# Methodological aspects in integrating physical and psychological descriptions of human activity[1]

*Renzo L. Beltrame*[2]

Human activity was historically described assuming the viewpoint of physics and the viewpoint of psychology. In integrating these two descriptions, we meet both technical and methodological problems. In this paper, we will mainly concern with the methodological aspects, since the technical aspects would entail focusing on single, well-delimited problems.

We need some preliminary choices to delimit our discussion, and a first choice entails the way of studying the facts with which we will deal. We decide that the facts investigated, and the procedure employed to study them, must be repeatable without any restrictions on principles or methods. We do not discuss here whether this requirement alone can characterize the scientific method. We only observe that it ensures the unlimited possibility of proving or disproving a fact, and this property is a frequently cited character of scientific method[3]. This repeatability requirement will prove to be a very strong methodological choice, whose consequences clearly delimit our discussion[4].

The proposed repeatability is a mental attitude, a way of considering the facts[5]; although its consequences deeply influence the subsequent way of operating. In each experiment, for instance, we can have only one dependent variable, and we must study its dependence on only one independent variable. Then we must assign a constant value to all the other variables that



A very preliminary report on this subject appeared in December 1996 as CNUCE Report C96-31. A first version was presented as Report CNUCE-B4-1998-022 in December 1998 with the title *Integrating neuroscience and cognitive science. Methodological aspects* - 2nd Version October 1999. An abridged version with the same title (August 1999) is in *Studi in memoria di Silvio Ceccato*, Quaderni di *Methodologia* 7, Roma 1999, pp. 61-119. Because of this destination, the paper presupposes a certain acquaintance with the ideas of the Italian Operative School (IOS), and the bibliographic references are tailored to this framework. This report maintains the same approach. An extensive bibliography of IOS can be found in *Methodologia Online* at the URL: http://www.cnuce.pi.cnr.it/methodologia/biblio.htm

2. NATIONAL RESEARCH COUNCIL OF ITALY - Research Area of Pisa. *email*: renzo.beltrame@cnuce.cnr.it

3. I think of Popper's falsification thesis. See K.R. Popper, *The logic of scientific discovery*, 1934, 1959.

4. This point was discussed in R. Beltrame, "On brain and mind", *Methodologia*, 10 (1992), pp. 7-13.

we think may influence the experiments. These conditions are all necessary to have repeatable experiments. In mathematics, we have to deal with mental facts and their relations. Demonstrations take the role of the experiments in physics, we use explicit definitions to code mental facts and pieces of reasoning, and we introduce physical objects as symbols and rules for combining them. Then strings become suites of physical objects - pictures, drawings - and the demonstration becomes equivalent to a sequence of rewriting strings. The rewriting procedure starts from the initial string and reaches the thesis string by using the specific hypotheses and the theorems that we previously proved: that is, it proves the equivalence of certain strings. The rewriting operation thus becomes a physical process by which one or more physical objects replace another physical object, and we use this fact to do arithmetic on machines: both the old mechanical ones, and the current electronic computers[6].

The repeatability requirement is incompatible with a statement of complete freedom of the individuals that we are studying; at least if we interpret this freedom as the impossibility to test every statement about the individuals' behavior by using repeatable experiments. We usually save the repeatability by introducing a suitable set of parameters that identify in a repeatable way the state and the characteristics of the individuals that we are studying[7].

Since we focus on methodological aspects, we will assume that the physical description will satisfy the following requirements. The predictions must lead to repeatable experiments. We will systematically use the cause-effect relation, instead of a mere correlation between the events, and a bijective function must hold between the things that we relate as causes and their effects. We thus will assume a strictly deterministic viewpoint. Since we have to predict the energy exchanges, we must deal with an isolated system by including in our dynamics a suitable part of the environment of classical biological systems. The physics inherits from elementary classical mechanics the use of a mental scheme in which the cause of a body movement is external to the body itself; so we will assume that the cause of any physical process is a physical thing different from the physical thing which changes. We also will refer to a dynamics of a physical system, which may be geometrically represented by trajectories that do not intersect in phase space; and we will see that this representation offers a good intuitive framework to our discussion. Although the assumptions that characterize this physical description are difficult to satisfy in practice[8], they become immediately evident the differences between the two descriptions - physical and psychological; and this fact is essential in a methodological discussion.

Psychology classically defines its items in a different way, and this way will lead to a different dynamics. In a psychological description of human activity, we have to deal with mental activity. We decide not to identify mental activity with physiological activity of the subject. Furthermore, we will require the theoretical possibility that a mental fact or activity can occur again during the

---

5. When, for instance, a celestial body approaches our sun, this mental attitude requires that we measure a certain number of parameters that concern the body, the sun, and the component of the solar system. We must measure the parameters that we think to be necessary for checking whether another celestial body will have the same behavior, when it approaches our sun with the same values of the measured parameters. The repeatability as mental attitude was discussed following this viewpoint in R. Beltrame, "Appunti di metodologia operativa: i caratteri costitutivi della scienza", *Ricerche Metodologiche*, 3 (1968), pp. 23-40 (in Italian).

6. The recent sophisticated computer programs of symbolic manipulation in algebra or in mathematical analysis are methodologically grounded on this viewpoint.

7. This problem has a long history that we can trace back to Aristotle.

8. Difficulties mainly arise from the mass of information that we must involve, and from the essential nonlinearities of the theory. Clearly, we might trace back the differences between the two dynamics also when we use a more realistic physical description, for instance a description that follows the approach of statistical mechanics. Nonetheless, statistical mechanics would require a presentation that is more cumbersome, and that would mask essential differences between the physical and the psychological approach. However, the main reason is that I did not yet outline these differences with sufficient clarity in the framework of statistical mechanics, and of continuum mechanics.

life of the same subject, and that it can occur to different subjects: that is, in system that did not have the same evolution. This is a strong reason for defining mental things, since it is the root of their possible intersubjective character, and so of communication.

In this paper, we will assume that mental facts and activities are defined by an injective function into a subset of the physical processes that occur in the system that we consider to be doing the mental activity. Since we choose a mapping into physical processes, the mental activity so defined can be considered as having a private character without contradiction. Since physical processes are defined in a way that satisfies the repeatability requirement, we can satisfy the repeatability requirement also in deciding when a mental fact or activity occurs. Since we also decide to use only a subset of the physical processes that we singled out to describe the dynamics of the systems that we consider as doing mental activity, we will show that our way of defining mental facts and activities agrees with all our previous choices. However, a further physical activity now accompanies the occurrence of a mental fact or activity, besides that we used to define it; and this further physical activity will depend on the current state of the system that is doing the mental activity. Since the subsequent physical activity usually depends also on this further physical activity, we will show that we must go back to the physical description to predict the flow of the mental activity in a deterministic way, and that we can set only correlation between the occurrence of mental things. Moreover, the correlation will acquire an essential, probabilistic character.

In psychology, we usually use a mental scheme in which subjects may be cause of their behavior: we think they to cause both their physical and mental activities. We will show that this viewpoint prevents from having an isomorphism between the dynamics of the physical activity and the dynamics of the psychological activity, and it also prevents us from assuming a reductionistic position. If we define mental things in such a way that a private character will follow from the definition, we will see that this choice is not fully compatible with the repeatability requirement. So, we will avoid this choice, and we will show that we can restore many practical consequences by passing to the privacy: that is, by passing to a regulated behavior.

In the physical theory that we will assume as reference theory for our methodological discussion, the equations which describe the system evolution completely describe the dynamics of the system. Therefore, they describe the flow of the activity, the constraints on this flow, and the development of the system. We will show that we lose this syncretism, when we take the viewpoint of psychology. Learning will appear only in psychological description; because in physical description architectural and functional changes of material are sufficient. So, we will define it by using only a part of the physical process that we must introduce to obtain a deterministic description of the physical behavior of our systems. Constraints will lose the deterministic character that we usually assign to them, and they will predict the occurrence of the constrained fact only in probabilistic way. The conditions, that we require to hold in physics to apply a cause-effect relation, are not compatible with the analogous conditions that we require to hold in psychology. The physical description and the description of psychology cannot thus have the same dynamics, and we cannot assume a reductionistic position. We will show that we neither can map isomorphically one dynamics onto the other.

Only practical reasons thus motivate the choice of the terms of the injective mapping that we use to define mental things, since definitions are neither true nor false, but only less or more useful. We can freely choose the starting point of our descriptions as well. So, we introduce no hierarchy a priori, and we cannot support any type of methaphysics. We still have to avoid ontological dualism between physical and mental things[9], and we will see that this problem has a simple solution when, in the dynamics of the mental activity, we consider the constraints that we usually impose to the development of our knowledge system. The requirement will be determinant to have a knowledge system that is free of contradictions in the parts that we use to do logical deductions. From a contradiction we can deduce both a statement and its negation, and we use logical deduction to obtain predictions that relate to our practical activity, including critical relations of our body with other physical bodies. So, we must avoid contradictions in this scheme.

In this paper we mainly have to deal with mental activity, and with the conditions of its occurrence. In some cases a mental activity occurs, but we are only concerned with the mental thing that has this activity as constitutive, or with its consequences. As a rule we will explicitly declare the point of view, but sometimes we will avoid to mention it explicitly, not to worsen the readability of the paper. This point may become critical in discussing mental categorization because, when something is mentally categorized in a certain way, the mental category and its consequences are frequently presented as a further property of the thing thus categorized. Finally, we implicitly assume that mathematical properties hold, that are necessary to have well defined the elements involved in the discussion. We may justify this decision because mathematical formalization of the ideas presented in this paper is out of the scope of the paper.

[9]. This is a way to formulate the old problem of the dichotomy between mind and body, or the more recent dichotomy between brain and mind.

# Main characters of the integration

When we discuss the integration between physical and psychological description of human activity, we have to characterize both physical and mental facts and activities[10]. Since we inherit methodological problems from the philosophical tradition, of which the ontological dualism and the various kinds of reductionism are significant examples, we consider it safe to discuss briefly some issues that we will presuppose in the following of our discussion.

In past papers[11] we can find a way of defining physical and psychic things by using mental activity. We still can interpret this operation as a description of our way to think of physical and psychic things. Many properties are preserved in this characterization, that our culture assigns to these things. In particular, it is compatible with the conditions that we usually require to consider psychic things as having a private character. The characterization still shows that, if we wish not to contradict ourselves, then we must think of both physical and psychic things as being subjects of the actions and the changes on other things of the same type. We will avoid to discuss here the detail of this characterization. We only recall that the last property was obtained by defining physical and psychic things as having a localization (in space for physical things, and in time for psychic things), and as being related to a thing of the same type. The characterization equally starts from perception or mental representation to arrive to physical and psychic things. We thus decided, for instance, that the mental representation of a physical process and its observation through a physical apparatus both belong to the world of physical facts; although we can distinguish the two orders of facts, and we usually mark the difference. An analogous conclusion holds for psychic facts.

However, we introduced the further requirement that facts and procedure with which we deal in our study, must be repeatable without restrictions on principles or methods. We do not accomplish this requirement when the observation involves someone's account, description or testimony as a constitutive element: for instance, when the subject that we think to do the mental activity is a constitutive element. For the same reason, we cannot use accounts, descriptions, or testimonies of the persons, who we think as doing the mental activity, to identify the mental facts in experiments; and the testimony of the observer cannot be constitutive in an experiment[12]. More generally, we cannot claim to observe in a repeatable way the occurrence of things that we consider to have a private character because this way of considering a thing implies limitations on the possibility of observing it, and so the two ways of considering a thing are not compatible[13]. In experiments, we thus cannot assume things having a private character as dependent variable, as independent variable, and as one of the parameters that characterize the experiment. In particular, we cannot give this role to mental things. Accounts, descriptions, and testimonies can only serve as indications to get back directly to what we want to assume either as the dependent variable, or as the independent variable, or as a parameter that characterizes the experiment.

Although these constraints directly relate to the experiments, they also influence the theories, because a theory must give predictions that we can be test by such a kind of experiments to satisfy the previous repeatability requirement. When we refer to the previous scheme, in which

---

10. This point was discussed with more detail also in R.Beltrame, "Methodological aspects of the mental facts definition, and of their dynamics", in *Categories, Time and Language*, Quaderni di *Methodologia* 5, Roma 1998, pp. 45-100; and in a previous version as CNUCE Report C97-25, 1997 (both in Italian).

11. In the framework of the ideas of the Italian Operative School this point was firstly outlined in S. Ceccato, *Un tecnico tra i filosofi*, Vol II, Padova 1966, in the section "Modificazioni ed innovazioni [1965]" pp. 27-30 (in Italian).

12. If the subject's testimony is constitutive, then we could not compare the results of experiments carried out on different subjects, and we should find the same limit if the testimony of the experimenter is constitutive.

13. The statement means that we cannot assume the consequences of the two categorizations to hold together.

we defined physical and psychic things by using mental activity, only the situations in which physical things are all obtained from perception satisfy our repeatability requirement[14]. If we decide to satisfy this requirement, we must use physical situations of the previous type to define mental things; and, if we still consider this requirement as a character of the scientific method, then we must define mental facts and activities by using physical facts of this type, before introducing them in a scientific context. Finally, this way of defining mental things does not contain the condition that we require to consider them as having a private character. We can resort to legal constraints to achieve through privacy the same practical consequences that we expected from things that we can consider to have a private character as consequence of their definition.

We will come back on these points in the following of the paper, because they relate to the integration program that we will discuss. Here, we will continue by stating the further characters that we consider to be optimal for the physical description, and by describing a way to define mental things, that make easier our integration program.

## The characteristics of our reference physical description

As we pointed out above, we assume in this paper that facts and procedure, with which we deal in our discussion, must be repeatable without restrictions on principles or methods. We saw that this choice still forces us to deal with physical things that are all obtained from perception. We assume that this condition holds when we will refer to physical things in the following of the paper.

Furthermore, physics inherits from elementary classical mechanics the use of a mental scheme in which the cause of a body movement is external to the body itself. So, we cannot assume a mechanical body as causing its movement. We find it explicitly stated in Euler's *Mechanica*[15], and we must consider this assumption to be part of the definition of mechanical body when we are dealing with its dynamics. We still think of the action of a mechanical body on another mechanical body as a physical process, and this process implies a change in the agent too. The causes of this process must be external to the agent, to agree with the assumption stated above. Therefore, we can satisfy the previous requirements if we conceive of the action of a mechanical body on another mechanical body as an interaction, and if we assume interaction to be elemental in mechanics[16]. When the interaction is between two bodies, the previous choice implies two actions of equal intensity and opposite[17].

When in physics we represent elemental interactions by forces, this decision is equivalent to other strong methodological choices. Since a vector mathematically represents a force, and vectors are defined on linear spaces, we can compose them linearly[18]. When we use a linear law of

---

14. Things that we historically consider as belonging to physics satisfy this limitation. Physicists, however, may deal with situations in which physical things are partially obtained from mental representation.

15. In Newton's formulation: "Corpus omne perseverare in statu suo quiescendi vel movendi uniformiter in directu, nisi quatenus a viribus impressis cogitur statum illum mutare.", it is not sure whether the cause of a mechanical change must be external to the physical body. No doubt it is possible with regard to Euler's formulation: "Corpus absolute quiesciens perpetuo in quiete perseverare debet, nisi a causa externa ad motum sollicitetur." [L. Euler, *Mechanica sive motus scientia analytice exposita*, 1736, Ed. P. Stäckel. Leipzig, 1922, Vol. I, p. 27]. Feynman makes an analogous assumption by stating "that the force is equal to zero unless some physical body is present" [R.P. Feynman, R.B. Leighton, M. Sands, *The Feynman lectures on Physics*, *cit*., Vol. I-1, pp.12.1 ff.]. In elementary mechanics we also think of the mechanical body as being atomic and not composed of parts; and this character must be considered part of the definition of mechanical body. Indeed, a single scalar and a direction, that is a single vector, completely describe the action of the environment on the body. Finally, when we think of the mechanical body as being composed of parts, this viewpoint is applied to the single parts of a body which we consider as being atomic (that is, the parts that we decided not to split again).

16. I think that we maintain this assumption in continuum mechanics as well, although its formulation is not so immediate.

17. The extension of this scheme by linearity to the case of N bodies is at the basis of the classical mechanics of systems.

composition the result has always the same properties as the components, and we can safely transfer all the properties of the components to the result. Furthermore, the components are all independent, because in a linear composition a component that enters with zero weight does not modify the effect of the other components.

We pay for these very useful properties of the linear composition law with the constraint that the elements, which enter the combination, must be of the same type. When we instead use a nonlinear composition law, we can combine elements of different types. However, a component that enters with zero weight may cancel the action of another component, because the result may depend on the product of the weights. Therefore we cannot use a linear law of composition when we compose elements of different types, or when we wish to obtain a result whose properties are different from the properties of the components. We will come back on this point because of its importance for our integration problems.

In classical non relativistic mechanics vectors are defined on spaces whose model is a three-dimensional Euclidean space. So, we have a finite orthonormal system, which is also a basis, and we have a scalar product from which we can obtain the projections of a vector onto another vector: therefore, also the projections of a vector onto the elements of the basis[19]. Moreover, we also define as a vector the displacement of a mechanical body, which is the final effect of a force. We thus can define the scalar product of a force and the displacement of the point to which the force is applied. In this way we obtain the value of the energy exchanged by the system as an effect of a displacement when a force is acting on the body.

In physics we further assume that forces, which we use to describe elemental interactions, are conservative[20]. Furthermore, the forces that we use as elemental forces must not have an explicit dependence on time[21]. We recall that a force is said to be conservative when its work in moving a mechanical body does not depend on the trajectory along which the physical body is moved, but only on the starting and ending points of its trajectory. Conservative forces thus induce energy exchanges that do not depend on the particular process, and the quantity of energy exchanged is described by the differences of a scalar function: the potential. Finally, it is possible to prove that, when the force results from composition of conservative forces, it is conservative, and in this condition the total exchange of energy is the algebraic sum of the energy exchanges that depend on each potential.

We emphasize that the previous assumptions have a methodological character. An explicit dependence on time of the interactions that we use as elemental in the theory would exclude the repeatability of the experiments. The requirement that elemental interactions be represented by conservative forces is equivalent to state that we can predict completely the energy exchanges between the system and its environment, and between the parts of the system. So, we better can reverse the reasoning. We can assert that these requirements follow from the decision of having repeatable experiments, from the decision of predicting completely the energy exchanges

---

18. The electrostatic action of N charged particles on one charged particle is a good example. It is a vector which is the sum of the N actions of each charged particle on the target one; although the single interaction is a nonlinear function of the mutual distance between two charged particles.

19. They are also the components of a vector in the direct sum that represents the vector in the given basis.

20. See, for instance, R.P. Feynman, R.B. Leighton, M. Sands, *The Feynman lectures on Physics*, *cit*., Vol. I-1, pp.14-8 and seq.

21. On this point see, for instance, L.D. Landau, E.M. Lifshitz, *Course of Theoretical Physics*, Vol. I, *Mechanics*, 2nd Edition, London, 1969; and also W. Kölher, "Psychology and evolution", *Acta Psychologica*, 7, 1950. We recall that the basic relation of elementary Newtonian mechanics: $F=ma$, is invariant for reflection of the time coordinate: that is, by the change of the time coordinate $t$ with $-t$. The reason is that acceleration is a second derivative with respect to time, and its sign does not change by changing $t$ with $-t$. A very subtle discussion of the friction phenomena in relation with this point can be found in R.P. Feynman, R.B. Leighton, M. Sands, *The Feynman lectures on Physics*, *cit*., Vol. I-1, 12-2.

between the parts of the system, and from the decision of predicting completely the energy exchanges between the system and its environment. The last decision is equivalent to state that we consider the system and its environment as being isolated, so that the total energy is constant in such enlarged system. When we develop a theory, or when we apply it to a particular case, we thus have to enlarge the biological system to a part of its environment such that the biological system with this environment part can be considered as being an isolated system. Some types of evolution thus may require particular characteristics of the biological architecture, or particular conditions of the environment, or both.

However, only experiments can prove whether the properties mentioned above, and their consequences hold for a particular physical process. We have to prove whether we can pose a one-to-one relation between a vector and the values of the observables by which we manage the particular process. Then, we have to prove whether this vector has the properties of a conservative force. Finally, we have to prove whether this conservative force does not explicitly depend on time. When these properties hold, in the theory we can substitute the occurrence of that physical process with the action of a conservative force that does not explicitly depend on time. Otherwise we have to deal with more information, or we must drop a deterministic explanation.

In elementary Newtonian mechanics we can geometrically depict the evolution of a system as a trajectory in a Euclidean space of six dimensions[22], the so-called phase space. As the system develops in time from an initial state, the image point traces a trajectory in phase space. Therefore, a trajectory can be defined as a mapping of the real interval [0,1][23] into this phase space. The shape of the trajectories clearly depends on the interactions in the system[24].

We extend this representation to more complex systems by assigning a suitable number of dimensions to phase space[25], and the shape of the trajectories still depends on the interactions in the system. When the system satisfies the conditions stated above, the trajectories, which describe the possible evolution of the system, do not intersect[26]. In this case, the state of the system at one instant of time uniquely determines the state of the system at any later time. We can reword this property by saying that each trajectory can be considered as being the effect of unique, specific set of physical facts. A bijection thus holds between this set of physical facts considered as being the cause, and the trajectory considered as being the related effect[27]. Therefore, this geometric representation depicts a strictly deterministic dynamics. Figure 1 shows the effects of losing the property that the trajectories do not intersect. The left hand of Figure 1 shows immediately that, starting from the state A, we can have two possible trajectories: the trajectory from A to B, and the trajectory from A to C; and we have an analogous situation when the trajectory has a loop. The conditions that determine A may thus predict either B or C as possible future states of the system. On the right, the different conditions that predict the two states

22. We recall that in this context a system is always thought of as being atomic, that is we do not consider it as being composed of parts.

23. We can identify this interval with an arbitrary interval of time because we can assume a suitable scale factor, and we are interested only in finite intervals of time.

24. We implicitly assume that the interactions are described by a potential which has no explicit dependence on time; otherwise, as we have seen, we may lose the repeatability of the experiments.

25. The phase space has a number of dimensions that is the double of the degree of freedom of the system.

26. A very clear and compact treatment of these topics can be found in J.L. Singe, *Classical Dynamics*, Encyclopedia of Physics, Vol. III/1, Springer-Verlag, New York, 1960, pp. 98 ff.

27. For the sake of simplicity, we can cite the inertial motions of a mechanical system. For instance, the trajectories of inertial motions with the same momentum are parallel straight lines in the three-dimensional subspace of phase space which identifies the spatial coordinates. To these lines we have to add the same point in the subspace of phase space which identifies the momentum coordinates, and we obtain the possible future trajectories of such a mechanical system. Clearly the trajectories do not intersect.


*Figure 1*

A and B can both predict state C as possible future states of the system. In this second case, the trajectories do not violate the requirement stated above when we move top-down. However, they might introduce contradictions in the theory when we assume that the elemental interactions are described by conservative forces, because the inverse processes do not satisfy the requirement that the related trajectories do not intersect in phase space, and conservative forces lead to reversible processes. Since our discussion has a methodological character, we will not discuss how we can circumvent the difficulties in the single cases; and we will refer to a representation of the dynamics in which trajectories have no intersection[28]

The geometrical representation of the dynamic of a system by trajectories that do not intersect in phase space thus means that we succeeded in individuating a suitable number of independent observables, and in confining the interactions, the nonlinearities, and the nonlocalities of the theory into the description of the trajectories. Furthermore, since we assumed that our system is isolated, situations have no interest in which all the observables maintain the same value over a finite interval of time, because an isolated system shall maintain that state since it remains isolated. Therefore, we will assume that a line in phase space always represents the dynamics of our systems, and we are no longer interested in a trajectory when it reduces to a point. Note that, although trajectories that do not intersect in phase space describe the dynamics of a system, this property does not necessary hold when we consider projections of trajectory segments onto subspaces of phase space. This remark will be crucial in the following discussion.

The conditions discussed above are rather severe, and we expect difficulties to satisfy them in biology. As we know from the physics of complex systems, we do not find methodological obstacles to imagining a theory of the behavior of biological systems in which all the intermediate explanatory elements are physical processes that occur in the biological system, and in its environment. We neither find methodological obstacles in imagining that we can describe these physical processes according to the requirements discussed above. The practical difficulties are a different thing, because systems that are studied by biology usually cannot maintain the architecture and the activity on which we are interested without exchanging matter and energy with their environment. This means that, without these exchanges, these systems lose the properties by which we study them, and very frequently they disassemble. For this reason, biology frequently assumes to study open systems. Clearly this statement does not fit with our previous assumptions. In our methodological discussion, we thus will not assume that biological systems are studied as open systems, although we are fully aware of the practical difficulties that are implicit in developing a theory in which we must include the environment to obtain a satisfactory dynamics of a biological system.

This strategy has today severe limits when we try to apply it in biology, because we usually do not know with sufficient detail the quantitative aspects of the energy exchanges in biological processes, and we always have poor knowledge of the parts of the enlarged system[29] that are

28. Matematically, the inverse map of a trajectory into the real interval [0.1] is a function.

involved in these energy exchanges. Moreover, when we make *in vitro* experiments, conditions of the experiment, that are often equivalent to postulating practically unlimited sources and sinks of energy, may mask these problems. So, in biology the energy balance equations do not play the essential role that they have in physics. When we deal with systems that we consider as doing mental activity, we meet practical difficulties because the part of their environment may be large, that allows us to consider the enlarged systems as being isolated.

Scientific experiments lead to analogous problems, but a well-assessed strategy was devised to manage the difficulties. Since scientific praxis requires that experiments be repeatable, in each experiment we must study how a single variable depends on another single variable after having set the value of a certain number of other observables. The values of these observables characterize the conditions in which the experiment is done, and we carefully must reproduce them to repeat the experiment correctly. When we can consider our system as an isolated system, all the observables belong to the system. When the system is not an isolated system, the observables that characterize the conditions of the experiment still may belong to the environment. The strategy assumes that a surface separates the system from its environment, and in laboratory experiments the system is always a bounded region of a tridimensional space. We then substitute the value of the environment observables with the values of suitable observables on this surface, and we use these values to describe the interaction between the system and the environment at a given instant of time.

Furthermore, single experiments study a particular aspect of the system's behavior: the relation between the dependent and the independent variables, having fixed certain conditions. The theory then integrates the results related to different conditions. If our interest is only in steady states of the system, then we obtain a first level of integration by planning a series of experiments in which we impose different values on the independent variable, and in which the control variables that characterize the experiment have the same fixed values. In this way we obtain a relation between the dependent and the independent variables of the experiments, and this relation holds when the control variables have the fixed values assigned to them in the series of experiments. The theory usually requires several of these series of experiments to describe how the relation between the dependent and the independent variable depends on the control variables of the experiments. Moreover, the theory requires experiments that have interactions with the environment as independent and dependent variables, because biological systems are usually open to exchanges of matter and energy with their environment. Therefore we must use the strategy described above only as a tool to simplify the management of the experiments, but we shall assume that a satisfactory theory must involve isolated systems as we discussed above.

When the analysis of steady states does not give a satisfactory description of the system's behavior, we have a higher order of complexity because in each experiment we have conceptually to substitute the single value of the observables with a function of time[30]. This substitution raises methodological problems, because we cannot violate, even implicitly, the requirement that the experiments are repeatable. Furthermore, when a system is in a steady state, we can refer to the same state the value of an observable irrespective of the duration of the measurement; and all the measurements of the observables refer to the same state of the system, even if a certain interval of time separates two measurements[31]. Both these very convenient properties do not

---

29. We refer here to the biological system and a suitable part of its environment so that we can consider the enlarged system as being isolated.

30. More generally, time here means an observable whose values have the mathematical properties of a totally ordered set.

31. This property is particularly useful when we have to determine the values of a function derivatives. Recall that the derivative of a function is a continuous linear operator at every point in which it exists. For real functions defined on a real space having finite dimensions, we thus need an array of values to characterize its derivative at a given point.

hold when the system is not in a steady state. The measurement techniques thus become more difficult, and in the theory we have to decide how to relate the result of a measurement with the value of the observable that we introduced in the theory, or that we planned to measure[32].

Other practical difficulties arise from the number of elements involved: that is, from the number of dimensions of the phase space, and so from the bulk of information that we have to know. A reasonable estimate is that the human brain contains about $10^{11}$ neurons. This figure alone should force us to apply the approach of statistical mechanics. Moreover, we must consider each cell as being a complex system, and we must account for a considerably greater number of elements to obtain a physical description with the characters outlined above. However, the most severe difficult arises because the interactions between the elements of our theory are typically nonlocal and nonlinear, as we will show in the next sections. In statistical mechanics, free-particle models are somewhat simple, although we have to deal with a number of particles that is in the range of Avogadro's number: that is, in the order of $10^{24}$ particles per mole[33]. Despite the difficulties mentioned above, the characters that we proposed for the physical description have a very high conceptual and methodological importance. They characterize a reference theory that will be a good instrument to clarify the foundations of the physical and psychological descriptions of the behavior of our systems. Today, we cannot realize a physical theory with these characters, due to the practical difficulty of obtaining and managing sufficiently detailed information about the interaction between the parts of a biological system, and between the biological system and its environment. However, when we are interested in a limited volume of phase space, and in a limited interval of time, the picture described above also can have practical relevance.

In the next sections we will see that in psychology we develop a theory that has different characters, mainly because we have very strong reasons to define mental things by using only a part of the physical processes that we must introduce to have a physical description that satisfies the previous requirements. We automatically will obtain a dynamics in which, when one of these things is a mental thing, a bijective function does not hold between the things that we use as cause and the things that we use as the related effect. More generally, this statement holds for every thing is defined by using only a part of the physical processes that we must introduce to have a deterministic theory of the physical system activity[34]. It thus holds, for instance, for a movement of an animal, or for a part of the cell activity like DNA transcription. Therefore, the dynamics of this type of things does not have the properties of a dynamics which can be geometrically represented by trajectories that do not intersect in phase space. It has instead the properties of the trajectory projections onto subspaces of phase space. Since our aim in this paper is to clarify the methodological differences between the physical and the psychological descriptions, and the sources of these differences, hereafter we will systematically refer for the physical description of the system behavior to a theory with the characters that we outlined in this section, and we will call it the reference theory. We also will refer to the properties of a picture in which the evolution of our systems is described by trajectories that do not intersect in phase space. As we will see in the following of the paper, this picture will prove to be very useful, because it immediately visualizes the characters that we will discuss.

---

32. We have to decide, for instance, whether we will use the measured value as the value of the observable at a certain instant of time, or as the average value over a certain interval of time. This point is discussed in great detail in W. Grandy Jr., *Foundations of Statistical Mechanics*, *cit,* particularly at the beginning of the Vol. 2, *Nonequilibrium Phenomena*.

33. See, for instance, W. Grandy Jr., *Foundations of Statistical Mechanics*, Vol. 1, *Equilibrium Theory*, *cit.*, Chap. 5.

34. We emphasize that this statement, and its consequences, hold for the elements that are so defined in biology, in physiology, and in physics as well. Here, we limit ourselves to this remark, because it is out of the scope of this paper to develop this very important topic.

## Defining mental things

We recall that we decided that the following conditions must hold in our discussion on integrating physical and psychological description of human activity:

- the investigated facts, and the procedure employed to study the facts must be repeatable without any restriction on principle or method;
- we require the theoretical possibility that a mental fact or activity can occur again during the life of the same subject, and that it can occur to different subjects.

As we have seen above, we cannot claim to observe in a repeatable way the occurrence of things that we consider as having a private character, because the observation should involve someone's account, description or testimony as a constitutive element: in our case the subject that we think to do the mental activity. In particular, only the situations in which physical things are all obtained from perception satisfy our repeatability requirement. So, when we decide to satisfy this requirement in studying humans, we cannot use accounts, descriptions, or testimonies of the persons, who we think as doing the mental activity, to identify the mental facts. For the same reason the testimony of the observer cannot be constitutive of an experiment[35]. In scientific experiments the dependent variable, the independent variable, and the parameters that characterize a scientific experiment can only be physical facts that relate to the body of the person that we assume as doing mental activity, or physical transformations that he does on other objects, and these physical facts must be obtained from perception. Although these constraints directly relate to the experiments, they also influence the theories, because in scientific activity a theory must give predictions that can be tested by scientific experiments. Furthermore, if we consider the repeatability requirement as a character of the scientific method, then we must define mental facts and activities by using physical facts, before introducing them in any scientific context.

We can satisfy both the requirements stated at the beginning of this section when we assume that mental facts are defined through a mapping into physical things. In the following of the discussion we thus will assume that definitions use physical processes that occur in the physical system that we assume to be doing mental activity. We further characterize the mapping in the following way. We decide that a mental fact or activity occurs every time the physical process occurs that we used for defining it, and we still decide that, whenever we predict the occurrence of a mental fact or activity, we also predict the occurrence of the physical process that we used to define it. Finally, when the physical process does not occur, that we used to define a mental fact or activity, we decide that the related mental fact or activity did not occur either.

In this way, we can assert without ambiguity whether a mental fact occurs, and we can test its occurrence by repeatable experiments on the systems that we plan to use in the experiments. In mathematics it is usual to characterize the mapping that we proposed above, as an injective function $f:(M \rightarrow P)$ of the set $M$ of the mental facts and activities that we have to define, into a subset $P$ of the physical facts occurring in the systems that we plan to use in the experiments[36].

---

[35] If the subject testimony is constitutive, then we could not compare the results of experiments carried out on different subjects, and we should find the same limit if the testimony of the experimenter is constitutive.

[36] We recall some mathematical definitions that we use here. A map is defined by a triple $(G, X, Y)$ where $X$ and $Y$ are sets, and $G \subseteq X \times Y$; the set $G$ is said to be the graph of the map. A map will be called a function when it is single-valued: that is, when it assigns to each element $x \in X$ exactly one element $y \in Y$ such that $(x, y) \in G$. The functions will be notated $f:(X \rightarrow Y)$ and $y = f(x)$. The set $X$ is called the domain of the function $f$, and the subset $f(X) \subseteq Y$ its range. When $x \neq y$ implies $f(x) \neq f(y)$ the function is said to be injective. When $f(X) = Y$ the function is said to be surjective (onto). A function is said to be bijective when it is both injective and surjective. A function $f$ is said to be left invertible when there exists a function $g:(Y \rightarrow X)$ such that $gf$ is the identity function on the set $X$. A function $f$ is said to be right invertible when there exists a function $g:(Y \rightarrow X)$ such that $fg$ is the identity function on the set $Y$, and a function is said to be invertible when it is both left invertible and right invertible; we can prove that an injective function is left invertible, and that a bijective function is invertible.

Clearly, we cannot introduce hypothetical physical facts in the definitions, and we cannot substitute a physical process with a mental category or more generally with another mental fact or activity, because we would really define a mental thing through other mental things[37]. We thus obtain an unsatisfactory definition when, for instance, we use something that is described only as a change of state in a physical system[38].

As we discussed in the previous section, we will refer to a deterministic dynamics of the systems that we think of as being able to do mental activity: that is, we will refer to a dynamics in which we decide to explain the occurrence of the facts by one-to-one cause-effect relations. We showed above, that an injective function into physical processes is sufficient to satisfy the repeatability requirement in defining mental facts and activities. Now, we have to decide whether all the physical processes that we introduced in the physical description of the system behavior are to be used in defining mental facts and activities.

The choice of using all these physical processes seems methodologically the simplest one, but we can immediately note that mental facts and activities so defined might not occur again during the life of the same subject or to subjects having a different history, because we decided to use as reference a strictly deterministic physical description. Furthermore, this solution would lead us to define more mental facts than those we use in our cultures. We thus assume that only a part of the physical processes, that were necessary to describe deterministically the dynamics of our systems, are used to define mental facts or activities. Formally, this choice means that the injective function into physical processes, which we will use in defining mental facts or activities, is not surjective; thus, it is not a bijection and it is only left-invertible. Many physical processes can share the part that we used to define mental things, and we will see that we obtain a dynamics in which the occurrence of a mental fact or activity cannot be predicted only by the occurrence of other mental facts.

The choice of the physical processes to use in defining mental things is a critical decision, as in any theory. We have to decide how much our definitions will be independent from the peculiarities of the physical architecture of the system; and this architecture also depends on the history of the biological system and of its interactions with the environment, because memory phenomena typically occur in biological systems. We can give the best solution to these problems when we are dealing with a specific situation. However some general remarks are possible. We clearly must exclude physical processes that would force us to assume that mental activity occurs continuously. When in physical description of the behavior of a biological system we find that the system is stable in a range of values of certain observables, we can use changes in the value of these observables to define mental facts and activities: for instance, quantitative changes in metabolic activity, or in molecule exchanges between cells and their intercellular space[39]. We thus have a great range of possibilities in defining mental activities.

---

[37.] This observation also holds when we consider more general levels of a theory. At these levels of a theory we must use mental categories to obtain the required generality, but, if we wish to start from one of these levels and to use a top-down approach, then we must develop the theory and introduce the necessary definitions until we reach the level of specificity that ensures the link with repeatable experiments.

[38.] This point was not sufficiently emphasized in my past papers: for instance, R. Beltrame, "La première machine sémantique", *4me Congres International de Cybernetique*, Namur, 1964; R. Beltrame, "L'analisi in operazioni", *Nuovo 75*, 1 (1967), pp. 17-21 (in Italian); R. Beltrame, Osservazione e descrizione meccaniche, in *Corso di Linguistica Operativa*, S. Ceccato Ed., Milano, 1969, pp. 115-139 (in Italian); R. Beltrame, "Perceptive Operations", *Thought and Language in operations*, I, 2 (1970), pp. 174-198; R. Beltrame, "Methodological aspects of a theory of the mental activity", *Methodologia*, 7 (1990), pp. 53-84 (in Italian).

[39.] When we mention the use of physical processes to define mental facts and activities, we shall think of the physical processes as having this wide meaning, and this meaning is in good agreement with the viewpoint of physics, where changes in the value of some observable are a way of defining a physical process.

We decided to define mental facts or activities by using physical processes, but we might decide to define mental states through a mapping of physical states onto mental states. If necessary, this mapping must satisfy the same properties as the analogous mapping that we proposed for defining mental facts or activities: that is, we must require that an injective function holds of mental states into the physical states, and that a one-to-one function holds between their occurrence. In physical description, however, we prefer to consider as a particular type of process the situation in which the values of the observables that characterize the process do not change during a certain interval of time. Moreover, we will not use a state of the physical system as cause, but we instead will use as cause the process that brought the system to that state. With these assumptions, we will use only processes in our theory.

We will see below that the problem of defining mental things has a conceptually simple solution at methodological level.

### Mental facts and mental activity

Until now we used the two phrases 'mental facts' and 'mental activity' without specifying their differences. They reflect two main schemes that historically were employed to think about mental things. The more common scheme thinks of mental things as entities, and the word 'mind' designates the collection of these entities. When we study the occurrence of these entities, we must introduce a specific activity to speak properly of their occurrence. Usually, this activity is simply ascribed, as a faculty, to the subjects that we consider as being able to do mental activity. The second scheme instead conceives mental things as activities. The word 'mind' then designates the subject of these activities, and the activities are qualified mental activities.

In the following of the paper, we will relate the two orders of things by thinking of mental activity as being constitutive of the entities of the first scheme[40]. We will use the second scheme discussed above for defining mental things. That is, we preferred to define mental activities by an injective function into a part of the physical processes that occur in the system that we consider as doing mental activity. We then think of mental facts as clusters of activities, and these activities become constitutive of mental facts. Mental facts can be different in different individuals, and they can have a different stability in the same individuals through their life. We are also eased in integrating our definition of mental activity with the physical description that we decided to assume as reference, because we have to map an activity onto another activity. Unfortunately, as we shall see below, no isomorphism holds between the physical and the psychological theory of the systems' behavior. The rules, which describe what physical process shall follow another physical process, do not usually map onto the analogous rules that relate to the mental activity, and we must limit this mapping to very particular situations. Thus no reductionism is possible.

If we would use the first scheme to define mental things, we will have a more direct connection with culture: that is, with the set of elements that are transmitted to individuals by the group in which they live. The reason is that, in this scheme, we directly deal with mental facts. We are however at a disadvantage in building a theory with a satisfactory degree of generality, because the choice of mental facts escapes with difficulty the influence of a particular cultural context. So, when we develop a theory, the habits, that are active at a particular historical moment in the group we are studying, may easily mask the possibilities of the biological architecture. A general

[40]. This strategy was followed by the Italian Operative School in developing a model of mental activity, A good description of this model can be found in S. Ceccato, "A Model of the Mind", in E. Caianiello Ed., *Cybernetics of Neural Processes*, Quaderni della Ricerca Scientifica, CNR Roma, 1965, pp. 21-79. A clear sketch of the history of the Italian Operative School can be found in V. Somenzi, "The Italian operative school", *Methodologia*, 1, 1987, pp. 59-66.

theory instead considers these habits as variables, because they explain and predict some behavior differences between individuals, and between different moments in the life of an individual.

Moreover, learning is a continuous source of new mental entities, and linguistic communication, both spoken and written, is a great source of training in humans. If we assume that all mental entities are atomic, then we can introduce new mental entities into the theory only by new definitions; and a theory of this type becomes unmanageable. We might try to circumvent this difficulty by developing a theory in which mental entities will be composed of a few other mental entities. However, we know that only exceptionally an entity will be decomposed into a pure sequence of more simple ones. The rule is a decomposition into more simple mental entities and their relations; and we must be aware that these relations are often a by-product of the decomposition criteria. They are thus part of the mental activity of the observer, and we cannot consider them as being part of the mental activity of the observed subject. We meet difficulties to integrate this approach with a physical description of the systems that we consider as doing mental activity. In particular, the occurrence of these entities and of their relations, and the conditions of their occurrence give rise to a rather intriguing theory.

In the following of the paper we will use both sentences, 'mental facts' and 'mental activities', with the meaning discussed above. We will use 'mental things' when our statement applies to both mental facts and mental activities.

In a representation of the dynamics of our systems as trajectories that do not intersect in phase space, mental things are defined by using projections, onto subspaces of phase space, of one or more segments of the trajectory that describe the evolution of the system in phase space, and the flow of its physical activity as well. Note that projections can have many configurations: for instance, they can be projections of the same segment onto different subspaces of phase space, or they can be projections of successive subsegments onto the same or different subspaces, and we implicitly define the timing pattern of their occurrence as well. We thus have many possibilities when we define a thing in this way. The simplest one consists in defining the occurrence of a mental thing by the occurrence of a process whose geometrical representation is a segment of line into a subspace of phase space. Since many trajectory segments can share the same projection onto a subspace of phase space, the occurrence of what we defined by a projection can be obtained by doing the physical activity that we described by the trajectory segments that share the projection[41]. We can thus realize the same mental thing in different contexts of activity, and by a different biological architecture. It can be done, in particular, by the same individual in different moments of his life, or by different individuals of the same biological species, or by individuals of different biological species. We thus find the properties mentioned above, and we can also escape the necessity of defining anthropomorphically the mental activity.

If we prefer to avoid this geometrical representation, we can simply reword the previous picture in the following way. The trajectories in phase space become the description of how the physical system evolves from certain initial conditions, and the equations that describe this evolution fully describe the dynamics of the system. The trajectory segments in phase space become the physical processes that we introduced in our theory to explain the behavior of our systems so that cause-effect relations will be one-to-one. Their projections become the subprocesses of the physical processes that we used for defining mental things, or other elements of psychological theory, in such a way that they can occur again in the life of the same subject, and in different subjects.

---

[41]. This fact shows a further source of the effects that we usually ascribe to the plasticity of the nervous system, and this source does not require the local changes in the biological system architecture, that we mentioned in discussing memory phenomena. In particular, we are not required to introduce new learning activity.

However, constitutive activity usually does not interest the subjects who are doing mental activity, because they are mainly concerned with relations among the things that the analyst considers as being results of constitutive mental activity. Our languages reflect these alternatives, because they have an equal possibility to emphasize a relation among things, or the mental activity by which someone sets a relation among things. We can say, for instance, 'the cat was near the door', or 'I saw the cat near the door', or 'I am thinking that the cat was near the door', and so on[42]. When we concern ourselves with relation among things, we deal with things that we can continue to describe through their constitutive mental activity, but we enter the realm of complex mental facts[43].

In the following of the paper, we will systematically refer to the way of defining mental activity by an injective function into a part of the physical processes that are necessary to describe deterministically the physical behavior of our systems. This assumption will prove to be very useful in discussing the methodological problems that we meet when we integrate the description of our systems' behavior that follows the viewpoint of physics with the description that follows the viewpoint of psychology[44]. Furthermore, this approach allows an unlimited number of mental facts, and we have no difficult to accept that our systems will be able to produce or define new mental facts. This problem will have its natural place in the dynamics of mental activity, that we will discuss in the second part of the paper; because the definitions of mental activities and of mental facts, do not contain the conditions of their occurrence. This aspect will be the main topic of the second part of the paper, when we will outline the dynamics of mental activity.

### Further remarks on defining mental things

The oldest and steadiest way to realize a mapping between physical and psychological facts is a relation between functions and organs, where functions pertain to the psychological description, and organs pertain to a physical description. This strategy has a certain number of disadvantages, mainly because the relation organ-function is useful only when the organ is specific: that is, when it is related to a single function, and it is a well-delimited anatomical piece. Many situations cannot satisfy these requirements: typically, for instance, the colors whose characters can vary continuously. In fact, an extremely high number of organs should be necessary. We meet an analogous difficulty when we think of the function as being realized by an integrated activity of different parts, and the integrated activity depends on external factors. A good example is given by a cat that coordinates its movements to land on its paws after it has fallen off a wall. The movements and their coordination hardly are ever identical, because they depend on the initial conditions of the fall, and clearly we cannot suppose that each coordination have its proper organ, because the number of possible different situations is extremely high, and the organ-function relation should lead to an unlikely number of organs.

The relation function-functioning is suitable for defining mental facts when we can assume that a function is realized in only one way, that is by means of a unique physical process. In this case, however, we can use a direct mapping into this process, and we relapse into the way of defining mental things that we proposed above. The use of a function-functioning relation may become misleading because, when we realize a function, we can think that we also attain an aim. In this case we have as constraint on our mental activity that the activities by which we can accomplish the same aim will be considered as being equivalent and interchangeable to attain

---

42. We have no *regressum ad infinitum*. We only have to describe the mental activity by which we obtain the different situations that we can think of, and the mental activity by which we consider a thing as being a mental thing.

43. We outlined few situations of this type when we discussed how to think of physical and psychic things in terms of mental activity, and when we showed that many usual properties follow from a requirement not to have contradictions.

44. We do not exclude other ways of defining mental things, and they can be more suitable for different purposes.

the aim. We thus lose the injective mapping that is necessary to have a suitable definition[45]. Furthermore, the idea of function is related to the idea of purpose. In scientific theories, however, we prefer to introduce only material or efficient causes, because we can immediately plan an experiment in which we start the process that in the theory is considered to be the material cause and we look for the expected effect. If we will instead use a final cause, then we fall into a rather intriguing situation, because a final cause is thought to be at the end of the process that it causes, and so we must introduce another thing that promotes the expected result. In conclusion, either we would lose the one-to-one function into physical things that we required to our definitions of mental things, or we shall complicate the theory in an unacceptable way, because we must duplicate the elements that we think to promote the occurrence of the facts.

Furthermore, in psychology subject has often the role of acting cause in passing from purpose to action. When the biological organism acting as subject has a too poor complexity, other explanatory elements were introduced, and instinct is the most common one. However, biology today has no necessity to introduce in its explanations purposeful elements, even survival. We can use a mental scheme in which we associate a different life expectation of the organism to the biological processes that occur in it. When we sample the organisms in our observations, the life expectation associated to a biological process becomes a monotone function of the probability to find an organism in which that process occurred. So, we do not require any purposeful element to obtain a satisfactory theory of evolution, and a satisfactory explanation for the observed distribution of the various species[46]. In my opinion, because of this change of perspective, purposeful behaviors survive now in psychology only among the highly complex behaviors, and we find another good argument to avoid organ-function or function-functioning relation when we define mental things.

In past papers I tried to define mental things by assuming that they have as counterpart physical processes which have a common part[47], and this idea can be traced back to the notion of selective attention in W. James' *The Principles of Psychology*[48]. The picture that we outlined in the previous section allows us to give the following meaning to this way of defining mental things. The reference physical description, as we have seen, requires a certain number of processes, and we decided to use only a part of these processes to define mental things. When the dynamic of our systems can be represented by trajectories that do not intersect in phase space, the physical processes that we use to define the mental things are represented by projections of segments of the trajectories that describe the system dynamics, and each projection is onto a suitable subspace of phase space. Let $\{S_i\}$ the set of these subspaces. Since we required to define mental things with physical processes that have a common process as component, two conditions must be satisfied. These projections must have a common projection onto a subspace of phase space that must be a nonempty intersection of the $S_i$. The subspace that is the intersection of the $S_i$ must be orthogonal to the subspaces of all the projection that are not used to define mental things[49]. Probably we may satisfy these requirements in defining mental things, because phase space has a great number of dimensions, and we can expect to find a projection which is shared

45. Since the life expectation of a biological organism usually increases when the organism can attain a certain result by using more than one process, we might think of having proposed a useful definition.

46. See for instance L.L. Cavalli-Sforza, M.W. Feldman, *Cultural transmission and evolution: a quantitative approach*, Princeton, 1981.

47. See R. Beltrame, "Perceptive Operations", *cit.*, pp. 179-183; and the review of the past model of the mind in R. Beltrame, "Methodological aspects of a theory of the mental activity", *cit.,* (in Italian). In these papers I did not stress sufficiently that mental things are to be defined. So, this character may be also thought as a property of the mental things, instead of a requirement of their definition. If we decide to use a different strategy for defining mental things, then this character has to be proved by means of experiments, because it relates to physical facts.

48. See W. James, *The Principles of Psychology*, 1890, Dover, New York 1950, Vol. I, pp. 402 ff.

by a great number of trajectory segments. However, the condition of having a common physical process as counterpart, does not follow from the assumptions made at the beginning of the paper: it is a further property that we can require to our definitions of the mental things.

A statement that we cannot attend to more than one mental thing at once, is only compatible with a decomposition of the mental facts or activities into a chain of other mental facts or activities. It is not compatible with a decomposition into a net. The physical description does not have this restriction, and we meet one of the reasons that prevent an isomorphism between physical and psychological description of the behavior. When we define mental things through an injective function into physical processes, we can get around this limitation by considering a suitable subset of a net of physical processes as being one process. However, this trick fully works only when we define mental things that we consider as being atomic, otherwise we must carefully check against possible incompatibilities.

We can use mental things to define a new mental thing, but only if we previously defined them by an injective function into physical things. Since this use becomes simply a substitution of names, it becomes a shortcut of no theoretical interest in a methodological discussion, although it can be useful in communicating our definitions. In general, the new mental things result from a nonlinear law of composition, and we can describe this nonlinearity by saying that we compose things that are thought to have qualitative differences. The properties of the result are thus different from the properties of the components, and we must investigate the properties of each mental thing that we defined in this way.

We can assert that the occurrence of a mental thing implies the occurrence of its constitutive activity. This assertion becomes a truism when we assume that the injective function into physical processes, by which we define a mental thing, also defines its constitutive activity[50]. However, subjects are rarely interested in constitutive activity of mental facts. This interest is typical of a well delimited chapter of psychology, and the more frequent interest is in relations among things. Moreover, subjects are frequently interested in relations among physical and psychic things. In this framework, subjects usually think of mental facts as facts whose occurrence induces the occurrence of other facts, frequently of physical facts: for instance, the utterance of a word or phrase is thought to follow the occurrence of a mental activity. This way of thinking introduces the further requirement that the occurrence of a mental fact shall be followed by the occurrence of a physical process. The framework that we previously outlined eliminates the difficulties of the classical ontological dualism. When we refer to a geometrical representation of the dynamics of our physical systems as trajectories that do not intersect in phase space, the previous requirement acquires the following general representation. The counterpart of linguistic activity is a correlation between projections of trajectory segments: one projection represents the physical process that we used to define the thing that we assume to be the designated thing, the other represents the physical process that we used to define the thing that we assume as designation[51]. Clearly, the consequences follow of relating things that we defined as projections, onto subspaces of phase space, of trajectory segments in phase space. As we have seen, many trajectory segments can share the same projection, and we do not succeed in connecting deterministically the occurrence of things that we defined as above.

---

49. This condition ensures that the characterizing process belongs only to the processes that are used to define mental things.

50. This categorization is plainly acceptable because we required a bijection between the occurrence of a mental thing and the occurrence of the physical process that we used to define it.

51. The projections can be either onto the same subspace of phase space, or onto different subspaces.

As immediate corollary, we cannot use language to define mental things according to the requirements that we stated at the beginning of the paper. Two historical facts confirm this remark. Certain sounds and graphic material are assumed to designate the same mental fact at the interior of the same language, and the equivalence is here set at level of designating things. Facing to the clear differences in the designating material of different languages, we meet the assumption that the same mental thing underlies different languages. Aristotle explicitly stated this assumption in his *De Interpretatione*[52]; and the weaker assumption that a common mental activity underlies different languages does not face to the difficulties. Furthermore, subjects can use spoken or written language to designate the same mental fact, and they can use one language of those that they know. We thus lose again the injective function that is necessary for a definition.

In general, we meet logical difficulties when we try to define a mental fact by using a relation with a physical fact like, for instance, a cause-effect, or a stimulus-response. If we use the occurrence of the physical fact, that is one term of the relation, to define the occurrence of the mental fact, then the relation is not necessary, and we can use a direct mapping into the physical fact. If we instead use a physical fact that we can consider as being in the stated relation with a certain other physical fact for defining a mental fact, then this physical fact still must be unique, otherwise we would ambiguously define the mental fact. However, here too, the relation is not necessary, because we can define the mental fact by mapping it directly into this last physical fact[53]. Clearly, we have an unsatisfactory definition when we define a mental thing by means of a relation to another mental thing, typically a mental category. We have no suitable individuation of the occurrence of a mental fact or activity when we use only mental categories applied to other mental categories: for instance, the mental category of cause applied to the mental category of something. We must substitute the something category with a physical fact whose occurrence shall be unambiguously identified, and shall be checked by means of repeatable experiments, in the system we are studying. However, when we decide to satisfy the constraints stated above, we are practically led to define mental things by means of an injective function into physical processes that occur in the system that we consider as being doing the mental activity.

This point is rather critical, and we prefer to add few examples. We start from the use of a cause-effect relation with a physical thing to define a mental thing. Let the physical thing that we use to define the mental thing be the effect in this cause-effect relation: that is, the mental thing is defined as being the cause of the occurrence of the physical thing. However, in the physical description it is related to another physical thing through a cause-effect relation: it is related to the physical thing that we consider as being the cause of its occurrence. Subtle problems of compatibility thus arise when we integrate the two viewpoints. When we are dealing with definition of mental things, if the occurrence of the physical thing that we use to define the mental thing is represented by the projection, onto a subspace of phase space, of a trajectory segment, then it can have different physical processes as possible cause. So, our definition is not unique when we integrate the description of psychology with the physical description. On the other side, if the occurrence of the physical thing that we use to define the mental thing is represented by a segment of a trajectory in phase space, then our definition is again not unique, because segment of different length, which precede the segment used in the definition, can equally be assumed as being the cause of the occurrence of this segment. Moreover, the mental thing so

---

[52] We find: "Spoken words are the symbols of mental experiences and written words are the symbols of spoken words. Just as all men have not the same writing, so all men have not the same speech sounds, but the mental experiences, which these directly symbolize, are the same for all, as also are those things of which our experiences are images." *De Int*. I, 16a in *The Works of Aristotle*, W.D. Ross Ed.,Vol I, Oxford, 1963.

[53] This point was not sufficiently stressed in R. Beltrame, "On brain and mind", *cit.*

defined cannot occur again in the life of the same subject, because we assumed that the trajectories do not intersect in phase space. So, in both cases we do not have a satisfactory definition.

We meet analogous problems when we try to use the stimulus-response relation. Yet in a very simple experiment where we ask the subjects to push a button when they see a flash of light, we have a correlation between a visual perception and a voluntary movement in a subject that was strongly conditioned to correlate the two facts; and the experiments on animals clearly show the necessity of this conditioning. At the level of a physical description we thus need a very sophisticated theory to disregard in the whole neural process the part that can be referred to the visual perception, the part that has to be ascribed to the conditioning, and the part that we can refer to the voluntary movement. At the level of a psychological description, we still need a sophisticated theory to predict how strong correlation the conditioning induces between the visual perception and the observed movement, because the interval time that we measure between the stimulus presentation and the voluntary movement, may depend on the strength of the conditioning too. The difficulties quickly increase when an injective function fails to hold between the physical stimulus and the perceptual fact; and this situation is unfortunately the rule when the stimulus exceeds rather low levels of complexity.

We again meet analogous problems when we try to use purposive behavior to define mental things. When different activities bring to the same proposed result, we have the constraint to consider them as being equivalent means to achieve the proposed aim. This constraint is quite strong in our culture, although we have the possibility to maintain the differences among the activities by considering them as being a better or worst mean to attain the proposed aim, or by explaining why the subjects use different means to achieve the same aim; but this requires further mental activity. Hence, we cannot generally associate to an aim a unique activity as a mean to accomplish it. The existence of only one way to obtain a proposed result is matter of experiment, and we expect that this situation be very rare in biological systems, because the possibility to obtain a result through different trajectories of activity increases the life expectation of the biological system. The experience confirms this state of facts. For instance, we can take a book from our desktop by using different patterns of our muscles' activity; and we cannot assume that we have only one way to obtain the pattern of motoneurons' activity, which will lead to a certain pattern of muscles' activity, at least until we have experimental evidence of such a fact. From the above remarks we obtain a very sharp conclusion: we cannot use the subjects' aims to define mental activity because in general we do not succeed in setting an injective function of the mental things into the physical behavior.

Although the previous situations are not suitable to define mental things according to the requirements of this paper, they maintain a great interest for our discussion because subjects usually do not deal with the constitutive mental activity, but mainly concern themselves with relations among things that have the characteristics of the mental facts, that we discussed in the previous section. In the following of the paper we thus avoid to define mental things through the ways that we discussed above, and we will consider everything that relates to mental facts as being part of the dynamics of mental things.

## First differences between the two descriptions

As we have seen, we decided to define mental things by an injective function into physical processes. In a representation of the physical system dynamics as trajectories that do not intersect in phase space, mental things are thus defined through trajectory segment projections onto subspaces of phase space, and many trajectories can share the same projection. The main reason for defining mental things in such a way that the same subject will have the possibility to repeat them in different moment of his life (different segments of the same trajectory can share the same projection), and different subjects still have the possibility to repeat them (segments of different trajectories can share the same projection). We recall that the introduction of physical things is required by the repeatability constraint of scientific praxis. The use of a mapping, instead of an identification, follows from the decision to maintain the greatest number of properties that our culture attaches to mental things. In particular, we use perception, space localization and a relation with a thing of the same type when we deal with physical things; and this is too limiting to cover the whole field of mental facts.

The same injective function that we used to define mental things subsists, by our decision, between the occurrence of a mental thing and the occurrence of the physical thing that we used to define it, and we decided that a mental thing did not occur when the physical thing does not occur, which we used for defining it. We thus must choose the physical things among the physical changes and processes that we observe on the systems that we consider as doing the mental activity. Since we introduced an injective function to define mental things, we can investigate whether an isomorphism holds between the dynamics of mental things, and the dynamics of the physical facts that we used to define them.

As mentioned above, physics inherits from elementary classical mechanics the use of a mental scheme in which the cause of a body movement is external to the body itself. So, we cannot assume a physical thing as causing its changes. In psychology, we instead use a mental scheme in which we think that what we consider as being a subject may be cause of its behavior, and in particular of its mental activity. Thus in psychology we think of the subjects as being the cause both of mental activities, and of physical changes in themselves and in their environment. Moreover, we think of the subjects as being the only producers of their mental activity: that is, we think that something else cannot directly produce the mental activity of a subject, though it can induce the subject to do a mental activity.

No methodological reason forces us to assume a different constitutive mental activity of the cause-effect relation in physics and in psychology. We thus assume the constitutive mental activity of the cause-effect relation to be the same, and we make this assumption for all mental categories and categorization schemes. This assumption simplifies the definition of general notions, like cause and effect, although we have to set our definitions in such a way that they agree with the experimental results about the occurrence, in different contexts, of the physical processes that we used to define the mental categories and the categorization activity. As consequence of the previous assumptions, we must assume that different conditions hold in physics and in psychology to consider as being correct the choice of the things that we relate as cause and effect. No global isomorphism thus holds between the two dynamics, and we can employ the designation of one order of things to indicate the other, but we must be aware that the exchange only refers to names, and not to things.

When we view animals and humans as biological systems, we describe them and their behavior with the schemes of physics[54], and we automatically introduce the assumptions that are implicit in these schemes. We cannot thus maintain in this kind of description the scheme of psychology, because we would have to introduce the subject as cause of physical processes that occur in itself, and this fact will lead us outside physics. Yet we cannot base a psychological description of animal and human behavior on the schemes of physics. In these schemes every change has its cause in something that is different from the thing that is changing. Then we lose

54. Biochemistry, molecular biology, and electrophysiology are in fact grounded on physics.

the subject as it is thought of in psychology and its autonomy, whose consequences are today an essential character of the psychological description of human behavior. When we are dealing with the definition of mental facts or activities, the repeatability constraint forces us to have only a mapping of mental things into physical things. However, we also want to predict the occurrence of mental activity, and we want to test the predictions by repeatable experiments. We cannot thus assume that the subject who is behaving as being the cause of the predicted behavior, because we lose the repeatability of the experiments when we conceive of the subject as a particular individual at an instant of time. Nevertheless, the two schemes are both acceptable and useful. We can use them together, but we must be aware that we cannot freely transfer our deductions from one scheme to the other, and that we cannot claim that all the deductions of the two schemes hold together. Without this awareness we may introduce contradictions, and we may easily show examples of this misleading possibility, for instance by referring to bacterial chemotaxis.

Motile bacteria will swim toward higher concentrations of certain chemical substances that we know to increase their life expectation (favorable chemicals), and they swim away from higher concentrations of chemical substances that we know to reduce their life expectation (noxious chemicals). Such a behavior is very subtly adapted and we know many details of it in *Escherichia coli (E. coli)*[55]. The bacterium swims by using flagella. Counterclockwise rotation of the flagella allows all the flagella to draw themselves together into a coherent bundle, and the bacterium swims uniformly in one direction. Clockwise rotation of the flagella causes them to fly apart, the bacterium tumbles chaotically, and its motion lacks statistically preferred direction. Without environmental changes, the counterclockwise direction of the rotation is reversed every few seconds for a brief interval of time, producing a characteristic pattern of movement in which a straight line is interrupted by abrupt, random changes of direction. Therefore changes can be detected, which may occur in different places of the environment. When swimming at a constant velocity, the spatial gradient of chemical substances is detected as change in the chemical's concentration over time. If the concentration of noxious chemicals increases, then rotation reverses more frequently, thus inducing a more frequent change in the direction of the motion. If the concentration of noxious chemicals decreases, then rotation reverses less frequently, and the bacterium goes away from high concentrations of noxious chemicals. We observe an analogous procedure when the concentration relates to favorable chemicals. If the concentration increases, then rotation reverses less frequently, and the bacterium goes toward regions of higher concentrations of favorable chemicals. If the concentration decreases, then rotation reverses more frequently and the bacterium moves in different direction, but the frequency of reversing the rotation never goes to zero. So, even in favorable conditions, the possibility of better conditions is always explored.

For this bacterium we have rather detailed hypotheses to explain the observed behavior in terms of physical processes, starting from a small family of transmembrane proteins whose level of activation increases when they bound to a noxious chemical, and decreases when they bound to a favorable chemical. The activation induces a chain of chemical reactions. They involve the concentration of cytoplasmic proteins, and the multiproteins complex that acts as flagellar motor. The result is a clockwise rotation of the flagella and thus a tumble. The response time is about 200 milliseconds. We know many other details of the adaptation process that enables these bacteria to have a very good response. They can detect concentration changes over a range from less than $10^{-10}$ M to over $10^{-3}$ M for some favorable chemicals.

This very simple example shows that contradictions may arise when we decide to think of a behavior as being intelligent only when we consider the system as causing the occurrence of its

55. See B. Alberts, D. Bray, J. Lewis, M. Raff, K. Roberts and J.D. Watson, *Molecular biology of the Cell*, 3rd Edition, Garland, New York, 1994, pp. 773-778, and the related bibliography.

behavior. Since in physics we use a mental scheme in which the cause of a change is a different thing from the changing thing, if we decide to consider a behavior as not being intelligent when we think that its occurrence is provoked by a cause external to the system, then we should refuse to consider as being intelligent every behavior whose occurrence we explained in terms of physics. This conclusion will hold for more complex behavior as well, and in particular for human behavior; but the contradiction arises out exclusively from our pretension that two incompatible sets of conditions hold together: the conditions that we require to apply the cause-effect relation in physics, and the conditions that we require to apply it in psychology.

We might weaken the opposition between the two viewpoints, and even remove it, by changing one of them, for instance the point of view of psychology. It should however be necessary to reconsider a large part of our culture, which is based on the freedom of the acting subject, and, like ethics and criminal law, derive a statement of personal responsibility from this assumption[56]. This solution thus raises serious practical problems. Although the repeatability requirement in studying facts leads us to lose a private character of mental things as a consequence of their definition, we prefer to maintain two different theories of the behavior for the systems that we consider as being able to do mental activity: a physical, and a psychological theory. Our program of integrating these two theories will have as necessary link only the injective function between physical and mental things that we used to define mental things. We still required that mental facts and activities will be defined in such a way that they can occur again during the life of the same subject, and that they can occur to subjects having a different history. We thus decided to define mental things by using only part of the physical processes that are necessary to describe deterministically the dynamics of our systems when we consider them as being physical systems. This decision has strong consequences on our integration program, and in the next sections we will deal mainly with these topics:

- the nonlinear and nonlocal character of the interaction among the parts of a biological system;
- the description of memory phenomena, both in the physical and in the psychological approach, and their differences;
- the constancies of mental activity;

Then, we will outline the dynamics of mental activity, with a particular emphasis on the characteristics that constraints assume in this dynamics.

## The nonlocal and nonlinear character of the interaction

In this section we will briefly discuss two global aspects of the dynamics of the systems that we consider as being able to do mental activity: the nonlinear aspects of this dynamics, and its nonlocal character. We recall that we decided to deal with an isolated system. Interactions are thus among the parts of such an isolated system, and the total energy of this system is constant. We start with the nonlocal character, which is more immediate.

In a theory of a system like a crystalline solid, we obtain good results if we introduce the interaction of each element with only the few elements immediately surrounding it, and in which we think that this situation holds for all the elements of the system. Clearly we have an exception for the elements at the boundary of the system with its environment. The interactions of these

---

[56]. The tendency to consider human behavior as being strongly dependent on external conditioning arose during quite recent criminal trials in Italy. The problem was recently discussed during a conference in Washington, *Neuroscience and the Human Spirit* sponsored by the Ethics and Public Policy Center, Washington DC, 24-25 Sept. 1998; see also "Does neuroscience threaten human values?", *Nature Neuroscience*, 1, 7 (1998), pp. 535-536. Another related viewpoint is the distinction between the faculty of understanding and the faculty of will in discussing whether the persons are in full possession of their faculties. Finally, this point is also related to the discussion given below on the paradigms used in doing mental activity.

boundary elements determine a large part of the system's interaction with its environment; the other part being described as a further interaction of each element with an external field: that is, an interaction with a field that covers the system, and that we think of as being caused by other physical systems.

In biological systems, we find two phenomenological data that prevent us from assuming a short range interaction as a general prototype of the interactions among the parts of the system. A piece of cat does not behave like a cat; instead a reasonably small amount of sodium chloride behaves like sodium chloride. Therefore the description of the interaction among the parts must have considerable differences in biological and in physical systems, and different theoretical models are required. If macroscopic parts lose the behavior in which we are interested when we isolated them from the surrounding ones, then we must add to the theory significant interactions among distant parts of the system. We still must add actions of the environment onto the system; because we again observe that, when an environment action ceases to act, this fact causes the loss of the behavior we are interested in. This situation usually occurs at the level of cell: thus, it is almost the rule in biological systems.

Indeed, in biological systems we frequently observe the degeneration of the parts that become excluded, for any reason, from interacting with other parts of the system, or with the environment. In some conditions this lack of interaction induces a change of function; for instance when we observe a modification of the extension of the cerebral cortex areas interested in visual, auditory, and tactile activities, as a consequence of lesions or diseases that strongly reduced the visual or auditory function. In other conditions we can see, particularly in animals, a voluntary behavior to deprive oneself of a body part that has lost its functionality, for instance as a consequence of a lesion. Finally, if long range interactions cease for a sufficient interval of time, then the system loses its interconnections and its stability, so that, at room temperature, it starts to decompose itself. It is common knowledge that we have to maintain the biological material at a reasonable low temperature to preserve its architecture, and to avoid its decomposition. A computer card, instead, has a reasonable stability at room temperature both when it is functioning in a computer, and when it does not function, for instance, because it is not powered[57].

Since in biological systems we must use long range interactions, and since the system's stability requires an intense activity, we can expect that at least two ways of storing energy will be significant. The most frequently mentioned way is the presence of molecules that participate in chemical reactions, and a release of energy is associated with them. ATP (adenosine 5'-triphosphate) is one of these molecules. The second way is the energy exchange between parts of the system such that the loss of energy is very low during the exchange. The mathematical prototype of this energy storage is the harmonic oscillator, but every periodic process may in principle be a good candidate to store energy in this way, and, significantly, biological systems show many periodical processes. We thus have two ways to think of the process of storing energy in our systems, and their dynamics is different.

Despite the strong necessity to consider interactions among remote parts of biological systems, we can study some aspects separately. A good example of this strategy is the theory of various types of the so-called receptors. We think of receptors as parts of the biological system

---

[57.] Note that we cannot define the analogous of free particle in mechanics, or of the void in field theory, when we del with biological systems: that is, we cannot define a situation in which we assume that no interaction is acting because a biological system is typically an open system. We have to define these things for the reference physical system that we outlined in a previous section, and which is an isolated system. However, we will not concern with this problem because we shall wander from the main topic of this paper, which refers to the methodological aspects of integrating the approaches of physics and of psychology.

that respond to environment actions only in a narrow band, and with a high gain. The main problem of receptors' theory is usually the correlation of the receptors' activity with the physical actions to which they can respond, and the very high specificity of the interaction allows us to study separately the many kinds of receptor, although the successive activity that they promote must be studied as we previously discussed. When we have environment actions that depend on previous actions of the system we are however forced to enlarge the study, and to include in the theory a suitable part of the environment. Actions that modify the subject's environment offer an example of this necessity. Actions onto the environment, which imply the activity of muscles, determine the actions of the environment on the sensory receptors, which follow from the previous surrounding modifications, and in the theory we must connect these activities. Situations of this type occur just for a simple displacement of an object, and they show other strong reasons for extending the system with which we have to deal in the theory. These extensions quickly lead to the isolated system that we proposed for the reference physical theory. In this enlarged system, we describe the previous actions through cause-effect relations between physical processes that occur in certain parts of the isolated system.

We will continue our discussion with two topics about nonlinear character of physical and psychological descriptions. The nonlinearities that arise from using a constructivistic approach in psychological descriptions; and how, in a physical description of our system's behavior, a nonlinear dynamics may arise.

In a psychological approach we frequently use the strategy of defining cognitive facts by decomposing them into other, more simple ones, and their mutual relations[58]. In this way we obtain a more compact description of cognitive facts, because the description is based on few facts and relations, which are atomic in the scheme of analysis. Recall that they are atomic either because we do not succeed in further decomposing them by using the same criteria, or because we decide to stop the decomposition at a certain level of granularity. When we wish to build a theory starting from a decomposition of the type described above, we thus need a certain number of elementary situations, and one or more composition laws of the elementary situations. The form of the composition laws shall be independent of the number of components and of their order; otherwise we would have to devise a different theory for every different compound, and so we do not have the general theory that we usually require. Clearly the result of the composition depends on the components and, possibly, on their order too.

However, only a linear law of composition ensures that the result will have the same properties as the components, and we pay for this very useful and general property with the constraint of combining only elementary situations of the same type[59]. Thus, we cannot use a linear law of composition when we want to compose elementary situations of a different type, or when the result has different properties than the components. On the other hand, when we use a nonlinear law of composition, we can combine elementary situations of different types, but we must check whether those properties of the compound subsist that were predicted by the current theory, because all the properties of the compound generally do not follow by a logical deduction from the properties of the components. Moreover, we must investigate whether the compound has new

[58] As we mentioned above, this strategy was used by S. Ceccato in "A Model of the Mind", *cit.* G. Vaccarino extensively uses the same strategy in his works on mental categories. See, among others, G. Vaccarino, "Elementary categories I", *Methodologia*, 3 (1988), pp.5-72; G. Vaccarino, "Elementary categories II", *Methodologia*, 4 (1988), pp. 7-61; G. Vaccarino, *Prolegomeni - Vol. I*, Roma, 1997; *Vol II*, Roma, 2000 (all in Italian).

[59] The electrostatic action of N charged particles on one charged particle is a good example. Here the resulting action depends on N, but the type of composition law does not. We have the same theory for every value of N, and the resulting interaction has the same properties as the components, because the composition law is linear.

properties, and we must devise a theory that will explain these new properties starting from the properties of the components and of their mutual relations.

The classical theory of electromagnetic field offers a clear example of this state of facts. We take an electric charge, for instance a little sphere with a positive charge, and we move this sphere at a certain velocity. We may try to predict the resulting effect by combining two situations whose theory is well known, the electrostatics and the elementary mechanics. However, a new effect arises, because we obtain a magnetic field too. This further effect is a property that we cannot logically deduce by electrostatics and elementary mechanics, and its knowledge must be obtained by experiments on the situation that results from moving a mechanical body that carries an electrical charge. These experiments are also necessary to describe the dependence of these effects on other observables, and then to enlarge the theory. Finally, since the experimental situation is changed, we still need further experiments to check whether the relations among the observables continue to hold, which were predicted by classical mechanics and electrostatics: that is, by the theories of the two situations from which we started. Here, again, only experiments can decide the changes, and we know that in general the laws of classical mechanics and of electrostatics do not hold, but we have to amend them so that they give results that agree with the experiments in the new range of conditions[60].

It is outside the scope of this paper to discuss how in physics a theory of the electromagnetic phenomena was obtained, which satisfies the methodological requirements stated in the previous sections[61], but this example shows a situation that occurs rather frequently. When we combine elementary situations of different types we are using a nonlinear law of composition, and we cannot predict the properties of the compound by deducing them logically from the properties of the components. In physics, as we mentioned above, we must use experiments to check whether the properties of the compound subsist, which are predicted by the current theory, and to investigate possible new properties of the compound. In mathematics we usually define new objects, and we must deduce what is implicit in these new definitions. We have an example of this procedure when we think that a geometrical entity with the characters of a surface can be obtained by composing entities with the properties of a line. If the lines are straight lines, the surface is a plane, and on the plane we can define a new class of geometrical objects, angles, whose properties we have to deduce from a new definition, because they could not be defined on a line.

The examples show a general fact. When two, or more, different physical processes occur together, we must test by means of experiments whether we observe new effects and changes in the effects that each process produces when it acts alone. A nonlinear composition law thus implies that processes cannot be considered as being independent, and models become useless whose global properties and dynamics follow from statistics in which we assumed the elemental interactions to be independent, or equally probable. Even if we take an approach that uses the correlation between the observed events to explain and predict the behavior of our systems, we expect acceptable results only from models in which a strong correlation was introduced between

---

60. We know that, when the velocity of the charged sphere is relatively low, the surfaces having the same electrostatic potential can again be considered as spheres with the center on the moving charge; that is the same theory holds that we find when the charge is at rest. When the velocity is near the velocity of light in a very rarefied gas (the so-called void), these surfaces must be considered ellipsoids, Lorentz's transformations hold, and the mechanical momentum becomes a nonlinear function of the velocity. More details can be found, for instance, in R.P. Feynman, R.B. Leighton, M. Sands, *The Feynman lectures on Physics*, *cit*.,

61. Recall that the magnetic field generated by a moving electrical charge depends on the velocity of the moving electrical charge. So, in this formalization we have a first time derivative, and it is not invariant under time reflection. We know, however, that we can introduce a vector and a scalar potential, thus transforming the original formalization into a formalization which has the required properties, and which equally satisfies the experimental results. See, for instance, M. Kaku, *Quantum field theory. A modern introduction,* Oxford University Press, New York, 1993, Chap. 4.

the events, and we do not expect to obtain satisfactory predictions by a scheme of random, independent events. However, we shall have the related mathematical difficulties.

Furthermore, in the experiments we cannot deal with Boolean variables: for instance, the presence or absence of a chemical substance. In a linear dynamics the dependence on one parameter does not alter the dependence on other parameters, and we can correctly study the dependence on one parameter by excluding the others. In a nonlinear dynamics this strategy may give worse results, because we can have a dependence on the product of two or more parameters. Then, by assigning a zero value to one parameter, we may mask the dependence on others. In each experiment the relation between dependent and independent variables depends on the values of the parameters that characterize the experiment. However, in a linear dynamics we know the dependence law by definition, in a nonlinear dynamics, we instead must devise a suitable dependence law. This task requires a greater number of experiments than in the case of a linear dependence, because we must test with different combinations of the values of the parameters that characterize a single experiment. We often describe a situation in which we have nonlinearities as a situation in which we have synergies. We emphasize that, when we assign a function to a single anatomical piece, or to a single chemical substance, e.g. a protein, we are implicitly considering the dynamics of our system to be linear with respect to the realization of that function, although the function may be promoted by a nonlinear dynamics.

When we consider a mental fact as being composed of other, more simple, mental facts, this composition typically has a nonlinear character, because the complexity of a mental fact is usually referred to the addition of elements having qualitative differences, and a linear composition law instead requires that we add different quantities of the same thing. Therefore in studying the dynamics of mental facts, we must expect that each new fact will require a particular study to determine its properties, because these properties cannot normally be deduced from the properties of the facts that we used to define it by composition. This difficulty is probably the main difficulty of the classical logic; but it also strongly reduces the practical interest in a constructive viewpoint in defining mental things.

When we come back to the physical description we can recall other situations that we know to lead to nonlinearities. Although we describe the interactions between physical things by conservative forces, these forces might not depend linearly on the independent variables of the interaction. For instance, we put two electrically charged bodies at a certain mutual distance to produce electrostatic forces. Experiments show that electrostatic force is conservative, but it depends on the product of the two charges, and on the inverse square of the mutual distance between the two charged bodies. In these conditions, nonlinear equations describe the behavior of the charged bodies, and this conclusion continues to hold when we have a system composed by many parts, although we can linearly combine the conservative forces that describe the interactions between these parts. Other sources of nonlinearities may arise when in the physical theory we do not succeed in describing interactions by means of conservative forces[62]. In these cases, energy exchanges also depend on the particular process that the system is doing, and a principle of superposition does not hold. Finally, we remember that, when we are dealing with physical systems that cannot be considered as being isolated, the principle of superposition requires linear boundary conditions to hold as well.

When we think of the possible sources of nonlinearities, we find that the physical description of the biological systems, which we are concerned with, shows many other situations that lead to a nonlinear dynamics. For instance, the physical description of the memory phenomena, which

---

[62]. We will briefly discuss this type of situation in Appendix A - Further remarks on the physical description.

are highly significant in our systems, leads to a nonlinear dynamics, as we will see in the following section. The kinetics of two parallel chemical reactions, which involve a common molecule, leads to a system of non linear differential equations, even if we do not consider diffusion phenomena. The generation of an action potential at the axon hillock of a neuron has a nonlinear dynamics; and so on. We thus find nonlinearities yet at a very elementary level of the physical description.

**Memory phenomena.**

In discussing memory phenomena in the framework of the physical description, we must be aware that we decided to refer our discussion to an isolated physical system[63]. Furthermore, conservative forces that do not explicitly on time represent the interactions that we use as elemental in the dynamic of the isolated system. In this context, we usually speak of memory phenomena[64] when in the theory that explains and predicts the behavior of the system, the values of the variables that we have defined depend on the values that these and other variables assume both at the same instant of time, and on the past. When we use this characterization, memory becomes an aspect of the dynamics of the system, and we systematically will refer to this general characterization in the following of the paper.

Another, less general, way to characterize memory phenomena into the physical description says that the response of the system to actions of the environment depends on these actions, and on the history of the system's activity. We can apply this characterization only to the parts of the isolated system that we remembered above; and, in particular to biological systems. According to this possible interest, we will discuss some aspect of memory phenomena referring to the parts of the isolated physical system. However, this approach is not optimal, as we shall see below.

In a physical description, we can relate memory phenomena to two different schemes: the mutual movements of the parts of the system that are involved in elemental interactions, and the interaction delay when elemental interaction refers to distant pats of the system.

The first scheme is the simplest one. Since the parts of the isolated system change their mutual positions, the interactions still change; and we have a so direct link with the dynamics of the global system, that it is difficult to separate the description of memory phenomena from the description of the dynamics of the global system. This is a very important point, and we implicitly will come back to it along the paper. We can turn back to traditional memory phenomena by introducing a material with suitable characteristics. These characteristics conceptually depend at each point on interaction, and we could evaluate them by using the methods of statistical mechanics. These methods, however, are rather difficult in our case, mainly because of nonlinearities and interaction among distant parts of the system. So, we can use functionals of the activity history to describe mathematically these modifications[65], and we can still use this technique to model phenomena of fading and forgetting, although the functionals will take a more complex form. As we have recalled, the elemental interactions between the parts of the system are represented in this theory by conservative forces that do not depend explicitly on time. Clearly we must define as many parts in the isolated system as are necessary to have well defined elemental interactions, and to obtain suitable explanations and predictions of the facts in which we are interested. In this framework, memory phenomena become changes in the mutual positions of the parts of

---

63. Recall that we require the system to be isolated in order to predict the energy exchanges. By isolated system we mean the biological system plus a part of its environment such that their sum could be considered as being an isolated system.

64. A certain number of problems discussed in this section were discussed in R. Beltrame, "Memory and mental activity", *Methodologia*, 12/13 (1993), pp. 173-180.

65. In general these functionals may also depend on the past history of the time and space derivatives of the variables that we use to describe the system dynamics.

the system, because the spatial configuration of the interacting parts defines the material and its characteristics. We can introduce a locality principle[66]: that is, the changes in each part of the system depend on what happened in the past time only to that part and to its immediate neighborhood. It is acceptable because it has an experimental basis, and because we can deduce it by a definition of the architecture in a more analytic theory[67]. Furthermore, the architectural changes must be interpreted in a broad sense. We can, for instance, invoke different concentrations of certain molecules in a part of the system for explaining why the same process causes different processes; or we can have a protein *A* which is a gene regulatory protein that activates its own transcription. If an action turns on the expression of the protein *A* in a cell, then all the descendants of that cell will produce the protein *A*[68]. We thus can interpret local changes in the biological material as architectural changes.

We think of such a type of modifications as being stable: that is, we assume that their effects on the behavior of the system will be maintained until further modifications occur in the material; and this is a further consequence to describe them through elemental interactions. The technique often forces this aspect, and it offers several examples of objects in which this way of considering a physical system with memory is particularly evident: for instance, the magnetic disks commonly employed in computers.

The actions of the environment are a conspicuous source of physical activity that induces changes in the architecture of a biological system. It is a matter of experiment to describe the correlation between these actions and the physical processes that occur in certain parts of the biological system. It is again a matter of experiment to determine in which measure the actions of the environment are correlated. Indeed, we can expect that such a correlation will originate a correlation between the changes in the architecture of the biological system, so that a different correlation will lead to a different organization of the architecture. Although we cannot expect a simple link between the two orders of facts, this link can be conceptually an alternative to an innatistic position, and to the position that random events (that is, independent and equally probable events) will lead to an organized architecture.

We apply the second scheme to memory phenomena in physical description, when we think of a physical system as being composed of interacting parts, when we refer to a scheme in which we consider the change in a physical quantity at a certain point of the system as being the cause of the changes of the same or of another physical quantity at a different point in the system, and when we decide that it is significant a delay between the occurrence of the two processes that we consider cause and related effect[69]. If we consider significant this delay, the values of a physical quantity at a certain point and time depend on the values that the same or other physical quantities assume at different points and at past instants of time. This scheme, that we will call

[66] See C. Truesdell, *A first course in Rational Continuum Mechanics*, Vol. I *General concepts*, New York,1977; and M. Silhavy, *The Mechanics and Thermodynamics of Continuous Media*, Springer, 1997.

[67] A concise discussion of this point can be found in C. Truesdell and W. Noll, *The non-linear field theories of mechanics*, *cit.*, Sect. 3.

[68] See B. Alberts, D. Bray, J. Lewis, M. Raff, K. Roberts and J.D. Watson, *Molecular biology of the Cell*, *cit.*, p. 444, and the related bibliography. Nevertheless, these last types of phenomena may also be formalized as phase transitions.

[69] When the effect in the interaction follows the cause with a certain delay, it is usual to speak of delayed action, or of delayed interaction, both when the cause and the effect occur at the same point, and when they occur at different points. When the delay is considered significant, and when cause and effect occur at different points, it is often satisfactory to express this delay as a linear function of the distance between the two points where the changes of the physical quantities occur; and, in this situation, the term 'propagation speed' designates the constant rate in the linear function. Nevertheless, the reasons for introducing this concept in a theory, with the related problems about a thing that would travel from one point to another, really relate to the decision to write equations of balance for certain physical quantities, which must hold at every instant of time both for the system, and for its parts. A very good discussion on this point can be found in R.P. Feynman, R.B. Leighton, M. Sands, *The Feynman lectures on Physics*, *cit.*, Vol. II, pp. 27.1 ff.

interaction delay, offers a further way of describing memory phenomena in physical systems, and it is noteworthy that, in this conditions, the system shows phenomena of memory without us having to assume changes in the material and the architecture of the system[70].

If the interaction between the parts of the system is active for a long time, then the past values of the variables that affect the actual value of the observables, may still depend on the values that certain variables assumed in other points at earlier instants of time, and so on. We must describe memory phenomena in a way that does not violate, even implicitly, the repeatability of the experiments. As we have seen in a previous section, this implies that interactions that we use as elemental in the theory must not depend explicitly on time[71]. Clearly, the interaction can change in dependence on the space position of the interacting elements[72]. However, we cannot consider the delay in interaction as being an explicit dependence of the interaction on time because it is a characteristic of the physical phenomenon that we consider as interaction, and its properties follow from specific experiments[73].

The state of the system now technically depends on the history of the system, because we have a back propagation chain of dependencies on the past activity of the system. We easily assure the repeatability of the experiments when we succeed in defining state variables, because the knowledge of the value of these variables is equivalent to the knowledge of the system's history when we formulate predictions about its future behavior. Probably, the best example of this technique is in elementary Newtonian mechanics. In this theory we have a vector whose value corresponds to a linear functional of the history of the forces that acted, over a certain interval of time, on the so-called material point: that is, on a mechanical body that we assume as being atomic. This vector is the momentum; and the velocity becomes a state variable, when, in this context, the mechanical body is also assumed as having a constant mass. Unfortunately, there is no general method to define state variables, and it is usually very difficult to define suitable state variables for a complex system. Nevertheless, when we assume a methodological attitude, it seems to me the only safe strategy. Hence, in the reference physical theory, which was essentially introduced to have a clear methodological discussion, we will assume that we succeed in defining suitable state variables, because we assumed that elemental interactions have potential.

We can consider the repeatability constraint to be practically satisfied also when a knowledge of the system's history over a limited interval of time is sufficient to formulate predictions about the future behavior of the system: that is, when we obtain satisfactory predictions by limiting the back propagation chain of the dependencies to a reasonably short interval of time. Furthermore, when for a sufficient interval of time we have no interaction between two parts of the system, the effects of the previous type of memory also cease on these parts. Let interactions involve only limited parts of the system, and these parts make a different activity. The interaction delay can exhaust its effects, because we can predict a decay of this type of memory when activities alternate, and they involve interactions among disjoint parts of the system, or, at least, they have as target disjoint parts of the system. We thus expect that the effects of this type of memory decay,

---

70. We recall that the occurrence of memory phenomena of this type is very frequent in natural systems. Systems without memory are nevertheless of theoretical interest because of their simple mathematical treatment, and because the actual production of the artifact relates to systems with a behavior strictly stereotyped, repetitive: that is, a behavior that we want to be independent of the system's history.

71. More generally it must be invariant for translations of the completely ordered parameter that we use to describe a process. The interval [0,1] of the set R of real numbers is usually assumed as a prototype of the formalization of this parameter.

72. If we describe interaction by a field, this means that the field is stationary; that is, it does not depend explicitly on time.

73. When we assume this viewpoint, it is not strange that the delay in electromagnetic interaction only depends, in certain conditions (a motion of the interacting bodies that does not change their distance and whose velocity is constant), on the distance between the two interacting bodies, and it does not even depend on the direction of the velocity, as the Michelson-Morely experiment proved.

when we alternate very different activities, and we know that such an alternation usually reduces fatigue. We may think that a good contribution to the decay of this type of memory, both in man and other mammals, is given by alternating two periods in which we have a very different activity: a diurnal conscious activity, and the nocturnal sleep.

In biological systems we have cells that die and are replaced by new ones at rather regular intervals of time, and the constituents of the cell are regularly replaced with new ones with very few exceptions. At the level of a single cell we have, for instance, continuous phenomena of endocytosis and exocytosis, and, more generally, soluble, or secretory proteins, and other substances are thrown in the intracellular space, and are imported from it. Newly synthesized plasma membrane lipids, transmembrane proteins, and cytoplasmic proteins replace the old ones. Cytoskeleton has a dynamics, and so on. Indeed many of these processes can be also receptor-mediated, and so actions of the cell's environment can modulate them[74]. We may think that these substitutions of old biological material with new material contribute to canceling the link with the past activity that is induced by the interaction delay. We thus can explain why the practical possibility does not fail to repeat a large part of the experiments, although the interaction delay introduces a dependence on a back chain of past facts.

Let the system, which we are concerned with, occupy a region of space such that we can neglect the delay of the interaction. We can simplify the study by substituting the knowledge of the external actions with the knowledge of the values that significant physical quantities assume on a closed surface that envelops the system. This strategy is frequent in laboratory experiments. However, we must have a satisfactory theory that can predict the values of these physical quantities on the closed surface that envelops the system[75], and the energy flow across this surface. Otherwise we do not succeed in integrating the experimental result into a more general theory, or in transferring the results from *in vitro* experiments to *in vivo* systems. Finally, in integrating the physical and the psychological descriptions of memory phenomena we must be aware that we can easily define a mental thing by a mapping into a physical process; but we have difficulties to map it into a system condition, like a pattern of molecules' concentration. We proposed to avoid this difficulty by introducing the process that brings the system to that state; but we usually need a very detailed knowledge of the system dynamics to employ this strategy.

In psychological descriptions different ways are in use of considering memory phenomena. Here, we will discuss conscious memories, and we will show that a reasonable hypothesis seems to introduce a mental categorization for describing conscious memory phenomena. Learning is another element of the psychological description that is usually related to memory phenomena, and memory (both reflexive and declarative) as well. However, we prefer to discuss them below, in the framework of the constraints on the mental activity.

Let we decide to describe mental facts by regarding them as activities and by giving their constitutive operations. In this framework it was proposed that, when we speak of a mental fact as being a conscious memory, we consider the mental fact as being repetition of another mental fact, and we consider the latter as having occurred in the past[76]. Following this hypothesis a mental fact becomes a conscious memory as a result of a mental categorization, which follows the scheme described above. Two sets of conditions thus constrain the occurrence of a conscious

---

[74] About endocytosis and exocytosis traffic at the level of single cell a good starting point is in B. Alberts, D. Bray, J. Lewis, M. Raff, K. Roberts and J.D. Watson, *Molecular biology of the Cell*, *cit*., Chap. 13. However, there is a rapidly increasing bibliography on the replacement of the cell's constituents, and its dynamic.

[75] Another way of describing this difficulty is that we must know which physical processes produce the observed values of the physical quantities on the closed surface that envelops the laboratory system. Otherwise the relation between the dependent and the independent variable only holds for a pointwise value of the physical quantities on the closed surface that envelops the laboratory system.

memory. A first set relates to the possibility of executing the constitutive activity of the mental fact that should be the content of the conscious memory. The second set relates to the categorization of a mental fact as being a repetition of a mental fact that occurred in the past to the subject of the conscious memory. We thus expect a selective loss of the conscious memory of those facts for which subjects cannot produce one of the two previous constitutive activities for any reason, although the facts occurred many times in their past. For instance, achromatopsias are known, which follow from brain lesions, in which an adult man loses the ability both to perceive and to remember colors, even if he had perceived and remembered colors several times before incurring the disease.

Today we do not succeed in defining a mental categorization by means of an injective function into suitable physical processes that occur in the system that we think of as doing the mental categorization. In particular we do not succeed in finding suitable elements to characterize the conditions that lead to the proposed categorization in a context where conscious memories may arise. We have in fact to explain why in a certain moment a person considers a certain mental fact to be the repetition of a past fact, and we also have to explain why the subjects report facts that are sometimes the same as the ones that occurred, and sometimes they are different[77]. This is a strong limit, because we cannot explain and predict whether a conscious memory will occur, its contents, and the moment in which it will occur to a particular subject, and the integration with the physical description of the system dynamics becomes unattainable. Our discussion thus limits to the consequences of the occurrence of a conscious memory.

From thinking of one thing as being a repetition of another, we also expect that subject thinks of the two things as being equal. Furthermore, in the comparison that is part of the constitutive operations of the equality, the proposed categorization scheme implies that we use as paradigm what subjects think to have occurred in the past. We become aware of this fact when a disagreement with this paradigm (for instance by means of factual or document checking, testimonies, etc.) leads subjects to inserting suitable causes for explaining the failure of the equality that they expected as a consequence of the applied mental categories. Since expectations arise from mental categorization, when no check occurs, the subsequent behavior continues as if the expected consequences held[78].

This behavior, which is quite general, assumes particular relevance in our case. The stimulus is weakened to check whether the conditions hold to apply the categorization scheme proposed for the conscious memories, and this effect will become progressively stronger when such a situation is repeated. Motivations, of which the person might not be completely aware, can strengthen the tendency to avoid any check. Moreover, a subsequent memory can base itself on a previous one, rather than on the original situation: that is, in the categorization subjects assume the actual mental activity to be a repetition of one that occurred in a previous memory. They thus apply a transitive property. The consequences are well known. We can have facts that the subjects consider as being good memories, which may either result not to have occurred, or they reveal significant differences from the facts that subjects consider as memories when some-

---

76. This characterization was proposed in S. Ceccato, *La fabbrica del bello*, Rizzoli, Milano, 1987, pp. 234-36 (in Italian). It is also interesting to see the Aristotle's discussion on this point in his *De Memoria*, *Parva Naturalia*, 450a.25 ff. We emphasize that we speak of conscious memory about mental facts, and we do not speak of conscious memory about mental activity. Therefore, I think that we must preliminarily consider something as being a mental fact through a suitable mental categorization.

77. Clearly equality and differences result here from a comparison between what a subject reports as a memory, and the contents of a physical record of the fact which the subject is talking about.

78. We avoid talking about consequences that are assumed to be true or verified, because a check is implied, which was excluded by hypothesis.

one checks them. Since the persons consider these facts as really occurred in their past life, we may have relevant consequences on their behavior, which may reach mental disease.

We can apply the previous way of considering conscious memory, to a crucial point in Freud's development of psychoanalysis[79]. Freud reports that many of his patients remembered, under analysis, seduction situations (that is, passive sexual experiences) that they claimed to have suffered during their childhood; but these memories turned out to be untrue when a later check was made on the patient's history. We know that gestures of affection may frequently assume sexual connotation after the sexual differentiation is completed in adolescence, particularly when they involve the tactile sensory system. Let a person starts from the memory of an affection gesture that involve the tactile sensory system, and that relate to his childhood. If he now feels this gesture as having a sexual connotation, and he considers this situation as being a repetition of what occurred during his childhood, then, in the scheme proposed above, this situation becomes a good memory of what the person felt during his childhood. Through the same mechanism the subject may attribute an analogous feeling to the person who made the affection gesture. Furthermore, persons must use thought to conclude that their actual feeling differs from their feeling during childhood. So, they must agree with a paradigm that is transmitted by culture, whose content is precisely that a difference in our feelings is introduced by the biological process of sexual differentiation during the adolescence; so that we normally must refer sexual attraction or repulsion only to persons that have reached this level of sexual differentiation[80].

The characterization of the conscious memories as involving a mental categorization is also compatible with a possibility that is particularly attractive for long term memory, particularly the memory that spans over months or years. Let us define cognitive facts as being the result of constitutive activities, to which certain physical activities will correspond. From this point of view, a mental fact or a movement have the same type of physiological counterpart. Furthermore, they have the training as the same source of learning, because the subject has to become able to execute certain activities. In these conditions, a conscious memory can arise in two steps. The first step involves the procedural memory by which we are able to do a certain mental activity; the second step is the categorization outlined above. It is the activity by which we consider the actual cognitive fact as being the repetition of a cognitive fact occurred in the past. For instance, the persons become able to represent mentally the face of their parents, and we usually ascribe this ability to procedural memory. Then a conscious memory arises, when they categorize the mental representation of their father face as being the repetition of a cognitive fact that occurred in the past. In particular we expect that yet fading and forgetting will follow the same rules and the same dependence on aging of the fluency of other activities: for instance, movements. The loss

---

79. We will quote Freud's first communication in his letter to Fliess of September 21, 1897: «Then the surprise that in all cases, the father, not excluding my own, had to be accused of being perverse - the realization of the unexpected frequency of hysteria, with precisely the same conditions prevailing in each, whereas surely such widespread perversions against children are not very probable. The incidence of perversion would have to be immeasurably more frequent than the resulting hysteria because the illness, after all, occurs only where there is a contributory factor that weakens the defense. Then, third, the certain insight that there are no indications of reality in the unconscious, so that one cannot distinguish between truth and fiction that has been cathected with affect.», and later he notes: «It seems once again arguable that only later experiences give the impetus to fantasies, which hark back to childhood, and with this factor of a hereditary disposition regains a sphere of influence from which I had made it my task to dislodge it - in the interest of illuminating neurosis.» S. Freud, *The complete letters of Sigmund Freud to W. Fliess 1887-1904*, transl. J.M. Masson, Harward University Press, Cambridge, 1985, pp. 264-5.

80. This picture again agrees with Freud's analysis of pathological behavior. The critical point is the equilibrium between thought and sensations. Moreover, when the cultural paradigm is not accepted, the subjects may suffer the consequences to think of the sensations that they attribute to the partners of the imagined sexual act. Depending on the distribution of pleasure and repulsion between the partners, we can find the wide range of reactions that Freud and other psychoanalysts clearly described and studied.

of memory by effect of aging usually does not involve the well-assessed things, but the memory of what happened in the past minutes, or hours, with the related consequences.

We may try to explain other memory functions that we meet in psychology by involving mental categorization. A subject, for instance, can consider that a thing is the same thing that occurred in his history, and this categorization might be a good candidate for the type of recalling that is indicated in our languages by a usage of pronouns and definite article. In physical descriptions, on the other hand, we can only use the two schemes discussed at the beginning of this section: changes in the material, and delay in interaction. In particular, as we shall see in a next section, we have no necessity to introduce learning in physical description. Since we decided to define mental thing so that many physical processes can share the part that we used to define the same mental thing, many physical processes can realize the occurrence of a mental thing. Our definitions of mental things thus have a certain degree of independence from the architecture of the physical system that realizes their occurrence, and from the history of the interactions between the system's parts, where we clearly refer to the enlarged physical system that encompass the biological system and a suitable part of its environment. Moreover, the occurrence of the same mental fact or activity does not necessary induce identical changes in the architecture of the physical system, because these changes may depend on the occurrence of physical processes that were not used to define the mental thing. Although these remarks have a methodological character, we can expect that they have very deep and subtle consequences on the dynamics of our systems. In particular they will be related to the learning of mental things, and, more generally, the learning of things that we defined in the way mentioned above.

## Constancy phenomena and mental categorization

When we take the viewpoint of psychology, we find constancies in behavior although the same set of environment actions, to which that behavior was connected, will repeat identically with a low probability[81]. The physical actions of the environment, which we consider as being atomic in our theory, can occur identically several times, and this fact has a methodological character[82]. However, they usually do not induce the external behavior of interest for the psychology when they occur alone, and a set of these atomic environment actions is required to induce such a behavior. The same set will occur identically after a reasonable interval of time with low probability. As example, we can cite: the spectrum and the intensity of enlightenment, the mixing of objects in a visual field, and their distances, the spectrum of sound waves, etc.

Classical constancy phenomena in the psychology of perception offer a good example of situations in which subjects report the same perceptive result although physical stimulation is different. For instance, the subjects usually report that they see their hands as having the same size at different distances, though the visual angle is very different, and the extension of the stimulated region in the retina as well. We see objects of the same color through a great range of light colors and intensities. Many conditions, however, influence the occurrence and the strength of the constancy phenomena in visual perception. Significantly, size constancy of our hands is more evident when distances are in the range of reaching and grasping, and it fails when we look at a photo of the two hands placed at different distances. The constancy of colors is more evident when it involves objects whose color is well-known to subjects. Furthermore, constancies are more strong in the adult life.

---

81. In this section we will speak of environment actions because it is a common usage in psychology. When we consider our system as being an isolated system these actions simply become actions of certain parts of the enlarged system on other parts.

82. In fact we must choose atomic actions that satisfy the repeatability requirement, and, because we assume them to be atomic, they must have the possibility to reoccur identically.

Let us consider in a physical description the two sets of processes that are involved in the previous description of constancy phenomena: that is, the set of physical processes that are the counterpart of environment actions in the psychological description, and the set of processes that we used to define the constancy content in the psychological description. Geometrically we cannot think of these two sets of physical processes as being represented by trajectory segments in phase space, otherwise we would have a bijective function between the two orders of facts: that is, no constancy of the type described above. We must instead think of them as being represented by projections, onto suitable subspaces of phase space, of trajectory segments. This representation highlights an important consequence. The process, that we consider as being the counterpart of environment actions in constancy, is still represented geometrically by a projection. Many trajectory segments can share this projection, and we cannot assume the projection to determine the following activity of the system. A program, consequently, would be contradictory of obtaining a unique cause for each constancy, and a unique explanation of its occurrence as well.

We have phenomena that are analogous to constancy when we recognize the same object in different contexts, because the same pattern of environment actions has a very low probability to occur again identically. We have effects on the subsequent behavior, which are analogous to the effects of the perception constancies, also when we categorize a thing in certain ways: for instance when we categorize a thing as being the same after a certain delay in time, although some characters may be different. This situation is particularly evident when the time interval is large, and it is quite common. It occurs, for instance, when in our languages we use verbs with which we describe that a thing changes some of its characteristics: like color or shape.

If we assume the constitutive activity of the mental category to be the same although the related mental categorization may involve different things, then mental categorization becomes another situation analogous to constancy. However, since we can propose more complex schemes for mental categorization, a situation is also possible analogous to the situation of chemistry. In a chemical molecule the bounded atoms only maintain part of the characteristics that they have when we consider them as being isolated, like, for instance, in spectroscopy. Nevertheless, we can develop a theory of the chemical bond by using the electron wave functions that were obtained from the theory of isolated atoms; but we must introduce further elements to obtain more realistic results. We use, for instance, a linear combination of a certain number of these wave functions; and, in this way, we have further terms into the computation of bond energy[83].

In mental categorization we may expect an analogous situation: that is, we may maintain part of the characteristics of the mental category and of the categorized thing, and we will add further characteristics. We can obtain reliable elements for choosing between these alternatives only from experiments on the physical system that we consider as doing mental categorization. In any case, we recall that, when we think of mental categorization as being a composition of more simple mental things, mental categorization results from a nonlinear composition, because the components are different. We must study the properties of the result in each single case, and we must expect properties that are not the simple union of those of the components. However, we have no clear idea about defining mental categories and mental categorization along the lines that we discussed above.

We also observe phenomena that in a certain way are the inverse of constancy, when we observe that we can correlate a different behavior to environment actions in which the part remains equal, that we assume as being sufficient to produce the observed behavior. Classical figure-ground alternations are good, controlled examples of these situations: for instance, the

---

[83]. A very clear discussion of this point can be found in L. Pauling, *The nature of the chemical bond*, Third Edition, Cornell Univ. Press, New York, 1960, particularly on pp. 215-220, where the author discusses the nature of the theory of resonance.

*Figure 2*

well-known Rubin figure-ground alternation where we sometimes see a pair of faces, and sometimes a black vase (Figure 2 left), or where we alternatively lose as face the left or the right part of the figure (Figure 2 right)[84]. The physical situation that we use as perceptive stimulus remains equal in both the alternatives, and in these cases we may avoid to inform the subject of the two alternatives, although this last condition is not general.

Besides these experimental figures, we have situations in which environment actions can support different perceptive, or mental activity; although we assume to remain equal when we consider two successive perception activities. For instance, we may designate the pattern in Figure 3 as a line, or as an angle, and we also can accept that someone talks of a black pigment on the white paper of a page. In the framework of the Italian Operative School, this example was frequently used as a didactic tool to make a person aware of the role of mental activity. In particular, it was used to break the idea that we can set a one-to-one link between a physical description of the situation that is used as stimulus, and the occurrence of a mental fact, or of a linguistic behavior[85]. In this didactic context, a linguistic designation of the different alternatives was frequently used as constraint to induce different mental activities.

Perspective is another situation of this type, because a two-dimensional pattern leads us to perceive the room and the objects represented as being three-dimensional. This habit is today very strong, and we usually cannot escape it, because camera images, particularly the images that we see on television, are very frequently linear perspectives[86]. Nevertheless, we can see a perspective pattern as being two-dimensional, for instance when we are drawing it as an application of geometry, and we have again the possibility to think of the pattern as pigment on its support: paper, canvas, table, or wall. These alternatives still require further environment

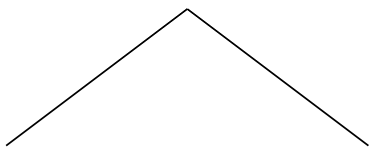

*Figure 3*

---

[84] The two figures are taken from E. Rubin, *Visuell Wahrgenommene Figuren*, Kopenhagen, 1921.

[85] When the subjects consider the figure as a line or as an angle, we found some differences also in the movement of the eyeballs; see R. Beltrame, A. Berbenni, and G. Galassi, "Contribution to the studies of the movements of the eyeballs during optical perception by means of high speed motion picture photography", *Proceedings of the 7th International Congress on High-speed Photography*, edited by O. Helwich, Zurich, 1965, pp. 257-64.

[86] A possible genesis of the linear perspective considered as a mental habit was discussed in R.Beltrame, *The Renaissance perspective. Birth of a cognitive fact*, Quaderni di *Methodologia*, 3, Roma 1996, 120 pp. A revision of this paper appeared as CNUCE Report C97-24, last revision Nov. 1998, (all in Italian).

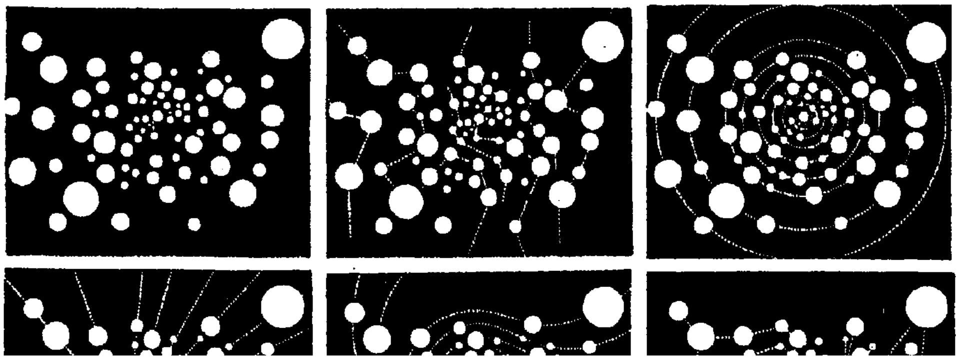

*Figure 4*

actions, for instance a particular context, or a previous activity, which acts as a sufficiently strong constraint to direct the activity in a direction that will be different from the more usual one.

In these cases, however, we have an intermediate activity, whose role is determinant to obtain the result. The perceptive situations illustrated in Figure 4[87] show good examples of the role of such an intermediate activity. We can easily verify that the white circles have the same diameter and the same reciprocal positions in all the six figures. The further lines suggest different perceptual organization of the figure, and they seem to be quite necessary when we wish to obtain perceptual organizations that we can categorize as being ordered situations. In these cases we can reasonably assume that the actions of the environment are different, because the further lines assume great importance. Therefore an equality can result only by a comparison of the figures according to a different kind of criteria: the diameter of the circles and their reciprocal positions.

Mental categorization also participates to constancy phenomena when we consider the same thing in different ways: for instance, as cause or effect, as the same or another thing, as a part or a rest, and so on. Moreover, mental categorization still participates to this aspect because it plays an important role in characterizing mental attitudes. We can define a mental attitude as a particular way of operating, which can be characterized by the occurrence of certain mental constructions, usually mental categories, or by the frequency of their occurrence[88]. With this type of definition we can distinguish several mental attitudes, and not only those that historically received a designation, like, for instance, esthetical or ethical attitudes. However, we can think of many facts mentioned in this section as being a constraint on mental activity, and so as part of the dynamics of our systems. Therefore, although we might mention many other situations of the type that we discussed in this section, we prefer to continue our discussion dealing with the activity flow, and its constraints.

---

87. The figures were prepared by P. Parini for the exhibition "Mind and Image", Gallery of Modern Art, Bologna, 1978.

88. A certain number of mental attitudes were defined following the approach outlined here in S. Ceccato, "A Model of the Mind", *cit.*; and in R. Beltrame, "Perceptive Operations", *cit.*

# Methodological aspects of dynamics

In this section we will focus on the flow of mental activity, and we will compare the dynamics of mental activity with the dynamics of the physical processes that we defined to obtain a suitable description of the system activity when we consider the system as a physical system. The dynamics of mental and physical activities is a critical topic in the integration of physical and psychological descriptions, because definitions are neither true nor false, but they are only less or more useful to do something else. The development of a theory is one of the main purposes in a scientific context, and dynamics is an essential part of any theory: it is thus a critical test of the definition's usefulness. We start by briefly outlining the main differences that dynamics assumes in physical and psychological descriptions.

In our discussion we will refer again to a physical representation of our systems dynamics in which we systematically use the cause-effect relation, and in which we choose the things to consider as causes and effects so that a bijective function holds between the causes and their effects. We recall that the systems must be the usual biological systems extended to a suitable part of their environment so that the enlarged physical system can be considered as being isolated. In this hypothesis, we can describe both the actions of the environment on the biological system, and the actions of the biological system on its environment as being interactions between parts of the enlarged system, and so we completely can predict the energy exchanges. Clearly, the total energy of the enlarged system is constant. As we discussed in a previous section, we can meet practical difficulties to fulfill these assumptions, mainly because of the difficulties in collecting the information needed to develop such a theory for biological systems; but we have no conceptual difficulty. We will use these assumptions because they characterize a theory in which the differences between the physical and the psychological description become very sharp, and the problems acquire a sharp formulation. Furthermore, we obtain a theory that has a very fine granularity, because the strict determinism forces us to define a higher number of physical processes and observables, than in a theory that has a probabilistic approach; and these are good reasons to refer to this theory in discussing the dynamics of our systems.

In this theory the equations that describe the evolution of the system completely describe the dynamics of the system. Since we assumed that a bijective function of the causes onto the related effects holds, different configurations of the values of the observables that characterize a state of the system completely characterize a different evolution. Therefore, the equations that describe evolution also describe the flow of the physical activity. We recall that we decided to describe the flow of a physical process as being continuous, because we decided to describe as being a particular process the situations in which the values of the observable do not change for a certain interval of time. Thus, we can geometrically think of a physical process as a continuous line in a space having a suitable number of dimensions, and we can decompose it as a sequence of subprocesses that occur in contiguous intervals of time[89]. We recall that we decided not to introduce states as explanatory elements, but we instead decided to use the process that led the system to a certain state. We thus consider only process as conceptually atomic in our theory. Finally, we also recall that a trajectory can remain for a long time at the interior of a small volume of phase space without having any intersection with itself or other trajectories. A system thus can remain for a long time at the interior of a certain range of physical conditions without violating the requirements of our reference physical theory.

---

89. The concurrent processes scheme maintains this character, although we can have parallel subprocesses. Musical notation shows this character, because pauses are fully notated. They are explicitly notated when we have parallel processes, as, for instance, in a symphony score.

A psychological description is conceptually more complicated, because we decided to define mental things through an injective function into physical processes that are characterized by a lower number of parameters than those which are necessary to give the previous physical description of our system's dynamics. The occurrence of mental things thus requires as a counterpart the occurrence of only a part of the physical processes that we introduced in the physical description that we use as reference. As we have seen, things that we defined in this way can occur more than once during the life of a same subject, and they can occur in subjects having different characteristics: more precisely, they do not require a further instance of the same physical system to occur again. This situation holds for the dynamics of all the things whose definition involves only a part of the processes that are necessary in the reference physical theory, irrespective of the fact that these things are mental things. We frequently meet things of this type in psychology, because much physical behavior, for instance movements, is defined in this way. Therefore, we define in this way also the muscles' activity that is responsible for the utterance of the words and the sentences of our languages. A large part of human behavior is thus defined in this way.

We will clarify the consequences of the previous decision by referring to the properties of a system dynamics that can be represented in phase space by trajectories that do not intersect. In this discussion we will refer to mental things, although many results hold for all things whose definition involves only a part of the processes that are necessary in the reference physical theory. In this picture, mental things mirror the properties of projections, onto subspaces of phase space, of one or more segments of the trajectory that describe the evolution of the system in phase space, and so the flow of its physical activity as well. Note that projections can have many configurations: for instance, they can be projections of the same segment onto different subspaces of phase space, or they can be projections of successive subsegments onto the same or different subspaces, and we implicitly define the timing pattern of their occurrence as well. We thus have many possibilities when we define a thing in this way. The simplest one consists in defining the occurrence of a mental thing by the occurrence of a process whose geometrical representation is a segment of line into a subspace of phase space. Since many trajectory segments can share the same projection onto a subspace of phase space, the occurrence of what we defined by a projection can be obtained by doing the physical activity that we described by the trajectory segments that share the projection[90]. We can thus realize the same mental thing in different contexts of activity, and by a different biological architecture. It can be done, in particular, by the same individual in different moments of his life, or by different individuals of the same biological species, or by individuals of different biological species. We thus find the properties mentioned above, and we can also escape the necessity of defining anthropomorphically the mental activity.

If we prefer to avoid this geometrical representation, we can simply reword the previous picture in the following way. The trajectories in phase space become the description of how the physical system evolves from certain initial conditions, and the equations that describe this evolution fully describe the dynamics of the system. The trajectory segments in phase space become the physical processes that we introduced in our theory to explain the behavior of our systems so that cause-effect relations will be one-to-one. Their projections become the subprocesses of the physical processes that we used for defining mental things, or other elements of psychological theory, in such a way that they can occur again in the life of the same subject, and in different subjects.

---

[90]. This fact shows a further source of the effects that we usually ascribe to the plasticity of the nervous system, and this source does not require the local changes in the biological system architecture, that we mentioned in discussing memory phenomena. In particular, we are not required to introduce new learning activity.

A global determinism clearly does not hold between the occurrence of facts whose definition uses only a part of the physical processes that we defined for developing a deterministic physical description: that is, a description in which we explain the occurrence of the physical processes by using one-to-one cause-effect relations. Limited forms of determinism are however possible. When we refer to a geometrical representation in which the dynamics is described by trajectories that do not intersect in phase space, this local determinism condition has the following geometrical representation. Let A and B be the processes that define the facts that we wish to consider respectively as being the cause and the related effect. According to our previous decisions, they are represented by line segments in certain subspaces of phase space. The determinism condition means that all the trajectory segments whose projection is B follow a segment of the same trajectory whose projection is A, and all the trajectory segments whose projection is A precede a segment of the same trajectory whose projection is B. We still require that a trajectory segments whose projection is different of B does not follow a segment of the same trajectory whose projection is A, and a trajectory segments whose projection is different of A does not precede a segment of the same trajectory whose projection is B. When the definition of A or B involves more projections these conditions must hold for all projections, and their timing pattern. When we claim for a chain of cause-effect relations these conditions must hold for all the trajectories that share as projection one of the elements of the chain.

This picture shows that local determinism critically depends on the shape of the trajectory segments. Therefore it mainly depends on the interactions that are currently active in the enlarged system: that is, in the biological system extended to the part of its environment that allows us to consider this extended system as being isolated. It also can depend on the history of these interactions, possibly through state variables, because we usually have memory phenomena. It still depends on the state of the enlarged system, although this dependence may be weak when a trajectory remains for a long time in the same volume of phase space without intersections, and so many trajectory segments can satisfy the same subset of physical conditions. However, we expect that the more the situation is complex the less is the probability to have local determinism, because the previous conditions may not hold for some trajectory segments whose previous segment satisfies the conditions stated above. We need a detailed knowledge of the dynamics of the particular class of systems to quantify these aspects, but we also expect that we have to treat probabilistically phenomena of this type, at least starting from a certain degree of complexity.

Another strategy describes a correlation between the occurrence of the things so defined that a global determinism does not hold. When we decide to use a correlation between facts or activities, we must be aware that in general we renounce to individuate what determines the existence of the correlation, and our optimal result is to show the conditions under which a correlation holds. Moreover, when we try to employ a deterministic approach, we must be aware that, either we use a correlation as a definition with the related problems[91], or we need further information to pass from a correlation to a cause-effect relation, because both the correlated facts may be effects of a third fact. We must be fully aware of this point when we interpret a scientific result, or we forecast its practical applications, and biology offers very interesting examples of such situations.

We set the correlation between things that mimic the properties of projections, onto suitable subspace of phase space, of trajectory segments[92]. Since many trajectory segments share the

---

[91] In physics, for instance, we use a correlation between two facts for defining an interaction between two things, but the interaction that we defined in this way must be used as atomic in the theory.

[92] If the correlation would be between trajectory segments, we should have a deterministic situation.

same projections, we are not sure of the consequences that follow the correlated facts; and we may meet unexpected results. For instance, we inherit from the history of biology an evolution scheme in which a new behavior grows together with related changes in biological architecture. In these cases, it is also traditional to correlate the two orders of facts. Since the state that corresponds to the architectural changes has the characteristics of a projection as well, many trajectory segments can share it. So, different physical processes can reach it, and we know that techniques of biochemistry or of molecular biology can induce the same architectural changes. Correlation, however, depends on the characteristics of the trajectory segment. Therefore, the correlation may hold when the state belongs to certain trajectory segments, and it cannot hold when the state belongs to other trajectory segments. In our example, the new behavior can be obtained when a system activity induces the architectural changes, and it cannot be obtained when we induce the changes through techniques of molecular biology[93].

When we use a probabilistic approach, we must start from the projections by which we defined a mental or psychological fact, and we must define the probability that each projection occurs. Matematically, this probability is related to the ratio between the number of trajectory segments that share a projection[94], and the number of trajectory segments that share more general properties. The choice of these properties, that define the possible segments, can depend on the problem we are dealing with. For instance, we can choose the number of trajectory segments that share the beginning of the projection segment, but we can impose more strict conditions. We can try to use the same class of possible processes to define all the probabilities, and we thus will obtain a more general theory. However, I think that a bottom-up approach should be preferable in this type of problems. Suitable mathematical conditions must hold to ensure that this ratio will have a finite real number as limit, and these mathematical conditions become constraints on the dynamics. In particular, we may require ergodicity to simplify the link between the theory and the experimental results, though ergodicity is rather difficult to prove as property of a physical system. We will not concern ourselves with other details of a probabilistic approach to the dynamics of our systems, because the mathematical aspects would require a long and accurate treatment. The main points of our discussion maintain their methodological validity if we conceptually substitute single values of the physical observables with distributions. However, this substitution implies an often sophisticated use of tools of the functional analysis, with the related updates of the details of the methodological framework.

Since a long chain of facts is less probable than a shorter one when the facts were defined through projections of trajectory segments, we also expect less coherence in the system's behavior when it involves such a type of facts. This remark agrees with the results of experimental psychology in which we observe coherence on the motivations of the subjects' behavior in the short period, and lack of coherence in the long period. This change in the criteria that drive a same behavior is usually referred to changes in the experience of the subject. We can add other rea-

---

93. Some interesting results are reported in V. Porciatti, T. Pizzorusso, and L. Maffei, "Vision in mice with neuronal redundancy due to inhibition of developmental cell death", *Vis Neurosci* 1999 Jul-Aug;16(4):721-6. They experimented with transgenic mice overexpressing *bcl-2*, which, due to inhibition of naturally occurring cell death, have much larger brain and optic nerves as compared to wild type mice. By recording Local Visually Evoked Potentials (VEPs) from the primary visual cortex in response to patterned stimuli, they found that the representation of the visual meridian was displaced by about 15% in the *bcl-2* mice, but visual acuity, contrast threshold, and response latency were normal, indicating that compensatory mechanisms can ensure normal basic properties of vision in spite of marked neuronal redundancy. See also Porciatti V, Pizzorusso T, Maffei L , "The visual physiology of the wild type mouse determined with pattern VEPs", *Vision Res* 1999 Sep;39(18):3071-81. Other behavioral experiments of the same laboratory show that *bcl-2* mice have normal behavioral performance in a T-maze apparatus (L. Gianfranceschi, A. Fiorentini, L. Maffei, and V. Porciatti, "Behavioural visual acuity of wild-type and *bcl-2* transgenic mouse", *Society for Neuroscience Abstracts*, 1996,1060)

94. For simplicity sake, we can think of a single segment of line, but we can have more complex types of projection, as we discussed above.

sons that, for simplicity sake, we will refer to mental facts. We have seen that it is practically impossible to have an identical repetition of a long chain of mental facts. Subjects thus frequently shorten the chain of facts that lead to a particular behavior, still because they have constraints on time. A decision is thus motivated by a limited number of elements, that are less than those we consider to influence that decision when we are dealing with a general theory. These elements can change from one occurrence of the decision and another, because subjects use the mental facts whose occurrence is more probable in that moment.

The geometrical framework that we outlined above offers a way of interpreting some elements that were historically introduced in psychology to explain the occurrence of psychological facts. As example, we will discuss here motivation. Let us define motivation and drivers by using only a part of the processes that are necessary to predict a flow of the physical activity with the characteristics of the reference theory mentioned above. They can occur again in the life of the same subject, and they can occur identically in different subjects, but such a definition is not sufficient to ensure a one-to-one cause-effect relation. With this type of definition, the properties of motivation and drivers mirror the properties of projections, onto subspaces of phase space, of trajectory segments. Many trajectories of phase space thus can share a projection. Therefore, we need further conditions to predict deterministically the occurrence of a motivation, but we also must avoid a *regressum ad infinitum*. Moreover, we usually have several motivations and drivers for the occurrence of the same mental thing. Finally, the current trajectory segment implies the occurrence of further physical processes besides the physical processes that we used to define the mental things and its motivation. These further physical processes may differ from one occurrence to another, and it is not so immediate to individuate the elements that are their counterpart in a psychological description. The consequences of this fact are rather subtle, and they are not well studied. For instance, we can meet them in clinics, as psychosomatic effects or diseases. This further physical activity is also essential to explain the occurrence of other, subsequent effects, and among these effects we can have mental facts. The general result is a theory in which explanations of single facts taken in isolation, and short time correlation prevails, but a real dynamics is practically absent.

The previous geometrical representation can offer an intuitive picture of the occurrence of another interesting fact, which has far reaching consequences. Since we can have trajectory segments that are orthogonal to certain subspaces of phase space, they project themselves onto these subspaces as points, and we do not consider these projections as representing a process. When the system traverses these trajectory segments, we do not observe occurrences of processes that we defined as lines into the orthogonal subspaces. We thus can explain through the shape of the trajectories in phase space, why a system acquires or loses a behavior that we defined by using the projection of trajectory segments, and we can predict how long these changes last. We emphasize that effects of this type do not necessarily require changes in the architecture of the biological system, because the shape of a trajectory segment depends on the interactions among the parts of the enlarged system.

This picture can be used to describe the dynamics of other classes of facts. We consider the projection of a trajectory segment onto a subspace $S_1$ of phase space; the next trajectory segment will be orthogonal to $S_1$, and we consider its projection onto a subspace $S_2$ of phase space. Finally, the next trajectory segment will be orthogonal to $S_2$, and we consider its projection onto a subspace $S_3$ of phase space. This situation can depict the scheme of our thinking of two things in a certain mutual relation: for instance, a cause-effect, or a part-all relation. We may use the projection onto $S_1$ to define one of the thing that are in mutual relation, and a part of the constitutive activity of the mental category that characterize the relation. We may use the projection onto $S_3$ in an analogous way with respect to the second thing that is related to the first one. We may use the projection onto $S_2$ to define the remaining part of the constitutive activity of the mental category that characterize the relation. Clearly, we might have more complex schemes of subspaces and timing pattern, but we prefer to point out the essential role that the definition of mental facts acquires in these schemes.

We will mention only another related scheme. Subjects can speak of a relation between things that occurred in different time during their life, and that may be separated by a temporal gap. We can apply the previous picture to the moment in which subjects speak of the two things in mutual relation; but things may have the characteristics of conscious memories that we described above, although different, and more complex schemes are possible. In the previous scheme, for instance, the projection onto $S_1$ may be abandoned for a certain interval of time; then resumed, and the scheme can continue as described above. We will come back on these points when we will discuss constraints in the description of psychology.

When we consider a single trajectory, different points map into different instant of time that refer to the life of a same system, and we can use the shape of the trajectory in the neighborhood of different points to explain a different correlation between the trajectory projections. In this picture, we can explain learning as the effect of an activity – the training – whose occurrence brings the system on a point of its trajectory from which the correlation between certain projections of successive segments of trajectory assumes a higher value. These projections are the physical processes that we used to define the things that learning involves. We emphasize that learning belongs to psychological descriptions in which it is often introduced as a faculty: that is, we do not explain it. Thus, in explaining learning, we must start from the physical description of the system dynamics, and we must use experiments to obtain an acceptable description. In physical description, we only need changes in the physical architecture of the system. In this dynamics we must describe the changes that training induces on the physical architecture, and the effects that these architectural changes induce on the successive physical activity of the system. Finally, we have to choose our definitions of the things that learning involves so that we obtain the observed correlation between their occurrence before and after training. We emphasize that these conclusions hold for every thing that we defined by using a physical process that is geometrically represented by projections, onto suitable subspaces of phase space, of trajectory segments. In training we deal again with physical processes that are represented by projections of trajectory segments. Since many trajectory segments can share a projection, we need further information on the state of the extended physical system to know the trajectory segment that is occurring. Today, we rarely have sufficient information to single out the occurrence of only one trajectory segment. Therefore, we do not succeed in predicting deterministically the effects of training, and its effectiveness as well. The effects depend on the trajectory segment that occurs, and we found a further explanation of a well known character of learning. It is strongly dependent on the particular individual, and on his conditions as well. Furthermore, teaching acquires the same characteristics.

Another consequence of our decision of defining psychological facts in this way is the double mental attitude that we can assume when they occur. We can consider the occurrence of the physical process that we used to define the thing, either as the occurrence of the defined thing, or as embedded in the full process that realizes its particular occurrence. In the first case we stress the repeatability of the thing. In the second case we instead stress the determinism and the singular aspects of the particular occurrence, but we must go back to the physical description. We often apply the two viewpoints to the same situation in successive moments, and many interesting consequences arise from the second one[95].

We will not discuss the very extensive use of this double possibility in many fields, because this discussion would lead us out of the scope of this paper. We only mention that in linguistic behavior we can focus ourselves on the relation between designating and designated thing as it is defined in linguistics for the particular language, or we can focus ourselves on what we consider that our interlocutor wished to communicate. In the second case, we consider the previous relation between designating and designated thing as being the way of communicating, and we usually have to enlarge the context for obtaining a satisfactory linguistic communication. We typically need to know which previous mental activity led a person to speak or write a certain sentence, when we focus ourselves on what we consider that our interlocutor wished to communicate, and we usually must infer this knowledge from the previous and the next physical activity of our interlocutor; but we need this knowledge also when the sentence is, sometimes intentionally, elliptical or ambiguous. We can alternate the two viewpoints in successive moments; but we cannot freely mix the deductions that we obtained from them, and this fact is immediately evident in literary criticism.

We often define things that are geometrically represented by projections of trajectory segments, in physical descriptions as well. This situation comes, for instance, when we deal with a physical process that is defined to occur in the biological system, instead of in the enlarged system that supports a deterministic explanation of the occurrence of physical processes. Many conclusions of the previous discussion apply to these situations, because they are methodological consequences of the way of defining something. We mention that we will typically observe many ways of realizing a physical process that we defined in this way, when we deal with the enlarged system. These ways correspond to all the physical processes that have that process as subprocess. Since a further physical activity accompanies each realization, and it can be different in different instances, we must expect that different conditions can lead to the occurrence of a process defined in this way, and that different consequences can follow its occurrence. Experiments only can decide in which extension and details the consequences that we discussed above apply to the different cases, because we are dealing with physical processes. However, we meet here a critical point, since the previous conclusions can apply to many processes in a cell, for instance, to RNA transcription in eucaryotes.

This discussion shows the central role that the dynamics of a physical system with the characters of the reference physical system has in developing the dynamics of the system's behavior. We emphasize that this physical system is still characterized by the interactions of the biological system with its environment. If we would apply the previous conclusion only to the biological system, we will obtain a very misleading picture of its behavior. Consequently, we must be aware that experimental results conceptually refer to different physical systems when we dropped one or more interactions with the environment, through blocking or deprivation techniques. The integration of their results into an overall dynamics is thus critical.

### Constraints in psychological description

As we have seen, when we refer to a picture of the system's dynamics as trajectories that do not intersect in phase space, the equations that describe the trajectories also describe the connection between the states of the system, and they describe the constraints on flow of the physical activity as well. When we take the viewpoint of psychology, we need analogous constraints on flow of mental activity, and, more generally, on flow of psychological activity. We can give an intuitive outline of the situation by referring to a picture of the system's dynamics that we mentioned above. When constrained activity is so defined that it can occur again in the life of the same subject and it can occur identically in subjects with different characteristics, it has properties that mirror those of projections, onto subspaces of phase space, of trajectory segments. In

[95] Humanities typically use a mixing of the two viewpoints, and the second one prevails in criticism.

discussing constraints we thus meet again the alternative between repeatability and determinism that we discussed above. If we assume a deterministic approach, we must go back to physical description, and constraints become those of the trajectory segment that generates the projections. If we decide to stay in psychological description, because we will see culture as source of constraints, then we must describe constraints on psychological facts as constraints on an activity that mirrors the properties of projections of trajectory segments, and these constraints have conceptually different characters than those of physical description.

If in physical description, we conceptually refer to a dynamics that can be represented by trajectories that do not intersect in phase space; then we can predict deterministically the evolution of the system when we know a state of the system, because a point completely individuates a trajectory[96]. This property of the trajectories does not hold for their projections onto subspaces of phase space. So, even if we know the equations that describe the line onto which some trajectories project themselves, we cannot infer deterministically the occurrence of a projection segment from the occurrence of a previous segment of the same projection. This conclusion becomes immediately intuitive when we remember that many trajectory segments can share the same projection. A trajectory segment thus can share a segment of a projection with another trajectory segment, and do not share the successive segment of the projection. Therefore, only a part of a projection can occur, depending of the trajectory segment that is occurring, and the system can abandon the constrained activity. In psychological description constraints are thus weaker than in physical description, because they only predict a probability that the constrained activity will occur. In particular, we cannot infer the occurrence of a mental fact from the occurrence of a part of its constitutive activity. In psychological theories we thus may interpret constrained activity only as a paradigm.

Projections, as we have seen, can assume many configurations, and constraints as well. Let a mental fact be defined through a physical process that is represented by a segment *MN* of line in a subspace *S* of phase space. The mental fact occurs when a trajectory segment occurs in phase space, that has *MN* as projection onto the subspace *S*. We recall that we can distinguish two cases. No part of the trajectory segment is orthogonal to the subspace *S*. Some parts of the trajectory segment are orthogonal to the subspace *S*. In the first case the inverse function of *MN* into time is continuous, like the analogous inverse function of every trajectory segment in phase space. In the second case this function is not continuous, and we can describe the mental fact that is defined through *MN* as composed by at least two spans of mental activity that are not temporally contiguous. Since the previous case is only a simple example of a large class of situations that can be more complex, in discussing constraints, we will distinguish constraints that describe a span of activity that flows without interruptions, and constraints that describe an activity that flows with a certain number of interruptions.

This dichotomy is essentially a scheme of discussion, because the occurrence of a constrained activity can easily show a mixing of the two types of constraints. For the first type of constraints we can think at procedural memory items whose execution is defined to flow without interruptions. However, the action of procedural memory is often accompanied by an activity that we can describe as having the function of monitoring the state of the system. Typically, it stops the driving function of the procedural memory item when the state of the system does not match certain conditions: usually, when the parameters that characterize the state of the system are outside certain ranges[97]. Walking is a good example of this situation, and it is often presented as an example of hierarchical scheme of motor control in neurophysiology[98]. In this framework, walking

---

96. These assertions are equivalent to the previous assertion that trajectories do not intersect in phase space.

is described as an activity in which the details of the muscles control do not require a conscious intervention of the subject, who, for instance, can freely think during walking; and we can describe this muscles control as iteration of a procedural memory item. However, when an obstacle, or another cause, unbalances the body more than a certain amount, we usually have a shift to an activity that corrects the posture, and that often has the character of a conscious activity.

In discussing constraints, we must remember that a suitable psychological theory of human behavior has to satisfy the common assumption that considers this behavior as being anomalous when we observe a flow of small and disconnected pieces of mental activity: that is, when the behavior has a severe lack of stability and of coherence. We also consider an excessively stereotypical behavior as being equally anomalous, and we impute it to a poor mental activity of the subjects, or to an excessive polarization of their mental activity. Therefore, a satisfactory description of systems to which we attribute a sophisticated intelligent behavior, like human beings, must be equally far from these two extremes. If we assume that the course of mental activity has suitable constraints, then we may avoid psychological theories in which the behavior is too fragmented and disconnected. If the scheme of constraints is sufficiently rich and flexible, then we can avoid theories in which the behavior would be too stereotyped.

Training is the main source of constraints, and we previously show its interpretation in the physical description. When we think of procedural memory items whose activity is defined as flowing without interruptions, the classical Pavlovian conditioning is a way of realizing this training without necessarily introducing a mental activity, because it is usually described as follows. An indifferent cue, for instance a flashing light, when properly paired with an unconditioned stimulus (US), for instance a shock, can be trained to elicit some of the consequences of the US as a conditioned response (CR), for instance various indices of fear, and so the original indifferent cue becomes a conditioned stimulus (CS)[99]. Other training methods involve mental activity, and they are usually described as the repetition of a voluntary activity until the subject becomes able to do this activity without driving it consciously. We will point out some differences between these two types of training.

In Pavlovian conditioning we have a new stimulus that elicits the same response of the unconditioned stimulus. So, we only have a new correlation among facts. Mathematically, the mapping of the CRs into the CSs is not a single value mapping, and this means that we cannot infer unambiguously the stimulus from the response. This fact prevents us from using, as a general strategy, stimulus-response relations of this kind to define a mental thing. We cannot, for instance, define a mental thing as being the stimulus of a physical thing that we consider as being a response.

97. We can think of such a kind of procedural memory items either as a single process of suitable complexity, or as two or more concurrent processes. As mentioned above, we can freely choose one or the other scheme, however in biological systems we have some problems. The scheme of concurrent processes is really useful when no interaction affects the parallel processes between two subsequent synchronization points. When, like in mammals, we have endocrine and immunological systems that are highly pervasive, we must carefully check that a decomposition in concurrent processes satisfies the requirement indicated above.

98. See, for instance the part devoted to the control of movement in E.R. Kandel, J.H. Schwartz, and T.M. Jessel, *Principles of Neural Science*, 3rd edition, Elsevier, 1991, pp. 533 ff.

99. The conditioned stimulus theory has to explain the situation described in the text, to which we refer here as Experiment 1, and these further experimental results. Experiment 2 points out that if two equally salient cues, for instance a flashing light (CS1) and a tone (CS2), appear simultaneously during conditioning trials before the shock (US) occurs, then each of the cues can separately elicit a fearful reaction (CR) on recall trials. Experiment 3 is constructed by doing Experiment 1 before Experiment 2. When the tone (CS2) is presented on recall trials, it does not elicit a fear reaction (CR). Experiment 4 is like Experiment 3, but the US is varied in the compound trials. For example, the US1 which follows the light (CS1) is a prescribed shock level, and the US2 which follows the compound light and tone (CS1+CS2) is a sufficiently different shock level. If US1<US2, then the tone elicits a fear reaction, whereas if US1>US2, the tone elicits a relief reaction. See, for instance, S. Grossberg, "How Does a Brain Build a Cognitive Code", *Psych. Rev.*, 87 (1980), pp. 1-51, with the related bibliography.

We instead think that voluntary actions (for instance, voluntary movements) usually have a goal, and so we usually explain their occurrence by a final cause. However, a final cause is not useful to test predictions about the occurrence of something, and an efficient cause is required to plan a scientific experiment. In a psychological description, the efficient cause of a voluntary action is usually the subject who is doing it, or a faculty, like will-power. In a physical description this solution cannot be accepted, because, by definition, the change must be induced by a physical thing different from the thing that is changing. So, we meet again a break of a possible isomorphism between the physical and the psychological approach to the dynamics of our systems.

Moreover, learning seems complex also when training follows the scheme of Pavlovian conditioning. According to the general discussion, we must describe training as repeating the projection of a trajectory segment, that takes the system in a volume of phase space where the correlation is high between the conditioned stimulus (CS) and the conditioned response (CR). However, we must explain why learning strengthens the correlation between the conditioned stimulus and the conditioned response, although in training procedure we have the occurrence of an unconditioned stimulus (US) between the CS and the CR. The changes in the state of the physical system are produced by iterated occurrences of processes that have as projection the physical counterpart of CS+US. We thus need a very articulated knowledge of the system's dynamics in this rather simple case as well. We must know which architectural changes are induced by the physical counterpart of CS+US, and we must know how the modified system changes its activity, because the physical counterpart of the CS occurs in different dynamic contexts[100]. Today, we do not have this knowledge. Furthermore, we cannot assert that we have the iteration of the same trajectory segment during training, and this observation can explain why it is difficult to obtain the same quantitative results in conditioning experiments.

We have an analogous situation when learning follows from the repetition of a voluntary activity until the subject becomes able to do this activity without driving it consciously. Since we define a voluntary activity by using only a part of the physical processes that are necessary in the reference physical theory[101], only a part of the physical processes that occur in the enlarged system must be equal at every repetition. When we repeat a voluntary activity, we have further physical processes, and they are usually different at each repetition. The changes in the architecture of the system thus can be different at each repetition, and nonlinearities usually emphasize this fact. However, the difficulties increase when learning follows from the repetition of a voluntary activity until the subject becomes able to do this activity without driving it consciously. Moreover, let the voluntary activity be defined by a process $v$ that is represented by a path into a subspace $A$ of phase space. We cannot use the process $v$ for defining the procedural memory item, because voluntary activity has a more complex physical counterpart. Let the activity, that we think to promote the voluntary activity, be defined by a process $c$ that is represented by a projection as well. The training succeeds when it carries the system in a volume of phase space in which a trajectory segment that has $c$ as projection is followed with high probability by a segment of the same trajectory whose projection onto a subspace $B$ represents the physical process that we used to define the procedural memory item. Hence, we need again a very articulated knowledge of the dynamics of the physical system to correlate repetition of voluntary activities with the learning of a procedural memory item.

We may observe difficulties in learning even though a subject correctly repeats the same voluntary activity, and the previous discussion may explain why the history by which we reach the

100. These two types of knowledge usually require different sets of experiments for repeatability reasons, and then the integration of the results.

101. For the discussion of this point see *The characteristics of our reference physical description* at page 6.

skill may become significant, when we learn to execute very fluently a series of complex movements, such as in athletics or in playing a musical instrument[102]. Let the first part of the planned movement have as a counterpart some physical processes, and let these physical processes, in the conditions of the movement's occurrence, belong to a trajectory segment whose continuation does not contain the processes that are the counterpart of the continuation of the planned movement. Clearly the planned movement cannot occur in these conditions, and we can only try to change the conditions under which to execute the movement, or to plan differently the details of the movement. We can expect analogous situations in medical rehabilitation, particularly when it significantly involves the plasticity of the nervous system.

The geometrical picture that we are using in this discussion is also useful to show a character of the dynamics of this type of constraints. As we have seen, the constrained activity will flow without interruptions. This assumption implies that in defining this type of activity we will use a physical process that satisfies two conditions. It must mirror the properties of the projection of a single segment of the trajectories that describe the system dynamics in phase space[103]. The inverse map of the projection into the trajectory segment that projects onto it must be continuous: that is, no subsegment of the trajectory segment is orthogonal to the subspace onto which we project the trajectory segment. These requirements limit the possibility of obtaining a new item of this type by joining items of the same type. Since the growth of this type of constraints cannot be reduced to a sequential composition of previous items, we meet a further source of nonlinearities in the theory.

When we go to the second type of constraints (constraints that describe an activity that can flow with a certain number of interruptions) we meet weaker limitations in combining items of constrained activity to obtain a new constraint. The occurrence of two previous items can be separated by the occurrence of trajectory segments that are orthogonal to the subspaces of the projections that were used to define the two items. However, we cannot use the temporal contiguity of two items for describing their link in the new span of constrained activity, and we often introduce a relation between the two items. In the geometrical representation that we are using, the relation can be defined through a projection of a trajectory segment onto subspaces orthogonal to the previous ones. Nevertheless, this scheme is a very simple one, and we can think of more complex situations. The use of a relation, as we will see below, offers a further way of introducing new constraints, and new items of so constrained activity typically arise with strong relations with the previous ones. Therefore, we can describe constrained activities as a system that grows during the life of an individual, and along the history of a group. In psychological descriptions, we usually identify this system with a conspicuous part of the experience and culture of the subjects.

Conditions under which a mental activity is performed are one source of this second type of constraints. For instance, the conditions of light, distance, etc., under which a perceptive result has to be attained for having a recognition of the objects, that we consider to be satisfactory. Subjects often signal the failure of these conditions by saying that the object appears with a certain shape or color, instead of saying that the object has certain shape or color. The constraints on mental categorization are another typical example, and this fact is particularly evident in a scientific context.

The systematic introduction of strict constraints is here a consequence of the repeatability requirement, and so we usually bind the use of the mental categories to the occurrence of specific technical procedures that involve physical things. For instance, we must use the techniques of

---

102. In music we have a long history of “methods” to learn playing an instrument, or to gain a particular skill in playing it.

103. Recall that we decided not to use the scheme of concurrent processes when we represent the dynamics of a physical system by means of trajectories in phase space.

geodesy and topography to assert that we measured again the distance between the same two points and their difference in height. 'Same' and 'other' are mental categories, and their occurrence uniquely requires that someone carries out the constitutive mental activity. However, we decide to use 'same' in this context only when certain technical procedures are well suited, otherwise we consider the categorization to be incorrect: that is, we recognize the category, and we consider as being incorrect its use in that context. We do not always succeed in finding suitable technical procedures to which a categorization can be bound. An example is the assertion that a certain volume contains the same physical particles that it had at a past instant of time, because we do not succeed in identify the single particle in quantum mechanics. We then change the thing that we categorize as being the same. In this case, we develop theories where the datum is only the number of particles of a certain type that occupy a given volume at a certain instant of time. Then, it is matter of mathematical technology to use directly the datum, or to introduce equivalent mathematical transformations[104].

A compliant use of mental categories in scientific theories and in the description of scientific experiments, allows us to infer the occurrence of mental categorization in the particular context, although this method is not suitable to define mental categories. Indeed, the inference refers to mental categorization: that is, it refers to a mental category applied to particular things, and it depends on all the things that constitute the current situation. Since we infer that a mental categorization occurred from the occurrence of the technical procedures on which we constrained the categorization, we understand why it is important to find suitable technical procedures on which a categorization is constrained. Moreover, we always assume that the related technical procedures were correctly applied when we use the categories in a scientific context, and we expect the consequences that follow from their correct application. For these reasons, when we mention a category in a scientific context, we also refer to the procedure that constrains its use in the current context. Low awareness of this fact often caused bad philosophical statements. We can suggest a way of defining mental categorization by referring again to the geometrical representation of a system dynamics as trajectories that do not intersect in phase space. Let $A$ be a subspace of phase space, and let $s$ be a projection of the trajectory segments. We can use $s$ to define a mental categorization when the projections of $s$ onto suitable subspaces of $A$ coincide with the projections that we used for defining respectively the mental category and the thing categorized. In this scheme we usually have constraints on the timing of these projections, that we omit for simplicity sake. Clearly, a prerequisite is that $A$ contains these subspaces. There is a large literature on mental categories and mental categorization in the Italian Operative School, and the reader can refer to the site that we mentioned in footnote at the beginning of the paper. We emphasize that, since we start from a projection $s$, many segments can share this projection, and they can belong to the same trajectory as well. We thus define mental categorization in such a way that it can occur again in the life of the same subject, and that it can occur identically in different subjects; but we have also the general consequences that we discussed above, when we plan to predict the occurrence of a mental categorization.

We often constrain mental categorization to characteristics of the things that we categorize, and we often describe these characteristics by quantities that vary continuously. In these situations we usually constrain the mental categorization to certain threshold values of these quantities. We can consider the categorization as being a qualitative difference; and in this case the

[104] A common strategy has two steps. We firstly write the mathematical relations that should hold among physical particles that can be distinguished. In a second step we impose the conditions that must be satisfied by the mathematical description when we exchange two or more particles. In such a kind of situation it would be a good policy to avoid the use of terms such as 'exchange force' or 'exchange interaction', which may be misleading.

things that we categorized support two different points of view, but only after categorization. We can consider them as things that were either categorized in a certain way or not, and so we have a qualitative difference. We can consider them only as having the characters to which we constrained the categorization, and from this point of view we have a continuous change in these characters. We thus have or do not have a qualitative difference depending on the viewpoint that we adopted, and we cannot expect that the things have this qualitative difference before the mental categorization. Let us, for instance, describe a characteristic of a physical body by its temperature. Due to the way in which we define and measure the temperature, we usually think of it as varying continuously. Let us now categorize this body as being cold. After categorization, we can think of the physical body as having the further qualitative character of being cold. Before we categorized it in this way, it was neither cold, nor hot. Moreover, we can say that it had a certain temperature only if we consider temperature as being a character that belongs to the definition of physical body: for instance, when we think of temperature as the average kinetic energy of the atoms or molecules, like in statistical mechanics of gases.

The characterization of a behavior as being intelligent shows another example of such a situation. We will use a simple physical behavior to clarify the kind of problems that we meet when we decide the requirements that must hold to consider a behavior or a system as being intelligent. We will take the example from elementary Newtonian mechanics, where the theory is well assessed. In elementary Newtonian mechanics, a direction and a scalar completely describe the actions on the physical system whose behavior we are studying; furthermore, a scalar *m*, the mass, completely characterizes the system. The well known relation:

$$F = \frac{d}{dt}(mv)$$

The relation links the action *F* to the change of the momentum *mv*, and describes the behavior of the system, when we assume the mass not to be a constant, but we assume that it is a scalar function of the time. We obtain by the derivative:

$$F = m\frac{d}{dt}v + v\frac{dm}{dt}$$

that is:

$$\frac{dv}{dt} = \frac{F}{m} - v\frac{\dot{m}}{m}$$

We can solve the problem when we know the history of the force and of the mass rate of change. In this condition we can compute the mass as a functional of the history:

$$m(s) = \int_0^s \dot{m}(t)dt$$

then we can calculate *v* by solving the differential equation written above. We are not interested here in the techniques to solve this equation, and in the properties of the solution. Our interest is instead on the different possibilities of producing changes of the system's behavior.

We can interpret the force *F* as describing the action of the environment on the system, and the acceleration as the response of the system to the environment action. The system response is a linear function of the environment action, when the mass *m* is constant. When the mass can vary, the system response instead depends on the force *F*, on two functionals of the history, *m* and *v*, and on the mass rate of change. Therefore, in this second case we have two ways of producing changes in the system's behavior: force action, and mass change. If we ascribe the change of mass to an environment action, then we have a system whose behavior only depends on the environment actions. We can describe the mass change as a function of a further external action *Q*, and we obtain a system whose behavior only depends on environment actions. Alternatively, we can ascribe the action of a force to the actions of the external environment, and we can think of mass changes as depending on certain characteristics of the system. In this way, we have a system that can change its behavior both by external, and by internal actions. However, this character is only a prerequisite to consider the system as having an intelligent behavior. Usually we require at least an adaptive behavior; and this in itself may not be enough, since we have many machines whose activity and performances are controlled by suitable parts of the machine itself.

We may consider our system with variable mass as being intelligent, when we think that its mass changes can be intentional: that is, when we think that the system can carry out mental activities, and thus it can mentally anticipate its behavior. In these conditions the adaptive behavior becomes a consequence, and we expect different instances of such a kind of behavior. We should find many ways of varying a feature, when, as in our example, the system can vary only one of its features. If we only find one way, then we might refuse to consider the system as being intelligent, or we could accept the categorization, and we would add an explanation of this atypical behavior. However, we are not forced to use this anthropomorphic definition of intelligence. Less constraining definitions might arise and be accepted, like in defining flight, where the definition was extended to include the flight of planes and helicopters. We conclude that we have a certain degree of freedom in the choice of the requirements to categorize a system as being intelligent, and we expect significant differences when we compare different historical moments.

Biology well supports these conclusions and it further stresses the character of the mental categorization that is involved in the characterization of intelligent systems and behavior. One example is the remarkable versatility in energy metabolism that is exhibited by purple photosynthetic bacteria. Many of these organisms can obtain cellular energy from light, from inorganic compounds, and even from organic compounds. The modes of producing cellular energy depend on the chemical and physical conditions of the environment, and they are so regulated to prevent unnecessary biosyntheses, like photosynthesis, which consumes large quantities of energy[105]. As second example we will remind the behavior of the ciliate protozoan *Didinium*[106]. It has a globular body, about 150 microns in diameter, encircled by two fringes of cilia; its front end is flattened except for a single protusion rather similar to a snout. The synchronous beating of the cilia allows the *Didinium* to swim in the water at high speed. When it encounters a suitable prey, that usually is another type of protozoan, it releases several small paralyzing darts from its snout region; then it attaches to and devours the prey by contracting its plasma membrane to engulf the other cell. The prey has often the same dimensions of the *Didinium* cell. We can explain most of this complex behavior by physical processes that take place in the cytoskeletral structures lying just beneath the plasma membrane. We intentionally choose two biological examples that involve single cell organisms, because they clearly show that in biology no nervous system, or neural network, is necessary to have an adaptive behavior that might be considered as being an intelligent behavior.

---

105. The example of the *Rhodobacter capsulatus*, whose adaptive behavior was reviewed in C.E. Bauer and T.H. Bird, "Regulatory circuits controlling photosynthesis gene expression", *Cell*, 1996, 85, pp.5-8, shows many aspects of the physical explanation of this adaptive behavior, with particular emphasis on the system that regulates the expression of photosystem genes in response to alterations of the environment. The different environmental conditions induce the activation of different transmembrane proteins, and through different chains of chemical reactions they induce a different rate of synthesis of the proteins that are involved in the three modes of producing cellular energy. We will outline that a change in proportions of the same elements gives here a physical explanation of the adaptive behavior.

106. See B. Alberts, D. Bray, J. Lewis, M. Raff, K. Roberts and J.D. Watson, *Molecular biology of the Cell*, *cit*., pp. 24-25.

The examples confirm that categorization introduces a distinction among things, in our case between intelligent and not intelligent things, and that the distinction depends on the categorization and its constraints (that is, on our cultural schemes) because we can easily find a continuity when we look at the conditions on which the categorization is constrained. Cerebral death offers another example of such situation, and in this case we link deep practical consequences to the mental categorization.

The consequences that we expect from the occurrence of certain facts are a further great source of constraints. We have constraints of this type when we assume that certain objects have a well defined role in certain processes, or that some facts shall follow from the occurrence of other facts. Since we do not necessarily require that the facts will be temporally contiguous, we have constraints of the second type. Few examples may better clarify the type of facts that we are referring to. We assume as paradigm that fire has the role of subject in an activity, burning, which transforms wood into ash. When the occurrence of the transformation and of the result is thought to be independent of our mental activity like in our case, we must check by observations and experiments whether the occurrence of the facts follows our assumptions. If our assumptions are not fulfilled, we often will explain the reasons, and in this case we use our assumptions as paradigm.

We have a further example when we assume that a subject acts to accomplish a certain result. Since we consider a subject's activity as being a purposeful activity, we are constrained to consider the activity as a mean to attain the proposed aim. When different activities bring to the same proposed result, other constraints induce us to consider these activities as being equivalent, from the viewpoint of attaining the proposed aim, although they can be thought of as being different from other points of view. Since this result follows from mental categorization, we always can concern ourselves with the differences between the activities that achieve the same aim. For instance, we can consider them as being a better or worst way of attaining the proposed aim, or we can explain why the subjects use different means to achieve the same aim. Note that low awareness of this character of mental categorization may lead to a rather naive philosophical realism. The previous example shows a frequent effect of mental categorization: it constrains a next, different mental categorization. When we discussed conscious memories, we met an example of this type of constraints. Since the subjects categorize a mental activity as a repetition of one that occurred to them in the past, they consequently consider the two activities as being equal. If a subsequent check shows differences, the subjects usually explain them, and in this case they use as a paradigm what we previously described as constraint.

Voluntary movements offer another significant example of these constraints. Let us consider, in a voluntary movement, the person or the animal that moves as being the subject of the movement. We will contradict ourselves when, at the same time, we would consider the movement as being made by something else. In fact, we would not consider as being voluntary a movement that we consider as being induced, for instance, by electrically stimulating suitable parts of the nervous system. Our cultural scheme considers that a person or an animal can be induced to do an activity in many ways, and we correlate the degree of freedom that we assign to the acting subject, with the strength of the constraints that we think to act on the subject. However, this more sophisticated scheme follows from a further assumption: we consider the subject of psychology, also as the physical system of biology.

Mental categorization critically relates to constraints on psychological activity also for another reason. When subjects mentally categorize something as “same”, or “equal”, or when they consider a mental fact as being a conscious memory, they are constrained to think that they repeated the activity that we consider as being the constitutive mental activity of the categorized thing. These constraints may not match with the constraints on thinking that they repeated the physical

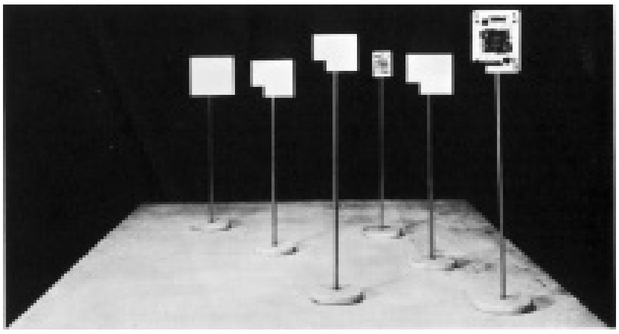

*Figure 5*

activity by which we defined the constitutive mental activity of the categorized thing. So, we can have a discrepancy between the effects of having repeated a certain activity and of considering to have repeated that activity, because the state of the physical system only depends on the physical activity that the subject has done. For instance, we may not observe the effects of the training that the subject assumes to have done; but the consequences of these discrepancies easily bring us into the field of mental diseases.

As we have seen, the second type of constraints is compatible with spans of constrained activity that can be described as combination of other spans of constrained activity that may be not contiguous in time. We often describe constraints of this type by using relations between the things that are part of the subjects' experience and culture, and they can show a fast evolution, at least in certain periods of the subject's life. Communication and reasoning thus become ways to set up constraints, and we can see culture as a system of constraints as well. Some elementary examples will highlight the kinds of situations, which we are referring to.

Let us have a color difference that we localize in our surrounding space, and that we think of as individuating a physical object. Adult persons usually think that there is also a tactile difference in the same place, and they expect to find it. For instance, we think of our hand reaching the place, and the change in tactile perception[107]. Conversely, we do not expect to find a tactile difference where we do not perceive visual differences. In fact, it is mandatory to mark clearly the presence of a glass door that is made of a single, transparent sheet, otherwise someone will walk into it. In this case, we can indicate the directions along which the paradigm grows. Very early in our life we get accustomed to adding a spatial localization to the color differences that we perceive in our visual field, and to think that we shall also find a tactile difference in the same place. This pattern of activities is learned as part of the coordination of the visual, motor, and tactile activity that we need to hold an object. Nevertheless, this simple paradigm becomes conditioned by other elements when our experience grows. For instance we do not add a tactile difference when the color differences involve something that we thought of as a plane figure, like a book illustration; and so on.

We can find another elementary example in a classical experiment on psychology of visual perception. In mono-ocular vision, and by suitably masking the context, the subjects report seeing experimental situations, like that in Figure 5, as being like that of the photograph in Figure 6[108]. So, they interpret the mutual positions of the objects as being in an order that is different from the order illustrated in Figure 5. We can explain this result by assuming that subjects think

[107] We can obtain illusive effects by synchronizing visual, hearing, tactile, and smell stimuli according to the patterns that a person expects, although they arise from different physical situations than the usual ones. This is the leading idea of virtual reality; where the term 'virtual' highlights that the sources of the stimuli are different from those we assumed as a paradigm for these stimulations.

that all the squares and the cards are complete: that is, without the cuts that we see in Figure 5. Furthermore, we can explain that the subjects do not think of the situation as that illustrated in Figure 5, although it might be possible, because it is quite improbable on the basis of their experience. After thinking of the objects in the mutual positions illustrated in Figure 6, the subjects see them as having a size that depends on these mutual positions, and on the visual angle from which they see each object. This angle, indeed, settles a relation between the size and the distance of the object, and this relation describes a constraint on mental activity that results from learning[109]. In the conditions of the experiment, it plays the same role.

A television screen is a two-dimensional surface, but we usually see the rooms and the objects that are presented on it as being three-dimensional. The camera lens gives a result that is usually very near to a representation of the room and the objects on a plane perpendicular to the optical axis of the lens, and that follows the rules of linear perspective. Since the Italian Renaissance, we learned to see things that are represented in linear perspective as being three-dimensional; and the great diffusion, in our time, of images that are produced in this way by optical systems confirms this habit.

Furthermore, in watching television we also became accustomed to identify the position of the camera with our observation point, and the axis of the lens with the principal axis of the vision field. These assumptions, and the movements of the camera when filming, reinforce the tendency to think of the things represented as being three-dimensional. Note that we experience effects that are similar to stereokinetic ones. The television screen, the photograph of Figure 6, and other similar situations are good examples of a common situation: an acquired habit leads us to do a mental activity with a higher probability than other possible ones, because, for instance, we usually see a perspective as a two-dimensional pattern when we are drawing it.

In the case of a television screen we have an immediate example of the increasing sophistication of the constraints' scheme. We agree to add a tactile difference where we located a visual difference, but constraints are now different. We have constraints that involve the objects repre-

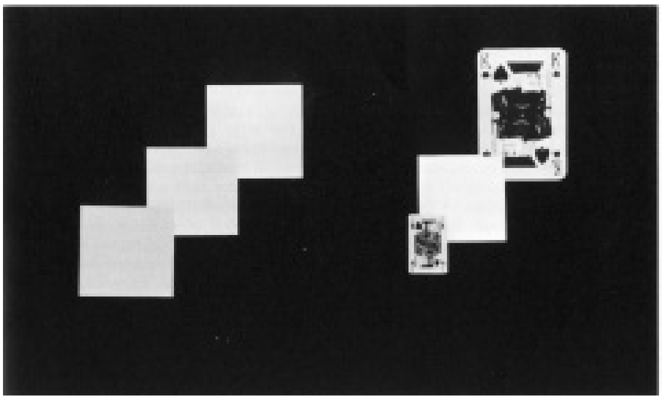

*Figure 6*

[108] For experiments of this type see: J.J. Gibson, *Perception of the visual world*, Boston, Hampton, 1950; W.H. Ittelson, "Size as a cue to distance: static localization", *American Journal of Psychology*, 64, 1951, pp. 54-67; W.H. Ittelson, "The constancies in perceptual theory", *Psych. Rev.*, 58, 1951, pp. 285-294; A. Dinnerstein, W. Epstein, "The influence of assumed size on apparent distance", *American Journal of Psychology*, 76, 1963, pp. 257-265; L. Ancona, *The dynamics of the perception*, Mondadori, Milano, 1970, pp. 53-70 (in Italian), from which the figures were taken; J.E. Hochberg, *Perception*, 2nd Ed., New York, Prentice-Hall, 1978.

[109] A good review of experimental results can be found in A. Yonas, C.E. Granrud, "The development of sensitivity to kinetic, binocular and pictorial depth information in human infants", in D. Ingle, D. Lee, M. Jeannerod (Eds.), *Brain Mechanisms and Spatial Vision*, Amsterdam, Martinus Nijhoff Press, 1984.

sented on the screen, and constraints that refer to objects of the environment of our body, like the television set. So, when two represented objects collide, we expect to see the usual consequences of a collision between two physical objects. However, we do not move from our chair when a car is represented on the screen as coming up to us. Such behavior requires a good level of cultural sophistication. The world of our experiences and of our knowledge must be applied to the situations that are represented on the screen; but, at the same time, we must expect that the represented actions have very different consequences on us than on the represented objects.

In other cases we observe a new, subtle use of existing constraints. Brunelleschi in his first experiment, which marks the beginning of modern perspective, used the acquired habits of his contemporaries to obtain that the observer gives a three-dimensional organization to the plane perspective of his drawing. He used the reflection on a flat mirror, and a very usual sight: the Baptistery as it is seen when a person comes out from the central door of the Florence cathedral[110]. These choices eliminate the ambiguity that is implicit in passing from the perspective painting to the place and the size of the objects that are represented in it. Since all the previous choices of Brunelleschi usually are not possible in painters' perspectives, suitable conventions about the characteristics of the represented things substituted them. The terrain is thought to be plain and horizontal, and it is usually an artifact: for instance, a rectangular place paved with square tiles. The vertical architectural elements - columns, or pillars - are thought to have the same height, and their sequences are thought to lie parallel or orthogonal to the plain of the perspective. In buildings, arches are thought to be semicircular; and so on. In conclusion, cultural facts lead again the subjects to perceive unambiguously as three-dimensional the objects and the places that are represented in the perspective plane[111].

Yet these few examples confirm our previous assertions. The second type of constraints still results from learning, and the constraints depend on the history of both the particular individuals and their cultural environment. However, we can continue to think of learning as before in the paper. For instance, when a subject follows a reasoning that involves cause-effect relations between certain things, either by reading a paper, or by hearing another person, he does a physical activity. If this activity brings the system in a volume of phase space where a correlation

---

110. The first Brunelleschi's experiment was described in this way by his biographer: "He first demonstrates his system of perspective on a small panel about half a *braccio* square. He made a representation of the exterior of San Giovanni in Florence, encompassing as much of that temple as can be seen at a glance from the outside. In order to paint it, it seems that he stationed himself some three *braccia* inside the central port of Santa Maria del Fiore. He painted it with such care and delicacy and with such great precision in the black and white colors of the marble that no miniaturist could have done it better. In the foreground he painted that part of the piazza encompassed by the eye, that is to say, from the side facing the Miseriocordia up to the arch and corner of the sheep, and from the side with the column of the miracle of St. Zenobius up to the corner of the straw, and all that is seen in that area for some distance. And he placed burnished silver where the sky had to be represented, that is to say, where the buildings of the painting were free in the air, so that the real air and atmosphere were reflected in it, and thus clouds seen in the silver are carried along by the wind as it blows. Since in such a painting it is necessary that the painter postulate beforehand a single point from which his painting must be viewed, taking into account the length and width of the sides as well as the distance, in order that no error would be made in looking at it (since any point outside of that single point would change the shapes to the eye), he made a hole in the painted panel at that point in the temple of San Giovanni which is directly opposite the eye of anyone stationed inside the central portal of Santa Maria del Fiore. for the purpose of painting it. The hole was as tiny as a lentil bean on the painted side and it widened conically like a woman's straw hat to about the circumference of a ducat, or a bit more, on the reverse side. He required that whoever wanted to look at it place his eye on the reverse side where the hole was large, and while bringing the hole up to his eye with one hand, to hold a flat mirror with the other hand in such a way that the painting would be reflected in it. The mirror was extended by the other hand a distance that more or less approximated in small *braccia* the distance in regular *braccia* from the place he appears to have been when he painted it up to the church of San Giovanni. With the aforementioned elements of the burnished silver, the piazza, the viewpoint, etc., the spectator felt he saw the actual scene when he looked at the painting. I have had it in my hands and seen it many times in my days and can testify to it." H. Saalman, *The life of Brunelleschi by Antonio di Tuccio Manetti*, English translation of the Italian text by C. Enggass, The Pennsylvania State University Press, 1970, pp. 42-44.

111. These aspects of Renaissance perspective were discussed with more details in R. Beltrame, *The Renaissance perspective. Birth of a cognitive fact*, *cit.* (in Italian).

holds as previously described, then we say that the subject learned how in our culture we use the cause-effect relation between that things. We meet difficulties to describe the details of the physical processes. Conceptually, however, the problem maintains a remarkable simplicity in this context as well.

Since the constrained activity often describes consequences that relate to subjects' body and its interactions with the objects of the environment, these consequences have a strong impact on the subjects' actions and behavior. Furthermore, constrained activity usually concerns situations that occur with reasonable frequency, or that are critical for the subjects' survival. As we have seen, when we take the approach of psychology, constraints do not predict a sure occurrence of constrained activity, and the occurrence of the constrained activity may fail. When the subject is aware of the failure[112], he can:

- add new conditioning elements, and then use a more extended scheme of constraints: that is, the subject require a richer and more articulated pattern of conditions to expect the occurrence of a fact[113];
- cease to consider a mental activity as being predictive of another, and the modified scheme again describes the new constraint;
- decide not to pursue the mental activity that h has just carried out, and to substitute it with a mental activity from which the occurred consequences can follow; for instance, persons usually cease to consider something as being nearer to them than another thing, when further tests do not confirm the result of their perception, and they often exchange the categorization of the two things.

We note that in the first two cases the subjects assume as paradigm the relation between what we previously described as constraint and constrained activity; and, when they modify in this way their system of constraints, they consider themselves as dealing with relations among things, rather than with constraints on their psychic activity. This approach is rather common, and it supports our previous discussion of constraints in terms of mental facts. We can think of constraints on mental activity, instead of on mental facts; but this option requires a deep knowledge of the dynamics of the physical activity. Therefore, we followed the previous approach because it mirrors the cultural schemes of which subjects often have a high level of awareness. Subjects very often use this approach - that is, physical or psychic things and their mutual relations - in deductive reasoning to predict facts of practical relevance. For instance, they predict consequences of their body's interaction with other physical things. For this reason, they use relations that occur frequently, and they change their choices an only when very strong reasons force them. Furthermore, since from a contradiction we can deduce both a proposition and the opposite one, the presence of contradictions in this scheme of things mutually related would destroy the practical relevance of the deductions. Subjects thus require that this scheme will be free of contradictions.

This aspect of the scheme allows us to avoid ontological dualism between physical and mental things, that we might otherwise inherit from the history of philosophy, and that will destroy any program of integration between physical and psychological descriptions of human activity. We can show the main aspect that the ontological dualism should explain by using the following simple example. We accept that fire occurs as a cognitive fact only if we have the related cognitive activ-

---

112. Constraints are introduced in the description by theorists. We cannot thus identify them with a mental activity of the observed subject, otherwise we will have a *regressum ad infinitum*.

113. The increased number of conditions which an individual requires to be fulfilled in order to expect a fact can explain why aged and experienced individuals are more skeptical about the possibility to obtain a certain result. The increased number of conditions can contribute to increase their reaction time as well, because the individual will wait for the occurrence of more conditions before reaction starts.

ity, and we still accept that this cognitive activity will occur only when we have someone who does it. Nonetheless we equally accept that the fire burns a piece of wood and transforms the wood into ash, with no dependence on someone's thinking of these facts. That is, the occurrence of these transformations can be neither forced, nor forbidden only by the mental activity of someone who thinks that they have or do not have to occur. After having thought of fire as being the subject of burning activity and of the related consequences, we must ascribe to the fire the activity of burning a piece of wood, and the related transformation of the wood into ash. We cannot ascribe it to another subject (for instance who is doing the mental activity of thinking that the fire burns a piece of wood) otherwise we would contradict ourselves, and we decide not to contradict ourselves because we want to make inferences and logical deductions that relate to physical facts whose occurrence also may involve our survival. Therefore it is not necessary to introduce two ontological different principles (one for the world of physical things, and the other for the world of mental facts) for explaining why the occurrence of a physical process is independent of anyone who thinks that this process has to occur or it does not.

We emphasize that this independence follows from two decisions: the decision to place ourselves in the framework of a knowledge system, and the decision to have a knowledge system without contradictions because we require that inferences and logical deductions do not admit both a proposition and its negation. Although this second constraint is not absolute in practice, its strength is as much higher as the check of the consequences is nearer, as we know by our experience. This statement agrees with our previous remark that a long chain of facts has less probability to occur again, than a shorter one, when facts have the properties of projections of trajectory segments in phase space. So, we expect that subjects show more coherence in their behavior over short period of time than over long period of time[114].

In the previous discussion of constraints, we mainly mentioned, as their sources, training procedures in which subjects are aware of obtaining a certain skill, or of increasing their knowledge system. However, actions of the environment on a biological system are not completely equally probable, and independent; they have correlation. Gravitational field, for instance, induces a statistical predominance of vertical and horizontal lines[115]. Other shapes and orientations have an analogous predominance because of the technological procedures that we use to produce our artifacts. The sounds of the spoken language and the alphabet, show other examples of correlation between actions of the environment, and we could continue our citations.

Correlation between environment actions clearly influences the changes in the physical architecture of the biological systems, although we expect a rather complex relation between the two orders of facts. Furthermore, constrained activity usually has as counterpart only a subset of the physical processes that occurred in the system during its execution, and the changes in the architecture of the system depend on all the physical processes that occurred in the system. The constrained activity thus can occur several times during the life of the biological system, but the biological system typically is in a different state at each occurrence, and so the repetition of the same constrained activity can induce different physical changes in the system. The biological systems modify their environment and these changes can depend on correlation of the previous environment actions. Further actions of the environment thus may depend on the previous changes that the biological system produced in its environment. Since we have a loop of activi-

---

[114] Note that we do not assume that mental activity has to satisfy an analogous requirement, because contradiction is a mental fact. When someone does a mental activity, we accept that we automatically have the mental fact which has that activity as constitutive, and we have no reason to introduce as limit the contradiction, because we consider contradiction as being a mental fact as well.

[115] Fluids have a trend to arrange themselves in a way that locally gives rise to horizontal planes. Trees. on the other side, have a strong trend to grow vertically, because soil supports well vertical load, but it has a poor resistance to shear stress.

ties, we must know the dynamics of the enlarged physical system, in which all actions have a common description as interactions between parts of an isolated system. We can consider the conditions of the occurrence of a physical process as constraints on this process as well. When these constraints concern physical processes that we used to define mental or psychological facts, they can become constraints in psychological description as well. We mention this further source of constraints because it does not require the subjects to be aware of the results, and neither of the activity from which a result originates.

In this optics, we will mention an effect that typically arises when we deal with mental categorization. Let us come back to conscious memories; and, as we discussed in a previous section, let us assume that they imply a mental categorization in which a mental fact is considered as being repetition of a fact that occurred in the past. Here, we will not concern ourselves with the details of the categorization activity, and we only will deal with the following alternative: either the conscious memory refers to a fact that occurred to the subject, or it refers to a fact that did not occur. In the picture that we systematically used along this paper, the alternative implies that segments of two different trajectories in phase space have the same projections onto subspaces of phase space. The two trajectories must be different because one has in the past a segment that has certain projections onto subspaces of phase space, and the other does not[116]. Since trajectory segments are different, we can expect different consequences from the occurrence of a same projection; and these consequences can refer to facts that are not immediately connected with those involved in the conscious memory. The situation that we depicted here is not specific of conscious memory; but it is typical of mental categorization, because it refers to the conditions that we require to hold for doing a certain mental categorization. When the conditions refer to the occurrence of a physical fact, we have the alternative that we mentioned above. This remark may enlighten an underlying mechanism from which neuroses can arise.

We will close this section by coming back to a point that we discussed in a previous section. When we define mental facts, we are completely free of choosing the mental and the physical facts that we connect, because we are dealing with definitions. We instead have no margin of freedom when we are dealing with physical facts that shall follow from other physical facts, because we decided that observation and experiment will be determinant in this case. In particular, we showed that interaction between remote parts is necessary to develop a theory of the physical activity in biological systems, that this theory is typically nonlinear, and that memory phenomena play an essential role.

Because of our freedom in choosing how to define mental activity, many points of this paper have the character of a discussion about the possible mental activity. One strategy deduces these possibilities from the characteristics of the physical description of the enlarged physical system (the biological system and a suitable part of its environment). Another strategy deduces these possibilities from the current knowledge system, from the learning rules, and from the knowledge of the interactions with the environment. The two strategies have opposite approaches: one refers to mental activity, the other deals with mental facts. However, they are not equally reliable. The first one really delimits the possibilities, because it is grounded on a deterministic dynamics of the physical system. The second one meets difficulties to account for the possible new definitions of mental things. The first strategy is thus more suitable for a general theory; the second strategy is more suitable to account for the development of which subjects are aware, and so it is very interesting in humanities. Moreover, we are completely free in choosing the physical process through which we define mental activities in our general theory. The possibility of a mental

[116] We remember that in this picture a trajectory is completely individuated by one of its points, because trajectories do not intersect.

fact is conceptually linked to the possibility of its realization into the dynamics of the classical biological system and a suitable part of its environment, such that we can consider the enlarged system as being isolated. This high degree of freedom is reduced by the particular evolution in the case of a single individual. In the geometrical picture that we systematically used along the paper, this corresponds to pass from the system of trajectories to a single trajectory. The possibilities are very high in these conditions as well.

# Conclusions

The main conclusion of this paper is that the theories of physics and of psychology about humans and biological systems activity are not isomorphic, and this conclusion essentially follows from decisions that have a methodological character.

In describing the activity of our systems considered as physical systems, we decided to satisfy the following requirements. The predictions must lead to repeatable experiments. The investigated facts and the procedures to study them shall be repeatable without any restrictions on principles or methods. The interactions that we use as elemental in the theory must have no explicit dependence on time, otherwise we lose the possibility to repeat experiments. We will systematically use the cause-effect relation, instead of a mere correlation between the events, and a bijective function must hold between the causes and their effects. Since we have to predict the energy exchanges, we must deal with an isolated system by including in our dynamics a suitable part of the environment of the classical biological systems. The physical changes are thought to be produced by a physical thing that is different from the thing on which we observe the change.

The previous requirements force us to set up a certain number of parameters, which refer to the environment, to assert that we repeat an experiment, and still for referring the results of several experiments to the same system. Furthermore, we must study interactions with the environment and with remote parts of the biological system, because the interaction among neighboring elements is not sufficient to account for the behavior of a biological system. Finally, interaction delay causes dynamic effects of memory, and it is a further source of nonlinearities in the dynamics of the system. Though we meet practical difficulties to realize a physical description with the characteristics that we mentioned above, we systematically referred to it, because it clearly shows the methodological differences between the descriptions that follow the viewpoints of physics and of psychology. For analogous reasons we frequently refer to a geometrical representation of a system dynamics as trajectories that do not intersect in phase space.

In describing the activity of our systems considered as being able of doing mental and psychic activity, we decided to satisfy the following requirements. The predictions must lead to repeatable experiments. Investigated facts and procedures for studying them shall be repeatable without any restrictions on principles or methods. Mental and psychological facts and activities must be defined in a way that will be compatible with the possibility of occurring again during the life of the same subject, and with the possibility of occurring to different subjects. We also think of subjects as causing both their physical and mental activities.

These decisions force us to define mental and psychic things by an injective function into only a part of the physical processes that we used for a physical description with the characters mentioned above. Furthermore, we decided to define mental activity in this way. So, integration of the two viewpoints becomes easier, because we have to correlate activities and physical processes. We think of mental facts as being constituted by mental activity, so that this approach allows a large number of mental facts; however, mental facts now become part of the dynamics of mental activity. We can relate the dynamics of the previous physical description to trajectories that do not intersect in phase space. When we refer to this geometrical representation, mental things are defined by using projections of trajectory segments onto subspaces of phase space. The projection can involve many disjoint subspaces, and the related timing pattern. As many physical processes can share the same subprocess, many trajectory segments can share the same projection. The same projection thus can occur again along the same trajectory, and it can occur along different trajectories. We thus fulfill the previous requirement that a mental fact can occur again during the life of the same subject, and that it can occur to different subjects. The consequences that follow form the previous way of defining thus have a methodological character, and they hold irrespective of the type of thing we define in this way. They equally hold, for instance, for a mental thing, or for a movement of a harm, or for a subprocess of a cell. As we have seen, a deterministic explanation requires an isolated physical system. Therefore, we cannot confine ourselves to a classical biological system still when we are working in these fields, and we must deal with a part of its environment such that the enlarged system can be considered as being isolated.

The system has many ways to realize the occurrence of a thing that we defined in the previous way, and we can see this fact as a great source of plasticity in its behavior. Therefore, we can assume two, very different, mental attitudes about the occurrence of a thing that we defined in this way. We can concern ourselves with the occurrence of the defined thing: that is, with the occurrence of the subprocess that we used to define it. We instead can concern ourselves with the full process that gives rise to the current occurrence of the defined thing in the enlarged physical system. However, we may suggest a third alternative. We can think of a projection as describing the conditions that we require to categorize mentally a fact as being a repetition of a same fact. This alternative too, has a methodological character; and it is not incompatible with the first one. I think that we can take a better decision when we will succeed in defining mental categorization along the lines that we outlined in this paper.

We must take the second point of view when we plan to explain deterministically the occurrence of things that we defined by using only a part of the physical processes that were necessary to have a deterministic explanation of the physical system activity. However, this point of view usually places us out of psychology, because we must use more things than those that have a correspondence in psychological description. Therefore, in psychological descriptions we usually set only a correlation between the occurrence of mental and psychological facts and activities. This correlation has an essentially probabilistic character, because many physical processes can share the same subprocess; and because further physical processes always accompany the occurrence of the facts, besides the processes that we used to define them. This further physical activity depends on the current state of the system, and the subsequent physical activity depends on the global physical process that occurred. In the approach of psychology, different facts thus can induce the occurrence of the same mental thing, and different occurrences of the same mental thing can induce different chains of mental or psychic facts.

In the physical theory that we assumed as reference theory for our methodological discussion, the equations which describe the system evolution completely describe the dynamics of the system. They thus describe the flow of the activity, the constraints on this flow, and the development of the system, in a syncretic way. When we take the viewpoint of psychology we lose this syncretism. We can still introduce constraints on flow of mental activity, and, more generally, on flow of psychic activity. They however lose the deterministic character that they usually have in the physical description. We obtain an intuitive explanation of this fact by coming back to a representation of the dynamics of a physical system as trajectories that do not intersect in phase space. Even if we know the equations that describe the line onto which trajectories project, we cannot infer the occurrence of a segment of this line from the occurrence of one of its parts. Since many trajectory segments can share a segment of the projection, a part of them may not share the successive segment of the projection. We thus cannot infer the occurrence of a mental fact from the occurrence of only a part of its constitutive activity. We interpreted this fact also by saying that an activity with these characteristics may be abandoned although we defined it as being constrained. Moreover, when a trajectory segment is orthogonal to a subspace of phase space, its projection onto this subspace disappears; and the trajectory also describes how long this fact subsists for the system. In the description of the psychology, a subject seems to acquire or loose a certain behavior, and the fact can be transient or permanent.

We introduced learning only in psychological description, because in physical description we can deal only with memory phenomena: that is, with changes in the material and physical architecture, and with the effects of the interaction delay on the dynamics of the system. In this framework, we can explain learning through the changes that training activity induces on the physical architecture and the related effects that these changes have on the subsequent activity of the system. In the approach of psychology, we must choose our definitions in such a way that we shall obtain a satisfactory correlation between the occurrence of the defined things before and after training. In physical description, learning succeeds when the training activity brings the system in a region of phase space such that the occurrence of a certain subprocess becomes more probable. Geometrically this means that the system trajectories frequently share the projection that we used to define the learned thing. Since many trajectory segments can share a projection, training and learning occur in context. This remark offers an explanation of the strong dependence of learning on the particular individuals, and on their conditions during training.

In this paper, we have given a high weight to the system activity, and this fact stresses the importance that the acquired habits have in determining the humans' behavior. This idea is very old, and we can trace back it to Aristotle[117]. It emphasizes the importance of education, with the related social and personal responsibilities, particularly because our way of defining mental things excludes that we can derive a private character from their definition; and we must obtain the same practical consequences by privacy: that is, by a legal statement, and social consent.

---

117. Aristotle, *Eth. Nic.*, II, **1**, 1103a 11 ff.

## Appendix A - Further remarks on the physical description

As we have seen, in a physical description the system dynamics can be optimally represented by a theory in which we use systematically the cause-effect relation, and in which we choose the things to consider causes and effects so that a bijective function holds of the causes onto their effects. We recall that in this context the systems become the usual biological systems extended to a suitable part of their environment so that the enlarged physical system can be considered as being isolated. Environment actions thus become interactions between parts of the enlarged system, and we can completely predict the energy exchanges. Clearly, the total energy of the enlarged system is constant. As we discussed in a previous section, we can meet strong practical difficulties to fulfill these assumptions, mainly because of the severe difficulties to collect the information which is necessary to develop such an optimal theory for the biological systems; but we have no conceptual difficult. We will maintain these assumptions because they characterize an optimal physical theory in which the differences between the physical and the psychological description become very sharp, and the problems acquire a more clear formulation. Moreover, I think that they continue to hold in a more realistic approach, for instance the approach of statistical mechanics, since they have a methodological character. In this physical description the equations that describe the evolution of the system completely describe the dynamics of the system. So, they also describe the connection among the various segments of activity and the constraints on the activity flow. We emphasize that different configurations of the values of the observables which characterize the state of the system lead to a different evolution, because we assumed that a bijective function of the causes onto the related effects holds in the reference theory. We also emphasize that a bijection between the causes and their effect is a reasonable requirement, but it is typical of a theoretical attitude: that is, when our aim is to build a general theory. In practical activities we usually do not require this property. Different procedures thus can lead to the same result, and this possibility allows us to achieve an aim following more than one way. However, we have different side-effects too, and these side-effects are sometimes very significant also when we assume a practical attitude. In these cases, we have to manage them, as, for instance, in clinics.

We have no methodological problem when we succeed in individuating physical processes whose occurrence is equivalent to the action of conservative forces, because these processes allow us to calculate the global energy exchange, and so to predict the behavior of the system. Furthermore, because the conservative forces have potential, we need to know only the differences of the potentials between the initial and the final states of the system in every process to calculate the total energy that is exchanged during the process. Nonetheless we succeed to apply this strategy only in a very limited number of cases; in all the other cases we are involved in practical difficulties.

If we succeed in handling the occurrence of a physical process as being equivalent to the action of a force, but the force is not conservative, then it is usual to develop a theory in which the action of suitable conservative forces explains the action of the nonconservative force, and it also predicts the energy exchange due to the action of the nonconservative force. Usually there are many ways to realize this result, and here again the experiments decide the choice. The discriminating elements in this choice are the agreement with the predictions of the amount of energy exchanged by the nonconservative forces, and the values of other observables. We usually explain in this way friction, plastic strain, and the heat exchange phenomena that occur together with mechanical phenomena. In my opinion, this strategy supports the idea that the requirements stated above (forces are conservative, they do not depend explicitly on time, and we have to deal with an isolated system) are well motivated methodological choices. However, we shall soon see that in many cases this strategy raises methodological problems as well.

The conservative forces that we introduce to explain the nonconservative force cannot have this force as resultant force, because this resultant force should be conservative, and this fact should contradict the hypothesis. For the same reason we cannot assume the nonconservative force to be only a component of the force obtained by the sum of the conservative forces, because this component too should be conservative. We can only assume the nonconservative force to be the statistical component of the action that the conservative forces exert in the direction of the nonconservative force. So, we can have zero as average value of the resultant of the conservative forces in other directions and during a certain interval of time, but the components of the conservative forces in these directions give a contribution to the energy that is exchanged in the same interval of time. However, the total energy exchange does not equal the energy exchange produced by the nonconservative force. The energy exchange becomes the sum of at least two parts that depend on the particular process. One of them is the work made by the nonconservative force, and the other is the further energy exchange that is necessary to equal the work made by the conservative forces that we conceptually introduce as methodological choice.

We have no problem when we know how to calculate the work that is made by the conservative forces. When instead we do not succeed in calculating the work made by conservative forces, we have to evaluate two energy exchanges that depend on the process by which the system passes from the same two states. We do not always succeed in finding two energy exchanges that depend on the particular process by which we pass from the same initial and final states, and whose sum depends only on these two states. In many cases we obtain only inequalities or bounds, but, in the more favorable cases too, we need a greater number of parameters than in the case in which we know how to calculate the work made by the conservative forces, because now we have to characterize the process.

When the occurrence of two processes can be assumed to be equivalent to the action of the same conservative force, and when one process leads the system from the final to the initial state of the other process, the sequence of the two processes leaves the system in the same state, and the total energy that is exchanged in the sequence of the two processes is clearly zero. Because we are thinking of isolated systems, we can conclude that a process whose occurrence is equivalent to the action of a conservative force is completely reversible. When we do not succeed in describing the actions of our system in this way, we frequently have to deal with irreversible processes, because the energy exchange now depends on the particular process as well, and may happen that we do not succeed to induce a physical process that is the inverse of a given one. Furthermore, we often meet the severe difficulties of studying nonequilibrium phenomena[118], because we had to assume that the nonconservative forces are the statistical components of conservative forces, and their average over a suitable interval of time may significantly depend on this interval length, and we might not succeed in approximating our processes with a sequence of equilibrium states[119]. We emphasize that nonequilibrium situations are quite the rule in physical descriptions, because they occur in studying transient phenomena, and transient phenomena are the core of every dynamic. We have again to deal with nonequilibrium phenomena when the

---

118. See, for instance, W. Grandy Jr., *Foundations of Statistical Mechanics*, Vol. 1, *Equilibrium Theory*, Boston, 1986; and Vol. 2. *Nonequilibrium Phenomena*, Boston, 1988. The introductory chapters of the second volume outline very clearly the methodological bases of the approach to nonequilibrium phenomena.

119. When we assume the system to be in an equilibrium state, we recall that a very strong methodological constraint is used, often implicitly. Feynman exposes it with the following words: "That every process must, in thermal equilibrium, be balanced by its exact opposite is called the *principle of detailed balancing*." R.P. Feynman, R.B. Leighton, M. Sands, *The Feynman lectures on Physics*, *cit*., Vol. I-2, 42-5.

value of an observable depends on the interval of time during which we maintain the interaction between the system and the measure apparatus. In developing a theory of nonequilibrium phenomena we thus must decide how to interpret the measured values of the observables, and this problem is often crucial for the theory. Finally, we may not succeed in decomposing a physical process into more simple processes whose occurrence be equivalent to the action of a single conservative force of our theory. In these conditions we again consider the occurrence of the process to be equivalent to the action of a suitable number of conservative forces, and we introduce new conservative forces in our theory. Then, starting from the results of the experiments, we must introduce suitable relations between the conservative forces, and their dependence on the parameters that characterize the process.

The differences that we stated between the approach of physics and the approach of psychology may be identified also when we will use a more realistic physical description, and when we will consider quantum mechanics aspects of the dynamics of the biological molecules. Nevertheless, I did not succeed in tracing them with sufficient clarity, when I tried to give a physical description of a biological system's behavior by following the approach of the statistical mechanics or of the continuum mechanics. I think that the conceptual scheme of the continuum mechanics[120] might be another good formal tool to describe biological systems, particularly the more complex ones. If we use a point of view that thinks of the system as being composed by discrete elements, then the biological systems would have an extremely high number of elements, thus it would become very difficult to manage, both conceptually and mathematically. Moreover, in these systems there is a traffic of chemical molecules and ions of different sizes among the different parts of each cell, among the various cells, and among cells and their extra cellular matrix. The continuum with microstructure[121] probably would offer a better viewpoint, but some difficulties arise from our aim to introduce delay in the interaction. In continuum mechanics extension is atomic. Thus, we do not define point values of the observables, but distributions, and we have to introduce fields to describe the interaction[122]. These facts should force us to develop the system dynamics with instruments that are slightly different from those discussed in this paper. So, we prefer not to deal with this possibility here. Moreover, the probabilistic character of the predictions, which we obtain from certain theoretical approaches of physics, may mask the consequences of having defined mental things by using only part of the physical processes, and it thus can mask the different origin of the probabilistic character of the predictions. The similarity does not really go beyond the use of the same mathematical instruments to formalize a probabilistic approach.

---

120. See C. Truesdell and R. Toupin, *The classical field theories*, Encyclopedia of Physics, Vol. III/1, Springer-Verlag, New York, 1960; C. Truesdell and W. Noll, *The non-linear field theories of mechanics*, Encyclopedia of Physics, Vol. III/3, Springer-Verlag, New York, 1965.

121. A good introduction is in G. Capriz, *Continua with microstructure*, Springer-Verlag, New York, 1984.

122. See for instance J. Glimm and A. Jaffe, *Quantum Physics. A functional integral point of view*, 2nd edition, Springer Verlag, 1987.