-computer interfaces. During the period of 1940's through 1970's, static interfaces for main frames were used in the form of teletype style. This was followed in the 1980's by more flexible interfaces for PCs – Windows, mouse and graphical tablet. With many computing devices available for single users, adaptive interfaces with more functionality and communication became available. The emergence of grid/pervasive computing paradigms is providing an impetus for intelligent neural, perceptual, attentive and other advanced interfaces which integrate adaptive interfaces with intelligent agents for making intelligent help and tutoring available to the user.
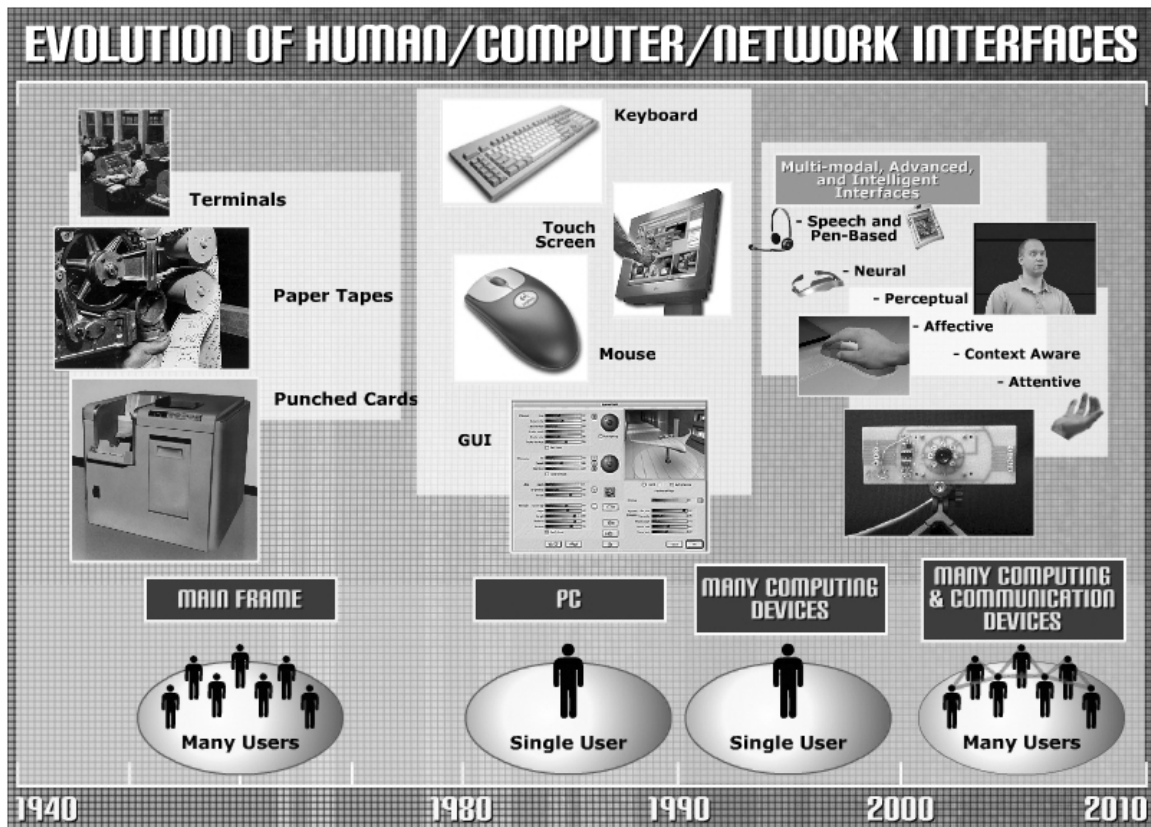

Figure 7

EMERGING COMPUTING PARADIGMS

The rapidly increasing power of computers and networks, and the trend of computers getting smaller, along with the increasing complexity of computing systems and the associated cost to manage them, led to three emerging computing paradigms, namely (Figure 8),

- Grid Computing,
- Ubiquitous/Pervasive Computing, and,
- Autonomic Computing
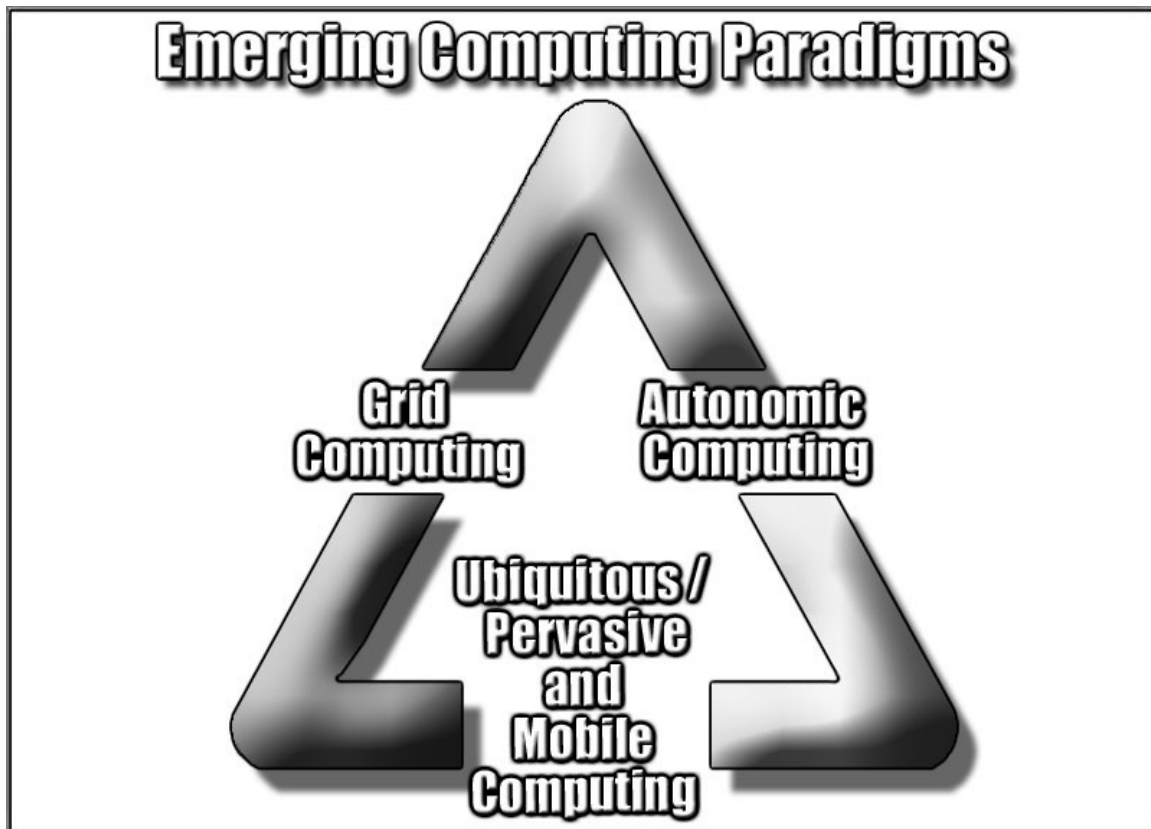
The three paradigms are described subsequently.

Figure 8

GRID COMPUTING

The rapidly increasing power of computers and networks in the 1990s, led the new paradigm of distributed computing. A flurry of experiments were conducted on "peer-to-peer" computing, all devoted to harnessing the computer power and storage capacity of idle desktop machines. These included cluster computing - using networks of standard single-processor workstations to solve single problems. At the same time, the high-performance computer community began the more ambitious experiments in *metacomputing*. The objective of Metacomputing was to make many distributed computers function like one giant computer – metasystem (e.g., the virtual national machine). Metasystems give users the illusion that the files, databases, computers and external devices they can reach over a network constitute one giant transparent computational environment.

The term *grid computing* is now used to refer to massive integration of computer systems to offer performance unattainable by a single machine. It provides pervasive, dependable, consistent, and inexpensive access to facilities and services that live in cyberspace, assembling and reassembling them on the fly to meet specified needs (Figure 9).
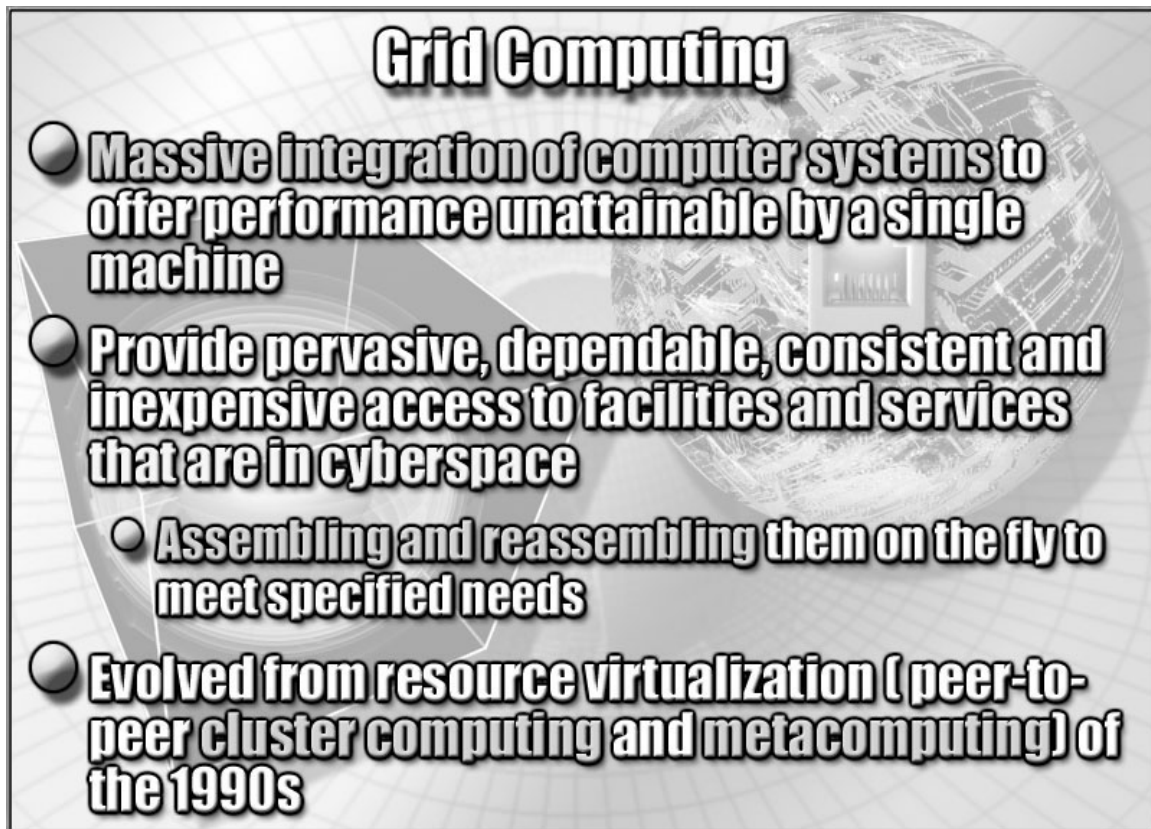

Figure 9

GRID TECHNOLOGIES AND INFRASTRUCTURE

The essential building blocks of grid computing are: Fast processors, parallel computer architectures, advanced optical networks, communication protocols, distributed software structures and security mechanisms (Figure 10).

Grid technologies enable the clustering of a wide variety of geographically distributed resources, such as high-performance computers, storage systems, data sources, special devices and services that can be used as a unified resource.

Although grid technologies are currently distinct from other major technology trends, such as internet, enterprise, distributed, and peer-to-peer computing, these other trends can benefit significantly from growing into the problem spaces addressed by grid technologies.
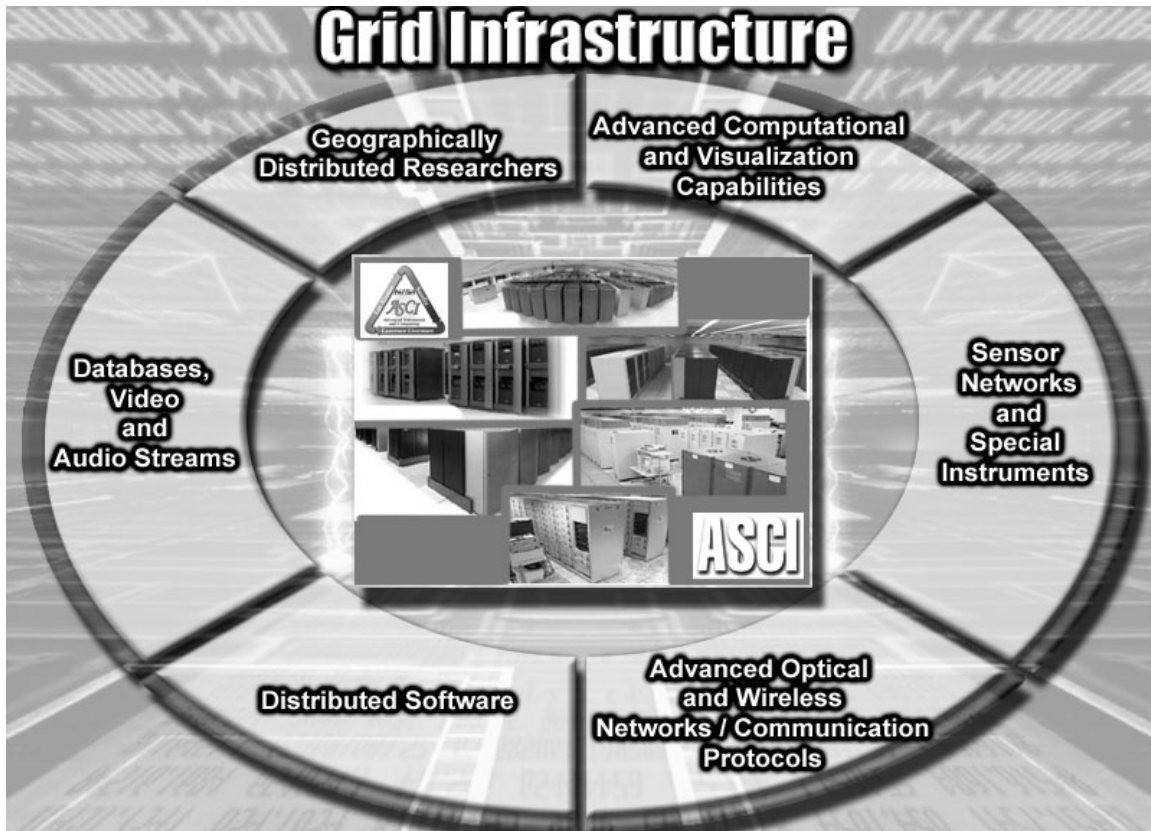

Figure 10

GRID COMPUTING PROJECTS

Once the concept of grid computing was introduced, several grid computing projects were launched all over the world. A sampling of grid computing projects are listed in Figure 11. In the future, grids of every size will be interlinked. The "supernodes" like TeraGrid will be networked clusters of supersystems serving users on a national or international scale. Still more numerous will be the millions of individual nodes: personal machines that users plug into the grid to tap its power as needed. With wireless networks and miniaturization of components, that can evolve into billions of sensors, actuators and embedded processors as micronodes.
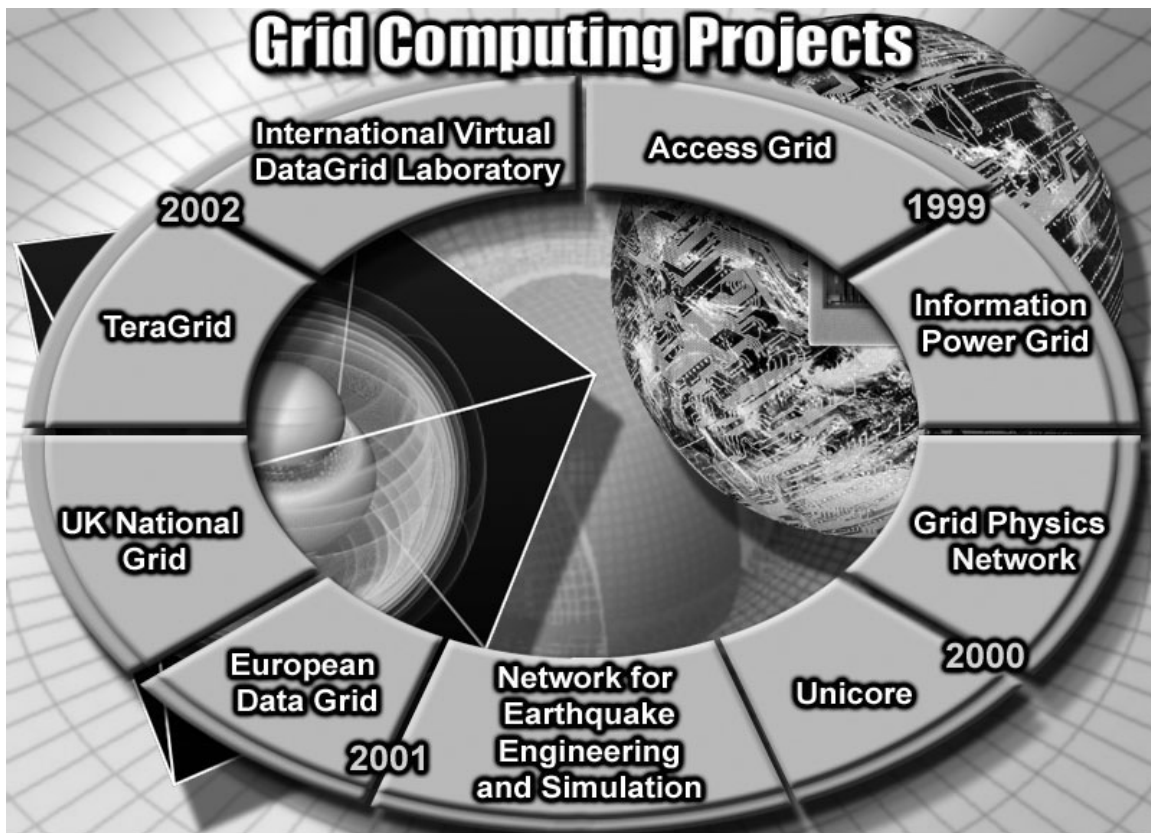
Figure 11

UBIQUITOUS / PERVASIVE COMPUTING

The trend of computers getting smaller is likely to lead to an environment with computing functionality embedded in physical devices that are widely distributed and connected in a wireless web.

In a seminal article written in 1991, Mark Weiser described a hypothetical world in which humans and computers were seamlessly united. This vision was referred to as *ubiquitous computing*. Its essence was the creation of environment saturated with computing and communication, yet gracefully integrated with human users.
In the mid-1990s, the term pervasive computing came to represent the same vision as that described by Weiser.

The key components of ubiquitous/pervasive computing are (Figure 12):

- *Pervasive devices*, including:
    - Small, low-powered hardware (CPU, storage, display devices, sensors),
    - Devices that come in different sizes for different purposes, and
    - Devices that are aware of their environment, their users, and their locations,
- *Pervasive communication* – a high degree of communication among devices, sensors and users provided by ubiquitous and secure network infrastructure (wireless and wired) and mobile computing,
- *Pervasive interaction* – more natural and human modes of interacting with information technology, and
- *Flexible, adaptable distributed systems* – dynamic configuration, functionality on demand, mobile agents and mobile resources
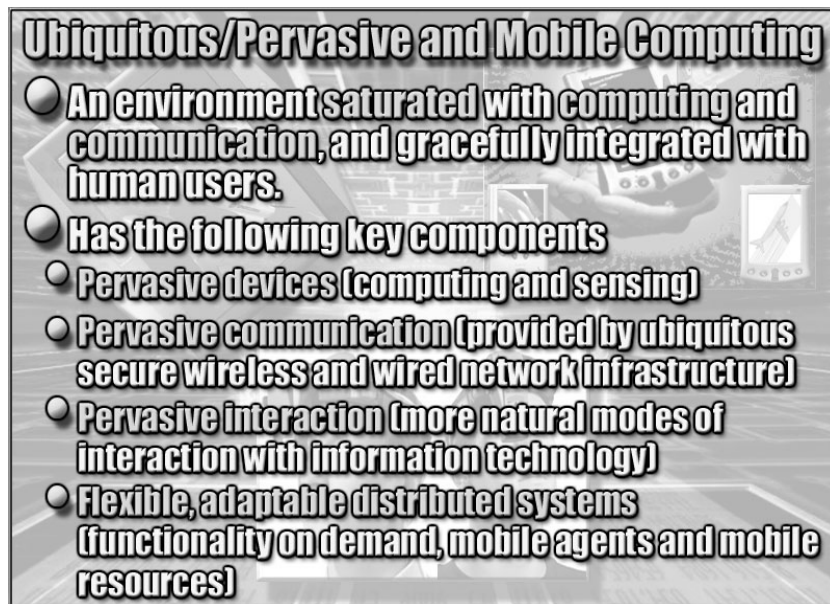

Figure 12

PERVASIVE COMPUTING FRAMEWORK

The technological advances necessary to build a pervasive computing environment fall into four broad areas (Figure 13): devices, networking, middleware and applications. Middleware mediates interactions with the networking kernel on the user's behalf and keeps users immersed in the pervasive computing space. The middleware consists mostly of firmware and software
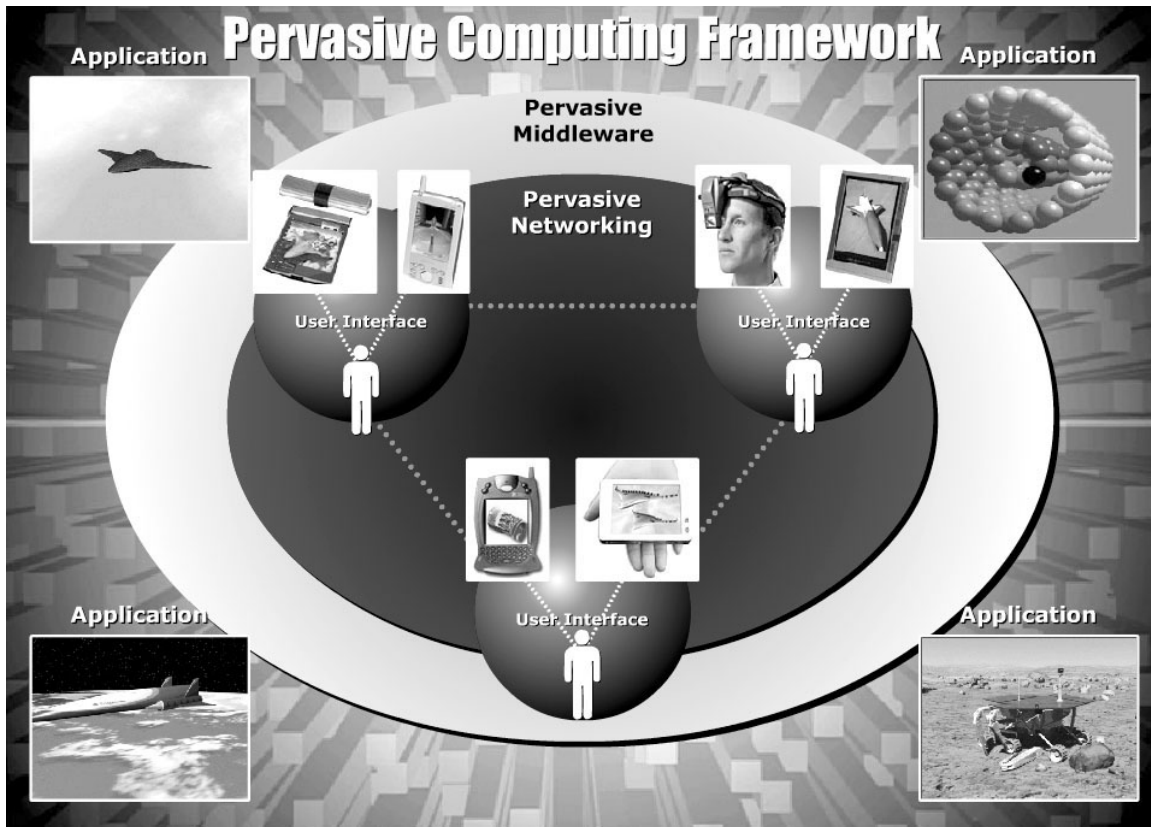

Figure 13

PERVASIVE COMPUTING INITIATIVES

A list of some of the pervasive computing initiatives is given in Figure 14. These include university initiative (AURA of Carnegie Mellon University, Endeavor of the University of California at Berkeley, the Oxygen Project of MIT, and Portolano Project of the University of Washington); Industry/university initiatives (Sentient Computing, a joint project of AT&T Laboratories and Cambridge University in the UK); and industry projects (Cooltown of Hewlett-Packard, EasyLiving of Microsoft Research Vision Group and WebSphere Everyplace of IBM).
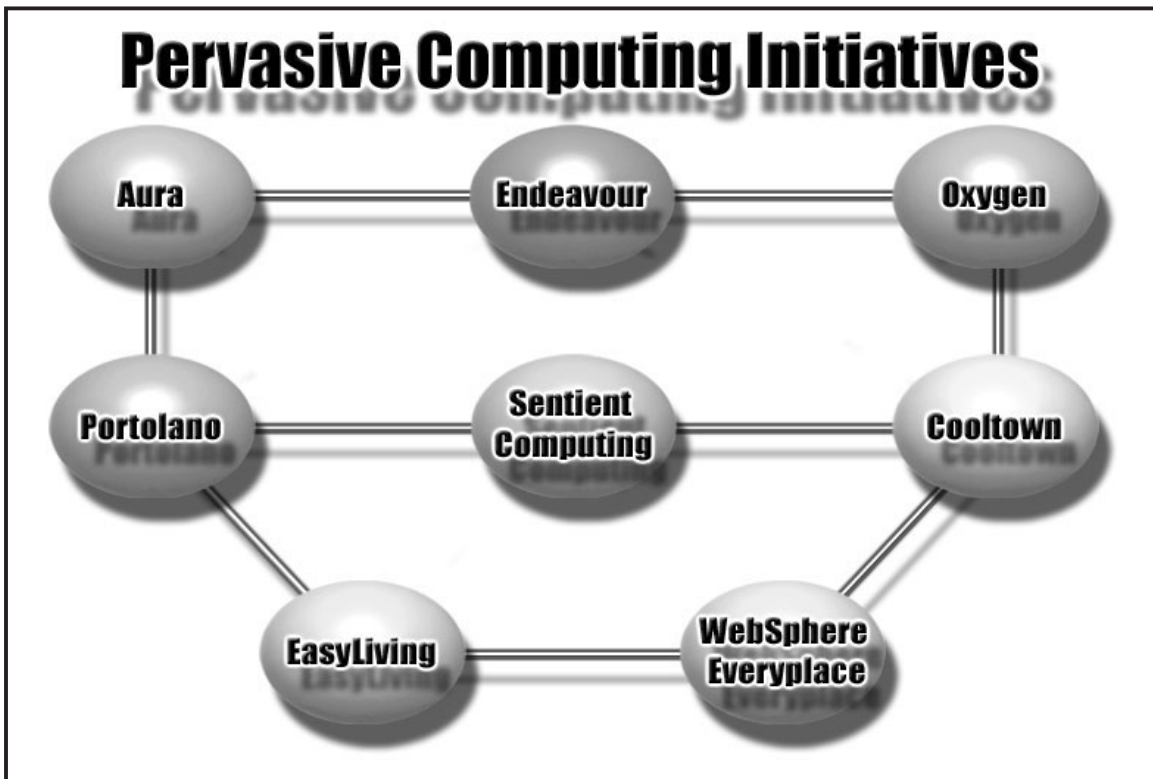

Figure 14

AUTONOMIC COMPUTING

The increasing capacity and complexity of the emerging computing systems, and the associated cost to manage them, combined with a shortage of skilled workforce are providing the motivation for a paradigm shift to systems that are self-managing, self-optimizing, and do not require the expensive management services needed today. A useful biological metaphor is found in the autonomic nervous system of the human body – it tells the heart how many times to beat, monitors the body temperature, and adjusts the blood flow, but most significantly, it does all this without any conscious recognition or effort on the part of the person - hence the name *autonomic computing* was coined.

Autonomic computing is a new research area led by IBM focusing on making computing systems smarter and easier to administer. Many of its concepts are modelled on self-regulating biological systems.

Autonomic computing is envisioned to include the ability of the system to respond to problems, repair faults and recover from system outages without the need for human intervention. An autonomic computing system consists of a large collection of computing engines, storage devices, visualization facilities, operating systems, middleware and application software (Figure 15).
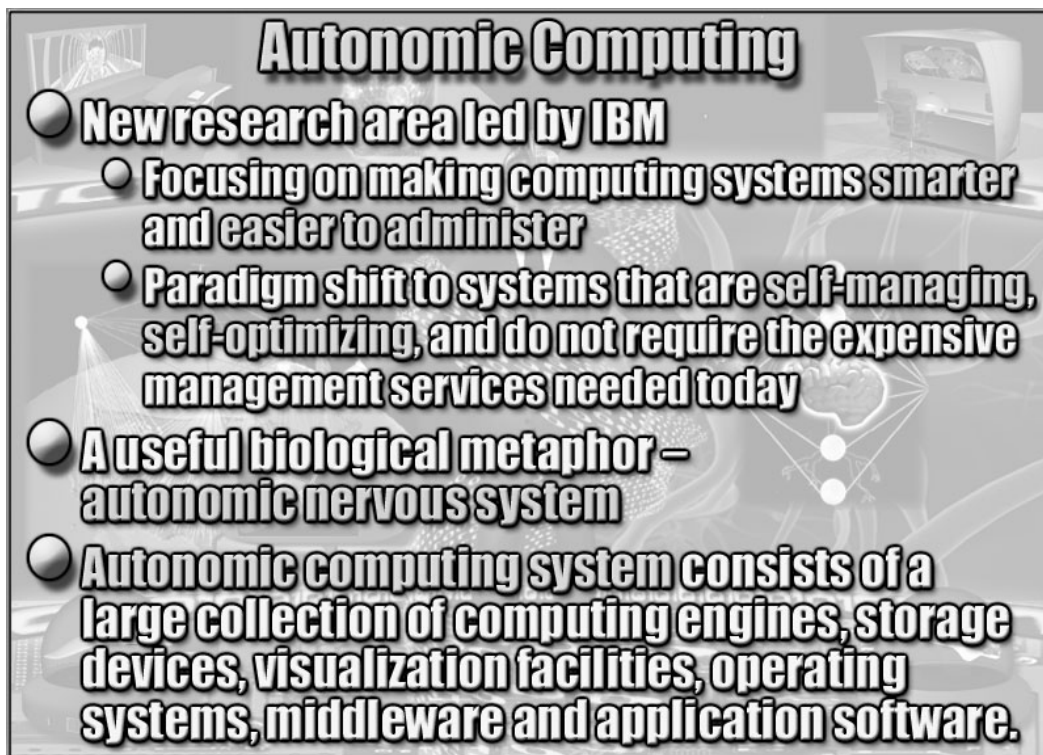

Figure 15

CHARACTERISTICS OF AUTONOMIC COMPUTING

Autonomic computing is envisioned to combine the following seven characteristics (Figure 16):

1. *Self-defining* - Has detailed knowledge of its components, current status, ultimate capacity and performance, and all connections to other systems.
2. *Self-configuring* – can configure and reconfigure itself under varying and unpredictable conditions. System configuration or setup must occur automatically, as must dynamic adjustments to that configuration to handle changing environments.
3. *Self-optimizing* – never settles for status quo. Always looks for ways to optimize its performance. Monitors constituent parts, and metrics, using advanced feedback control mechanisms and makes changes (e.g., fine-tune workflow) to achieve predetermined system goals.
4. *Self-healing* – able to recover from routine and extraordinary events that might cause some components to malfunction or damage. It must be able to discover problems, reconfigure the system to keep functioning smoothly.
5. *Self-protecting* – detect, identify and protect itself against various types of failure. Maintains overall system security and integrity.
6. *Contextually Aware* – This is almost self-optimization turned outward. The system must know the environment and the context of the surrounding activity, and adapts itself (in real-time) accordingly.
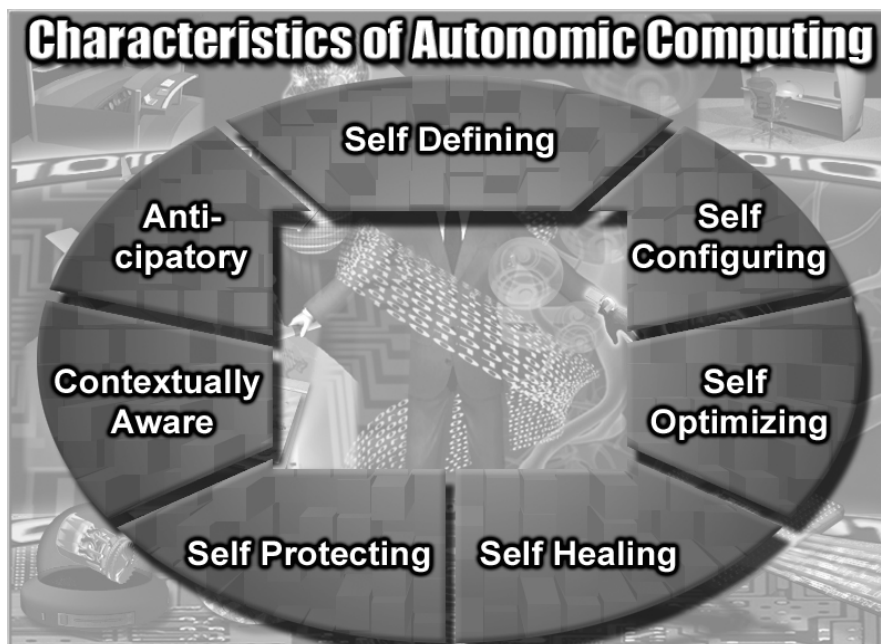7. *Anticipatory* – anticipates the optimized resources, configuration, and components needed.

Figure 16

FUTURE COMPUTING ALTERNATIVES

Silicon-based technology is expected to reach its physical limits in the next decades. But silicon and computing are not inextricably linked, although they often seem to be. For example, when silicon microelectronics reaches ultimate physical limits a number of new approaches and technologies have already been proposed. These include (Figure 17):

- Quantum computing,
- Molecular computing,
- Chemical and biochemical computing,
- DNA computing, and
- Optical and optoelectronic computing

None of these approaches is ready to serve as an all-purpose replacement for silicon. In fact, some approaches may be only appropriate as specialized methods in particular niches, such as high-level cryptography.
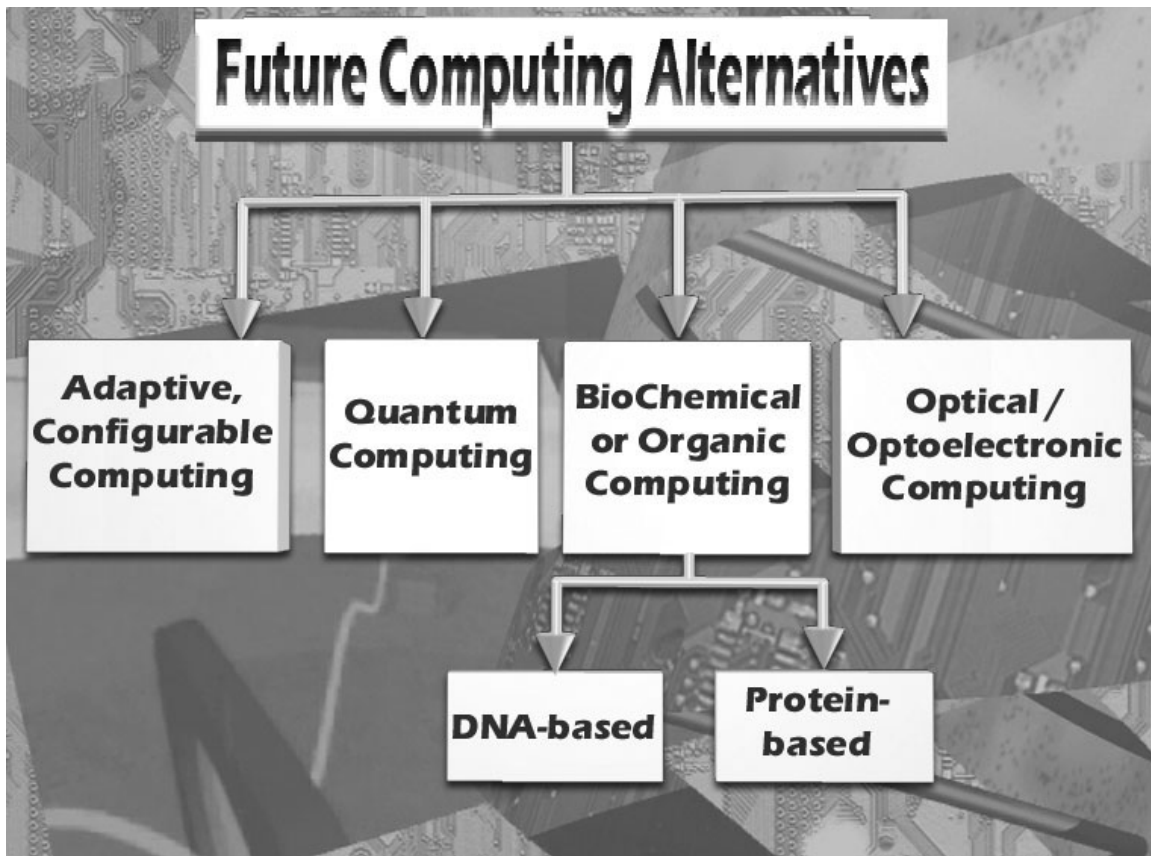

Figure 17

FUTURE COMPUTING ENVIRONMENT

Significant advances continue to be made in the entire spectrum of computing and communication technologies. Speculations about the future of computers and computing have been attempted in several monographs. Herein, only the emerging trends are identified, which include (Figure 18):

- An evolving computing paradigm combining ubiquitous / mobile / cognitive / autonomic computing and including:
    - Smart, self-regulating computing systems covering a spectrum of handheld, embedded and wearable information appliances and devices
    - Wide range of devices to sense, influence and control the physical world
    - Optical networks supplement by wireless communication

- Human-computer symbiosis characterized by:
    - Natural cooperative human-machine collaboration
    - Intelligent affective technologies to allow computers to know user's emotional states
    - Humans, sensors and computing devices seamlessly united

- Hierarchical knowledge nets:
    - Computer-supported distributed collaboration
    - Augmented / mixed reality and tele-immersion facilities
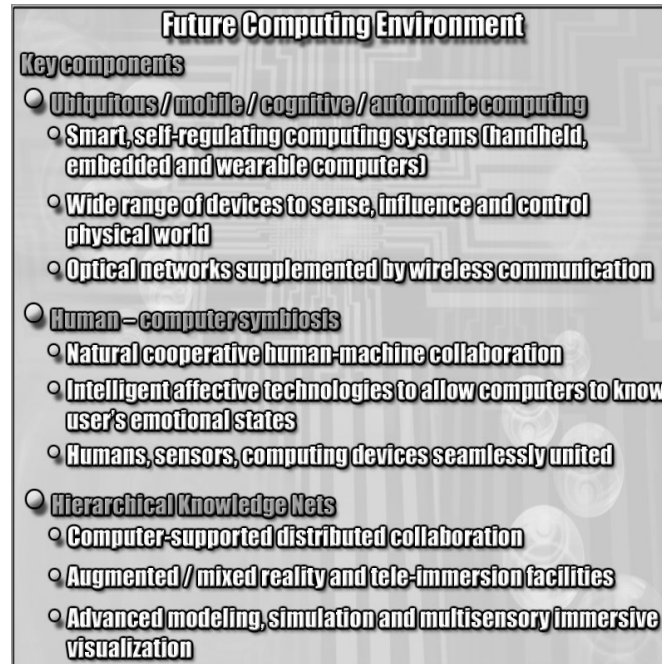   - Advanced modeling, simulation and multisensory visualization

Figure 18

EXAMPLES OF FUTURE AEROSPACE SYSTEMS AND SOME OF THEIR CHARACTERISTICS

The realization of NASA's ambitious goals in aeronautics and space with the current national budget constraints will require new kinds of aerospace systems and missions that use novel technologies and manage risk in new ways. Future aerospace systems must be autonomous, evolvable, resilient, and highly distributed. Two examples are given in Figure 19. The first is a biologically inspired aircraft with self-healing wings that flex and react like living organisms. It is built of a multifunctional material with fully integrated sensing and actuation, and unprecedented levels of aerodynamic efficiencies and aircraft control. The second is an integrated human-robotic outpost, with biologically inspired robots. The robots could enhance the astronaut's capabilities to do large-scale mapping, detailed exploration of regions of interest, and automated sampling of rocks and soil. They could enhance the safety of the astronauts by alerting them to mistakes before they are made, and letting them know when they are showing signs of fatigue, even if they are not aware of it.
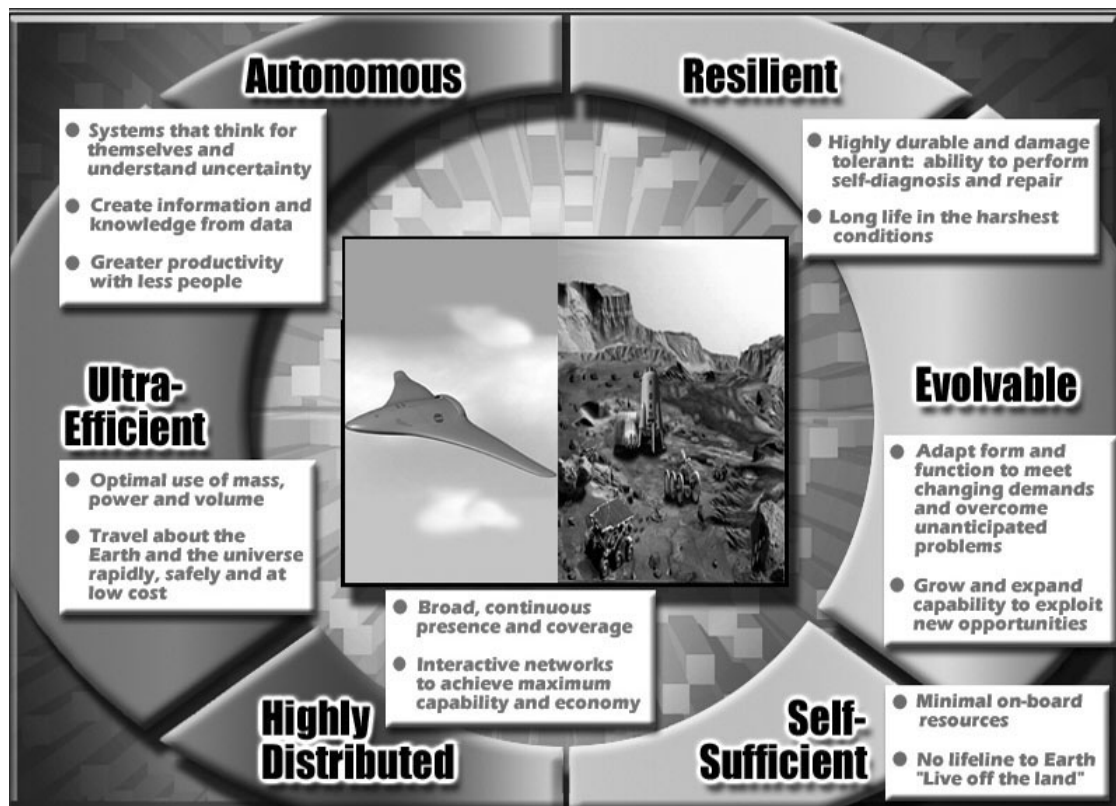

Figure 19

ENABLING TECHNOLOGIES FOR FUTURE AEROSPACE SYSTEMS

The characteristics of future aerospace systems identified in Figure 18 are highly coupled and require the synergistic coupling of the revolutionary and other leading-edge technologies listed in Figure 20. The four revolutionary technologies are nanotechnology, biotechnology, information/knowledge technology, and cognitive systems technology. The other leading-edge technologies are high-productivity computing; high-capacity communication; multiscale modeling, simulation and visualization; virtual product development; intelligent software agents; reliability and risk management; human performance, and human-computer symbiosis.
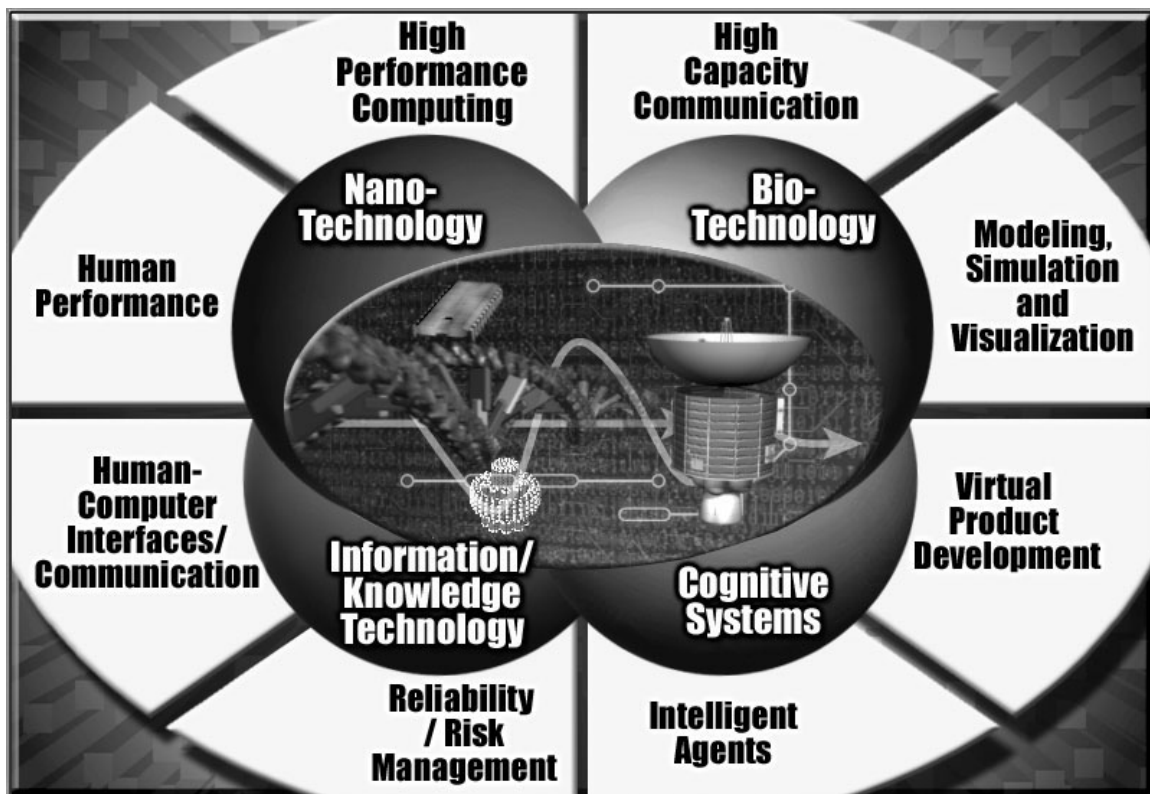

Figure 20

THREE NASA INITIATIVES

The realization of NASA's ambitious goals will require a diverse, technically skilled workforce – a new generation of scientists and engineers who can work across traditional disciplines and perform in a rapidly changing environment.

NASA has developed a number of new initiatives for assured workforce development. These include University Research, Engineering, and Technology Institutes (URETIs), the National Institute of Aerospace (NIA), and the Hierarchical Research and Learning Network (HRLN) (see Figure 21). The overall goal of these activities is to strengthen NASA's ties to the academic community through long-term sustained investment in areas of innovative and long-term technology critical to future aerospace systems and missions. At the same time, the three activities will enhance and broaden the capability of the nation's universities to meet the needs of NASA's science and technology programs.
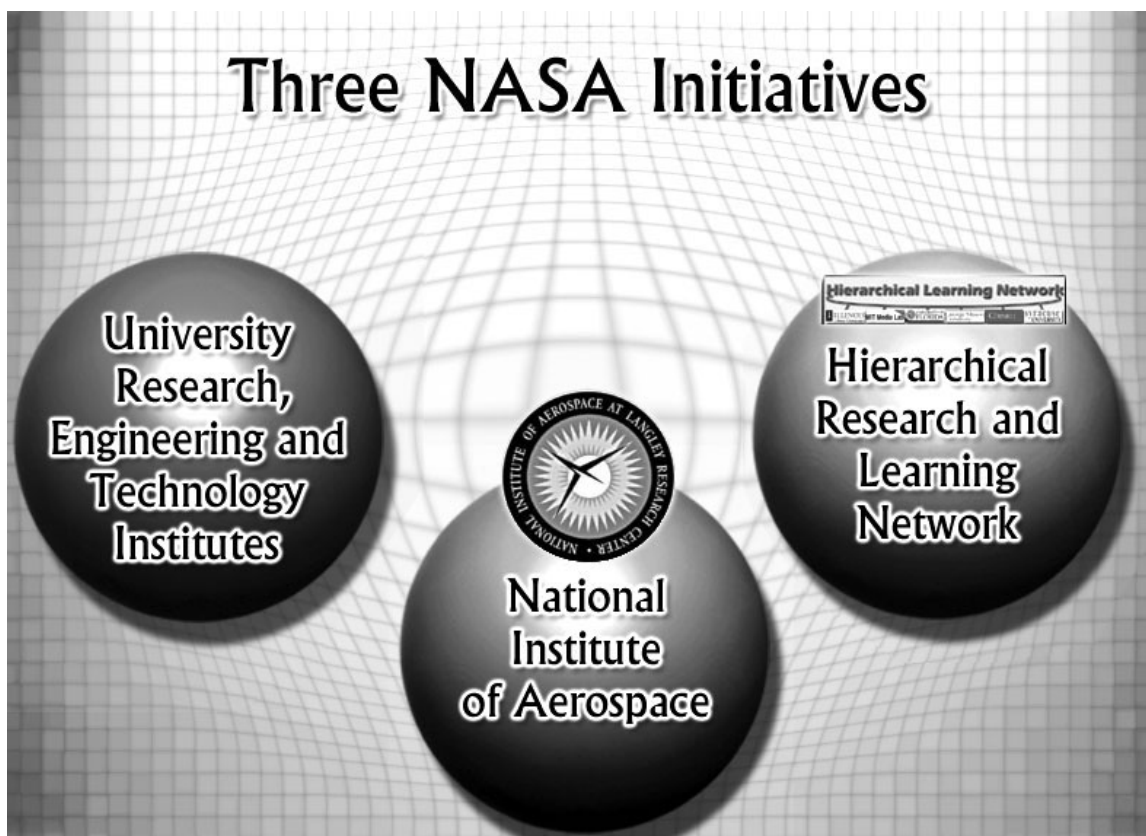

Figure 21

HIERARCHICAL RESEARCH AND LEARNING NETWORK

The Hierarchical Research and Learning Network (HRLN) is a pathfinder project for the future aerospace workforce development. It aims at creating knowledge organizations in revolutionary technology areas which enable collective intelligence, innovation and creativity to bear on the increasing complexity of future aerospace systems. This is accomplished by building research and learning networks linking diverse interdisciplinary teams from NASA and other government agencies with universities, industry, technology providers, and professional societies (Figure 22) in each of the revolutionary technology areas and integrating them into the HRLN.

HRLN is envisioned as a neural network of networks. It is being developed by eight university teams, led by Old Dominion University's Center for Advanced Engineering Environments.
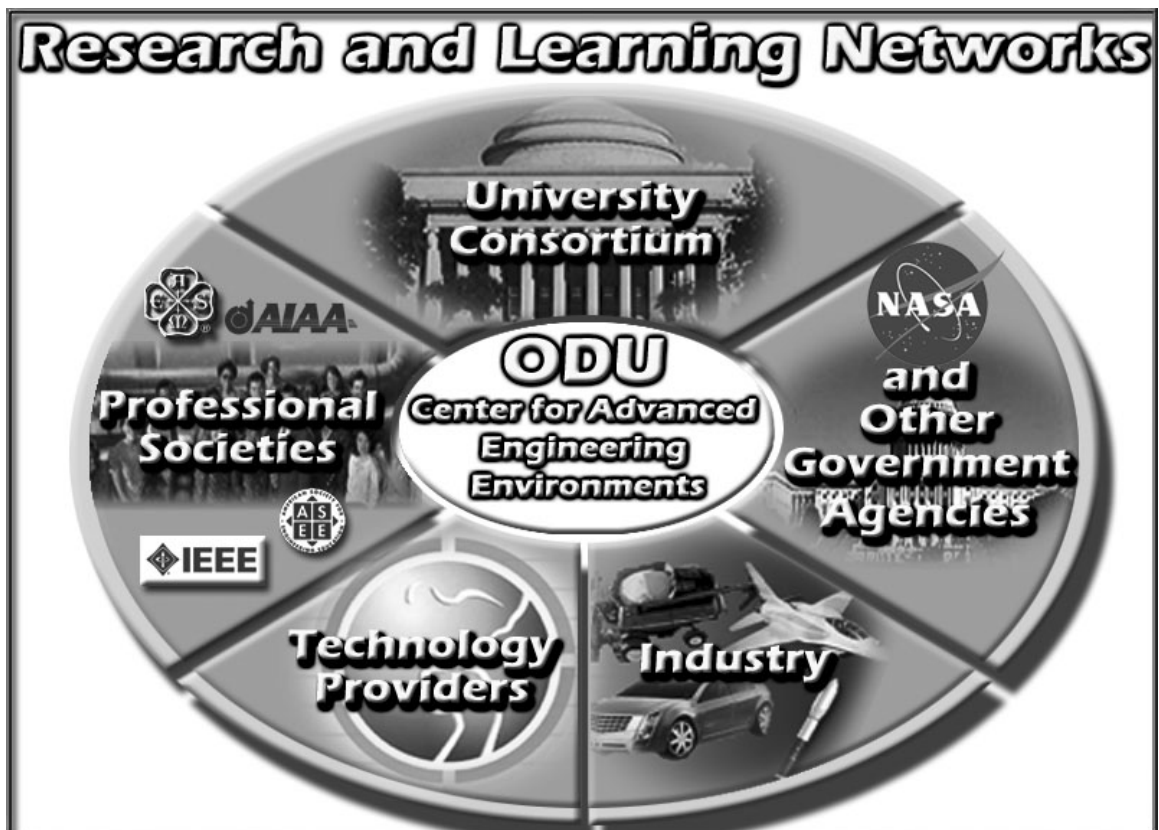

Figure 22

Figure 22 (continued)

The phases of implementing HRLN are shown in Figure 23. The first phase involves development of learning modules and interactive virtual classrooms in revolutionary technology areas, simulators of unique test facilities at NASA, and a telescience system – an online multi-site lab that allows real-time exchange of information and remote operation of instrumentation by geographically distributed teams. These facilities will be integrated into adaptive web learning portals in the second phase, which evolve into robust learning networks. In the final phase, the learning networks are integrated into the HRLN.

Figure 23

ADAPTIVE WEB LEARNING PORTAL
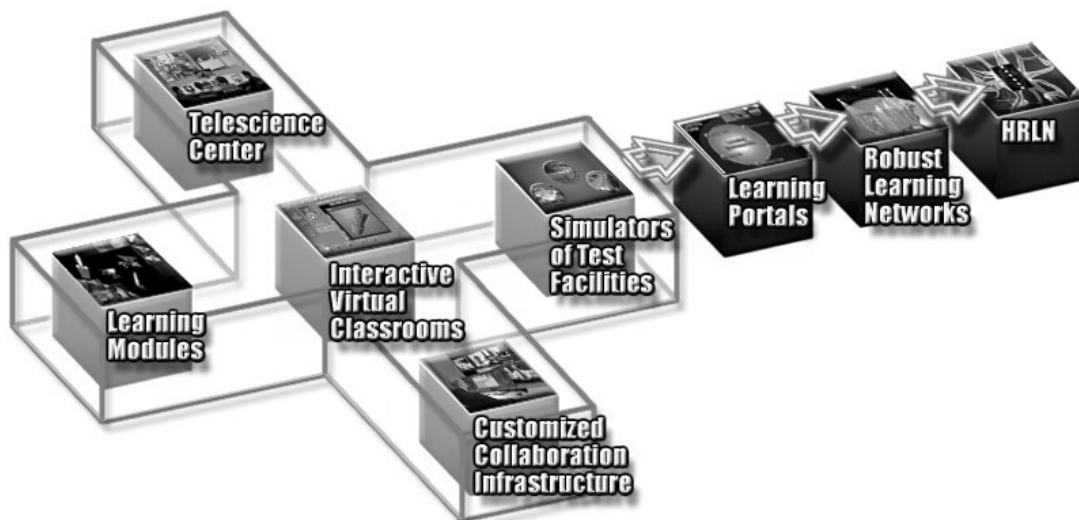
The Adaptive Web Learning Portal being developed as part of the HRLN project has the following major components (Figure 24):

- Advanced multimodal interfaces,
- Knowledge repository,
- Blended learning environment incorporating the three environments: expert-managed, self-paced, and collaborative,
- Learning management system, and
- Customized collaboration infrastructure
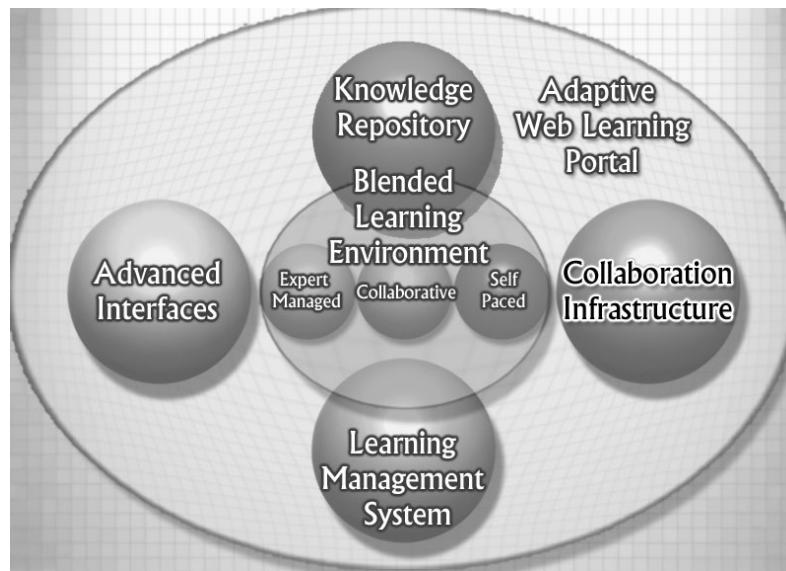
Figure 24

INTELLIGENT DESIGN ENVIRONMENT

The future design environment will enable collaborative distributed synthesis to be performed by geographically dispersed interdisciplinary/multidisciplinary teams. It will include flexible and dynamic roomware (active spaces/collaboration landscape) facilities consisting of (Figure 25):

- Portable and stationary information devices
- Novel multiuser smart displays
- Telepresence and other distributed collaboration facilities
- Novel forms of multimodal human/network interfaces
- Middleware infrastructures and intelligent software agents

Figure 25

OBJECTIVES AND FORMAT OF WORKSHOP

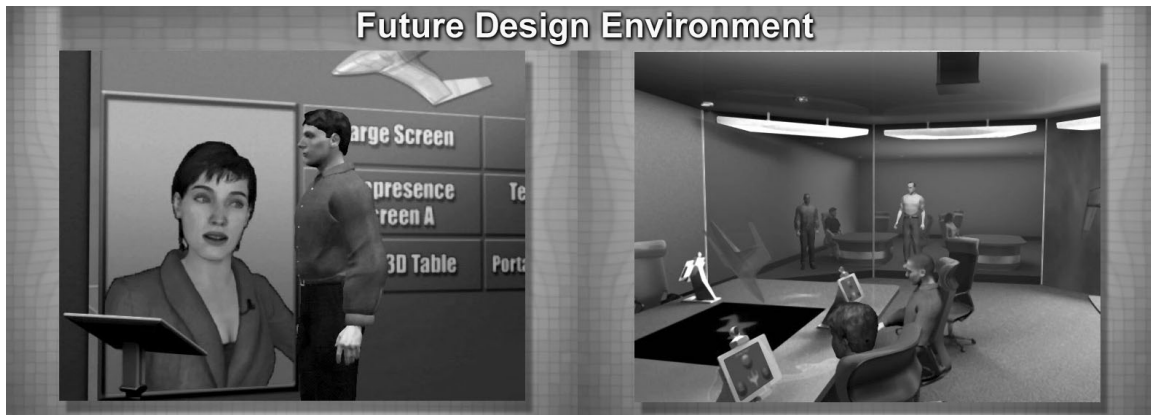The objectives of the workshop are to (Figure 26): a) provide broad overviews of the diverse activities related to new computing paradigms, including grid computing, pervasive computing, high-productivity computing, and the IBM-led autonomic computing; and b) identify future directions for research that have high potential for future aerospace workforce environments. The format included twenty half-hour presentations in nine sessions, and three exhibits.

- *Objectives:*
  - Overview of diverse activities related to emerging/new computing paradigms
  - Identify future directions for research for future aerospace workforce environments

- *Format:*
  - 20 presentations; 9 sessions
  - 3 exhibits

- *Proceedings:*
  - NASA Conference Proceeding

Figure 26

INFORMATION ON EMERGING / NOVEL COMPUTING PARADIGMS AND FUTURE COMPUTING ENVIRONMENTS

A short list of books, monographs, conference proceedings, survey papers and websites on emerging/novel computing paradigms and future computing environment is given subsequently.

Books, Monographs and Conference Proceedings:

[1]   Fogg, B.J., "*Persuasive Technology – Using Computers to Change What We Think and Do*", Morgan Kaufmann Publishers, 2003.

[2]   Grigoras, D., Nicolau, A., Toursel, B. and Folliot, B., (editors), "*Advanced Environments, Tools, and Applications for Cluster Computing*", NATO Advanced Research Workshop, Iwcc 2001, Mangalis, Romania, September 2001: Revised Papers, Springer-Verlag New York, Inc., May 2002.

[3]   Carroll, J.M. (editor), "*Human-Computer Interaction in the New Millennium*", ACM Press, New York, 2002.

[4]   Luryi, S., Xu, J., and Zaslavsky, A., "*Future Trends in Microelectronics: The Road Ahead*", John Wiley and Sons, Inc., 2002.

[5]   Calude, C.S., and Paun, G., "*Computing with Cells and Atoms: An Introduction to Quantum, DNA and Membrane Computing*", Taylor & Francis, 2001.

[6]   Barkai, D., "*Peer-to-Peer Computing – Technologies for Sharing and Collaborating on the Net*", Intel Press, 2001.

[7]   Nielsen, M.A. and Chuang, I.L., "*Quantum Computation and Quantum Information*", Cambridge University Press, 2001.

[8]   Hirvensalo, M., "*Quantum Computing*", Springer-Verlag TELOS, 2001.

[9]   Kim, D., and Hariri, S., "*Virtual Computing: Concept, Design, and Evaluation*", Kluwer Academic Publishers, August 2001.

[10]   Greenia, M.W. "*History of Computing: An Encyclopedia of the People and Machines that Made Computer History*". CD-ROM, Lexikon Services, 2000.

[11]   Ceruzzi, P.E., "*A History of Modern Computing*", Massachusetts Institute of Technology, 1999.

[12]   Foster, I., and Kesselman, C., (editors), "*The Grid: Blueprint for a New Computing Infrastructure*", Morgan Kaufmann Publishers, Inc., San Francisco, CA, 1999.

[13]   Denning, P.J., (editor), "*Talking Back to the Machine: Computers and Human Aspiration*", Springer-Verlag, New York, 1999.

[14]   Kurzweil, R., "*The Age of Spiritual Machines: When Computers Exceed Human Intelligence*", Penguin Putnam, Inc., New York, 1999.

[15]   Williams, C.P., and Clearwater, S.H., "*Explorations in Quantum Computing*", Springer-Verlag, New York, 1998.

[16]   Paun, G., Rozenberg, G., Salomaa, A., and Brauer, W., "*DNA Computing: New Computing Paradigms (Texts in Theoretical Computer Science)*", Springer Verlag, 1998.

[17]   Maybury, M.T., and Wahlster, W., (editors), "*Readings in Intelligent User Interfaces*", Morgan Kaufmann Publishers, Inc., 1998.

[18]   Denning, P.J., and Metcalfe, R.M., (editors), "*Beyond Calculation: The Next Fifty Years of Computing*", Springer-Verlag, New York, 1997.

[19]   Williams, M.R., "*A History of Computing Technology*", IEEE Computer Society; 2nd edition, 1997.

[20]   Shurkin, J., "*Engines of the Mind*", W.W. Norton & Company, New York. 1996.

[21]   Prince, B., "*High Performance Memories: New Architecture Drams and Srams – Evolution and Function*", Wiley, John & Sons, Incorporated, 1996.

[22]   Wherrett, B.S., and Chavel, P. (editors), "*Optical Computing*", Proceedings of the International Conference, Heriot-Watt University, Edinburgh, U.K., August 22 – 25, 1994, Iop Publishers, March 1995.

[23]   AcAulay, A.D., "*Optical Computer Architectures: The Application of Optical Concepts t Next Generation Computers*", Wiley, John & Sons, Inc., 1991.

Special Issues of Journals:

[1]   Vertegaal, R. "*Attentive User Interfaces*" Editorial, Special Issue on Attentive User Interfaces, Communications of ACM 46(3), March 2003.

[2]   "*Limits of Computation*", Special issue of Computing in Science and Engineering, May/June 2002.

[3]   "The Future of Computing – Beyond Silicon", Special Issue of Technology Review, MIT's Magazine of Innovation, May/June 2000.

[4]   Caulfield, H.J., "*Perspectives in Optical Computing*", IEEE Computer, Vol. 31, No. 2, February 1998, pp. 22-25.

[5]   "*50 Years of Computing*", Special issue of IEEE Computer, Vol. 29, No. 10, October 1996.

Survey Papers and Articles:

[1]   Compton, K., and Hauck, S., "*Reconfigurable Computing: A Survey of Systems and Software*", ACM Computing Surveys, Vol. 34, No. 2, June 2002, pp. 171-210.

[2]   Waldrop, M.M., *"Grid Computing"*, Technology Review, May 2002, pp. 31-37.

[3]   Noor, A.K., "*New Computing Systems and Future High-Performance Computing Environment and Their Impact on Structural Analysis and Design*", Computers and Structures, Vol. 64, Nos. 1-4, July-August 1997, pp. 1-30.

[4]   Weiser, M., "The Computer of the 21st Century", Scientific American, Vol. 265, No. 3, September 1991, pp. 66-75.

Websites:

1.   MIT Project Oxygen – Pervasive Human-Centered Computing
http://oxygen.lcs.mit.edu

2.	Autonomic Computing – Creating Self-Managing Computing Systems
http://www-3.ibm.com/autonomic

3.	Pervasive Computing – Anywhere. Anytime. On Demand.
http://www.darpa.mil/ipto/research/hpcs

4.	The Globus Project
http://www.globus.org

5.	Quantum computation: a tutorial
http://www.sees.bangor.ac.uk/~schmuel/comp/compt.html

6.	Stanford University, U.C. Berkeley, MIT, and IBM Quantum Computation Project
http://divine.stanford.edu

7.	DNA Computers
http://members.aol.com/ibrandt/dna_computer.html

8.	Publications on DNA based Computers
http://crypto.stanford.edu/~dabo/biocomp.html

9.	European Molecular Computing Consortium (EMCC)
http://openit.disco.unimib.it/emcc