The New Engineering

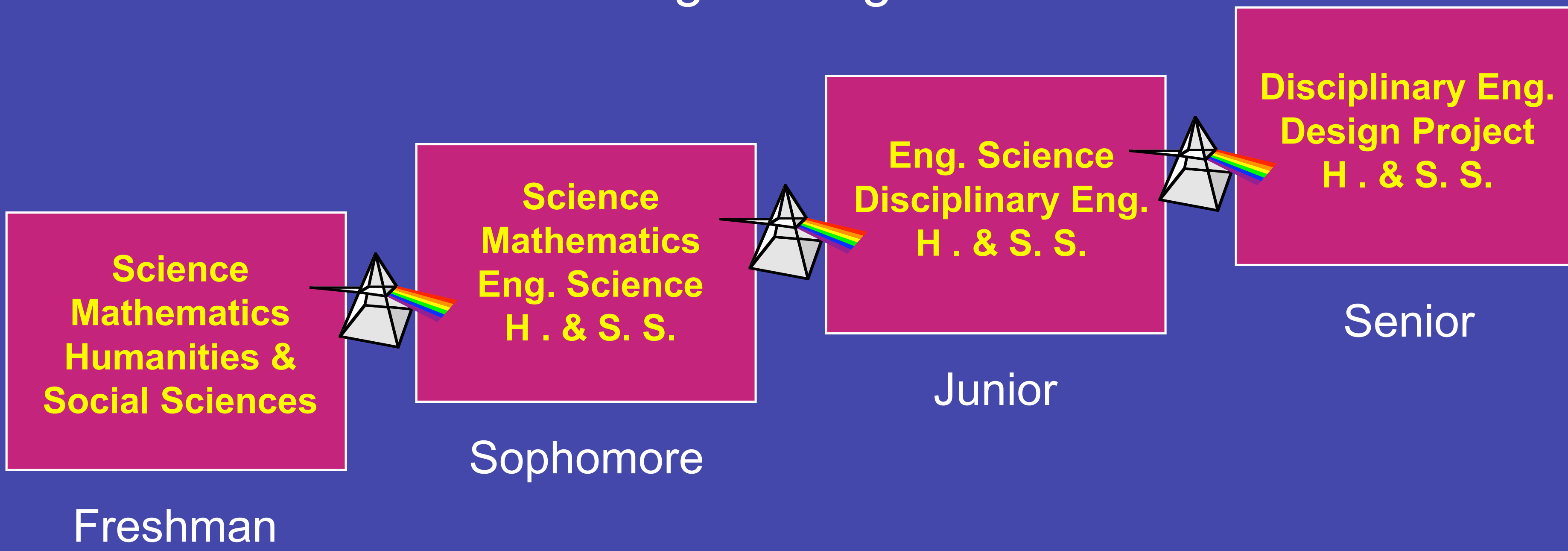
Challenges
for the 21st Century

Traditional Engineering Education

- Highly sequential, a pyramid of prerequisites
- Highly specialized within majors
- Little flexibility (few free electives)
- Stress scientific analysis rather than design and synthesis
- Too much technical content at the expense of a broader, liberal education

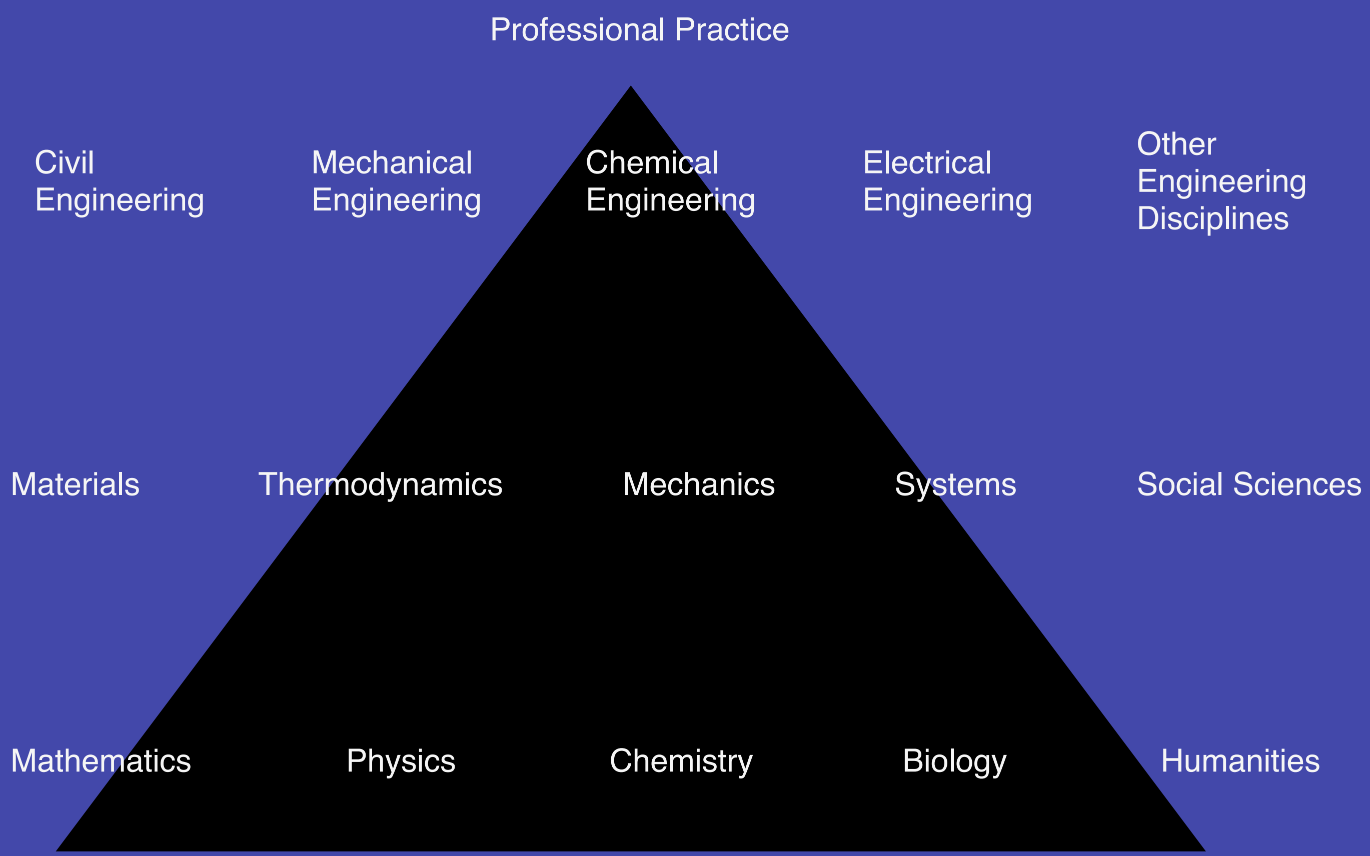
Traditional Undergraduate Curriculum

Passing Through Filters



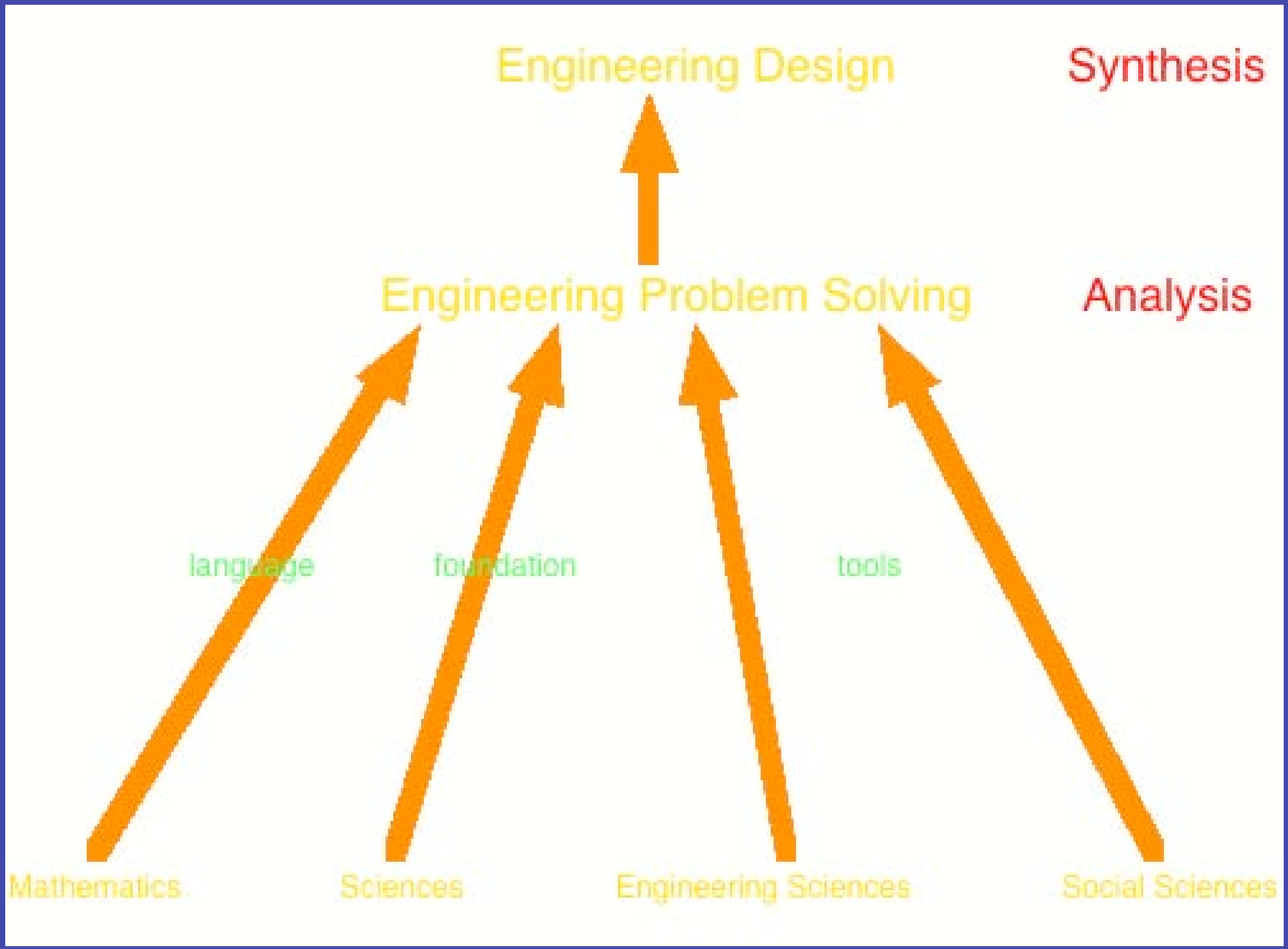
Bordogna, NSF

An Engineering Education



The Education Pyramid

The Engineering Curriculum



Some Concerns

Engineering as a profession is changing rapidly. While engineers are expected to be well-grounded in the fundamentals of science and mathematics, they are increasingly expected to acquire skills in communication, teamwork, adaptation to change, and social and environmental consciousness.

Most engineering graduates today will find themselves in technical careers for only a short time, if at all. The increasing importance of technology to our world has made an engineering degree an excellent preparation for many other careers and professions: business, law, medicine, teaching, government service, even politics.

The current engineering curriculum provides students with little appreciation for the vast range of careers that will be open to them. Indeed, because of the early focus on science and mathematics, students really do not learn much about the engineering profession until late in their studies (if then).

The Challenges

An engineering career typically lasts 35 to 40 years. Yet the value of professional engineering expertise depreciates rapidly in many areas, so that obsolescence may become a serious problem as soon as 3 to 7 years after completion of formal education.

In the average engineering project, the first 10% of the decisions (which do not involve engineering) commit 90% of the resources (which do involve engineering).

Engineering is the only profession for which a four-year program is all that is required for professional status. There is a concern that engineers will be technicians in the future, in the service of better educated and prepared leadership drawn from other professions.

A lifetime for learning...

We have to start with the fact that engineering students are not super people who can learn all then need during four years in college. Nor need they.

Getting the full array of technical and contextual knowledge that they will need is a lifetime goal.

Their four years of engineering education can only be the initial launch for such a career.

But it has to be a well-planned, precision launch that will keep the student's career "in orbit" for a lifetime.

Why Change?

- Intelligence technology offers greater creative opportunity; ability to work smarter.
- Global workplace demands multi-cultural skills; expanding social infrastructure needs talent for complexity.
- Massively-integrated populations place environment, health, and safety at front end of design.
- Eclectic, constantly changing work environment calls for astute interpersonal skills.
- Changing demographics; success in serving a diverse customer base requires a diverse workforce.

What do employers want?

- Graduates who can communicate well.
- Graduates who can appreciate diversity.
- Graduates who are committed to a lifetime of learning.
- Graduates who not only can tolerate change but can drive change.

Some Observations about Education

Peter Drucker: “We will redefine what it means to be an educated person. Traditionally an educated person was someone who had a prescribed stock of formal knowledge. Increasingly, an educated person will be someone who has learned how to learn, and who continues learning throughout his or her lifetime.”

Ancient Chinese proverb:

I hear, and I forget.

I see, and I remember.

I do, and I understand!

A 21st Century World

Information Explosion

Global Economy

Cognitive Revolution

International Competition

Diverse Workforce

Finite Resources

Defense Reinvestment

Environmental Sustainability

Shared Wealth

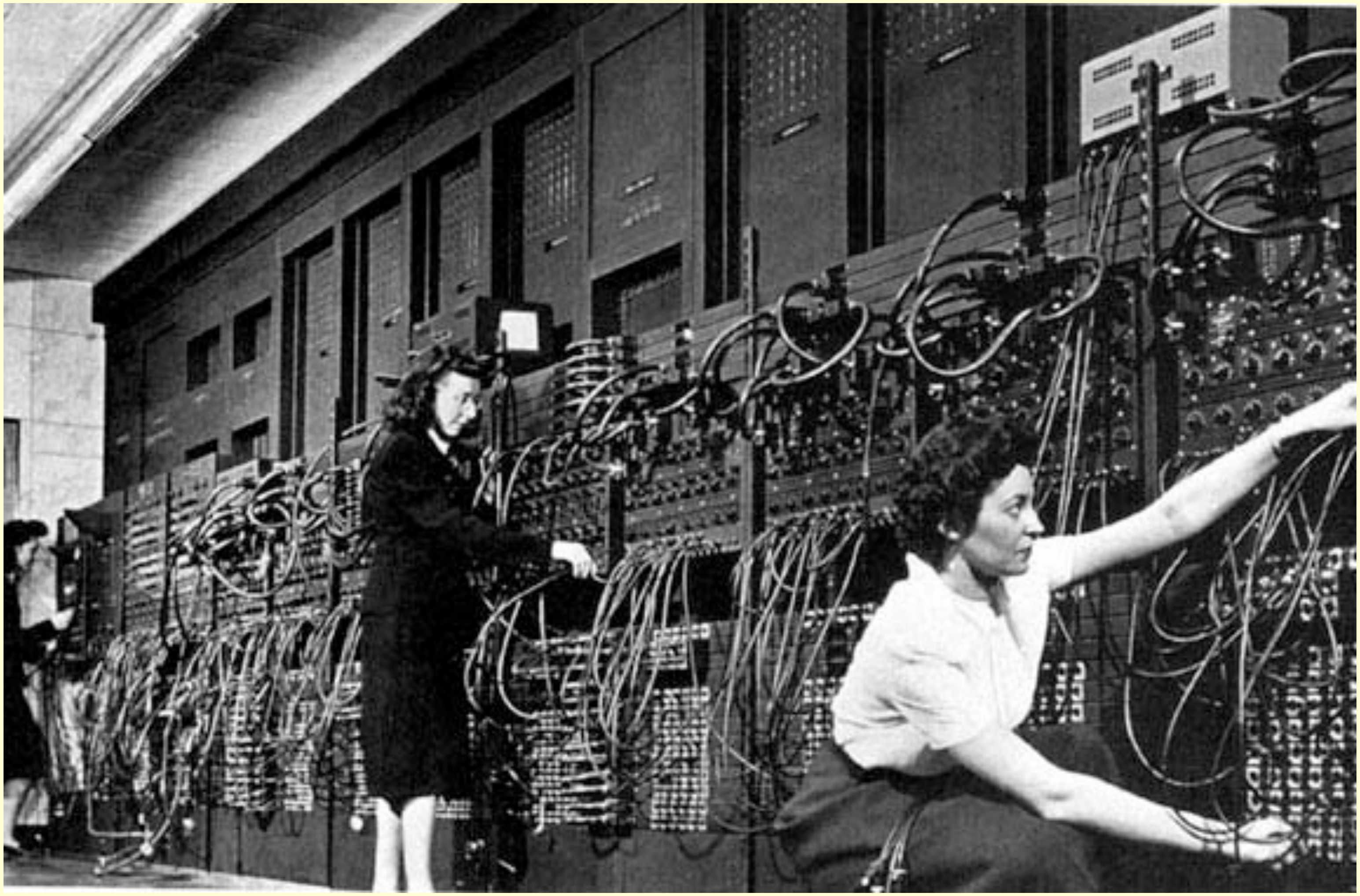
Dual Use

Demographic Shifts

Bordogna, NSF

Information Technology

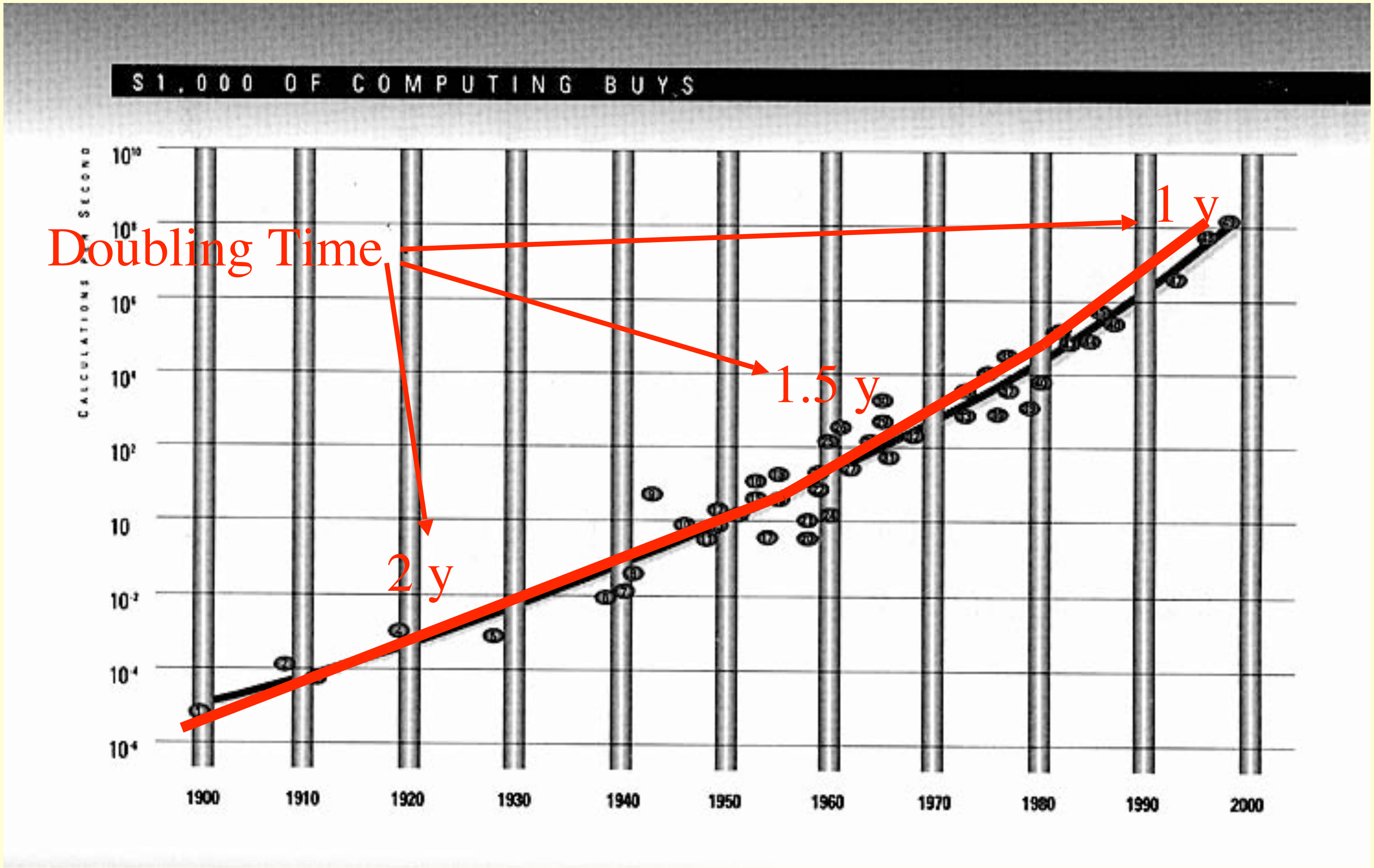
From Eniac



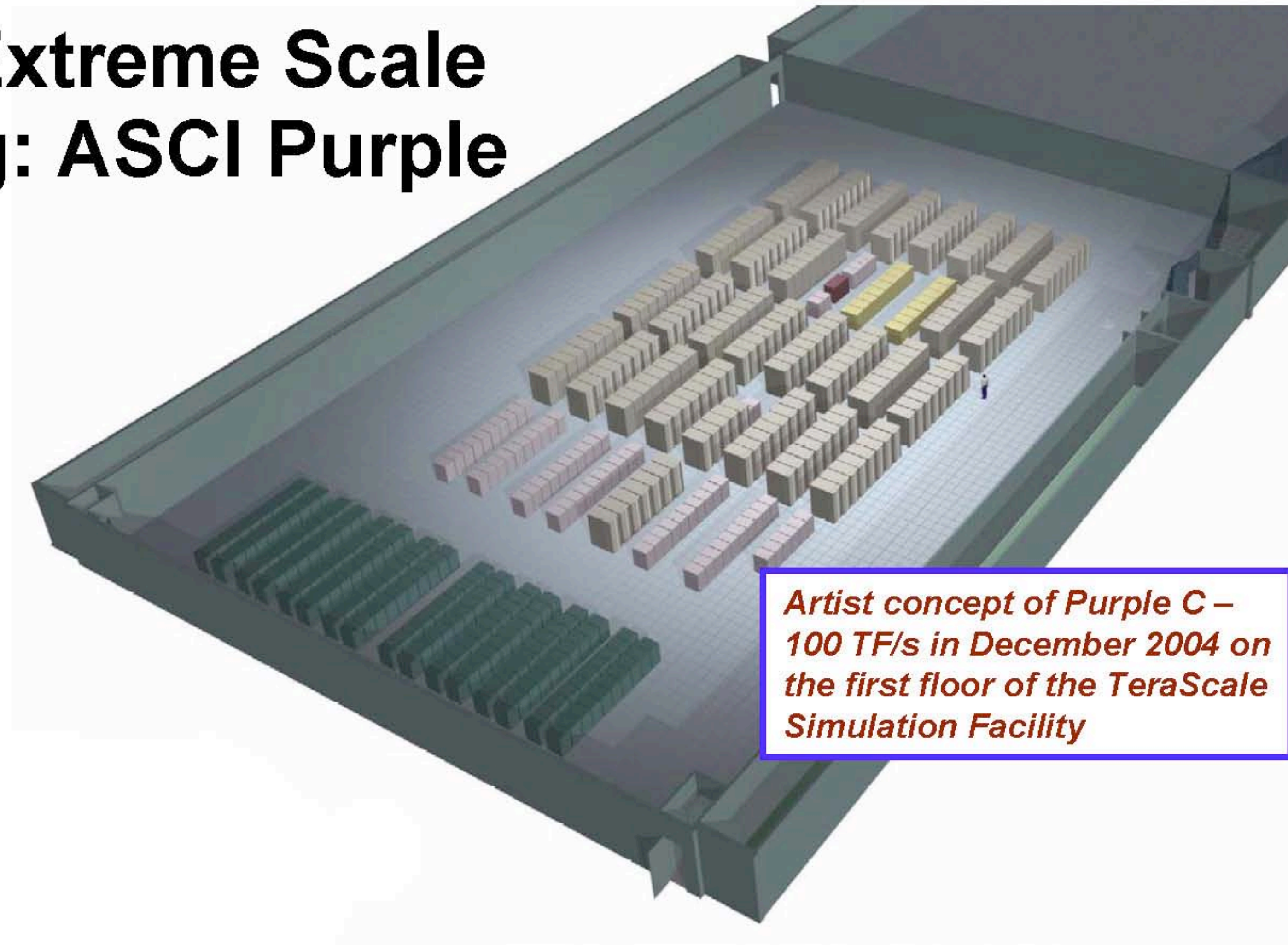
To ASCI "Q" … and beyond

Japan Earth Simulator

The Evolution of Computing



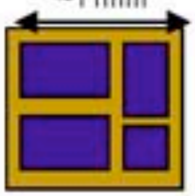
Defining Extreme Scale Computing: ASCI Purple



Artist concept of Purple C – 100 TF/s in December 2004 on the first floor of the TeraScale Simulation Facility

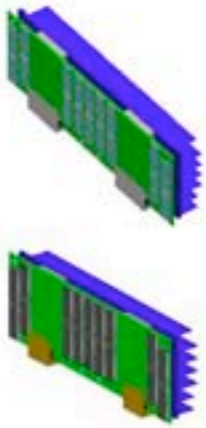
*Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

Building BlueGene/L



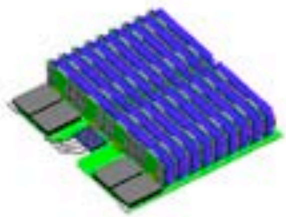
Compute Chip

2 processors
2.8/5.6 GF/s
4 MiB* eDRAM



Compute Card
I/O Card

FRU (field replacable unit)
25mmx32mm
2 nodes (4 CPUs)
(2x1x1)
2.8/5.6 GF/s
256/512 MiB* DDR
15 W



Node Card

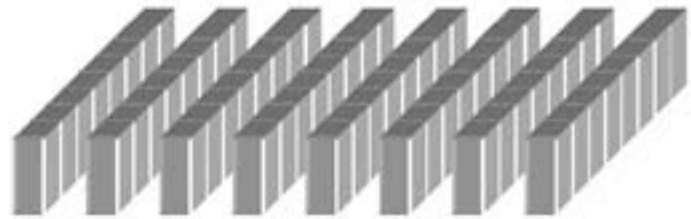
16 compute cards
0-2 I/O cards
32 nodes
(64 CPUs)
(4x4x2)
90/180 GF/s
8 GiB* DDR

Midplane

SU (scalable unit)
16 node boards
512 nodes
(1,024 CPUs)
(8x8x8)
1.4/2.9 TF/s
128 GiB* DDR
7-10 kW

Cabinet

2 midplanes
1024 nodes
(2,048 CPUs)
(8x8x16)
2.9/5.7 TF/s
256 GiB* DDR
15-20 kW



System

64 cabinets
65,536 nodes
(131,072 CPUs)
(32x32x64)
180/360 TF/s
16 TiB*
1.2 MW
2500 sq.ft.

(compare this with a 1988 Cray YMP/8 at 2.7 GF/s)

* http://physics.nist.gov/cuu/Units/binary.html

ASCI Purple (2004):

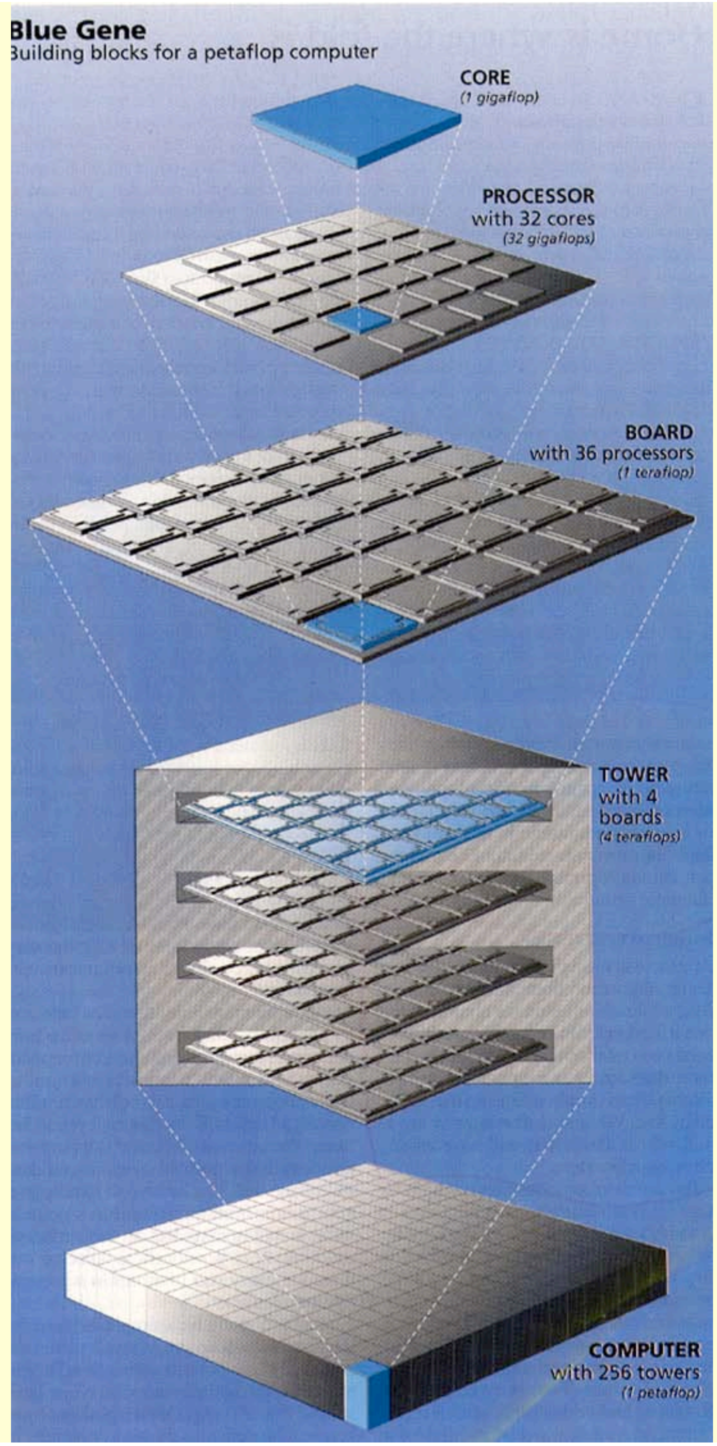
100 TeraFlops

IBM Blue Gene L (2004):

360 TeraFlops

IBM Blue Gene P (2006):

"Several" PetaFlops




No
Stopping
Parking
Loading Or
Unloading
Along
Curve Or
Roadway
P.D.Q.
53'
PDQ

Computer-Mediated Human Interaction

- **1-D (words)**
  - Text, e-mail, chatrooms, IM, telephony
- **2-D (images)**
  - Graphics, video, WWW, multimedia
- **3-D (environments)**
  - Virtual reality, distributed virtual environments
  - Immersive simulations, avatars
  - Virtual communities and organizations
- **And beyond… (experiences, "sim-stim")**
  - Telepresence
  - Neural implants

Evolution of the Net

- Already beyond human comprehension
- Incorporates ideas and mediates interactions among millions of people
- 500 million today; more than 1 billion in 2010
- Internet II, National Lamba Rail, TeraGrid
- Semantic Web, Executable Internet, Web Services, Cyberinfrastructure

Another Way to Look at It …

A "communications" technology that is increasing in power by a factor of 1,000 every decade will soon allow any degree of fidelity that one wishes. All of the senses will be capable of being reproduced at a distance … sight, sound, touch, taste, smell … through intelligence interfaces.

At some point, we will see a merging of

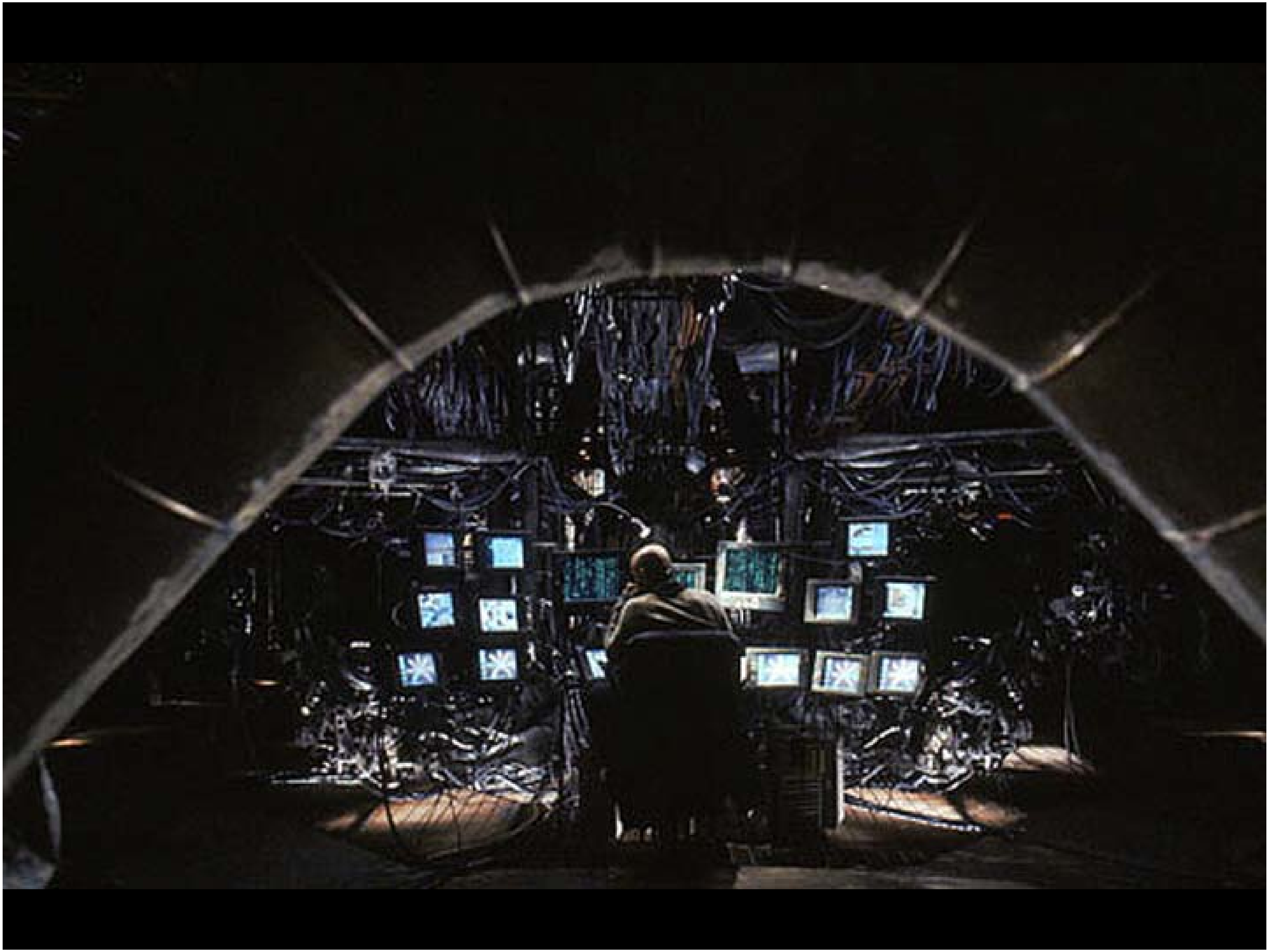
…natural and artificial intelligence

…reality and virtual reality

…carbon and silicon …

Some Other Possibilities

- **Ubiquitous computing?**
  - Computers disappear (just as electricity)
  - Calm technology, bodynets
- **Agents and avatars?**
  - Fusing together physical space and cyberspace
  - Plugging the nervous system into the Net
- **Emergent behavior?**
  - … Self organization
  - … Learning capacity
  - … Consciousness (HAL 9000)

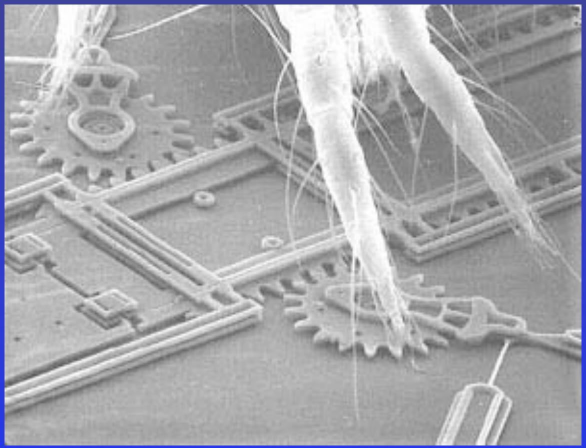


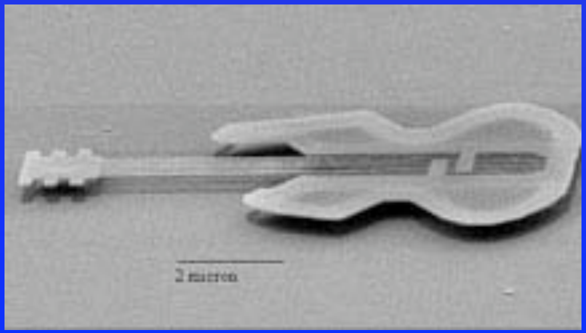
Nanotechnology

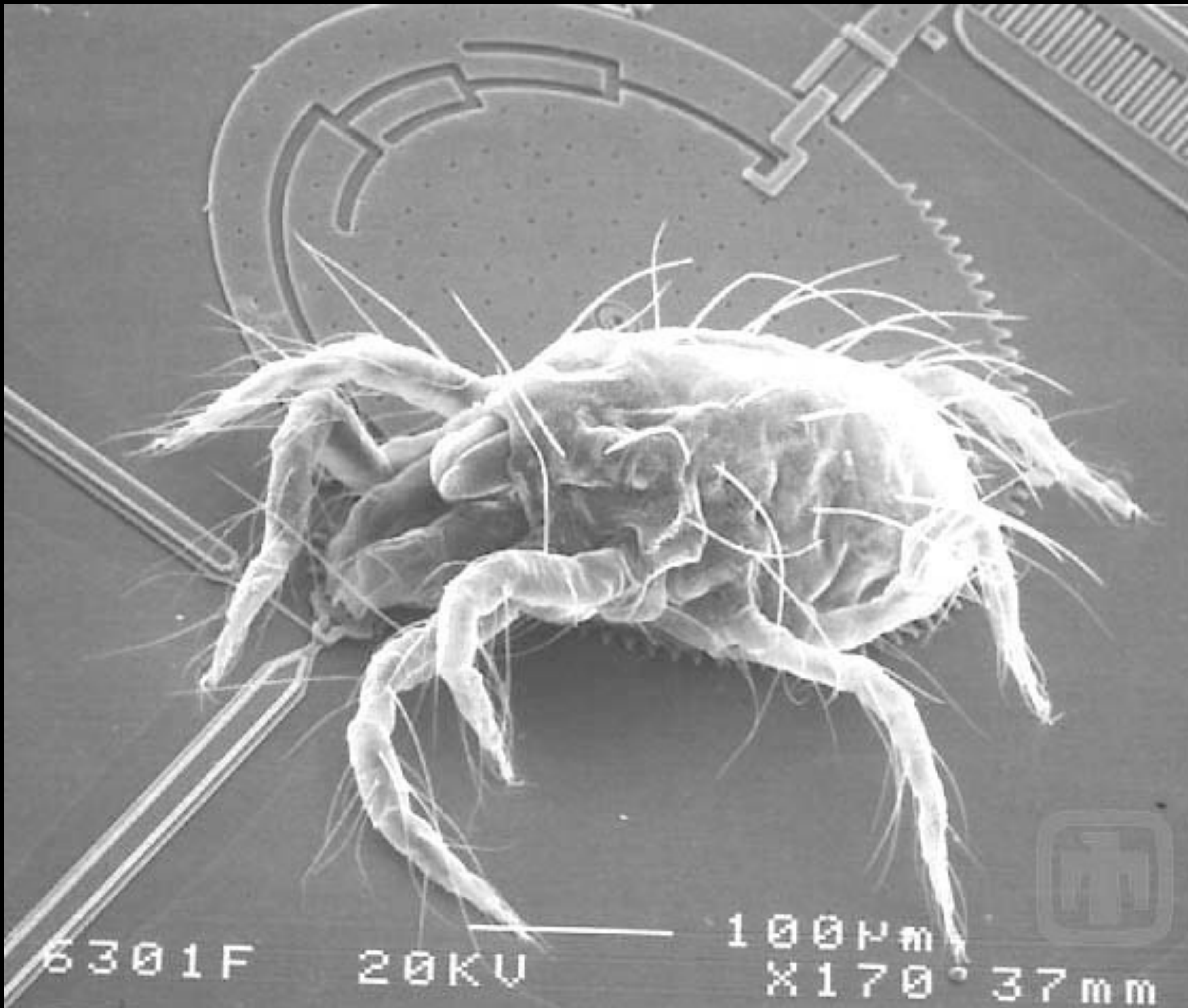
MEMS

MEMS: Micro electromechanical machines

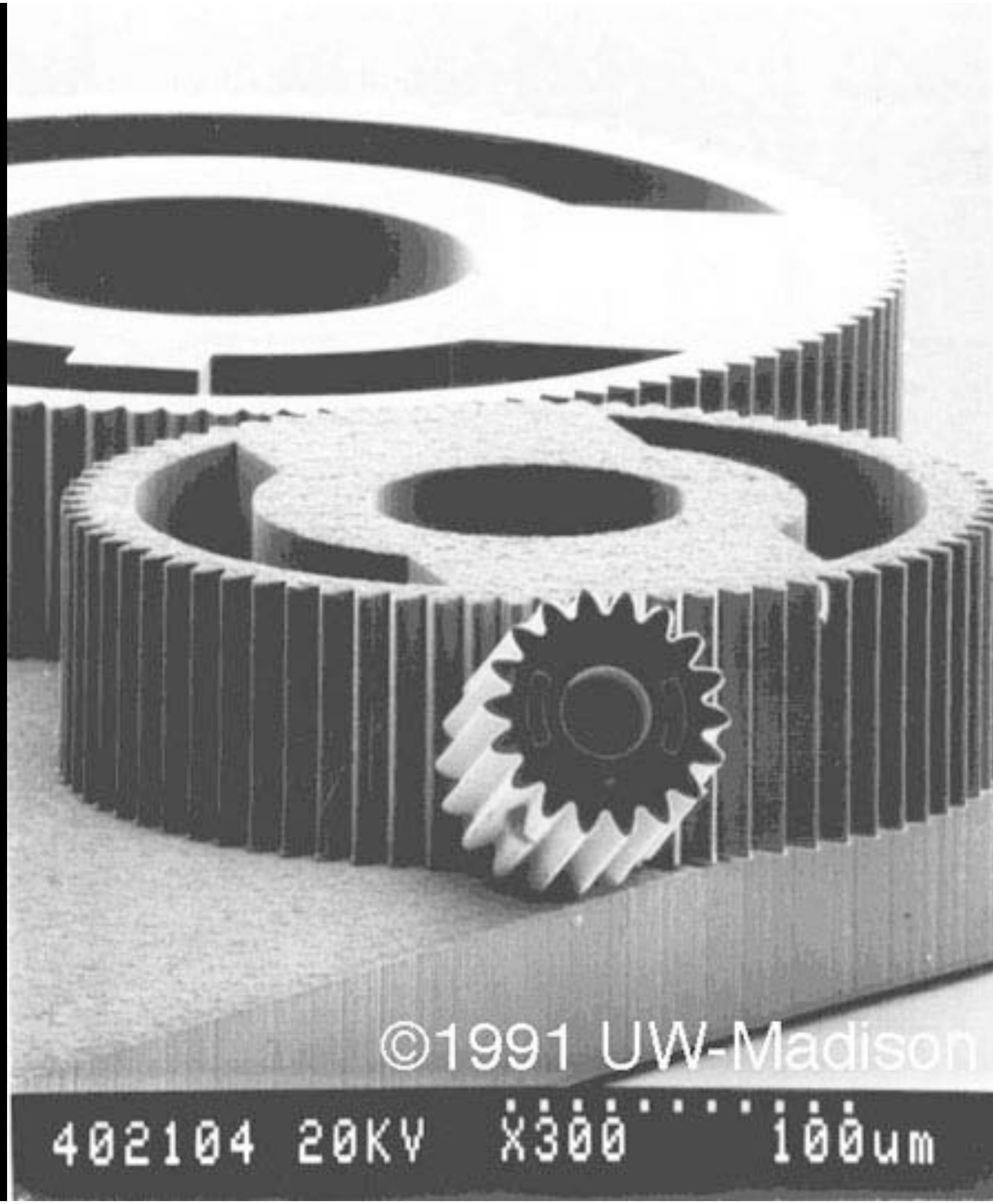
Engineers have developed the capacity to fabricate microscopic gears, machines, and motors out of silicon, much as they do electronic circuits. These are typically of submicron size.

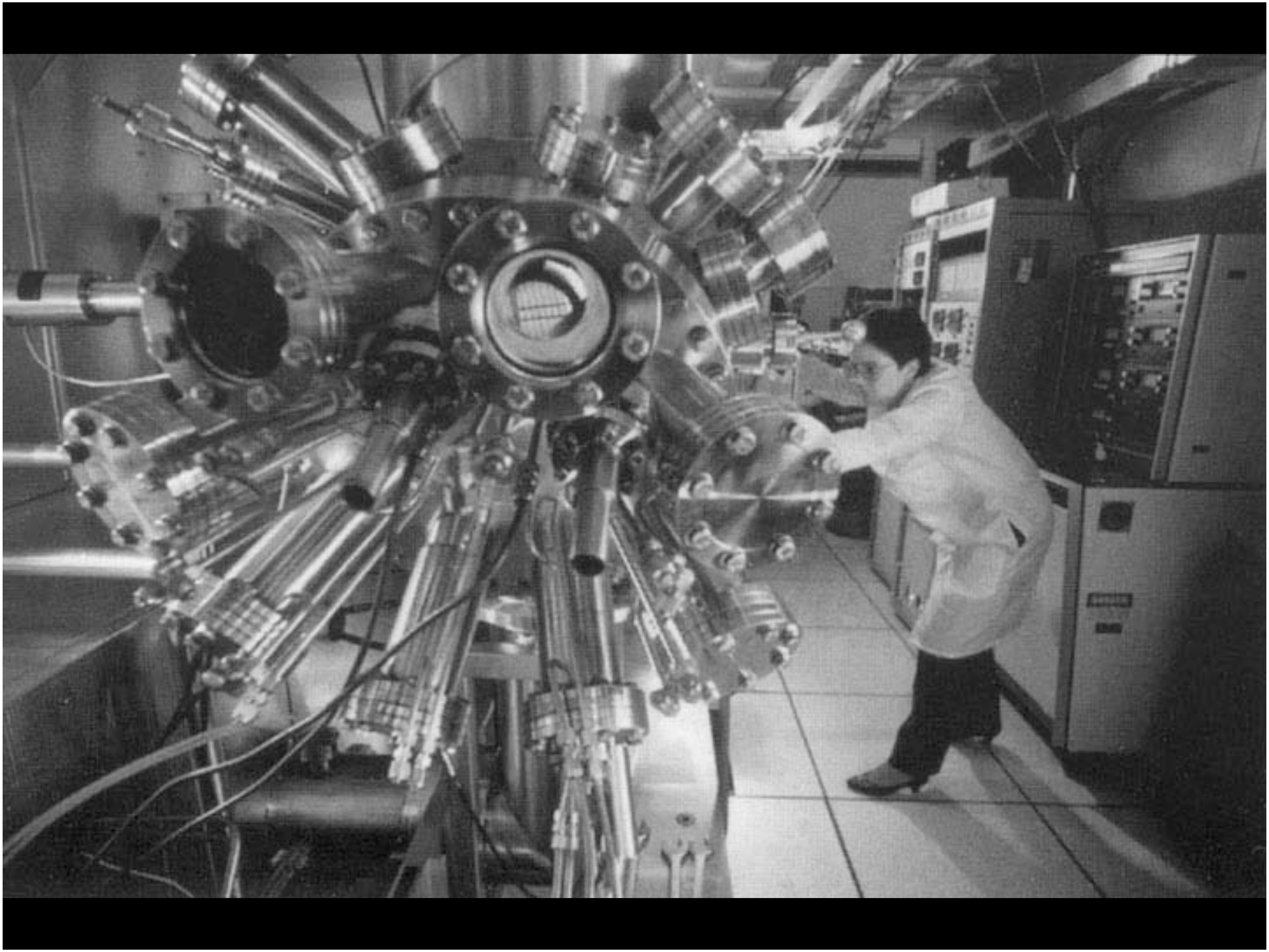




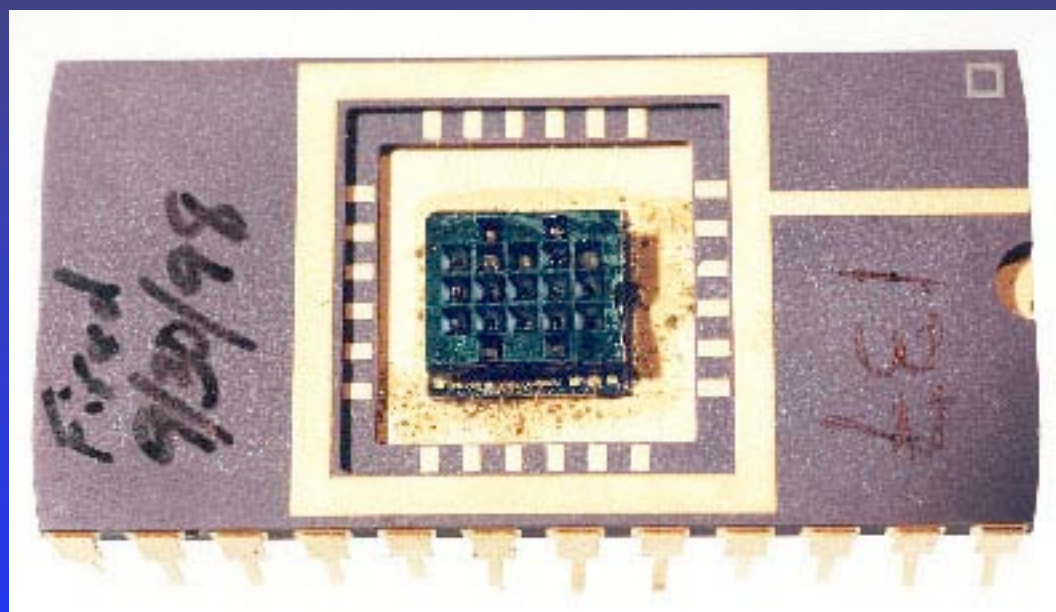


100µm
6301F 20KV X170 37mm


©1991 UW-Madison
402104 20KV X300 100um



MEMS Micropropulsion



A digital propulsion “rocket chip” contains 15 individual thrusters in the central 3x5 array. The diverzing nozzles are fed by cylindrical chambers filled with led styphnate and ignited by polysilicon resistors.

Nanotechnology

Nanotechnology is the creation of functional materials, devices, and systems through control of matter on the nanometer length scale and exploitation of novel phenomena and properties (physical, chemical, biological) at that length scale.

Note: Several length scales

MEMS: micro electromechanical systems

Molecular nanotechnology

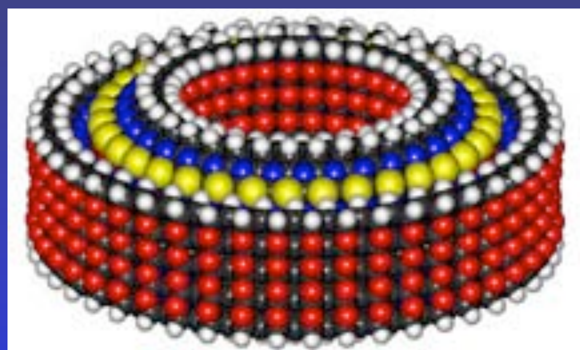
NEMS: nano electronmechanical systems

Nano Tools

Screw and bearing

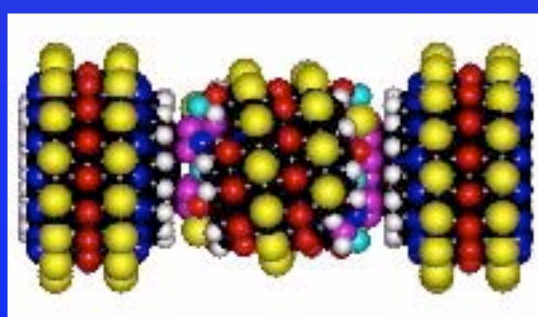
Atomic construction

Molecular Nanomachines



Bearing

A differential gear



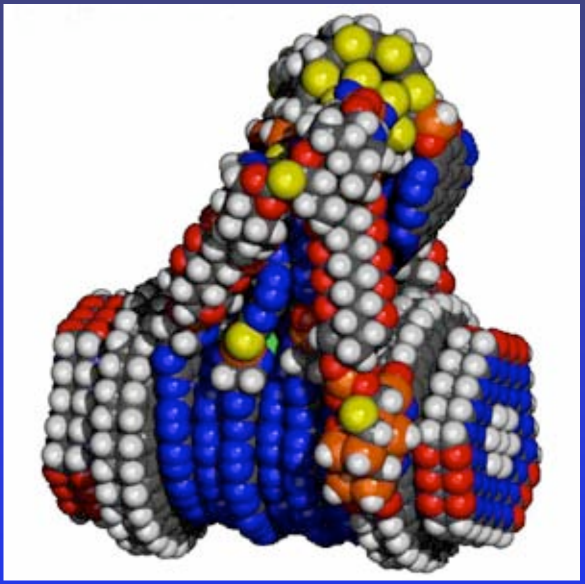
Pump

A planetary gear

Nano Assemblers

These second generation nanomachines will do all that protein machine can do and more. They will be able to bond atoms together in virtually any stable pattern, adding a few at a time to the surface of a workpiece until a complex structure is complete.

Think of such nanomachines as assemblers.



Nano Assembler
(Stewart Platform)

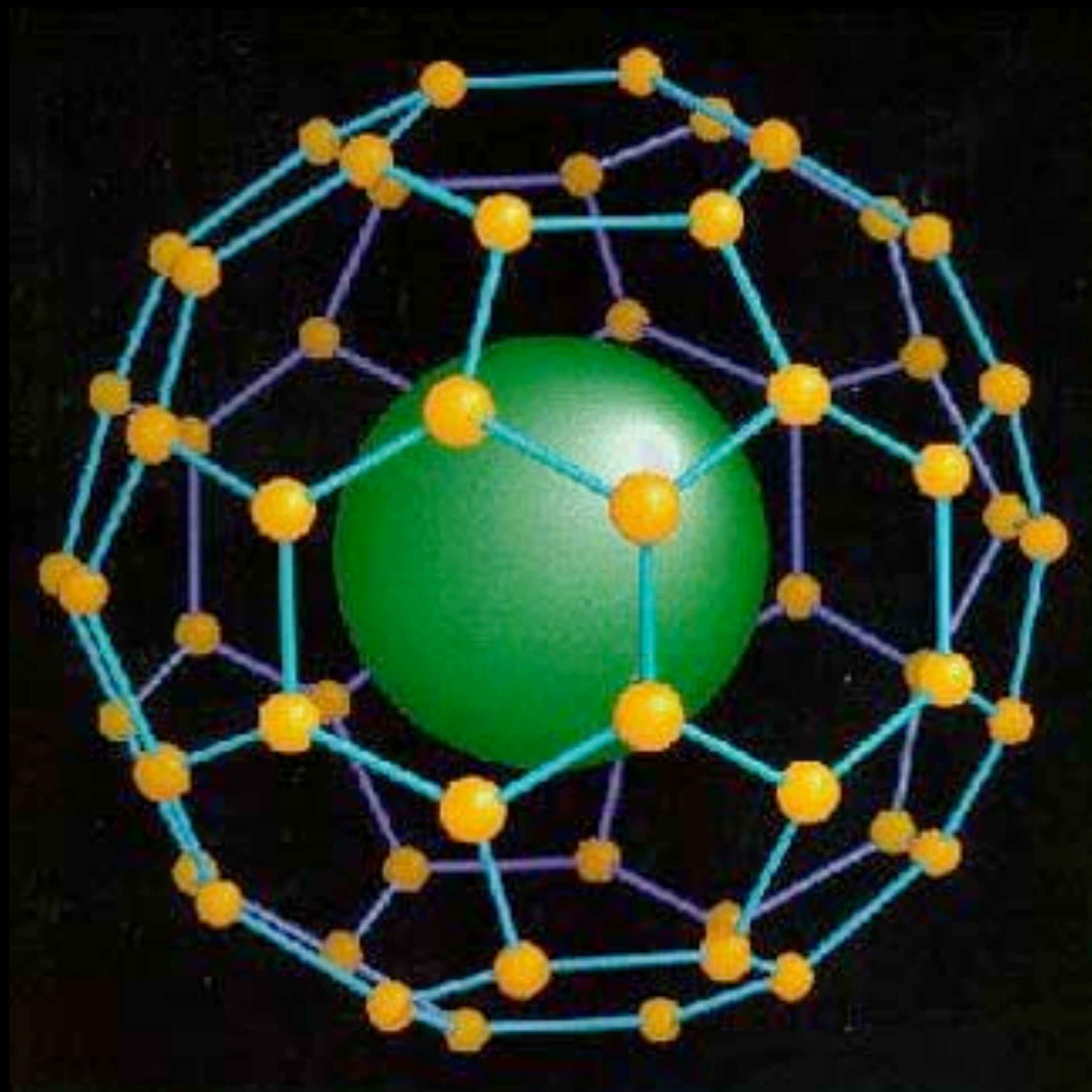
Universal Assemblers

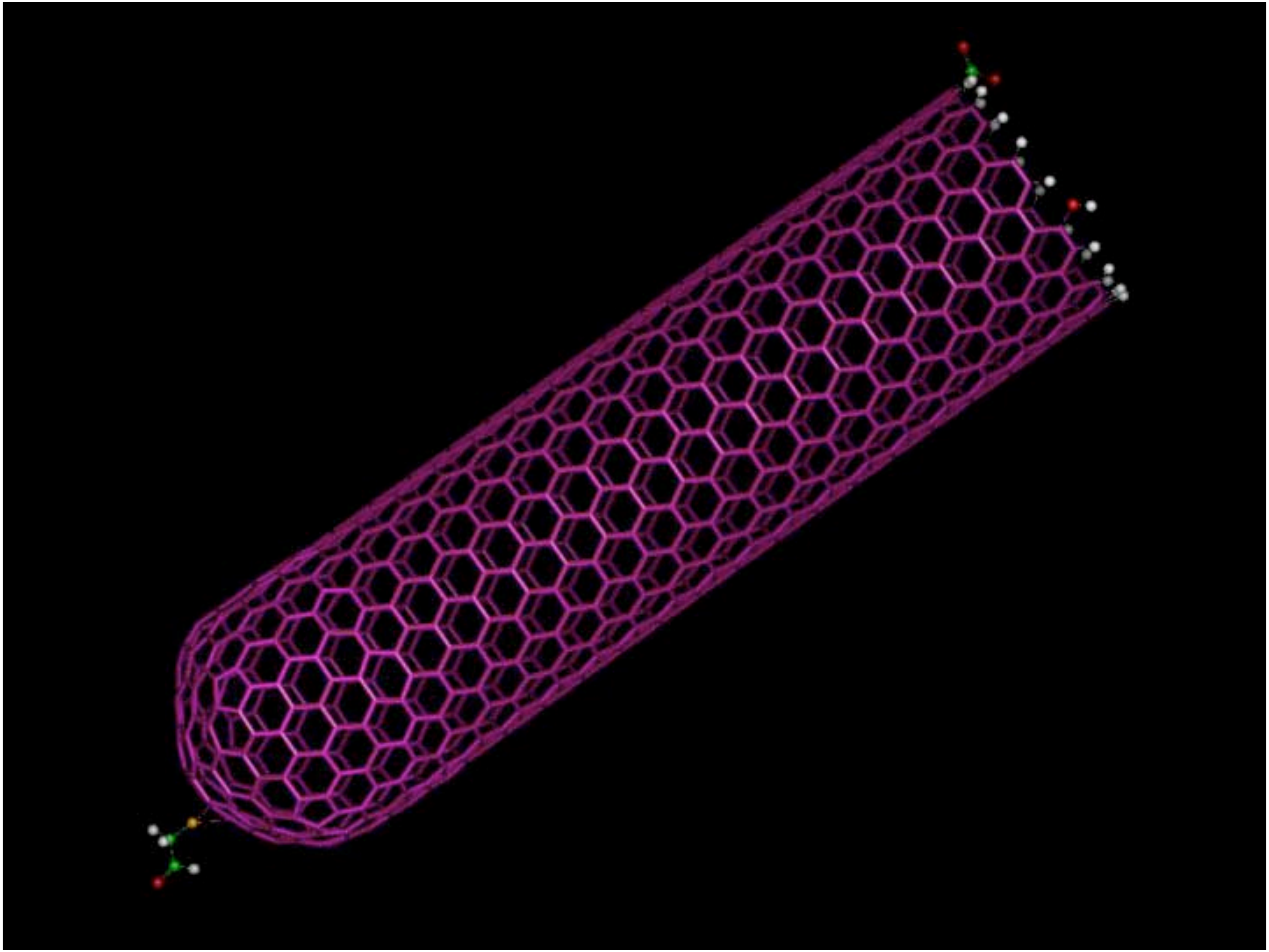
Because assemblers will let us place atoms in almost any reasonable arrangements, they will let us build almost anything that the laws of nature allow to exist.

In particular, they will let us build almost anything we can design, including more assemblers.

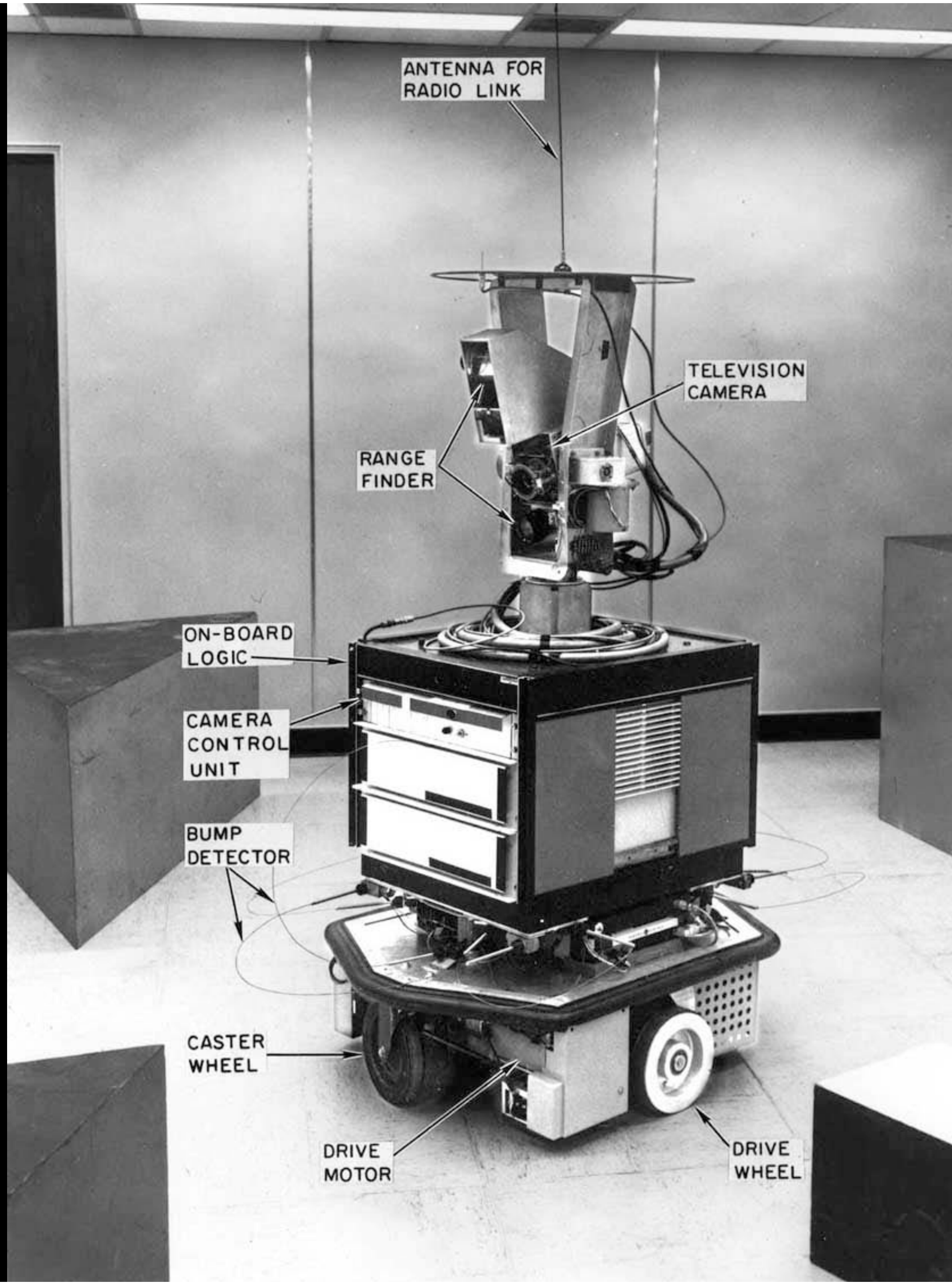
The consequences of this will be profound, because our crude tools have let us explore only a small part of the range of possibilities that natural law permits. Assemblers will open up a world of new technologies.

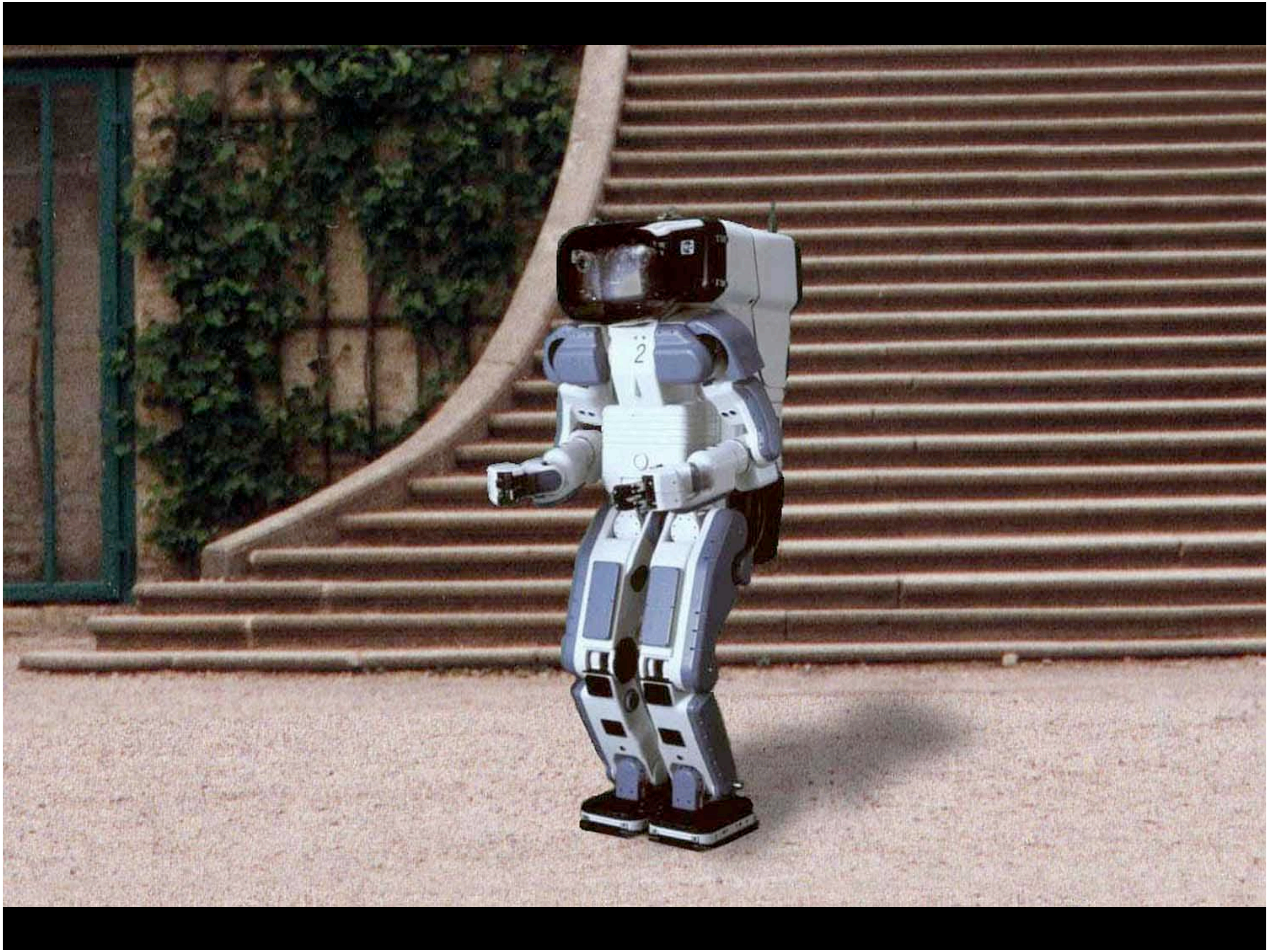
Advances in the technologies of medicine, space, computation, and production–and warfare–all depend on our ability to arrange atoms. With assemblers, we will be able to remake our world or destroy it.





Robots


ANTENNA FOR RADIO LINK
TELEVISION CAMERA
RANGE FINDER
ON-BOARD LOGIC
CAMERA CONTROL UNIT
BUMP DETECTOR
CASTER WHEEL
DRIVE MOTOR
DRIVE WHEEL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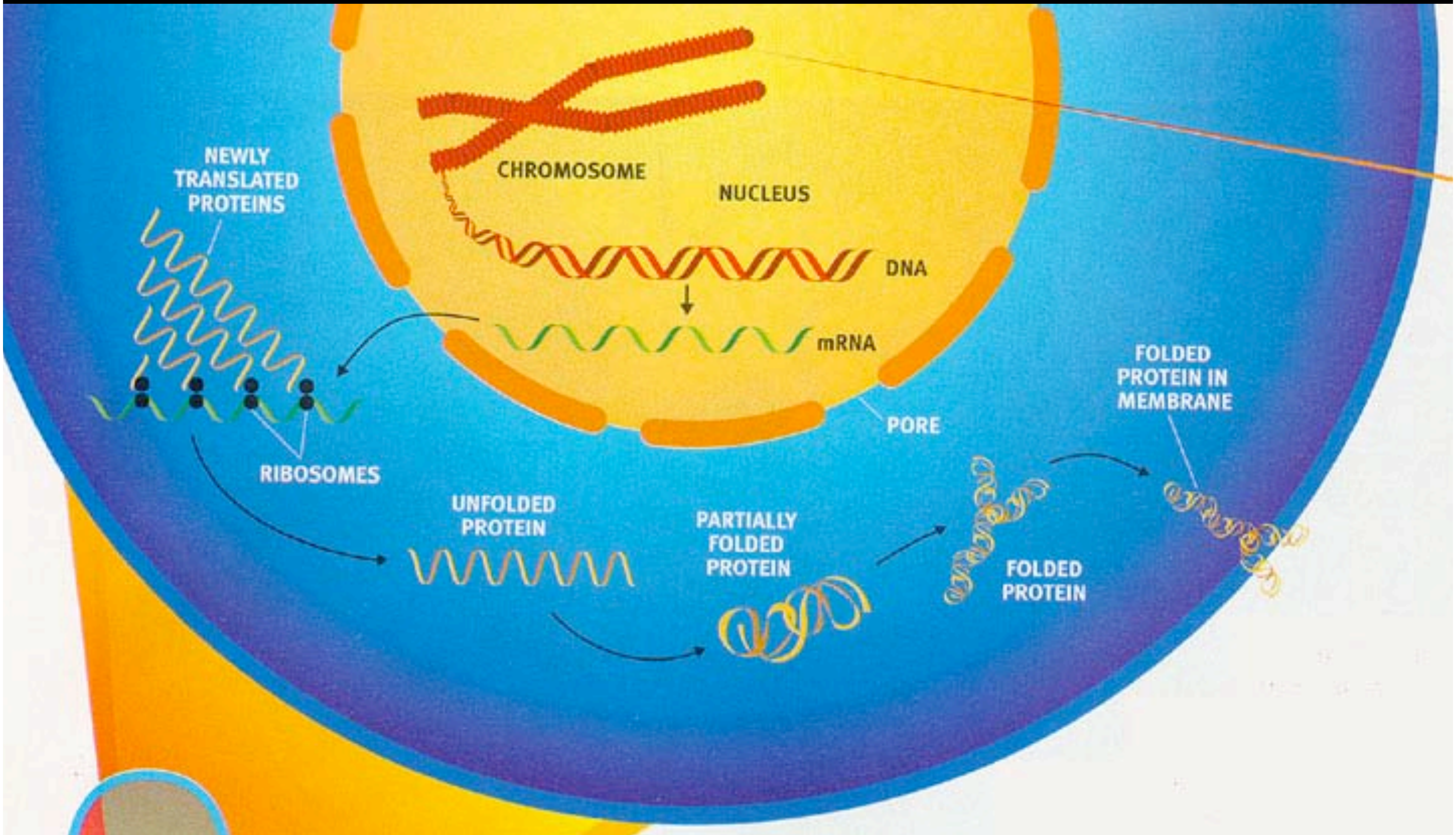
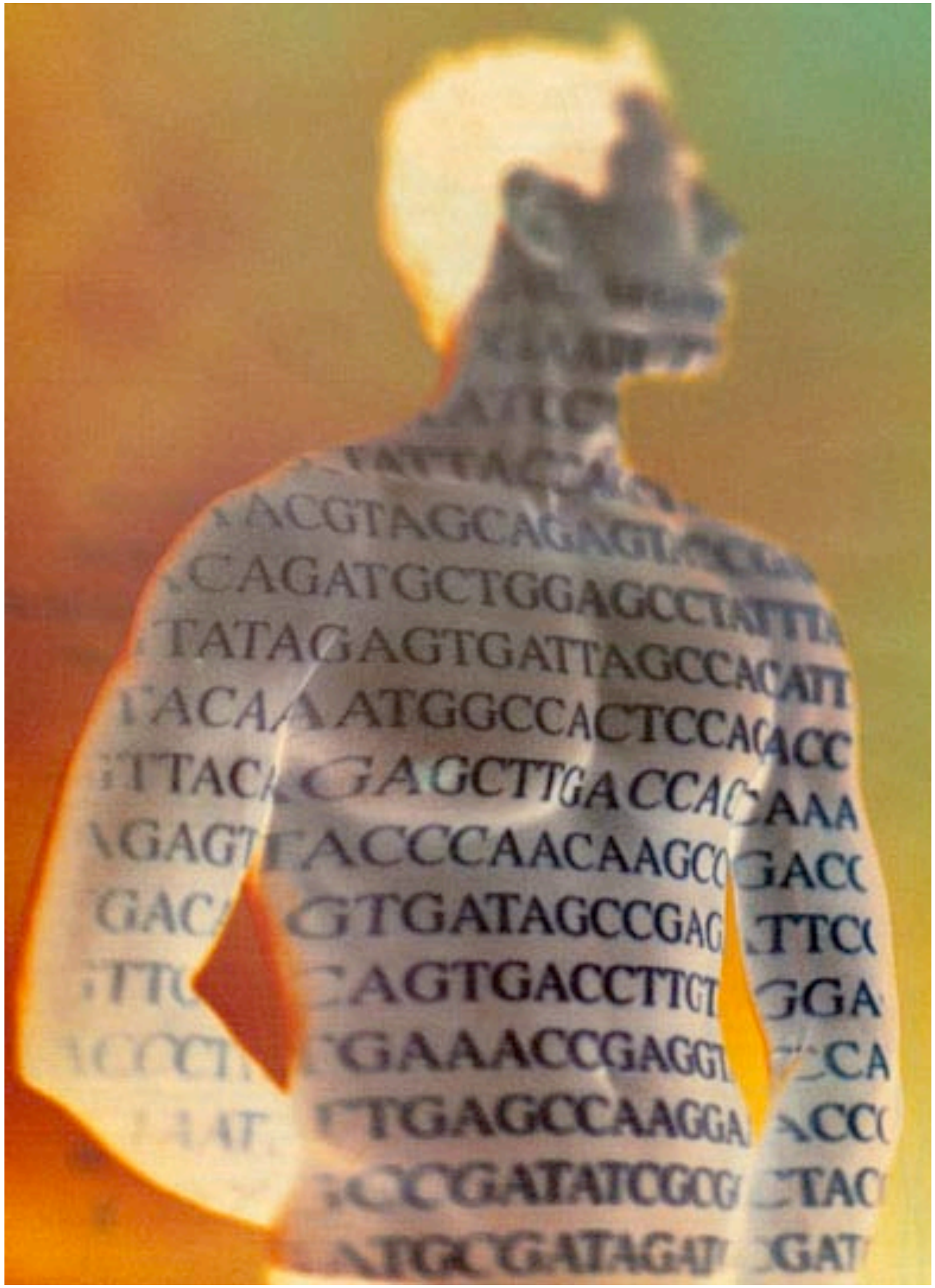
TERMINATOR 2
JUDGMENT DAY

Biotechnology


CHROMOSOME
NUCLEUS
DNA
mRNA
NEWLY TRANSLATED PROTEINS
RIBOSOMES
PORE
FOLDED PROTEIN IN MEMBRANE
UNFOLDED PROTEIN
PARTIALLY FOLDED PROTEIN
FOLDED PROTEIN



The Human Genome Project

"The human genome project is about deciphering the twenty-four human chromosomes. And by deciphering, we mean a number of things.

There are three billion letters in the DNA language. There are twenty-four human chromosomes. There are a hundred or so different human genes. And, of course, the human genome is probably the most incredible software program that has ever been written.

Here is a program that dictates and directs the development of the most fascinating of all processes, starting with a single cells, the fertilized egg, and going to ten to the fourteenth cells in a developed human organism--and being able to carry out the chromosomal choreography that specifies for each of the different cell types the right subset of those hundred thousand genes that have to be uniquely expressed."

Leroy Hood

Cloning

Cloning or nuclear transfer is an asexual way of reproducing an animal. Rather than using a sperm and an egg cell and getting a genetic mix between two animals, making a unique offspring, coning uses an egg cell which is stripped by its DNA and a cell from the body of an existing animal. That body (somatic) cell is then placed into the egg cell.

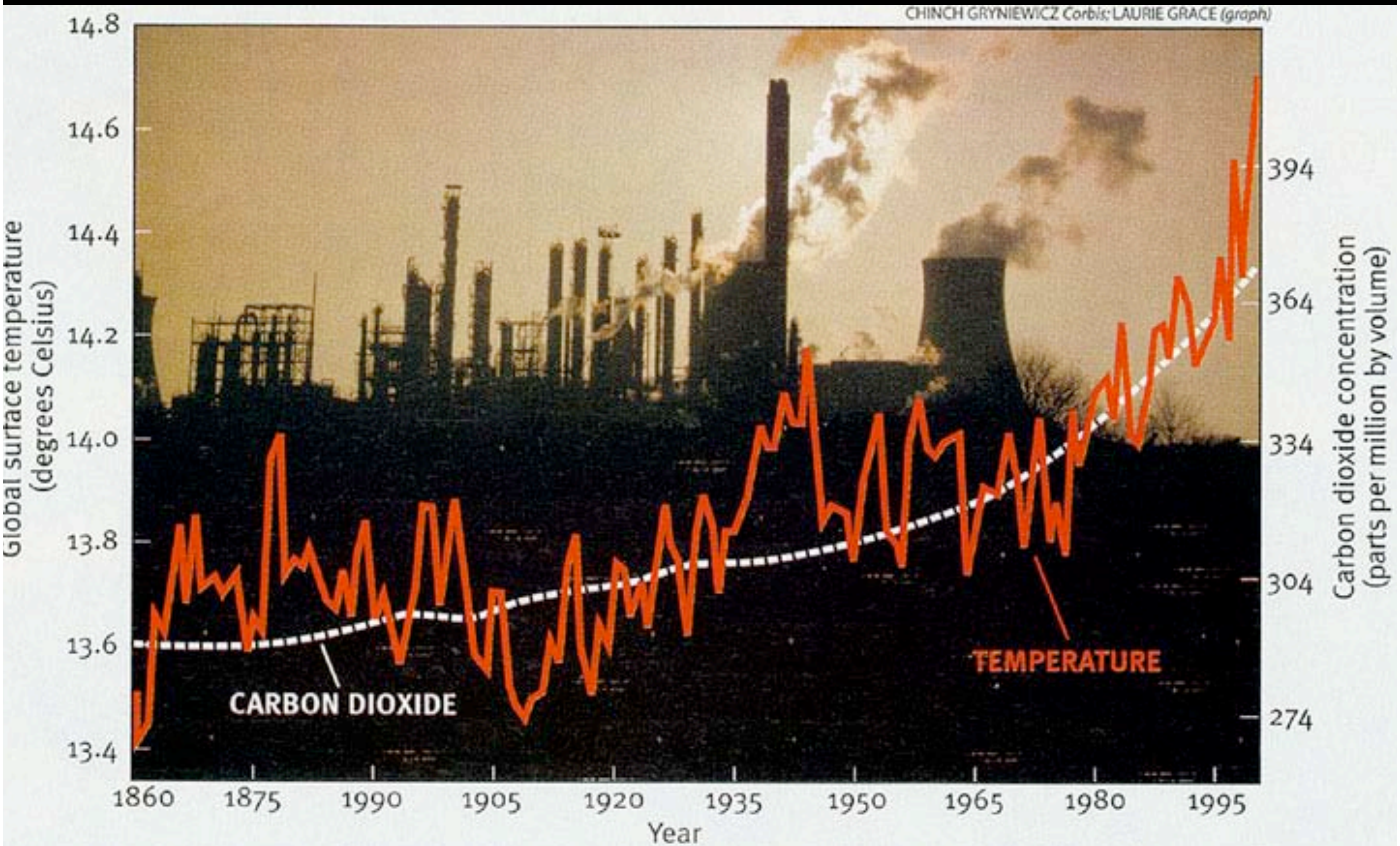
Note that cloning results in the creation of an embryo without sexual reproduction. As a result, the cloned species is genetically identical to the donor.

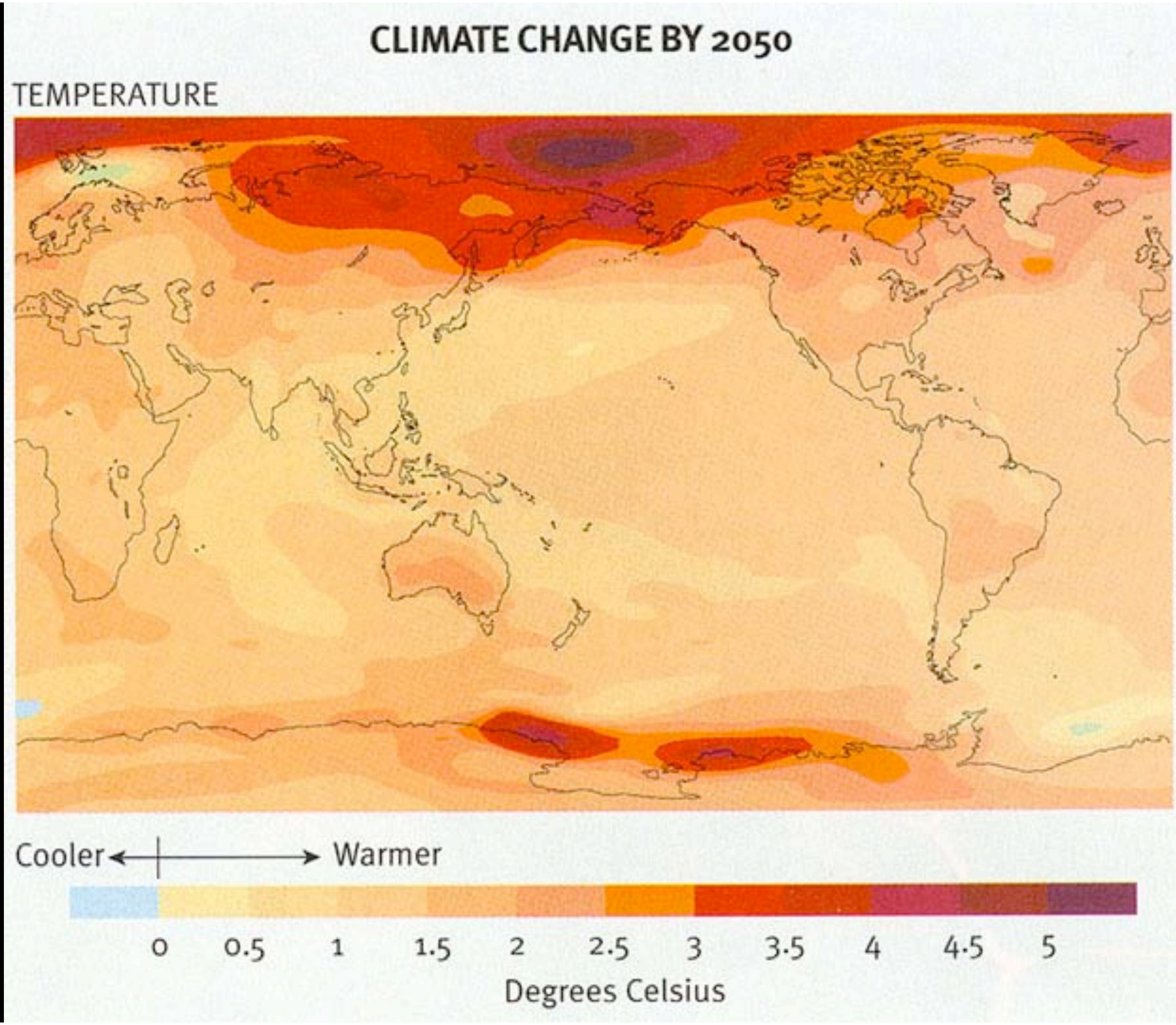
Human Genetic Engineering

Somatic manipulation seeks to change the genetic makeup of particular body (somatic) cells that comprise the organs and tissues (lungs, brain, bones, etc.) of a single person. For example, human gene therapy might cure diseases such as cystic fibrosis by inserting a corrective gene into malfunction lung cells. Changes in somatic genes are not passed on to one's children.

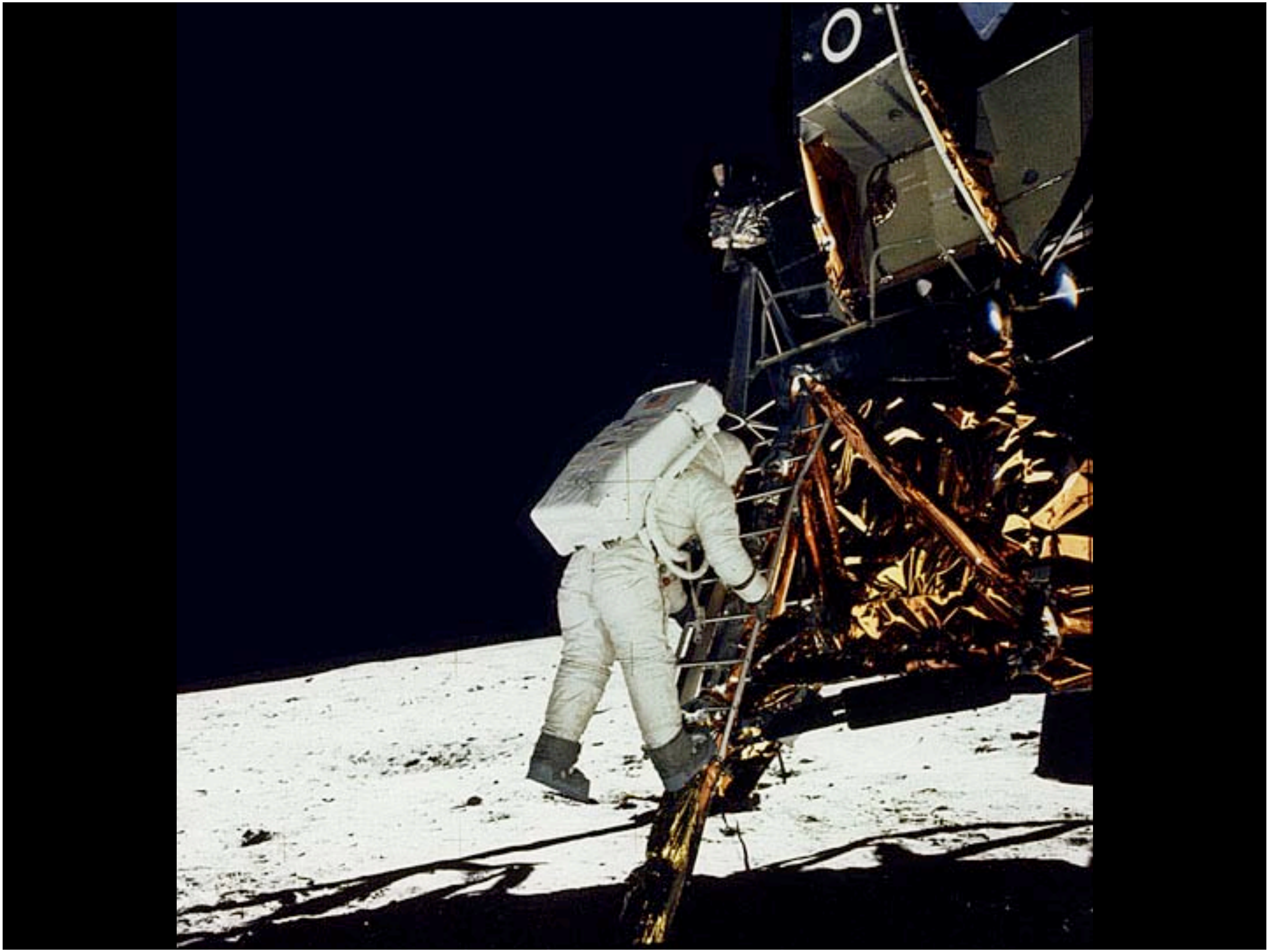
Germline genetic manipulation changes the sex cells (I.e., the sperm and egg, or germ, cells), which pass the parental genes to the next generation. While germline engineering is sometimes suggested as a way to prevent transmission of genetic diseases, the same result can be achieve by preimplanation screening and other means. Germline engineering is necessary, however, to go beyond disease prevention and modify the genetic endowment of children otherwise expected to be healthy. Modifications would be passed along to future generations.

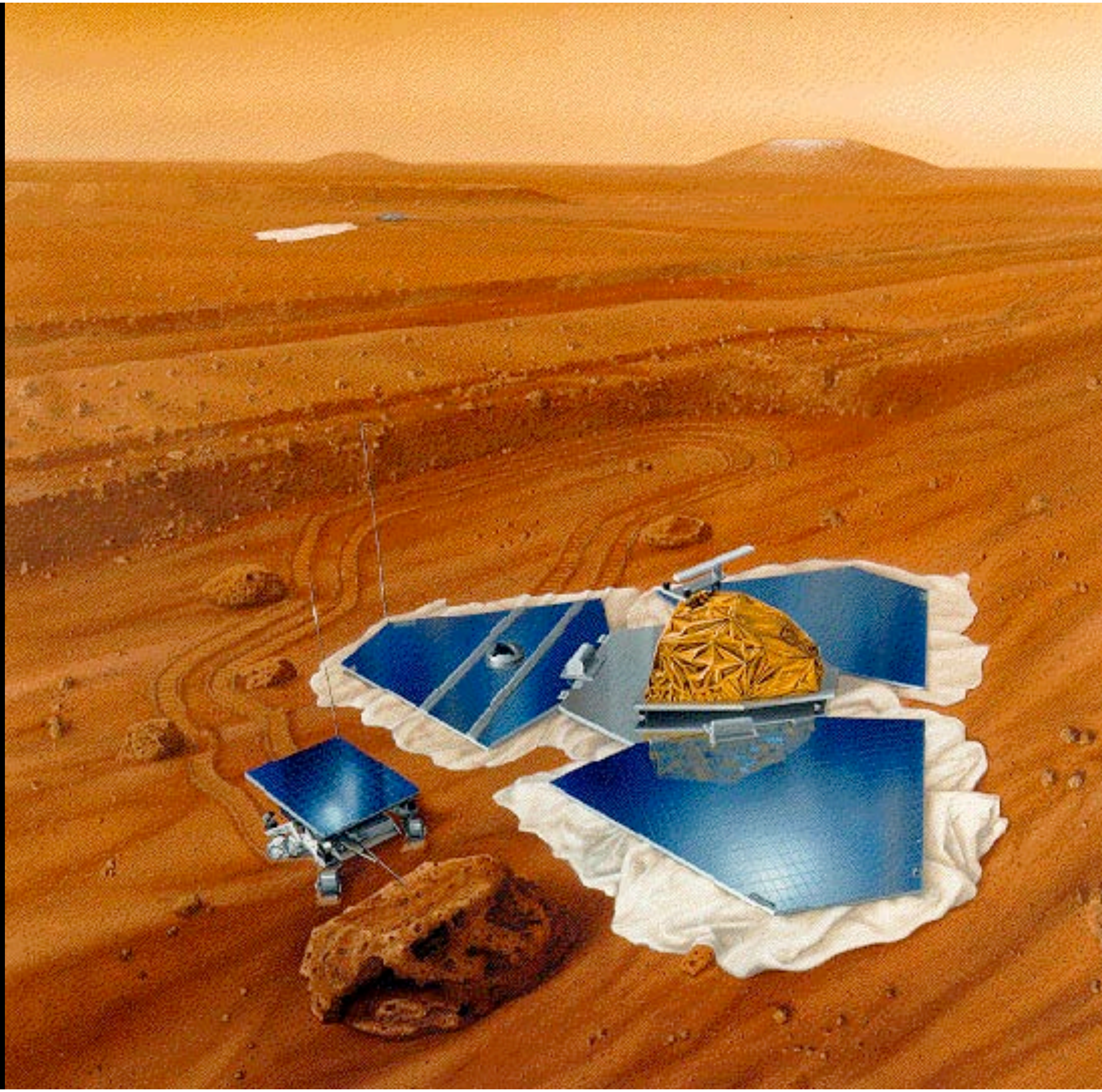
Global Change

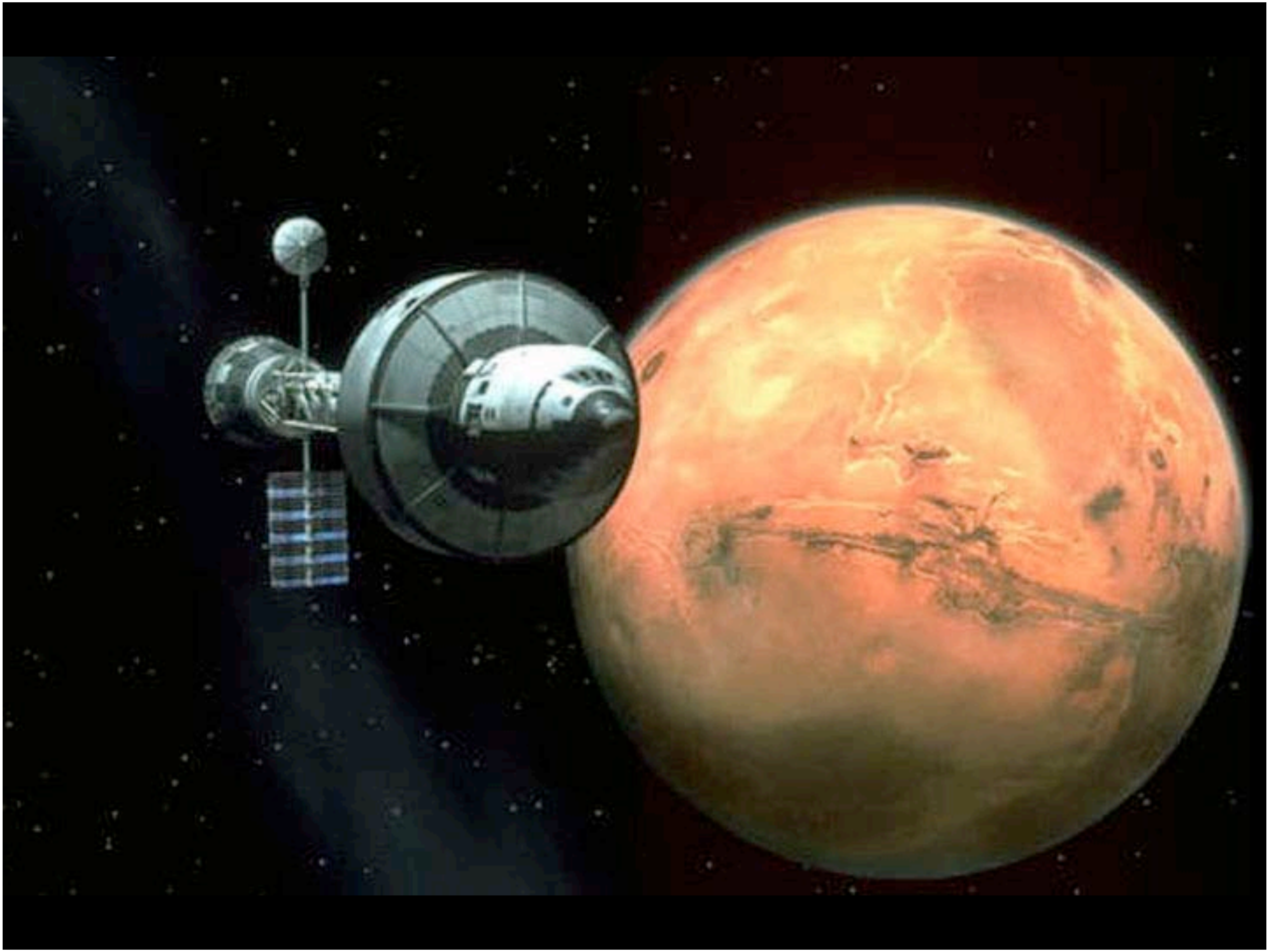

CHINCH GRYNIEWICZ Corbis; LAURIE GRACE (graph)
Global surface temperature (degrees Celsius)
14.8
14.6
14.4
14.2
14.0
13.8
13.6
13.4
Carbon dioxide concentration (parts per million by volume)
394
364
334
304
274
CARBON DIOXIDE
TEMPERATURE
1860
1875
1990
1905
1920
1935
1950
1965
1980
1995
Year

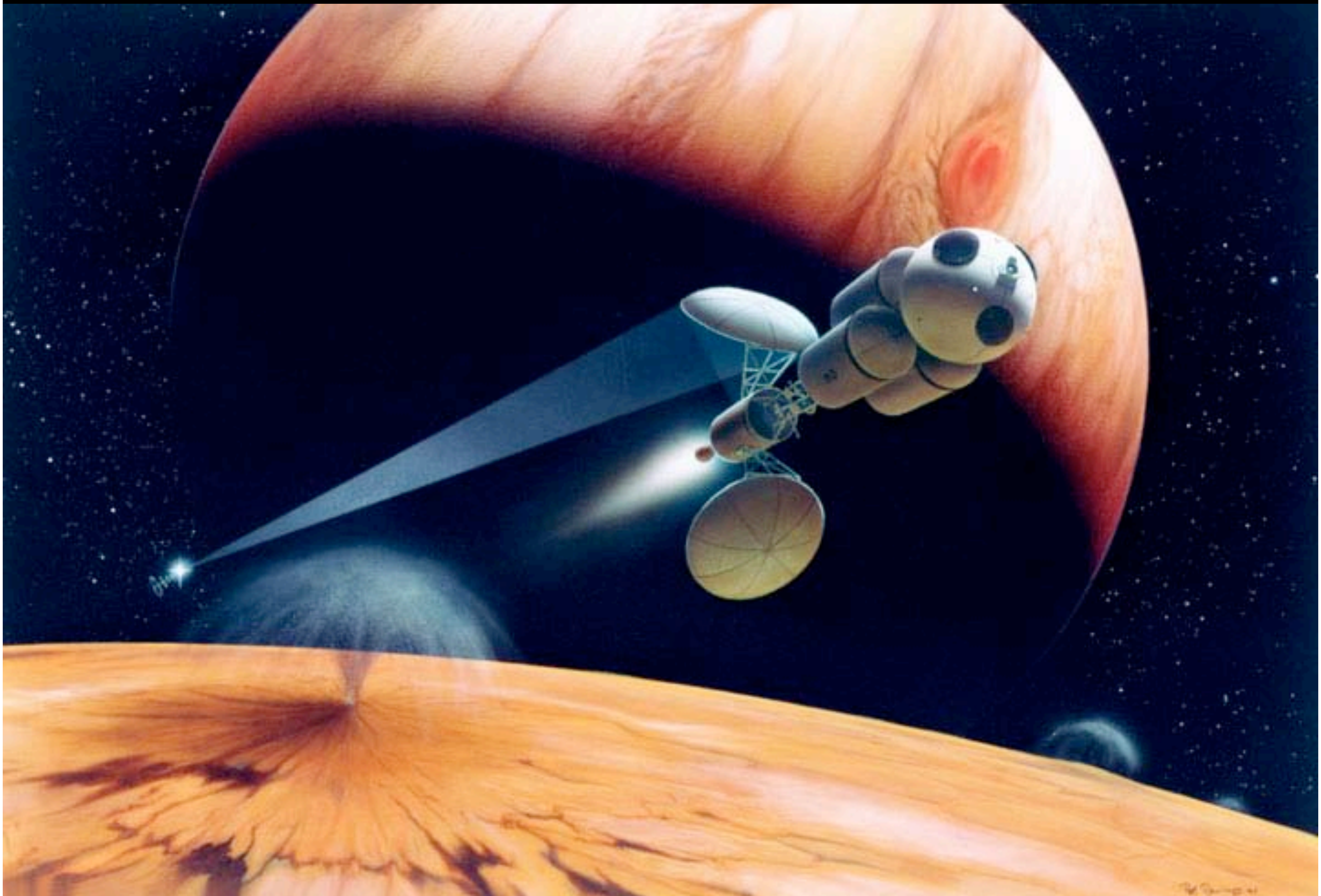

CLIMATE CHANGE BY 2050
TEMPERATURE
Cooler
Warmer
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Degrees Celsius

Space Exploration

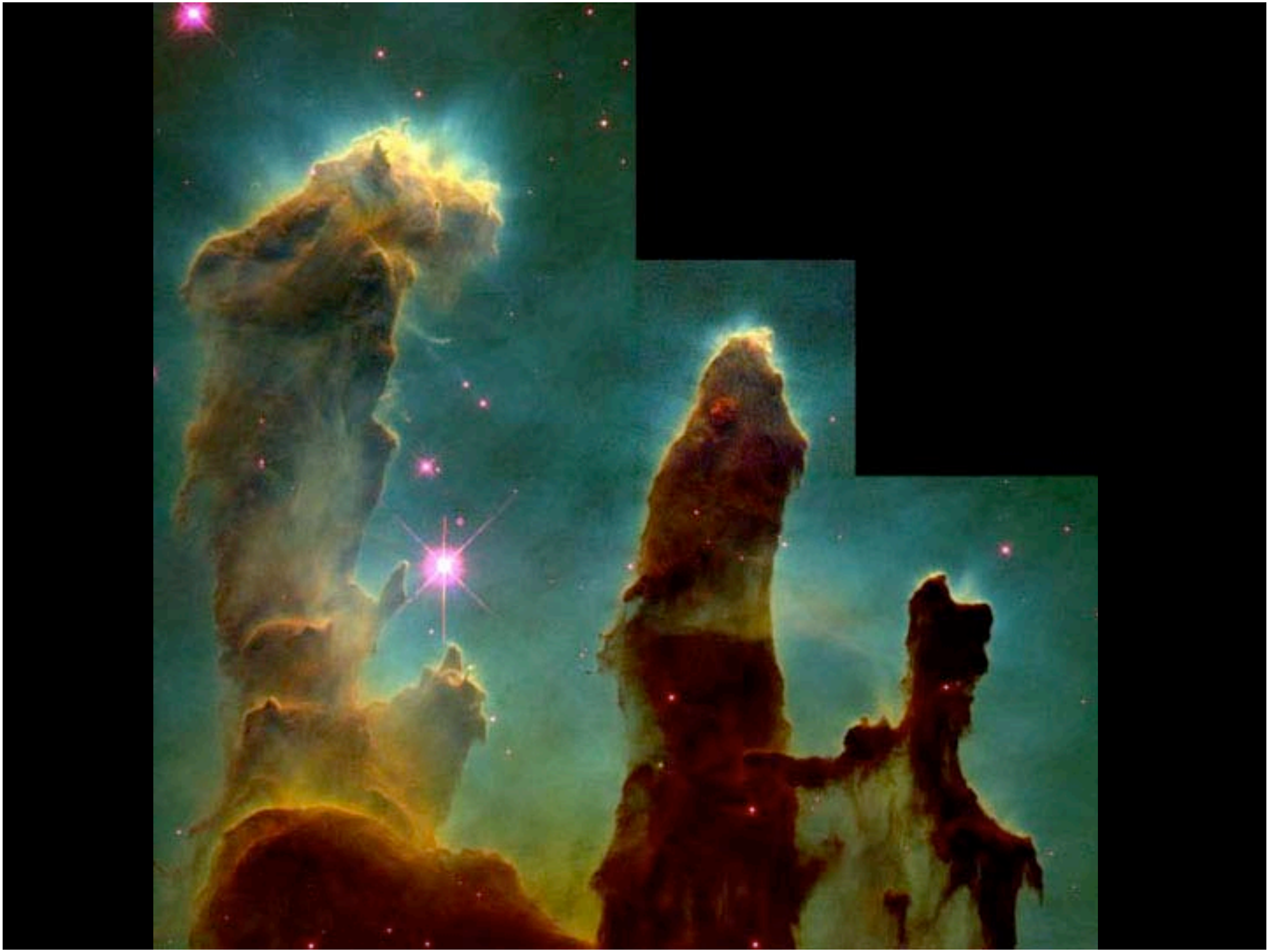


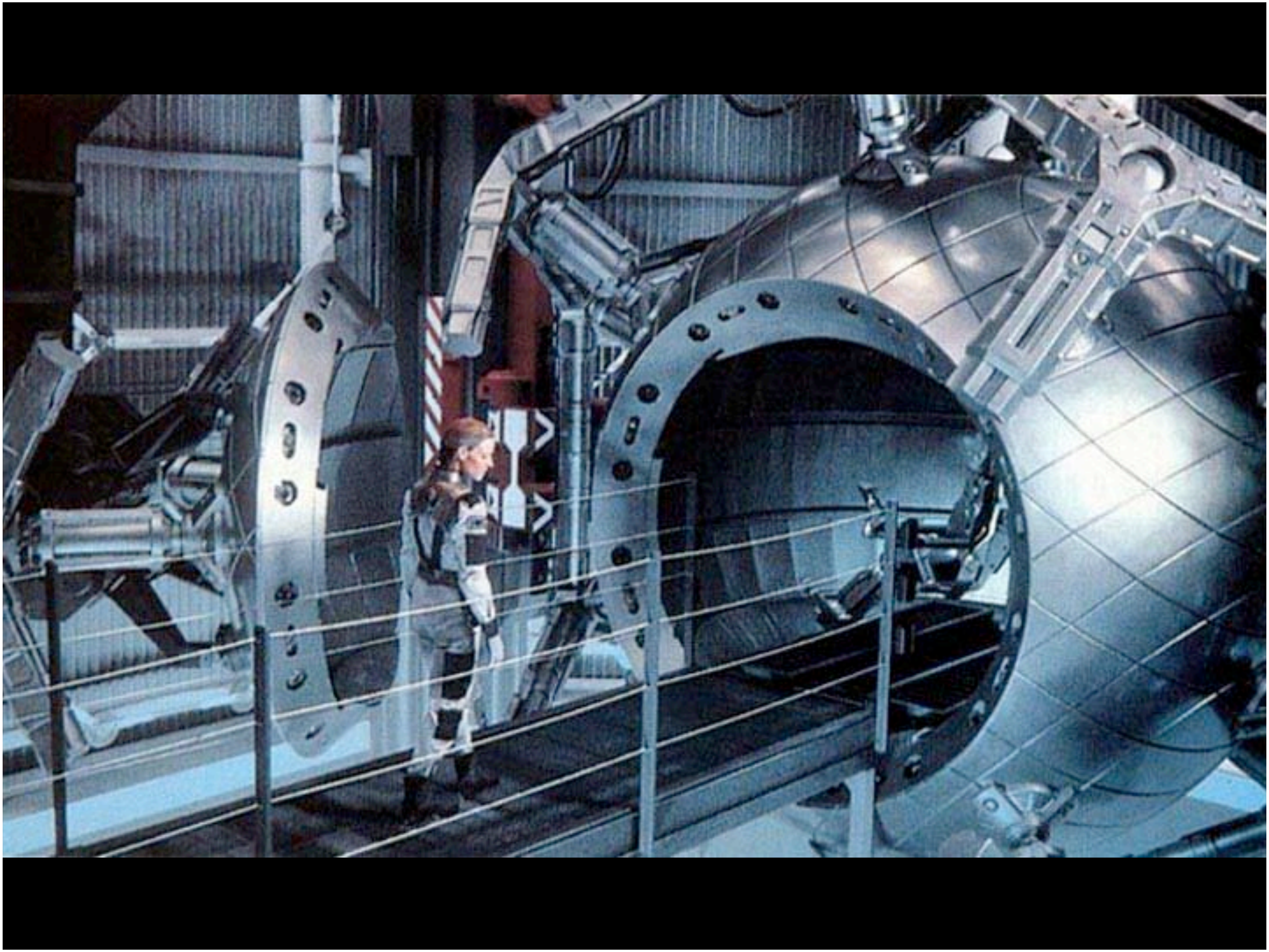


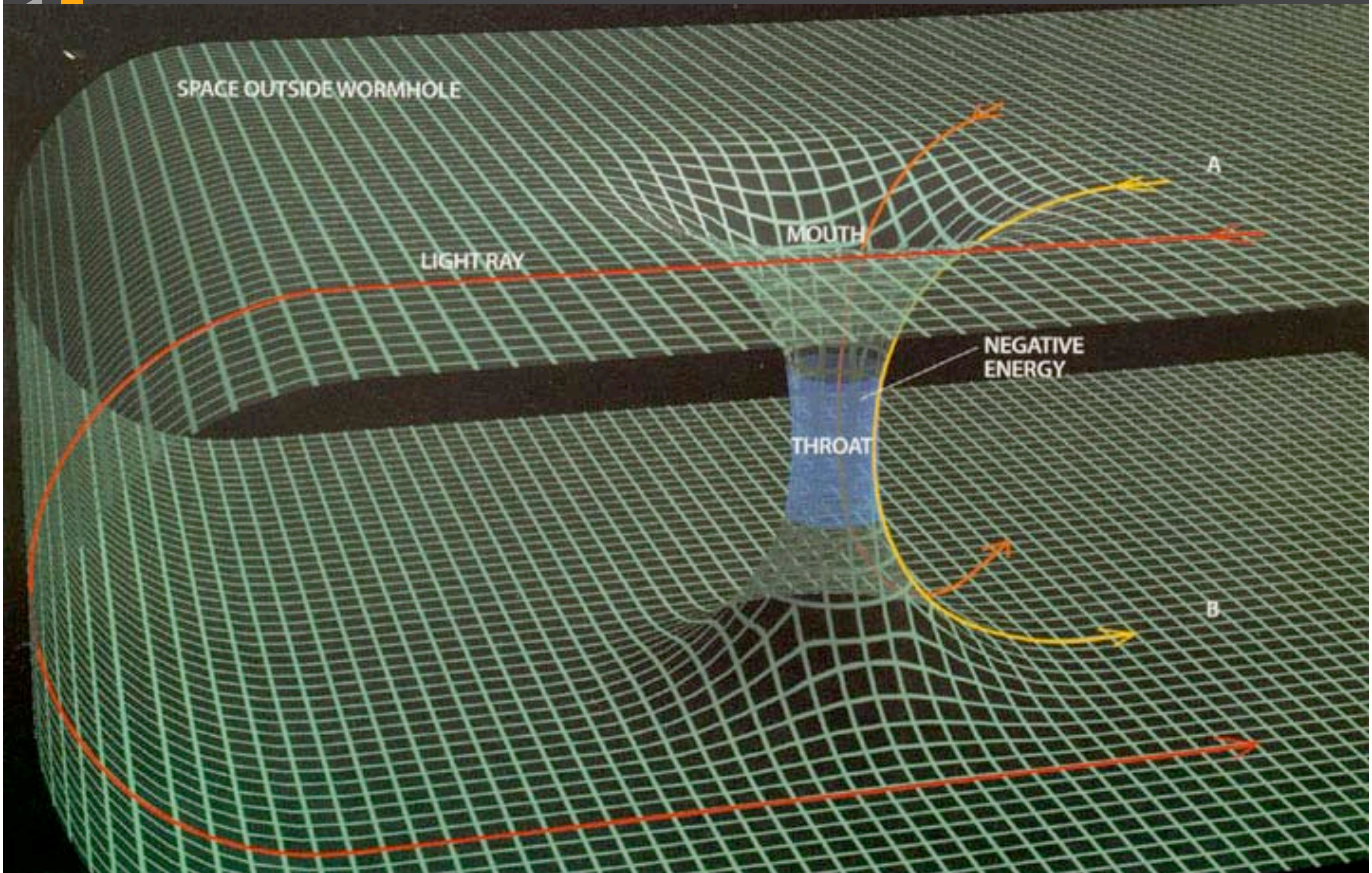


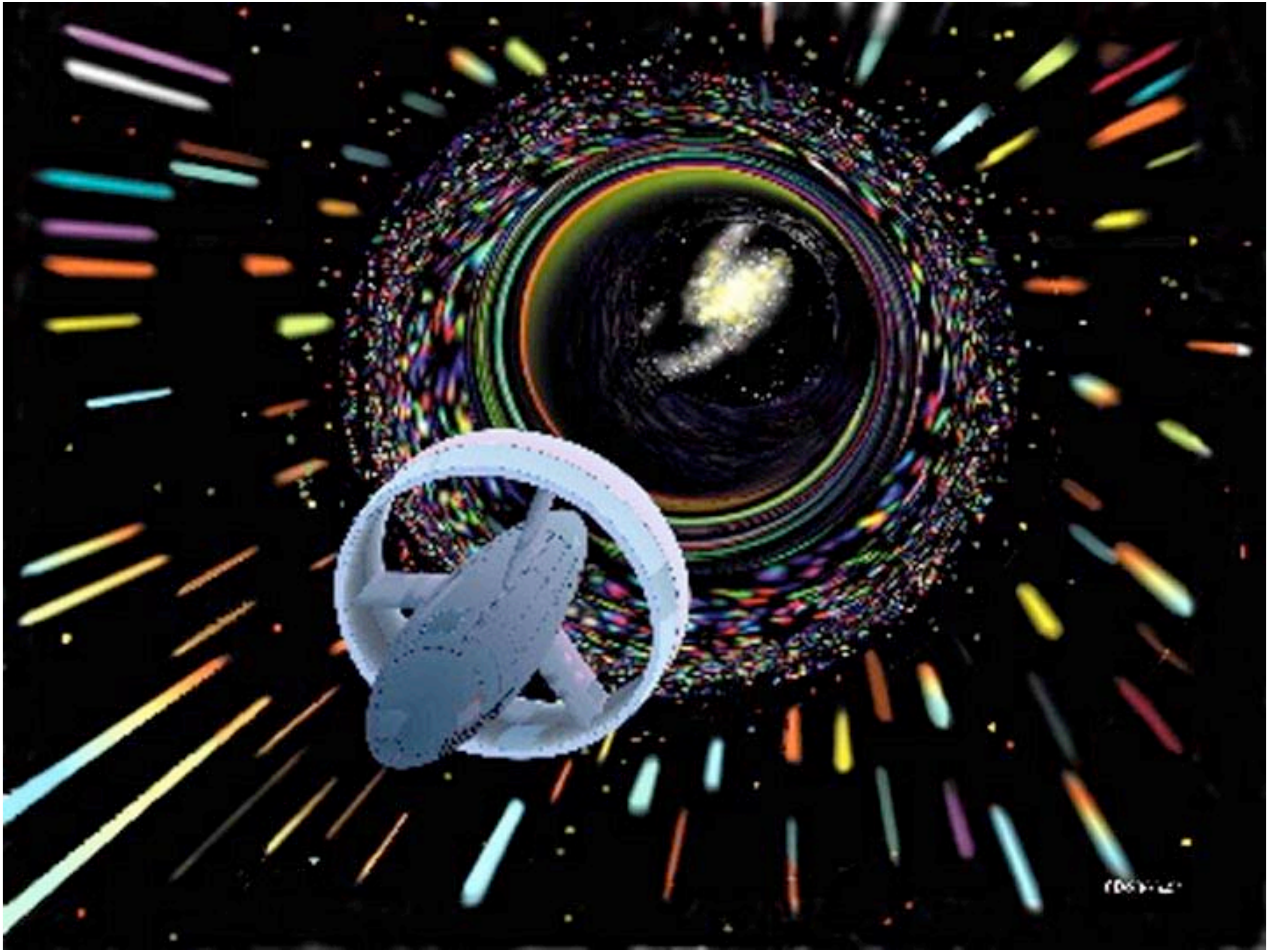


The Stars






SPACE OUTSIDE WORMHOLE
A
MOUTH
LIGHT RAY
NEGATIVE
ENERGY
THROAT
B



What is the reality of "breakthrough physics"?

Remember, a century ago scientists did not know about:

- The theory of relativity (and $E = m c^2$)
- Quantum mechanics
- Digitial computing
- DNA

Why should we presume our current understanding of the university (e.g., the speed of light as a bound on the speed of physical objects) is correct?

Technological Singularities

Bill Joy*

"Accustomed to living with almost routine scientific breakthroughs, we have yet to comes to terms with the fact that the most compelling 21st Century technologies—robotics, genetic engineering, nanotechnology—pose a different threat than the technologies that have come before. Specifically, robots, engineered organisms, and nanobots share a dangerous amplifying factor: They can self-replicate. A bomb is blown up only once—but one bot can become many and quickly get out of control."

*Chief Scientist, Sun Microsystems (inventor of Berkeley Unix and Java)
**B. Eng., U. Michigan, '67

What could happen?

We could develop intelligent machines that self-replicate and evolve beyond the intelligence and control of humankind.

We could genetically engineer new organisms that become a plague destroying natural species.

We could create nanotechnology assemblers that propagate through self-assembly and evolution into a “gray goo” that exhausts the resources of the planet..

20th Century Technologies

NBC: nuclear, biological, chemical

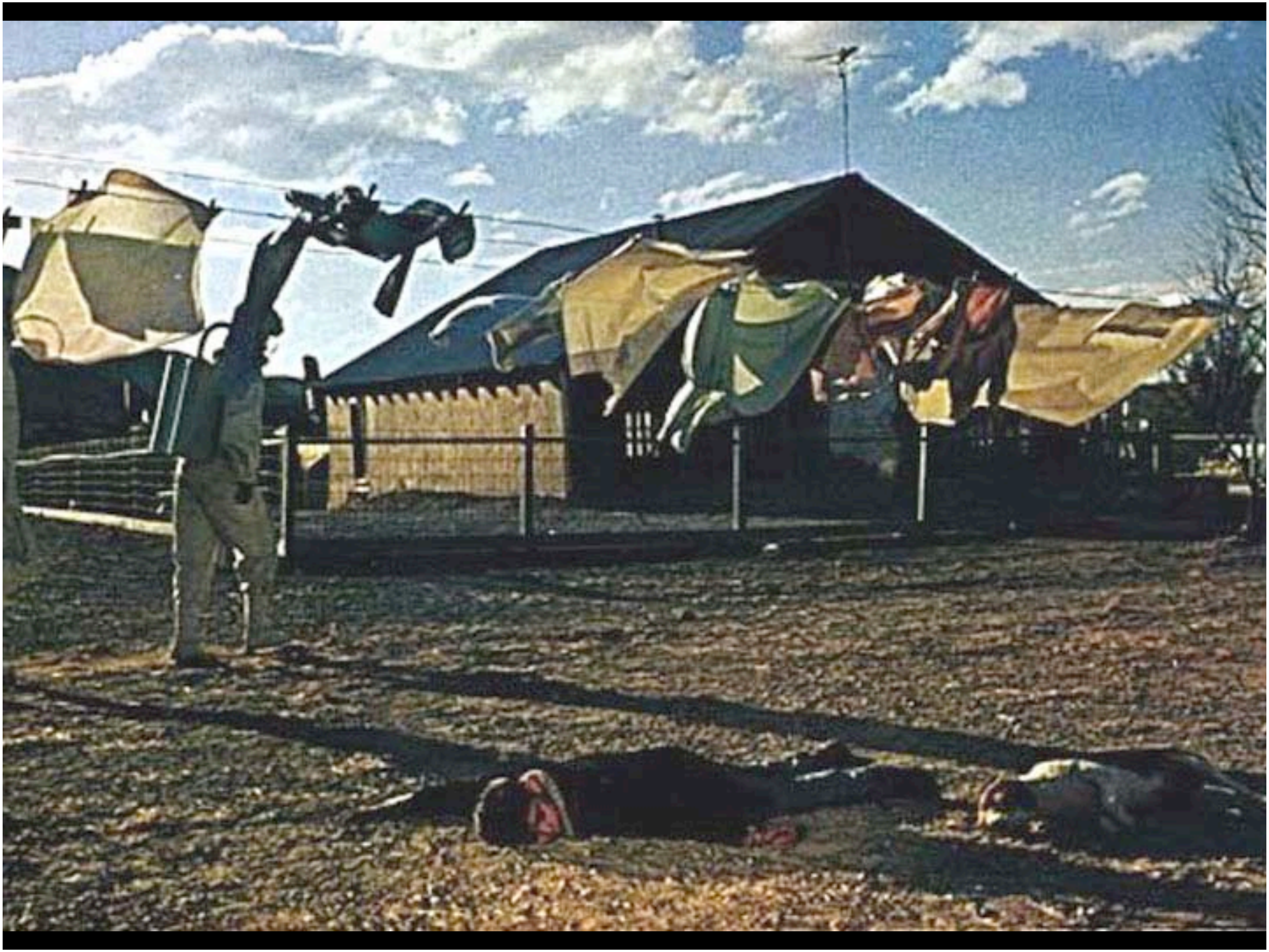
WMD: weapons of mass destruction


GRAND
FORKS
26
25
24
22
21
27
28

21st Century Technologies

GNR: Genetics, nanotechnology, robotics

KMD: knowledge-enabled mass destruction




TERMINATOR 2
JUDGMENT DAY

Vinge's Singularity*

The acceleration of technological progress has been the central feature of the past century. Vinge argues that we are on the edge of change comparable to the rise of human life on Earth. The precise cause of this change is the imminent creation by technology of entities with greater than human intelligence. There are several possibilities:

- There may be developed computers that are "awake" and superhumanly intelligent.
- Large computer networks (and their associated users) may "wake up" as a superhumanly intelligent entity.
- Computer/human interfaces may become so intimate that users may reasonably be considered superhumanly intelligent.
- Biological science may provide means to improve natural human intellect.

*Vernor Vinge, "The Coming Technological Singularity: How to Survive in the Post-Human Era"

A Technological Singularity

When greater-than-human intelligence drives progress, that progress will be much more rapid. In fact there seems no reason why progress itself would not involve the creation of still more intelligent entities, on a still shorter timescale.

Vinge calls this a “singularity”, the point where our old models must be discarded and a new reality rules. As we move closer to this point, it will loom vaster and vaster over human affairs until the notion becomes common place. Yet when it finally happens, it may still be a great surprise and a greater unknown.

John von Neumann also speculated that “the ever accelerating progress of technology and changes in the mode of human life gives the appearance of approaching some essential singularity in the history of the race beyond which human affairs, as we know them, could not continue.”

Beyond the Singularity?

Perhaps it was the science-fiction writers who felt the first concrete impact. More and more these writers felt an opaque wall across the future. Once they could put such fantasies millions of years in the future. Now they saw that their most diligent extrapolations resulted in the unknowable…soon. Once, galactic empires might have seemed a post-human domain. Now, sadly, even interplanetary ones are.

Vinge argues that we cannot prevent the singularity, that its coming is an inevitable consequence of human's natural competitiveness and the possibilities inherent in technology. And yet we are the initiators. Even the largest avalanche is triggered by small things. We have the freedom to establish initial conditions, make things happen in ways that are less inimical than others. Of course, as with starting avalanches, it may not be clear what the right guiding nudge really is.

21st C Engineering
The New Profession

Meeting the Challenge

Next Generation Engineering Career Paths

- Sustainable development: avoiding environmental harm; energy / materials efficiency
- Life cycle / infrastructure creation and renewal
- Micro / nanotechnology / microelectromechanical systems
- Mega systems
- Smart systems
- Multimedia and computer-communications
- Living systems engineering
- Process quality / control
- Management of technological innovation
- Enterprise transformation
- . . . ?

Next Generation Engineering Skill Set

- Systems integration; synthesis
- Engineering science; analysis
- Problem formulation as well as problem solving
- Engineering design
- Ability to realize products
- Facility with intelligent technology to enhance creative opportunity
- Ability to manage complexity and uncertainty
- Teamwork; sensitivity in interpersonal relationships
- Language and multi-cultural understanding
- Ability to advocate and influence
- Entrepreneurship; management skills; decision making
- Knowledge integration, education and mentoring

Next Generation "Core" Curriculum*

- conservation laws
- biochemistry
- scalar wave equation
- genetics
- dynamical systems
- evolution
- cell biology
- physical forces
- geochemistry
- atmospheric chemistry
- quantum mechanics
- discrete mathematics
- logic and probability
- chemical bonding
- information theory
- electrical circuits
- statistical mechanics
- thermodynamics
- chemical equilibrium
- condensed matter
- systems engineering
- complexity
- collective properties
- chaotic systems
- neurobiology

*Caltech

More fundamentally…

Less emphasis on “reductionist” science (e.g., physics)
More emphasis on “information -rich” sciences (e.g., biology)

Less emphasis on technical material
More emphasis on humanities, arts, and social sciences

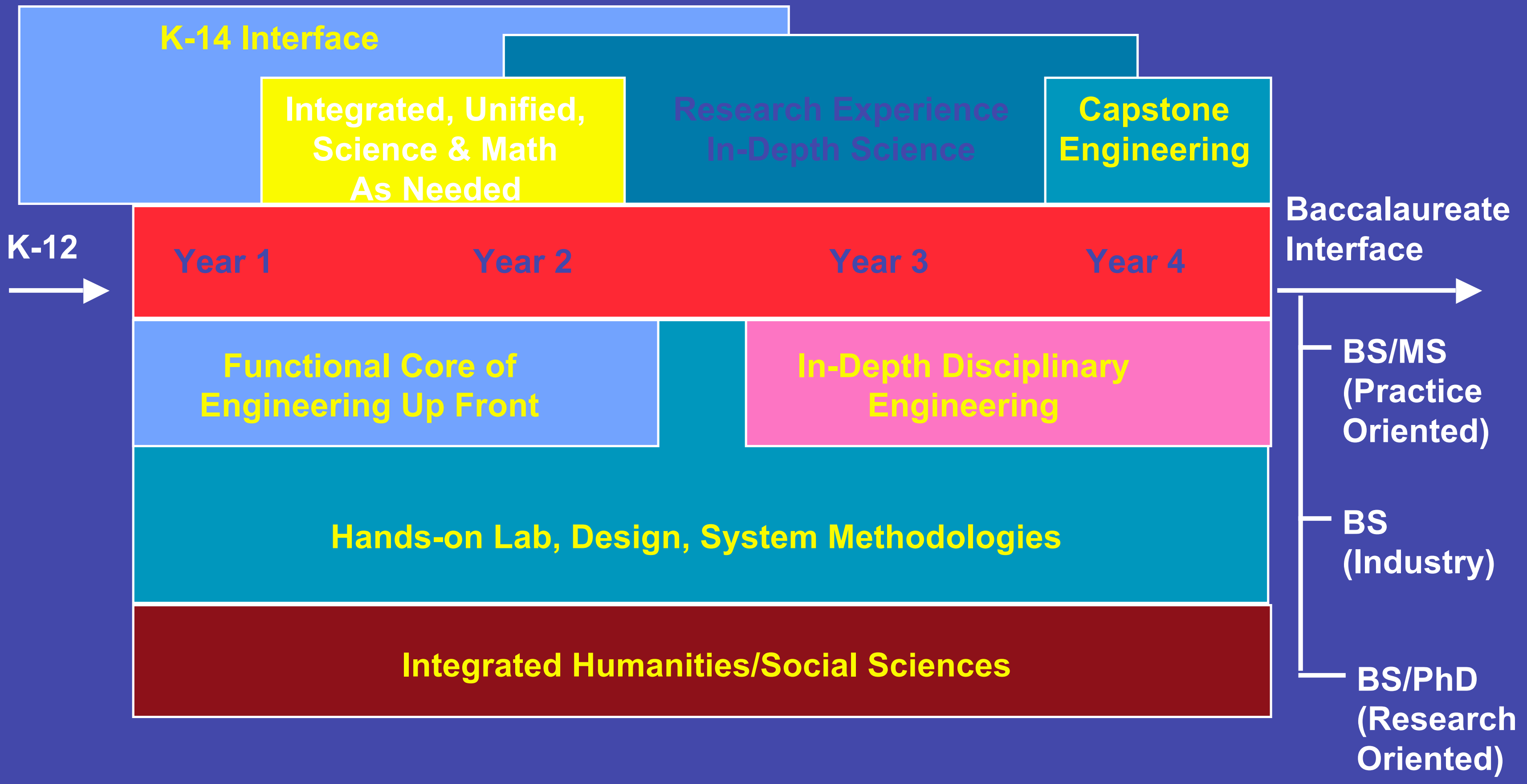
Less emphasis on analysis
More emphasis on synthesis

Consilience

"Most of the issues that vex humanity daily cannot be solved without integrating knowledge from the natural science with that of the social sciences and humanities. Only fluency across the boundaries will provide a clear view of the world as it really is, not as seen through the lens of ideologies and religious dogmas or commanded by myopic response to immediate needs."

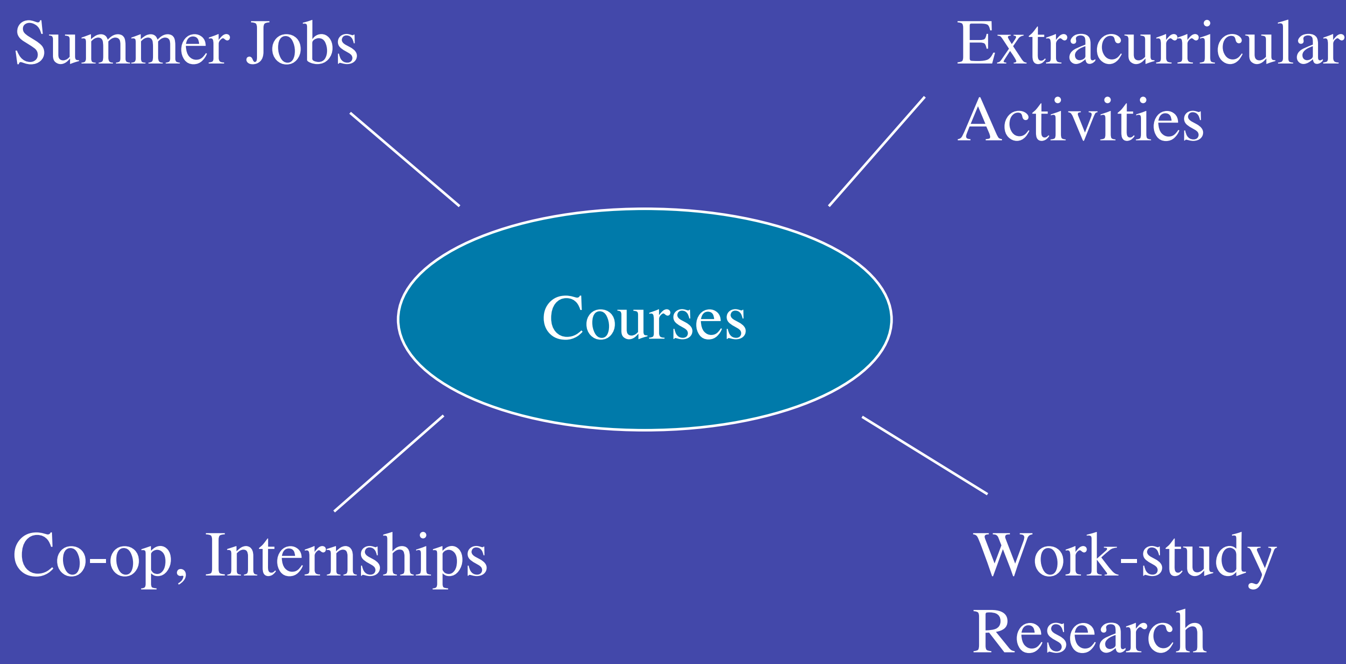
E. O. Wilson

Holistic Engineering Curriculum



Bordogna, NSF

Look at entire college experience



Components of a Holistic Baccalaureate Education

Vertical (In-depth) Thinking	Lateral (Functional) Thinking
Abstract Learning	Experiential Learning
Reductionism - Fractionization	Integration - Connecting the Parts
Develop Order	Correlate Chaos
Understand Certainty	Handle Ambiguity
Analysis	Synthesis
Research	Design / Process / Manufacture
Solve Problems	Formulate Problems
Develop Ideas	Implement Ideas
Independence	Teamwork
Technological - Scientific Base	Societal Context / Ethics
Engineering Science	Functional Core of Engineering

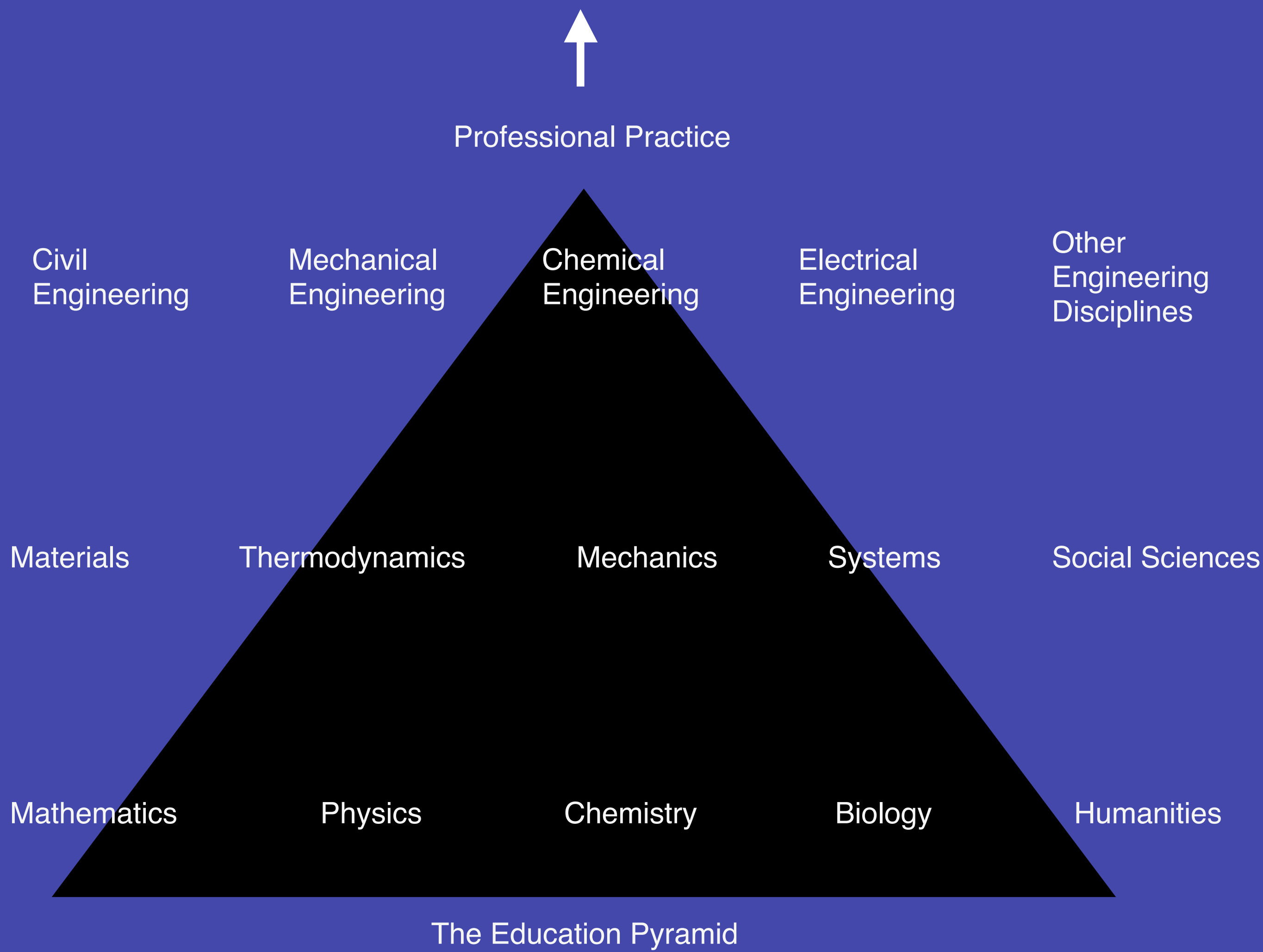
Bordogna, NSF

Challenges for 21st Century Academe

Educate students to:

- See the world whole; sense the coupling among seemingly disparate fields of endeavor
- Perform synthesis in balance with analysis
- Build connections between the world of learning and the world beyond
- Innovate

An Engineering Career



Alternative Careers