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Overview of Nanobiotechnology

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Outline

The ability to manipulate matter at the atomic and molecular levels is likely to change the way almost everything is designed and made, from computers to engineering systems to objects not yet imagined. For nanometer-scale objects, biological systems provide a rich storehouse of interesting ideas and strategies, and this is why there has been synergistic coupling between nanotechnology and biotechnology. The field of nanobiotechnology is garnering much interest around the world. In January 2000, the President announced the establishment of the National Nanotechnology Initiative and has made it a top priority.

An attempt is made in this overview to define some of the buzzwords and set the stage for the succeeding presentations. This presentation is divided into four parts (see Fig. 1). The first part identifies the major characteristics of future aerospace systems that distinguish them from the current systems. The second and third parts describe the revolutionary and key technologies and future research and learning environments required for the realization of future systems. The fourth part lists the objectives of the workshop and the sources of information about nano and biotechnologies.

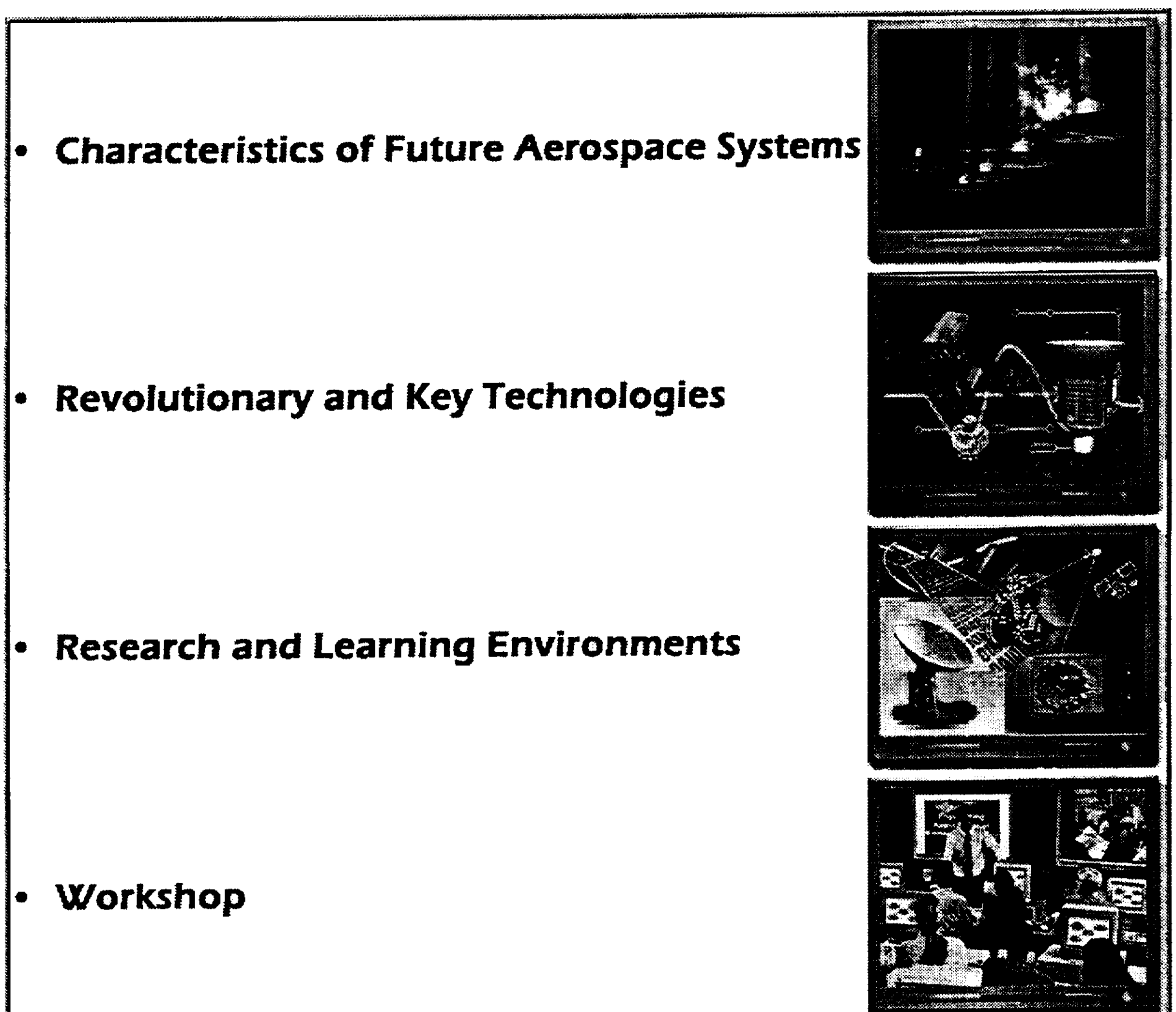


Figure 1

Characteristics of Future Aerospace Systems

The early part of this century will witness a new era of aviation systems, space transportation and space exploration, including sustained in-depth scientific studies performed in increasingly remote environments with very ambitious goals. The realization of these goals with the current national budget constraints will require new kinds of missions and aerospace systems that use novel technologies and manage risks in new ways. Future aerospace systems must be autonomous, evolvable, resilient, and highly distributed (Fig. 2). Space systems must also be able to perform their missions with no (or extremely infrequent) ground support; exploit and use local resources; and routinely close decision loops in real time to handle contingencies and replan mission tasks when necessary.

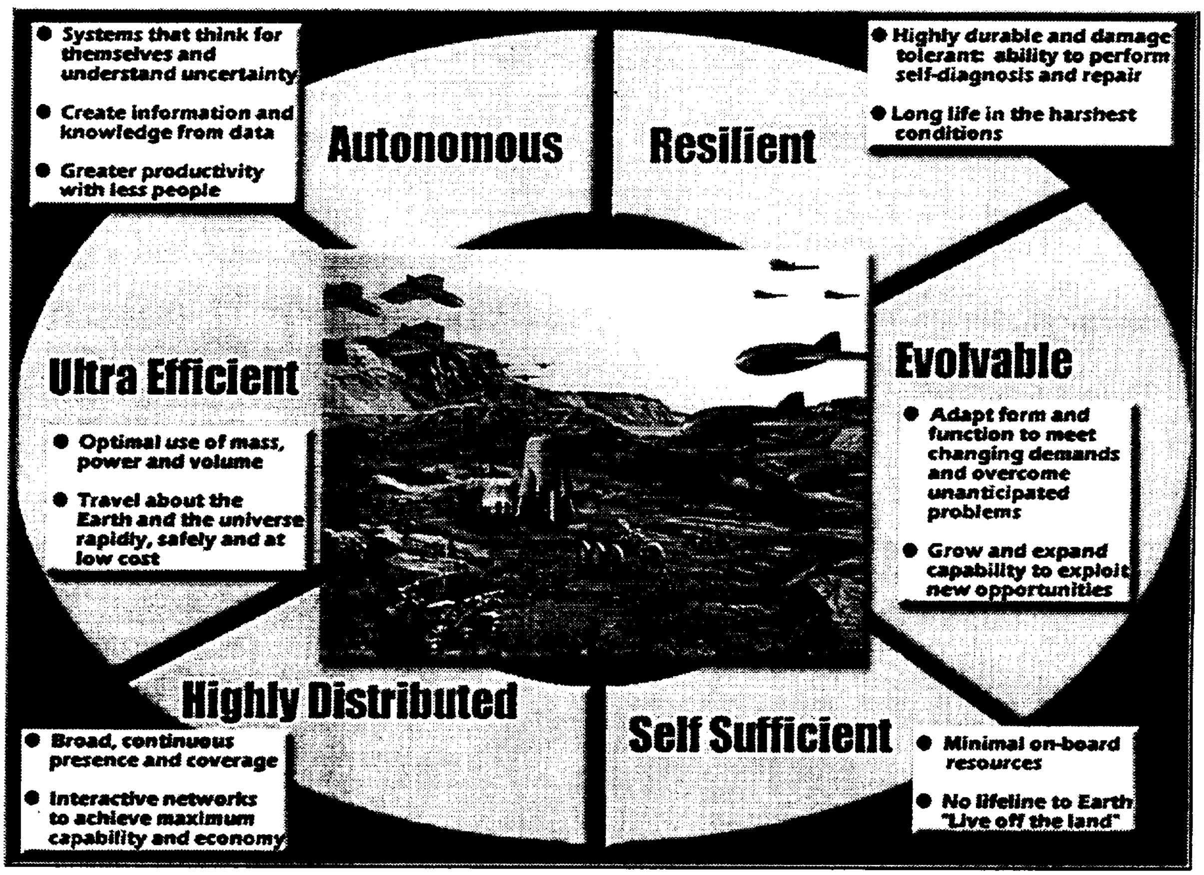


Figure 2

Revolutionary and Key Technologies

The characteristics of future aerospace systems identified in Fig. 2 are highly coupled and require the synergistic coupling of the revolutionary and other leading-edge technologies listed in Fig. 3. The three revolutionary technologies are nanotechnology, biotechnology and information/knowledge technology. The other leading-edge technologies are high-performance computing, high-capacity communication, modeling, simulation and visualization, intelligent software agents, human performance, and human-computer interfaces and communication.

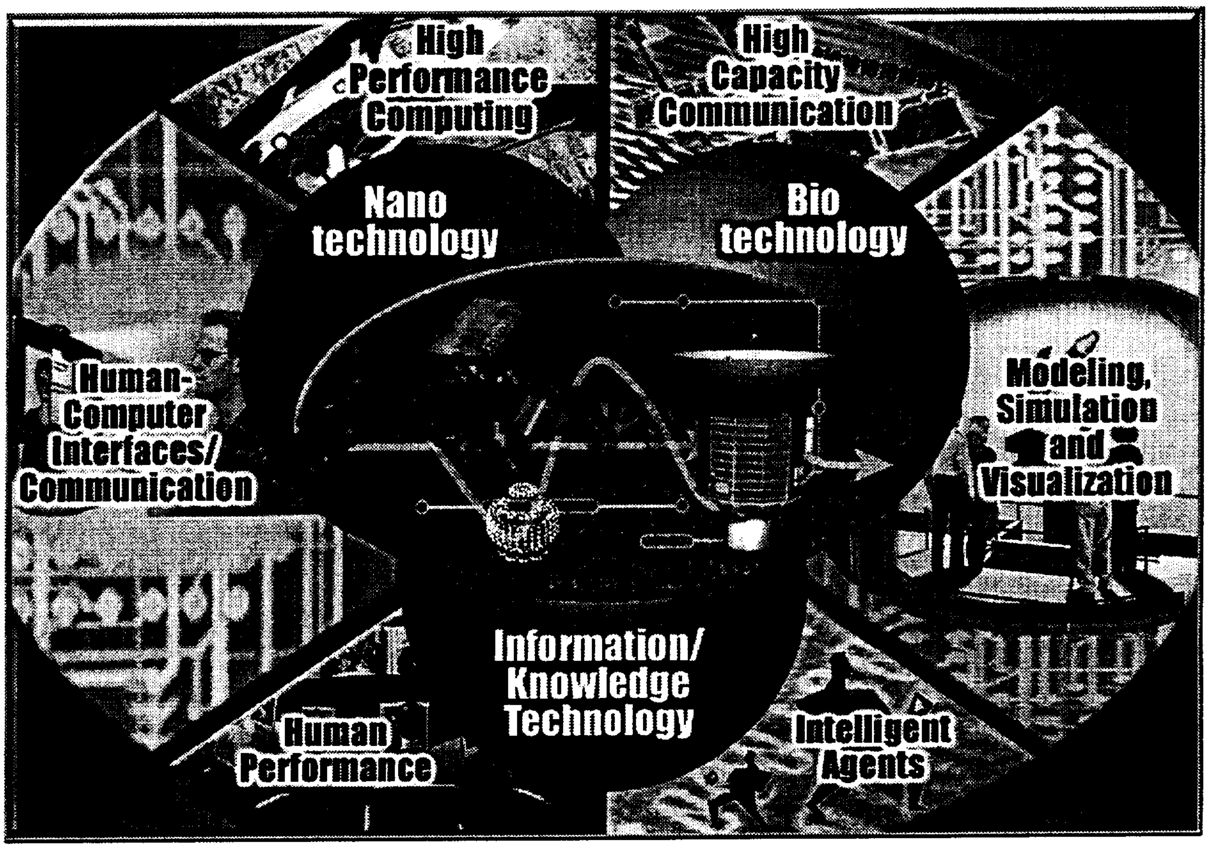


Figure 3

Definition and Evolution of Nanotechnology

The term nanotechnology has often been used to refer to any technique able to work at submicron scale. Herein, nanotechnology is defined as an innovative technology aimed at (see Fig. 4):

- Creation of useful materials, devices and systems through the control of matter at the nanometer length (atomic or molecular) scale. This is accomplished by having every atom or molecule in a designed location; and
- Exploitation of novel properties and phenomena developed at that scale.

The utilization of functional structures with at least one characteristic dimension measured in nanometers results in materials and systems that can be rationally designed to exhibit novel and significantly improved physical, chemical, mechanical and electrical properties, phenomena and processes.

The current nanotechnology revolution is a result of the continuing efforts at size reduction and miniaturization, and the development of nanoscience for understanding, visualizing and controlling matter at the atomic and molecular scales (Fig. 4).

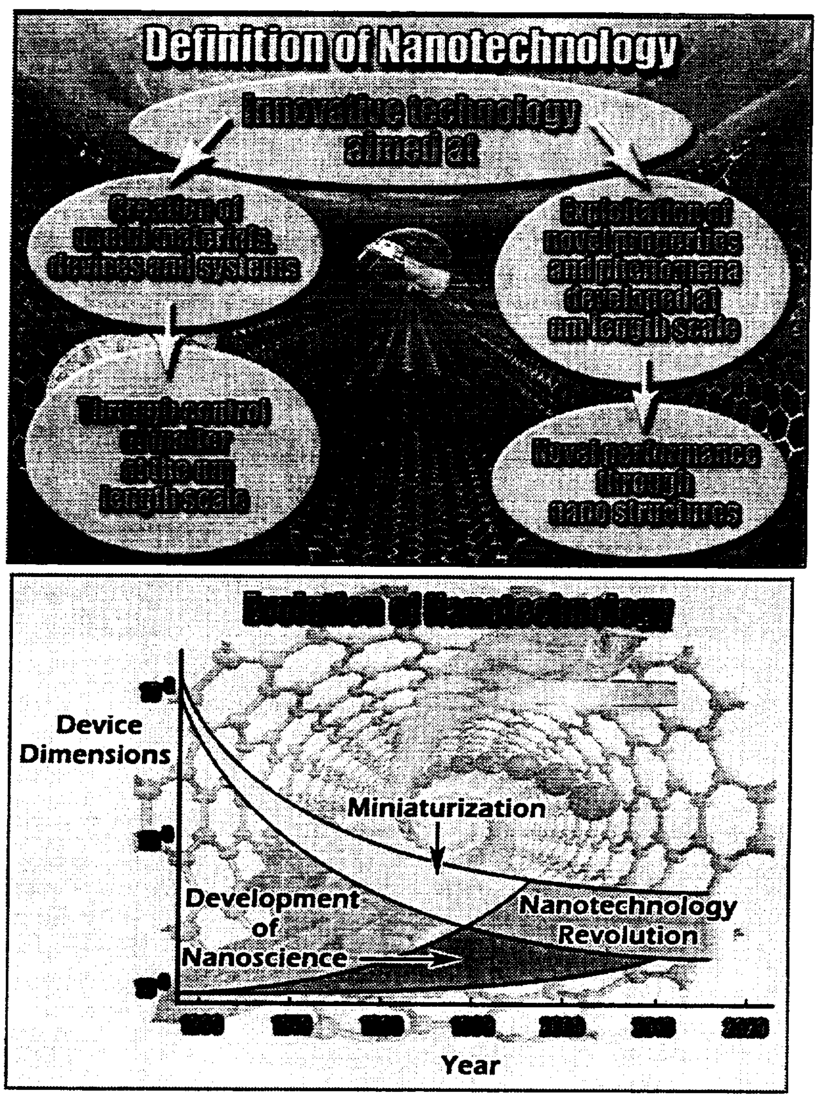


Figure 4

Nanoscale Building Blocks

Figure 5 shows some of the nanoscale building blocks. These are:

• Nanotubes, a new class of molecular-scale fibers with potential mechanical, chemical and electronic applications. The diameter of the nanotube is of nanometer size, and the length can be more than a micrometer. Carbon nanotubes exhibit extraordinary mechanical properties. Young's modulus, over one Tera Pascal, as stiff as diamond, and tensile strength ~ 200 GPa.

• Nanostructured materials are solids composed of structural elements, mostly crystallites, with a characteristic size (in at least one direction) of a few nanometers.

• Ordered nanocavities and nanopore arrays for growth templates.

• Nanoscale particles. These are 1-10 nm in diameter, and are made up of from 10 to 10,000 atoms. Their properties are different from either atoms or the bulk material.

• Molecular building blocks for self-assembling materials.

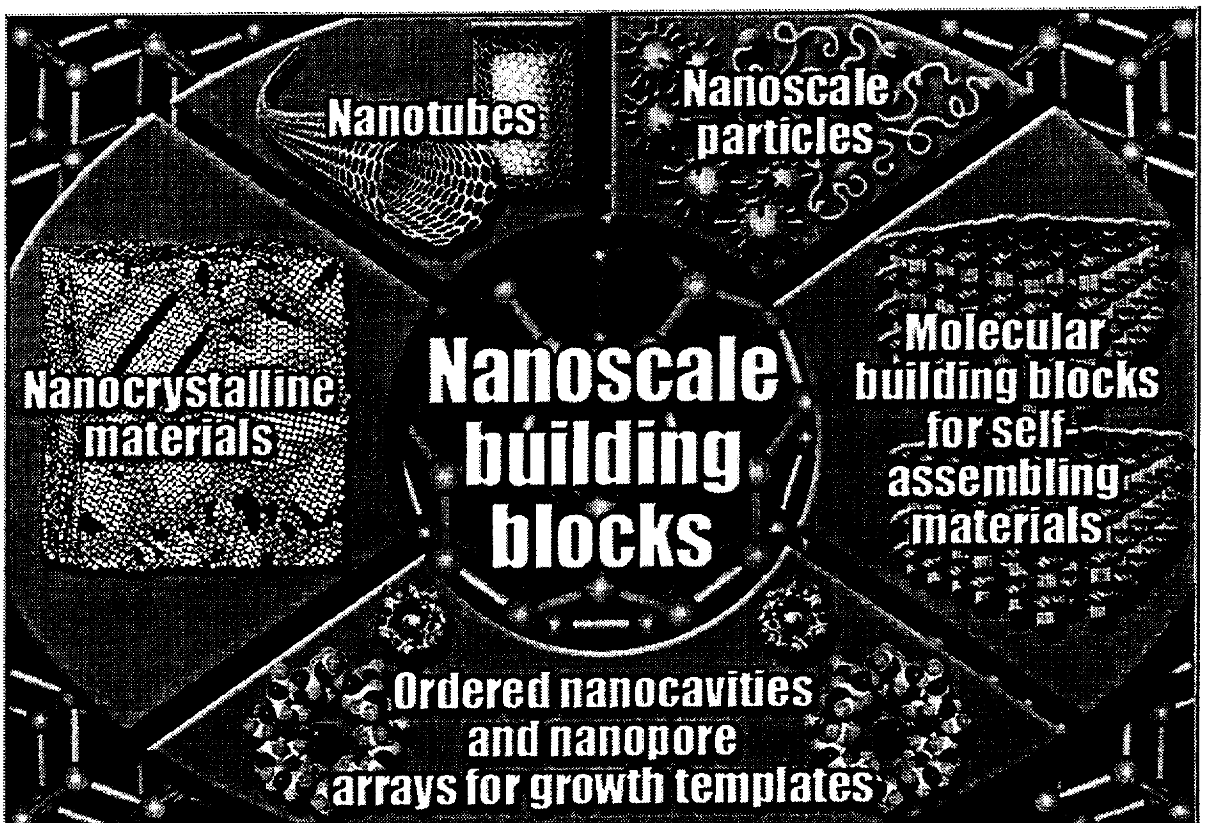


Figure 5

Nanoscale Tools

The nanoscale tools can be grouped into three categories (Fig. 6):

- Detection, imaging (atomic resolution) and characterization.
- Fabrication and manipulation.
- Modeling and simulation, including atomistic-scale modeling and molecular dynamics simulations. Scanned probe microscopy enabled viewing and moving atoms.

The devices that image, characterize nanoscale materials and move them (provide programmable positional control) are:

- Scanning Tunneling Microscope (STM) - used for characterization of nanoscale materials.
- Atomic Force Microscope (AFM) - used for characterization of nanoscale materials.
- Scanning Probe Microscope (SPM) - used for imaging individual atoms and molecules, manipulating and arranging them one at a time.

Because of the interdisciplinary nature of these activities, it is anticipated that future research will involve collaboration between geographically dispersed teams.

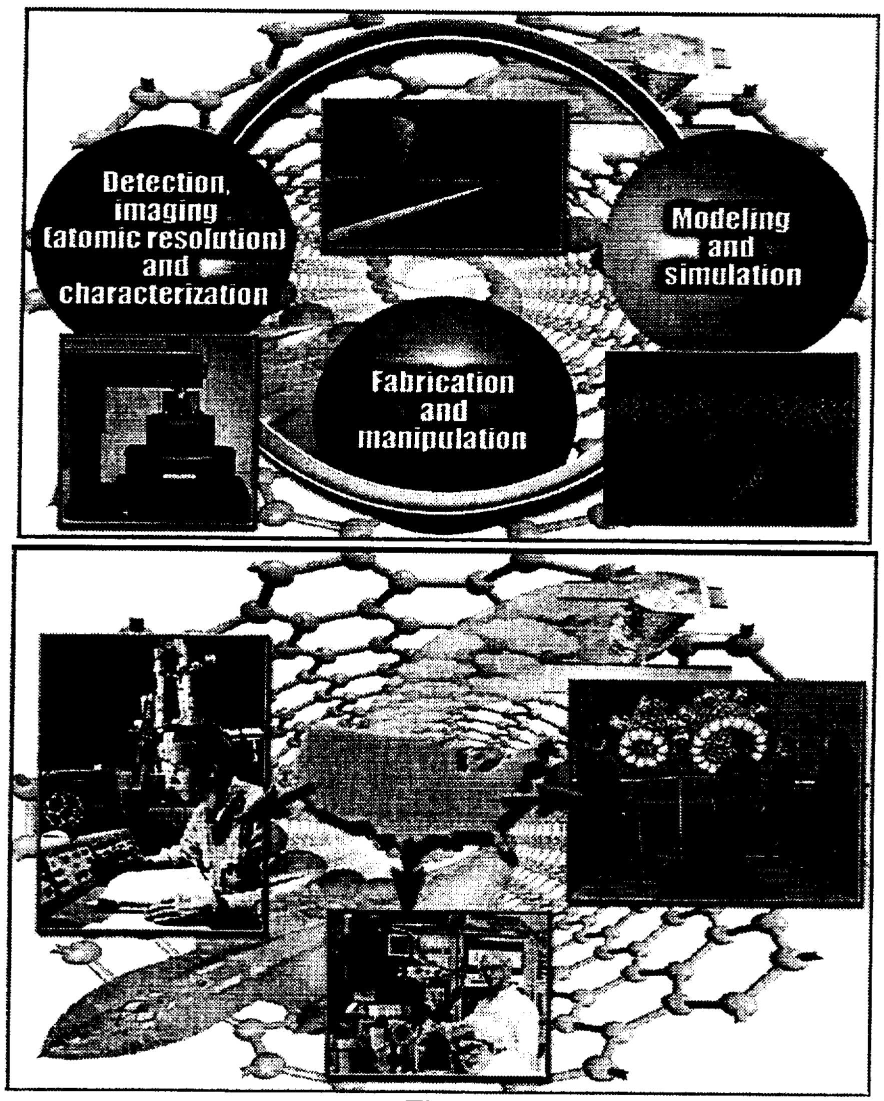


Figure 6

**Development of Nanostructure Materials,
Devices and Nanosystems**

The use of nanoscale tools and nanoscale building blocks will enable the development of nanostructured materials (e.g., nanostructured metals, composites and ceramics, active and self-repairing materials); nanostructure devices (e.g., inexpensive tiny fast computers, sensors and actuators); and eventually low-cost nanosystems (e.g., diamondoid structured vehicles that can carry substantially more payload - Fig. 7).

Among the challenges to be met in realizing these goals are:

- Synthesis of materials by design.
- Determination of the nanoscale initiatives of materials failure.
- Development of cost effective and scalable production techniques.

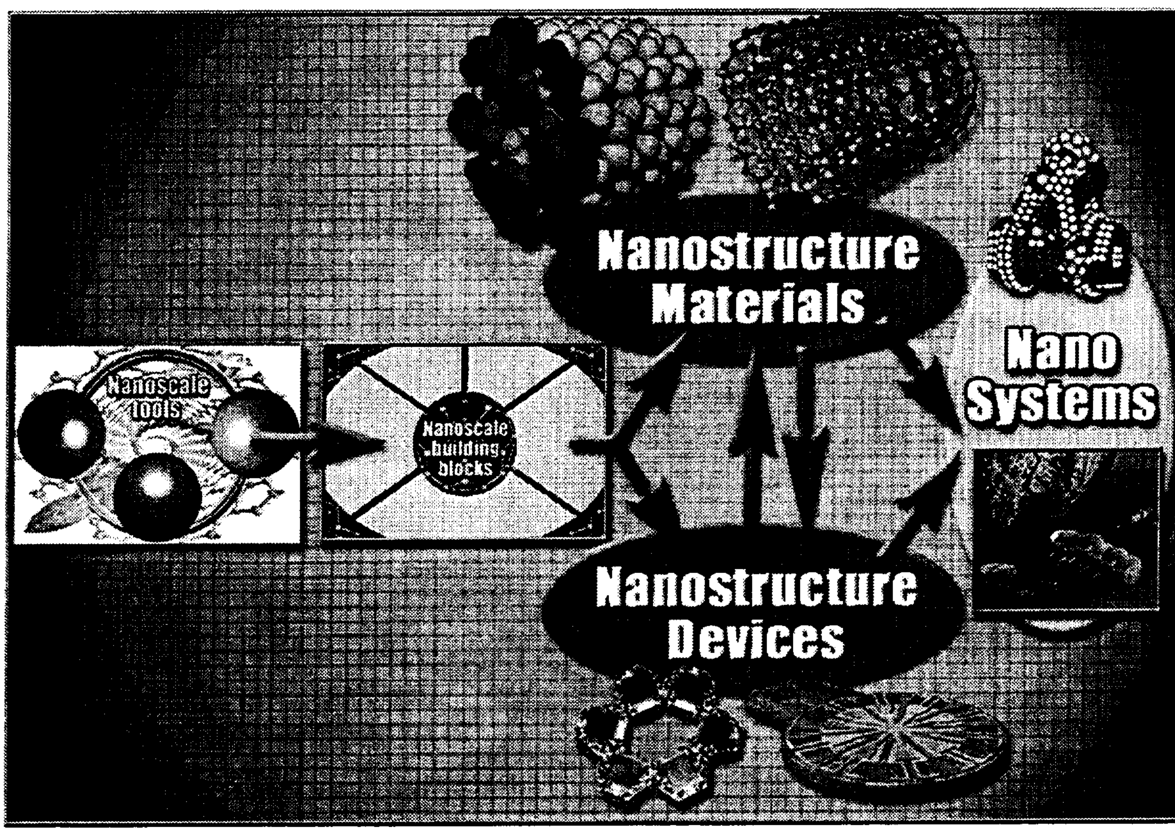


Figure 7

Enabling Technologies/Challenges

Among the enabling technologies/challenges for the development of nanotechnology are (see Fig. 8):

- Characterization and chemical analysis at finer size scales.
- Manipulation of matter at the atomic/molecular scale.
- Multiscale modeling of nanostructuring, from atomic to mesoscopic to macroscopic level, and the resulting material properties at each of these levels.
- Control of nanostructure size and size distribution.
- Roles of surfaces and interfaces in nanostructured materials.
- Thermal, chemical and structural stability of nanostructured materials and devices in the face of temperature and other environmental changes.
- Reproducibility and scalability of nanoparticle synthesis and consolidation processes.

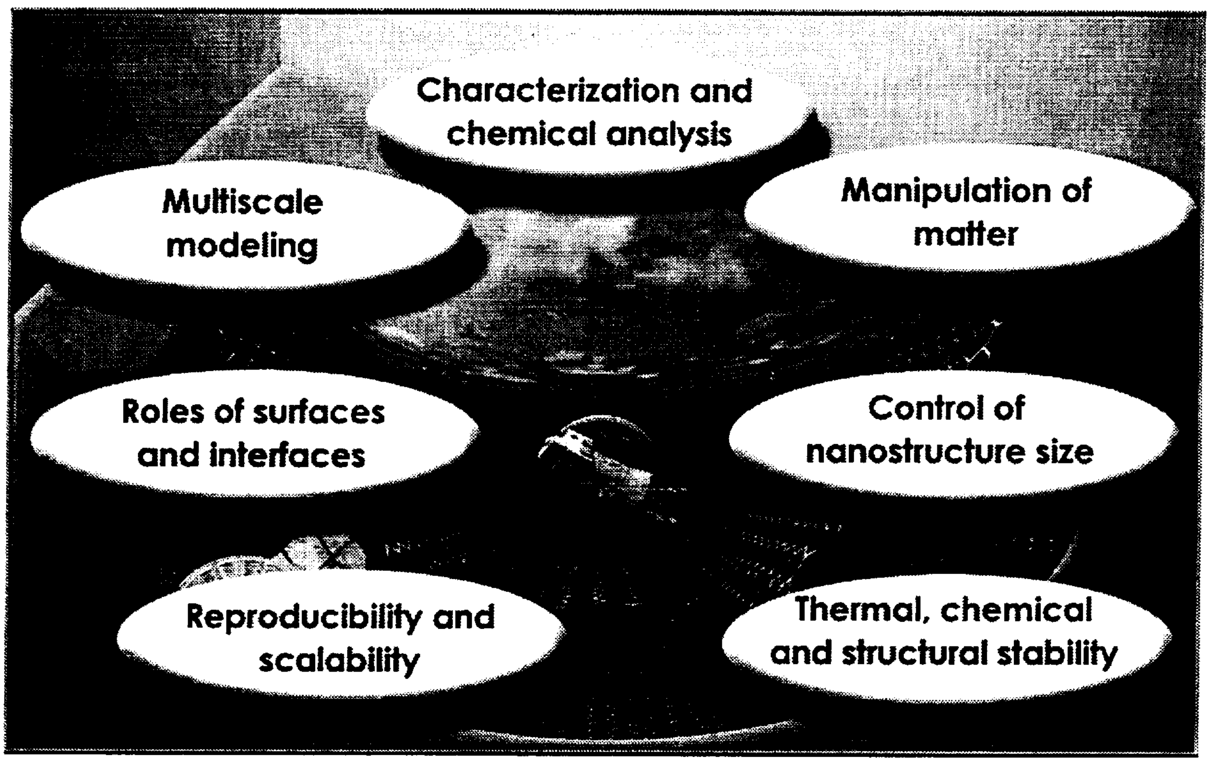


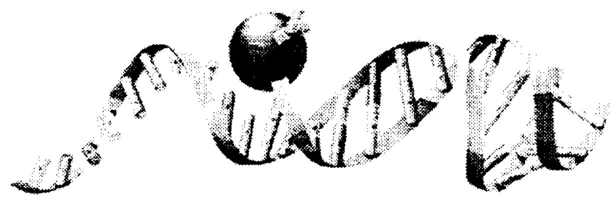
Figure 8

Definition of Biotechnology

Since biology can be viewed as a way of making things work on a very small scale, biotechnology can be defined as the application of biological knowledge and techniques to produce innovative engineering materials, devices and systems (Fig. 9). Biology does not just supply a metaphor, but an actual implementation technology for engineering systems.

Definition of Biotechnology

- Application of biological knowledge and techniques to produce innovative engineering materials, devices and systems.



- Biology is not just used as a metaphor, but as an actual implementation technology for engineering systems.

Figure 9

Hierarchical Biological Structures

The hierarchical biological structures are shown in Fig. 10, starting with the carbon atom as the chemical building block of all matter. Next comes the molecule (e.g., ATP - Adenosine Triphospate) which is a group of atoms with specific properties. Molecules are collected into organelles (10 ~ 100 nm in size). Organelles are collected and work together in cells, which are the basic units of life. Cells aggregate into tissue. The next level is the organ, which is the structure in an organism performing a specific function. The organism (e.g., fish) is a living entity. A localized group of organisms of the same species form a population. Interacting populations form a community. Future robotic and robotic-human outposts can be thought of as communities in the same sense.

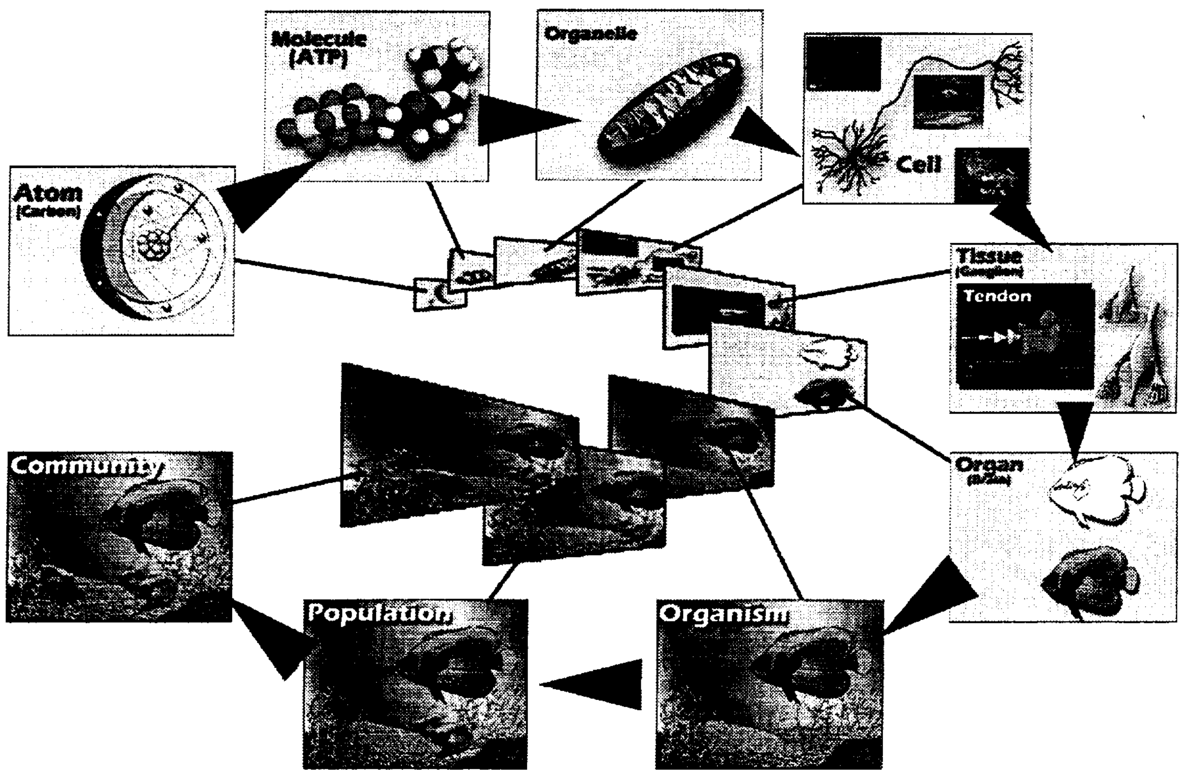


Figure 10

Examples

Three examples of application of biotechnology are shown in Fig. 11:

• Biomolecular materials are designed to have molecular-level properties and characteristics, such as self-assembly of biological materials.

• Biosensors that combine a biological recognition mechanism with a physical transduction technique.

• Chemical and biochemical computers that process information by making and breaking chemical bonds. They store logic states of information in the resulting chemical (i.e., molecular) structures. Examples of biochemical computers are DNA-based and protein-based computers.

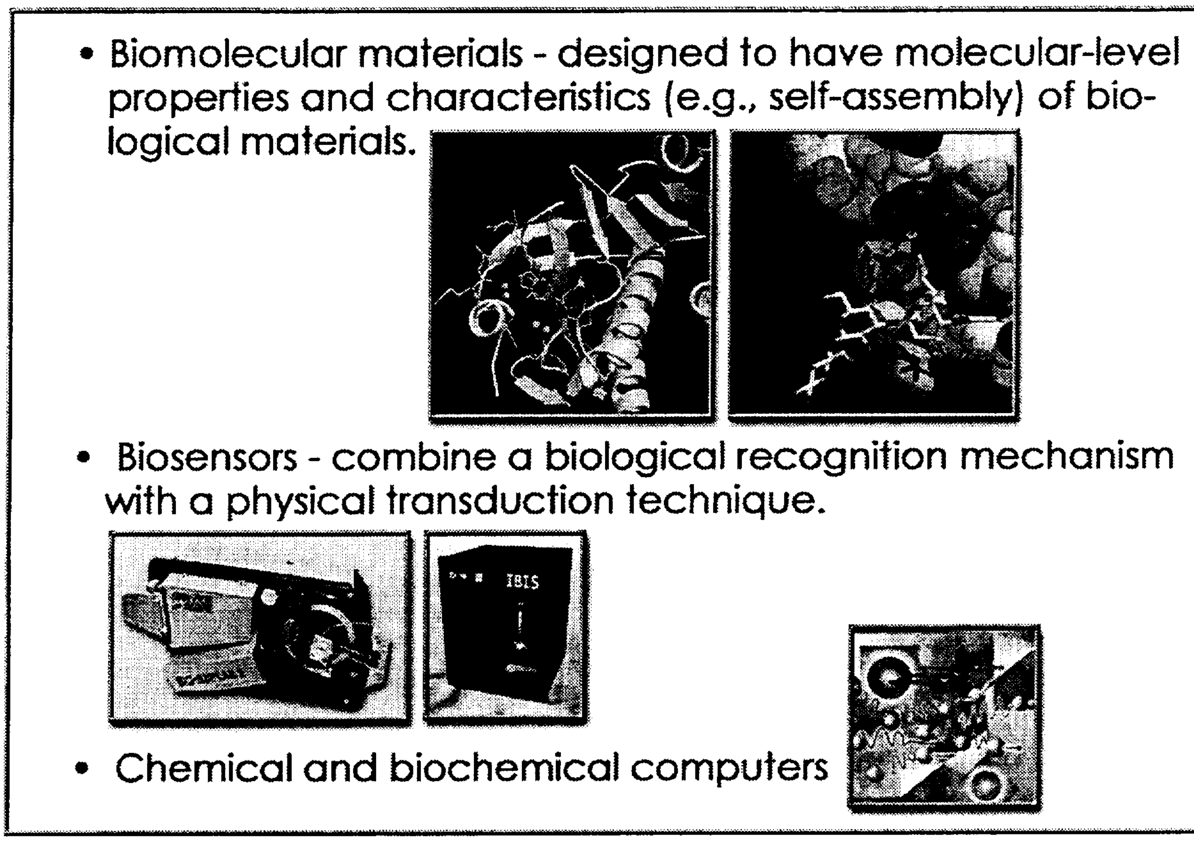


Figure 11

Three Levels of Biotechnology Applications

Three levels of biotechnology applications can be identified (Fig. 12):

• The first is to mimic biological systems (both animal and plant). Applications include: nanoscale, intelligent biologically inspired sensors and instruments (neuromimetic silicon chip - biologically inspired object tracking systems, fully integrated visually aware system - eye-brain module of a thinking spacecraft); and biorobots (robotic systems that are designed as models of particular biological systems).

• The second is to embed biological elements to create hybrid systems. An example of that is a hybrid nanomechanical device (integration of biological motors with NEMS).

• The third is to create fully biological and life like systems. Examples include embryological electronics (with reproduction, adaptation and evolution); protective sensitive material for radiation shielding; and highly intelligent structures that design themselves.

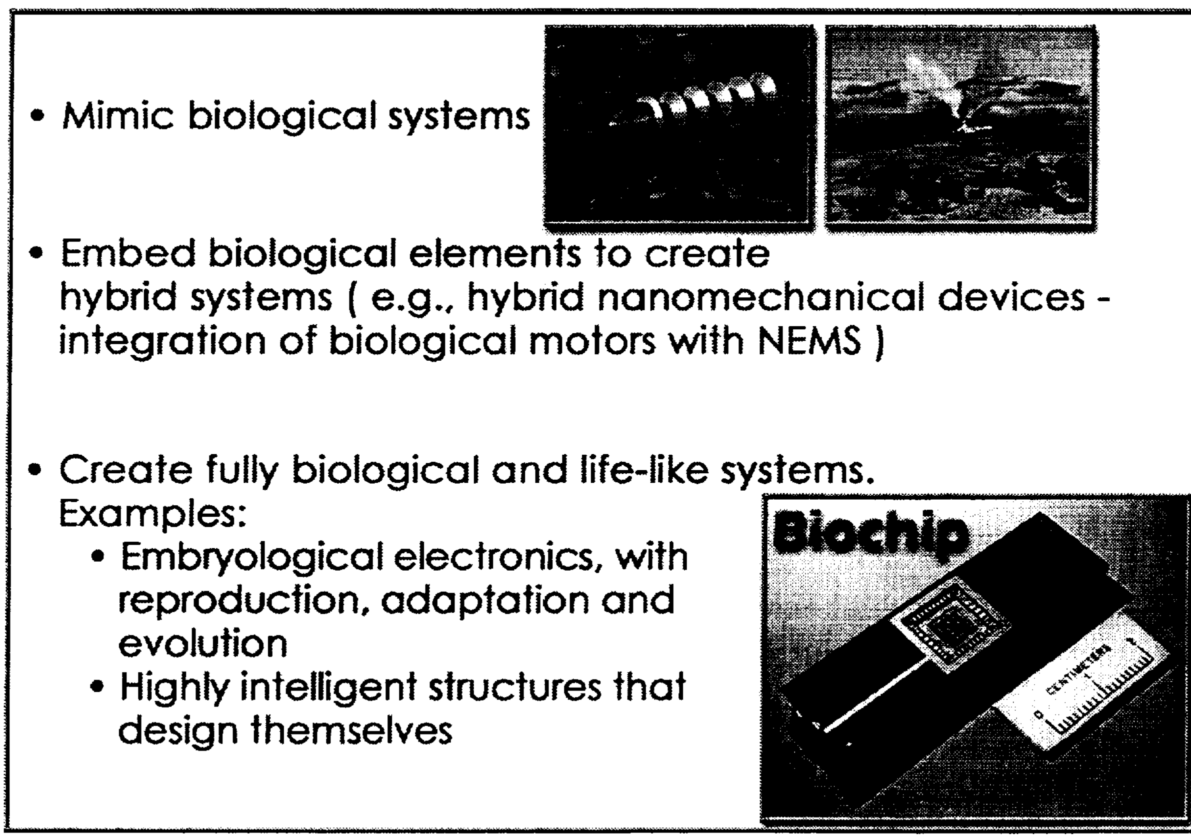


Figure 12

Biomimetics

Biomimetics refers to mimicking biological synthesis in producing man-made materials. This technology aims at developing novel synthetic materials by understanding and exploring the processes with natural (biological) structural systems employed to build strong and durable structures. This requires knowledge of how biological organisms organize, create, and synthesize systems with smart functions (systems that contain inherent receptors for information).

Some of the unique characteristics of biological systems that are important for future aerospace systems (Fig. 13) are:

- Multi-functionality. Individual components participate in more than one function. This is manifested by the integration of material capabilities, structural and functional requirements.
- Hierarchical organization. A tendon, for example, which serves as a link between muscle and bone, has a very complex structure.
- Adaptability. A bone adapts slowly to a change in loading by changing its own mass and microstructure while maintaining its primary function.
- Self-healing/self-repair.
- Durability.

One of the important characteristics of biologically structured systems is that they do not distinguish between materials and structures. The design and development of natural organisms is an integrated process in which component functions are multiple, and result in a cost effective and durable structure whose performance matches the demands brought upon the living system.

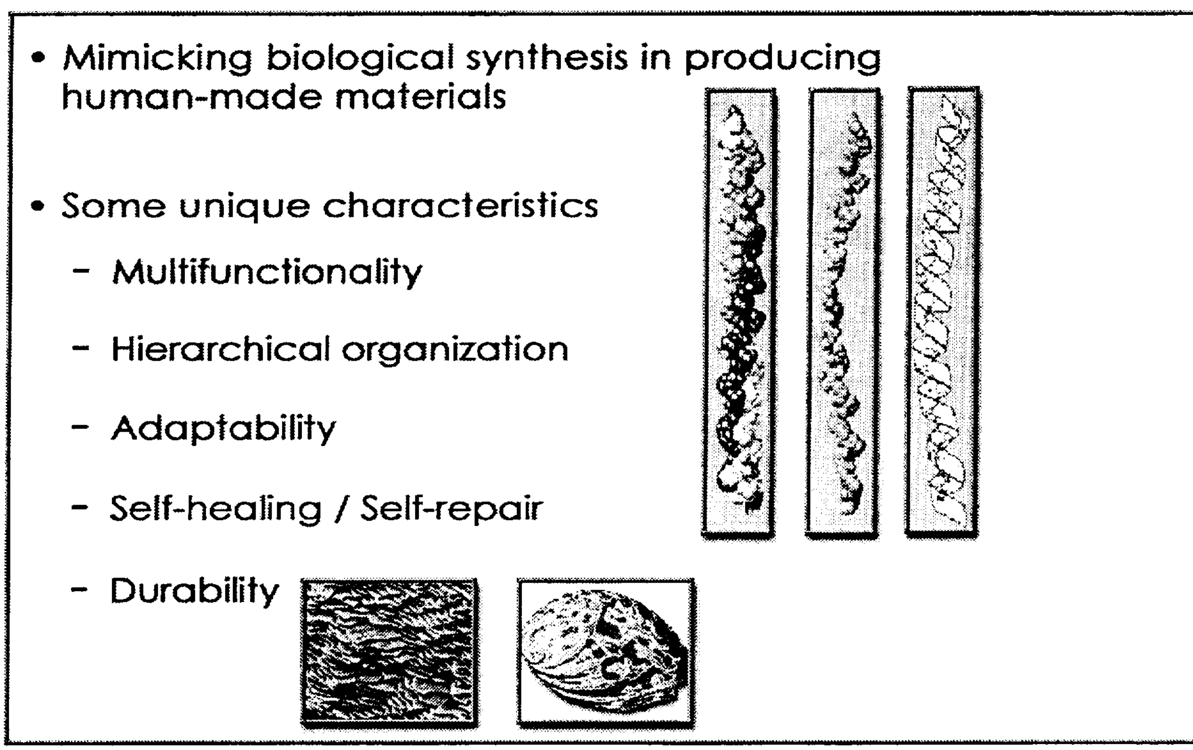


Figure 13

Engineering Applications of Nanobiotechnology

Realizing the potential of nanobiotechnology in engineering systems requires multidisciplinary teams of experts in a number of areas (Fig. 14):

- Condensed matter physics/solid state chemistry - to perform the synthesis of more complex molecules.
- Molecular biology - to manipulate with great precision, a wide range of molecular phenomena occurring in living organisms.
- Materials science - to develop stronger, lighter, more useful materials.
- Molecular manufacturing - to build better small devices at lower cost.
- Engineering disciplines - to create innovative device and system concepts.

The integration of these activities can lead to precise molecular control, and to building large structures to complex atomic specifications (by direct positional selection of reaction sites).

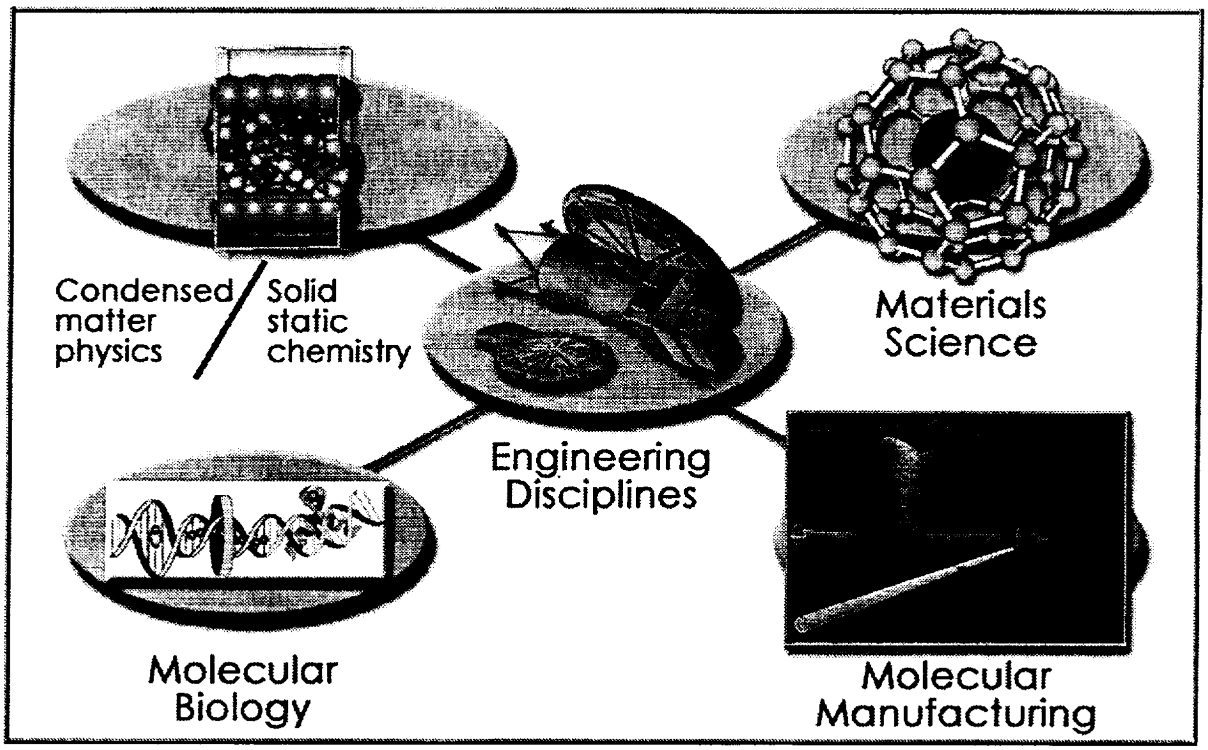


Figure 14

Computing Alternatives Beyond Silicon

The number of transistors per chip has been steadily increasing, in accordance with Gordon Moore's predictions (Moore's Law). It is expected that by 2008, over 16 billion devices will be packaged on a single chip. This means fabricating features that are smaller and smaller. A few years thereafter (2012), the limit of Moore's Law will be reached - one electron per device (Fig. 15). Therefore, in order to continue the trend of miniaturization, alternatives to silicon have to be identified. Among the alternatives being studied are quantum computing (using quantum dots); molecular computing; and biological and DNA computing. All of these alternatives are in the domain of nanobiotechnology.

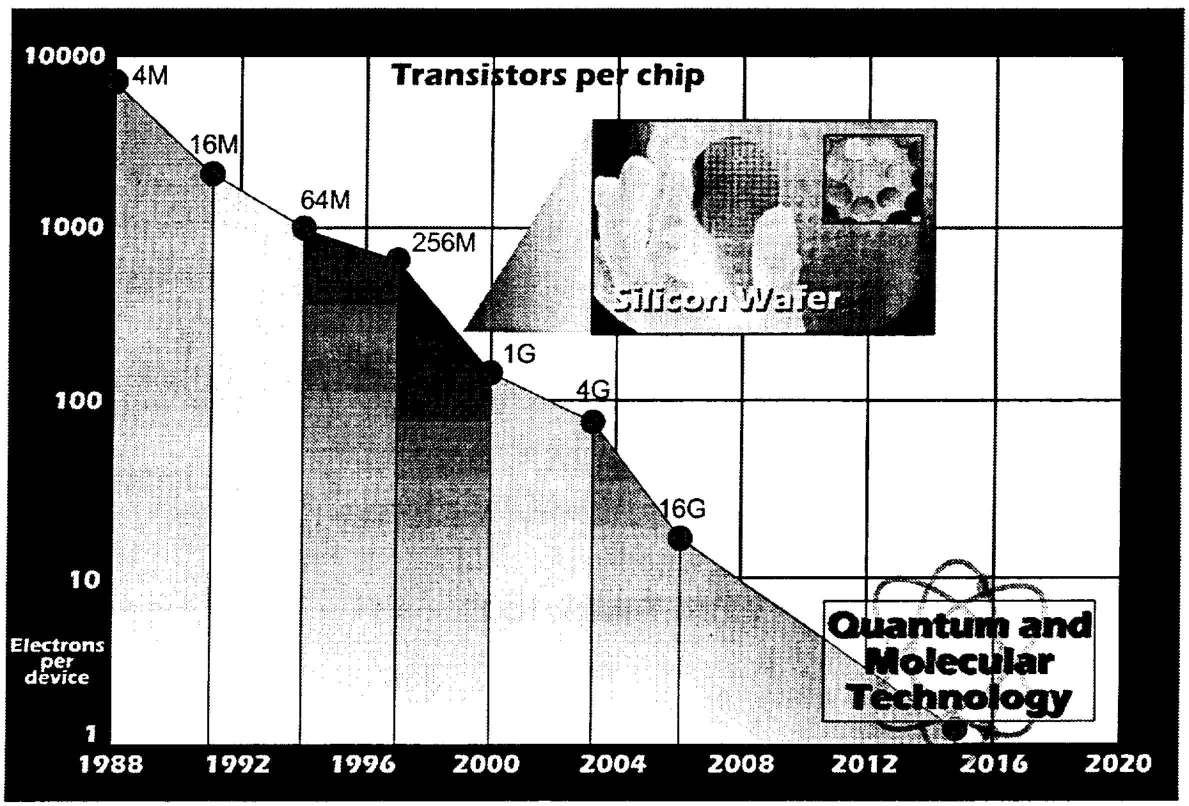


Figure 15

Molecular Electronics (Moletronics)

The field of molecular electronics (moletronics) seeks to use individual molecules to perform functions in electronic circuitry now performed by semiconductor devices. Individual molecules can conduct and switch electric current and store information. Electronic devices constructed from molecules will be hundreds of times smaller than their semiconductor-based counterparts. Figure 16 shows Mark Reed's depiction of a molecular electronic circuit with memory elements and electrical connectors. A general purpose molecular computer has three components: switching device, memory, and interconnects. Examples of the three components are shown in Fig. 16. Moletronics exploits what molecules are good for: self-assembly, thermodynamic equilibrium, and charge storage media.

- Individual molecules can
  - Conduct and switch electric current
  - Store information
- General-purpose molecular computer has
  - Switching device (like a transistor)
  - Memory
  - Interconnects (connecting arbitrarily large numbers of devices and memory elements)
- Moletronics exploits what molecules are good at
  - Self assembly
  - Thermodynamic equilibrium
  - Charge storage media

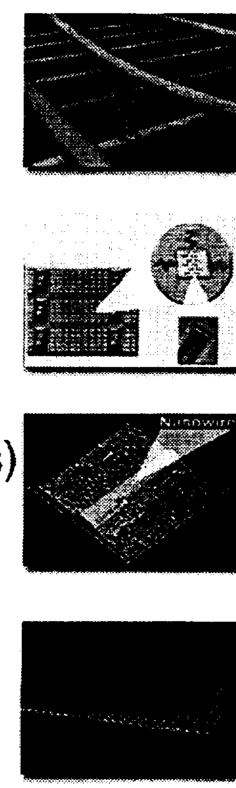


Figure 16

Current State and Potential of Moletronics

In July 1999, researchers from Hewlett Packard and the University of California at Los Angeles built an electronic switch consisting of a layer of several million molecules of an organic substance called rotaxane. The device had only two terminals. Complex logic circuits require more than two terminals.

Although at the present time no methods exist for connecting large numbers of devices, moletronics has the potential for overcoming physical limitations associated with feature size reduction, power consumption, switching speed and cost of foundry (Fig. 17).

- Current state
  - Individual molecule switches (with only two terminals) and memory elements. Complex logic circuits require more than two terminals
  - No methods exist for connecting large numbers of devices
- Has potential for overcoming physical limitations:
  - Feature size reduction
  - Power consumption
  - Switching speed
  - Cost of foundry

Figure 17

Teramac Configurable Custom Computer

Teramac is a one Tera Hertz massively parallel experimental computer built at Hewlett Packard Laboratories to investigate a wide range of computational architectures (Fig. 18). It is constructed with conventional silicon integrated circuit technology, but many of its problems are similar to challenges faced by nanoscale computing paradigms. It contains 220,000 (3%) hardware defects, any one of which could prove fatal to a more conventional machine. It incorporates a high communication bandwidth that enables it to easily route around defects. It operates 100 times faster than a high end single processor workstation (for some of its configurations). It demonstrates that it is not necessary to chemically synthesize devices with a 100% yield and assemble them into a completely deterministic network in order to obtain a reliable and powerful system.

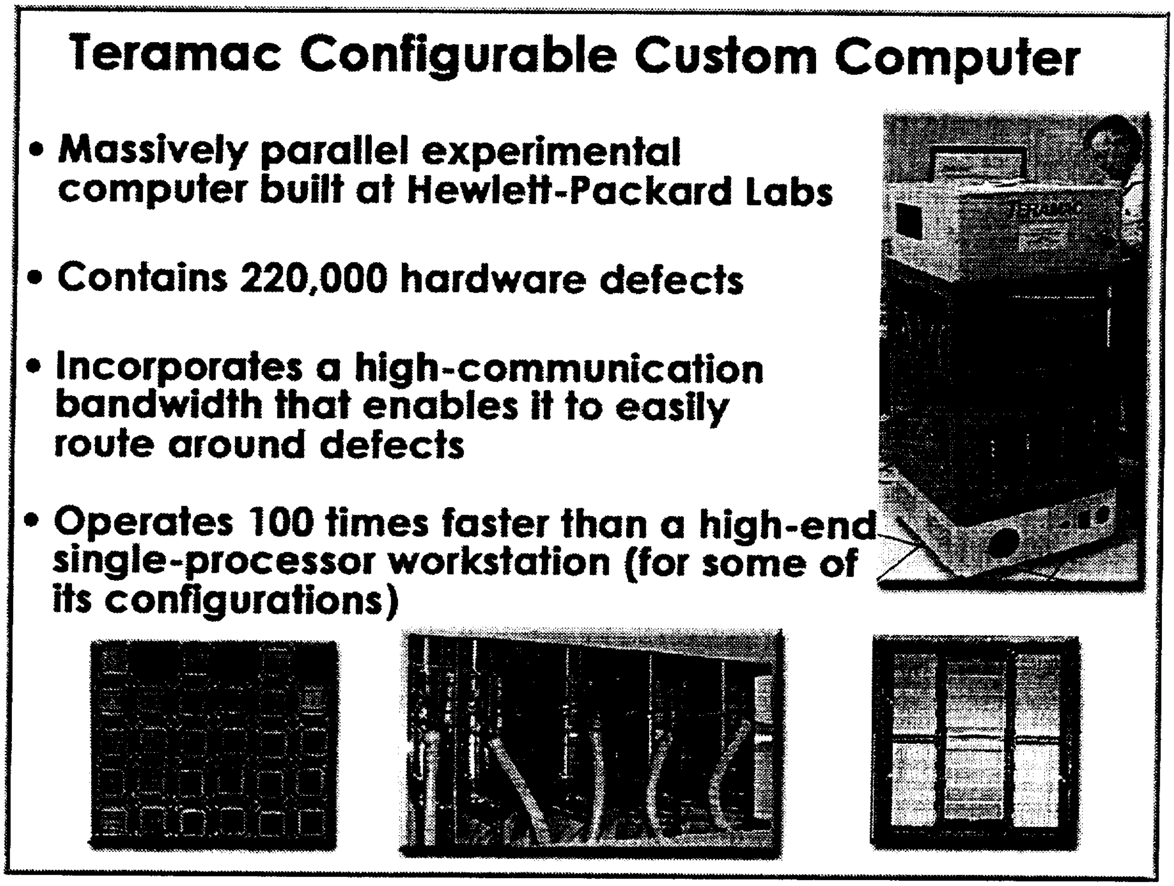


Figure 18

Amorphous Computing Paradigm

Amorphous computing refers to the development of organizational principles and programming languages for obtaining coherent behavior from a myriad of unreliable parts, interconnected in unknown, irregular time varying ways. This is analogous to the fact that principles of growth in biological organisms and genetic programs are used for generating well defined shapes and functional structures from the interaction of cells with variable numbers and variable arrangements. The basic concept is to mimic the formation of a complex biological entity using a programmatic interface.

Through the integration of nanofabrication and cellular bioengineering, amorphous computing has the potential of:

• Tailor making biological cells to function as chemical factories for the assembly of nanoscale structures.

• Assembling systems incorporating a myriad of information processing units (sensors, actuators and communication devices).

• Mixing these with structural and other materials producing super-intelligent programmable materials (senses and reports on the environment and structural integrity).

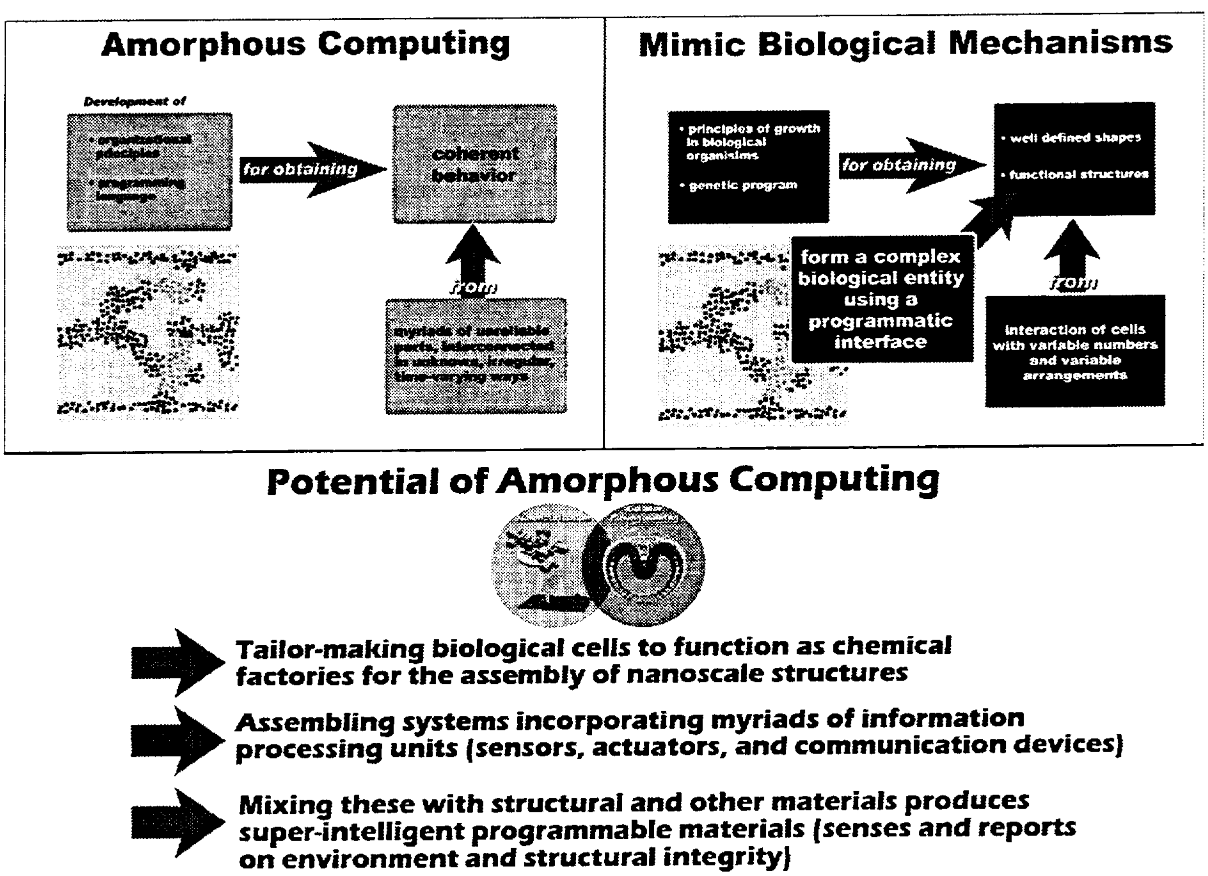


Figure 19

Interagency Working Group on Nanoscience and Engineering (IWGN)

In 1997, the United States conducted 40% of the world's research and development but spent less than 27% on government sponsored nanotechnology research. By contrast, Europe and Japan sponsored 29% and 28% on nanotechnology research. In recognition of the potential impact of nanotechnology on our economy and our society, an interagency working group on nanoscience, engineering and technology (IWGN) has been established. The proposed research and development funding on nanotechnology for FY 01 is $495 million. IWGN recommended a steady increase of investment, reaching $2.786 billion in FY 05. NASA's share of the research and development nanotechnology funding in FY 01 is 4%. Among the research areas to be addressed by NASA are nanostructured materials and thin films; nano and bioinspired devices; radiation tolerant electronics; self-healing systems; nanosensors and biomedical nanotechnology.

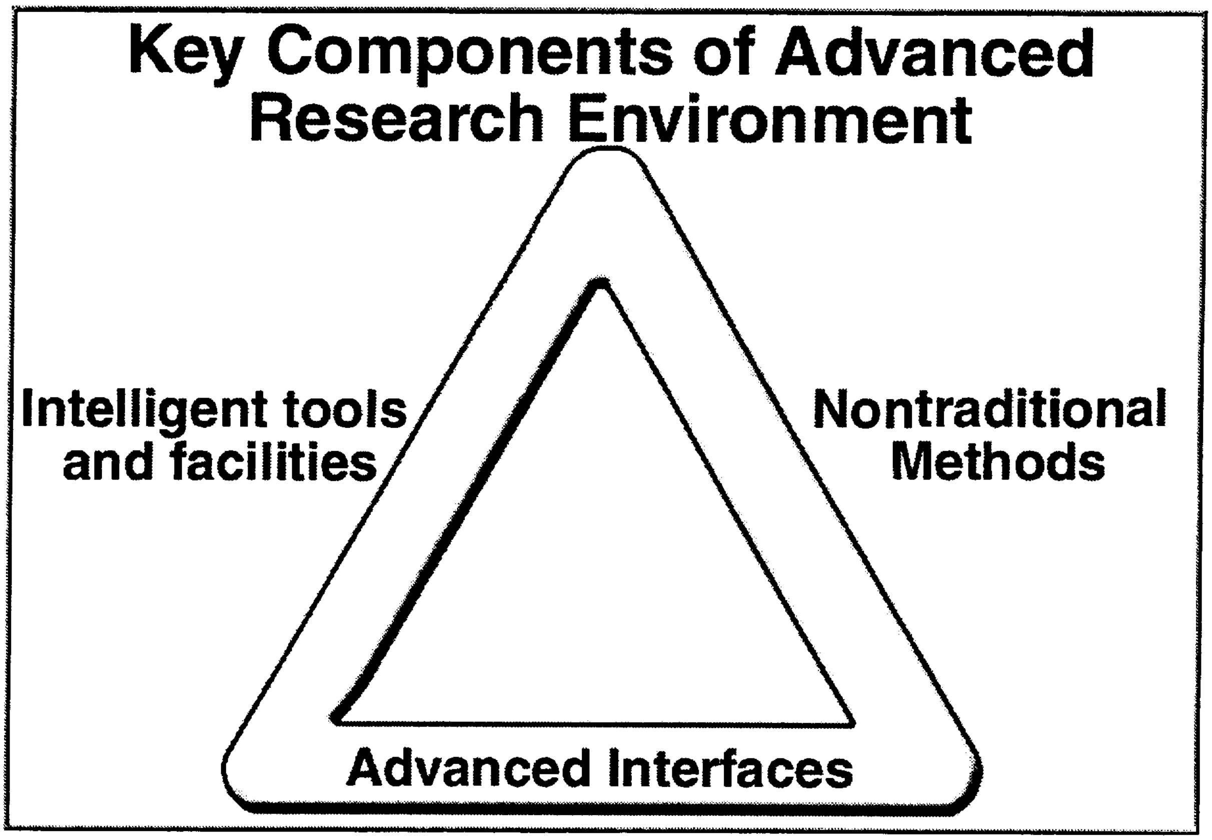


Figure 20

IWGN Grand Challenge Areas

IWGN identified nine grand challenges as essential for the advancement of nanotechnology (as listed in Fig. 21):

- Nanostructured materials include smart multifunctional materials.
- The goal of nanoelectronics is to improve computer speed and efficiency by a factor of millions, increase the memory storage/unit surface area by a factor thousands fold, and increase the communication bandwidth a hundred times.
- Nanostructured and smart materials can potentially build lighter and more efficient transportation vehicles, corrosion free bridges and no-maintenance roads.
- The development of biosensors and new imaging techniques and tiny smart medical devices will contribute to major advances in health care.

IWGN Grand Challenge Areas

- Nanostructured materials "by design" are stronger, lighter, harder, self-repairing, and safer
- Nano-electronics, optoelectronics and magnetics
- Microcraft space exploration and industrialization
- Economical and safe transportation
- Efficient energy conversion and storage
- Advanced healthcare, therapeutics and diagnostics
- Bio-nanosensor devices for communicable disease and biological threat detection
- Nanoscale processes for environmental improvement
- National security (military dominance with reduced manpower)

Figure 21

Forces Driving a Change in Research and Learning Environments

After decades of evolutionary change, revolutionary changes are both needed and possible for creating effective research and learning environments. The change is driven by four categories of forces (Fig. 22):

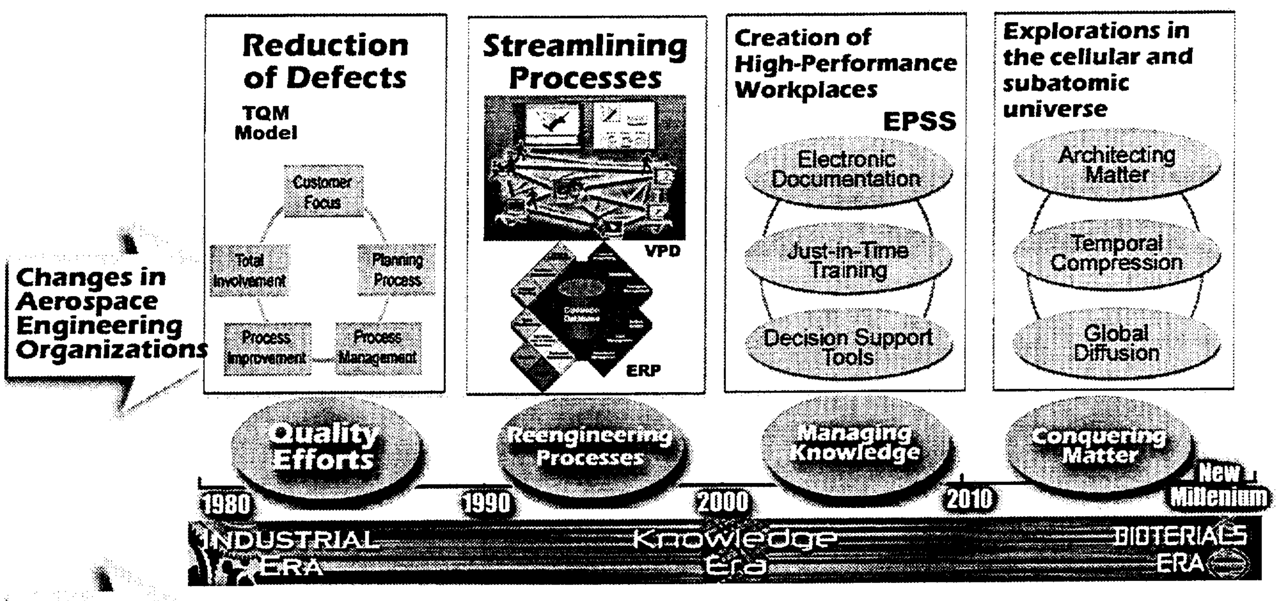
• Changes in high tech organizations. Quality was the focus of high tech organizations in the 1980's. In the 1990's, the move from the industrial to the knowledge era shifted the focus to re-engineering and streamlining the processes, and then to managing knowledge and creation of high-performance workplaces. In the future there is likely to be a move to the biological and advanced materials era (referred to as the bioterials era). The focus of high tech organizations will shift to explorations in the cellular and subatomic universe - architecting matter. Facilities will be developed for temporal compression and global diffusion.

• Economic pressures. Economic stresses and customer demands for cheaper, better, faster products have driven high tech organizations from mass production to mass customization, and to the adoption of lean production system concepts. They have integrated simulation and design tools with other tools and facilities for lean engineering, manufacturing, and supplier management.

• Impact of advances in technology. The synergistic coupling of several leading edge technologies will have a significant impact on future products and engineering systems. To realize the potential of this synergism, high tech organizations will have to provide effective diverse team collaboration facilities and interdisciplinary research networks, as well as a conducive life long learning environment in the workplace.

• Paradigm change in human/machine/network interaction. Wireless connectivity among diverse teams and embedded devices, including thousands of embedded nanodevices per person, will become the norm. Consequently, there is a move from human-centered (interactive) computing to human-supervised (proactive) computing. The wireless connectivity will enable the development of virtual interfaces with experiments and fabrication facilities.

Forces Driving a Change in Research and Learning Environments (Cont'd.)



Economic Pressures

- ▲ **Lean production systems concepts (lean engineering, manufacturing, supplier management)**
- ▲ **Mass customization**

Impact of Advances in Technology

- ▲ **Synergistic coupling of several leading edge technologies**
- ▲ **Need for diverse team collaboration facilities, interdisciplinary networks, and lifelong learning environment in the workplace**

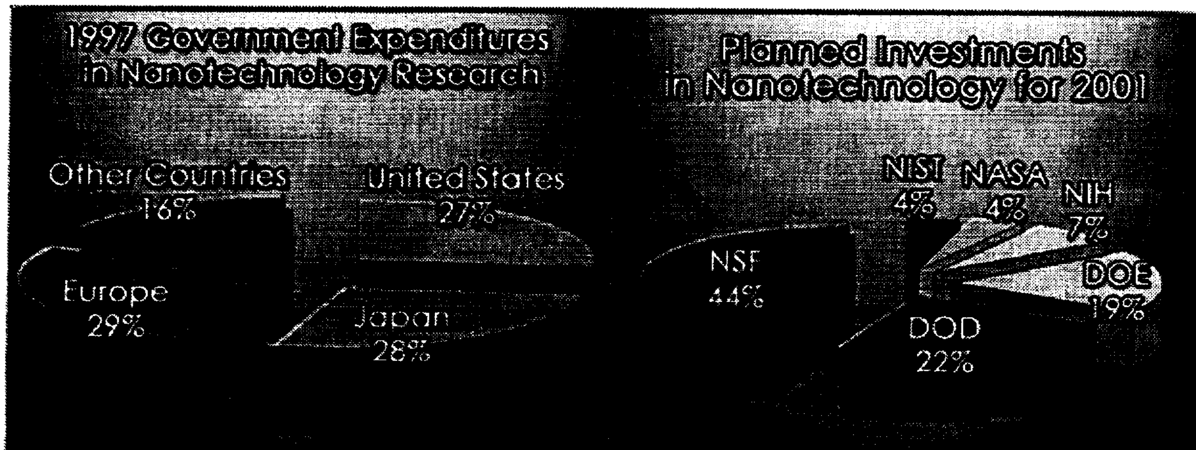
Paradigm Change in Human/Machine/ Network Interaction

- ▲ **Wireless connectivity among diverse teams and embedded devices (including thousands of embedded (nano) processors per person)**
- ▲ **Virtual interface with experiments and fabrication facilities**
- ▲ **Move from human-centered (interactive) computing to human-supervised (proactive) computing**

Figure 22

Key Components of Advanced Research Environment

The realization of the full potential of nanobiotechnology in aerospace and other engineering fields requires an advanced research environment that links diverse teams of scientists, engineers and technologists. The essential components of the environment can be grouped into three categories: intelligent tools and facilities, nontraditional methods, and advanced interfaces (Fig. 23).



Some of NASA's Nanotechnology activities:

- **Nanostructured and thin-film materials**
- **Nano and bio-inspired devices, radiation-tolerant electronics and self-healing electronics**
- **Nanosensors and biomedical nanotechnology**

Figure 23

Intelligent Tools and Facilities

These include high fidelity rapid modeling and life cycle simulation and visualization tools; distributed high capacity computing, communications and networking facilities; synthetic immersive environment; automatic and semiautomatic selection of software and hardware platforms; collaborative group support and decision making facilities; computer simulation of physical experiments and remote control of these experiments. The life cycle simulation tools include tools for cost estimation, product assurance, safety analysis, risk management, virtual manufacturing and prototyping, testing for qualification, maintenance and operations, and life cycle optimizations. In all of these tools extensive use should be made of intelligent software agents and information technology (Fig. 24).

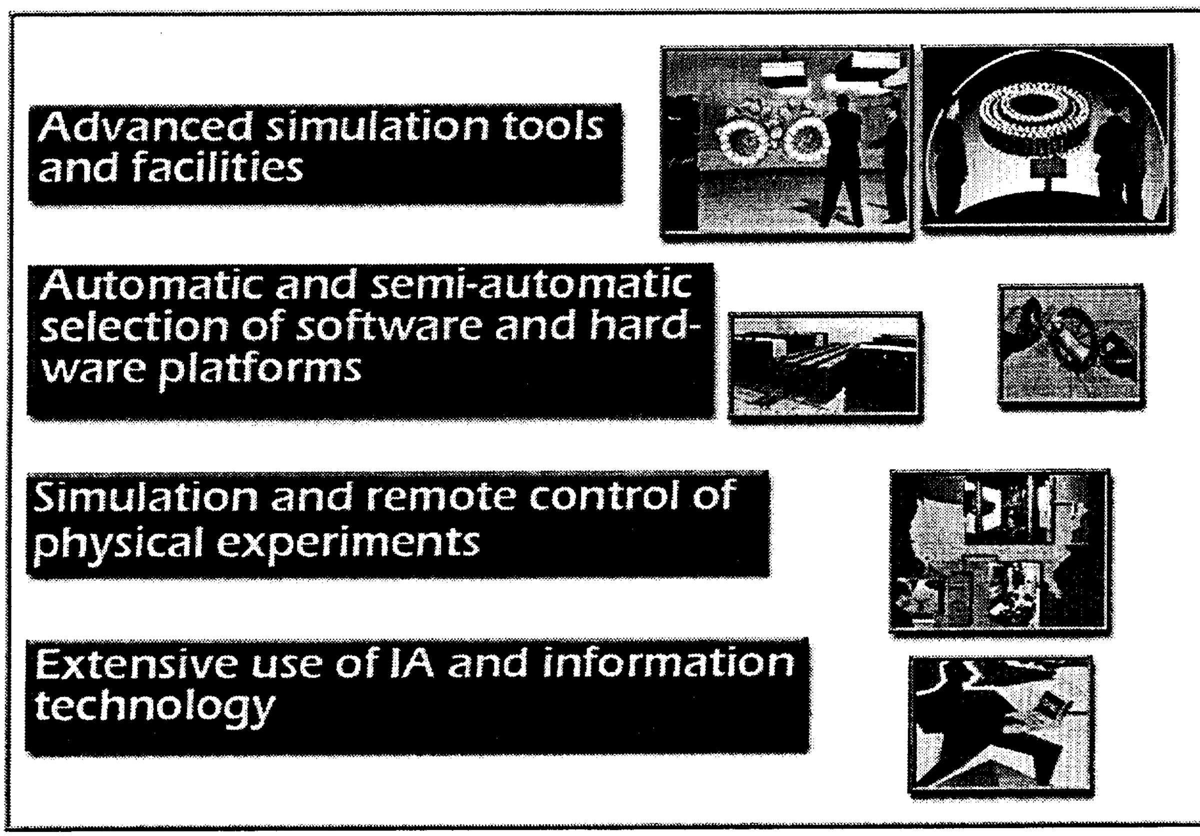


Figure 24

Advanced Human/Computer Interfaces

Although the WIMP (windows, icons, menus, pointer) paradigm has provided a stable and global interface, it will not scale to match the myriad form factors and uses of platforms in the future collaborative distributed environment. Perceptual user interfaces (PUIs) are likely to meet those needs. PUIs integrate perceptive, multimodal and multimedia interfaces to bring human capabilities to bear on creating more natural and intuitive interfaces. They enable multiple styles of interactions, such as speech only, speech and gesture, vision, and synthetic sound, each of which may be appropriate in different applications (Fig. 25). These new technologies will enable broad uses of computers as assistants, or agents, that will interact in more human-like ways.

- **Integrates perceptive, multimodal and multimedia interfaces to bring human capabilities to bear on creating more natural and intuitive interfaces**
- **Enables multiple styles of interactions and broad uses of computers as assistants**

Figure 25

Nontraditional Methods

These include multiscale methods, strategies for highly coupled multiphysics problems, and nondeterministic approaches for handling uncertainty in geometry, material properties, boundary conditions, loading and operational environments (Fig. 26).

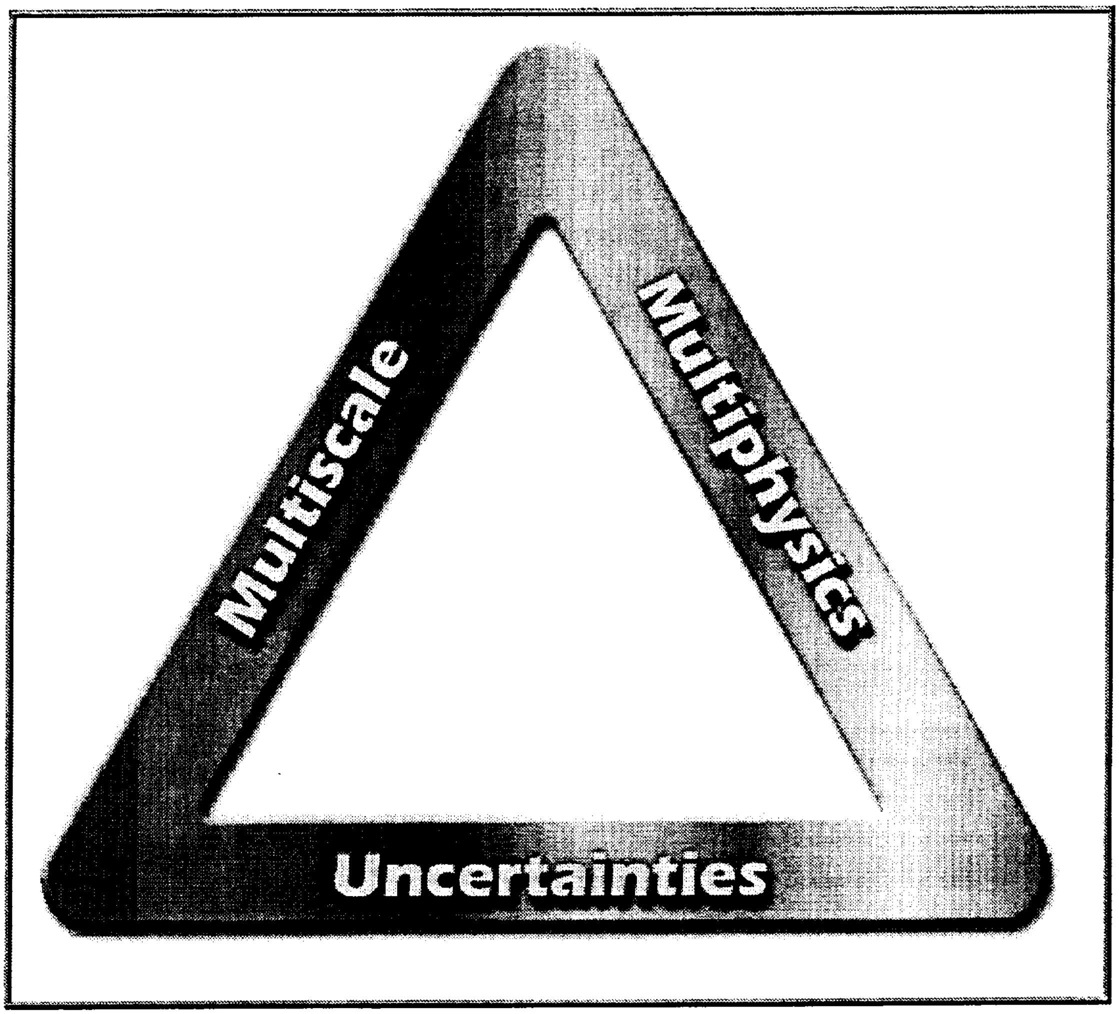


Figure 26

Multiscale Modeling

Multiscale methods integrate disciplinary approaches. Examples are quantum mechanics, molecular dynamics and continuum mechanics for the study of fracture phenomena and molecular robotics; and multiscale material modeling used in computationally driven material development. The hierarchy of material models that has developed is shown in Fig. 27. The models are arranged according to the phenomena they describe and the length scale at which the phenomena are studied (from 10^{-10}m to 1 m). The disciplines involved include computational chemistry (quantum mechanics and molecular dynamics), computational material science, and computational structural mechanics. However, many gaps still exist in the hierarchy of models, and to date no rational way exists to integrate these models and to couple them with experiments in order to relate the phenomena at the very small length scales with the macroscopic behavior. The central paradigm of the computationally driven material development activity is the sequence interrelation of processing, structure, properties, and performance of materials.

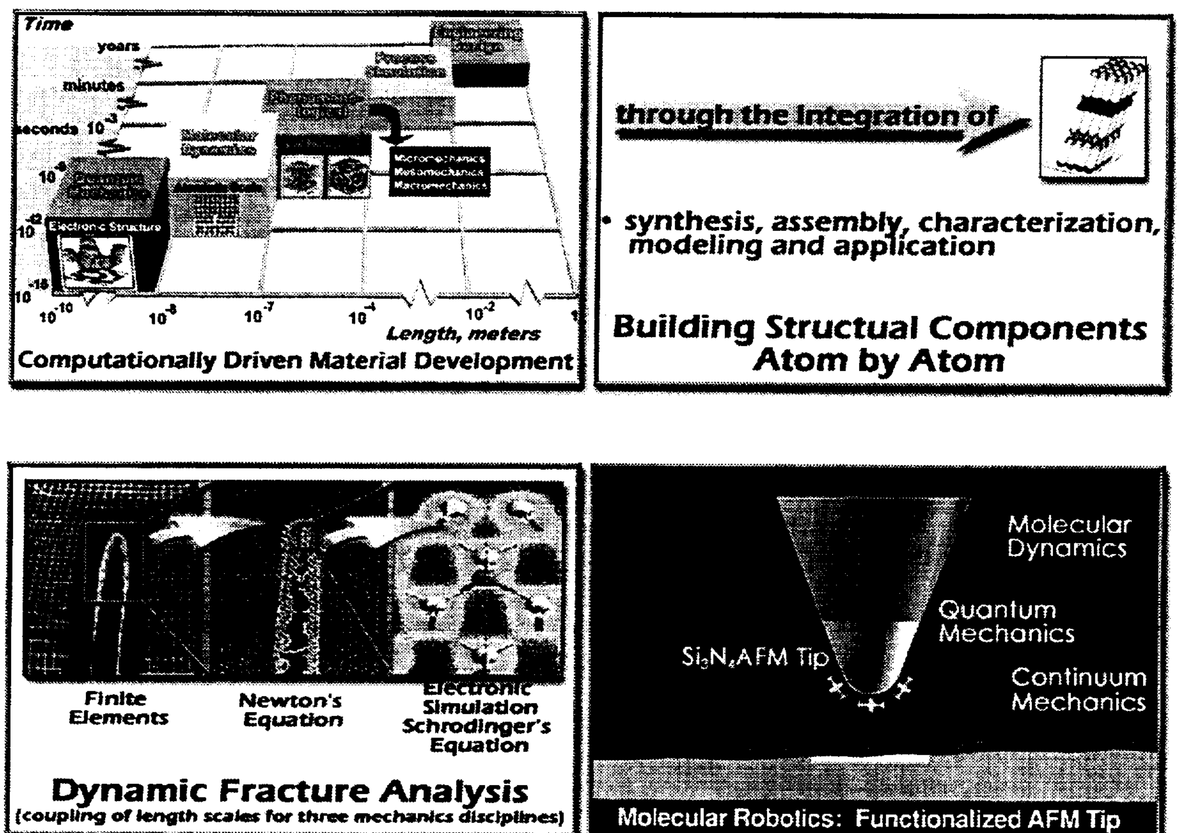


Figure 27

Highly Coupled Multiphysics Problems

Figure 28 shows an example of highly coupled multiphysics problems - the strong couplings between mechanical, electric, thermal and magnetic fields in smart materials. Two general strategies are used for solution of multi-physics problems: the staged solution strategy and the coupled solution strategy.

Staged Solution Strategy. The multiple fields are treated separately. The discrete models for each of the fields may be developed separately. Coupling effects are viewed as information that must be transferred between the discrete models of the different fields. A modification of this strategy is the multistagger solution strategy in which a partial decoupling is made of the full system. The full system of coupled equations is partitioned into smaller subsystems of equations. Each subsystem is solved separately under the assumption that the variables of the other subsystems are frozen (temporarily).

Coupled Solution Strategy. The multiple field problem is treated as an indivisible whole. The discrete models of the different fields are tightly coupled.

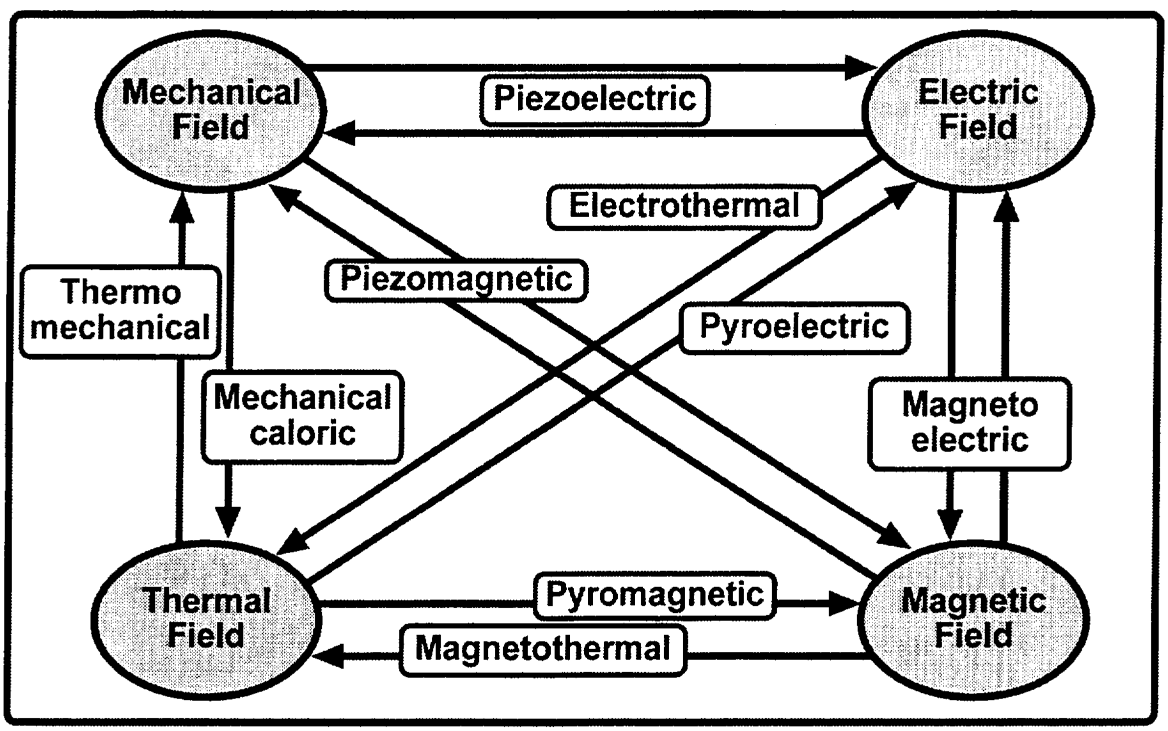


Figure 28

Types and Modeling of Uncertainties

Although it is difficult to list all the sources and kinds of uncertainties, the following five can be identified (Fig. 29):

• Probabilistic uncertainty, which arises due to chance or randomness;

• Resolutionary uncertainty, which is attributed to limitation of resolution (e.g., sensor resolution); and

• Fuzzy uncertainty, due to linguistic imprecision (e.g., set boundaries are not sharply defined).

• Uncertainty due to limited information available about the system (for example, in the early stages of the design process).

• Model uncertainty, which is attributed to lack of information about the model characteristics.

Some of the aspects of modeling uncertainty are listed in Fig. 29 below. The impact of these uncertainties on the reliability and certification of future systems are among important research areas.

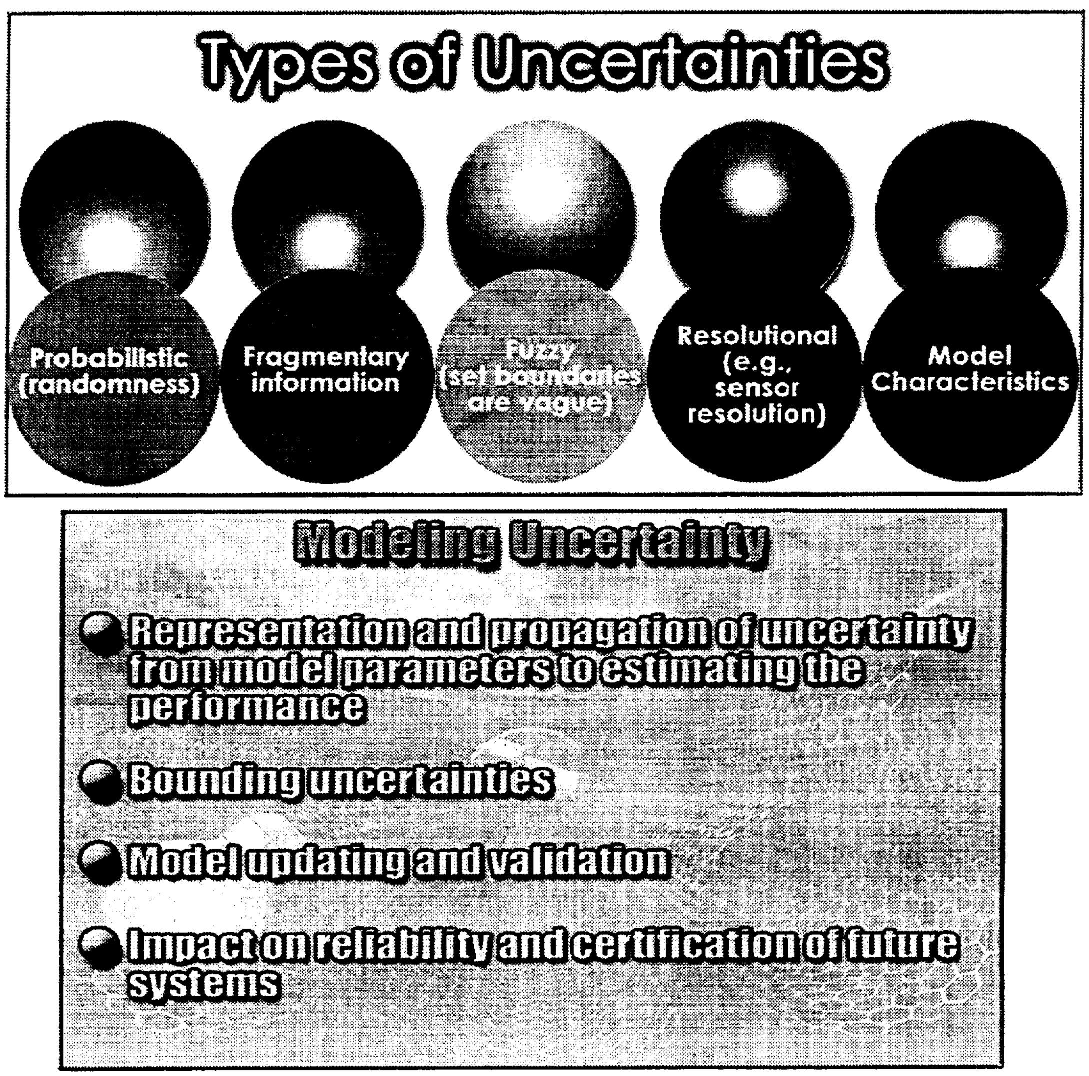


Figure 29

Principle of Complexity

One of the important consequences of uncertainty is its effect on precision. As the uncertainty and/or complexity of an engineering system increases, the ability to predict its response diminishes, until a threshold is reached beyond which precision and relevance become almost mutually exclusive. Consider, for example, numerical simulations in which sophisticated computational models are used for predicting the response, performance, and reliability of the engineering system, but the system parameters are little more than guesses. Such simulations can be characterized as Correct but Irrelevant Computations (CBIC); that is, forcing precision where it is not possible.

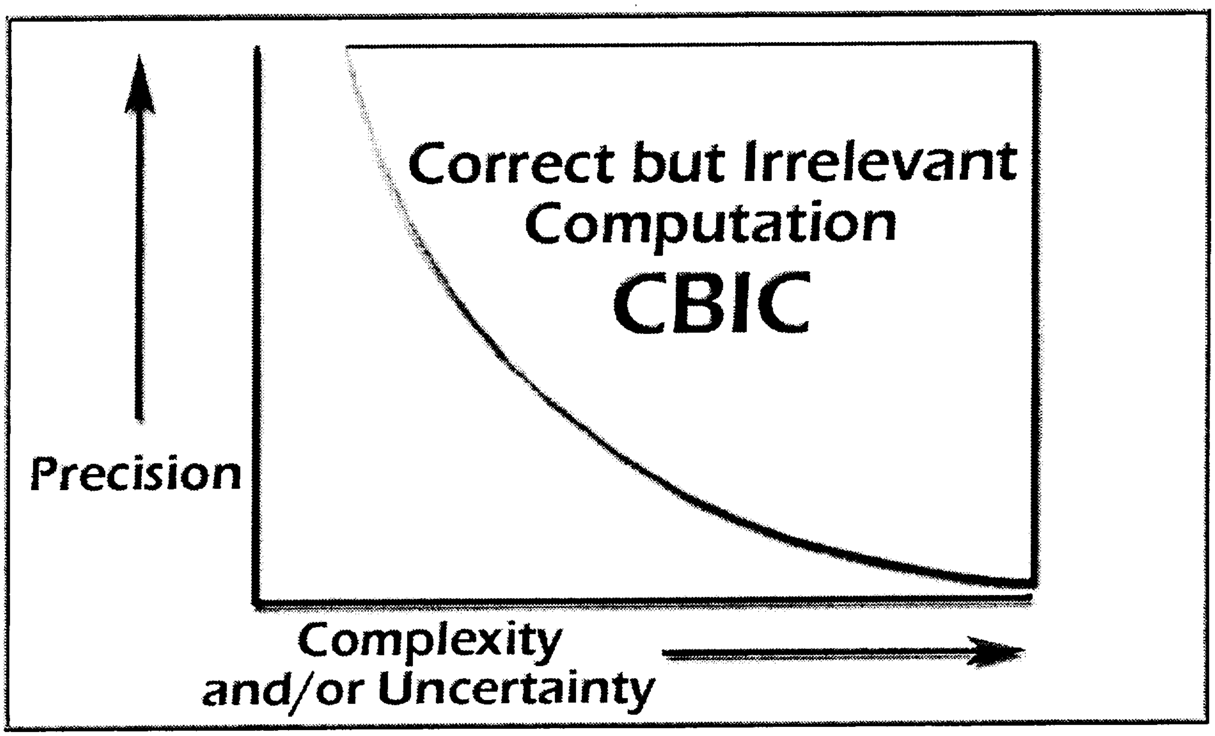


Figure 30

Nondeterministic Analysis Approaches

Three general approaches can be used for the analysis of systems with uncertainties; namely (Fig. 31): probabilistic methods for random processes; fuzzy sets; and set theoretical or antioptimization methods. The domain of application of each of these techniques is identified in Fig. 31.

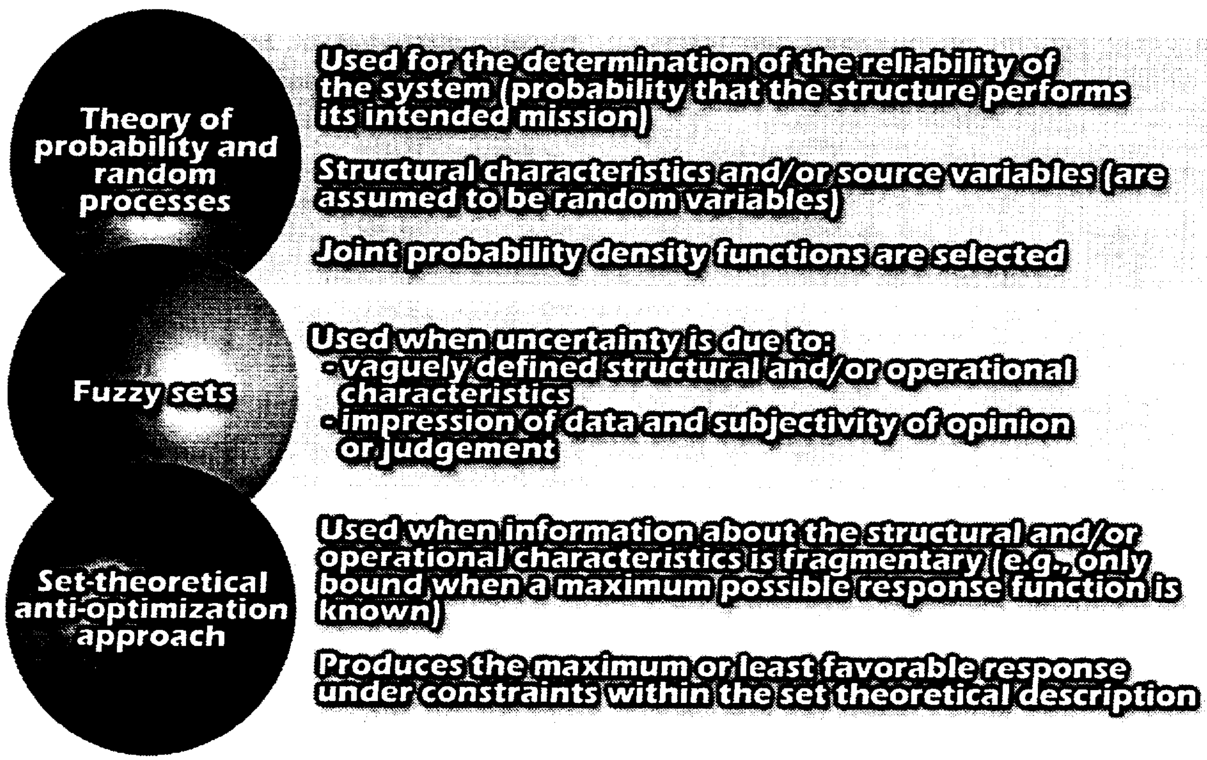


Figure 31

Advanced Learning Environments

In order to meet the life long learning demands of the future, three categories of learning environments are needed; namely, expert led group learning; self paced individual learning; and collaborative learning (Fig. 32). The three environments, in combination, can reduce the time and cost of learning, and sustain and increase worker competencies in high tech organizations.

The human instructors in these environments will serve many roles, including inspiring, motivating, observing, evaluating, and steering the learners, both individually and in distributed teams.

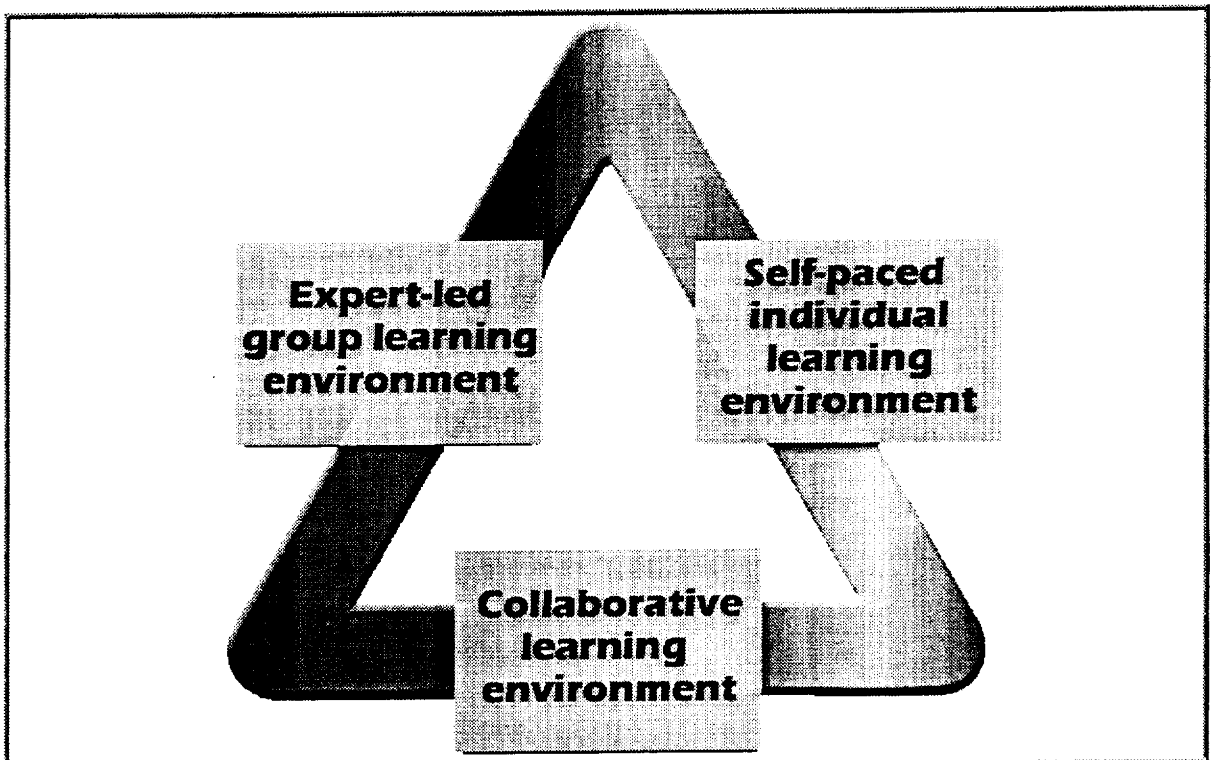


Figure 32

Expert Led Learning Environment

The human instructors in expert led distributed learning in a virtual environment serve as coaches, guides, facilitators, and course managers. Their presentations focus on a broad overview of the topic and its diverse applications (Fig. 33), and end with more penetrating, what-if questions that can enhance the critical thinking and creativity of the learners. Elaborate visualization and multimedia facilities are used in the presentations. Routine instructional and training tasks are relegated to the self-paced individual environment.

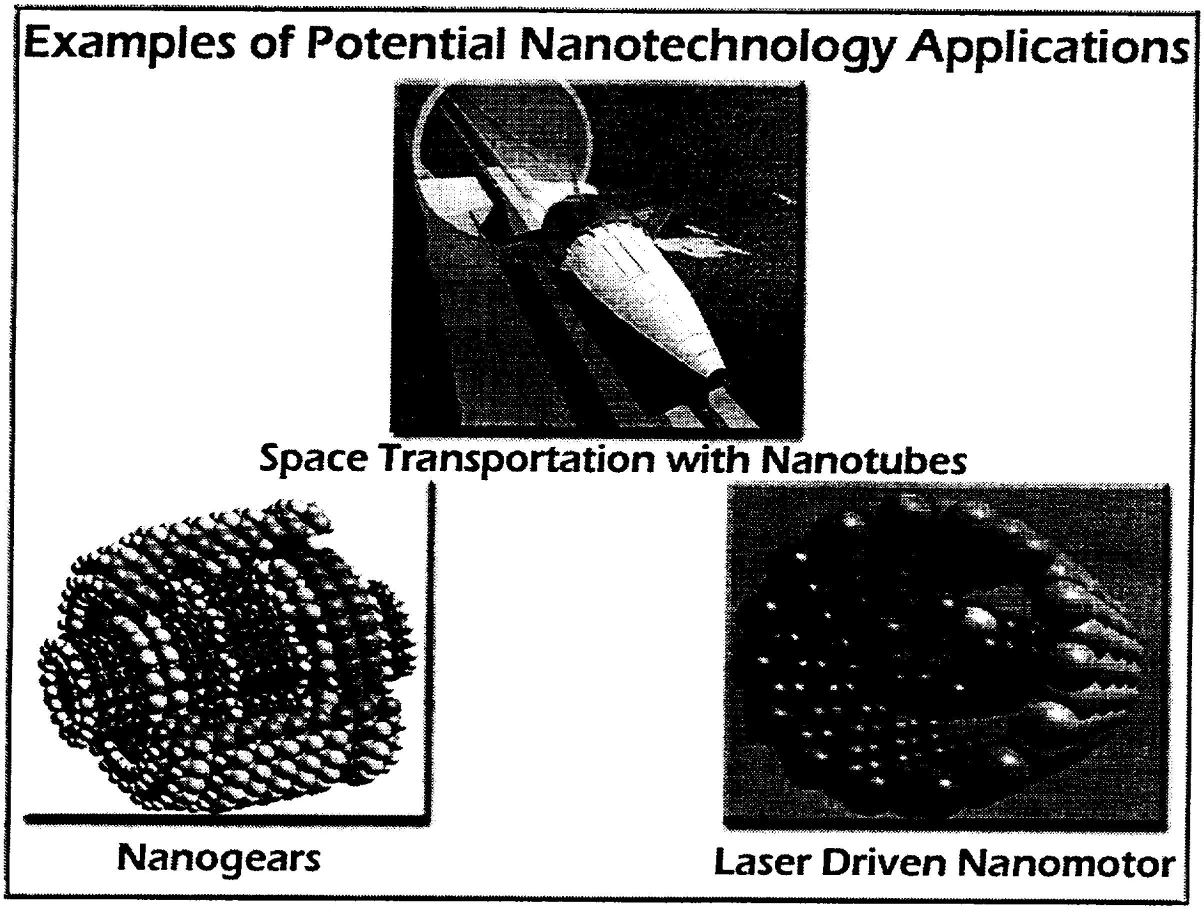


Figure 33

Self-Paced Learning Environment

The individual learning environment engages the learner and provides a high degree of tailored interactivity. It can be used for self-paced instruction of routine material not covered in the lecture. Using virtual instructors assigned by the human instructors can enhance such instruction. It can be used to study physical phenomena that can be coupled with biological processes using advanced visualization, multimedia and multisensory immersive facilities. The individual learning environment can serve to carry out virtual experiments - computer simulation of physical experiments (Fig. 34).

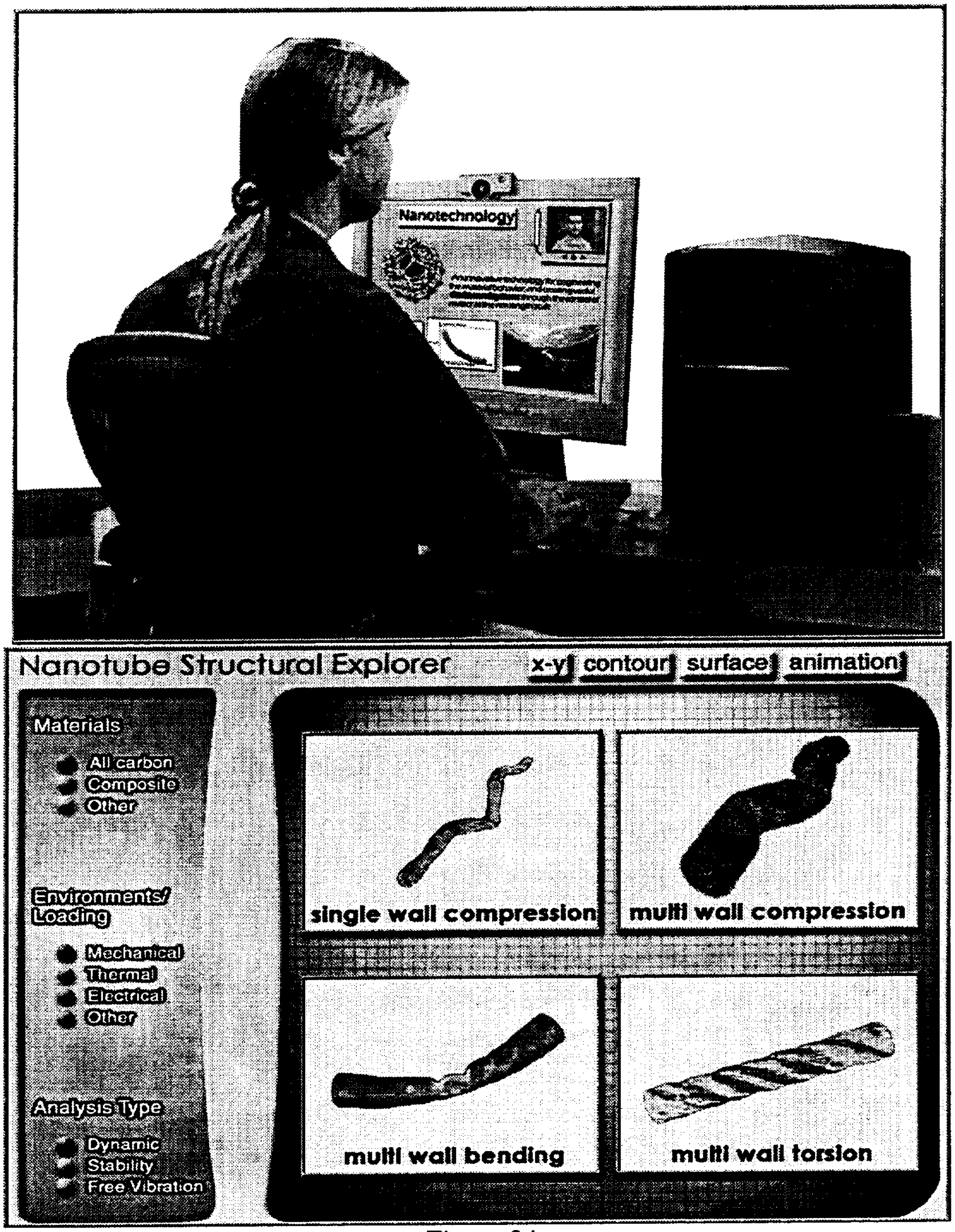


Figure 34

Collaborative / Distributed Learning Environment

Collaborative learning environments teach teamwork and group problem solving. Instructors and learners can be geographically dispersed. Eventually, they can be brought together through immersive telepresence facilities to share their experiences in highly heterogeneous environments involving different computing platforms, software and other facilities, and they will be able to work together to design complex engineering systems beyond what is traditionally done in academic settings. Because participants can be virtually collocated without leaving their industry and government laboratories, collaborative learning environments can enable the formation of new university, industry and government consortia. The ultimate goal of these learning facilities is to create an intellectual environment, where academic and experiential learning are effectively and efficiently co-mingled. In such an environment, academic rigor is learned in concert with professional job performance, and academic complexities are addressed within the industrial concern.

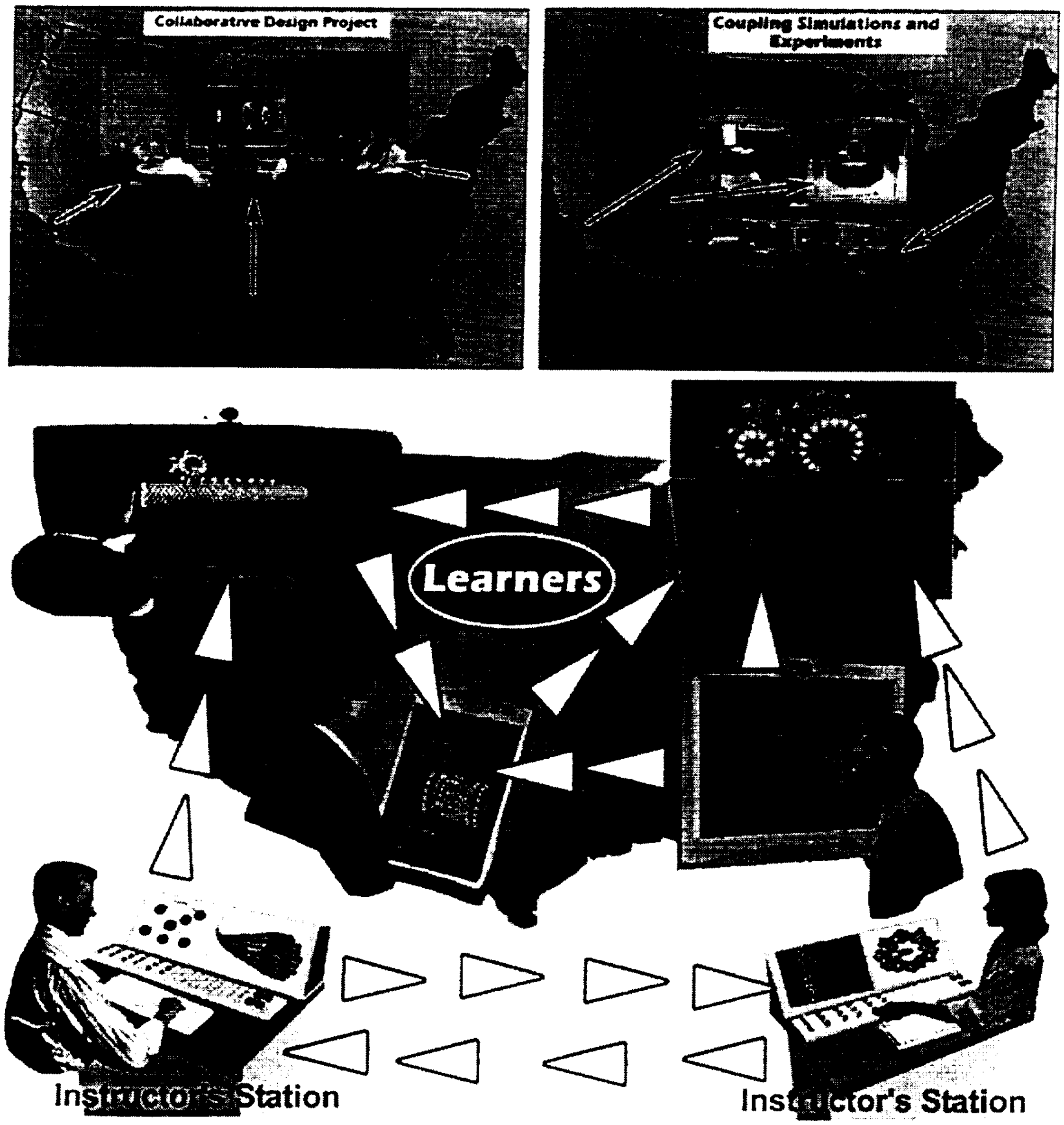


Figure 35

Virtual Classroom

Online training and virtual classrooms are typically used to provide learning environments with custom self-instruction, flexible tutorial support, and choice of both the place and time of learning. Three categories of facilities are used in these environments; namely: instruction, including multimedia lectures, links to other resources and tools for searching, browsing, and using archived knowledge; communication, including email, UseNet, chat centers, video and Internet conferencing; and course management and performance evaluation (Fig. 36).

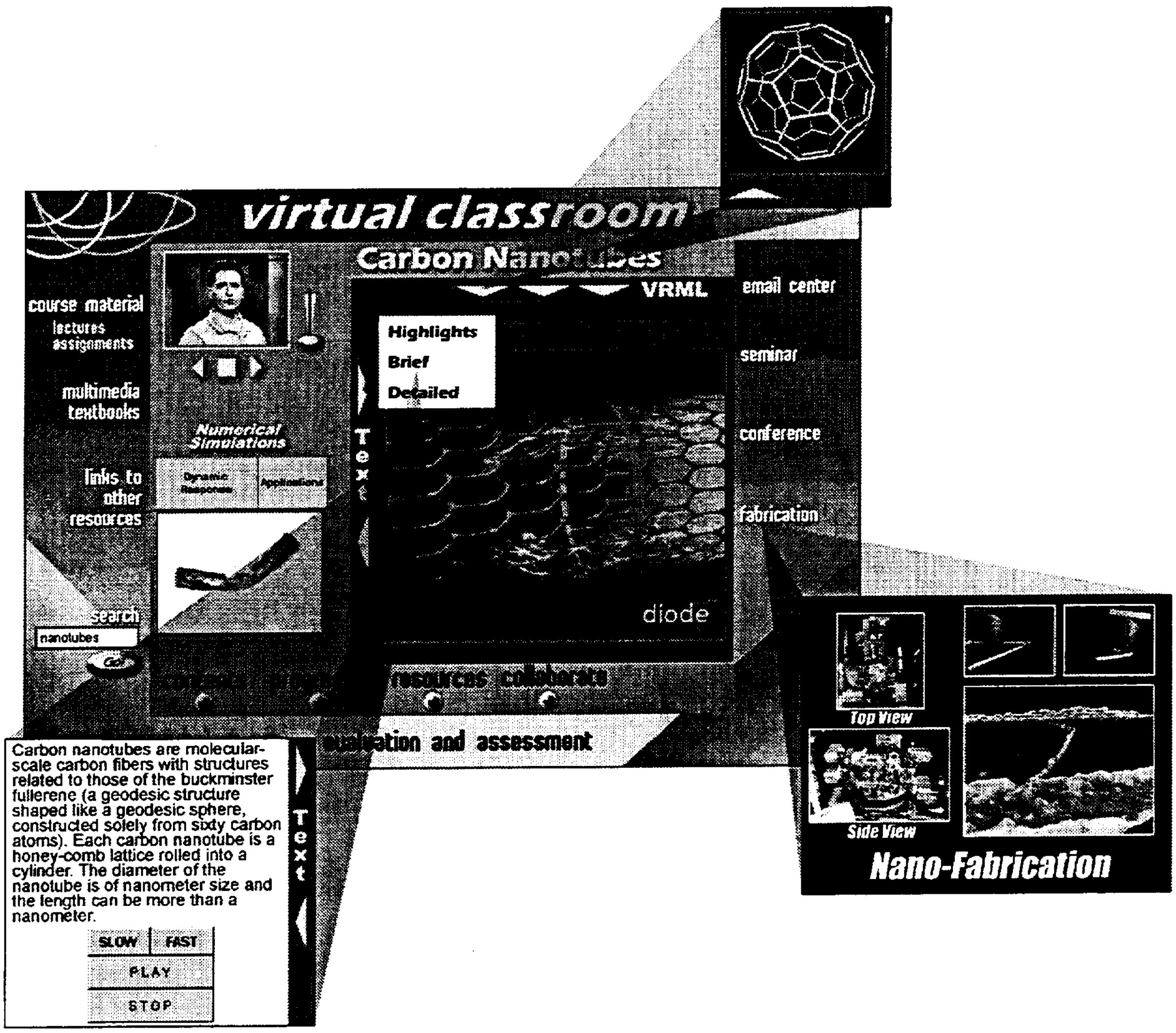


Figure 36

Objectives and Format of Workshop

The objectives of the workshop are to a) provide an overview of the diverse activities in nanobiotechnology; and b) identify the potential of these technologies to future aerospace systems. The workshop, including eighteen presentations and three exhibits, illuminate some of the key issues in nanobiotechnology and provide fresh ideas for future research and development.

Objectives and Format of Workshop

Objectives

- Overview of diverse activities in Nanobiotechnology
- Identify potential for aerospace systems

Format

- 18 presentations, 7 sessions
- Exhibits

Proceedings

- Printed (NASA CP)
- Electronic

Figure 37

Sources of Information on Nanobiotechnology

Extensive literature now exists on different aspects of nanobiotechnology. Several monographs, conference proceedings, and overview papers have been published on these subjects. In addition, a number of new journals are now devoted to the subject. Information on the research activities in these areas is also available on the Internet (Fig. 38).

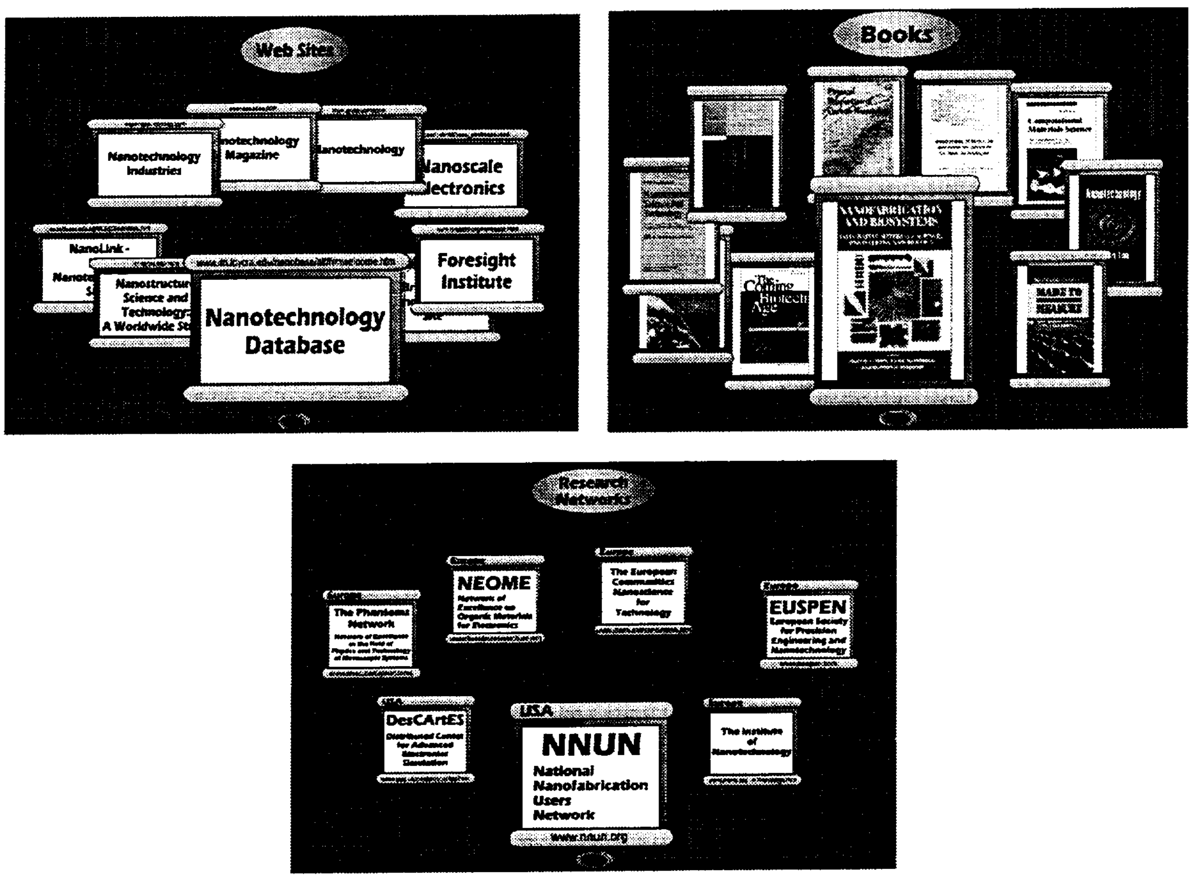


Figure 38

Web Sites for Information on Nanobiotechnology

- **Nanotechnology Research Directions: IWGN Workshop Report**
  http://itri.loyola.edu/nano/IWGN.Research.Directions/

- **Nanostructure Science and Technology - A Worldwide Study**
  http://itri.loyola.edu/nano/toc.htm

- **Nanotechnology Database**
  http://itri.loyola.edu/nanobase/alt/frmwelcome.htm

- **The Nanotube Site**
  http://www.pa.msu.edu/cmp/csc/nanotube.html

- **The National Biotechnology Information Facility (NBIF)**
  http://www.nbif.org/indxbdy.html

- **Internet Robotics Info**
  http://www.cs.indiana.edu/robotics/world.html

- **Information Resources for Biotechnology**
  http://www.library.ucsb.edu/subj/biotech.html

- **Internet Resources: Information Technology**
  http://bubl.ac.uk/link/i/informationtechnology.htm

- **Internet Resources for Bioinformatics**
  http://www.science.gmu.edu/~ntongvic/Bioinformatics/index.html

- **Bioinformatics and Computational Biology**
  http://www.unl.edu/stc-95/ResTools/biotools/biotools4.html

Figure 39