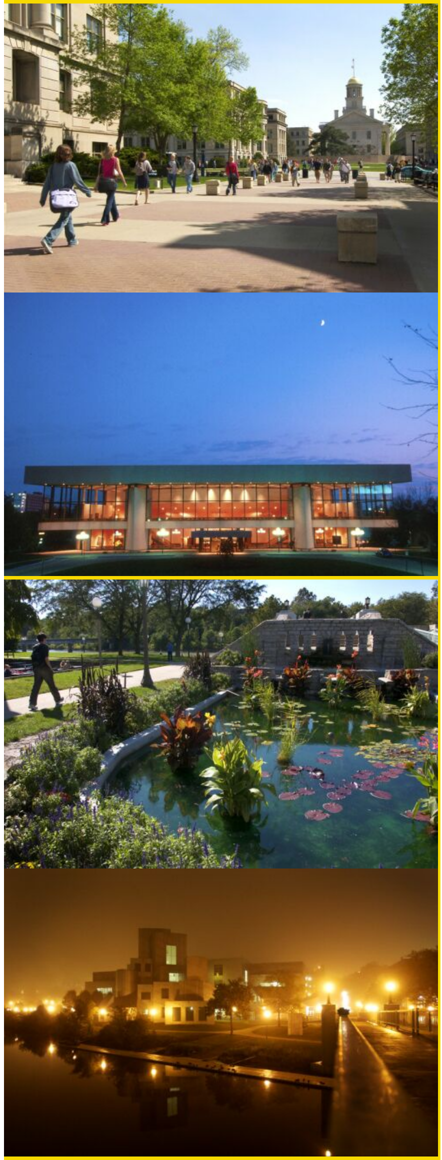


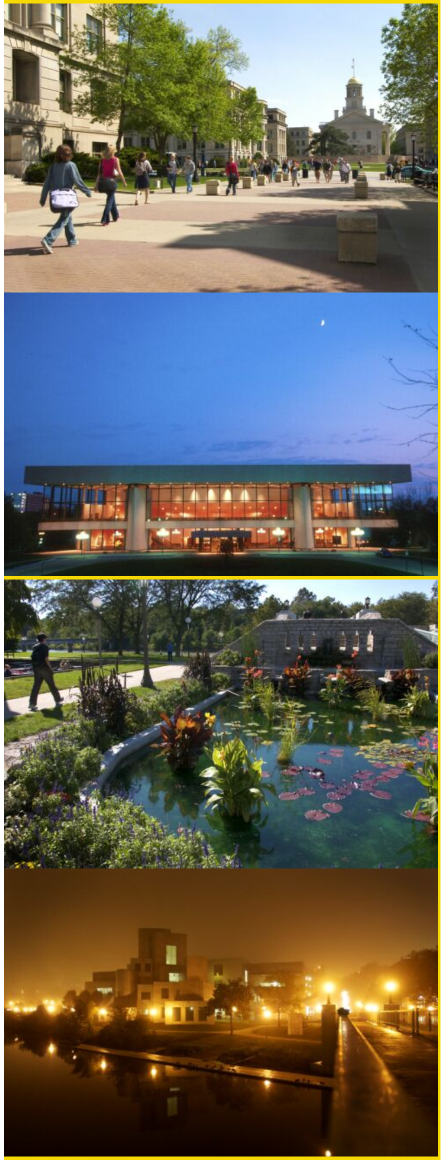
Future of Environmental Monitoring

R. Rajagopal, PhD
Professor
Geographical and Sustainability Sciences
The University of Iowa

August 7, 2014
Environmental Measurement Symposium
Washington, DC

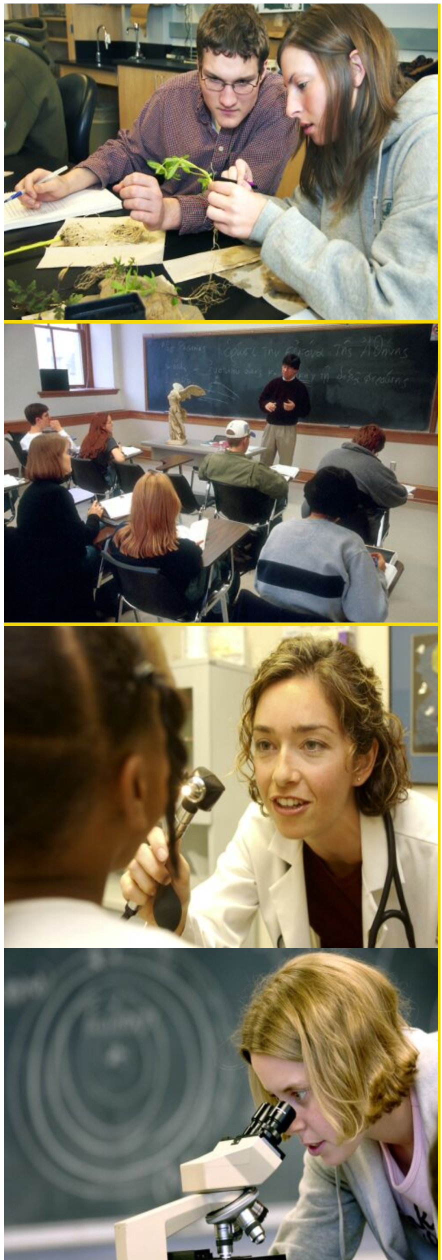
The University of Iowa

Iowa City, Iowa USA



Centrally isolated

The University of Iowa



The University of Iowa

Running theme of the Symposium

Integration – How are we going to tie all these data together?

- Political
- Policy
- Administrative
- Economic
- Scientific and technical
  - Ecological
  - Statistical
  - Geographic

On GIS Salespeople

A GIS salesperson dies and goes to Heaven. Saint Peter gives him a chance to look at the new quarters, both in Heaven and Hell, before deciding.

The GIS salesperson looks in Hell and finds that people are having a lot of fun and having great parties, whereas, those in Heaven were meditating and leading a sedentary life.

On GIS Salespeople

So have you decided asks St. Peter? The salesperson quietly responds by saying that he has chosen to go with the other crowd.

As he entered Hell, he was shocked to see whipping and burning of people in oil was going on. He asks Satan what is the deal, earlier I saw a great party place.

Satan says what you saw was a demo…

On GIS Consultants

A GIS consultant was visiting a sheep farmer in rural Iowa and said that he was going to predict the number of sheep in the farmer's flock. Using state-of-the-art GIS/GPS, the consultant predicted 846 sheep in the flock. The farmer was amazed and let the consultant have a sheep. The consultant picked an animal and put it in his van.

Just as the consultant was leaving, the farmer said how about giving me a chance to get even? If I can guess what your profession is, can I have something in return. The consultant said, fine. The farmer said you must be a consultant.

The consultant was surprised and asked the farmer, how did he know?

On GIS Consultants

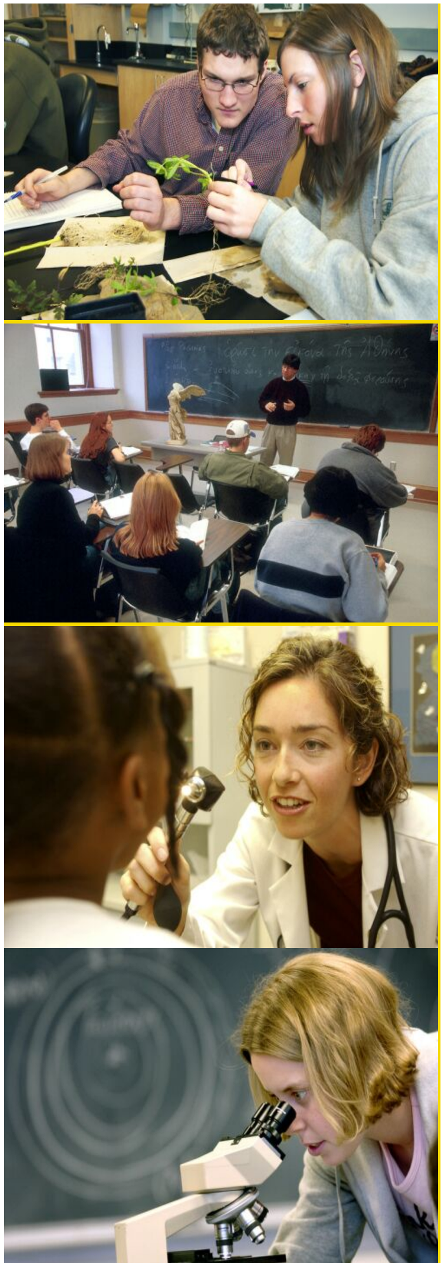
The farmers response was:

- **First you came here without being invited.**
- **Secondly, you charged me a fee to tell me something I already knew.**
- **Thirdly, you do not understand anything about my business, and I'd really like to have my dog back.**

Geographic Information Systems

Knowing where things are, and why they are there, is essential to rational decision making.

Adapted from Jack Dangermond, ESRI, A major GIS company



The University of Iowa

Capacity of humans from sensing to comprehension.

Statistics, Sampling, & Forensics

Unscramble these words

U G N	6
R D G U	24
O T A N B	120
O I R N H E	720
E H W A R E T	5,040
U B I A T E S L	40,320
T D E I O C N R U	181,440

Statistics, Sampling, & Forensics

Unscramble these words

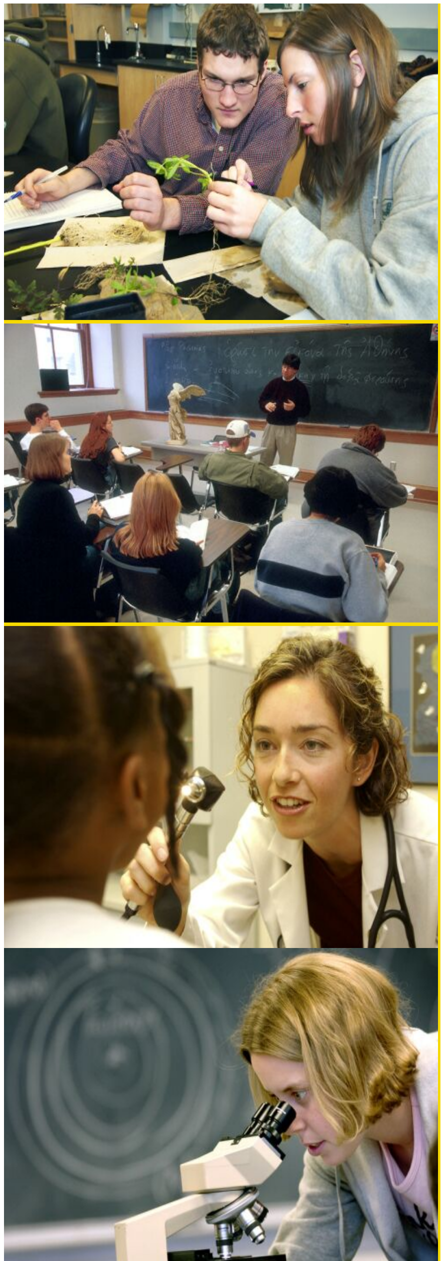
OLIUSTAMENSU

479,001,600

Brain & Comprehension

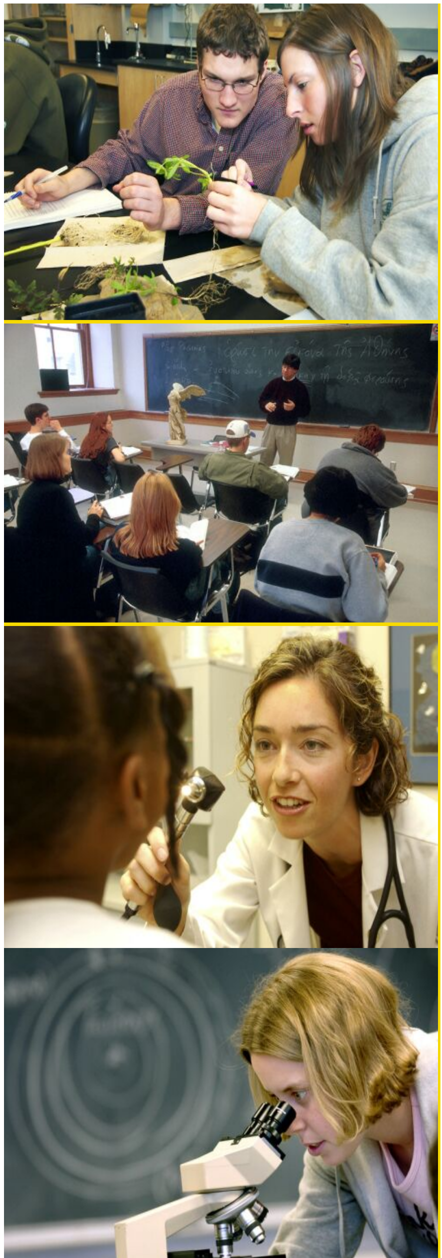
THIS WILL TRIP U OUT!!
Don't delete this just because it looks weird.
Believe it or not, you can read it.

I cdnuolt blveiee taht I cluod aulaclty uesdnatnrd waht I was rdgnieg.The phaonmneal pweor of the hmuan mnid aoccdrnig to rscheearch at Cmabrigde Uinervtisy, it deosn't mttaer in waht oredr the ltteers in a wrod are, the olny iprmoatnt tihng is taht the frist and lsat ltteer be in the rghit pclae. The rset can be a taotl mses and you can sitll raed it wouthit a porbelm. Tihs is bcuseae the huamn mnid deos not raed ervey lteter by istlef, but the wrod as a wlohe. Amzanig huh? yaeh and I awlyas thought slpeling was ipmorantt!



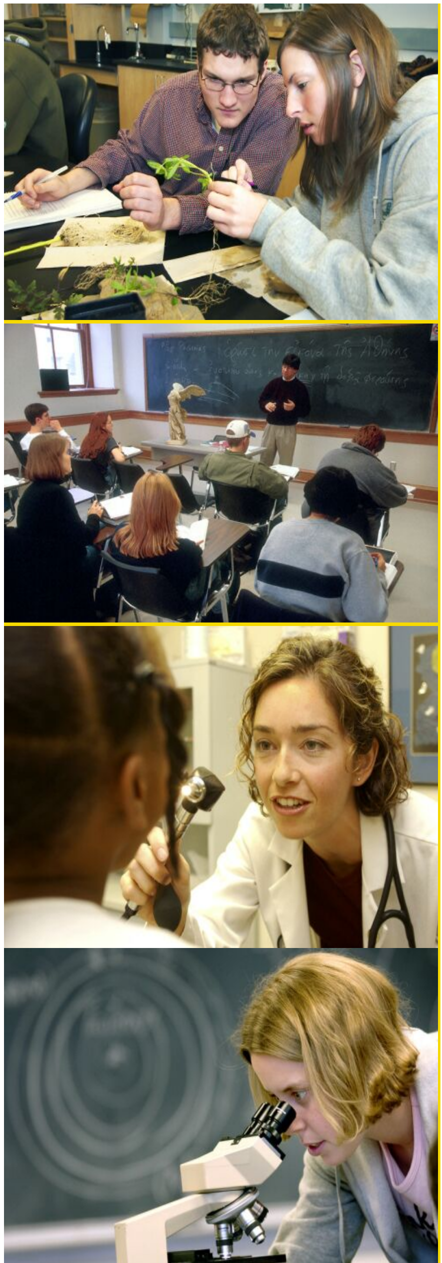
The University of Iowa

Why do we take environmental measurements?



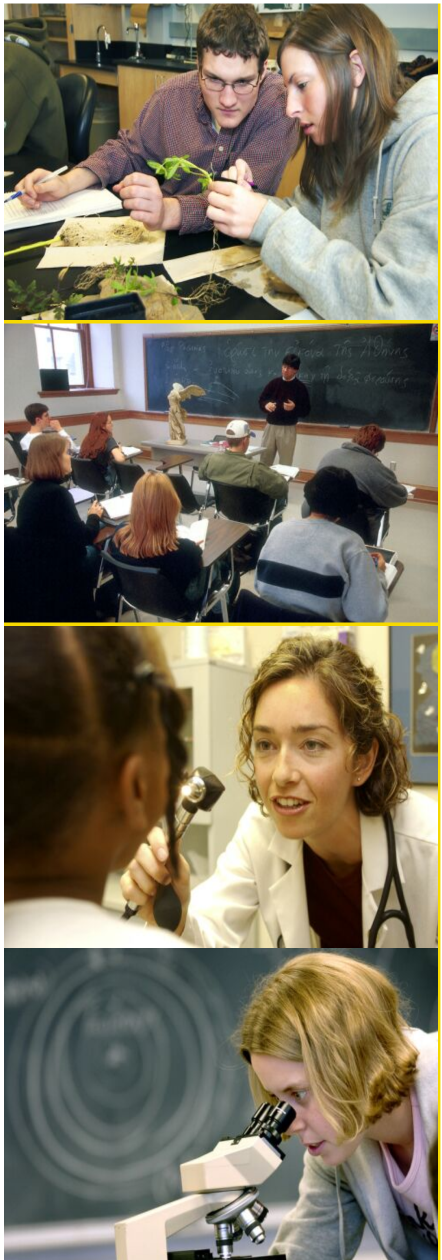
To understand the structure and function of ecosystems.

THE UNIVERSITY OF IOWA



THE UNIVERSITY OF IOWA

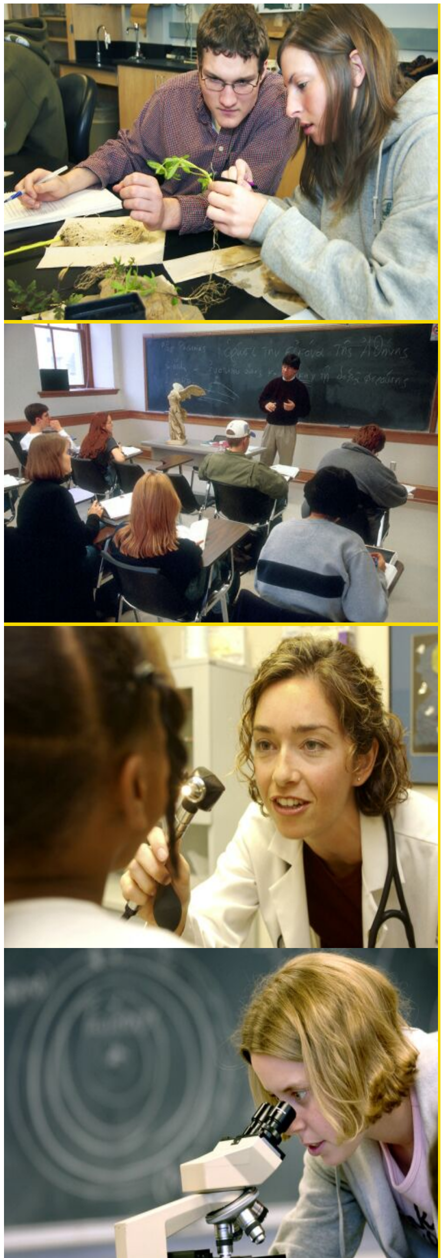
Ecosystem: The interacting system of a biological community and its non-living environmental surroundings.



Ecosystem is a system of living (plant, animal, and microorganism communities) and their associated non-living environment interacting and functioning as a whole.

The University of Iowa

Ecosystems have no fixed boundaries; instead, based on the purpose of analysis, a fish tank, a single lake, a watershed, or an entire region could be considered an ecosystem.

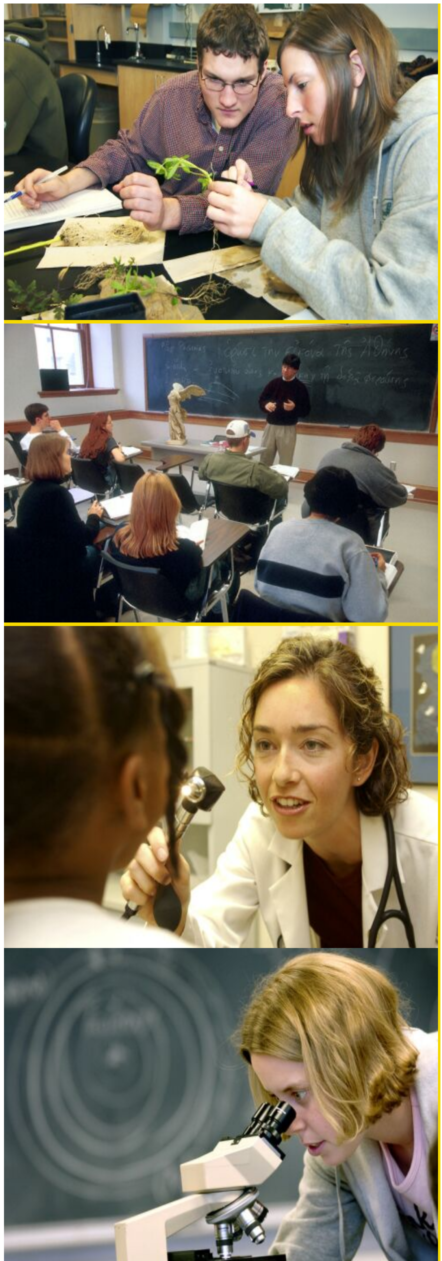


At least one component of an **ecosystem** must be living.

THE UNIVERSITY OF IOWA

The University of Iowa

Structure: How is the system organized, arranged, or put together?



How are you able to do the following?

Finding books in the library

Ability to navigate on highways

Looking up a telephone number

Locating things on the Web

Surveying the content of books

Calling anybody around the world

Recalling information from memory

THE UNIVERSITY OF IOWA

On Organization

- Zen and the Art of Motor Cycle Maintenance by Robert Pirsig (1974)
- www.visualcomplexity.com

Scale in Systems

Explore the universe of

big things to small things

Over 41 orders of magnitude

Source:

http://csaweb.yonsei.ac.kr/~rhee/2000/universe/

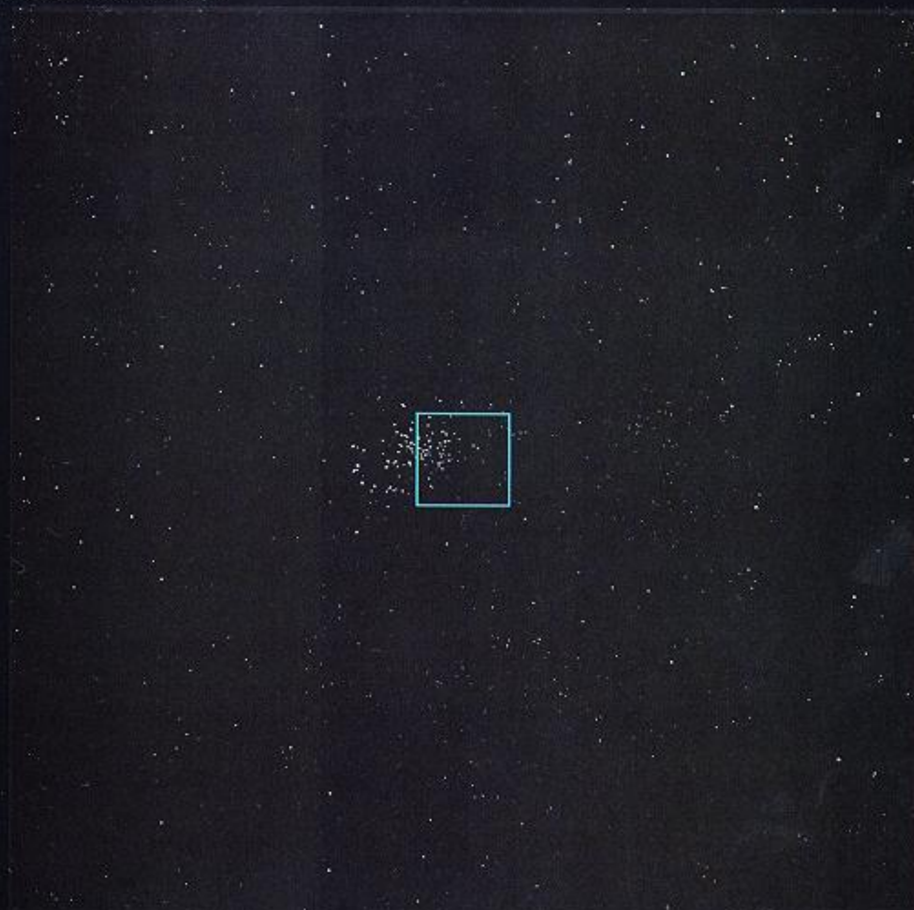
10^{25} meters

~1 billion light-years

Most of space looks as empty as this, the glow of distant galaxies like clotted dust. This emptiness is normal; our own bright home-world is the exception. A tenfold larger view would show no new structure, no new void; the universe is roughly uniform at such dimensions. Novelty on so grand a scale is to be sought over time rather than from place to place. All swift change is in the past. This view will dim slowly, for a few billion years at least, as the faint clusters drift still farther apart.

10^{24} meters

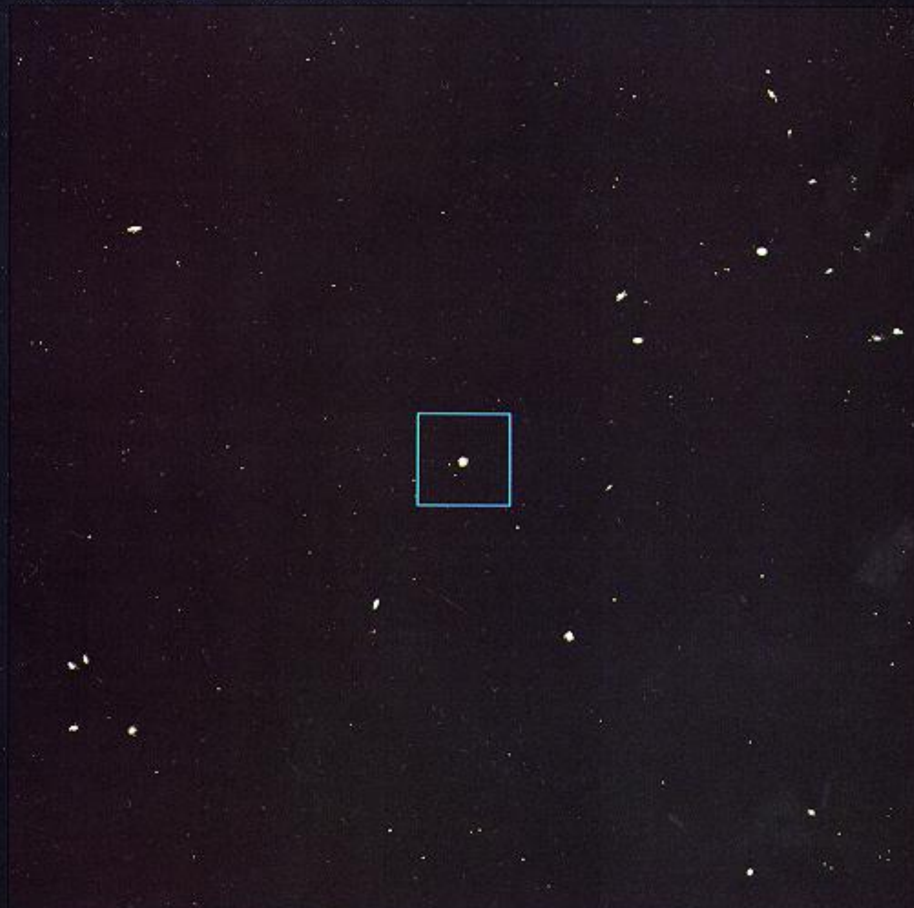
~100 million light-years



We look toward our distant home in the Milky Way. But we see mostly one large intervening cluster of galaxies, called the Virgo Cluster. Galaxies as a rule associate into orbiting clusters and groups. There is reason to believe that our Milky Way is itself an outlier of the big Virgo Cluster, responsive to its steady gravitational pull: part of a supercluster. Out there beyond the Milky Way is a good-sized volume nearly devoid of noticeable galaxies.

10^{23} meters

~10 million light-years ~3 megaparsecs



These are the galaxies of our own cosmic region, each single bright spot made by the summed light of stars by the billion. Their mutual gravity binds stars into galaxies, every one a complex swarm of moving stars.

10^{22} meters

~1 million light-years

This flat circular disk is our own Galaxy, the Milky Way, with its spiral structure. It travels in space with two satellite galaxies, the irregular little Clouds of Magellan. Not many galaxies are larger than ours; nor are many seen that are smaller than the Clouds.

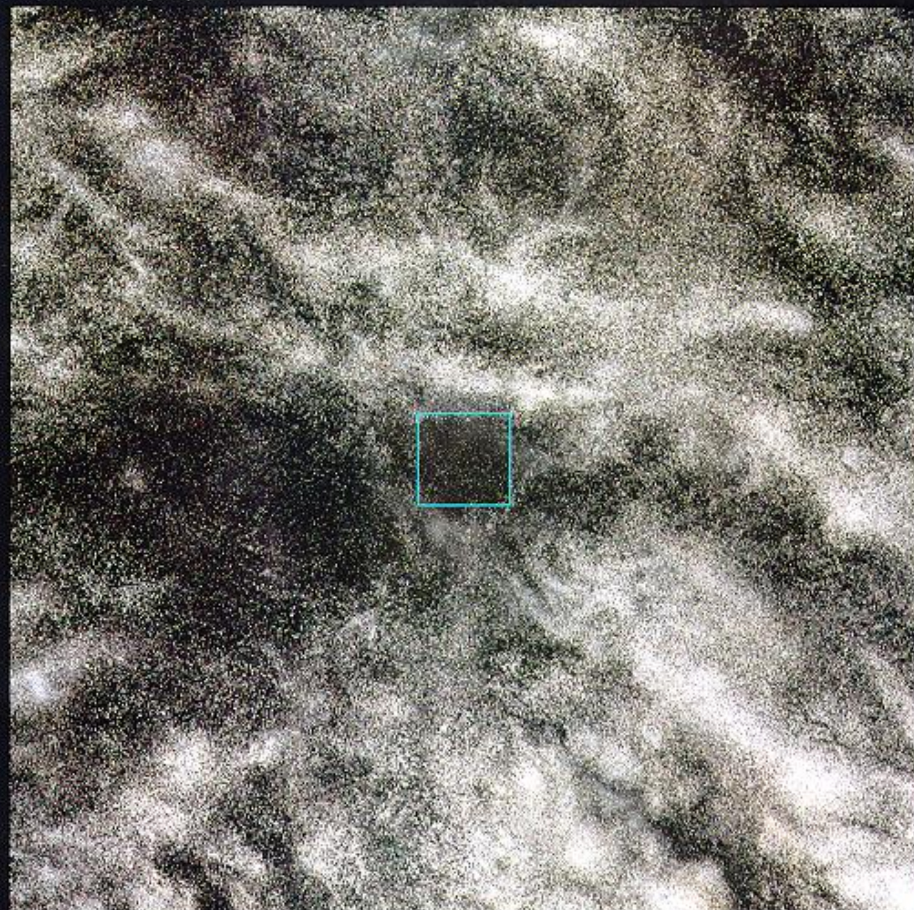
10^{21} meters

~100 thousand light-years

We look face-on directly at the Milky Way spiral. A hundred billion stars mutually bound by gravity encircle the central region, some passing close in, some in wider orbits. Our own sun swings with the rest in dignified passage clockwise about the distant galactic center, once every three hundred million years. External galaxies akin to our own are scattered throughout space as far as we can see. They too rotate slowly as they drift.

10^{20} meters

~10 thousand light-years



Clouds of stars and glowing gas, with patches of darkening dust, mark the slow-changing spiral patterns of the Galaxy disk. Our distant sun cannot be seen here, but it is in the center of the image, near the border of one spiral arm.

10^{19} meters

~1 thousand light-years

In this view we are within the disk of the Galaxy, right among a host of stars visible here as individuals. Almost every star of the thousand mapped by the old watchers of the sky, those who first gathered stars into constellations, lies within this square, our own galactic neighborhood. There are many other stars as well, too faint for the eye to see.

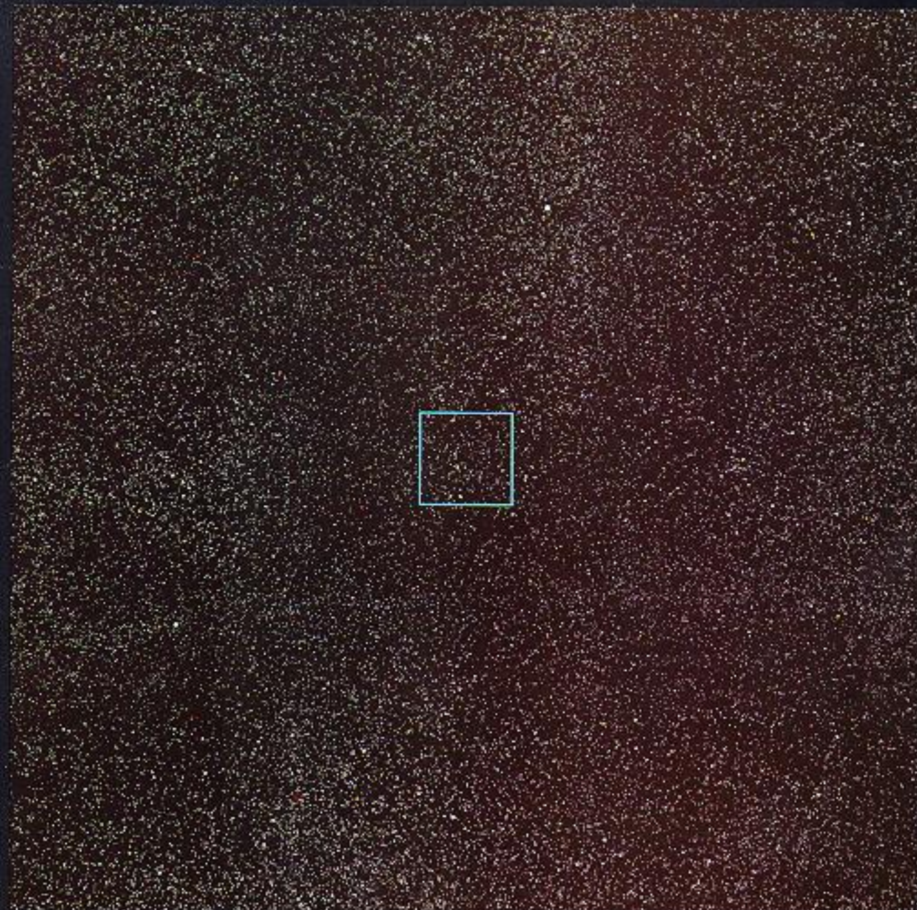
~100 light-years

10^{18} meters

A skyful of distinct stars: One among them, central, but too faint to pick out, is our sun. The star Arcturus, prominent in the northern sky of earth, shines brightly. Arcturus is intrinsically more luminous than our sun, and here we are nearer to it as well.

10^{17} meters

~10 light-years ~3 parsecs



Most of the matter we know is formed into stars, spheres of gas nourished by central nuclear fires that often maintain the glow for a very long time. At this point in the journey, with no star nearby, we see the realm of the stars chiefly as a distant background, no different from the night sky we view from earth. For several frames the star background remains unchanged: The visible stars are strewn so deep in space that these steps are small in comparison. Hence they cause no noticeable shifts.

~1 light-year   10 trillion kilometers

10^{16} meters

Here one central star is brighter than the rest, only because it is so much nearer. That star is the sun. The contrast between night and day, between the cold glitter of the starry sky and life-giving warmth, is the consequence simply of our planet's location next to one modest star. Once we have drawn away from the sun, we can recognize that it is one star among many stars, and all distant stars are in some way suns.

10^{15} meters

1 trillion kilometers

Only the sun is to be seen, against a background of fainter stars beyond. Once that was all we knew of the frontier of the sun's system. We know now that a great cloud of icy comets orbits slowly here, though invisible in the weak sunlight. We see comets only as year after year a few fall into the brighter regions near earth. There we catch sight of them, moving in the sky like temporary planets, the sun's fires boiling out their long faint tails.

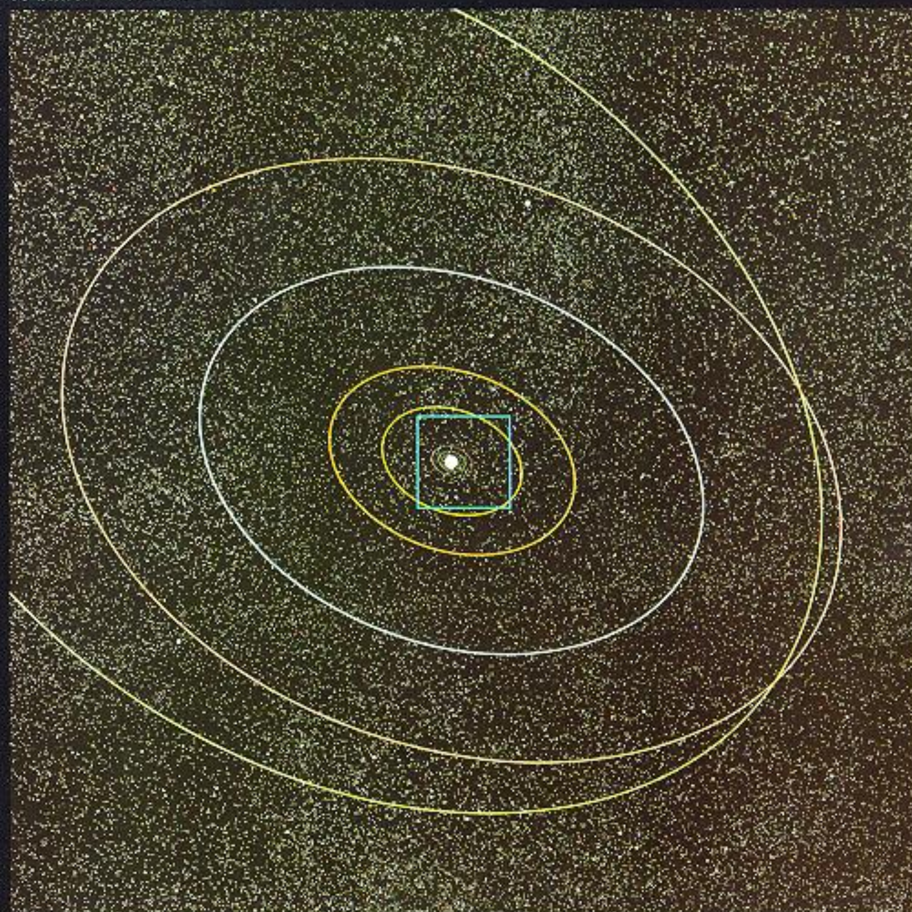
10^{14} meters

100 billion kilometers

All the sun's planets circulate within the small square. From earth the planets have always stood out, a few strange bright stars restlessly wandering in a skyful of unchanging patterns. Seen here from outside, the planets take on their Copernican aspect; they move around the sun on these nested ellipses, mapped by colored lines.

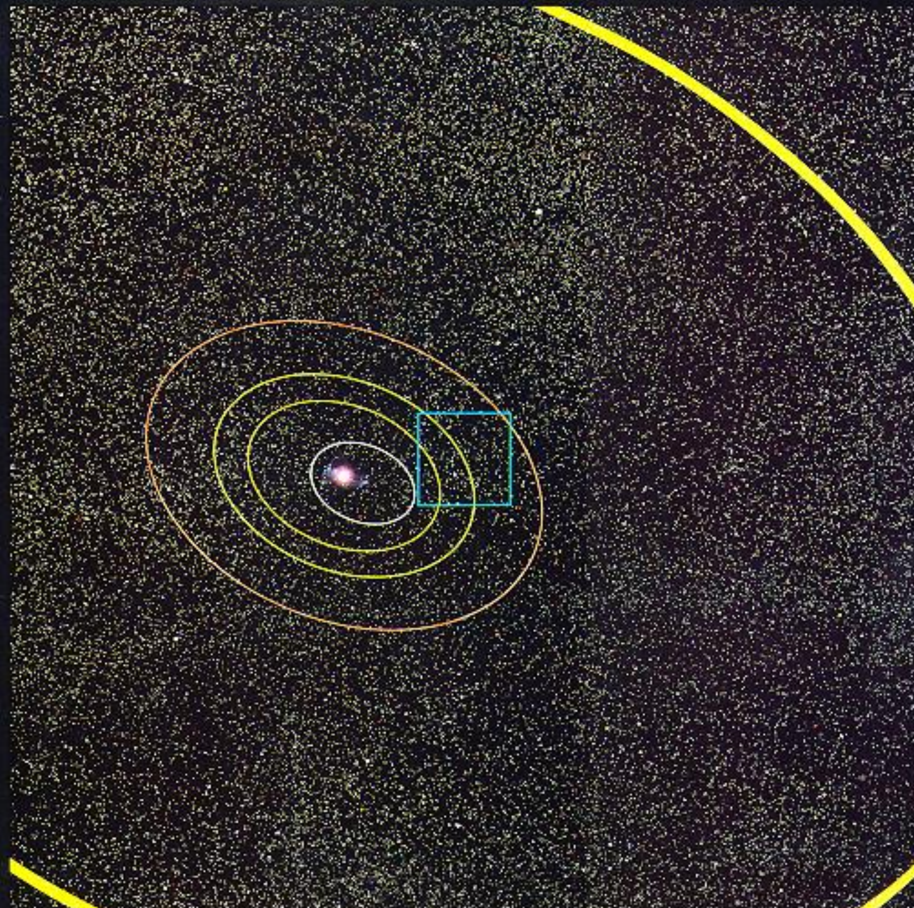
10^{13} meters

10 billion kilometers



The paths of the outer planets fill this picture. That strongly tilted orbit belongs to little, awry Pluto. The four others are those of big Neptune, Uranus, Saturn, and Jupiter, with their many satellites. Between Jupiter's path and the sun run the inner planets in their smaller orbits. The planets circulate counterclockwise here, all in nearly the same plane, which we view at an angle: The planetary system, apart from Pluto, is flat as a pancake.

1 billion kilometers ~7 astronomical units

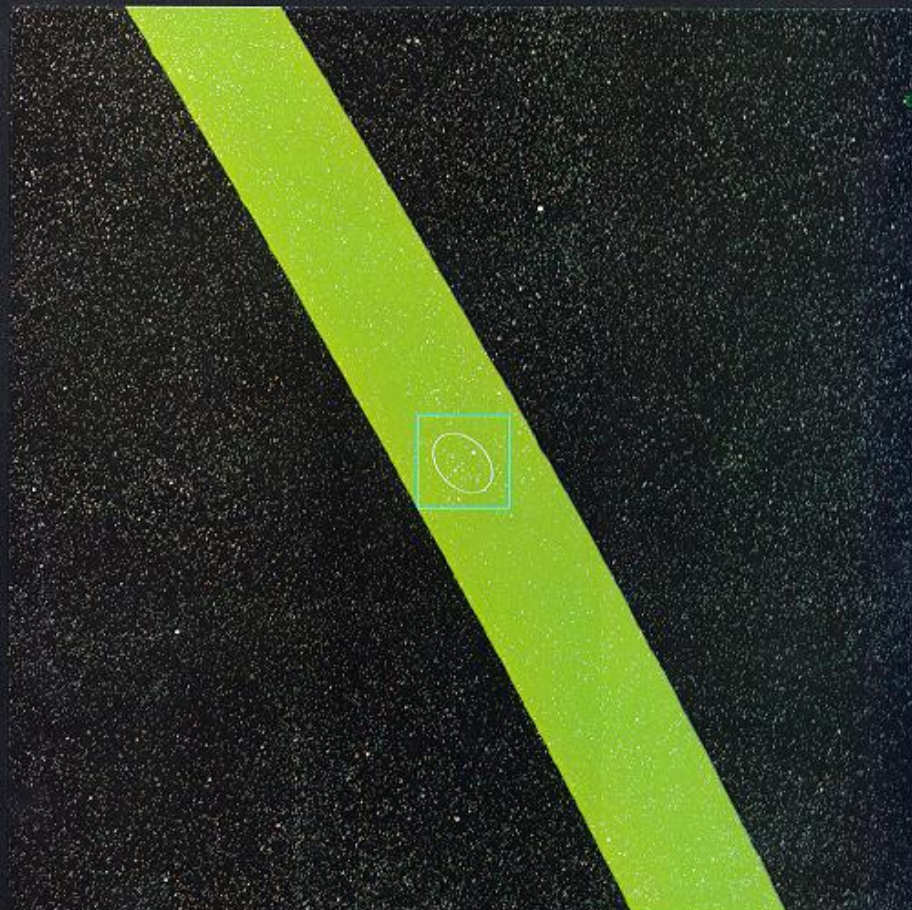


Enclosed in the path of massive Jupiter, these are the orbits of the smaller earthlike inner planets: Mars, Earth, Venus, Mercury. Another swarm of objects too small and faint to make out without telescopic aid is present as well: Asteroids and meteors ply this darkness in the belt between the orbits of Mars and Jupiter.

Now we see the inner solar system. The green arc is traversed by planet Earth during some six weeks each September and October.

10^{10} meters

10 million kilometers



This path marks the earth's way for four days in October; within it the moon's route is indicated relative to earth. The moon at all times lies somewhere on that small ellipse which moves along with the earth in its orbit.

1 million kilometers

10^9 meters

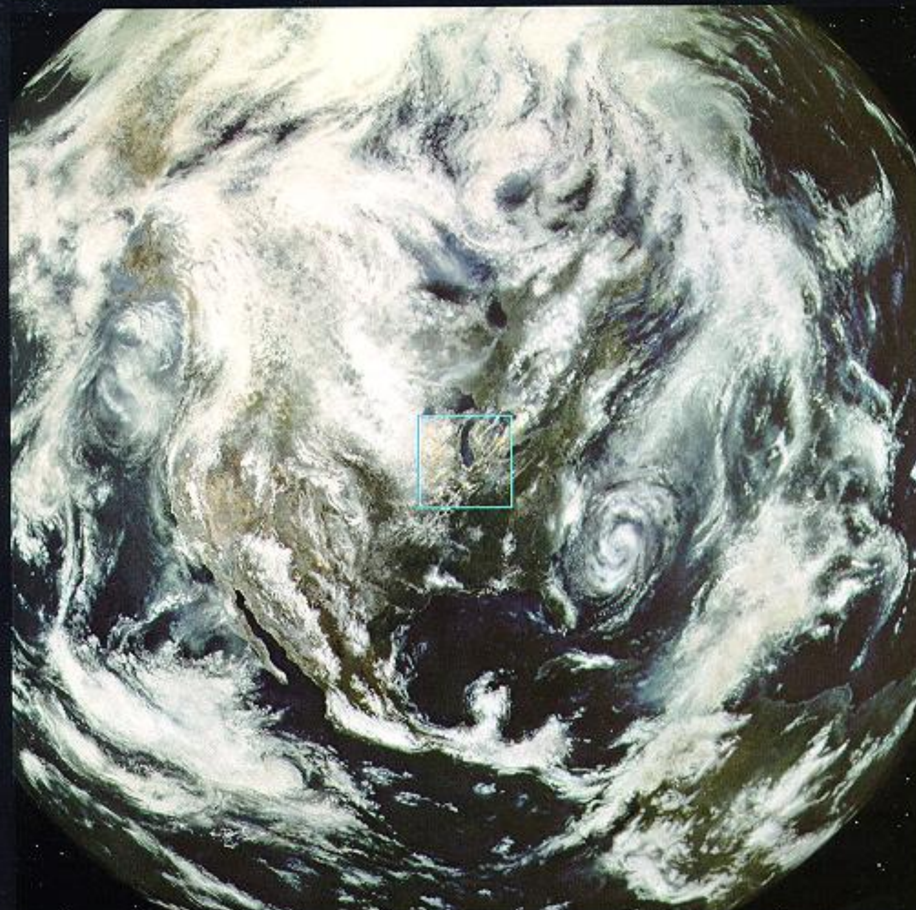
The farthest place our own kind has yet visited is the companion moon, our nearest celestial neighbor. Bright moonlight and the tides witness her proximity.

10^8 meters

100 thousand kilometers

The whole earth appears, isolated, elegant, and fragile. We recognize our globe in open space, a spacecraft in orbit, no Atlas and no turtles to support it. Its smooth, swift motion around the sun carries it across such a square as this every hour.

10 thousand kilometers



The earth in detail: blue sky, white clouds, dark seas, brown lands, a globe turning always eastward. The makers of maps had for three centuries prepared us for this sight, but it became real to eyes as well as to mind only around 1967.

1 thousand kilometers 1 million meters

This region, viewed from a low orbit, holds the whole of Lake Michigan; the broad sheet of water, like the flat silted lands around it, was formed by continental glaciers in the most recent geological past, a few tens of thousands of years ago. The day's weather is marked by clouds arrayed in streets and clumps. Though we are looking at the homes of tens of millions of people, the work of human hands is hardly to be seen.

100 kilometers

The metropolitan area of Chicago nestles at the south end of the lake. On a day like this, someone walking along the street might have looked up to a blue sky; but the camera plane was flying so high it would have been hard to pick out. The lattice visible among so many blurred streets is the mile-square grid of wide Chicago boulevards.

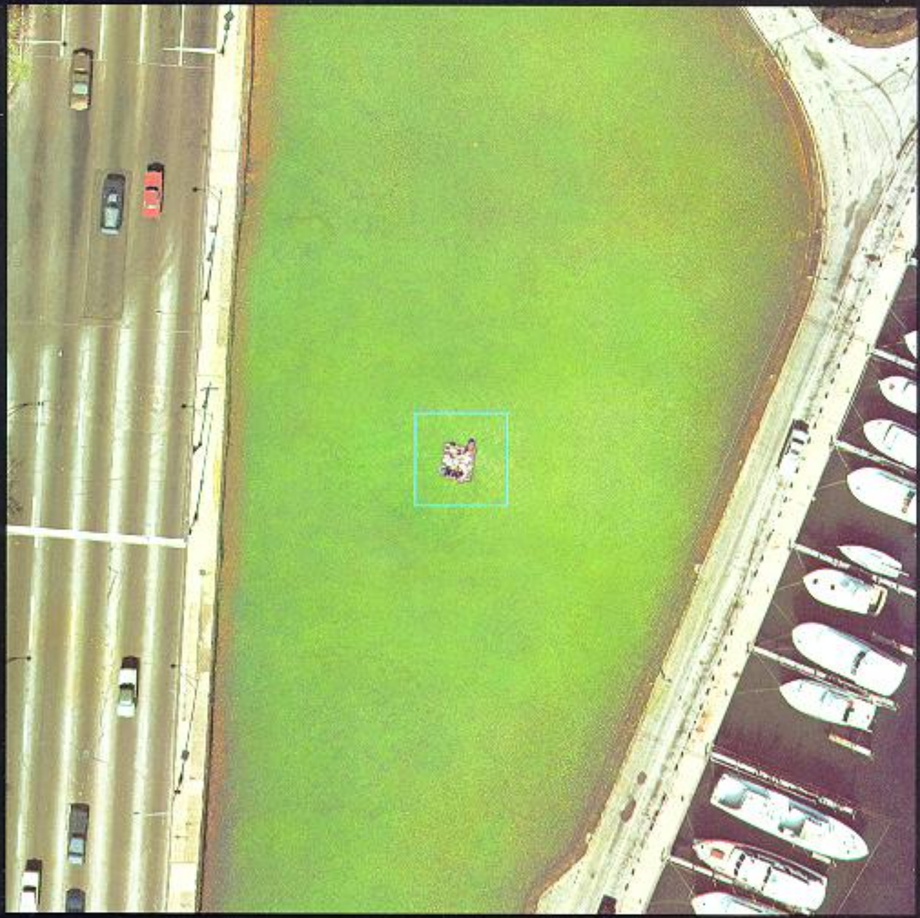
10 kilometers ~6 miles

The heart of the city appears, place of home and work for a million people. The whole structure shown here—city districts, parks, harbor—is familiar to them. The conflagration of 1871 burned the city of wooden houses which then lay within this square. Most of the detail shown is newer, though the street and railroad layout survived the fire, as in the future they will outlive most of the individual buildings.

1 kilometer 1 thousand meters

Now we look at a view that is not a maplike tracery of symbols, but a scene of familiar places within the city: Lake Shore Drive, Soldiers' Field, an airstrip, boat docks, museums.

100 meters



The picnic in the park is not far from the roaring highway and the boats at their docks. The picnickers can enjoy a sense of privacy all the same, for no one else is near. Were people evenly spread over all the world's land area, these two could lay claim to six times the area of this whole square. To raise their own grain, they would need to cultivate only this grassy plot.

10^1 meters

10 meters

A man and a woman are at a picnic in the park. This picnic is the center of every picture outward to the view among the galaxies.

10^0 meters

1 meter $\sim$1 yard

This is the scale of human companionship, conversation, touch: A man is asleep on a warm October day. Around him are necessities and pleasures for mind and body. Between this image and the next frame inward, the size of the image would for once match the size of what it represents. "Of all things man is the measure," wrote Protagoras the Sophist.

10^{-1} meters

0.1 meter 10 centimeters

The scale is now intimate: This is the look of the back of your own hand, a little enlarged. That animate structure, guided by eye and mind, joined over time by many another in the human endeavor, has fashioned all the representations we have of the world, including this of the hand itself.

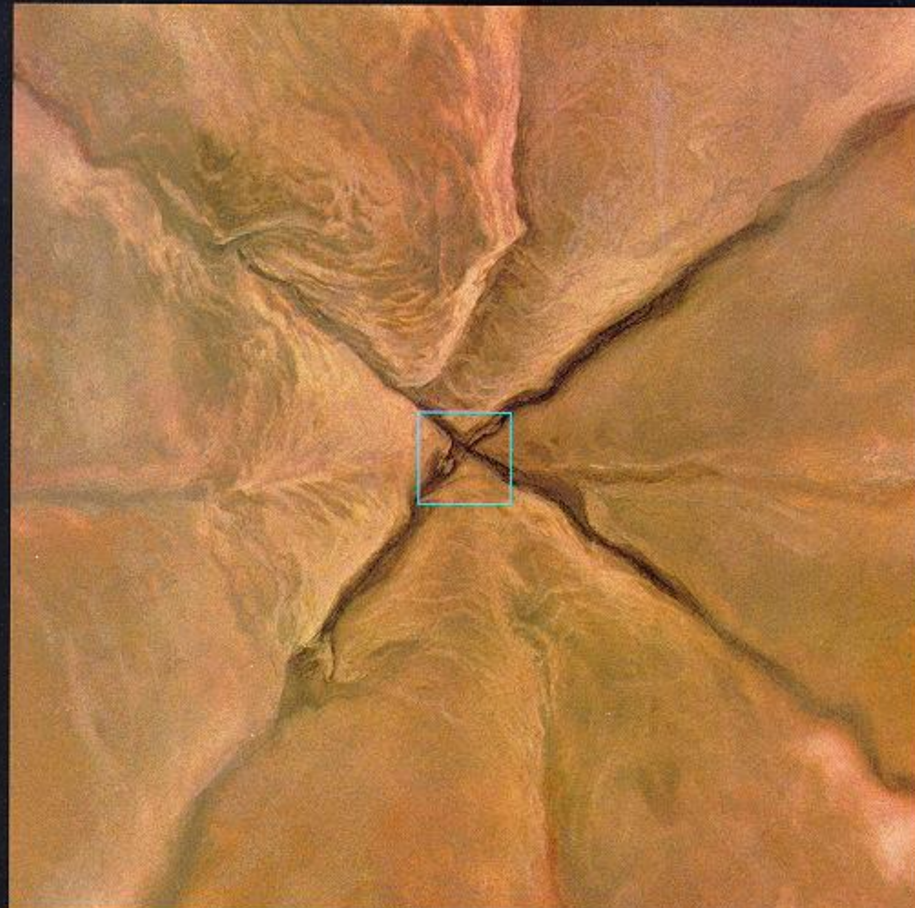
10^{-2} meters

1 centimeter

A searching look at the skin as if through a strong magnifier. The creasing is both the sign and the means of the skin's flexibility.

10^{-3} meters

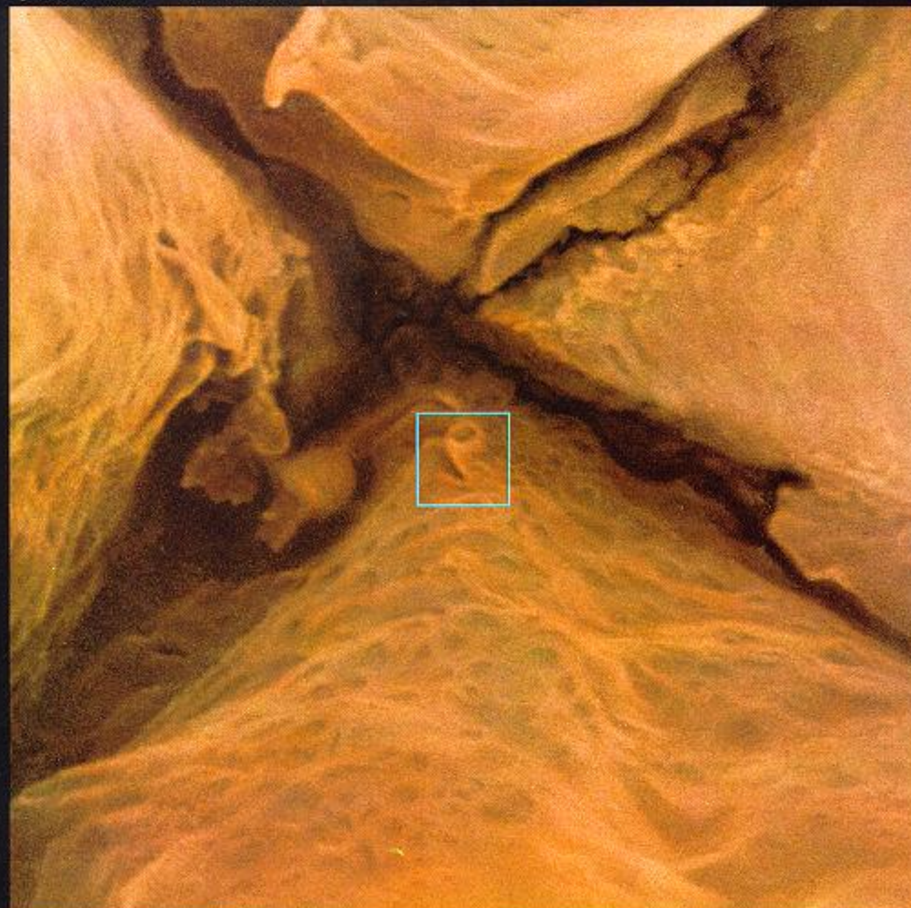
0.1 centimeter 1 millimeter



Here we share the world of the microscopist, who has unlocked so much of nature. For each image still closer in than this one, we come nine-tenths of the remaining distance toward the inner end of our journey, just below the skin of the man, within a cell passing along a tiny blood vessel.

10^{-4} meters

0.1 millimeter   100 microns



Unexpected detail appears; we can scarcely orient ourselves. Deeper still, we enter an intimate world within, as unfamiliar to us as the distant stars.

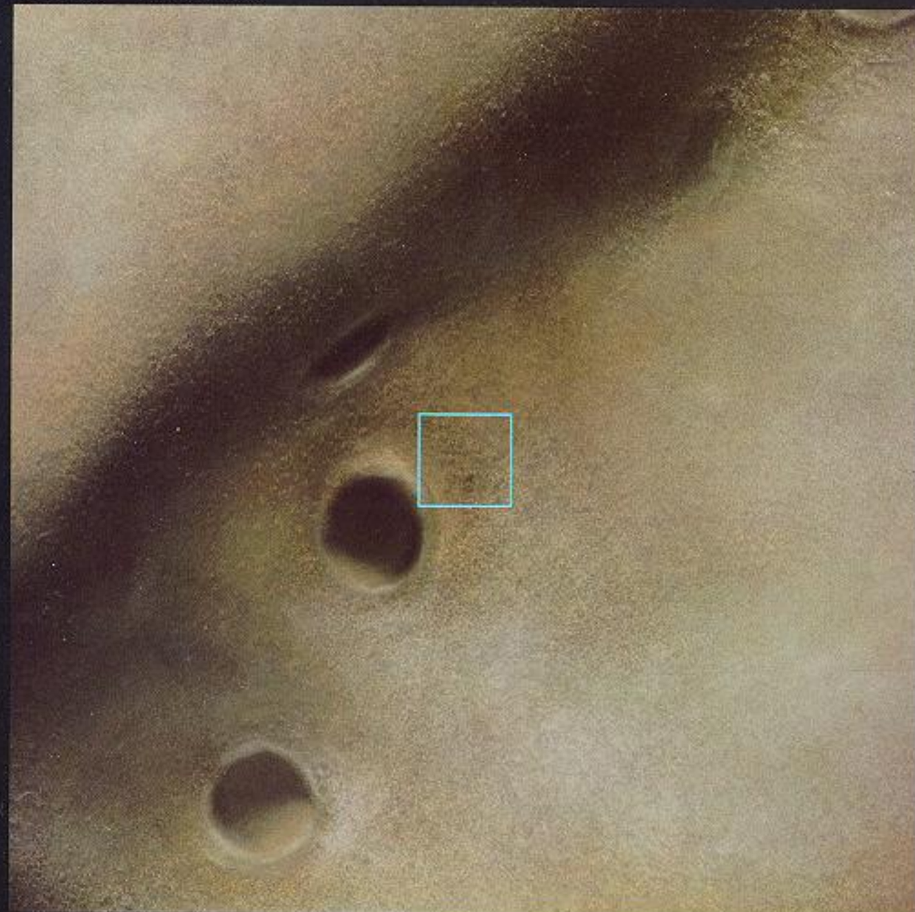
10 microns

10^{-5} meters

We pass through the living skin to enter a capillary vessel, where blood oozes by. Most blood cells are the small, incomplete, short-lived disks that give red blood its color; this white cell, a lymphocyte, is a long-lived participant in the complex cellular and chemical strategy called the immune system, the body's defense against infection.

1 micron 1 micrometer

10^{-6} meters



We are inside the ruffly lymphocyte, only to face another surface, a protective membrane within the cell that encloses its nucleus. The minute pores allow materials from within to enter the larger volume of the cell. Every complete cell has such a nucleus, whose molecular products inform the entire life of the cell. In one human body are a hundred times more cells than there are stars in the Galaxy.

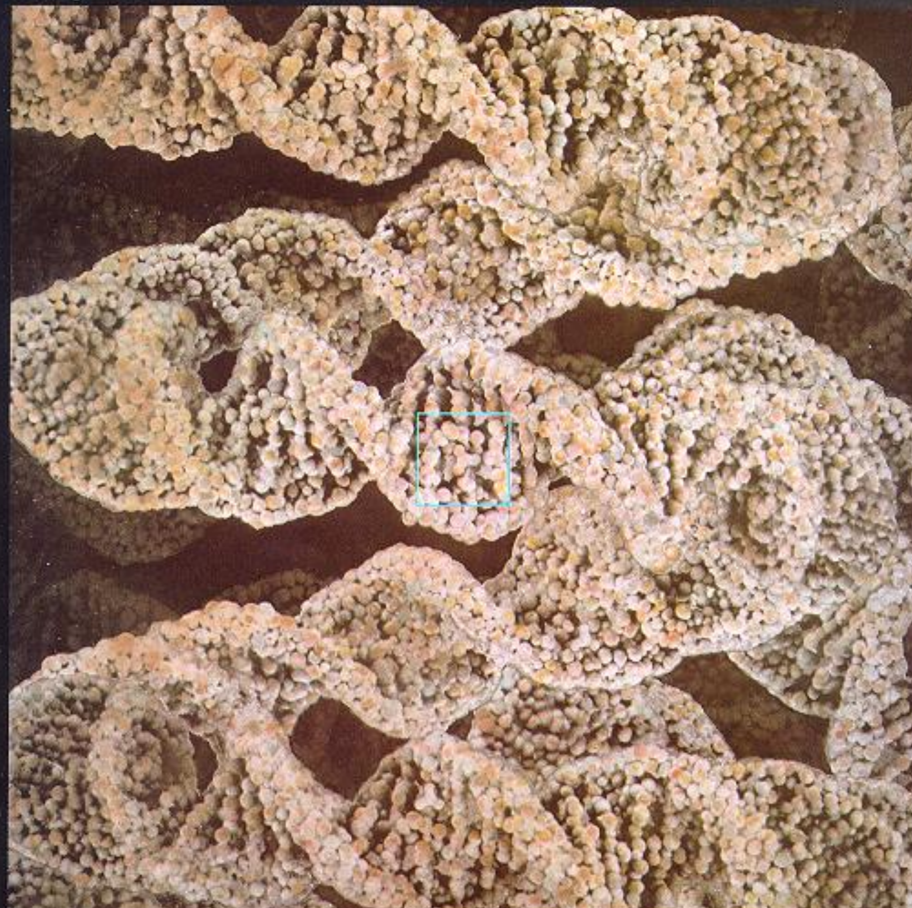
10^{-7} meters

0.1 micron 1 thousand angstroms

Held safely inside the cell nucleus are enormously long molecules, the coiled coils of DNA, cunningly spooled and folded within this tiny space. These vital instructions are carefully duplicated at every cell division. One such thread of DNA, a few centimeters long, is stored in each of the forty-six chromosomes within the nucleus of every human cell.

100 angstroms

10^{-8} meters



In this close-up the DNA is seen as a long twisted molecular ladder, the double helix. The individuality of the organism is held in the running sequence of the differing rungs. That chemical message is spelled out at great length in a molecular alphabet of four letters. One alphabet serves all life, but the tale retold in every cell of the body differs from individual to individual. The two rails of the ladder come apart during cell duplication, each to act as a template for one complete new copy of the ladder of rungs.

10 angstroms   1 nanometer

10^{-9} meters

These building blocks are molecular typography, the letters of the genetic message. It is their particular order that spells out the long text. The forms are chemical patterns, the ordinary stable structures of bound atoms, themselves indifferent to life. The central carbon atom is bonded to three visible hydrogen atoms (and to another atom that lies behind). A similar linkage might well be found abundantly among carbon and hydrogen atoms drifting in the cold thin clouds of interstellar space.

1 angstrom

10^{-10} meters

The quantum laws of atomic scale require a description of electron motion that is more subtle and less sequential than for the moving particles of ordinary experience. Accordingly, the dot texture shown does not map individual electrons; instead, it suggests the cloud of electrical charge the electrons paint out during their symmetrical but untrackable quantum pattern of motion. In that cloud the surface electrons are shared by the bonded atoms.

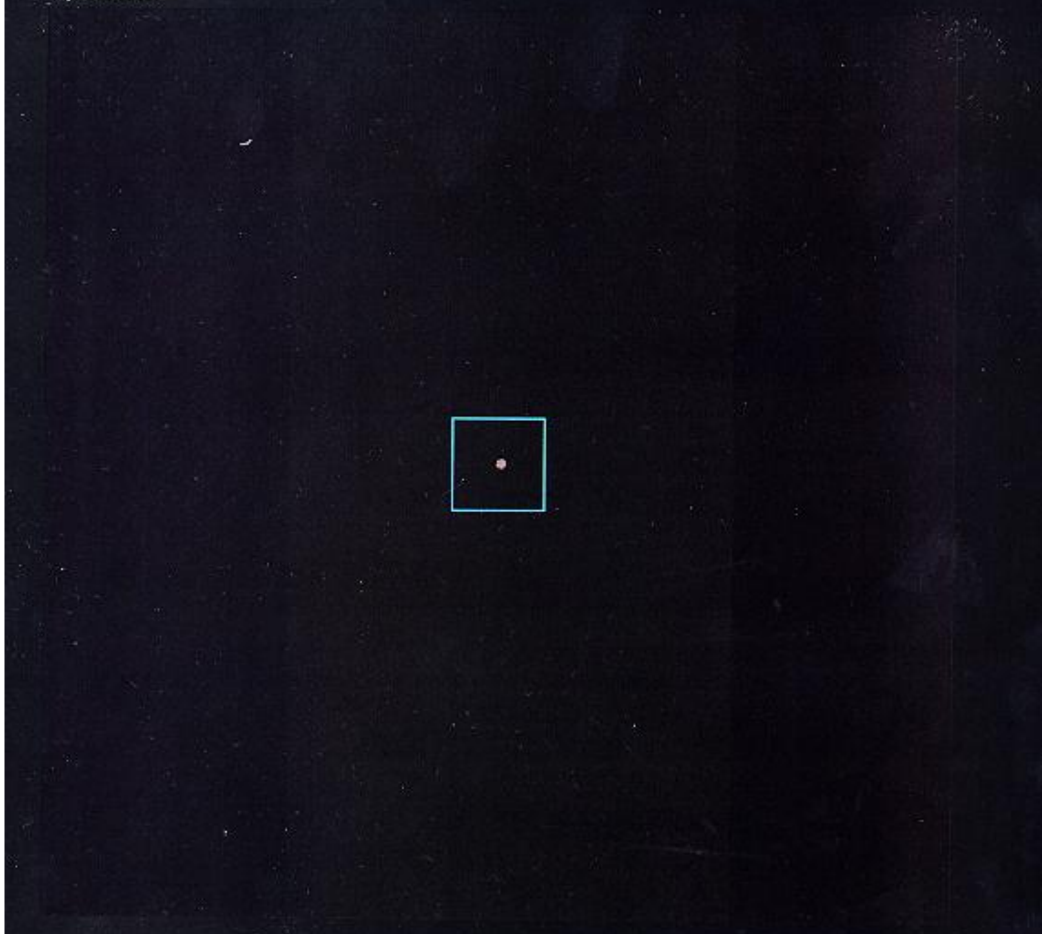
10^{-11} meters

0.1 angstrom 10 picometers

Now we are among the two innermost electrons of the carbon atom. They mark out in their dance a neat sphere of electric charge. The four outer electrons of carbon can come and go, whether in flame, in diamond, or in DNA. But these inner electrons remain indifferent to ordinary experiences, which cannot disturb their seclusion; they respond only to the nucleus within.

1 picometer

10^{-12} meters



The compact core of the atom begins to appear. The balance of atomic force is set by this nucleus, whose strong electrical attraction binds the electron dance. To bind six negatively charged electrons, exactly six positive protons must cluster within the nucleus: That number (the atomic number) defines the element carbon. We know about a hundred distinct species of these tiny proton clusters, the elements: Modular but diverse, they determine the material universe.

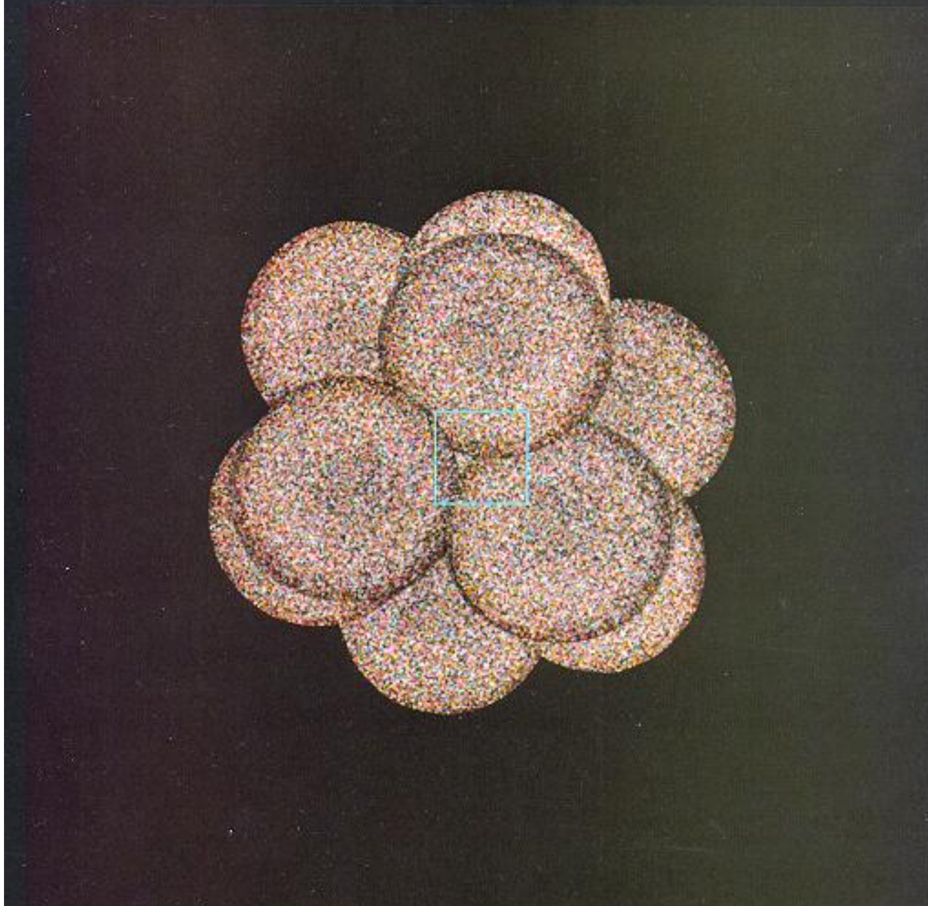
10^{-13} meters

0.1 picometer 100 fermis

We see clearly the minute and massive kernel of this particular carbon atom. Its close-packed nuclear components are in vigorous quantum motion, but here the motion is profoundly restricted and fluidlike. Bound by nonelectrical nuclear forces of terrible strength but of very limited reach, the six neutrons and six protons seem to touch. With twelve nuclear particles, this nucleus is dubbed carbon-12: The most common isotope of carbon, it is the modern standard of atomic weight.

10 fermis

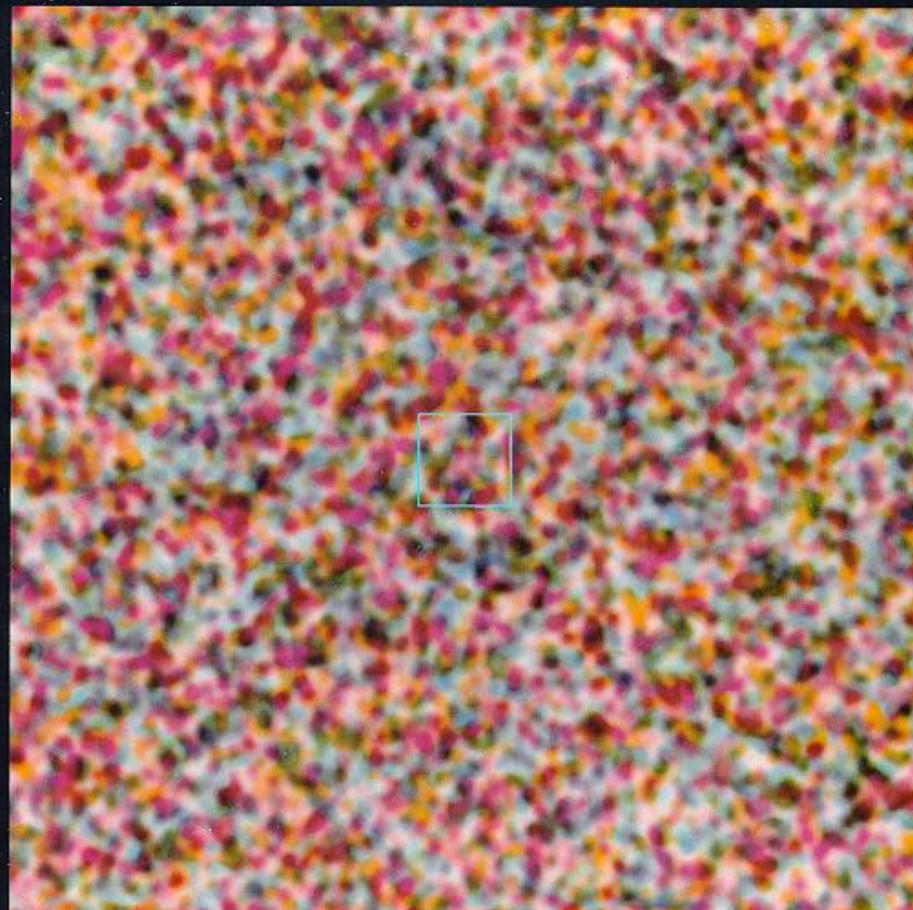
10^{-14} meters



A transient view of the eternally dancing structure of stable carbon-12. Those neutrons and protons that join to form it are universal nuclear modules. Protons are found free as natural hydrogen; neutrons can be set free by energetic nuclear reaction as in the fission of uranium. Study of these particles as independent objects has revealed one more analogue to chemistry: They too react upon collisions at high enough energy to produce a host of new particles, mostly transient ones.

10^{-15} meters

1 fermi

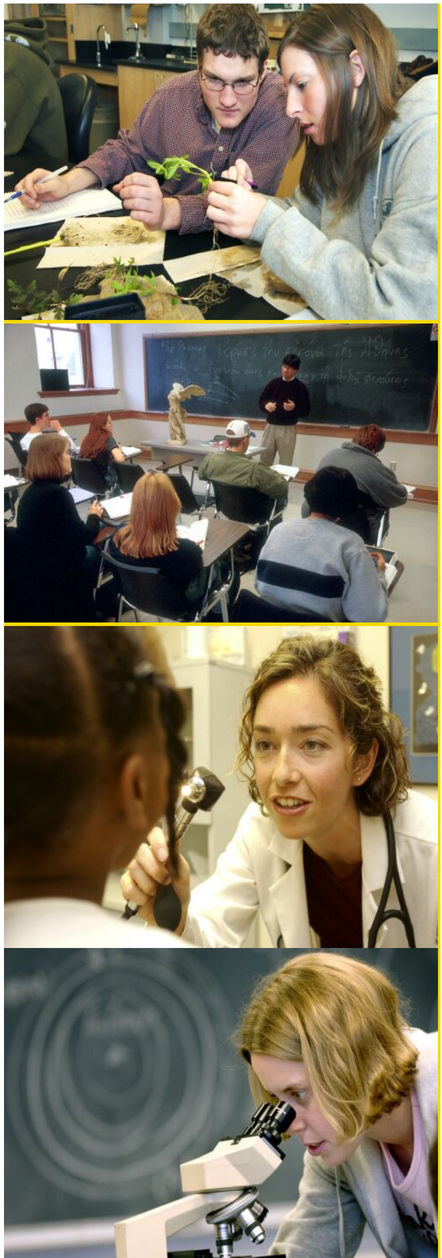


Even the proton has its inner structure, symmetrical, shifting, again untrackable. Here still stronger forces operate at still shorter ranges. These arise among fast-moving quarks in intense interaction. The pattern of colored dots is no photo but an abstract symbol of the physics we just begin to comprehend.

10^{-16} meters

0.1 fermi

What will we see, and what will we come to understand, once we enter the next levels?



The University of Iowa

Technology: Electron microscopes to radio-telescopes has enabled us to visualize these things

BIOSPHERE

All those regions of Earth's waters, crust, and atmosphere in which organisms can exist

↓↑

ECOSYSTEM

A community and its physical environment

↓↑

COMMUNITY

The populations of all species occupying the same area

↓↑

POPULATION

A group of individuals of the same kind (that is, the same species) occupying a given area

↓↑

MULTICELLED ORGANISM

An individual composed of specialized, interdependent cells most often organized in tissues, organs, and organ systems

↓↑

ORGAN SYSTEM

Two or more organs interacting chemically, physically, or both in ways that contribute to survival of the whole organism

↓↑

ORGAN

A structural unit in which a number of tissues, combined in specific amounts and patterns, perform a common task

↓↑

TISSUE

An organized group of cells and surrounding substances functioning together in a specialized activity

↓↑

CELL

Smallest unit having the capacity to live and reproduce, independently or as part of a multicelled organism

↓↑

ORGANELLE

Inside all cells except bacteria, a membrane-bound sac or compartment for a separate, specialized task

↓↑

MOLECULE

A unit in which two or more atoms of the same element or different ones are bonded together

↓↑

ATOM

Smallest unit of an element (a fundamental substance) that still retains the properties of that element

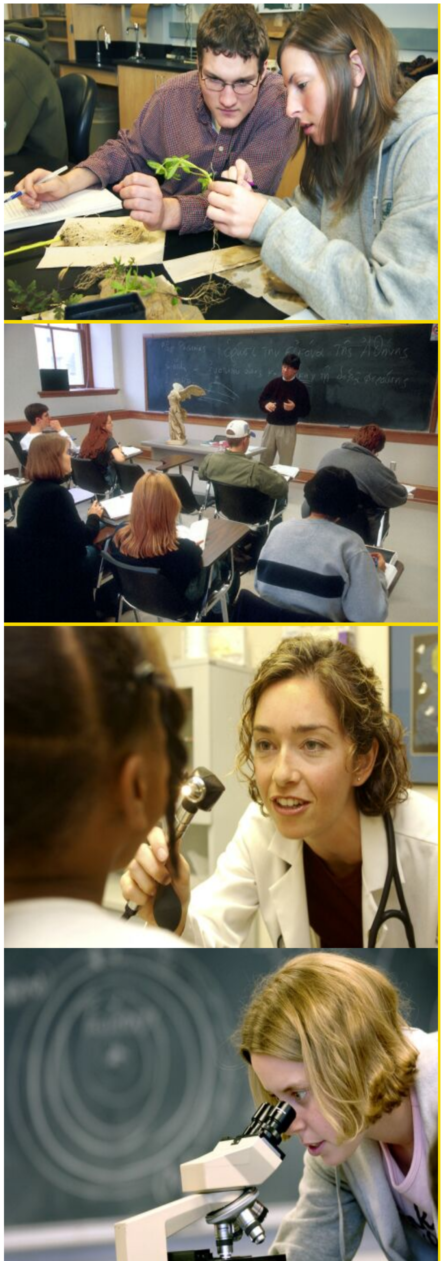
↓↑

SUBATOMIC PARTICLE

An electron, proton, or neutron; one of the three major particles of which atoms are composed

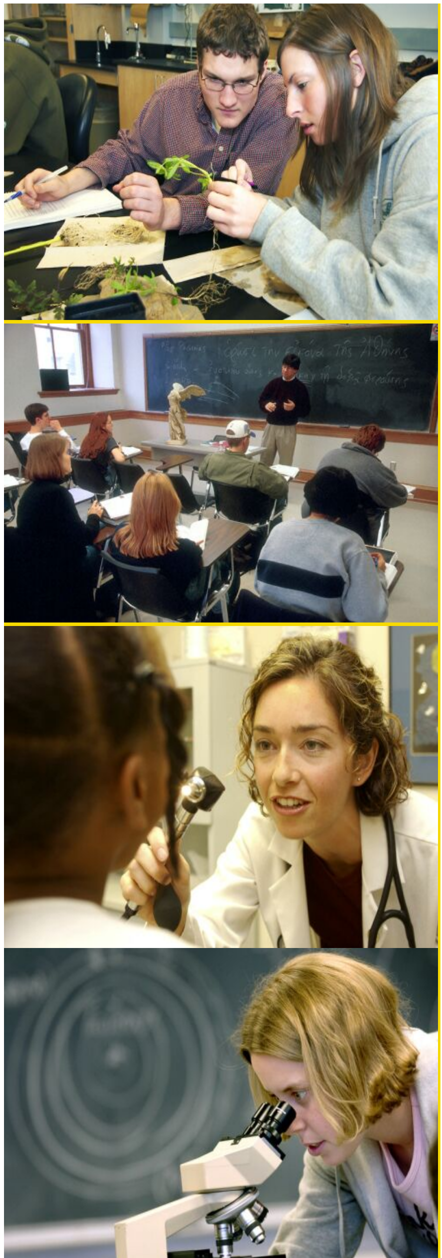
Function: The purpose or why a system is organized in a particular way defines its function (such as biogeochemical cycling).

The University of Iowa



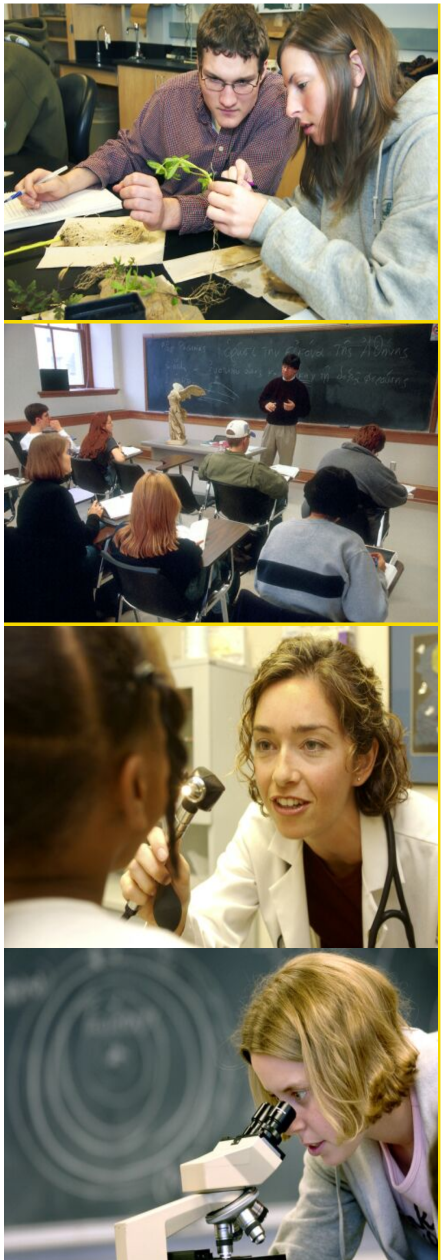
Function: In the case of humans, some of the functions include circulation, respiration, digestion, reproduction, and so on.

The University of Iowa



On wrong questions -- Dan Livingston – On sensors and systems.

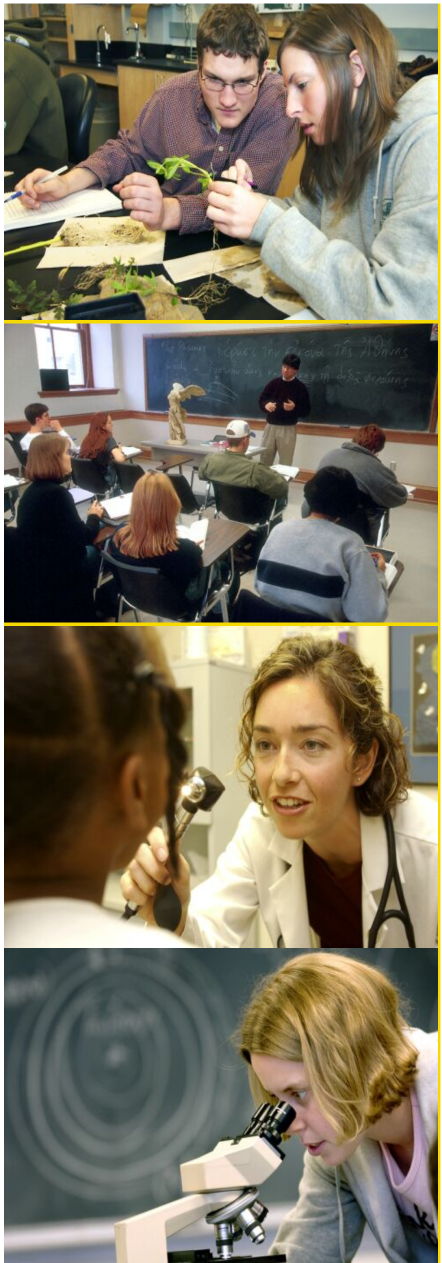
The University of Iowa



The University of Iowa

Identify the functions of:

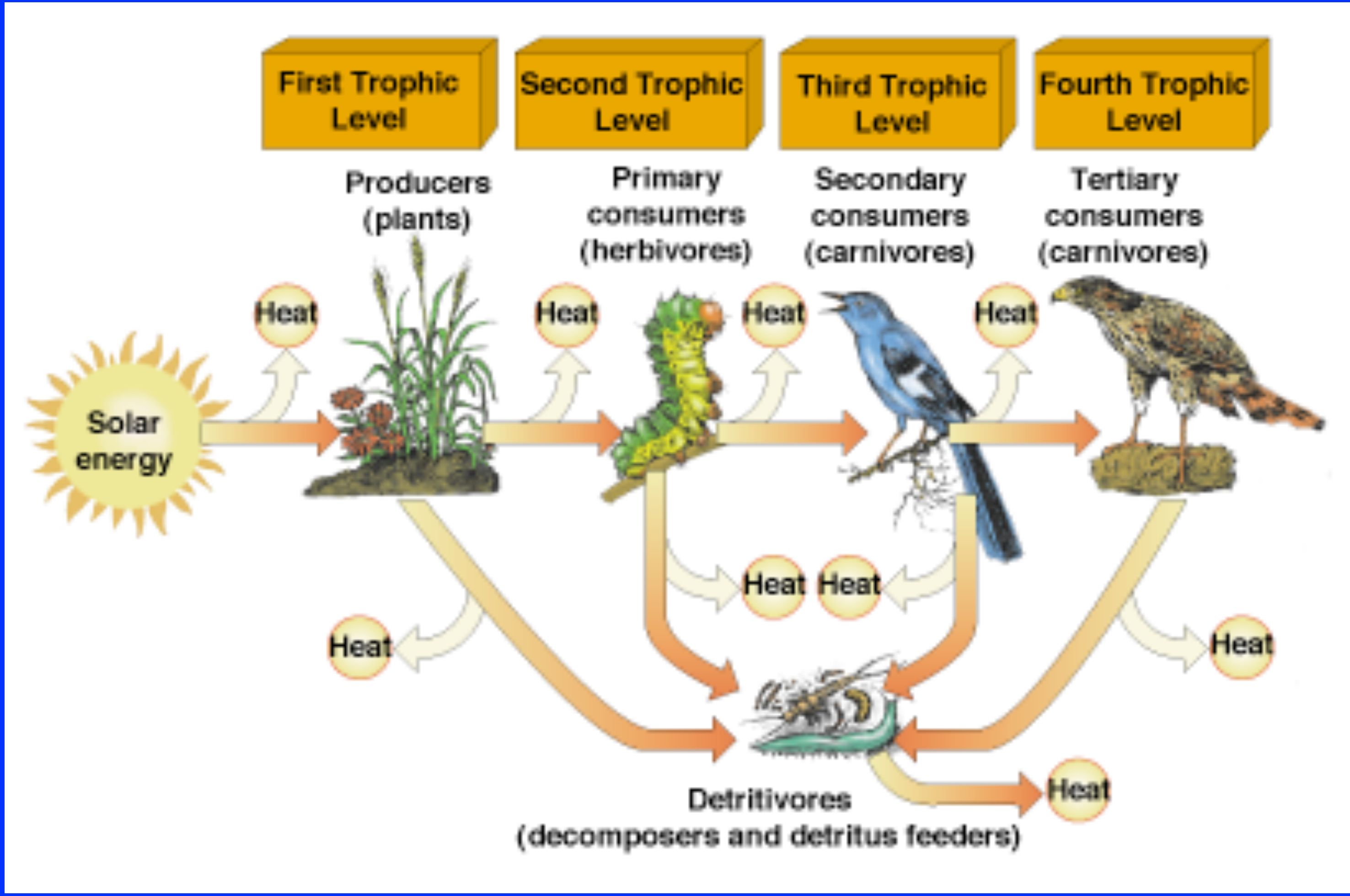
- This room
- A human body
- An automobile
- Washington DC
- Ecosystems
- Biosphere



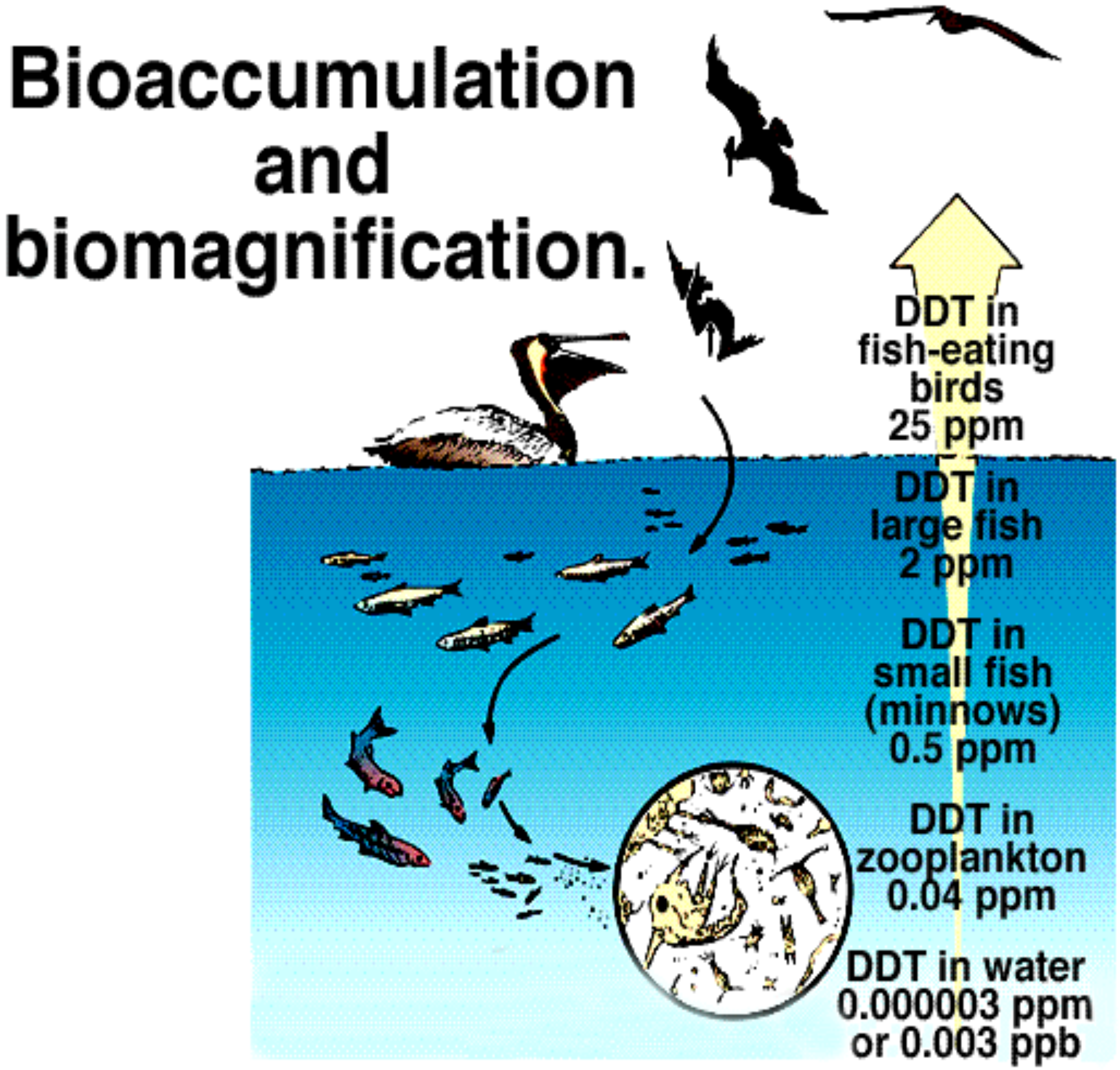
The University of Iowa

On the difference between terrestrial and aquatic systems (food chains and webs).

Terrestrial Foodchain



Aquatic Foodchain



To understand the structure and function of ecosystems?

Environmental Measurements

Units of Measurements

Environmental Measurements

Metric System

Distance	Weight	Volume	Scale
Nanometer	Nanogram	Nanoliter	10^9
Micrometer	Microgram	Microliter	10^6
Millimeter	Milligram	Milliliter	10^3
Centimeter	Centigram	Centiliter	10^2
Meter	Gram	Liter	1
Kilometer	Kilogram	Kiloliter	10^{-3}

Environmental Measurements

Cubic Feet Per Second (CFS): A measure of the volume of a substance flowing through space within a fixed period of time. (in this case, one second).

Environmental Measurements

mg/l	ug/l	ng/l
ppm	**ppb**	**ppt**
$1/10^6$	**$1/10^9$**	**$1/10^{12}$**

Environmental Measurements

- Bioconcentration
- Bioaccumulation
- Biomagnification

Environmental Measurements

Bioconcentration: The accumulation of a chemical in tissues of a fish or other organism to levels greater than in the surrounding medium.

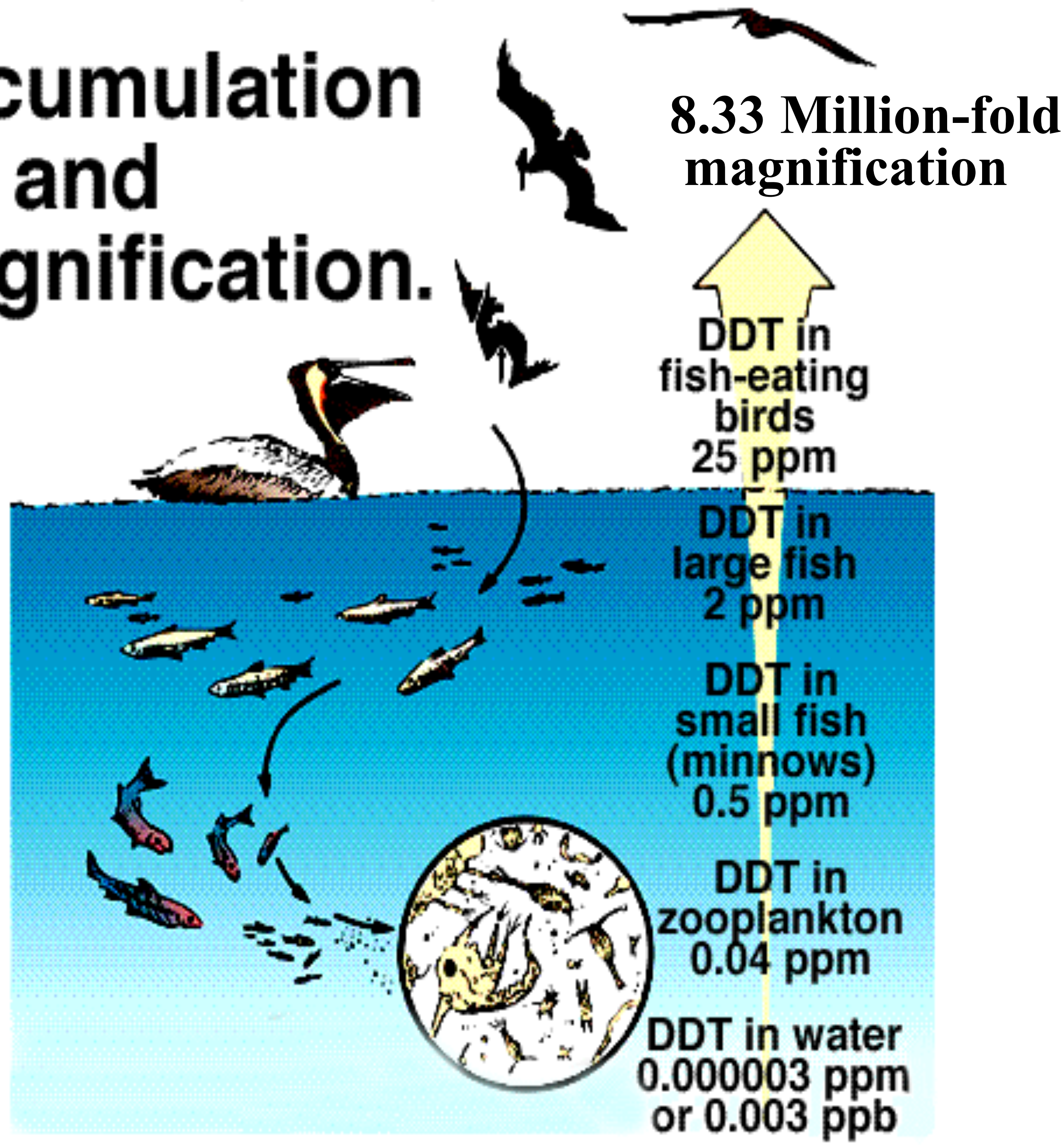
Environmental Measurements

Bioaccumulation: The increase in concentration of contaminants in living organisms as they take in air, water, or food because the substances are very slowly metabolized or excreted.

Environmental Measurements

Biomagnification: Refers to the process whereby certain substances such as pesticides or heavy metals move up the food chain, work their way into rivers or lakes, and are eaten by aquatic organisms such as fish, which in turn are eaten by large birds, animals or humans. The substances become concentrated and magnified in tissues or internal organs as they move up the chain.

Bioaccumulation and biomagnification.



Environmental Measurements

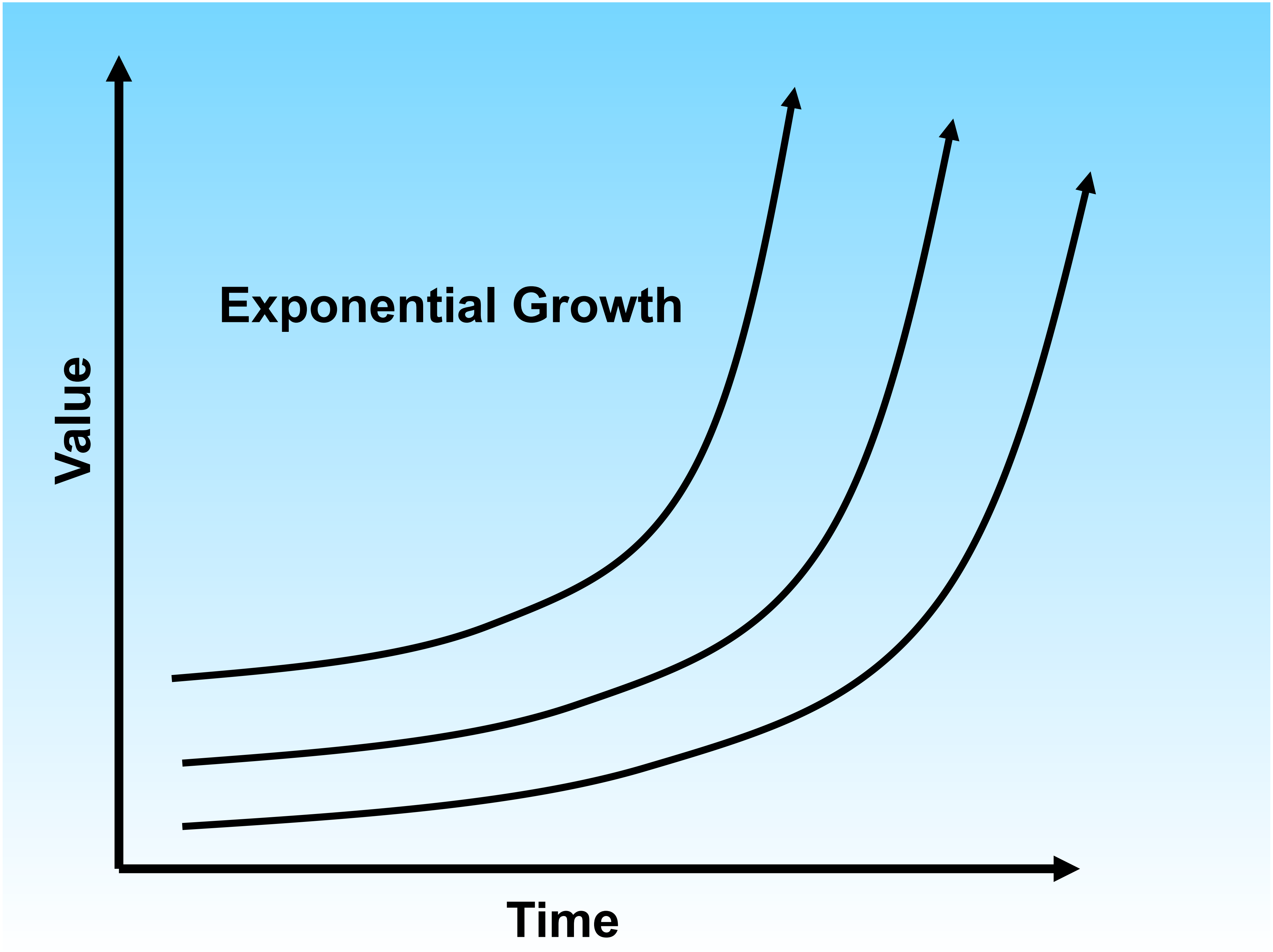
- Habitat
- Persistence
- Synergism

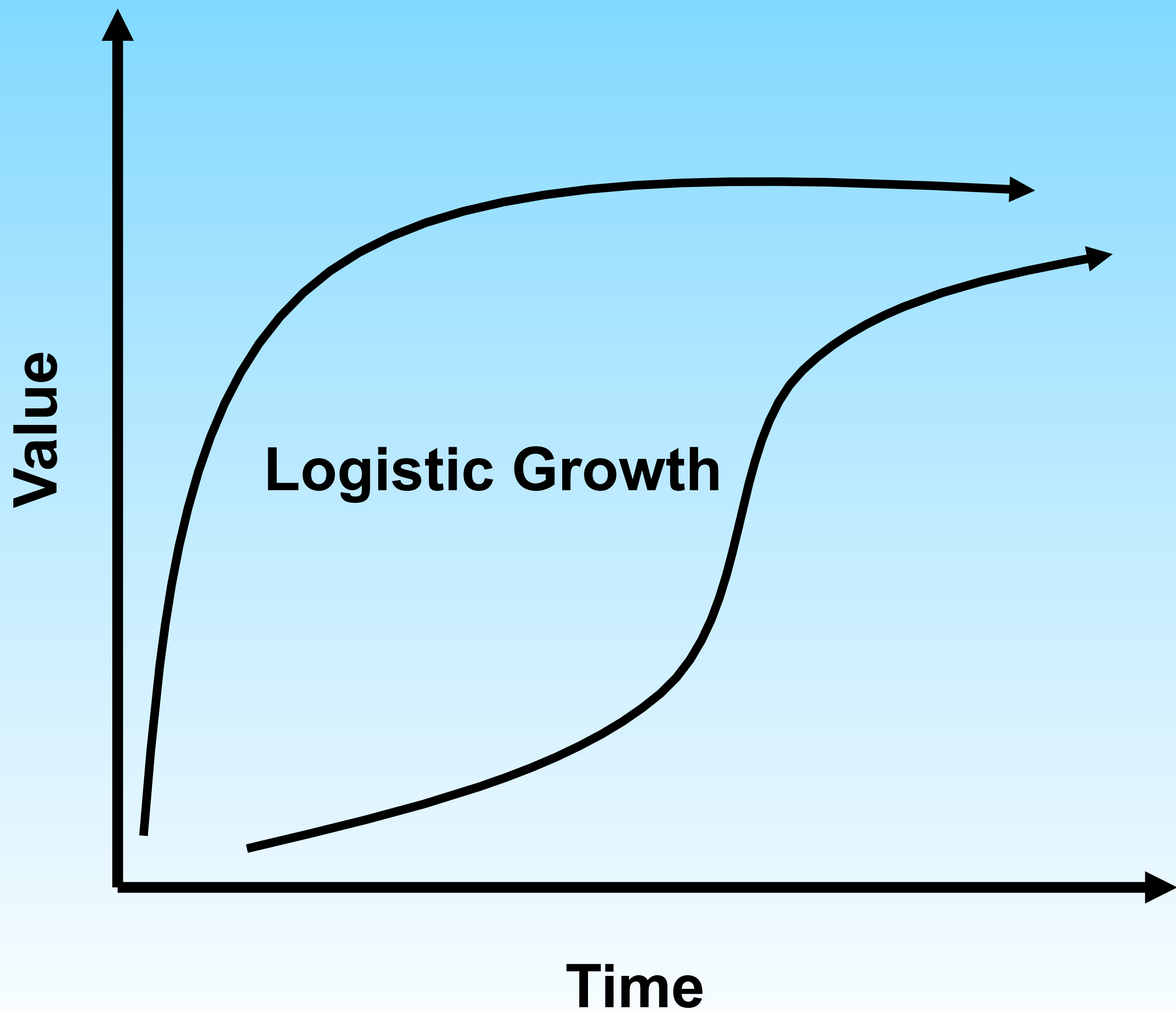
Environmental Measurements

Concepts in Growth

Environmental Measurements

- **Concepts in Growth**
  - **Arithmetic**
  - **Exponential**
  - **Logistic (Sigmoid)**


Exponential Growth
Value
Time


Value
Logistic Growth
Time

Environmental Measurements

Ecological Principles

Stability

Diversity

Complexity

Information Feedback

Positive

Negative

Self Regulation

Environmental Measurements

Stability: Persistence of structure over time.

Environmental Measurements

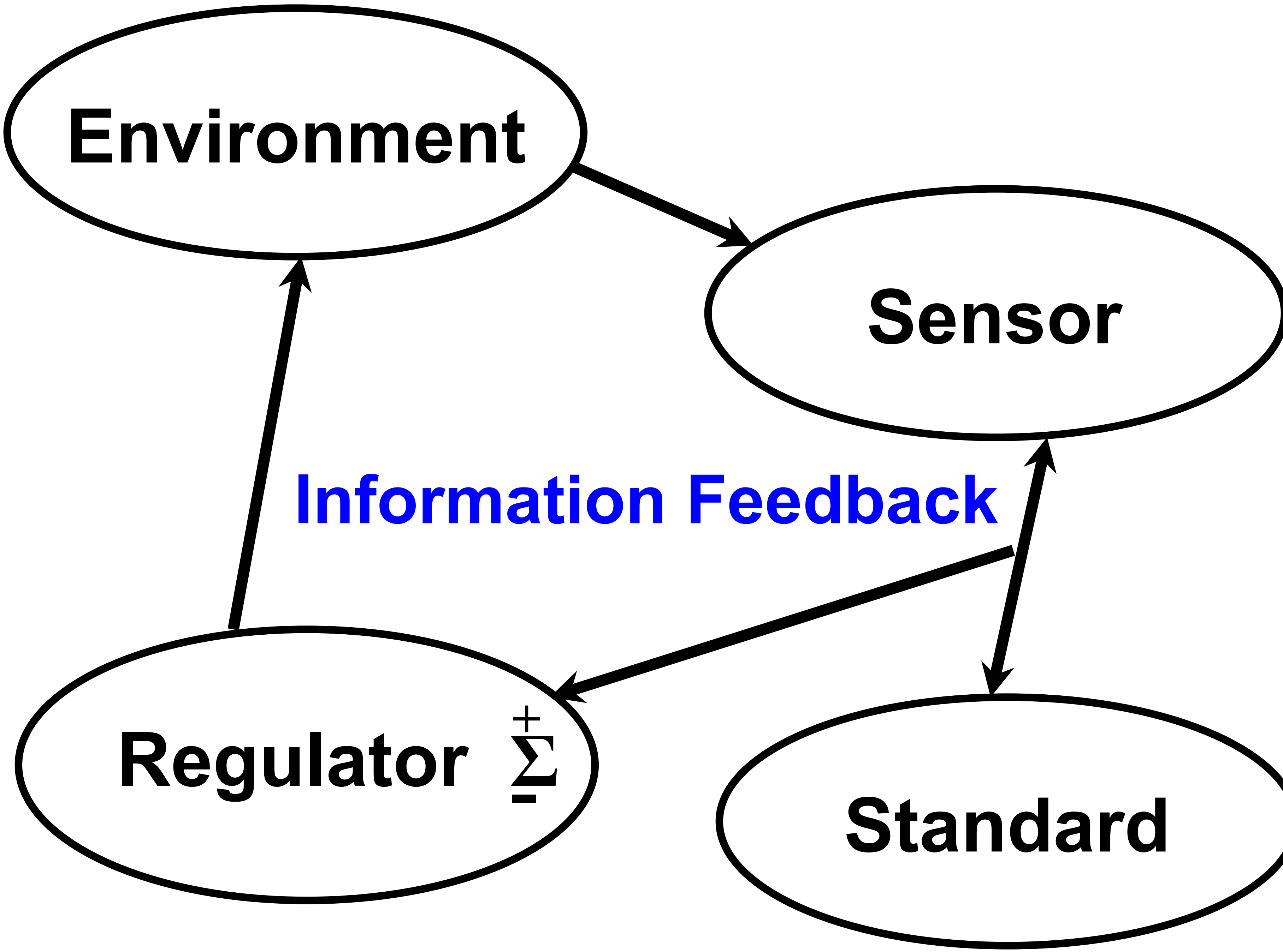
Diversity: A measure of variety and density.

Environmental Measurements

Biodiversity: Refers to the variety and variability among living organisms and the ecosystems in which they occur. Diversity can be defined as the number of different items and their relative frequencies.

Environmental Measurements

Complexity: A measure of richness of interactions in an ecosystem.



Environment
Sensor
Information Feedback
Regulator
+
Σ
-
Standard

Environmental Measurements

Information feedback systems consist of an environment, a sensor, a standard, and an action device. The sensor senses the environment, compares the result to a standard, and takes action to alter the environment resulting in a new environment. The sensor goes back to work and the process begins again. This process is known as information feedback.

Environmental Measurements

Negative Feedback: If the sensor and/or the action device is (are) able to perform appropriately and all actions lead to changes in more than one direction, the feedback is characterized as negative (Examples include: all living and functioning organisms in good health).

Environmental Measurements

Self-regulation: Ability to function within a framework of negative feedback.

Environmental Measurements

Regulation is not a bad word

Environmental Measurements

2014 Draft Report o Congress on the Benefits and Costs of Federal Regulations and Unfunded Mandates on State, Local, and Tribal Entities. OMB (2014). Office of Information and Regulatory Affairs. 107p.

Estimates of the Total Annual Benefits and Costs of Major Federal Rules by Agency, Oct 1, 2003- Sep 30, 2013 (Billions of 2010$)

Agency	# of Rules	Billions 2010$ Benefits	Billions 2010$ Costs
Agriculture	4	1-1.4	1-1.4
Energy	14	11-20	5-7
HHS	18	20-45	3-6
Homeland S	2	0-1	0.1-0.3
HUD	1	3	1
Justice	4	2-5	1-1.3
Labor	8	9-26	3-6
DOT	28	19-32	8-15
EPA	34	165-850	38-46
DOT & EPA	3	33-60	9-17
Total	116	262-1,042	69-102

Environmental Measurements

Across the federal government, the rules with the highest estimated benefits and costs, by far come from the EPA and in particular from its office of Air and Radiation. EPA rules account for 63 to 82% of the monetized benefits and 46 to 56% of the monetized costs. Rules that have as either primary or significant aim to improve air quality account for 98 to 99% of the benefits of EPA rules (OMB, 2014).