First Thoughts

Complexity = new way of thinking about collective behavior of macroscopic collections of interacting systems that can evolve in time.

These collective phenomena or emergent properties can be described only at higher levels than those of individual systems, i.e.,"the whole is more than sum of its parts" - just as van Gogh painting is so much more than collection of bold brushstrokes.

Conventional science is often blind to the connections that can be drawn in such complex phenomena.

Most scientists today restrict themselves to a detailed study of one small aspect of a single sub-discipline within one tiny branch of the tree of science

This is inevitable - advanced research has become focused on minutiae.

The background expertise and sophistication of techniques deployed in any field are so complex that it is difficult to arrive at the cutting edge of knowledge in any field without immense effort and time.

Such specialization brings with it, within every small area of inquiry, a unique methodology and jargon that is hard for an outsider to make sense of, let alone discover whether any common conceptual framework can be shared with other scientists working in different fields.

The problem, however is that most real-world problems do not fit into neat compartments.

To solve them, we must be able to communicate across traditional boundaries and approach issues in a collaborative, integrated way.

Many scientists(all specialists), feel suspicious of, if not threatened by, this message. and the present education system hardly prepares us for such an approach.

Nobel laureate Murray Gell-Mann argued that we must get away from idea that serious work is restricted to "beating to death a well-defined problem in a narrow discipline, while broadly integrated thinking is relegated to cocktail parties”.

In academic life, in bureaucracies, and elsewhere, we encounter a lack of respect for the task of integrating knowledge.

In centuries past, it was possible for intellectuals to be genuine polymaths(expertise spans significant number of different subject areas), making important contributions across a range of human thought and ideas(most ancient scientists were polymaths by today's standards.)

This seems impossible today!

Creating Complexity

For complexity to emerge, 2 ingredients necessary as we will find out.

First, is an **irreversible medium** where things happen such that time flows from the past(closed system) toward the future(open system).

The reason for stating the obvious here is that laws of motion used to describe behavior of matter on microscopic level **do not distinguish** one direction of time from another.

Yet we know from tendency of ice cubes to melt that a preferred direction of time is singled out at the macroscopic level.

The second ingredient is **nonlinearity**.

We are all familiar with linear systems, which have been the mainstay of science for 300 years.

A typical linear relationship for some system implies that a system + an infinitesimal perturbation always remains close to the original system.

Using such a relationship we can predict that the volume of water flowing down a drain doubles when tap drips for twice as long.

Nonlinear systems **do not obey** such simple rules of addition.

Nonlinearity allows small changes on one level of organization to produce large effects at the same or different levels.

Nonlinearity also produces “complex” and frequently unexpected results.

Irreversibility and nonlinearity characterize phenomena in all sciences.

For example, the complexity of markings on butterfly's wings or leopard's spots, the shape of spleenwort fern, and the rhythm in living systems such as palpitations of a heart, the firing of nerve cells within brain, etc.

Related, but more subtle, chaotic forms of complexity also arise from nonlinearity.

For example, apparently random weather patterns, outbreaks of flu epidemics, spread of information and ideas, etc.

The Origins of Complexity

Matter has an innate tendency to “self-organize” and generate complexity.

Starting with the birth of universe at the "big bang”……………..

At first, matter consisted of soup of elementary particles and fields, but within a billionth of second of Big Bang, it coalesced into subatomic particles (quarks, leptons, and gauge bosons).

These common building blocks obey straightforward mathematical laws, yet they generated structures of remarkable complexity such as galaxies, stars and planets.

Energy and chemical elements produced by stars have led to emergence of intricate structures such as organized human brains, etc.

But cosmology, astrophysics, and particle physics are far from whole story.

In case of life on earth, complexity in nature is affected by competition for finite resources.

Darwin popularized the notion of survival of fittest - the struggle of every species - and every individual within that species - to adapt or optimize its ability to survive.

As time goes by, an individual's environment - and therefore its chance of survival - is subject to changes as food supplies become exhausted, local climate alters, or a killer virus spreads.

As other species evolve and compete within same environment, an organism must continually adapt in order to survive.

A monkey is only one of millions of patterns in space and time resulting from evolution of a rainforest.

A monkey embodies a vast range of complexity, from chemical reactions within its cells to electrical activity within its brain.

Comprehending the complexity of life is the biggest challenge facing modern science.

Savoring Simplicity

For millennia, those seeking to understand natural world have been seduced by simplicity.

Their mission has been to reduce the universe down to its component parts.

This so-called **reductionism** is the quest to explain complex phenomena in terms of something simpler - something with very simple parts.

Nowhere is the reductionist view more prevalent than in elementary particle physics, where the drive is to find a "Theory of Everything" expressed as a few equations that describes the fundamental interaction between all forms of matter.

What used to be physicist's best game in town - searching for simplest components of matter, the elementary particles, and their origins - is, however, not looking so good since no one has been able to find the fundamental components and their simple laws even though search has been decades long.

Even worse is the increasing lack of contact of many of the new theories with the observable or “real” world.

In life sciences, the "doctrine of DNA” followed from discovery by Franklin, Crick and Watson in 1953, of the double helix structure of DNA molecule.

The science of molecular biology arose and thereafter, large parts of biology could be rationalized on basis of molecular actions.

No one can deny tremendous impact on our lives of this triumph of reductionism.

Because of its power, reductionism is all too often perceived as the universal route to understanding.

Yet it has driven a wedge between science and other aspects of human life.

Reductionism, used naively, offers an analysis of phenomena by splitting them up into their smallest possible pieces

Modern science, however, is so good at splitting problems into pieces that one often forgets how to put them together again or simply puts them together incorrectly.

People are depicted as little more than survival robots who spread genes.

Pain, suffering, and civil disorder are nothing more than manifestations of defective genes, and so on.

The reductionist view that everything can be boiled down to atoms and molecules is widely viewed by nonscientists as a philosophy that erodes our belief in "humanity" and the value we place on it.

After all, basically, a human body = few dollars worth of chemicals.

Moreover, if mankind is ruled by natural forces, by deterministic mechanisms, we cannot develop a theory of human action based on free will.

The vision of world that naive reductionist science has proclaimed is a cold and solitary one that sets mankind apart from an unseeing and uncaring universe.

This is not an inspiring image, and has led many to be critical of science and the scientific method, since they have little bearing on much of human experience.

As a result, this austere world-view has been instrumental in promoting a view of science as separate from rest of human culture.

Complexity allows for a more holistic perspective and insights into many difficult concepts, such as life, consciousness, and intelligence, that have consistently eluded science and philosophy.

For example, the question of whether viruses are living or nonliving is frequently debated.

From point of view of complexity, the question is meaningless, since life is a property of large collection of entities undergoing evolution or natural selection, rather than a term that can be applied to any single entity within it.

Indeed, there is growing support for basing a description of life on **emergence** and **complexity** as we shall see.

Life is not some sort of essence added to a physical system, but neither can it simply be described in ordinary physical terms.

It is an **emergent** property which manifests itself when physical systems are organized and interact in particular ways.

In the animal kingdom, there is similar debate over where to draw the line defining the place at which consciousness and intelligence begin and actions of unthinking automata end, although it certainly depends on complexity of nervous system involved.

One of the long-term implications of acceptance of evolution is that we see all of life as a continuum, therefore there is no precise break between other animals and ourselves ..... the more we become aware of some very human-like capacities in animals such as higher apes, I think, the more worried one is that they may have something at least beginning to approximate consciousness.

For similar reasons, artificial life, artificial consciousness, and artificial intelligence cannot be assigned simple sharp boundaries dictated by a reductionist world-view.

The human brain is supreme example of complexity achieved by biological evolution.

Nowhere is tension between reductionism and emergence more keenly felt.

It is clear that the brain's functioning depends on wealth of microscopic, cellular, and subcellular detail, yet it is equally evident that its extraordinary capabilities are **emergent** properties of entire organ.

Consciousness is one such property, and from it flows human emotions and other values.

Thus, through its emphasis on study of the whole, rather than individual parts, complexity offers means for transcending materialistic limitations of reductionism and allows us instead to to build a bridge between science and the human condition.

Now on to the details.

We start with Chaos and Fractals.

This will build up our knowledge in several areas
that we will need for our later understanding