

Quantifying Anticipatory Characteristics. The AnticipationScope™ and the AnticipatoryProfile™

Mihai Nadin

Abstract Anticipation has frequently been acknowledged, but mainly on account of qualitative observations. To quantify the expression of anticipation is a challenge in two ways: (1) Anticipation is unique in its expression; (2) given the non-deterministic nature of anticipatory processes, to describe quantitatively how they take place is to describe not only successful anticipations, but also failed anticipations. The AnticipationScope is an original data acquisition and data processing environment. The Anticipatory Profile is the aggregate expression of anticipation as a realization in the possibility space. A subsystem of the AnticipationScope could be a predictive machine that monitors the performance of deterministic processes.

Keywords Anticipation • Diagnostic • Possibility • Prediction • Process

1 Introduction

The year is 1590. Hans and Zacharias Jansen make public a description of what will eventually lead to the future light microscope. It was not a cure for malaria, dysentery, or African trypanosomiasis; but without the microscope, progress in treating such and other diseases would have taken much longer. The microscope allows for “mapping” the reality invisible to the naked eye. It helps in the discovery of “new territory”. Under the microscope’s lens, the “world” becomes “larger.” Understanding the “larger” world becomes a goal for a variety of sciences. Bacteria and cells are identified. It soon becomes clear that micro-

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organisms constitute the vast majority of the living realm. It also becomes clear that sight—the most natural of human senses—implies awareness of resolution. Since the retina is made of cells, it is possible to distinguish between two (or more) microentities only if they are at least a distance of $150 \cdot 10^{-6}$ m; otherwise, the eye cannot distinguish between them. In order to make the “invisible” (what the naked eye cannot see given its cellular make-up) visible, a lens was used in order to obtain a larger image of what the eyes could not distinguish. It took 220 years before achromatic lenses (that Giovanni Battista Amici used in his microscope) made possible the realization that cells (which Robert Hooke called by this name in 1665) exist in all organisms. Today this is common knowledge; at that time it was revolutionary.

The microscope, used in physics as well as in biology, helps to describe the matter that makes up everything that is (The sophisticated electronic microscope uses electrons instead of light.). It does not help to describe behavior at the macrolevel of reality. It only assists humans in figuring out what things are made from and how these components behave. And this is exactly what distinguishes the *AnticipationScope*TM from the enlargement machinery deployed in order to get a better look at lower-scale aspects of reality, or to “see” far away (telescopes were only a beginning).

In a day and age of advanced molecular biology and genetic focus, the *AnticipationScope* can be understood as a “microscope” for the very broad composite spectrum of conditions affecting the adaptive system: Parkinson’s disease, autism, schizophrenia, obsessive-compulsive disorder, post-traumatic stress disorder, Alzheimer’s. It does not visualize viruses or bacteria, but behavior. By generalization, it is a scope for human performance. The list of what can be perceived via the *AnticipationScope* is open. Brain imaging—the in brain scope a variety of implementations and processing techniques—is an attempt at mapping the brain. It has helped in understanding brain functionality, neurological disorders, and the efficiency of pharmacological treatments.

However, it does not allow for a closer look at unfolding human action as an integrated function across multiple systems, including sensory perception, cognition, memory, motor control, and affect. It may well be that the *AnticipationScope* is a digital processing platform corollary to brain imaging; or at least that the knowledge gained through the *AnticipationScope* can be correlated with that gained through brain imagery, or through molecular biology methods.

2 What Do We Map?

The operative concept upon which the entire project is grounded is *anticipation*. Since the concept is not mainstream in current science, the following example serves as an explanation. Anticipation, as a life sciences knowledge domain, spans a broad range of disciplines: cognitive science, bioinformatics, brain science, biophysics, physiology, psychology, and cybernetics, among others. The concept

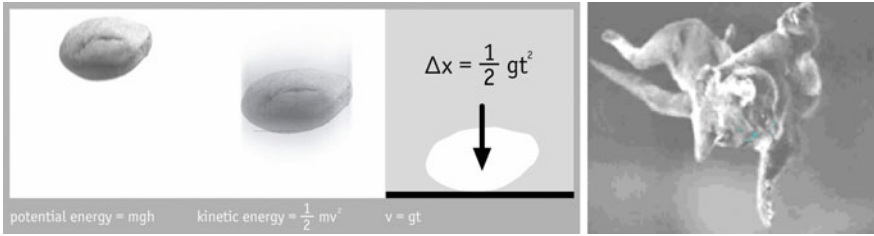


Fig. 1 Anticipation. *Left:* The falling of a stone. *Right:* The falling of a cat

challenges the reductionist-deterministic understanding of the living as a machine, subject only to physics, and the associated techniques and methods for “repairing” it. Given the concept’s novelty, I shall explain anticipation using an example (see Figure 1)

The state of a *physical* (non-living) entity—the falling stone—is determined by its past state and current state (weight, position in space). The state of a living entity—the falling cat—is determined by its past and present, *but also by a possible future state* (safe landing). The falling of a cat involves what are known as adaptive processes [16]. The falling of a stone exemplifies a deterministic phenomenon. It can be described to a high degree of precision: the same stone, falling from the same position will fall the same way regardless of the context (day/night, no one looking/many observers, etc.).

$$x(t) = f(x(t - 1), x(t)) \tag{1}$$

In the realm of physics, the experiment is reproducible. No matter how many times the stone falls, no learning is involved. A cat, while always subject to the laws of physics—the cat is embodied in matter, therefore gravity applies to its falling—exemplifies a non-deterministic phenomenon. Non-deterministic means that *the outcome cannot be predicted*. The cat might land safely, or it might get hurt. Even under the same experimental conditions, a cat will never fall the same way twice (not to mention that the cat that fell once is different from the cat that fell again—it aged, it learned). Adaptive characteristics change with learning (practice, to be more precise). Every experiment—assuming for argument’s sake that someone might subject a cat to repeated falling (ethical considerations suspended)—returns a different value. Adaptive processes are involved. The cat’s fall is associated with learning. Adaptivity changes with experience. As the context changes (falling during day or night, the number and type of observers, landing on grass or on stones, etc.), the outcome (how the cat lands) changes. Both a deterministic component and a non-deterministic component (the possible future state, i.e., where and how to land safely) affect the current state.

$$x(t) = f(x(t - 1), x(t), x(t + 1)) \tag{2}$$

In respect to the deterministic aspect: If the cat falls a short distance, its ability to influence the outcome is diminished. If it falls from a very high distance, the

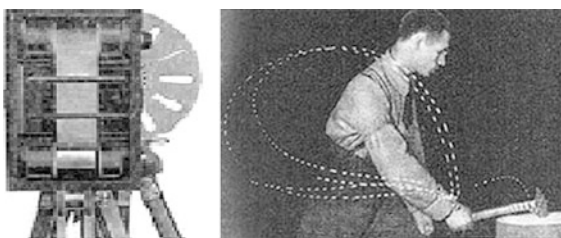
body's acceleration affects the outcome: the cat will get hurt despite trying to land safely. In summary: there is a juxtaposition of a deterministic action-reaction process—the falling of a stone, subject to the laws of gravity—and a non-deterministic, anticipation-action-reaction process—the falling of a cat is subject to gravity, but also subject to its own active participation in the process. In the first case, the knowledge domain is physics; in the second case, the knowledge domain involves physics, but extends to biology, physiology, motoric, neuroscience, and adaptive systems. The falling of a stone is representative of physical processes (a limited number of parameters relatively independent of each other). The falling of a cat is representative of complex processes: high number of variables, and usually reciprocally dependent variables. The mapping of repetitive processes—such as the falling of the stone—is fundamentally different from the mapping of unique complex processes. Let us now examine the conceptual underpinning of the anticipatory behavior example.

2.1 Conceptual Aspects

In respect to the history of interest (accidental or systematic) in anticipatory manifestations, one statement can be made: experimental evidence has been reported since the early beginnings of science. Theoretical considerations, however, have been more focused on particular forms of anticipation [9–11]. The earliest known attempts to define a specific field of inquiry [14] remain more of documentary relevance. It was ascertained very early that anticipation is a characteristic of the living. In this context, the focus on human movement is not accidental. Motor control remains an example of the many attempts to understand anticipatory aspects (such as those of the falling cat, mentioned above), even if anticipation as such is not named. In this respect, it is worth bringing up the so-called “Bernstein Heritage” [8]. Nikolai A. Bernstein's work (as contradictory as it is in its many stages) is a reference impossible to ignore (Fig. 2).

Since our particular focus is on quantifying anticipatory behavior, his kymocyclograph [2] deserves at least mention. It allowed him to take note of the uniqueness of human motion, replacing the mechanistic view with a dynamic view. The device is an original construction with many ingenious solutions to the problems posed by recording human motion. It is a camera conceived to allow

Fig. 2 *Kymocyclograph* conceived by Bernstein (1928) and hammering worker. *Left:* Kymocyclograph, *Right:* hammering worker



measurement of human movement. The focus was on “studying the *what* of movement (trajectories)” and “the *how* (‘analysis of underlying mechanisms’)” [4]. Of course, Bernstein’s contributions are related to quite a number of other individuals (Popova, Leontief, Luria, Vygotsky, Gel’fand, Tsetlin, etc.).

It is worth mentioning that before Bernstein, Georges Marinescu [1], using a cinematographic camera, focused his studies (starting 1899) on gait disorders, locomotor ataxia, and other aspects of motoric neurological disorders. He was among the very first to recognize that film images could provide insight regarding the nature of changes in human movement (This reference does not necessarily relate directly to the subject of anticipation as such.). As already indicated, a theoretic perspective will eventually be advanced to those many researchers of human movement who already noticed anticipatory features in the way people move or execute operations using tools.

2.2 *Anticipation and Change*

Anticipation is an expression of change, i.e., of dynamics. It underlies evolution. Change always means variation over time. In its dynamics, the physical is subject to the constant rhythm associated with the natural clock (of the revolving Earth). The living is subject to many different clocks: the heartbeat has a rhythm different from saccadic movement; neuron firing in the brain takes place at yet another rhythm; and so does metabolism. The real-time clock that measures intervals in the change of the physical (day and night, seasons, etc.) and the faster-than-real-time clock of cognitive activity—we can imagine things well ahead of making them—are not independent of each other. A faster-than-real-time scanning of the environment informs the cat’s falling in real time. A model of the future guides the action in the present. This is not unlike our own falling, when skiing downhill at high speed or when we accidentally trip. In the absence of anticipation, we would get hurt. Reaction is too slow to prevent this. The information process through which modeling the future takes place defines the anticipation involved. When this information process is affected by reduced perception, limited motor control, deteriorated reflexes, or short attention span, falling can become dangerous. Older people break bones when falling not only because their bones are getting frail (change in the physical characteristics), but also because they no longer “know” how to fall. In such cases, the anticipation involved is deficient.

3 Anticipation and Aging

It is in the spirit of this broad-stroke explanation of anticipation that a project entitled *Seneludens* (from *senescere*, getting old, and *ludere*, playing) was initiated by the antÉ - Institute for Research in Anticipatory Systems at the University of

Texas at Dallas. The gist of this project [11] is to compensate for aging-related losses in motor control, sensation, and cognition. The goal is to stimulate brain plasticity through targeted behavioral training in rich learning environments, such as specially conceived, individualized computer games (part of the so-called “serious games” development). These are customizable perceptual, cognitive, and motoric activities, with a social component that will strengthen the neuromodulatory systems involved in learning. Improved operational capabilities translate into extended independence and better life quality for the aging. For this purpose, the Institute has formed research alliances with, among others, professionals involved in the medical support of the aging. From the many topics brought up in conversations with the medical community (e.g., University of Texas-Southwestern, a world renowned medical school, and Presbyterian Hospital, both in Dallas, Texas), one informs the goal of the endeavor: “How do you quantify anticipation? Isn’t it, after all, reaction time?” (reflex time). It is not enough to assume that it is not.

Newton’s action-reaction law of physics explains how the cat reacts on landing, but not how it anticipates the fall so that it will not result in pain or damage. The dimension of anticipation might be difficult to deconfound from reaction; but that is the challenge. And here lie the rewards for those who are engaged in addressing health from the perspective of anticipation. If we can quantify anticipation, we can pinpoint the many factors involved in the debilitating conditions affecting the aging (and not only the aging). The scientific hypothesis we are pursuing is: Spectrum conditions (e.g., Parkinson’s, dementia, autism, etc.) are not the result of diminished reaction; rather all are expressions of reduced or skewed anticipation. Losses in sensorial acuity and discrimination, in motor control; diminished and deviating cognitive performance; affected memory functions—they all contribute to the loss of anticipation.

From all we know, anticipation is a holistic, i.e., integrated, expression of each individual’s characteristics across multiple systems. Of course, the goal is to prove this statement, and based on the proof, to address, from the perspective of the unity between mind and body, the possibility to re-establish such unity.

3.1 Specifications

All of the above makes up the background against which the AnticipationScope introduced in the first lines of this text is defined: to conceive, design, specify, test, and implement an integrated information acquisition, processing, interpretation, and clinical evaluation unit. The purpose of measurement is to produce a record of parameters describing human action in progress. This is a mapping from processes that result in motoric activity to an aggregate representation of the action as meaningful information. The outcome of the AnticipationScope, within which an individual is tested, is his or her Anticipatory ProfileTM.

By way of explanation, let us consider current research in the genetic, or molecular, make-up of each human being. Indeed, medicine and molecular biology contributed proof that symptoms are important in dealing with disease; but molecular differences among individuals might be more important. We are past the one-drug-fits-all practice of medicine. The goal is to provide “personalized medicine” in which treatment is tailored not only to the illness, but also to the genetic or metabolic profile. Truth be told, this is an ambitious project. So is the Anticipatory Profile, but at the level of defining action characteristics of each person. The assumption that everyone runs the same way, jumps in an identical manner, hammers a nail in a standardized fashion, etc. is evidently misleading. If we could all run and jump the same way, champions would not be the exception. Their Anticipatory Profile is different from that of anyone else just trying to keep in shape. In Bernstein’s time, the Soviet regime wanted scientists to study how to make every worker more productive (Machines do exactly that.). In our time, we want to understand how differences in anticipatory characteristics could lead to improved performance of artists, athletes, pilots, and of everyone enjoying a certain activity (tennis, skiing, hiking, swimming, golf, etc.).

Variations in the Anticipatory Profile are indicative of the adaptive capabilities of the individual. When we break down in our actions, it is useful to see whether this is due to an accidental situation or a new condition. Accordingly, the AnticipationScope could potentially identify the earliest onset of conditions that today are diagnosed as they eventually become symptomatic, usually years later. Indeed, as we shall see later on, Parkinson’s is diagnosed six years after onset-only when it becomes symptomatic. By that time the process is irreversible.

This impedes the ability of the medical community to effectively assist those affected and eventually to cure them. Moreover, since we miss the inception of the condition affecting adaptive capabilities, we still do not know how they come about. In addition, the AnticipationScope can serve as a platform for evaluating progress in treatment. Data from the AnticipationScope can facilitate the type of inferences that the medical community seeks when addressing spectrum conditions. Regarding the functions of the AnticipationScope, we shall return to them once a more detailed description of what it is and how it works is presented.

3.2 The Design

Given the fact that anticipation is always expressed in action, the AnticipationScope combines the highest possible resolution capture of movement correlated with the capture of associated physiological and cognitive data. This sounds a bit complicated (not unlike the cMicroscope, announced by Changuei Yang and his team at the California Institute of Technology: a microscope on a chip with microfluidics). To explain as intuitively as possible what the AnticipationScope is, let us present another example: “... *when a man stands motionless upon his feet, if he extends his arm in front of his chest, he must move backwards a natural weight*

equal to that both natural and accidental which he moves towards the front,” (Leonardo da Vinci 1498). His observation is simple: a physical entity modeled after a human being (in wood, stone, metal etc.) would not maintain its balance if the arms attached to this body would be raised (because the center of gravity changes). Figure 3 makes the point clear:

Leonardo da Vinci made this observation, prompted by his long-term study of the motoric aspects of human behavior. Five hundred years later, biologists and biophysicists addressing postural adjustment [6] proved that the compensation that da Vinci noticed—the muscles from the gluteus to the soleus tighten as a person raises his arm—slightly precedes the beginning of the arm’s motion. In short, the compensation occurred in anticipation of the action. The AnticipationScope quantifies the process by capturing the motion, not on film (as did Marinescu and Bernstein) or video, but in the mathematical description corresponding to motion capture technology. Sensors, such as EMG (electromyography), goniometry, accelerometry, blood pressure, and EEG (electroencephalography) capture the various preparatory processes, as well as the reactive components of the balancing act (see Figure 4).

By design, the AnticipationScope is supposed to deliver an aggregate map of the human being recorded in action. Since anticipation is always expressed in action, such a map is indicative of the holistic nature of human actions, regardless of whether they are small tasks or elaborate compound endeavors. Behind the aggregated map is the understanding that in the past medicine focused on reductions. For instance, the cardiovascular profile (cf. Figure 5) is a mapping from parameters characteristic of blood circulation. Even today, preliminary to a physician’s examination, a nurse or an assistant will, on a routine basis, check blood pressure and heart rate. These measurements are performed even before a dental check-up or an eye examination. Additionally, there are other partial mappings that a physician will consider: temperature, stress and hormonal profiles; a motor dynamics profile, if you visit an orthopedist’s office (Fig. 5).

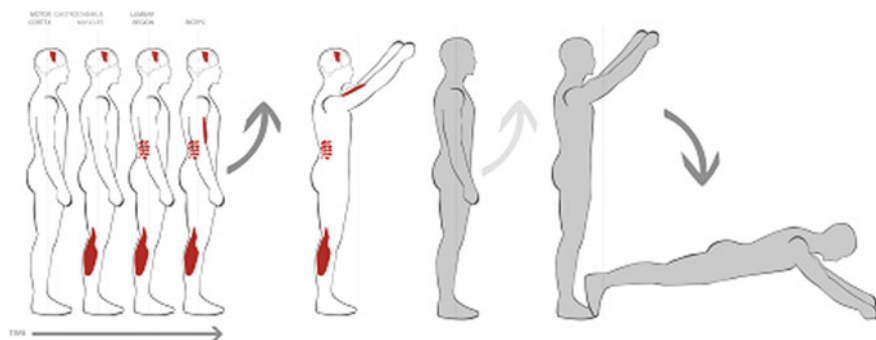


Fig. 3 *Dynamics of motion in the living and in the physical object (What does change in the center of gravity entail?). Left: Dynamics of motion in the living. Right: Dynamics of motion in the physical*

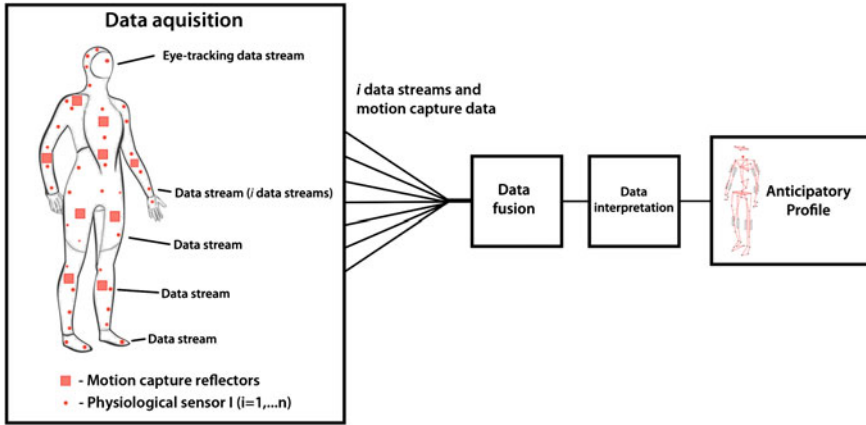


Fig. 4 Information processing model

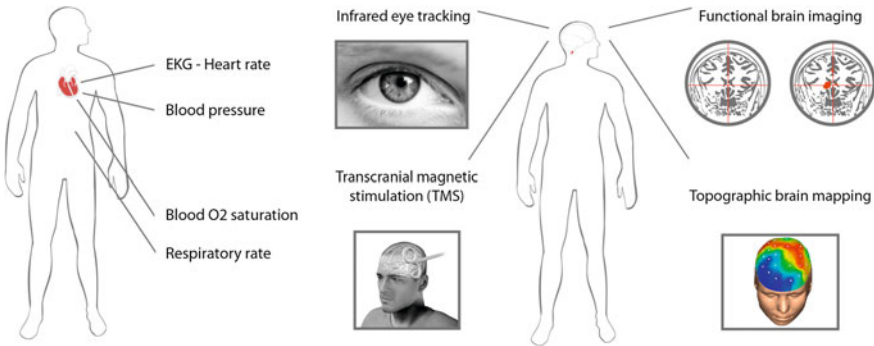


Fig. 5 The cardiovascular profile versus The neural profile. Left: The cardiovascular profile is a particular mapping focused on the heart and blood flow—a. Right: The neural profile

The measurement of body temperature (or of specific body parts), of galvanic skin response, or of muscle activity is indicative of physiological processes relevant to the diagnostic procedure. In recent years, given progress in imaging technology, the neural profile (Figure 5) is now possible. It integrates parameters significant to visual perception, to the performance of particular brain components (either under external stimulation or during experiments designed to engage such components), or to the brain as a whole. Evidently, the outcome of such measurements and evaluations is different in nature than determining blood pressure or body temperature. Each is already a composite expression of quite a number of processes involved in facilitating human action (Figure 6).

The Anticipatory Profile could be seen as an integrated map—although in its more comprehensive structure, it goes well beyond what each partial map provides in terms of meaningful information. The diagram Fig. 6 might suggest a simple additive procedure. In reality, the Anticipatory Profile is the expression of

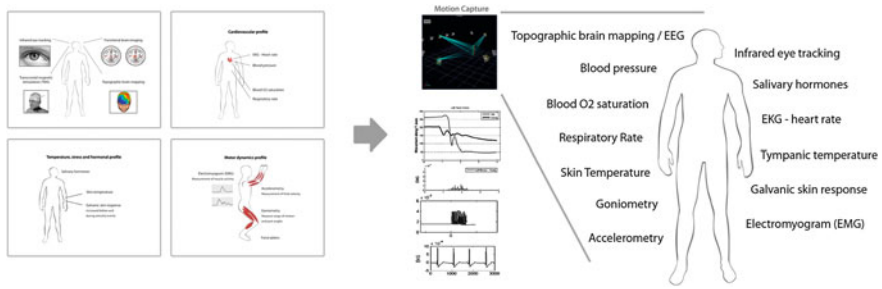


Fig. 6 Four profiles: aggregation of a cognitive and physiological map

integration and differentiation. Getting sweaty palms as we become aware that we have just been through a dangerous situation prompts more than galvanic response, even more than an accelerated heartbeat. All these partial descriptions—that is, time series of data associated with integrated physiological, neurological, and cognitive processes—contribute to a broader image of the individual. An identity comes to expression, quite different from person to person. The various aspects of data types and data integration will be discussed after examination of the architecture of the entity defined as the AnticipationScope.

3.3 Architecture of the Data Acquisition Platform

The research leading to an integrated mobile AnticipationScope starts with the double task of:

- a. understanding the nature of subjecting the human being to measurement;
- b. integrating unrelated technologies with the aim of producing a comprehensive representation of how the anticipation is expressed in action.

Each of the two tasks deserves further elaboration. Assuming that sensors could be devised to measure everything—given the dynamic condition of the living, this means an infinity of parameters—the problem to approach would be that of significance. In other words, how to reduce the infinite set of parameters to those that carry significant information about the anticipatory condition of an individual. The science necessary for this is inter- and cross-disciplinary. Therefore, the research team consisted of physicians, biologists, neuroscientists, and computer scientists. A large number of graduate students from the associated disciplines and from the game design program joined in the effort (some also served as subjects) (Fig. 7).

In respect to the architecture, the goal was to conceive a heterogenous data acquisition platform associated with the appropriate data processing and data interpretation facility. It was supposed to be an environment in which subjects carry out ordinary tasks: sitting on a chair, climbing stairs, throwing or catching a ball, walking, and running. Some tasks were to be performed on cue; others within

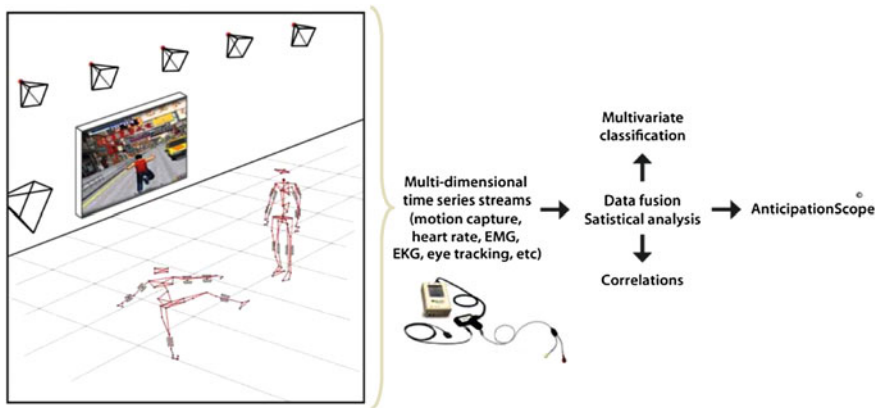


Fig. 7 Architecture of the integrated AnticipationScope

a “natural” sequence: climb stairs, reach a platform where sitting was available, “climbing down.” Since to measure is to disturb the measured (Heisenberg’s uncertainty principle of 1927), our focus was on minimizing the disturbance. This is possible because sensors of minimal weight are attached to the subject’s clothing, and measurement does not affect the person subject to it or the parameters we want to evaluate. Examination of the architecture allows a simple observation: we are dealing with multi-dimensional time series streams. As a consequence, in order to make sense of the huge amount of data generated in real time, we need to provide data fusion procedures. Statistical analysis is the underlying mathematical foundation for producing multivariate classifications and for discovering correlations. In order to explain the technical challenge of the enterprise, let us shortly mention that the problems to be addressed correspond to (a) a great variety of data types; and (b) the need to find a common denominator for different time scales.

3.4 Data Types and Time Scale

A variety of sensors (for evaluating muscle activity, skin conductance, heart rate, respiration patterns, etc.) affords data characteristic of the measured parameters. The simple fact that an EMG sensor returns microvolts, while a skin conductance sensor returns micro-siemens, and the heart rate measured in beats per minute, is indicative of the nature of data acquisitions and the variety of measurement units. In computer science jargon, we deal with integers, Booleans, floating-point numbers, even alpha-numeric strings. Since we also evaluate color (of skin, eyes, etc.), we deal with a three-byte system (denoting red, green, and blue). Moreover, data types are associated with allowable operations (In some cases, as in color identification, addition and subtraction are permissible, but multiplication is not.).

Moreover, composite types, derived from more than one primitive type, are quite often expected. Arrays, records, objects, and more composite types are part of the data processing structure. The intention is to transcend the variety of concrete data types harvested in the AnticipationScope and eventually develop generic programming. We are frequently challenged by the need to calibrate data from one type of sensor (such as the motion capture sensors, 120 frames per second) with data from another type (EMG, for instance, at a much lower rate) before any integration can be carried out. Multiple data sources, distributed all over the body, also pose problems in respect to noise and wireless integration. Finally, the volume of real-time data generated within a session is such that storage, processing, self-correction procedures, and database management exclude the possibility of using readily available software.

As an example of how data integration is carried out let us consider only the aggregation of EMG and Motion capture data (Fig. 8):

Each EMG electrode measures the electric activity from the associated muscles. We follow a traditional measure to extract the feature of the EMG using the Integral of Absolute Value (IAV).

We calculate IAV separately for individual channels. Each channel corresponds to one EMG sensor. Let x_i be the i th sample of an EMG signal/data and N be the window size for computing the feature components. In a stream of EMG signal, let IAV_j be the *Integral of Absolute Value* of j th window of EMG, which is calculated as:

$$IAV_j = \frac{1}{N} \cdot \sum_{i=(j-1) \cdot N+1}^{j \cdot N} |x_i| \quad (3)$$

With the global positional information for all segments, it becomes difficult to analyze the motions performed at different locations and in different directions. Thus, we do the local transformation of positional data for each body segment by shifting the global origin to the pelvis segment, since it is the root of all body segments. As a result, positional data of each segment with respect to global origin is transformed to positional data with respect to pelvis segment or joint as origin. The advantage of this local transformation is that the human motions were independent of the location of the participant in the room (which is helpful in some

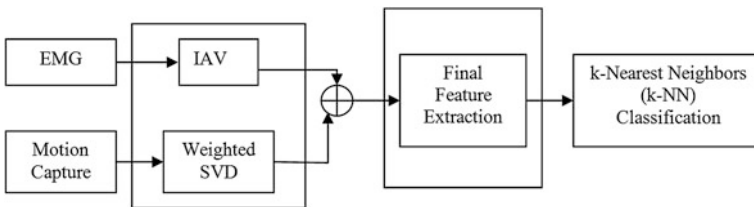


Fig. 8 Existing architecture for integrating motion capture and EMG data streams for quantifying the anticipatory characteristics of humans

tasks where the location of the participant in the room or the direction he/she is facing poses a problem).

An appropriate mapping function is required to map 3D motion joint matrices into 3D feature points in the feature space. In our implementation, we used the linearly optimal dimensionality reduction technique singular value decomposition (SVD) for this purpose. For any $l \times 3$ joint matrix A and window size N , the SVD for the j th window is given as follows:

$$A_{N \times 3}^j = U_{N \times N}^j \bullet S_{N \times 3}^j \bullet V_{3 \times 3}^j \quad (4)$$

S^j is a diagonal matrix and its diagonal elements are called singular values. For combined feature extraction techniques for EMG and motion capture data, we use the sliding window approach to extract the features from motion matrix data and EMG sensor data. To get a final feature vector corresponding to a window of a motion, we combine these two sets of features and map it as a point in multi-dimensional feature space, which is a combination of EMG and motion capture feature space. We do the fuzzy clustering using fuzzy c-means (FCM) on these mapped points to generate the degree of membership with every cluster for each point. Due to the non-stationary property of the EMG signal, fuzzy clustering has an advantage over traditional clustering techniques. For a given motion, range of highest degree of membership for each cluster among all the divided windows of a motion becomes the final feature vector for the given motion. The separability of these feature vectors among different motions depends on the fuzzy clustering. This extraction technique projects the effects, of both motion capture and EMG in a single feature vector for the corresponding motion (Fig. 9).

After the extraction of the feature vectors, similarity searching technique can be used to find the nearest neighbors and to do a classification for the motions. Our experiments show that classification rate is mostly between 80–90 %, which is understandable due to uncertainty of biomedical data and their proneness to noise. Some other unwanted environment effects such as signal drift, change in electrode characteristics, and signal interference, may affect the data. Other bio-effects, such as participant training, fatigue, nervousness, etc., can influence the effectiveness of

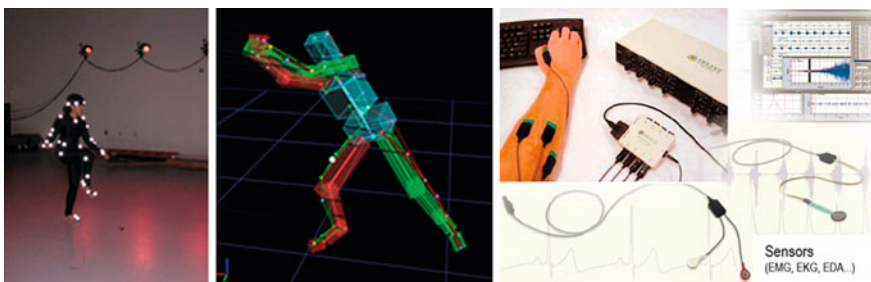


Fig. 9 A session in the AnticipationScope, *Left*: Subject of Experiment; *Middle*: Mapping of data *Right*: Integration of sensors

the biomedical activity. We also analyze the k-NN feature space classifier to check that, among the retrieved k-nearest neighbors, how many are a similar match or how many are in the same group of query. Since we consider the raw signal, the average percentage of correct matches among k-nearest neighbors is about 90 %.

4 The Unity Between Action and Perception

The basic premise of the entire design of the AnticipationScope is derived from the knowledge gained in recent years through single-neuron recordings [13] on the unity between action and perception. Brain activity is specific to the task embodied in the goal, not to the particular effectors. When an object is grasped, neurons are activated regardless of the hand (left or right), or of the toes (left or right foot) that might be used, or even if the mouth is used. *Purpose drives the action.* Anticipation is always purpose related. Gallese in [5] brings this observation to a clear point: “*The object representation is integrated with the action simulation.*” This broad understanding of the unity of perception, activation processes, control mechanisms, and the motoric will guide the realization of the AnticipationScope as a space of interaction between the subject of inquiry and objects associated with actions.

Measurement within the AnticipationScope is goal related since anticipations are always in respect to the outcome of an action. Anticipation is not prediction, i.e., not a probabilistic process, but rather one driven by the evaluation of possibilities. The congenial perspective of the vast amounts of data collected (a variety of interactively selectable time correlated streams) is that of structural measurement process. The biologically inspired Evolving Transformation System (ETS) is the mathematical foundation for the structural measurement process [7]. ETS is a dynamic record of the interaction of elements involved in the functioning of a system, better yet in its self-organization. Each time we are involved in an action, learning takes place. The result is what we call experience [12].

As stated above, the output of the AnticipationScope is the individual Anticipatory Profile, which carries information about synchronization processes. Anticipation is an individualized expression, the “fingerprint” of human action. Variations in the Anticipatory Profile are indicative of the individual’s adaptive capabilities. Disease or aging can affect the values. Accordingly, the AnticipationScope could help identify the earliest onset of conditions that today are diagnosed only when they become symptomatic—usually years later; in the case of Parkinson’s disease, six years later. Delayed diagnosis (even of autism, despite its early onset) has negative consequences for the ability to assist in a timely and effective manner. We probably also miss important information that might guide us in becoming pro-active, as well as in finding a cure in some cases. To return to the example of Parkinson’s disease: festination (loss of the center of gravity adaptive performance, eventually resulting in “running steps”) could be revealed early through the AnticipationScope. Using data gathered from one sensor at a time—as practiced in describing, incompletely, ataxia, hemiparesis, dyskinesia, etc.—is a

reductionist approach, useful but incomplete. Opposed to this is the integration of data from multiple sensors and from the motion capture that describes movements. This is the only way to capture the integrated nature of anticipation. Thus we gain a holistic understanding of the affected human being, in addition to specialized knowledge. The human being is a relational entity—while each component is relevant, the outcome is not reducible to the function of one or another part of our body, but rather to their interrelationship, how they synchronize.

5 Suggestive Directions

In using imaging and measurement, medicine acts upon representations. Data describing the body in action is a good representation for defining how well integration over many systems (neuronal, motoric, sensory, affective, etc.) takes place. In the spectrum condition, one or several systems either cease performing, or their performance no longer makes integration possible. Examining how the decline in anticipation results in maladaptive conditions is a life-science specific epistemological task. It challenges current scientific models. To make the point clear, here are some suggestive aspects, presented tentatively as information to be eventually tested in the AnticipationScope:

(1) Parkinson's Disease (PD)

- a. Early onset detection of akinesia, tremor, rigidity, gait and posture abnormalities. PD patients show impaired anticipatory postural adjustments due to deviated center of gravity realization, resulting in a delay in step initiation, or in “running steps”;
- b. PD tremor is different from other forms of tremors (e.g., cerebellum tremors, essential tremors). This could be distinguished early with integrated motion capture and synchronized biosensors;
- c. PD gait: the typical pattern can be datamined by analyzing integrated motion capture and sensor data;
- d. Even minute PD-associated changes in the control system can be identified;
- e. Pre-pulse inhibition, also known as acoustic startle, could be an early indicator for diagnosing PD. The AnticipationScope will have to integrate sound, image, tactility, even smell and taste. Frequently, in PD the loss of smell precedes the characteristic tremor. Given the adaptive significance of smell in anticipatory processes, we should be able to trace changes in smell in a context of actions (such as orientation) affected by such changes.

(2) Dementia

- a. Dementia due to Alzheimer's can be distinguished from non-Alzheimer's dementia (such as fronto-temporal dementia, FTD). FTD is characterized by an early appearance of behavioral symptoms (lack of inhibition, impulsive or inappropriate behavior, outbursts) compared to AD;

- b. Unlike FTD, AD patients display an early difficulty in learning and retaining new information.

Observation: Given the possibility of monitoring any system, i.e., generating a representation of its functioning (pretty much like the Anticipatory Profile that aggregates a “film” of the action and sensorial information), we could conceive of a subsystem of the AnticipationScope as a diagnostic environment for any machine. Data is collected from all components. This is the way in which the behavior of the system can be modeled. For such a system to be effective, prediction algorithms need to be developed having in mind that real-time prediction of a system’s behavior is a matter of high-performance computation and of extremely efficient data mining. In 2009, years after the AnticipationScope was first made public, [15] of the California Institute of Technology came up with the notion of “*cognitive signal processing*.”

6 Qualified Gazing into the Crystal Ball

The next challenge is the creation of a wearable AnticipationScope that integrates motion capture and wireless sensors in a body suit (see Figure 10).

The next step, to be carried out would entail a daunting task: to see how you feel. A colleague (Bruce Gnade, Distinguished Chair in Microelectronics, with whom I cooperate) shared the following with me:

Similar to what happened in silicon integrated circuit technology 40 years ago, flexible electronics is now at a point where system design and process integration will drive the technology. The use of an electronic textile-like architecture provides the ability to integrate several different materials and functions into the same fabric. Many of the discreet components needed for complex circuits and sensors have been demonstrated on flexible substrates: transistors, diodes, capacitors, resistors, light emitting diodes, and photo-detectors. The next step in developing the technology is to integrate these discreet components onto a single textile.

Such a wearable AnticipationScope might even become a therapeutic medium: it would not only represent the individual’s anticipatory state in the form of an

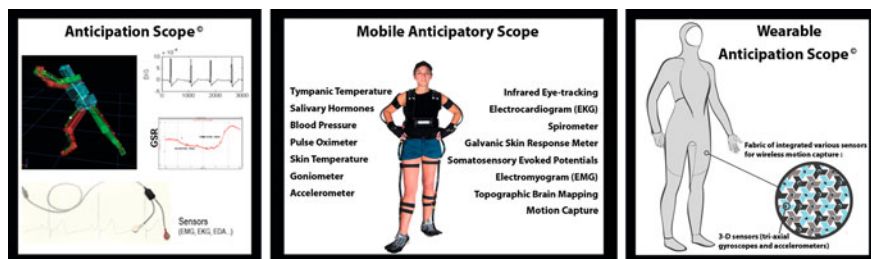


Fig. 10 The wearable AnticipationScope: a possible development

Anticipatory Profile, but also allow for very sophisticated operations on such representations. Imagine: you are wearing the AnticipationScope. The 3D sensors describe your movement; the physiological and neurological sensors describe the anticipation involved. Wireless networking facilitates the real-time processing of data on high-performance computers. You can literally see an image of your own heart beating, or other functions, e.g., what happens when you are stepping, jumping, sitting down, catching a ball, hammering, designing a house, or making a model (real or virtual) of the house. Then, using biofeedback, you can reduce your heartbeat, or work on your gait and posture, or optimize your activity, etc., and immediately find out how the integrated Anticipatory Profile is affected. Accessing the integrated expression of our functioning, and trying to influence one or another variable, such as those affecting control and motoric functions, might prove to be therapeutic in more ways than we can fathom today.

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