

SAPIENCE, CONSCIOUSNESS, AND THE KNOWLEDGE INSTINCT (PROLEGOMENA TO A PHYSICAL THEORY)

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Abstract

The chapter describes a mathematical theory of sapience and consciousness: higher mental abilities including abilities for concepts, emotions, instincts, understanding, imagination, intuition, beautiful, and sublime. The knowledge instinct drives our understanding of the world. Aesthetic emotions, our needs for beautiful and sublime are related to the knowledge instinct. I briefly discuss neurobiological grounds as well as difficulties encountered by previous attempts at mathematical modeling of the mind encountered since the 1950s. Dynamic logic, the mathematics of the knowledge instinct, is related to cognitive and philosophical discussions about the mind and sapience.

Keywords: *the mind, sapience, dynamic logic, emotions, concepts, consciousness, the knowledge instinct.*

1. Introduction. Abilities of the Mind

The mind understands the world around by relying on internal representations, the models of the world that were learned previously, an hour ago, earlier in life, in childhood, and ultimately, relying on the inborn genetic information. These internal models of the mind are related to Plato's ideas ($\epsilon\iota\delta\epsilon$) [¹, ²], Aristotelian forms [³, ⁴], Kantian ability for understanding [⁵, ⁶], Jungian archetypes [⁷,], and various mechanisms of concepts discussed in artificial intelligence, psychology, cognitive science and neural networks [⁸]. Mind brings concept-models in correspondence to objects and situations in the world; in the result, there appear phenomena, internal mind's perceptions (or representations, which could be conscious or unconscious to varying degrees). Concepts (say, a word "chair", written or spoken) are very different from objects (a chair one sits on). In our brain there are inborn structures that were developed over hundreds of millions of years of evolution specifically to enable fast learning (in childhood) of combining into a single concept-model a spoken, written, drawn, imagined and real chair. Let's note that the "real chair" is what is seen by our eyes, but also what is sensed as a "seat" by the sitting part of our body. Therefore "chair" is a bodily-sensed-spatio-thought concept. The process of comparing concept-models to objects around us is not simple, nor straightforward. An

ability for finding correspondence between concepts and objects Kant called judgment [⁹]; he identified this ability as a foundation for all higher spiritual abilities of our mind, or sapience.

Ability for concept-models was evolved during evolution to enhance survivability; it works together with other mechanisms developed for this purpose, first of all, instincts and emotions. Instincts are like internal sensors that generate signals in neural networks indicating the basic needs of an organism, say hunger [¹⁰]. Connection of instincts and concepts is accomplished by emotions. In a usual conversation, “emotions” refer to a special type of behavior: agitation, higher voice pitch, bright eyes, but these are just shows of emotions. Emotions are evaluations “good-bad”. Evaluations not according to concepts of good and bad, but direct instinctive evaluations better characterized in terms of pleasure or pain. An emotion evaluates a degree to which a phenomenon (objects or a situation) satisfies our instinctual needs. Emotions are signals in neural pathways that carry information about object values from instinct-related brain areas to perceptual, cognitive, decision-making and behavior-generating areas. Emotions “mark” perceived phenomena with their values for instinct satisfaction. There are inborn as well as learned emotional responses. A mathematical description of “marking” of concepts by emotions was first obtained by Grossberg and co-workers in the late 1980s, e.g., [¹¹]. Every instinct generates evaluative emotional signals indicating satisfaction or dissatisfaction of this instinct. Therefore emotions are called evaluative signals. These signals affect the process of comparing concept-models to objects around us (this explains why a hungry person “sees food all around”). So, instinctual needs affect our perception and cognition through emotions; and model-concepts formed in evolution and culture originally are intended for survival and therefore for instinct satisfaction. This intentionality of the mind was a subject of much discussions and controversies [¹²]. Many emotions originate in ancient parts of the brain, relating us to primates and even to lower animals [¹³]. Ability for concepts includes learning and recognition (that is creating and remembering models as well as recognizing objects and situations more-or-less corresponding to earlier learned models). A short description in this section did not touch on many of mind’s properties, a most important being behavior. This chapter will be mostly concerned just with one type of behavior, the behavior of learning and recognition.

The next section briefly reviews mathematical approaches to describing the mind proposed since the 1950s and discusses difficulties encountered along the way. Then I formulate a mathematical theory providing a foundation for an initial description of the mind abilities discussed above. It will be extended to consciousness and higher cognitive abilities, abstract concepts, abilities for beautiful and sublime. Arguments will be presented why feelings of beautiful and sublime are inseparable aspects of sapience. Concluding sections discuss relationships between the theory and concepts of the mind originated in multiple disciplines as well as future directions of experimental programs and theoretical development towards physical theory of sapience.

2. Computational Intelligence since the 1950s

Perception and cognition requires to associate subsets of signals corresponding to objects with representations of objects in the mind (or in an algorithms). A mathematical description of this seemingly simple association-recognition-understanding process was difficult to develop. A number of difficulties encountered during the past fifty years were summarized under the notion of combinatorial complexity (CC) [¹⁴]. CC refers to multiple combinations of various elements in

a complex system; for example, recognition of a scene often requires concurrent recognition of its multiple elements that could be encountered in various combinations. CC is prohibitive because the number of combinations is very large: for example, consider 100 elements (not too large a number); the number of combinations of 100 elements is 100^{100} , exceeding the number of all elementary particle events in life of the Universe; no computer would ever be able to compute that many combinations.

In self-learning pattern recognition and classification research in the 1960s the problem was named “the curse of dimensionality” [15]. Adaptive algorithms and neural networks, it seemed, could learn solutions to any problem ‘on their own’, if provided with a sufficient number of training examples. It turned out that the required number of training examples for “self-learning” required training using objects *in context, in combinations* with other objects, and therefore was often combinatorially large. Self-learning approaches encountered *CC of learning requirements*.

Rule-based artificial intelligence was proposed in the 1970’s to solve the problem of learning complexity [16, 17]. An initial idea was that rules would capture the required knowledge and eliminate a need for learning. However in presence of variability, the number of rules grew; rules became contingent on other rules; combinations of rules had to be considered; rule systems encountered *CC of rules*.

Model-based systems were proposed in the 1980s to combine advantages of self-learning and rule systems. The knowledge was to be encapsulated in models, whereas unknown aspects of particular situations were to be learned by fitting model parameters [18]. Fitting models to data required selecting data subsets corresponding to various models. The number of subsets, however, is combinatorially large. A general algorithm for fitting models to the data, multiple hypothesis testing [19] is known to face CC of computations. Model-based approaches encountered *computational CC* (N and NP complete algorithms).

It turned out that CC was related to the type of logic, underlying various algorithms [20]. Formal logic is based on the “law of excluded middle,” according to which every statement is either true or false and nothing in between. Therefore, algorithms based on formal logic have to evaluate every little variation in data or internal representations as a separate logical statement (hypothesis); a large number of combinations of these variations cause combinatorial complexity. In fact, combinatorial complexity of algorithms based on logic is related to Gödel theory: it is a manifestation of the inconsistency of logic in finite systems [20]. Multivalued logic and fuzzy logic were proposed to overcome limitations related to the law of excluded third [21]. Yet the mathematics of multivalued logic is no different in principle from formal logic, “excluded third” is substituted by “excluded n+1.” Fuzzy logic encountered a difficulty related to the degree of fuzziness, if too much fuzziness is specified, the solution does not achieve a needed accuracy, if too little, it will become similar to formal logic. Complex systems require different degrees of fuzziness in various elements of system operations; searching for the appropriate degrees of fuzziness among combinations of elements again would lead to CC. Is logic still possible after Gödel? Bruno Marchal recently reviewed the contemporary state of this field [22], it appears that logic after Gödel is much more complicated and much less logical than was assumed by founders of artificial intelligence. Also, CC is still unsolved within logic.

Various manifestations of CC are all related to formal logic and Gödel theory. Rule systems rely on formal logic in a most direct way. Self-learning algorithms and neural networks rely on logic in their training or learning procedures: every training example is treated as a separate logical statement. Fuzzy logic systems rely on logic for setting degrees of fuzziness. CC of mathematical approaches to the mind is related to the fundamental inconsistency of logic.

3. Mechanisms of the Mind and the Knowledge Instinct

Although logic does not work, but the mind works. Let us turn to the mechanisms of the mind discussed in psychology, philosophy, cognitive science, and neurobiology. Possibly, we will find inspiration for developing mathematical and physical theory of the mind. The main mechanisms of the mind include instincts, concepts, emotions, and behavior. Each of these mechanisms can be described mathematically. Among the mind's higher abilities, the most directly accessible to consciousness are concepts. Concepts are like internal models of the objects and situations in the world; this analogy is quite literal, e.g., during visual perception of an object, a concept-model in our memory projects an image onto the visual cortex, which is matched there to an image, projected from retina (this simplified description will be refined later).

Instincts emerged as survival mechanisms long before concepts. Grossberg and Levine [23] separated instincts as internal sensor indicating the basic needs, from "instinctual behavior," which should be described by appropriate mechanisms. Accordingly, I use word "instincts" to describe mechanisms of internal sensors: for example, when a sugar level in blood goes below a certain level an instinct "tells us" to eat. Such separation of instinct as "internal sensor" from "instinctual behavior" helps explaining many cognitive functions.

Instinctual needs are conveyed to conceptual and decision-making centers of the brain by emotional neural signals. Whereas in colloquial usage, emotions are often understood as facial expressions, higher voice pitch, exaggerated gesticulation, these are outward signs of emotions, serving for communication. A more fundamental role of emotions within the mind system is that emotional signals evaluate concepts for the purpose of instinct satisfaction [23]. As we discuss in the next section, this emotional mechanism is crucial for breaking out of the "vicious circle" of combinatorial complexity.

An important aspect of our minds is that concept-models always have to be adapted. The same object is never same: distance, angles, lighting, other objects around always change. Therefore, concept-models always have to be adapted to concrete conditions around us. An inevitable conclusion from mathematical analysis: humans and higher animals have a special instinct responsible for cognition. In thousands of publications describing adaptive algorithms, there is always some quantity-structure within the algorithm, which measures a degree of correspondence between the models and the world; this correspondence is maximized.

Clearly, humans and animals engage into exploratory behavior, even when basic bodily needs, like eating, are satisfied. Biologists and psychologists discussed various aspects of this behavior. David Berlyne discussed curiosity in this regard [24]; Leon Festinger, introduced the notion of cognitive dissonance and described many experiments on the drive of humans to reduce dissonance [25]. Until recently, however, it was not mentioned among 'basic instincts' on a par with instincts for food and procreation. The reasons were that it was difficult to define, and that its fundamental nature was not obvious. The fundamental nature of this mechanism is related to the fact that our knowledge always has to be modified to fit the current situations. Knowledge is not just a static state; it is in a constant process of adaptation and learning. Without adaptation of concept-models we will not be able to understand the ever-changing surrounding world. We will not be able to orient ourselves or satisfy any of the bodily instincts. Therefore, we have an inborn need, a drive, an instinct to improve our knowledge. I call it *the knowledge instinct*.

Evaluating satisfaction or dissatisfaction of the knowledge instinct involves emotional signals that are not directly related to bodily needs. Therefore, they are 'spiritual' or aesthetic

emotions. I would like to emphasize that aesthetic emotions are not peculiar to perception of art; they are inseparable from every act of perception and cognition. The mind involves a hierarchy of multiple levels of concept-models, from simple perceptual elements (like edges, or moving dots), to concept-models of objects, to relationships among objects, to complex scenes, and up the hierarchy... toward the concept-models of the meaning of life and purpose of our existence. The ability for perceiving beauty is related to the highest levels of this hierarchy. The tremendous complexity of the mind is due to the hierarchy, yet few basic principles explain basic mechanisms of the mind at every level of the hierarchy.

4. Modeling Field Theory and Dynamic Logic

Modeling field theory (MFT) is a neural architecture mathematically implementing mechanisms of the mind discussed above [2]. MFT is a multi-level, hetero-hierarchical system. The mind is not a strict hierarchy; there are multiple feedback connections among nearby levels, hence the term hetero-hierarchy. At each level in MFT there are concept-models encapsulating the mind's knowledge; they generate so-called top-down neural signals, interacting with input, bottom-up signals. These interactions are governed by the knowledge instinct, which drives concept-model learning, adaptation, and formation of new concept-models for better correspondence to the input signals.

Neurons at a given hierarchical level, we enumerate by index $n = 1, \dots, N$. These neurons receive bottom-up input signals, $\mathbf{X}(n)$, from lower levels in the processing hierarchy. $\mathbf{X}(n)$ is a field of bottom-up neuronal synapse activations, coming from neurons at a lower level. MFT describes each neuron activation as a set of numbers, $\mathbf{X}(n) = \{X_d(n), d = 1, \dots, D\}$. Top-down, or priming signals to these neurons are sent by concept-models, $\mathbf{M}_h(\mathbf{S}_h, n)$; we enumerate models by index $h = 1, \dots, H$. Each model is characterized by its parameters, $\mathbf{S}_h = \{S_h^a, a = 1, \dots, A\}$. Models *represent* signals in the following way. Say, signal $\mathbf{X}(n)$, is coming from sensory neurons activated by object h , characterized by parameters \mathbf{S}_h . Model $\mathbf{M}_h(\mathbf{S}_h, n)$ predicts a value $\mathbf{X}(n)$ of a signal at neuron n . For example, during visual perception, a neuron n in the visual cortex receives a signal $\mathbf{X}(n)$ from retina and a priming signal $\mathbf{M}_h(\mathbf{S}_h, n)$ from an object-concept-model h . A neuron n is activated if both a bottom-up signal from lower-level-input and top-down priming signal are strong. Various models compete for evidence in the bottom-up signals, while adapting their parameters for better match as described below. This is a simplified description of perception. The MFT premise is that the same laws describe the basic interaction dynamics at each level. Perception of minute features, or everyday objects, or cognition of complex abstract concepts is due to the same mechanism described below.

Learning is driven by the knowledge instinct. Mathematically, it increases a similarity measure between the sets of models (knowledge) and bottom up neural signals, $L(\{\mathbf{X}\}, \{\mathbf{M}\})$. The similarity measure is a function of model parameters and associations between the input bottom-up signals and top-down, concept-model signals. For concreteness I refer here to an object perception using a simplified terminology, as if perception of objects in retinal signals occurs in a single level.

In constructing a mathematical description of the similarity measure, it is important to acknowledge two principles (which are almost obvious). First, the visual field content is unknown before perception occurred and second, it may contain any of a number of objects.

Important information could be contained in any bottom-up signal; therefore, the similarity measure is constructed so that it accounts for all bottom-up signals, $\mathbf{X}(n)$,

$$L(\{\mathbf{X}\}, \{\mathbf{M}\}) = \prod_{n \in N} l(\mathbf{X}(n)). \quad (1)$$

This expression contains a product of partial similarities, $l(\mathbf{X}(n))$, over all bottom-up signals; therefore it forces the mind to account for every signal (even if one term in the product is zero, the product is zero, the similarity is low and the knowledge instinct is not satisfied); this is a reflection of the first principle. Second, before perception occurs, the mind does not know which object gave rise to a signal from a particular retinal neuron. Therefore a partial similarity measure is constructed so that it treats each model as an alternative (a sum over models) for each input neuron signal. Its constituent elements are conditional partial similarities between signal $\mathbf{X}(n)$ and model \mathbf{M}_h , $l(\mathbf{X}(n)|h)$. This measure is “conditional” on object h being present, therefore, when combining these quantities into the overall similarity measure, L , they are multiplied by $r(h)$, which represent a probabilistic measure of object h actually being present. Combining these elements with the two principles noted above, a similarity measure is constructed as follows:

$$L(\{\mathbf{X}\}, \{\mathbf{M}\}) = \prod_{n \in N} \sum_{h \in H} r(h) l(\mathbf{X}(n) | h). \quad (2)$$

The structure of (2) follows standard principles of the probability theory: a summation is taken over alternatives, h , and various pieces of evidence, n , are multiplied. This expression is not necessarily a probability, but it has a probabilistic structure. If learning is successful, it approximates probabilistic description and leads to near-optimal Bayesian decisions. The name “conditional partial similarity” for $l(\mathbf{X}(n)|h)$ (or simply $l(n|h)$) follows the probabilistic terminology. If learning is successful, $l(n|h)$ becomes a conditional probability density function (pdf), a probabilistic measure that signal in neuron n originated from object h . Then L is a total likelihood of observing signals $\{\mathbf{X}(n)\}$ coming from objects described by models $\{\mathbf{M}_h\}$. Coefficients $r(h)$, called priors in probability theory, contain preliminary biases or expectations, expected objects h have relatively high $r(h)$ values; their true values are usually unknown and should be learned, like other parameters \mathbf{S}_h . However, in general, $l(n|h)$ are not pdfs, but fuzzy measures of signal $\mathbf{X}(n)$ belonging to object h .

We note that in probability theory, a product of probabilities usually assumes that evidence is independent. Expression (2) contains a product over n , but it does not assume independence among various signals $\mathbf{X}(n)$. There is dependence among signals due to models: each model $\mathbf{M}_h(\mathbf{S}_h, n)$ predicts expected signal values in many neurons n .

During the learning process, concept-models are constantly modified. Here we consider a case when functional forms of models, $\mathbf{M}_h(\mathbf{S}_h, n)$, are all fixed and learning-adaptation involves only model parameters, \mathbf{S}_h . More complicated structural learning of models is considered in [26, 27]. From time to time a system forms a new concept, while retaining an old one as well; alternatively, old concepts are sometimes merged or eliminated. This requires a modification of the similarity measure (2); the reason is that more models always result in a better fit between the models and data. This is a well-known problem, it is addressed by reducing similarity (2) using a “skeptic penalty function,” $p(N, M)$ that grows with the number of models M . For

example, an asymptotically unbiased maximum likelihood estimation leads to multiplicative $p(N, M) = \exp(-N_{\text{par}}/2)$, where N_{par} is a total number of adaptive parameters in all models [2].

The learning process consists in estimating model parameters \mathbf{S} and associating signals with concepts by maximizing the similarity (2). Note, all possible combinations of signals and models are accounted for in expression (2). This can be seen by expanding a sum in (2), and multiplying all the terms; it would result in H^N items, a huge number. This is the number of combinations between all signals (N) and all models (H). Here is the source of CC of many algorithms discussed in the previous section.

Fuzzy dynamic logic (DL) solves this problem without CC [28]. The crucial aspect of DL is matching vagueness or fuzziness of similarity measures to the uncertainty of knowledge of the model parameters. Initially, parameter values are not known, and uncertainty of models is high; so is the fuzziness of the similarity measures. In the process of learning, models become more accurate, and the similarity measure more crisp, the value of the similarity increases. This is the mechanism of dynamic logic. Mathematically it is described as follows. First, assign any values to unknown parameters, $\{\mathbf{S}_h\}$. Then, compute association variables $f(h|n)$,

$$f(h|n) = r(h) l(\mathbf{X}(n)|h) / \sum_{h' \in H} r(h') l(\mathbf{X}(n)|h'). \quad (3)$$

This looks like the Bayes formula for a posteriori probabilities; if $l(n|h)$ in the result of learning become conditional likelihoods, $f(h|n)$ become Bayesian probabilities for signal n originating from object h . In general, $f(h|n)$ can be interpreted as fuzzy class membership functions. The rest of dynamic logic operations are defined as follows,

$$df(h|n)/dt = f(h|n) \sum_{h' \in H} \{[\delta_{hh'} - f(h'|n)] \cdot [\partial \ln l(n|h') / \partial \mathbf{M}_{h'}] \partial \mathbf{M}_{h'} / \partial \mathbf{S}_{h'} \cdot d\mathbf{S}_{h'} / dt, \quad (4)$$

$$d\mathbf{S}_h / dt = \sum_{n \in N} f(h|n) [\partial \ln l(n|h) / \partial \mathbf{M}_h] \partial \mathbf{M}_h / \partial \mathbf{S}_h, \quad (5)$$

in eq. (4)

$$\delta_{hh'} \text{ is 1 if } h=h', 0 \text{ otherwise.} \quad (6)$$

Parameter t is the time of the internal dynamics of the MF system (a number of dynamic logic iterations). Gaussian-shape functions can often be used for conditional partial similarities,

$$l(n|h) = G(\mathbf{X}(n) | \mathbf{M}_h(\mathbf{S}_h, n), \mathbf{C}_h). \quad (7)$$

Here G is a Gaussian function with mean \mathbf{M}_h and covariance matrix \mathbf{C}_h . Note, a ‘‘Gaussian assumption’’ is often used in statistics; it assumes that signal distribution is Gaussian. This is not the case in (7): here signal is not assumed to be Gaussian. Eq. (7) is valid if *deviations* between the model \mathbf{M} and signal \mathbf{X} are Gaussian; these deviations usually are due to many random causes and, therefore, Gaussian. If there is no information about functional shapes of conditional partial similarities, still (7) is a good choice, it is not a limiting assumption: a weighted sum of Gaussians in (2) can approximate any positive function, like similarity.

Covariance matrices, \mathbf{C}_h , in (7) are estimated like other unknown parameters. Their initial values should be large, corresponding to uncertainty in knowledge of models, \mathbf{M}_h . As parameter values and models improve, covariances are reduced to intrinsic differences between models and signals (due to sensor errors, or model inaccuracies). As covariances get smaller, similarities get crisper, closer to delta-functions; association variables (3) get closer to crisp $\{0, 1\}$ values, and dynamic logic solutions converge to crisp logic. This process of concurrent parameter improvement and convergence of similarity to a crisp logical function is an essential part of DL. This is the mechanism of DL combining fuzzy and crisp logic. The dynamic evolution of fuzziness from large to small is the reason for the name “dynamic logic.”

Theorem. Equations (3) through (6) define a convergent dynamic MF system with stationary states defined by $\max \{\mathbf{S}_h\} \mathbf{L}$.

This theorem was proved in [28]. It follows that the stationary states of an MF system are the maximum similarity states satisfying the knowledge instinct. When partial similarities are specified as probability density functions (pdf), or likelihoods, the stationary values of parameters $\{\mathbf{S}_h\}$ are asymptotically unbiased and efficient estimates of these parameters [29]. A computational complexity of the MF method is linear in N .

The dynamic logic therefore is a convergent process. It converges to the maximum of similarity, and therefore satisfies the knowledge instinct. If likelihood is used as similarity, parameter values are estimated efficiently (that is, in most cases, parameters cannot be better learned using any other procedure). Moreover, as a part of the above theorem, it is proven that the similarity measure increases at each iteration. A psychological interpretation is that the knowledge instinct is satisfied at each step: a modeling field system with dynamic logic *enjoys* learning.

Here we illustrate operations of dynamic logic using an example of tracking targets below noise, which can be an exceedingly complex problem. A single scan does not contain enough information for detection. If a target signal is below noise, it cannot be detected in a single scan; combining information from multiple scans is needed. Detection should be performed concurrently with tracking, using several radar scans. A standard approach for solving this kind of problem, which has already been mentioned, is multiple hypotheses tracking [19]. Since a large number of combinations of subsets and models should be searched, it faces the problem of combinatorial complexity.

Figs.1 illustrates detecting and tracking targets below noise; 6 scans are used in this case concurrently for detection and tracking and a pre-detection threshold was set so that only about 500 point are to be considered in 6 scans. Fig.1a shows true track positions in 0.5km x 0.5km data set; 1b shows actual data available for detection and tracking (signal is below clutter, signal-to-clutter ratio is about -2dB for amplitude and -3dB for Doppler; 6 scans are shown on top of each other. The following figures (c) through (h) illustrate operations of dynamic logic: (c) an initial fuzzy model, the fuzziness corresponds to the uncertainty of knowledge; (d) to (h) show increasingly improved models at various iterations (total of 20 iterations). Between (c) and (d) the algorithm fits the data with one model, uncertainty is somewhat reduced. There are two types of models: one uniform model describing clutter (it is not shown), and linear track models with large uncertainty; the number of track models, locations, and velocities are unknown and estimated from the data. Between (d) and (e) the algorithm tried to fit the data with more than one track-model and decided that it needs two models to ‘understand’ the content of the data. Fitting with 2 tracks continues till (f); between (f) and (g) a third track is added. Iterations stopped at (h), when similarity stopped increasing. Detected tracks closely correspond to the truth (a). Complexity of this solution is low, about 10^6 operations. Solving this problem by

multiple hypothesis tracking with exhaustive search would take about $M^N = 10^{390}$ operations, a prohibitively large number, exceeding the number of all events in the Universe.

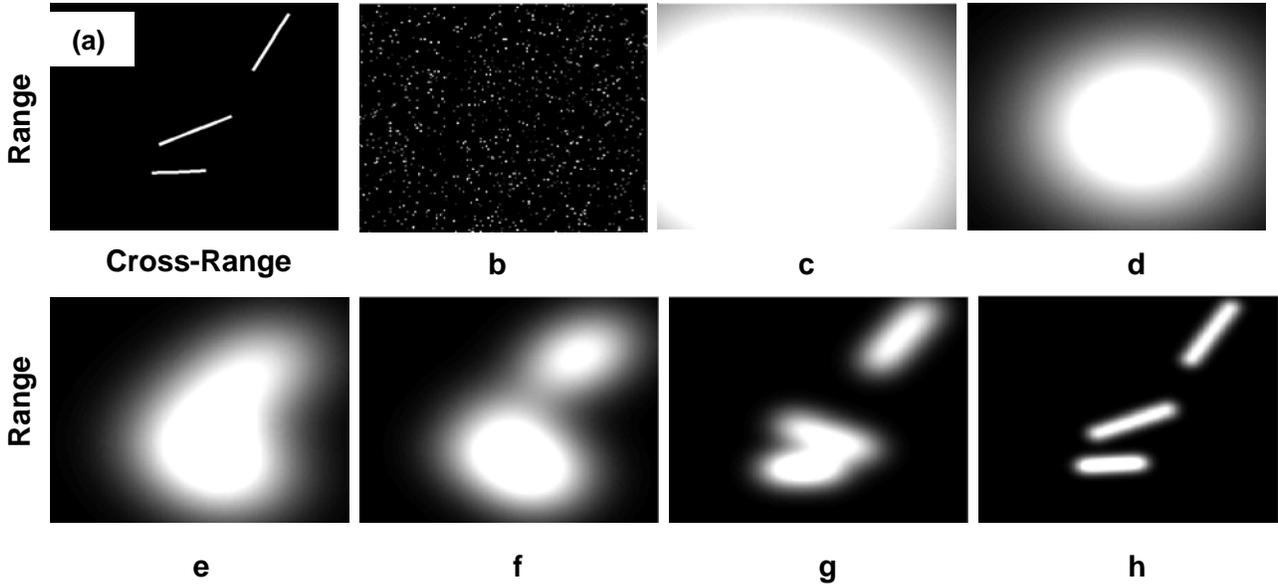


Fig.1. Detection and tracking targets below clutter: (a) true track positions in 0.5km x 0.5km data set; (b) actual data available for detection and tracking (signal is below clutter, signal-to-clutter ratio is about -2dB for amplitude and -3dB for Doppler; 6 scans are shown on top of each other). Dynamic logic operation: (c) an initial fuzzy model, the fuzziness corresponds to the uncertainty of knowledge; (d) to (h) show increasingly improved models at various iterations (total of 20 iterations). Between (c) and (d) the algorithm fits the data with one model, uncertainty is somewhat reduced. There are two *types* of models: one uniform model describing clutter (it is not shown), and linear track models with large uncertainty; the number of track models, locations, and velocities are estimated from the data. Between (d) and (e) the algorithm tried to fit the data with more than one track-model and decided, that it needs two models to ‘understand’ the content of the data. Fitting with 2 tracks continues till (f); between (f) and (g) a third track is added. Iterations stopped at (h), when similarity stopped increasing. Detected tracks closely correspond to the truth (a). Complexity of this solution is low, about 10^6 operations. Solving this problem by multiple hypothesis tracking would take about 10^{1500} operations, a prohibitive complexity.

5. Hierarchy, Differentiation, and Synthesis

Above, we described a single processing level in a hierarchical MFT system. At each level of a hierarchy there are input signals from lower levels, models, similarity measures (2), emotions, which are changes in similarity (2), and actions; actions include adaptation, behavior satisfying the knowledge instinct – maximization of similarity, equations (3) through (6). An input to each level is a set of signals $\mathbf{X}(n)$, or in neural terminology, an input field of neuronal activations. The result of signal processing at a given level are activated models, or concepts h recognized in the input signals n ; these models along with the corresponding instinctual signals and emotions may activate behavioral models and generate behavior at this level.

The activated models initiate other actions. They serve as input signals to the next processing level, where more general concept-models are recognized or created. Output signals

from a given level, serving as input to the next level, could be model activation signals, a_h , defined as

$$a_h = \sum_{n \in N} f(h|n). \quad (8)$$

The hierarchical MF system is illustrated in Fig. 2. Within the hierarchy of the mind, each concept-model finds its “mental” meaning and purpose at a higher level (in addition to other purposes). For example, consider a concept-model “plate.” It has a “behavioral” purpose of using a plate, say, for eating (if this is required by the body), this is the “bodily” purpose at the same hierarchical level. In addition, it has a “purely mental” purpose at a higher level in the hierarchy, a purpose of helping to recognize a more general concept, say of a “dining hall,” which model contains many plates.

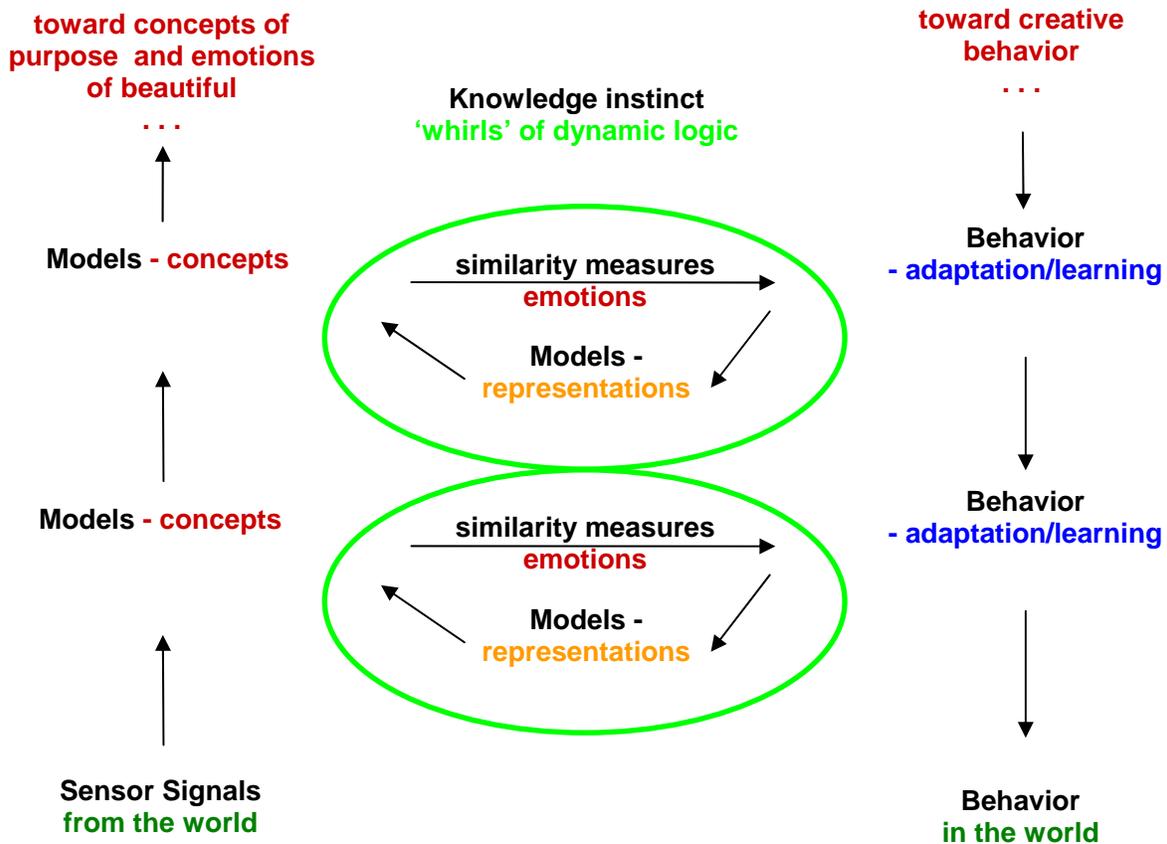


Fig.2. Hierarchical MF system. At each level of a hierarchy there are models-concepts, similarity measures-emotions, and actions (including adaptation, maximizing the knowledge instinct - similarity). High levels of partial similarity measures correspond to concepts recognized at a given level. Concept activations are output signals at this level and they become input signals to the next level, propagating knowledge up the hierarchy.

Models at higher levels in the hierarchy are more general than models at lower levels. For example, at the very bottom of the hierarchy, if we consider vision system, models correspond

(roughly speaking) to retinal ganglion cells and perform similar functions; they detect simple features in the visual field; at higher levels, models correspond to functions performed at V1 and higher up in the visual cortex, that is detection of more complex features, such as contrast edges, their directions, elementary moves, objects, etc. Visual hierarchical structures and models have been studied in details [^{8,30}]. At still higher cognitive levels, models correspond to relationships among objects, to situations, and relationships among situations, etc. Still higher up are even more general models of complex cultural notions and relationships, like family, love, friendship, and abstract concepts, like law, rationality, etc. Contents of these models correspond to cultural wealth of knowledge, including writings of Shakespeare and Tolstoy; mechanisms of the development of these models are reviewed later. At the top of the hierarchy of the mind, according to Kantian analysis [^{9, 31}], are models of the meaning and purpose of our existence, unifying our knowledge, and the corresponding behavioral models aimed at achieving this meaning.

Two aspects of the knowledge instinct are differentiation and synthesis. Differentiation or creation of more diverse concept-models with more concrete meanings was described in previous sections. Another aspect of the knowledge instinct is synthesis, creating a unified whole of the diversity of knowledge and meanings. Each model finds its more abstract, more general meaning at higher levels of the hierarchy. So each object-model finds its more general meanings in situation-concepts, where the object may occur. The higher up the hierarchy the more abstract and general are concept-models. These more general models usually are more fuzzy and less concrete than object models. One reason is that abstract concept-models cannot be directly perceived in the world, unlike object-models that can be matched to direct sensory perceptions. An illustration of vagueness of abstract concept-models one can obtain by closing eyes and imagining a familiar object, say a chair. An imagined chair is usually vague as compared to a perception of actual chair in front of our eyes. More concrete object-models are better accessible by consciousness; they are more amenable to conscious manipulations than abstract, fuzzy, less conscious models higher in the hierarchy.

An important aspect of synthesis is our symbolic ability, an ability to use language for designation and description of abstract concepts. Symbolic ability as described by MFT is considered elsewhere [⁶].

6. Consciousness and Sapience

Elementary processes of perception and cognition are described mathematically in this chapter by Eqs. (3-6); these processes maximize knowledge. Knowledge is measured by similarity between concept-models and the world. In these processes a large number of model-concepts compete for incoming signals, models are modified and new ones are formed, and eventually, connections are established between signal subsets on the one hand, and model-concepts on the other. Perception refers to processes in which the input signals come from sensory organs and model-concepts correspond to objects in the surrounding world. Cognition refers to higher levels in the hierarchy where the input signals are activation signals from concepts cognized (activated) at lower levels, whereas model-concepts are more complex, abstract, and correspond to situations and relationships among lower-level concepts.

Perception and cognition are described by dynamic logic. Its salient mathematical property is a correspondence between uncertainty in models and vagueness-fuzziness in associations $f(h|n)$. During perception, as long as model parameters do not correspond to actual

objects, there is no match between models and signals; many models poorly match many objects, and associations remain fuzzy. Eventually, one model (h') wins a competition for a subset $\{n'\}$ of input signals $\mathbf{X}(n)$, when parameter values match object properties; $f(h'|n)$ values become close to 1 for $n \in \{n'\}$ and 0 for $n \notin \{n'\}$. Upon the convergence, the entire set of input signals $\{n\}$ is approximately divided into subsets, each associated with one model-object. Initial fuzzy concepts become crisp concepts, approximately obeying formal logic. The general mathematical laws of perception, cognition, and high-level abstract thinking are similar.

The dynamic aspect of working of the mind, described by dynamic logic, was first given by Aristotle [³]. He described thinking as a learning process in which an a priori form-as-potentiality (fuzzy model) meets matter (sensory signals) and becomes a form-as-actuality (a crisp concept of the mind). He pointed out an important aspect of dynamic logic, reduction of fuzziness during learning: Forms-potentialities are fuzzy (do not obey logic), whereas forms-actualities are logical. Logic is not the basic mechanism of working of the mind, but an approximate result of the mind working according to dynamic logic.

The three famous volumes by Kant, Critique of Pure Reason, Critique of Judgment, and Critique of Practical Reason [^{5, 9, 32}] describe the structure of the mind similarly to MFT. Pure reason or the faculty of understanding contains concept-models. The faculty of judgment, or emotions, establishes correspondences between models and data about the world acquired by sensory organs (in Kant's terminology, between general concepts and individual events). Practical reason contains models of behavior. Kant was first to recognize that emotions are an inseparable part of cognition. Kant, however, missed the dynamic aspect of thinking, a pervading need for adaptation. Kant considered concepts as given a priori. The knowledge instinct is the only missing link in Kantian theory.

Thinking involves a number of sub-processes and attributes, some are conscious and others are unconscious. According to Carpenter and Grossberg [³³] every recognition and concept formation process involves a "resonance" between bottom-up and top-down signals. We are conscious only about the resonant state of models. In MFT, at every level in the hierarchy, the afferent signals are represented by the input signal field \mathbf{X} , and the efferent signals are represented by the modeling field signals \mathbf{M}_h ; resonances correspond to high similarity measures $l(n|h)$ for some subsets of $\{n\}$ that are "recognized" as concepts (or objects) h . This mechanism, leading to the resonances eqs. (3-6), is a thought-process. In this process, subsets of signals corresponding to objects or situations are understood as concepts, signals acquire meanings and become accessible by consciousness.

Why is there consciousness? Why would a feature like consciousness appear in the process of evolution? The answer to this question contains no mystery: consciousness directs the will and results in a better adaptation for survival. In simple situations, when only minimal adaptation is required, an instinct directly wired to action is sufficient, and unconscious processes can efficiently allocate resources and will. However, in complex situations, when adaptation is complicated, various bodily instincts might contradict one another. Undifferentiated unconscious psychic functions result in ambivalence and ambivalence; every position entails its own negation, leading to an inhibition. This inhibition cannot be resolved by unconscious that does not differentiate among alternatives. Direction is impossible without differentiated conscious understanding. Consciousness is needed to resolve an instinctual impasse by suppressing some processes and allocating power to others. By differentiating alternatives, consciousness can direct a psychological function to a goal.

Most of organism functioning is not accessible to consciousness; blood flow, breathing, workings of heart and stomach are unconscious, at least as long as they work as appropriate. The

same is true about most of the processes in the brain and mind. We are not conscious about neural firings, or fuzzy models competing for evidence in retinal signals, etc. We become conscious about concepts, only during resonance, when a model-concept matches bottom-up signals and become crisp. To put it more accurately, crisper models are better accessible by consciousness. Taylor emphasizes that consciousness requires more than a resonance. He related consciousness to the mind being a control mechanism of the mind and body. A part of this mechanism is a prediction model. When this model predictions differ from sensory observations, this difference may reach a resonant state, which we are consciousness about [³⁴]. In evolution and in our personal psychic functioning the goal is to increase consciousness. But, this is largely unconscious, because our direct knowledge of ourselves is limited to consciousness. This fact creates a lot of confusion about consciousness.

A detailed, scientific analysis of consciousness has proven to be difficult. For a long time it seemed obvious that consciousness completely pervades our entire mental life, or at least its main aspects. Now, we know that this idea is wrong, and the main reason for this misconception has been analyzed and understood: We are conscious only about what we are conscious of, and it is extremely difficult to notice anything else.

Jaynes noted the following misconceptions about consciousness [³⁵]: consciousness is nothing but a property of matter, or a property of living things, or a property of neural systems. These three 'explanations' attempted to dismiss consciousness as an epiphenomenon, an unimportant quality of something else. They are useless because the problem is in *explaining* the relationships of consciousness to matter, to life, and to neural systems. These dismissals of consciousness are not very different from saying that there is no consciousness; but, of course, this statement refutes itself (if somebody makes such a statement unconsciously, there is no point of discussing it). A dualistic position is that consciousness belongs to the world of ideas and has nothing to do with the world of matter. But the scientific problem *is* in explaining the consciousness as a natural-science phenomenon; that is to relate consciousness and the material world. Searle³⁶ suggested that any explanation of consciousness has to account for it being real and based on physical mechanisms in the brain. Among properties of consciousness requiring explanation he listed unity and intentionality (we perceive our consciousness as being *unified* in the space of our perceptions and in the time of our life; consciousness is about something; this 'about' points to its *intentionality*).

Searle³⁷ reviewed recent attempts to explain consciousness, and came to the conclusion that little progress was made during the 1990s. Penrose³⁸ suggested that consciousness cannot be explained by known physical laws of matter. His arguments descend from Gödel's proofs of inconsistency and incompleteness of logic. We have already mentioned that this, however, only proves³⁹ that the mind is not a system of logical rules.

Roughly speaking, there are three conscious/unconscious levels of psychic contents: (1) contents that can be recalled and made conscious voluntarily (memories); (2) contents that are not under voluntary control, we know about them because they spontaneously irrupt into consciousness; and (3) contents inaccessible to consciousness. We know about the latter through scientific deductions. But consciousness is not a simple phenomenon; it is a complicated differentiated process. Jung differentiated four types of consciousness related to experiences of feelings (emotions), thoughts (concepts), sensations, and intuitions [⁷]. In addition to these four psychic functions, consciousness is characterized by the attitude: Introverted, concentrated mainly on the inner experience, or extroverted, concentrated mainly on the outer experience. Interplay of various conscious and unconscious levels of psychic functions and attitudes results in a number of types of consciousness; interactions of these types with individual memories and experiences make consciousness dependent on the entire individual experience producing

variability among individuals. An idea that better differentiated, crisper model-concepts are more conscious is close to Jung's views. Mechanisms of other types of consciousness are less understood and their mathematical descriptions belong to future. Future research would also address emergence in evolution of different types of consciousness, elaborating on Jungian ideas.

In modeling field theory properties of consciousness are explained due to a special model, closely related to what psychologists call Ego or Self. Consciousness, to a significant extent, coincides with the conscious part of these archetype-models. A conscious part of Self belongs to Ego. Not everything within Ego (as defined by Freud) is conscious. Individuality as a total character distinguishing an individual from others is a main characteristic of Ego. Not all aspects of individuality are conscious, so, the relationships among the discussed models can be summarized to some extent, as:

$$\text{Consciousness} \in \text{Individuality} \in \text{Ego} \in \text{Self} \in \text{Psyche}.$$

Consciousness-model is a subject of free will; it possesses, controls, and directs free will. This model accesses conscious parts of other models. Among properties of consciousness discussed by Searle, which are explained by the properties of Consciousness-model are the following.

Totality and undividedness of consciousness are important adaptive properties needed to concentrate power on the most important goal at every moment. This is illustrated, for example, by clinical cases of divided consciousness and multiple personalities, resulting in maladaptation up to a complete loss of functionality. Simple consciousness needs only to operate with relatively few concepts. Humans need more differentiation for selecting more specific goals in more complex environment. The scientific quest is to explain these opposite tendencies of consciousness: how does consciousness pursue undividedness and differentiation at once? There is no mystery, the knowledge instinct together with the hierarchical structure of the mind hold the key to the answer. Whereas every level pursues differentiation, totality belongs to the highest levels of the hierarchy. Future research will have to address these mechanisms in their fascinating details.

Intentionality is a property of referring to something else, and consciousness is about something. This 'aboutness' many philosophers refer to as intentionality. In everyday life, when we hear an opinion we do not just collate it in our memory and relate to other opinions (like a pseudo-scientist in a comedy); this would not lead very far. We wish to know what are the aims and intentions associated with this opinion. Mechanisms of perceiving intent versus specific words were studied by Valerie Reyna and Charles Brainerd, who discuss the contrast between *gist* and *verbatim* systems of memory and decision making [⁴⁰]. Often, we perceive the *intent* of what are said better than specific words, even if the words are chosen to disguise the intent behind causal reasoning. The desire to know and the ability to perceive the goal indicates that in psyche, *final standpoint or purpose* is more important than the *causal* one. This intentionality of psyche was already emphasized by Aristotle in his discussions of the end cause of forms of the mind [³]. Intentionality of consciousness is more fundamental than 'aboutness', it is *purposiveness*.

The intentional property of consciousness led many philosophers during the last decades to believe that intentionality is a unique and most important characteristic of consciousness: according to Searle, only conscious beings could be intentional. But, the mechanism of the knowledge instinct leads to an opposite conclusion. Intentionality is a fundamental property of life: even a simplest living being is a result of long evolution and its every component, say a

gene, or a protein has a purpose and intent. In particular, every model-concept has evolved with an intent or purpose to recognize a particular type of signal (event, message, concept) and to act accordingly (e.g., send recognition message to other parts of the brain and to behavioral models). Aristotle was the first to explain the intentionality of the mind this way; he argued that intentionality should be explained through the a priori contents of the mind. Possibly, future theoretical developments of mechanisms of the knowledge instinct will explain the minds intentionality and purposiveness in its complexity.

Is there any specific relationship between consciousness and intentionality? If so, it is just the opposite of Searle's hypothesis of intentionality implying consciousness. Affective, subconscious, lower-bodily-level emotional responses are concerned with immediate survival, utilitarian goals, and therefore are *intentional in the most* straightforward way. A higher-intellectual-level consciousness is not concerned with the immediate survival, but with the overall understanding of the world, with knowledge and beauty; it can afford to be impartial, abstract, and less immediately-intentional than the rest of the psyche; its intentions might be directed toward meanings and purposes of life. As we discuss few pages below, the highest creative aspect of individual consciousness and the abilities of perceiving beautiful and sublime are intentional without any specific, lower-level utilitarian goal, they are intentional toward self-realization, toward future-self beyond current-self. Due to the current mathematical theories reviewed in this article we can more accurately manipulate these metaphorical descriptions to obtain solutions to long-standing philosophical problems. In addition, we can identify directions for concrete studies of these metaphors in future mathematical simulations and laboratory experiments.

Unity of consciousness refers to conscious mental states being parts of a unified sequence and simultaneous conscious events are perceived as unified into a coherent picture. Searle's unity is close to what Kant called "the transcendental unity of apperception." In MFT, this internal perception is explained as all perceptions, due to a property of the special model involved in consciousness, called Ego by psychologists. The properties of Ego-model explain the properties of consciousness. When certain properties of consciousness seem difficult to explain, we should follow the example of Kant, we should turn the question around and ask: Which properties of Ego model would explain the phenomenological properties of consciousness?

Let us begin the analysis of the structures of the Ego-model and the process of its adaptation to the constantly changing world, from evolutionary-preceding simpler forms. What is the initial state of consciousness: an undifferentiated unity or a "booming, buzzing confusion"⁴¹? Or, let us make a step back in the evolutionary development and ask, what is the initial state of pre-conscious psyche? Or, let us move back even further toward evolution of sensory systems and perception. When building a robot for a factory floor, why provide it with a sensor? Obviously, such an expensive thing as a sensor is needed to achieve specific goals: to sense the environment with the purpose to accomplish specific tasks. Providing a robot with a sensor goes together with an ability to utilize sensory data.

Similarly, in the process of evolution, sensory abilities emerged together with perception abilities. A natural evolution of sensory abilities could not result in a "booming, buzzing confusion," but must result in evolutionary advantageous abilities to avoid danger, attain food, etc. Primitive perception abilities (observed in primitive animals) are *limited* to few types of concept-objects (light-dark, warm-cold, edible-nonedible, dangerous-attractive...) and are directly 'wired' to proper actions. When perception functions evolve further, beyond immediate actions, it is through the development of complex internal model-concepts, which unify simpler object-models into a unified and flexible model of the world. Only at this point of possessing relatively complicated differentiated concept-models composed of a large number of sub-models,

an intelligent system can experience a “booming, buzzing confusion”, if it faces a new type of environment. A primitive system is simply incapable of perceiving confusion: It perceives only those ‘things’ for which it has concept-models and if its perceptions do not correspond to reality, it just does not survive without experiencing confusion. When a baby is born, it undergoes a tremendous change of environment, most likely without much conscious confusion. The original state of consciousness is undifferentiated unity. It possesses a single modality of primordial undifferentiated Self-World.

The initial unity of psyche limited abilities of the mind, and further development proceeded through differentiation of psychic functions or modalities (concepts, emotions, behavior); they were further differentiated into multiple concept-models, etc. This accelerated adaptation. Differentiation of consciousness is a relatively recent process [⁴²].

Consciousness is about aspects of concept-models (of the environment, self, past, present, future plans, and alternatives) and emotions to which we can direct our attention. As already mentioned, MFT explains consciousness as a specialized Ego-model. Within this model, consciousness can direct attention at will. This conscious control of will is called the free will. A subjective feeling of free will is a most cherished property of our psyche. Most of us feel that this is what makes us different from inanimate objects and simple forms of life. And this property is a most difficult one to explain rationally or to describe mathematically. But, let us see how far we can go towards understanding this phenomenon. We know that raw percepts are often not conscious. As mentioned already, for example, in the visual system, we are conscious about the final processing stage, the integrated crisp model, and unconscious about intermediate processing. We are unconscious about eye receptive fields; about details of visual perception of motion and color as far as it takes place in our brain separately from the main visual cortex, etc. [³⁰]. In most cases, we are conscious only about the integrated scene, crisp objects, etc.

These properties of consciousness follow from properties of concept-models; they have conscious (crisp) and unconscious (fuzzy) parts, which are accessible and inaccessible to consciousness, that is to Ego-model. In pre-scientific literature about mechanisms of the mind there was a popular idea of homunculus, a little mind, inside our mind, which perceived our perceptions and made them available to our mind. This naive view is amazingly close to actual scientific explanation. The fundamental difference is that the scientific explanation does not need an infinite chain of homunculi inside homunculi. Instead, there is a hierarchy of the mind models with their conscious and unconscious aspects. The higher in the hierarchy, the less is the conscious differentiated aspect of the models. Until at the top of the hierarchy there are mostly unconscious models of the meaning of our existence (which we discuss later).

Our internal perceptions of consciousness due to Ego-model ‘perceive’ crisp conscious parts of other models similar to models of perception ‘perceive’ objects in the world. The properties of consciousness as we perceive them, such as continuity and identity of consciousness, are due to properties of the Ego-model. What is known about this ‘consciousness’-model? Since Freud, a certain complex of psychological functions was called Ego. Jung considered Ego to be based on a more general model or archetype of Self. Jungian archetypes are psychic structures (models) of a primordial origin, which are mostly inaccessible to consciousness, but determine the structure of our psyche. In this way, archetypes are similar to other models, e.g., receptive fields of the retina are not consciously perceived, but determine the structure of visual perception. The Self-archetype determines our phenomenological subjective perception of ourselves, and in addition, structures our psyche in many different ways, which are far from being completely understood. An important phenomenological property of Self is the perception of uniqueness and in-divisibility (hence, the word *individual*).

Many contemporary philosophers consider subjective nature of consciousness to be an impenetrable barrier to scientific investigation. Chalmers differentiated hard and easy questions about consciousness [43] as follows. Easy questions, that will be answered better and better, are concerned with brain mechanisms: which brain structures are responsible for consciousness? Hard questions, that no progress can be expected about, are concerned with the subjective nature of consciousness and *qualia*, subjective feelings associated with every conscious perception. Nagel described it dramatically with a question: “What is it like to be a bat?” [44] But I disagree. I don’t think these questions are hard. These questions are not mysteries; they are just wrong questions for a scientific theory. Newton, while describing the laws of planet motion, did not ask: ‘What is it like to be a planet?’ (even so, something like this feeling *is* a part of scientific intuition). The subjective nature of consciousness is not a mystery. It is explained due to the subjective nature of the concept-models that we are conscious of. The subjectivity is the result of combined apriority and adaptivity of the consciousness-model, the unique genetic a priori structures of psyche together with our unique individual experiences. I consider the only hard questions about consciousness to be *free will and the nature of creativity*.

Let us summarize. Most of the mind’s operations are not accessible to consciousness. We definitely know that neural firings and connections cannot be perceived consciously. In the foundations of the mind there are material processes in the brain inaccessible to consciousness. Jung suggested that conscious concepts are developed by the mind based on genetically inherited structures, archetypes, which are inaccessible to consciousness [7]. The mind mechanisms, described in MFT by dynamic logic and fuzzy models, are not accessible to consciousness. Grossberg [8] suggested that only signals and models attaining a resonant state (that is signals matching models) could reach consciousness. It was further detailed by Taylor [34]; we are conscious about our models, when our model anticipation of reality contradicts sensory signals. Final results of dynamic logic processes, resonant states characterized by crisp models and corresponding signals are accessible to consciousness.

7. Higher Cognitive Functions

Imagination involves excitation of a neural pattern in a sensory cortex in absence of an actual sensory stimulation. For example, visual imagination involves excitation of visual cortex, say, with closed eyes [8, 30]. Imagination was long considered a part of thinking processes; Kant [9] emphasized the role of imagination in the thought process, he called thinking “a play of cognitive functions of imagination and understanding.” Whereas pattern recognition and artificial intelligence algorithms of recent past would not know how to relate to this [45], Carpenter and Grossberg resonance model [33] and the MFT dynamics both describe imagination as an inseparable part of thinking. Imagined patterns are top-down signals that *prime* the perception cortex areas (*priming* is a neural terminology for making neurons to be more readily excited). In MFT, the imagined neural patterns are given by models \mathbf{M}_h .

As discussed, visual imagination, can be “internally perceived” with closed eyes. The same process can be mathematically modeled at higher cognitive levels, where it involves models of complex situations or plans. Similarly, models of behavior at higher levels of the hierarchy can be activated without actually propagating their output signals down to actual muscle movements and to actual acts in the world. In other words, behavior can be imagined, along with its consequences, it can be evaluated, and this is the essence of plans. Sometimes, imagination involves detailed alternative courses of actions considered and evaluated

consciously. Sometimes, imagination may involve fuzzy or vague, barely conscious models, which rich consciousness only after they converge to a “reasonable” course of action, which can be consciously evaluated. From a mathematical standpoint, this latter mechanism is the only possible, conscious evaluation cannot involve all possible courses of action; it would lead to combinatorial complexity and impasse. It remains to be proven in brain studies, which will identify the exact brain regions and neural mechanisms involved.

MFT adds details to Kantian description of working of the mind in agreement with neural data: thinking is a play of top-down *higher-hierarchical-level* imagination and bottom-up *lower-level* understanding.. Kant identified this “play” [described by (3-6)] as a source of aesthetic emotion. Kant used the word “play,” when he was uncertain about the exact mechanism; this mechanism, according to our suggestion, is the knowledge instinct and dynamic logic.

Aesthetic emotions and the instinct for knowledge. Perception and cognition, recognizing objects in the environment and understanding their meaning is so important for survival that a special instinct evolved for this purpose. This instinct for learning and improving concept-models I call the instinct for knowledge. In MFT it is described by maximization of similarity between the models and the world, eq. (2). Emotions related to satisfaction-dissatisfaction of this instinct are perceived by us as harmony-disharmony (between our understanding of how things ought to be and how they actually are in the surrounding world). According to Kant [⁹] these are aesthetic emotions (emotions that are not related directly to satisfaction or dissatisfaction of bodily needs).

The instinct for knowledge makes little kids, cubs, and piglets jump around and play fight. Their inborn models of behavior must adapt to their body weights, objects, and animals around them long before the instincts of hunger and fear will use the models for direct aims of survival. Childish behavior just makes the work of the knowledge instinct more observable; to varying degrees, this instinct continues acting throughout our lives. All the time we are bringing our internal models into correspondence with the world. In adult life, when our perception and understanding of the surrounding world is adequate, aesthetic emotions are barely perceptible: the mind just does its job. Similarly, we do not usually notice adequate performance of our breathing muscles and satisfaction of the breathing instinct. However, if breathing is difficult, negative emotions immediately reach consciousness. The same is true about the knowledge instinct and aesthetic emotions: if we do not understand the surroundings, if objects around do not correspond to our expectations, negative emotions immediately reach consciousness. We perceive these emotions as disharmony between our knowledge and the world. Thriller movies exploit the instinct for knowledge: they are mainly based on violating our expectations; their personages are shown in situations, when knowledge of the world is inadequate for survival.

Let me emphasize again, aesthetic emotions are not peculiar to art and artists, they are inseparable from every act of perception and cognition. In everyday life we usually do not notice them. Aesthetic emotions become noticeable at higher cognitive levels in the mind hierarchy, when cognition is not automatic, but requires conscious effort. Damasio view [⁴⁶] of emotions defined by visceral mechanisms, as far as discussing higher cognitive functions, seems erroneous in taking secondary effects for the primary mechanisms. People often devote their spare time to increasing their knowledge, even if it is not related to their job and a possibility of promotion. Pragmatic interests could be involved: knowledge makes us more attractive to friends and could help find sexual partners. Still, there is a remainder, a pure joy of knowledge, aesthetic emotions satisfying the knowledge instinct.

Beautiful and sublime. Cognitive science is at a complete loss when trying to explain the highest human abilities, the most important and cherished abilities to create and perceive beautiful and sublime experiences. Their role in the working of the mind is not understood. MFT

explains that simple harmony is an elementary aesthetic emotion related to improvement of object-models. Higher aesthetic emotions are related to the development and improvement of more complex “higher” models at higher levels of the mind hierarchy. The highest forms of aesthetic emotion are related to the most general and most important models near the top of the hierarchy. According to Kantian analysis [^{9, 31}], among the highest models are models of the meaning of our existence, of our purposiveness or intentionality, and beauty is related to improving these models.

Models at the top of the mind hierarchy, models of our purposiveness are largely fuzzy and unconscious. Some people, at some points in their life, may believe that their life purpose is finite and concrete, for example to make a lot of money, or build a loving family and bring up good children. These models are aimed at satisfying powerful instincts, but not the knowledge instinct, and they do not reflect the highest human aspirations. Everyone who has achieved a finite goal of making money or raising good children knows that this is not the end of his or her aspirations. The reason is that everyone has an ineffable feeling of partaking in the infinite, while at the same time knowing that our material existence is finite. This contradiction cannot be resolved. For this reason, models of our purpose and meaning cannot be made crisp and conscious; they will forever remain fuzzy and partly unconscious.

Everyday life gives us little evidence to develop models of meaning and purposiveness of our existence. People are dying every day and often from random causes. Nevertheless, life itself demands belief in one’s purpose; without such a belief it is easier to get drunk or take drugs than to read this article. These issues are not new; philosophers and theologians expounded them from time immemorial. The knowledge instinct theory gives us a scientific approach to the eternal quest for the meaning. We perceive an object or a situation as beautiful, when it stimulates improvement of the highest models of meaning. Beautiful is what “reminds” us of our purposiveness. This is true about perception of beauty in a flower or in an art object. Just an example, R. Buckminster Fuller, an architect, best known for inventing the geodesic dome wrote: “When I’m working on a problem, I never think about beauty. I think only how to solve the problem. But when I have finished, if the solution is not beautiful, I know it is wrong.” [⁴⁷] The MFT explanation of the nature of beautiful helps understanding an exact meaning of this statement and resolves a number of mysteries and contradictions in contemporary aesthetics [^{48, 42}].

The feeling of spiritually sublime is similar and different from beautiful. Whereas beautiful is related to improvement of the models of *cognition*, sublime is related to improvement of the models of *behavior* realizing the highest meaning in our life. Beautiful and sublime are not finite. MFT tells us that mathematically, improvement of complex models is related to choices from infinite number of possibilities. A mathematician may consider 100^{100} , or million to the millionth power as a finite number. But for a physicist, a number that exceeds all elementary events in the life of the Universe is infinite. A choice from infinity is infinitely complex and contains infinite information. Therefore, choices of beautiful and sublime contain infinite information. This is not a metaphor, but exact mathematical fact. Beauty is at once objective and subjective. It really exists, cultures and individuals cannot exist without the ability for beauty, and still, it cannot be described by any finite algorithm or a set of rules.

Beauty of a physical theory discussed sometimes by physicists is similar in its infinity to beauty in an artwork. For a physicist, beauty of a physical theory is related to improving the models of the meaning in our understanding of the universe. This satisfies a scientist’s quest for the purpose, which he identifies with the purpose in the world.

Intuition. Intuitions include inner perceptions of object-models, imaginations produced by them, and their relationships with objects in the world. They include also higher-level models

of relationships among simpler models. Intuitions involve fuzzy unconscious concept-models, which are in a state of being formed, learned, and being adapted toward crisp and conscious models (say, a theory). Conceptual contents of fuzzy models are undifferentiated and partly unconscious. Similarly, conceptual and emotional contents of these fuzzy mind states are undifferentiated; concepts and emotions are mixed up. Fuzzy mind states may satisfy or dissatisfy the knowledge instinct in varying degrees before they become differentiated and accessible to consciousness, hence the vague complex emotional-cognitive feel of an intuition. Contents of intuitive states differ among people, but the main mechanism of intuition is the same among artists and scientists. Composer's intuitions are mostly about sounds and their relationships to psyche. Painter's intuitions are mostly about colors and shapes and their relationships to psyche. Writer's intuitions are about words, or more generally, about language and its relationships to psyche. Mathematical intuition is about structure and consistency within a theory, and about relationships between the theory and a priori content of psyche. Physical intuition is about the real world, first principles of its organization, and mathematics describing it.

Creativity is an ability to improve and create new model-concepts. In a small degree it is present in everyday perception and cognition. Usually the words "creativity," "creative," or "discovery" are applied to improving or creating new model-concepts at higher cognitive levels, concepts that are important for the entire society or culture. A crisp and specific model could only match a specific content; therefore it cannot lead to creation of new contents. Creativity and discovery, according to section 5, involve vague, fuzzy models, which are made more crisp and clear. It occurs, therefore, at the border between consciousness and unconscious. A similar nature of creative process, involving consciousness and unconscious, was discussed by Jung [⁴⁹]. Creativity usually involves intuition, as discussed above: fuzzy undifferentiated feelings-concepts.

Creativity is driven by the knowledge instinct. Two main mechanisms of creativity, the components of the knowledge instinct, are differentiation and synthesis. Differentiation is a process of creating new, more specific and more detailed concept-models from simpler, less differentiated and less conscious models. Mathematical mechanisms of differentiation were discussed in section 5. The role of language in differentiation of cognition was discussed in section 6, as mentioned, this research is in its infancy and a subject of future research.

Synthesis is a process of connecting detailed crisp concept-models to the unconscious, instincts, and emotions. The need for synthesis comes from the fact that most of our concept-models are acquired from language. The entire conceptual content of the culture is transmitted from generation to generation through language; cognitive concept-models cannot be transmitted directly from brain to brain. Therefore, concepts acquired from language have to be used by individual minds to create cognitive concepts. The mechanism of integrating cognition and language [⁶] explains that language concepts could be detailed and conscious; but not necessarily connected to equally detailed cognitive concepts, to emotions, and to the knowledge instinct. Connecting language and cognition involves differentiating cognitive models, developing cognitive models, which differentiation and conscious approaches that of language models. Every child acquires language between one and seven, but it takes the rest of life to connect abstract language models to cognitive concept-models, to emotions, instincts, and to the life's needs. This is the process of synthesis; it integrates language and cognition, concepts and emotions, conscious and unconscious, instinctual and learned. Current research directions discussed in section 6 are just touching on these mechanisms of synthesis. It is largely an area for future research.

Another aspect of synthesis, essential for creativity, is developing a unified whole within

psyche, a feel and intuition of purpose and meaning of existence. It is necessary for concentrating will, for survival, for achieving individual goals, and in particular for satisfying the knowledge instinct by differentiating knowledge. Concept-models of purpose and meaning, as discussed are near the top of the mind hierarchy; they are mostly unconscious and related to feelings of beautiful and sublime. A condition of synthesis is correspondence among a large number of concept-models. A knowledge instinct as discussed in section 3 is a single measure of correspondence between all the concept-models and all the experiences-data about the world. This is, of course, a simplification. Certain concept-models have high value for psyche (e.g., religion, family, success, political causes) and they affect recognition and understanding of other concepts. This is a mechanism of differentiation of the knowledge instinct. Satisfaction of the knowledge instinct therefore is not measured by a single aesthetic emotion, but by a large number of aesthetic emotions. The entire wealth of our knowledge should be brought into correspondence with itself, this requires a manifold of aesthetic emotions. Differentiation of emotions is performed by music [⁴²], but this is beyond the scope of this chapter.

There is an opposition between differentiation and synthesis in individual minds as well as in the collective psyche. This opposition leads to complex evolution of cultures. Differentiated concepts acquire meaning in connections with instinctual and unconscious, in synthesis. In evolution of the mind, differentiation is the essence of the development of the mind and consciousness, but it may bring about a split between conscious and unconscious, between emotional and conceptual, between language and cognition. Differentiated and refined models existing in language may loose connection with cognitive models, with people's instinctual needs. If the split affects collective psyche, it leads to a loss of the creative potential of a community or nation. This was the mechanism of death of great ancient civilizations. The development of culture, the very interest of life requires *combining differentiation and synthesis*. Evolution of the mind and cultures is determined by this complex non-linear interaction: One factor prevails, then another [⁴²]. This is an area for future research.

Teleology, causality, and the knowledge instinct. Teleology explains the Universe in terms of purposes. In many religious teachings, it is a basic argument for the existence of God: If there is purpose, an ultimate Designer must exist. Therefore, teleology is a hot point of debates between creationists and evolutionists: Is there a purpose in the world? Evolutionists assume that the only explanation is causal. Newton laws gave a perfect causal explanation for the motion of planets: A planet moves from moment to moment under the influence of a gravitational force. Similarly, today science explains motions of all particles and fields according to causal laws, and there are exact mathematical expressions for fields, forces and their motions. Causality explains what happens in the next moment as a result of forces acting in the previous moment. Scientists accept this causal explanation and oppose to teleological explanations in terms of purposes. The very basis of science, it seems, is on the side of causality, and religion is on the side of teleology.

However, at the level of the first physical principles this is wrong. The contradiction between causality and teleology does not exist at the very basic level of fundamental physics. The laws of physics, from classical Newtonian laws to quantum superstrings, can be formulated equally as causal or as teleological. An example of teleological principle in physics is energy minimization, particles move so that energy is minimized. As if particles in each moment know their purpose: to minimize the energy. The most general physical laws are formulated as minimization of action. Action is a more general physical entity than energy; it is an intuitive name for a mathematical expression called Lagrangian. Causal dynamics, motions of particles, quantum strings, and superstrings are determined by minimizing Lagrangian-action [⁵⁰]. A particle under force moves from point to point as if it knows its final purpose, to minimize Lagrangian-action. Causal dynamics and teleology are two sides of the same coin.

The knowledge instinct is similar to these most general physical laws: evolution of the mind is guided by maximization of knowledge. A mathematical structure of similarity (2) is similar to Lagrangian, and it plays a similar role; it bridges causal dynamic logic of cognition and teleological principle of maximum knowledge. Similarly to fundamental physics, dynamics and teleology are equivalent: Dynamic logic follows from maximization of knowledge and vice versa. Ideas, concept-models change under the ‘force’ of dynamic logic, as if they know the purpose: Maximum knowledge. One does not have to choose between scientific explanation and teleological purpose: Causal dynamics and teleology are equivalent.

8. Experimental Evidence, Predictions, and Testing

The mind is described in psychological and philosophical terms, whereas the brain is described in terms of neurobiology and medicine. Within scientific exploration the mind and brain are different description levels of the same system. Establishing relationships between these descriptions is of great scientific interest. Today we approach solutions to this challenge [⁵¹], which eluded Newton in his attempt to establish physics of “spiritual substance” [⁵²]. Detailed discussion of established relationships between the mind and brain is beyond the scope of this chapter. We briefly mention the main known and unknown facts and give references for future reading. Adaptive modeling abilities are well studied with adaptive parameters identified with synaptic connections [⁵³]; instinctual learning mechanisms have been studied in psychology and linguistics [⁵⁴]. General neural mechanisms of the elementary thought process (which are similar in MFT and ART [³³]) include neural mechanisms for bottom-up (sensory) signals, top-down imagination model-signals, and the resonant matching between the two; these have been confirmed by neural and psychological experiments [⁵⁵]. Ongoing research address relationships between neural processes and consciousness [^{56, 34}]. Relating MFT to brain mechanisms in details is a subject of ongoing and future research.

Ongoing and future research will confirm, disprove, or suggest modifications to specific mechanisms considered in sections 5 and 6. These mechanisms include model parameterization and parameter adaptation, reduction of fuzziness during learning, and the similarity measure described by eq.(2) as a foundation of the knowledge instinct and aesthetic emotion. Other mechanisms include on one hand, relationships between psychological and neural mechanisms of learning and, on the other hand, aesthetic feelings of harmony and emotions of beautiful and sublime. Future research will also investigate the validity of the dual integrated structure of model-concepts described by eq.(9) as a foundation for interaction between cognition and language and for symbolic ability. A step in this direction will be to demonstrate in simulations that this mechanism actually integrates cognition and language without combinatorial complexity. Specific neural systems will need to be related to mathematical descriptions as well as to psychological descriptions in terms of subjective experiences and observable behavior. Ongoing simulation research addresses the evolution of models jointly with the evolution of language [⁵⁷]. Also being investigated are the ways that MFT and the knowledge instinct relate to behavioral psychology and to the specific brain areas involved in emotional reward and punishment during learning [⁵⁸]. Interesting unsolved problems include: detailed mechanisms of interactions between cognitive hierarchy and language hierarchy [^{26, 27}]; differentiated forms of the knowledge instinct, the infinite variety of aesthetic emotions perceived in music, their relationships to mechanisms of synthesis [⁴²]; and interactions of differentiation and synthesis in the development of the mind during cultural evolution. Future experimental research will need to

examine, in detail, the nature of hierarchical interactions, including mechanisms of learning hierarchy, to what extent the hierarchy is inborn vs. adaptively learned, and the hierarchy of the knowledge instinct.

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