Lecture #4

Mind and Science.

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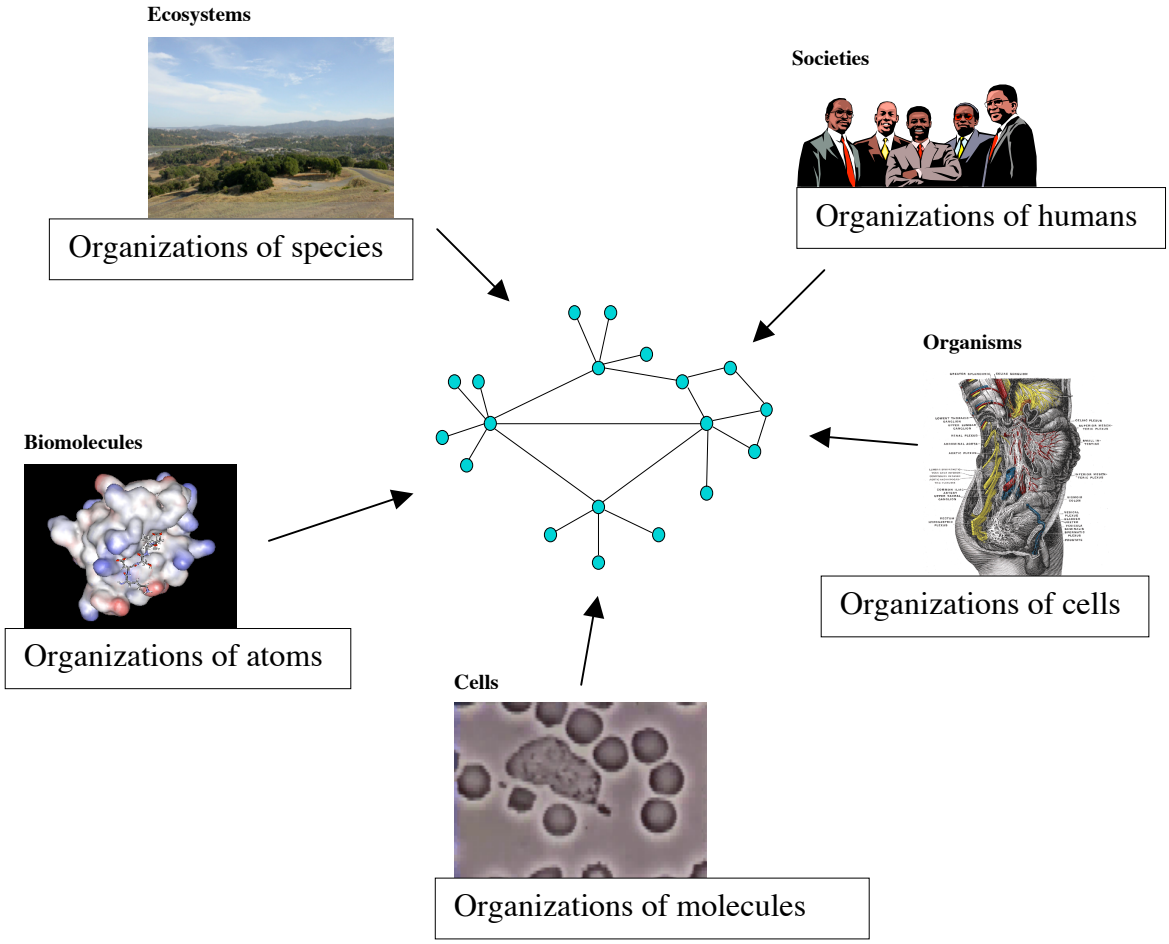
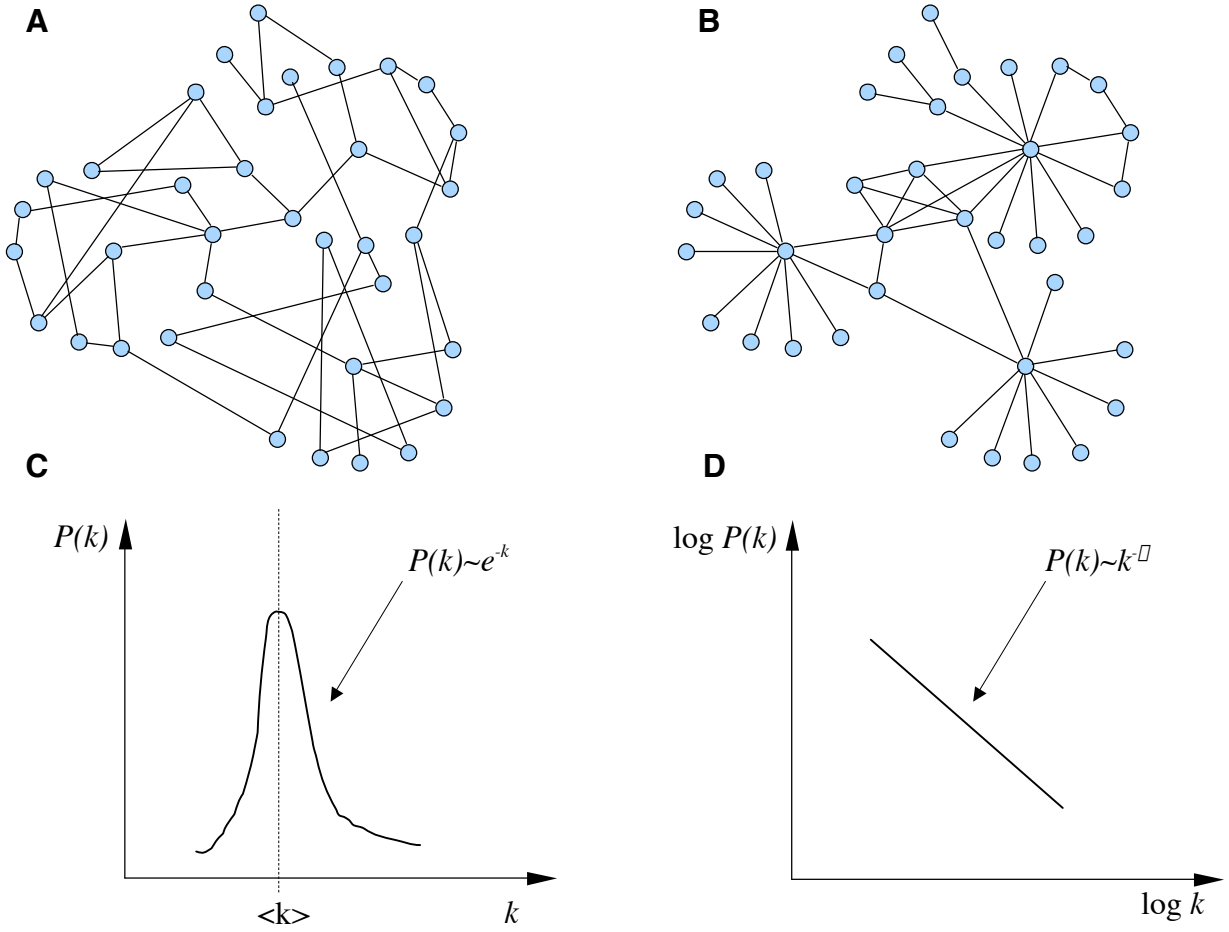
Networks

In the course of previous lectures we have introduced a network formalism in order to describe complex systems and to analyze their organizational structure. Certain properties stemming from organization of a system are independent on the nature of the components comprising the system, cannot be inferred from the studies addressing properties of isolated parts and, therefore, represent emergent properties of a system. The complex systems shown in *Slide 1* and many others can be represented in the form of a network, as a set of nodes and connections between them.



Slide 1. Network representation of organizations co-existing and co-evolving on different spatio-temporal scales.

The node can be any discrete system – molecule, human individual, power station, neuron, airport, computer, scientific article, etc. A connection can be, respectively, physical association, social interaction, high-voltage transmission line, synapse, flight route, data cable, citation, etc. We have learned as well, that there are different types of networks described, respectively, by different mathematical models. As an example we considered two major classes of networks, random and scale-free networks (see *Slide 2*.)



Slide 2. Examples of A) random and B) scale-free network. Both networks have 36 nodes and 44 links. However the organization of connections makes the difference. In the random network majority of nodes have 2 or 3 connections, making distribution of connectivities homogeneous. In the scale-free network contribution of hubs to overall connectivity of the network is dominating. *P(k)* is connectivity distribution, which in general case defined as the probability that a randomly chosen node in a network has exactly *k* links. For a given network *P(k)* is a fraction of nodes that have *k* links. **C)** For random network *P(k)* follows Poisson distribution, peaks at average connectivity <k> and exponentially decays at larger *k*. **D)** In scale-free networks dominated by a relatively small number of hubs *P(k)* follows power law.

Adopted from Jeong H, Tombor B, Albert R, Oltvai ZN, Barabasi AL. 2000. The large-scale organization of metabolic networks. Nature. 407(6804): 651-4.

On the left side of the slide you can see an example of random network and on the right side of the slide an example of scale-free network. Both networks shown have the same number of nodes, 36, and connections, 44. The nodes are positioned in the same spatial locations relative to each other in both examples. What is different between these two networks is ***the organization*** of connections between the nodes. In the random network each node has approximately the same number of connections. It is homogeneous in this sense. The contribution of any node to the overall connectivity of the network is approximately the same. The scale-free network has, on the other hand, very inhomogeneous distribution of links. There is a small, but significant number of nodes with large numbers of connections, while most of the nodes have very few links. Obviously, the contribution of highly connected nodes, or hubs, to the overall connectivity of the network is dominating, while the contribution of most of the nodes is relatively insignificant. We have learned as well that the connectivity distribution is one of the mathematical parameters that can be used for classification of networks. If you have a complex system to study, you can often represent this system as a network, or an ensemble of nodes and connections between them, and analyze the connectivity distribution of this network. If it follows a Poisson distribution, your network is a random network. If the connectivity distribution of your network obeys a power law, then it is a scale-free network. Having classified the network, you can then apply respective mathematical models to deduce the systemic properties of your complex system that stem from its organizational structure. The network formalism has opened an exciting opportunity to apply the powers of modern mathematics and computers to the unified description, analysis and simulation of a variety of different complex systems.

We have discussed a few remarkable discoveries that have emerged recently from the studies performed on model and real-world networks. First, the organizational structures of the majority of complex systems analyzed up to date from the domain of life, and those include social networks, airport networks, Internet, language conceptual network, cellular metabolic and protein interaction networks, etc., are described by scale-free network models. Remarkably enough, the power law connectivity distribution observed in real-life systems is emerging as one of the few universal mathematical laws of life. The second intriguing discovery is that a number of common emergent properties of different complex systems can be attributed to their scale-free organizational structure. These properties are:

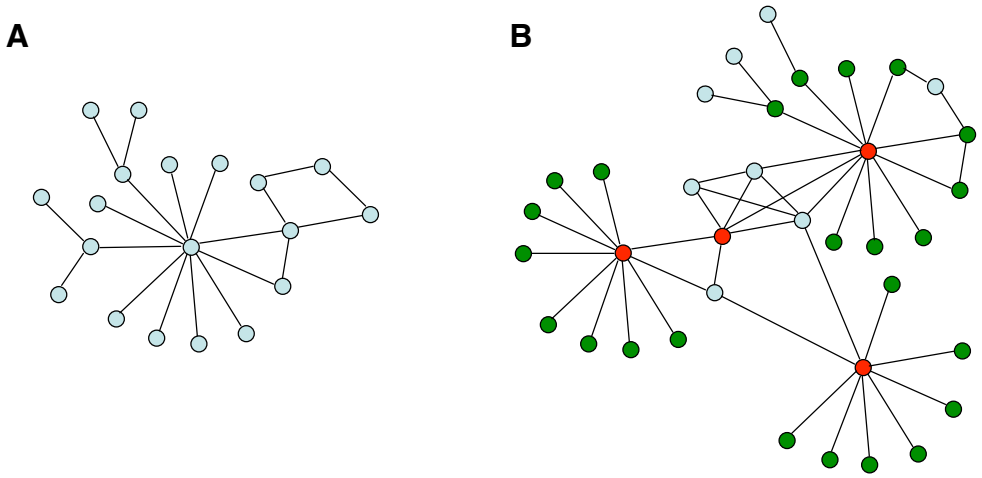
- existence of a relatively small, but significant number of highly-connected nodes;
- self-similarity (i.e. any part of the network is statistically similar to the whole);
- a relatively small diameter (i.e. any two nodes can be connected via few other intermediary nodes);
- high degree of tolerance to random failure of nodes;
- susceptibility to failure of highly-connected nodes.

plus “small-world” properties, such as:

- rapid propagation of information and energy in the network;
- rapid synchronization of distant nodes;

- enhanced computational power.

Since the network analysis is independent of the nature of the complex system, it is emerging as an extremely convenient tool for interdisciplinary research, for it allows visualization and comparison of many different complex phenomena within a unified conceptual framework, including those phenomena and systems that up to now defied any rational description. Besides providing insights into organization and workings of a system under study, the network description often reveals unexpected and remarkable similarity of patterns underlying dynamics and organizational structure of different complex systems. All the power and ramifications of the network conceptualization of different life forms have just began to be appreciated and new discoveries and surprises are warranted in the imminent future.



Slide 3. Different types of business organizational structures are represented by networks of different topology. A) Monarchy-type entrepreneurial company (take Ford Motor Company circa 1903, as an example) has a star topology. The performance and success of the organization is heavily dependent on capabilities and performance of one individual (Henry Ford, as an example) at the center of structure. Nodes are people. **B)** Democracy-type well-developed modern corporation (take the same Ford Motor Company today) is suggested to have a scale-free topology. Green nodes here are groups of people (departments) and highly connected nodes (red), or hubs, are committees of professional managers.
Disclaimer: The networks presented do not correspond to real structures and are used schematically to illustrate the point only.

As an example of how the network description could be helpful for understanding of complex phenomena we have considered the path many successful business firms follow in their development – the evolution from entrepreneurial or monarchy-type organization such as, for example, the Ford Motor Company in 1903 to a modern, well-developed democracy-type corporation like the same Ford Motor Company today. The performance of the monarchy-type organization, which can be approximated by a star-like network topology, is dependent in large measure on capability, knowledge and performance of one (or very few) human individual(s) comprising the center of the star network. Since capability and

performance of any human individual are inherently limited and unstable by nature, the excessive dependence on them compromises and endangers the normal development, growth and fitness of the organization in the long run. Competition between different organizational forms of businesses in conditions of market economy gradually propels the evolution of business organization through selection of most efficient (in relation to a certain cultural, economical and political context) organizational forms. Today in the large mature corporation the executive power and decision-making are passed down to and distributed among the specialized committees of professional managers. This type of organization, which can be approximated by scale-free network model, is not only more stable comparing to the monarchy-type, but is inherently more efficient and more competent, for the performance of the organization thus structured is not dependent on or limited by any human individual, but instead efficiently integrates energies, knowledge, skills and performances of many.

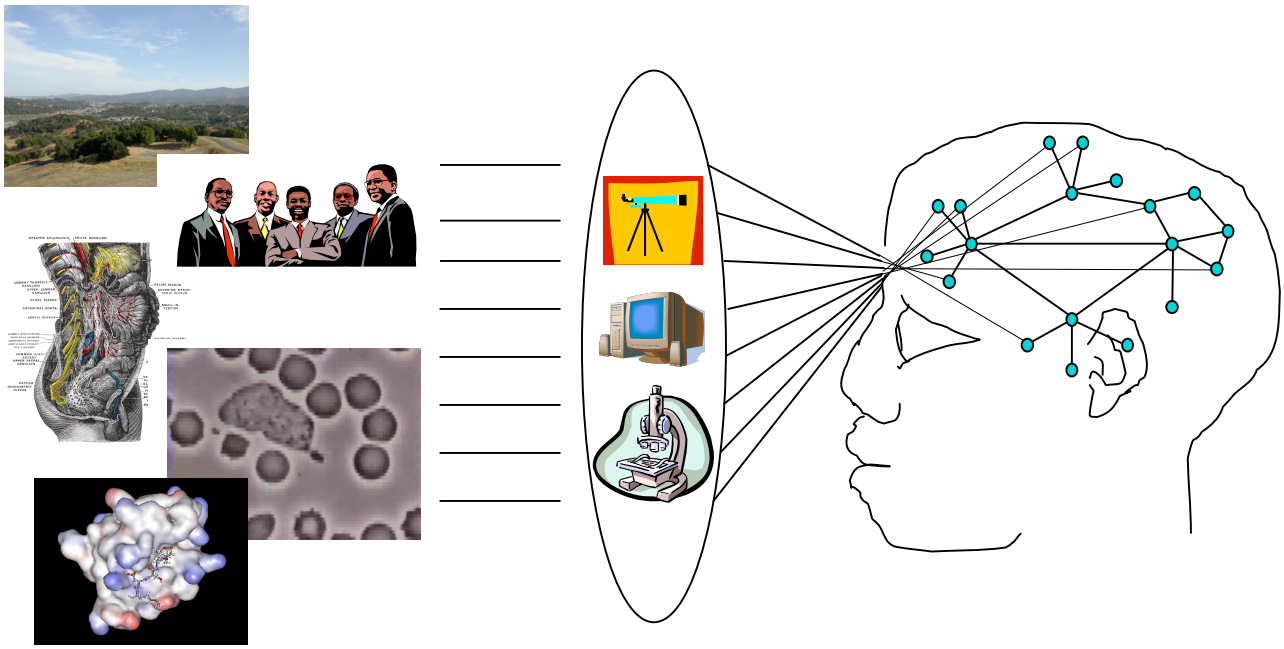
We shall continue to use network description throughout the course, but let us move to the topic of today's lecture.

Introduction

"Not knowing is true knowledge.
Presuming to know is a disease.
First realize that you are sick;
Then you can move toward health."

Lao Tzu, 600 BC

The ancient writings are often fascinating. Distorted and twisted by the intelligence of an interpreter and limitations of another language, they still manage to survive and to light up our world with their wisdom. But then I think that maybe it is the other way around - our culture has already reached such degree of development and sophistication, that a moderately good translator today is able to comprehend, to interpret and to communicate to everyone the highest intellectual achievements of ancient civilizations. And may be even to make them sound better than they were originally. Whatever the truth is, and I think it goes both ways, let me try to give one possible interpretation of the Lao Tzu's quote. What I believe was meant is the following. Consider *Slide 4*.



Slide 4. Relationship between the mind and the world. One process, evolving mind, is trying to create an adequate representation of another process, evolving objective world. Both the external world and the mind can be modeled as evolving networks that are coupled through perception/interaction.

On the left is a symbolic representation of the world, which is a constantly evolving dynamic system of interacting, interconnected and interdependent complex systems co-existing and co-evolving on different spatio-temporal scales. On the right is a symbolic representation of our cognition, or our mind, which can be thought of as another ever-evolving complex system of interconnected and interacting ideas, concepts, perceptions and feelings about the outside reality. One evolving system, or a process, our mind, is trying to make a proper representation or to model another evolving system, or a process, the world. For the sake of simplification let us freeze the outside world for a second. Imagine that it is static. Even frozen, it is still so complex, that it would take an eternity for individual mind to reach the degree of sophistication that would match the immense complexity of the world allowing comprehensive representation of the last. The world, therefore, is always only our mind's approximation of the world. Or, because our mind is evolving, it is actually a chain of approximations. With the time passing, one representation of the world becomes old and inadequate and is replaced by another, more adequate

model in an eternal effort of the mind to comprehensively describe and represent the outside reality inside us. How is the adequacy of our approximations defined? The adequacy of our representations is constantly tested through our interaction with the external world. We have a model of the outside reality. We interact with the world. If the outcome of our interaction is as expected and fit the model, then our representation of the world is adequate. If there is a systemic anomaly and unexpected reactions, then we may need to reconsider our model, adjust or even totally discard it as inadequate and replace it by a novel, more accurate representation. Therefore, the adequacy of our current model of the world is relative and defined by our performance in predicting outcomes of our interactions with the external reality. What does mediate our interactions with the outside world? - Our perception systems: vision, hearing, olfactory and tactile systems, and their ever-evolving technological extensions – microscopes (light, electron, fluorescent etc.), telescopes, radars, fMRI and PET scans, NMR spectroscopy etc – lion's part of the modern research technology are either systems of some kind of detection or systems of analysis of what has been detected. Notice please that the progress in the instrumentation, analysis and research is intimately linked, through a dialectic relationship, to the adequacy of our collective representation of the world. The faster the progress in technology and instrumentation the more precise and more varied information about the external world becomes available. The more and the better quality information is generated by research the more chances to discover surprising and unexpected observations and experimental facts that would challenge the adequacy of the current world model. What is true for our collective sub-consciousness is also true at the scale of individual human mind. The more in quantity and more manifold our life experiences are, the more we learn through living in the world, the more mature and adequate our representation of the world tends to become.

In reality the situation is more complicated because the external objective world is in a constant flow. It is changing. Therefore our mind, generating a chain of successive representations, strives to do two things simultaneously: 1) to keep up with the changing world and 2) to represent the relatively slow changing aspects of the outside reality to a more and more precise degree.

Let us return now to Lao Tzu:

"Not knowing is true knowledge." – however old, learned and wise we may be, our knowledge of the world is always a relatively primitive and coarse approximation of the reality. In addition, the world is in a constant change. Therefore, "the only thing I know is that I don't know" of Socrates.

"Presuming to know is a disease." - once we have assumed that we know something, we freeze the evolution of our cognition. We are stuck with our quickly becoming obsolete and inadequate model of that something. We are dead for development. We are mentally sick.

"First realize that you are sick;" - realization of relativity and the transient nature of any current world representation is a first and necessary step to continue with the development and evolution of our world model, the first step towards health.

"Then you can move toward health." – it does not say that we shall ever achieve health. It is a way with no end. The best our minds can do is to try to keep in harmony and synchrony with the unfolding world.

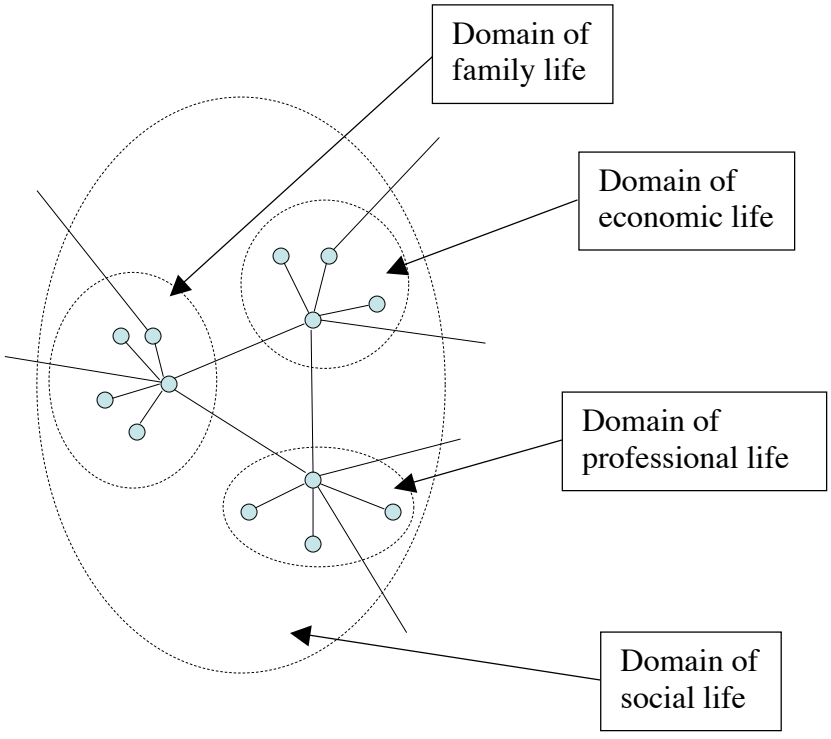
Sketches on The Network Theory of Mind.

Presented below is a model of how our mind is organized, how it develops and how it functions. It is, of course, a hypothetical model, as all of them are and will be, and therefore should be taken as such. It is an approximation. One can test and decide for oneself whether this approximation is adequate enough by applying this model as a framework to structure one's own experience and knowledge.

Definition:

Mind is an evolving metastable system of interacting, interconnected and interdependent concepts, ideas, perceptions, beliefs and feelings, which reflects and at the same time creates the objective world as our subjective representation. It is both a substrate and an instrument for our analysis, decisions and actions directed towards the world. It is integrated and interconnected and, therefore, is best represented as a dynamic network of concepts, ideas, perceptions, beliefs and feelings. It is born with us, develops and evolves as we grow older and age.

Let's consider an example of how this putative mind network could have looked like:



Slide 5. Schematic representation of the mind as a network. (See text).

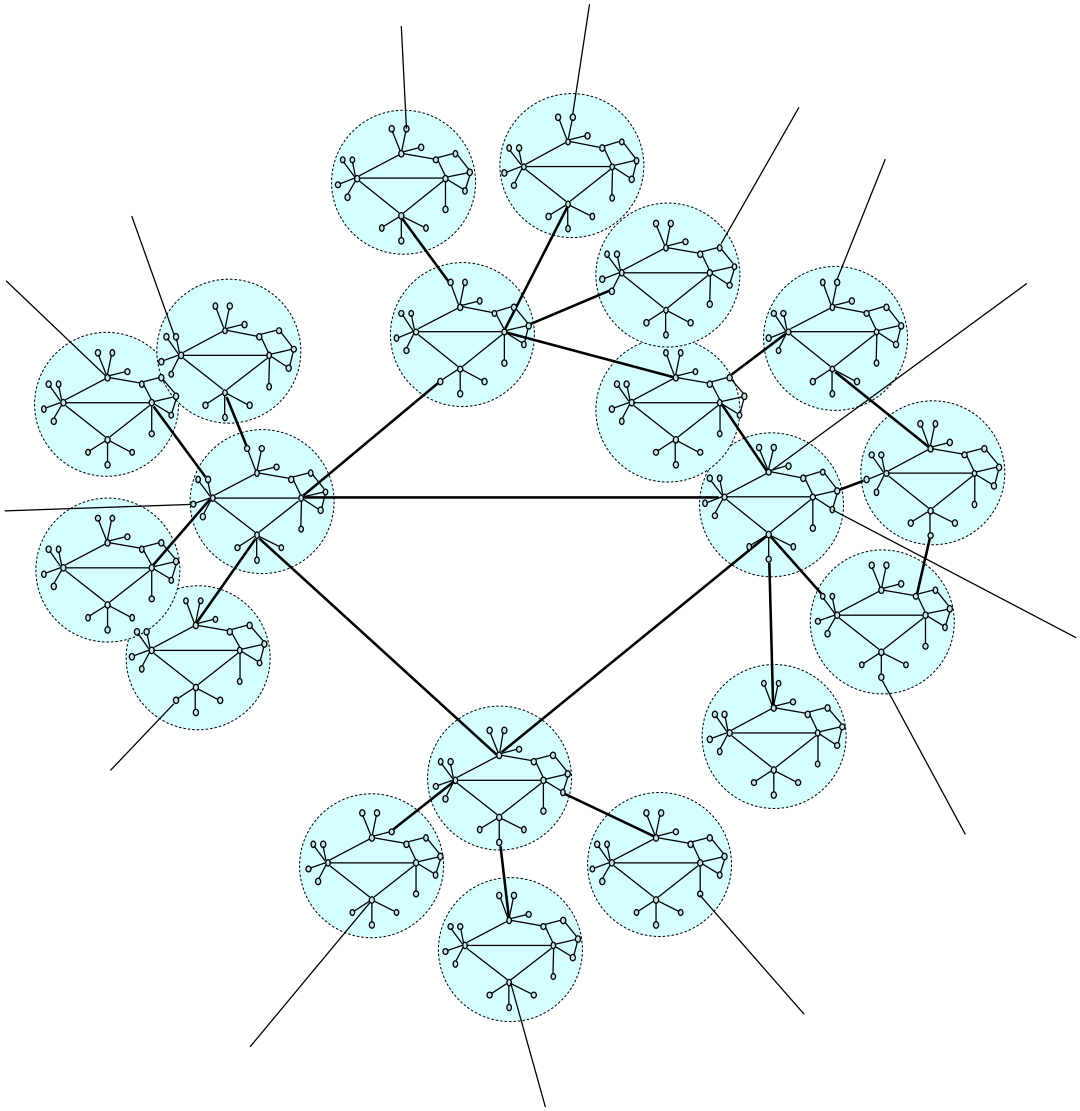
Nodes of the mind network are our concepts, perceptions, ideas, beliefs and feelings. The connections are interactions between them. The network presented here has a structure of a system of interconnected domains or neighborhoods. Let us call the paradigm something that unites and defines a particular domain of concepts, notions and ideas. Much like that something that defines domain of "chairs", which we discussed earlier. In network terms the notion of paradigm may refer to a certain organizational structure of interrelations between certain set of concepts, ideas, perceptions etc. Then we can talk about the domain of family life, the domain of professional life, the domain of economic life. Altogether they may constitute the domain of social life with its underlying paradigm, which is more or less definite but at the same time ever evolving set of interrelated and interdependent concepts, notions, ideas, beliefs and connections between them. If we go down the scale we can further differentiate and talk about the domain, and thus the paradigm, of a private life, etc.

Notice please the relativity of notions such as *node, domain and network*. We started to use these words in such a way that a system of tightly connected nodes we call *domain* and a system of interconnected domains we call a *network*. But imagine an enormous fractal-like network (*Slide 6*). Then the notions we introduced, *node, domain and network*, can be differentiated only within a certain scale. Node on one scale can be a domain or a whole network on another scale and *vice versa*.

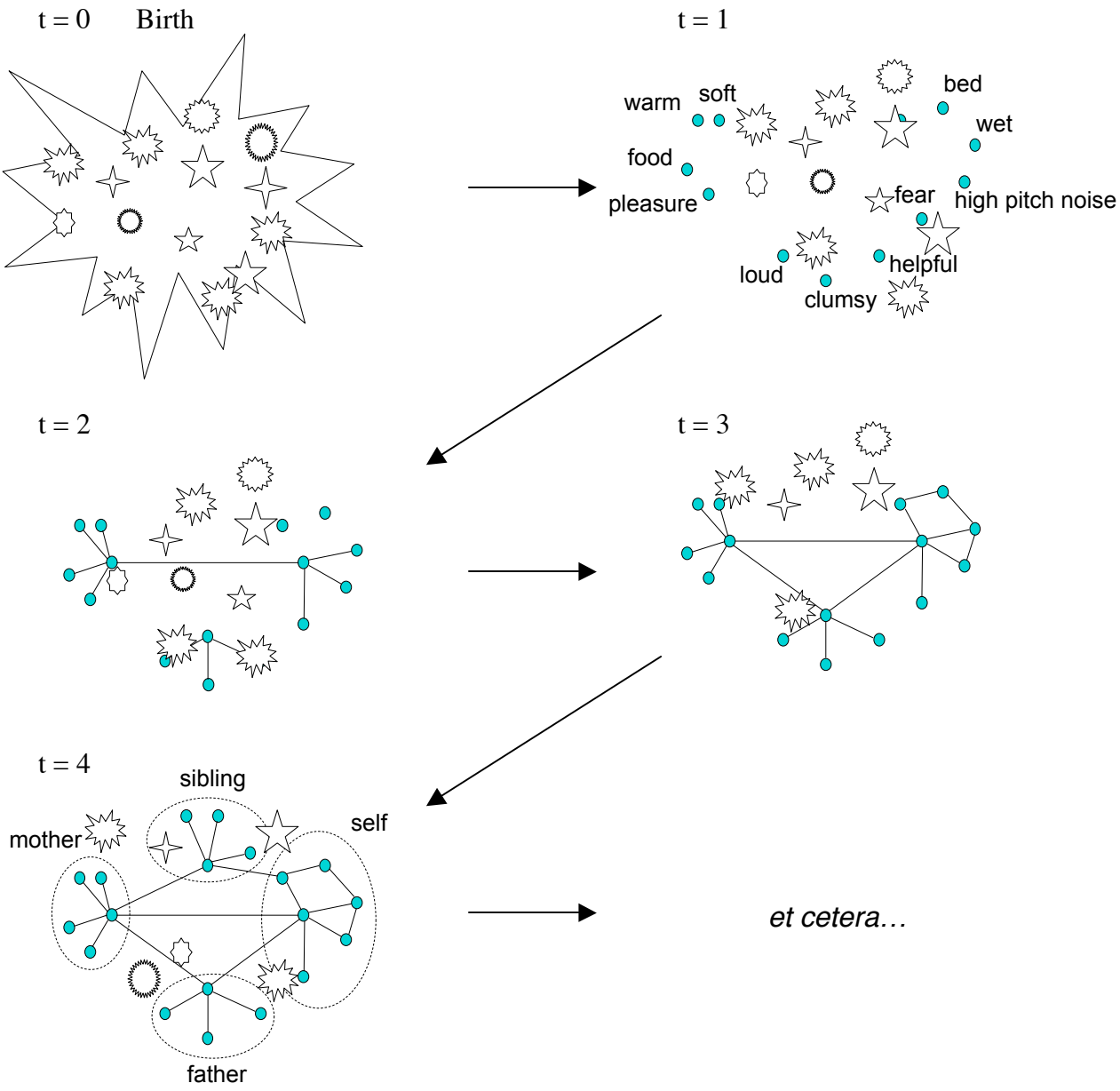
First steps.

Let us assume for simplification that before our birth there was no structured mind network (*Slide 7, t=0*). From the moment of birth on we are plunged into chaos of information and perceptions pouring from the external world through our sense organs onto developing molecular organizations of our brain and other organs of the body. Some of the perceptions are relatively constant or appear more frequently than others. For instance, consider perceptions of something that feels warm, soft and comfortable, is a source of food, sounds tender and reassuring, and is associated with disappearance of some painful or disturbing experiences. Each of those perceptions, being almost constantly present, may soon form a node of the virtual mind network and its respective physical correlate in the form of physico-chemical metastable molecular and/or cellular organization. As the mentioned perceptions are synchronized, i.e. tend to appear simultaneously most of the time, they may give rise to a concept and, respectively, node of the mother, along with the wiring of appropriate connections (*Slide 7, t=2*). First primitive and relatively undifferentiated, the concept of mother and its corresponding node/domain will develop over time into a more complex and differentiated structure. Another set of nodes may comprise perceptions of something loud, awkward in handling, not a source of food, but generally protective and sometimes useful. Simultaneous appearance of these perceptions would result in the emergence of concept and respective node of the father. As the father node and the mother node are often activated simultaneously, the connection will appear sooner or later between the respective nodes. The general pattern is as follows.

The chaos of self-organizing molecular and cellular activities of a newborn organism will be gradually structured through interactions with the environment giving rise to ordered metastable molecular organizations, which will soon be connected into one integrated system, the mind network, that reflects or approximates the spatio-temporal organization of perceived aspects of the external objective world. The formation of those molecular and cellular organizations and the establishment of interrelationships between them can be visually and conveniently represented as a growing virtual mind network of interdependent and interacting perceptions, concepts, feelings, ideas etc.



Slide 6. Example of a beginningless and endless fractal-like network. Notions such as *node*, *domain* and *network* are relative here and can be used as differentiated terms only with respect to a certain scale. The node on one scale is the domain or the network of other scales.



Slide 7. From perceptions to concepts, associations and paradigms. Schematic cartoon illustrates hypothetical scenario of how constant or repetitive patterns of external reality mold a chaos of perceptual activity of a newborn mind, igniting emergence and evolution of metastable mind network that models the outside reality. Stars symbolize chaotic activity of the mind, nodes of the network are perceptions, feelings, concepts etc, dotted lines delineate emerging domains.

Postulated properties of the mind network.

1. Connections and nodes are not constant. They may change and evolve during the course of individual life. Nodes may appear, disappear or be reconnected to other neighborhoods. Connections may grow stronger or weaker, appear and disappear;

2. Domains are interconnected as within the same scale, so between different scales. Change in any node or connection may potentially affect structure of a neighborhood, higher-level domain or the whole system;

Once upon time we all believed in the existence of Santa Claus and some of us might even have written letters to him. When this belief naturally withered away as we grew older and wiser, the disappearance of this belief affected not only our attitude to fairy tales, but also more general aspects of our perception of the outside world. Because the Santa Claus story had been planted in our minds by our parents, on this and other occasions we learned that some statements coming from them are in a contradiction with our own experiences and should be considered with a healthy lot of skepticism. And stories that come from our older siblings, and worse yet from our peers, should be taken with a deep discount. In this sense, a change in one node or domain of our mind network affected the more global arrangement of our model of the world. Though any individual change in the network has a low probability to precipitate a large-scale rearrangement in the structure of the mind network, it is impossible to predict what exactly will be "the straw that breaks the camel's back".

3. Development of the mind network proceeds through the following main types of change:

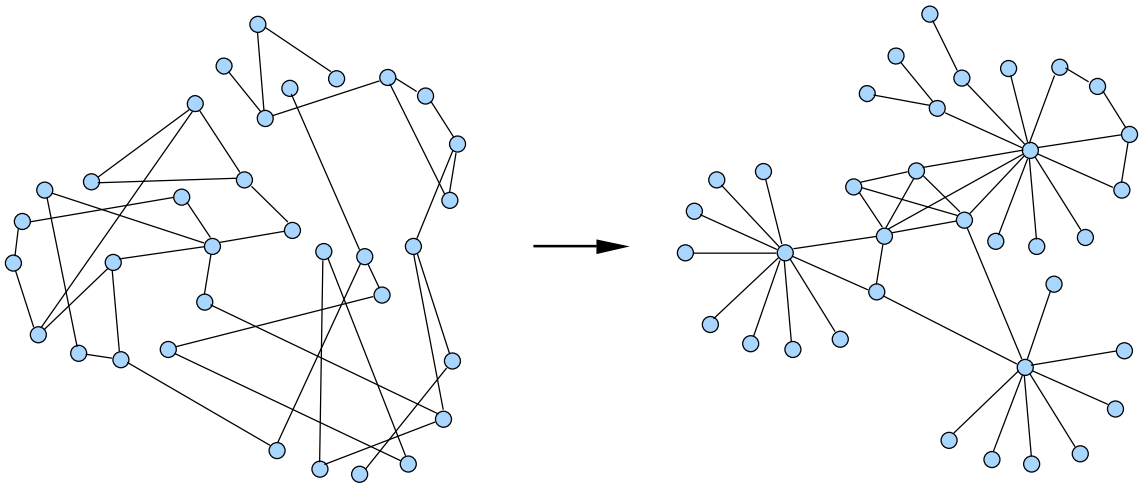
a) *Evolution: neighborhood development – cumulative accumulation of small changes.*
b) *Revolution: Gestalt switch-like domain transition – large-scale structural rearrangement, paradigm shift.*

"Neighborhood development" means strengthening or weakening of a few connections, appearance or disappearance of a few nodes, without a drastic change in the general organizational structure of the neighborhood. Example from socio-political network[] - republicans have won the majority over democrats in general elections, placed their nominees in key governmental positions, created some novel and dissolved some of the old departments, offices and relations. However, the paradigm of the

[] The example is chosen from socio-political sphere as it has an advantage of being intuitively clear and at the same time represents a conceptually unifying analogy indicating on common patterns underlying organizational dynamics of the individual mind and the society.

USA as a state, as a politico-economical network remains unchanged over a period spanning many elections. The global structure transition does not occur.

From time to time the revolution-like transitions take place in one or a few domains or even in the whole network. The respective historical analogy would be the bourgeois revolutions in XVIII-XIX Century Europe. In network terms it may mean appearance of new nodes/domains and disappearance of old ones in unusually great numbers and/or sudden rearrangement/rewiring of many interconnections/links within the network/domain where the transition takes place (*Slide 8*).



Slide 8. Example of domain transition (paradigm shift) in the mind network. Addition of a few novel concepts, ideas and/or connections to the growing network may precipitate a large-scale rearrangement in the organization of the network, "Aha!" moment, which is perceived by individual as a sudden insight, as a novel image of some aspect of reality or a new combination of an old set of ideas.

Domain transitions, or paradigm shifts, occur constantly within the mind network during our lives reflecting our development, learning and/or adaptation to changing environment. Sometimes a great number of domains experience transitions within a relatively short time in an avalanche-like fashion. As an example, there is a certain period in our development when transition from ideals of youth to realities of practical life occurs. It is perceived by almost everyone and has long been a fertile ground and a source of inspiration for many classical writings, such as, for example, Honore de Balzac's "Lost Illusions".

Though a domain transition, or paradigm shift, occurs in a Gestalt switch–like manner (see *Model of the paradigm shift* section in *Lecture 6*), in contrast to a visual Gestalt switch the paradigm shift is normally irreversible process over time. You can at any moment consciously switch between different perceptions of a visual Gestalt back and forth by focusing on some details of the picture. Though one can oscillate as a kid for a short time between the world where Santa Claus is real and the world where Santa

Claus is a fairy tale fiction, it is very difficult for a mentally normal, healthy adult to experience the emotional state of a little boy who suddenly asks the parents to keep quiet because he thinks that he hears jingle bells. Once lost, illusions do not come back. Rather they are replaced by other, different illusions.

4. Nodes and connections that are rarely used tend to weaken with the time. The frequently used ones are reinforced. Consequence: no interaction with the external world goes unnoticed, without some change in our system of paradigms.

Rarely used nodes, connections, domains and whole neighborhoods tend to weaken and to dissipate overtime (as they require constant expenditure of energy and matter for their maintenance, see postulate #7). One example of initial strengthening followed by dissipation – calculus. Many of you may remember how it was difficult to learn by heart and used initially the calculus tables back in the school. Then, after practice, we incorporated them into our sub-consciousness and started to use them automatically with great ease. Later we bought a calculator, and now one may catch oneself looking for the calculator to divide 24 by 3. Forgotten hobbies of childhood and early youth are another example. Though their respective domains of nodes and connections disappeared as coherent and active structures, many nodes were never lost but simply reassigned to other domains, where in some cases they are clearly recognizable today. Through learning and training during professional specialization we all create novel domains and sub-networks advancing us along a career path.

5. Most of the mind network operates subconsciously most of the time.

6. The reality is always met by the mind with a pre-existing model of the reality upon interaction. The pre-existing model constitutes the filter that selects experience on the one hand, and is being molded by experience on the other. It dictates our actions and is reinforced or changed according to the subjectively perceived success or failure of the interaction.

Let me give an illustration with an experiment on gravitation. I loose free the pen I have in my hand – it falls on the floor with a banging sound – no surprise or confusion in the audience. All events are anticipated and fit our model of reality. There is no mismatch between the model and the reality. Therefore, there is no surprise or confusion. An interesting and important point, all the mental processing, model creation and anticipation take place in us subconsciously and instantaneously. We do not actually think – this is a pen and we are on the planet Earth where gravitational laws of Newton rule, and if this fellow let this pen go it will definitely hit the floor in about a second, because the distance between the pen and the floor is one and a half meters high and the time of a fall, neglecting the resistance of the air,

can be calculated according to equation $t = (2h/g)^{1/2}$. No, we don't think that. You may say we feel it. It is subconscious. Some long time ago we did learn about gravitation, studied the respective equations and might even have performed some computation and hands-on activities pertaining to the Newton laws in the school. More importantly, we all have had endless practical experiences during our lives with the falling objects, some of them pretty painful. We internalized all those experiences, structured them with school lessons and they reside somewhere inside us as one of domains of our system of paradigms and model the reality. And help us to survive and to excel.

The human mind never operates in a paradigm vacuum. It interprets all the flow of external information in the framework of the paradigm system that already pre-exists in the mind at the moment of perception/interaction. There is an interesting dialectics in the interaction between our minds and the outside reality. On the one hand, new information and novel experiences coming from the outside world irreversibly affect and mold our system of paradigms. On the other, at the moment of interaction our mind network constitutes a selective filter, a structural form, a framework for perception that selects, interprets and accommodates external data to fit the pre-existing framework. Consider the following example[□□]. Experimental psychologists presented a set of playing cards to a number of human subjects. Each card in a set was shown only for a very short time initially and the subjects were asked to identify as many cards as they could. Gradually extending the exposure time, the experimenters found a recognition threshold, the shortest time at which all the subjects were able to correctly identify all the cards in a set. After that the experimenters introduced faulty cards in the set without informing their subjects. Faulty cards were identical in appearance to the normal cards, but colored against rules. Such as the black ninth of diamonds or the red queen of spades. Surprisingly, all cards were successfully identified by all subjects. The faulty cards were mistakenly assigned to one of the standard categories. Only very significant extension of the exposure time beyond the established recognition threshold led to gradual realization by few at first and then more and more participants that the set contained faulty cards in it. Some of the subjects failed to realize the presence of the faulty cards even at exposure times exceeding the recognition threshold by one order of magnitude. Remarkably, once the "new rules of the game" were realized by a subject, (s)he had no difficulties afterwards to correctly identify normal and faulty cards at the same recognition threshold. In this example, the pre-existing model of the situation, or the assumption that there are only four different types of cards in a set, literally blinded the subjects from seeing non-standard cards. Progressively longer exposure times led to a systematic and increasingly disturbing perception of some anomaly in the appearance of certain cards. Sudden realization of existence of faulty cards resulted in a more adequate representation of the reality. The mind network therefore selects experience on the one hand and is being molded by experience on the other.

[□□] The example is taken from "The Structure of Scientific Revolutions" by T. Kuhn.

Every time we interact with the external world, we subconsciously model the situation and anticipate a certain development of the situation according to this model. If the model is adequate and the reactions from the outside reality are as anticipated – there is no feeling of surprise, no confusion. Puzzlement, confusion, surprise are always signs of a mismatch between a model of reality and the reality itself. To resolve this mismatch, the mind usually takes one of two approaches (postulate #3) – 1) it solves the puzzle within the pre-existing framework, by introducing new and/or re-assigning old nodes and/or connections without much changing and largely preserving the organizational structure (paradigm) of the relevant domain or 2) it changes the framework itself through a transition within the relevant domain/network, which corresponds to a local (or global) paradigm shift ("Aha!" moment), so that a new framework/paradigm represents the reality better, becomes more adequate, and no mismatch occurs then upon repetition of the same situation.

Domains of the mind network have a tendency to be metastable and transitions occur only upon a consistent failure of the domain-underlying paradigm to explain facts of the reality. This is an important moment, so let me dwell a bit on this "*middle way between two opposites"* feature of the mind. In order to understand and to act adequately in the outside world we need to catch all this multifaceted outside reality into some relatively stable network of notions, concepts and ideas. In order to learn from experience, to perfect ourselves and to adjust to changes in the outside world, domains of our minds and underlying paradigms should have capabilities to undergo transitions, shifts and evolution. Therefore, the domains of the mind network possess two mutually contradictory properties maintained in a dynamic equilibrium – on the one hand, relative structural stability, which allows an unambiguous representation of the external world and provides stability against random noise and fluctuations, and, on the other hand, the plasticity to detect and to accommodate the appearance of novel, and changes in old, patterns of the outside world. The paradigm, on the one hand, provides a stable framework within which a particular aspect of the outside world can be explained and understood, and in this sense it is good and necessary. On the other hand it always limits our perception and comprehension of the reality by its own rigid framework. In this sense it is bad and limiting, for it makes us blind to everything that does not fit the paradigm.

Paradigm provides a form, or an organizational structure, which we, while developing, fill with the content coming from our experiences and learning. But periodically during development the content becomes so rich and manifold, that the existing organizational structure becomes limiting and, as consequence, the conflict between the form and the content emerges, develops and is finally resolved by the transition to a novel form, structure, or a novel paradigm. Transitions are unavoidable and even desirable provided one wishes to proceed with the development further. The temporal development of the mind can be pictured therefore as a gradual growth/evolution of a network punctuated by revolution-like transitions that may encompass at different times small or large parts or the whole network. The more

sophisticated reader may suggest a connection here to self-organized criticality of the complex system theory.

The balance between the two properties of mind, plasticity and stability, is normally different for the same person at different times in his(her) development. The child's mind is extremely plastic and susceptible to learning. New nodes and connections are added and/or reconnected at high rates in the growing network. It is in a constant chain of transitions adjusting to and learning the external world. Paradigm shifts are frequent and usual things. At the same time if you talk to your kids, you may notice that they always have a pretty self-consistent and holistic worldview. Today one. Tomorrow may be another. But within the day they live in their metastable model of the world, where everything is explained, logical and connected. We consider and call it naïve, a world of imagery, but they do not know another and their world is as real and serious for them as our adult world is for us. Someone said once: "grown up people don't stop doing stupid things. It is just that their idiocy is in correspondence with their age". In other words, at any time the world of adults is a world of imagery as well. It is a metastable model. The difference is that the adults have been developing and adjusting to the present world for a much longer time and their model of the outside reality is often more adequate than the one of a kid. But nobody can be sure that tomorrow the reality will be the same and, especially if the reality changes abruptly and on a large scale, that our current adult paradigms and models will remain adequate to comprehend and to interact with a new reality of tomorrow. On the scale of humankind, the developing minds of children and the young represent a plasticity reservoir of our collective sub-consciousness, while physical carriers of the current rigid paradigmal system or the current worldview are adults and old people, especially those occupying the key power positions where a few have capabilities to indoctrinate and to control the attitudes of many. And, as at the scale of the individual mind the shift of balance from plasticity to rigidity is indicative of the ageing process or a disease, so the incrustation of outdated ideas and preconceptions propagated through ossified organizational structures created and sustained by the powerful old are signs of an ageing and weakening society. "Presuming to know is a disease". The world is changing faster than our model of it.

7. The mind network in its physico-chemical description is a self-organizing molecular system. Between transitions it exists as a steady-state organization, which requires and is maintained by a continuous flow of energy and matter passing through it. (see *Lecture 7* for description of the cell as self-organization of molecules and the organism as self-organization of cells).

Conceptualization of the mind as a phenomenon of self-organization provides common language and, as consequence, an opportunity for knowledge exchange, mutual enrichment and unification of such traditionally separated disciplines as analytical psychology, neuroscience research in memory and consciousness, molecular and cellular biology, physics, organization science and others.

Random thought: Principle of parsimony as a counterpart of mind's economy principle.

The mind network often operates in conditions of time and energy deficit. In fact it is easy to make a case that there is a continuous evolutionary pressure on the mind to perform in the fastest and most efficient way possible. Since the mind network in its physical sense is a dynamic steady-state molecular organization requiring continuous flow of energy and matter for its maintenance, it will normally try to minimize a number of nodes and to optimize organizational structure of connections, balancing between the economy of resources on the one hand and the adequacy of representation on the other.

Consider now the principle of parsimony, which is an inherent part of scientific method and is coterminous with general common sense. It states that among several alternative explanations of a phenomenon, the one that requires minimum number of unproven assumptions should be preferred, for it is more likely to be fruitful. Or in words of Albert Einstein: "The supreme goal of all theory is to make the irreducible basic elements as simple and as few as possible without having to surrender the adequate representation of a single datum of experience". It is reasonable to suggest that the principle of parsimony is simply a reflection of the dynamic optimizational problem that the mind, as economic organization/network, is constantly dealing with – maximization of the adequacy of representation while minimizing resource expenditure.

8. Organization and functioning of every individual mind network is intimately linked to and in significant part defined by its cultural and physical environment. It is born from the environment, it is part of the environment and it is shaped by the environment during the process of mind development and individuation. It is always connected to and remains an organic part of the collective sub-consciousness and objective physical world.

Every new mind is born into both the objective world and the integrated system of subjective collective sub-consciousness. The last one can be thought of as ever-evolving network of interacting, interconnected and interdependent individual minds, which are evolving networks of ideas, concepts, beliefs, perceptions, feelings etc in themselves. Each newborn mind therefore becomes connected to, is molded by, and is integrated within a huge collective mind network. Consider the mind network shown in *Slide 6* as a representation of the collective mind network, where nodes are individual human minds, domains are local or professional communities and larger scale sub-networks are states and nations, while connections are interactions between people. It is at least amusing to reflect on the idea that certain people (nodes) and groups of people (domains) act as (carriers of) concepts, feelings, beliefs, ideas, paradigms that affect and in part define the dynamics of the collective mind network. At this larger scale it can be seen more clearly how dynamics of the mind, be it the collective or the individual mind, is always a

product of the interaction between self-organizing activity from within and the shaping influence of the external objective environment.

> *9. Each individual mind network is a unique organization. It is a product of the interaction between three interdependent forces driving the formation of the mind network organizational structure: i) activity of molecular self-organization within a physical individual organism; ii) individual practical experiences with an external world; iii) influence of collective sub-consciousness expressed through parents, friends, schools, social circle, religion, arts, science etc.*

The third force dominates heavily during earlier developmental stages of the individual mind network. We are programmed by our society, parents and education what the world is and what we should do and what we shouldn't. Adults always have a certain advantage over children at demonstrating on practice that their model of the situation is a more adequate one. As children we are segregated into the confinement of controlled experiences and our intuition and inner self are neglected and unanswered. Someone said once: "The only really important questions are those that every intelligent kid asks, and, having been left without an answer, stops asking and forgets." This initial stage however is necessary, for our mind network, instead of repeating and living experiences of previous generations itself, assimilates those experiences in a relatively short period of time through education and training. It is quickly molded on a paradigmal template and acquires the latest and presumably most adequate model of the world that we inherited from the previous generation (see *Lecture 6*). At some point during maturation an individual mind normally revolts against domination of the third force, learns to trust and to listen to its inner self and tests through its practical experiences and interactions with the outside reality the adequacy and usefulness of the inherited paradigmal forms. During the rest of life the individual human mind network continues to develop, adjusts and improves the inherited models and passes them down to the next generation by upbringing children and/or through the creation of products of culture.

Reflecting on the parallels between development and maturation of the individual human mind and the collective mind, one is compelled to conclude that the last one is a case of a kid growing alone without parents or other people around. It learns the world from scratch through trials and errors, often painful, laying down history as a memory of past experiences. In the same way as each individual human mind proceeds through a certain sequence of developmental stages, the collective mind passes through analogous phases but on its larger historical time scale. It is tempting to suggest that the current and immediate developmental task the collective mind faces today is a transition from a sub-conscious, irrational being, governed mainly by emotions and pleasure principle, to a self-conscious responsible organism learning to trust its own rationality and will.

Science as a collective rationality

What follows is a concise and schematic description of scientific development in the interpretation given by Thomas Kuhn in his classical work "The Structure of Scientific Revolutions" published in 1962. The aim is to illustrate the remarkable conceptual parallels between how individual human mind perceives and interprets the outside reality and how science as an establishment perceives and describes the world around us.

Thomas Kuhn has delineated scientific development as a process of emergence and evolution of scientific paradigms punctuated by scientific revolutions or paradigmal shifts that transform from time to time the very image of the reality studied, as opposed to the previously widely held and popular view on science as gradual accumulation of facts and assimilation of new theories describing some pre-defined and given reality. Metaphorically speaking, it was assumed before Kuhn that every new generation of scientists adds new pieces to the growing mosaic of scientific knowledge in an attempt to reveal a hidden pre-existing image, which would appear when all pieces are in place. It is tempting to suggest that this assumption is a direct and logical consequence of the Newtonian worldview, which is criticized in Lectures 6 and 7. Analyzing multiple examples from the history of sciences Kuhn presented an alternative image of scientific development. He has proposed that new discoveries and theories are not simply missing pieces of mosaic and that there is no pre-defined image to be uncovered. He argues that there are certain moments in scientific development, called scientific revolutions, when a new discovery or theory transforms the very image of "hidden" picture in a Gestalt switch-like process of large-scale rearrangement and re-interpretation of ideas, concepts and experimental facts, the process he called the paradigm shift.

Thomas Kuhn outlined several distinct phases in a life cycle of any paradigm:

Phase I. Pre-paradigmal state. There is no established paradigm in the field.

This phase is characterized by intensive experimentation and competition between multiple theories striving to provide the best framework for a self-consistent explanation of accumulating experimental evidence. There are no rules as to the choice of methods and questions asked in the field at this stage. Consider research on ageing as an example. There is no established theory of ageing today. Instead there are several competing claimants on the theory of ageing. Neither of them is good enough, though, to explain at least the majority of experimental observations in a self-consistent manner. Therefore, in large measure, there are no established rules as to what and how to measure or to study, or what model systems should be considered adequate.

Important notice: It is always useful to keep a bigger picture before the eyes. Though in our example research on ageing may be characterized today as relatively "chaotic" in respect to the possible choice of experimental and theoretical frameworks, it is not an isolated field, but a domain of a larger scale research establishment, which has its larger scale accepted paradigm limiting and directing the

choice of theoretical frameworks and experimental systems in research on ageing. For instance it is assumed that any ageing theory should be consistent with the laws of physics and chemistry underlying the behavior of molecules comprising biological systems. It is also useful to consider even broader picture and to realize that science itself is not an isolated unity, but is organically embedded into the fabric of a large-scale psycho-socio-economical system, the society. With its own dynamics, politics and its larger scale paradigm. Being part of the system, science is always limited and directed by society, whatever the claims of scientific ego and the science priesthood on objectivity and independence of scientific knowledge might be.

Phase II. Emergence of the paradigm.

Normally, with the time passing, one of the evolving theoretical frameworks becomes dominating as it manages to explain old and to predict novel experimental outcomes significantly better and in a more efficient way in comparison to other rival theories. From that moment on, the winning paradigm defines what experimental procedures and what type of questions should be considered legitimate in the field. The rest is discarded and even ostracized as non-scientific. This is necessary and important, for the winning paradigm concentrates all the cumulative scientific energy and resources (always limited) only on those questions and problems that it considers worth of pursuit. It ignores experimental facts that do not fit the paradigm. There are few of them initially, because scientists in their experimentation choose to ask only those questions, answers to which are anticipated by the current paradigm. One may notice here clear parallels with the processes discussed earlier that occur when our mind meets the external reality with a pre-existing model of it that essentially selects experience, and tends to blind and to divert the mind from anything that does not fit into the model. On the scale of collective mind the dominating paradigm re-writes textbooks and shapes education to produce a new generation of scientists who are programmed to think within the box of the current paradigm and trained to be proficient with its experimental tools and procedures. This results in further concentration of resources and ever-increasing efficiency with which problems deserving attention of the leading paradigm are solved.

Phase III. Filling in the form. Full development and triumph of the paradigm.

Paradigm is being refined during this phase. Research becomes largely a puzzle-solving activity - we have a certain problem, a puzzle. We know that it has a definite solution within the current paradigm. We solve it – we publish it. Some examples from molecular and cell biology: sequence the novel gene; sequence another genome; make a new gene knockout in mouse etc. In order to solve puzzles better, faster and more efficiently competitive scientists develop and implement increasingly sophisticated and precise equipment and introduce novel experimental methods and models.

Phase IV. Emergence of anomalies.

Advances in the instrumentation, experimental techniques and model systems allow scientists to probe the reality with an ever-increasing accuracy and reproducibility and to perform measurements of precision and scope that were unthinkable before. As a result increasingly more patterns and experimental facts are discovered that do not fit and cannot be assimilated within the existing paradigm. Introduction of multiplying *ad hoc* assumptions then becomes a first reaction of the proponents of the ruling paradigm to cope with the unfitting experimental evidence. However, sooner or later the systematic accumulation of inconsistencies is perceived as growing anomalies by an ever increasing number of researchers. The paradigm as a form becomes a limiting factor that impedes the development of knowledge content.

Phase V. Crisis of the paradigm.

Alternative theories are ignored and not considered by scientific community seriously while anomalies are relatively weak. They are often marked as “scientifically unsound”, “philosophical”, “obscure theorizing”, “nonsense” etc. However, as anomalies grow significantly in size and number, scientific community gradually splits and the state of affairs is established that is similar to the times when there was no dominating paradigm. Rules as to the methods used and the questions asked in the field are loosened.

Phase VI. Paradigm shift. Scientific revolution.

The loosening of rules and definitions of legitimacy pertaining to the experimental procedures used, the explanations put forward, the systems studied and the questions asked does not mean however that there is a period of time when science, or a particular field of it, functions without any paradigm. The old paradigm does not normally die or dissipate into chaos even if it is obviously unable to cope with rapidly accumulating inconsistencies. It is rather replaced by a new one in a Gestalt switch-like transition manner. Suddenly a new order is perceived in a novel combination of interrelations between old and new experimental facts and concepts. The new theory, or the shift to a new paradigm changes the very idea of what is being uncovered, through reshuffling and rearrangement of mosaic pieces. The idea literally changes the world. We live in the Newtonian world today, which is radically different from the world of the Middle Ages, which was radically different from the world of the earlier primitive human societies. We create the world by sub-consciously agreeing on a certain interpretation of the world and by acting according to it. Our collective representation is the world.

On will and responsibility.

Individual minds of individual scientists are those focal points through which and by means of which science probes and interprets the outside reality. This interpretation is passed through the network

onto the collective mind. However, there is a movement in the opposite direction too. As discussed above, the dominating paradigm of the collective directs scientists to what to probe and advise them on what interpretations should be accepted. Being the expression of the dominating political and economical organizations, the leading paradigm has at its disposal all the imaginable incentives to be very convincing. Discoveries of new facts, emergence of new interpretations, evolution and change of scientific concepts and paradigms happen first of all in and through the individual minds of individual scientists. And every one of them, at the bench, in the chair or in public offices, is always posed before a choice between comfortable and safe compliance (rewarded and praised) with what is wanted to be seen and heard by the dominating political and economical organizations, and a difficult path of insisting on what appears to be the truth of today. The first choice is a path of stagnating delusion that leads to sickness, the second is the way of will and responsibility leading us towards health.

References and acknowledgements:

1. Picture of the neutrophil chasing bacteria in Slide 1 was reproduced from http://expmed.bwh.harvard.edu/projects/motility/neutrophil.html with permission from Dr. T. Stossel, Harvard Medical School, Boston, USA.

2. Thomas S. Kuhn "The Structure of Scientific Revolutions" (The University of Chicago Press, 3rd edition, 1996).

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