New Foundations for Qualitative Physics

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Preamble

Physical reality is all the reality we have, and so physical theory in the standard sense is all the ontology we need. This, at least, was an assumption taken almost universally for granted by the advocates of exact philosophy for much of the present century. Every event, it was held, is a physical event, and all structure in reality is physical structure. The grip of this assumption has perhaps been gradually weakened in recent years as far as the sciences of mind are concerned. When it comes to the sciences of external reality, however, it continues to hold sway, so that contemporary philosophers – even while devoting vast amounts of attention to the *language* we use in describing the world of everyday experience – still refuse to see this world as being itself a proper object of theoretical concern.

Here, however, we shall argue that the usual conception of physical reality as constituting a unique bedrock of objectivity reflects a rather archaic view as to the nature of physics itself and is in fact incompatible with the development of the discipline since Newton. More specifically, we shall seek to show that the world of qualitative structures, for example of colour and sound, or the commonsense world of coloured and sounding things, can be treated scientifically (ontologically) on its own terms, and that such a treatment can help us better to understand the structures both of physical reality and of cognition.

A number of recent moves have been made by workers in the field of artificial intelligence in the direction of a theoretical account of the qualitative level of objective reality. We can point, for example, to the idea of a 'naive physics' as this has been propagated by Patrick Hayes,[1] and to the qualitative physics of Kleer and Brown.[2] Parallel ideas are present also in the project of a 'semiophysics' – a physics of the salient structures in reality – that has been advanced by the French mathematician René Thom. Thom's ideas are propounded, interestingly enough, in the form of a commentary on Aristotle's Physics.[3] For it was not always the case that philosophers were disposed to cast aspersions on the project of a science of the qualitative world. To Aristotle and his disciples physics itself was indeed a

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[1]. Patrick J. Hayes, "The Second Naive Physics Manifesto", in J. R. Hobbs und R. C. Moore (eds.), *Formal Theories of the Commonsense World*, Norwood, NJ: Ablex, 1985, 1-36.

[2]. J. D. Kleer and J. S. Brown, "A Qualitative Physics Based on Confluences", *Artificial Intelligence*, 24 (1984), 7-84 and in Hobbs and Moore (eds.), *op. cit.*, 109-183.

[3]. R. Thom, *Esquisse d'une Sémiophysique. Physique aristotélicienne et Théorie des Catastrophes*, Paris: Interéditions, 1988.

qualitative discipline, and modern-day practitioners in the field of naive physics have recognized that there are valuable insights to be gained from the work of medieval thinkers such as Buridan and Oresme, still working within a broadly Aristotelian framework.[4] Thomas Reid and other Scottish common sense philosophers can likewise be seen as having explored the world of qualitative reality in ways relevant to more recent experiments. In the writings of thinkers such as Reid, however, as also in the work of the medievals, the issue is for obvious reasons not addressed as to the proper relation between the (qualitative) description of commonsensical reality and physical science in the modern (quantitative) sense.

The question thus arises as to who, in the philosophical tradition, was the first exponent of what might be called a *sophisticated naive physics*, which is to say a theory of the commonsensical domain whose relations to physics proper are made the subject of explicit theoretical concern. Claims might be made in this respect for Whitehead, whose "On Mathematical Concepts of the Material World"[5] stands at the beginning of a long and valuable tradition of formal ontology embracing also, *inter alia*, the work of J. H. Woodger.[6] It seems, however, to have been Husserl's *Crisis of European Sciences* of 1936 which first addressed in explicit fashion the relation between the ontology of the commonsense world – called by Husserl the 'theory of the structures of the life-world' – and post-Galilean physics.[7] And Husserl's ideas as presented both in this work and also in his earlier writings on formal ontology[8] will surely be recognized by future researchers in the area of naive physics as one crucial philosophical pillar of their discipline.

It might, for a number of reasons, seem somewhat incongruous to run together such diverse intellectual currents under the single umbrella of what we are still somewhat loosely calling 'naive' or 'qualitative' physics. There is, first of all, an important divide between those, like Thom, who are concerned to develop the physics of salience as a mathematical discipline, and those, like Husserl, who see the structures of the life-world as demanding a theoretical treatment of a quite different sort. There is a deep divide also between those thinkers – such as Aristotle – who see the discipline of naive physics as a science with its own distinctive subject-matter,

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[4]. See e.g. John H. Holland, Keith J. Holyoak, Richard E. Nisbett and Paul R. Thagard, *Induction. Processes of Inference, Leaning, and Discovery*, Cambridge, Mass. and London: MIT Press, 1986, p. 208.

[5]. *Philosophical Transactions of the Royal Society of London*, series A, vol. 205, 1906, 465-525, repr. in F. S. C. Northrop and M. W. Gross (eds.), *Alfred North Whitehead. An Anthology*, Cambridge: Cambridge University Press, 1953, 7-82.

[6]. See e.g. his 1937 *The Axiomatic Method in Biology*, Cambridge: Cambridge University Press, 1937 and *The Technique of Theory Construction (International Encyclopedia of Unified Science*, vol. II, no. 5, 1939), Chicago: University of Chicago Press.

[7]. See E. Husserl, *The Crisis of European Sciences and Transcendental Phenomenology. An Introduction to Phenomenological Philosophy*, trans. by D. Carr, Evanston: Northwestern University Press, 1970.

[8]. These works and their influence are treated at length in B. Smith (ed.), *Parts and Moments. Studies in Logic and Formal Ontology*, Munich: Philosophia, 1982.

and those – like most contemporary workers in the field – who see naive physics in quite other (cognitive or psychological) terms. Of course, given the assumption mentioned at the head of this paper, it is not difficult to see why the first alternative should nowadays prove so unpopular. If reality *an sich* is conceived as being captured exclusively and exhaustively in the (suitably perfected) equations of a purportedly monolithic discipline of standard physics, then there would seem to be no room for any additional science of the structures of commonsensical reality – unless, that is, such a science should be a sort of psychology in disguise, a science of 'knowledge-simulations' or of 'mental models', readily associable with investigations e.g. in the sphere of 'children's physics'.[9] There is a danger, however, that the idea of a science of commonsensical reality will in this way be confused with the quite different and patently absurd idea of a 'commonsensical science' – a confusion of the sort which seems to lie at the heart of discussions of 'folk psychology' by Churchland and others.[10] Folk psychology is of course not a science, but a matter of sheer popular prejudice. From this, however, we clearly cannot conclude that there cannot be a sophisticated science of mind, and nor can we conclude from the muddled state of many folk beliefs about the commonsensical world that a sophisticated science of the structures of (the objective component of) this world is ruled out *a priori*.

Workers in the field of artificial intelligence may be able to afford to ignore such issues and concentrate on the practical job of simulating relevant human beliefs and processes of reasoning in formal theories, irrespective of the issue as to whether the propositions which thereby result are true or false of any independent reality. Thus they may take the view that all that matters, from their practical point of view, is merely the extent to which one obtains desired end-results in the sphere of automated reasoning. Neither the psychological nor the pragmatic conception of naive physics can be ultimately satisfying on their own terms however. For both leave open the question why it is that just these mental models or systems of beliefs should have arisen as they did and why they should have survived so long. Moreover, they leave open the question as to why it is that they should have the power to sustain so remarkable a facility of both thought and action. In order to answer these questions one must, it seems, adopt a wider theoretical focus, taking account of the structures of the world in which such thought and action is realized. One needs, that is, to place one's theories or simulations of the psychology of human thought processes within the wider framework of an ontology. One very tempting hypothesis then consists in the idea that the remarkable facility which humans manifest in thinking and acting on the level of everyday experience is made explicable, at least in part, precisely by the existence of corresponding stable structures on the side of reality.

It is this hypothesis – a hypothesis which comes down in the end to the view that there is a level of reality which enjoys a certain sort of intrinsic intelligibility –

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[9]. See Holland, *et al.*, *op. cit.,* pp. 206ff.

[10]. See e.g. P. Churchland, *Scientific Realism and the Plasticity of Mind*, Cambridge: Cambridge University Press, 1979.

which we shall pursue in what follows. Thus we shall be concerned to establish (the foundations of) a theory of the qualitative or commonsensical world conceived as a relatively autonomous level of reality confronting us in everyday experience.[11] Such a theory must rest on one or other form of Aristotelian ontology, in the sense of an ontology recognizing enduring animate and inanimate substances manifesting an opposition between form and matter, possessing sensible and non-sensible qualities and undergoing changes (events and processes) of various sorts. On the appropriateness of such an ontology there is wide agreement among all practitioners, whether they work in the field of philosophy or in artificial intelligence, and whether or not they are willing to give credence to the corresponding propositions as propositions which are true of some independent reality. Thus it is remarkable to observe the extent to which Hayes' list of conceptual 'clusters' or sub-theories of the discipline of naive physics as he conceives it[12] corresponds to the original master-list of categories supplied by Aristotle.

The Aristotelian ontology must in addition recognize species and genera (or 'natural kinds') which these entities, both substances and their accidents, instantiate, and it must recognize further that the instances in each kind are divided into circles of more and less standard or prototypical instances. The prototypical instances in each species can then be expected to be more readily discriminable (salient, *prägnant*) than their non-prototypical counterparts, and also more readily able to give rise to correspondingly skilled responses on the parts of perceiving and acting subjects. All of these features were investigated extensively by successive generations of philosophers inspired by Aristotle – up to and including Husserl. The Aristotelian qualitative ontology was however called into question by Galileo and his successors. Above all, substances and sensible ('secondary') qualities came to be eliminated from the view of the world accepted by the physicists, along with the whole apparatus of form and matter, natural kinds, prototypical instances, and so on.

Clearly, though, the qualitative or commonsensical ontology can be Aristotelian only in a broad sense. Thus the space of this ontology must be three-dimensional and global in type, as contrasted with the purely local space of Aristotle. Substances occupy volumes of this space and move continuously through it. They have closed spatial boundaries which delimit and separate them from other substances and they are capable of communicating impetus. And, most importantly for our present purposes, the sensible qualities inhering in such substances will manifest *qualitative discontinuities* which may or may not coincide with the boundaries which mark their exterior surfaces in space. Consider, for example, the case of a black dog with brown spots. Here, two sorts of qualitative discontinuities

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[11]. We are not, for the moment, interested in the precise relation between `qualitative' and `commonsensical'. Suffice it to say that the qualitative domain as specified below extends more widely than does the domain of commonsensical experience, for example in including non-spectral colours. On the other hand the world of commonsensical experience embraces dimensions of ontological form, above all the dimension of *substance*, which are skew to the strictly qualitative sphere.

[12]. See Hayes, *op. cit.,* pp. 18ff.

can be distinguished. On the one hand are the discontinuities corresponding to the exterior apparent contours of the dog; and on the other hand are the internal discontinuities on the surface of the dog (for example the contours of the spots on his back).

Manifestations of Matter. I: Spatial Movement

If, as we claimed, modern physics is not the science of some ultimate bedrock of reality, what, then, is it? Crudely speaking, it is a science which deals with a rather limited number of ways in which matter manifests itself in qualitative reality. It deals with these manifestations not, however, as denizens of the qualitative world but as it were in purified form, as quantities or magnitudes. Its purchase is, in other words, exclusively mathematical, and it seeks to use mathematical devices to *explain* the given manifestations by showing how they are subject to formal laws or principles. Qualitative reality is here, in a way, preserved; but it comes to be filtered entirely through structures of a formal or quantitative sort.

Classical mechanics, for example, seeks to explain in a mathematical way and in a single, unified framework all the diverse expressions of that manifest property of matter which is *spatial movement*, from the movements of pendulums and the orbits of planets to turbulence in fluid dynamics and the thermodynamic phenomena captured by statistical mechanics. Such movements are represented within the theories of mechanical dynamics either as vectors (in the case of velocities, accelerations, gradients, etc.), or as tensors (of impulsion, of deformations in continuous media, etc.), or as differential forms (of flux, divergence, rotation, etc.).

Vectors, tensors and differential forms, now, are all such as to possess intuitive geometrical meanings, in the sense that they can be understood as entities having determinate structures that are independent of the language and theoretical apparatus we use to describe them. One consequence of this, is that the descriptions of movement yielded by classical mechanics must be true independently of whatever we happen to choose as co-ordinate frame. This is an *a priori* (pre-physical) requirement on the descriptions of the theory. It implies, first of all, that the differential entities of which the theory treats must enjoy the specific mathematical property that they vary covariantly in respect to the Galilean relativity group. Because no point in time is distinguishable physically from any other, it is impossible physically to determine an absolute origin of time: with this fact is associated the relativity sub-group of time-translations. Similarly, it is impossible physically to determine an absolute origin for the co-ordinates of space, or an absolute direction in space, and with these facts are associated respectively the relativity sub-groups of spatial translations and spatial rotations.

The Galilean group is a group of *symmetries* of space and time: every point in space or time is indistinguishable from every other. In general, the symmetries of a theory express what it is impossible to know absolutely according to the theory. Because it is impossible physically to determine an absolute point in time or an absolute point or direction in space, we are forced to fix these entities conventionally: we choose arbitrarily a zero for time, a zero for space, a co-ordinate frame, units of measure, and so on, and it is precisely because these entities are not physical that our physical descriptions must be independent of the given choices.

It turns out, however, that this seemingly trivial *a priori* constraint has important physical consequences. A mechanical system is completely described by a certain function, called the Lagrangian, of the energy within it. One of the greatest theorems of classical mechanics, namely Noether's theorem (which can be generalized to physical theories of many other sorts), says that, if the Lagrangian is invariant through the transformations of any given sub-group of relativities, then there is a certain physical quantity correlated therewith, which is *conserved* through every movement of the system. The exact form of Noether's theorem is that to every one-parameter group of symmetries of the Lagrangian there is correlated a law of conservation of a physical quantity. Time translations are correlated in this way with the law of conservation of energy. Spatial translations are correlated with the law of conservation of kinetic momentum (impulse). And spatial rotations are correlated with the law of conservation of angular momentum.

From correlations of this type, which are established *a priori*, we can derive an enormous amount of physical descriptions – to the extent that many physicists will readily assert that the whole physical content of classical mechanics is exhausted by such laws of conservation. Einstein's celebrated law of the equivalence of mass-energy is itself a direct consequence of Noether's theorem applied to the new relativity group of four-dimensional Minkowskian space-time.

Manifestations of Matter. II: Spectral Rays

Matter manifests itself phenomenally not merely via movement but also for example via *spectral rays*. Quantum physics can be seen precisely as the physics which relates to this mode of manifestation of matter as classical mechanics relates to movement. In addition to 'external' space-time, with its Galilean or Einsteinian relativity group, quantum mechanics relates to what are called 'internal' quantum numbers. These are new physical quantities which characterize elementary particles (electric charge, isospin, charm, colour). And here again there are certain *a priori*, pre-physical constraints which prove to be of fundamental significance in determining the nature of the objects of the physical theory which results. For example it turns out empirically that in the nexus of strong nuclear interactions the proton and the neutron are indiscernible. The symmetry between the two is called the isospin symmetry. Applying Noether's theorem we get a conservation law which is the law of conservation of isospin in nuclear reactions.

Another example of this same phenomenon turns on the fact that it is impossible, within a single quantum system, to individuate by physical means an elementary particle in a group of elementary particles of the same type (for example one electron in an atom with many electrons). This fact, again, seems at first not to have much physical content, but to reflect only an inadequacy on our part, an *a priori* indiscernibility. The Lagrangian here becomes an operator which operates on a function describing the quantum state of the system. This Lagrangian is invariant with respect to the symmetry that is represented by the group of permutations of the particles within the system amongst themselves. Two alternatives turn out to arise here. In some cases permuting the particles leads to no change in the function: the function is symmetric. In other cases the function is antisymmetric and leads to a change of sign. This opposition could hardly be more important. It generates those physical properties of matter which are known in quantum mechanics as the correlation between spin and statistic. Those systems which are antisymmetric are constituted by particles – called 'fermions' – which have a half-integral spin (1/2, 3/2, 5/2, etc.). Such particles, which are particles of matter, are subject to Fermi's exclusion principle, which states that two fermions in the same position in space-time cannot have the same quantum numbers. It is this principle which explains, for example, why all the electrons of an atom must have different systems of quantum numbers (electrons are fermions). This explains in turn why one needs orbits of electrons, why matter does not collapse, and therefore also why matter exists macroscopically and so manifests chemical properties. Those systems, on the other hand, which are symmetric, are constituted by particles of integral spin. These particles, called bosons, are not particles of matter, but particles vehiculating interactions between particles of matter. For example it is well known that the photon is the particle vehiculating electromagnetic interaction. For the bosons Fermi's Exclusion Principle is not valid. Thus we can have superposition of bosons in the same position in space-time – which explains such physical phenomena as lasers and superfluidity. Here also, then, we have deep properties of matter, which are in fact the physical translation of certain *a priori* constraints.

Manifestations of Matter. III: Qualitative Discontinuities

An 'observable' in modern physics must be *measurable* – in conformity with the move effected already in the work of Galileo from qualitative to quantitative aspects of reality. But for something to be measurable, there has to be the possibility of invariance. Thus without the possibility of constant temperature, temperature could not be a physical magnitude. A physical magnitude presupposes the possibility of conservation in certain ideal conditions. But now again, this means that the required stability must be imposed as an *a priori* condition on the possibility of theory, and the sort of stability we impose will determine the sort of theory we end up with. This reinforces the correlation between *a priori* constraints and what the objects of the theory are.

We can now see clearly why physics of the post-Galilean sort cannot serve as the description of some autonomous bedrock of reality. Post-Galilean physics involves, if one will, an ineliminable (or irredeemable) Kantian dimension. It yields not a picture or description of some theory-independent reality, but a certain unified system of *quantities*, of mathematical reconstructions of regularities in the manifestations of matter, reconstructions that are in no small part dependent upon *a priori* constraints which must be satisfied if the given quantities are to be graspable at all. The world of standard physics is in this sense a human construction.

Our specific problem, now, is that of establishing how physical theories can be enriched sufficiently to capture in scientific fashion the features specific to qualitative reality. The ground of a solution is in fact already to hand: physics, for all that it is restricted to the quantitative, does indeed deal with just the manifestations of matter from out of which the qualitative world is composed. What it does not do is to deal with those very special sorts of ways in which manifestations of matter are composed or knitted together which are relevant to the world of qualitative experience. Can we, then, build up a science of the properly qualitative modes of manifestation of matter? Can we, in other words, find a way of bridging the gap between quantity and quality, or between the physical and the qualitative modes of manifestation of matter?

Here the obvious suggestion is that the qualities manifested locally in qualitative reality be represented as degrees of appropriate intensive magnitudes: colours via frequencies, qualities of hot and cold via temperatures, etc. Such representations will most importantly preserve the spatial or temporal *variations* in the represented qualities, and it seems reasonable to suppose that it is in such variations that the relevant qualitative information will be contained. Only some types of physical variation will however be able to represent variations of the qualitative sort. Simple mechanical systems (pendulums, for example) fall entirely out of court in this regard. How, then, are we to focus in on variations of the relevant types? Here the key idea is due to René Thom. Variations in intensive magnitudes will, clearly, be either continuous or discontinuous. Thom's idea is that the science we require should take as its primitive *qualitative_discontinuity*, which is to say discontinuous variations in qualities as represented quantitatively in the given fashion. The theory which results would then be a science of those manifestations of matter which are associated with discontinuities of variation in intensive magnitudes, just as classical mechanics is a science of those manifestations of matter we call spatial movement.

The steps involved in building up a science of qualitative reality along these lines can here be sketched only in broad terms:

i. we must first of all convince ourselves that the given primitive truly does yield a science of qualitative reality;

ii. we must give an adequate mathematical expression of the idea of qualitative discontinuity.

And finally

iii. we must give an account of how we can move from standard physics to a theory of the qualitative world of the sort desired.

We shall deal with each of these in turn.

Ad i: How do things appear in qualitative reality? For present purposes we may confine our attentions to sensible phenomena. We begin by drawing attention to three characteristic features of the ways things, events, etc. appear in sensation – features first picked out by Husserl:

1. Whatever appears, appears always from one side, presents one (continuously varying) face or aspect, and is correspondingly foreshortened or 'adumbrated'. The science of commonsensical reality thereby divides into one branch

which deals with the different sorts of substance, qualities, etc., as they are in themselves, and a second branch which deals with the corresponding types of adumbrations and with the relations between systems or chains of adumbrations and the structures which they are adumbrations of.

2. Whatever appears, appears in such a way as to manifest a foreground-background structure (there is an ever-present difference between topic or focus and the context against which this topic or focus is set into relief).

3. Whatever appears, appears in the context of a spatio-temporally extended whole. There is, in other words, a relation of foundation between sensible qualities and spatio-temporal extension (no colour can, as a matter of necessity, exist without spatial extension, no sound without duration, etc.).

Take, again, our example of the black dog with brown spots as this appears in visual perception. Here we can distinguish first of all the apparent contour of the form or shape of the dog: the exterior boundary of the dog as this appears to us at any given instant (and the fact that we can only perceive one apparent contour at a time is a typical example of foreshortening). Like the aspects of which they form a part, such apparent contours will typically vary continuously (for example as the dog trots off into the night), and it is an interesting problem to understand the relation between the three-dimensional boundary of the dog itself and the family of its two-dimensional apparent contours.

The perceived qualities of the dog, now, have a certain spatial extension, and it is in this context that the notion of qualitative discontinuity arises. The qualities distributed across any given spatial extent are either fused phenomenally in the sense that there is no observable separation between them (there is a smooth transition from one colour to another), or they are phenomenally 'separated', where there is discontinuous variation. (Of course something similar arises in relation to auditory qualities and their temporal duration.)

Here there is no intrinsic difference between the apparent contours which correspond to the perceived exterior of the dog and mark the distinction between foreground and background, and the perceived boundaries within the interior of the dog, for example the boundaries separating spots from their surroundings. In relation to either sort of case we arrive at the conclusion that a sensible phenomenon is set into relief in relation to other phenomena precisely where a discontinuity of the given sort has been created by the qualitative moments which fill its extension. Only thus can the phenomenon 'make itself count on its own and be noticed (stand forth for itself)'.[13] It is *separation*, in other words, which accounts for *salience*. Thus we have strong grounds for supposing that qualitative discontinuities can indeed serve as an organizing principle of the qualitative world of the sort we have been seeking.

A§d ii: In giving an appropriate mathematical expression to the notion of qualitative

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[13]. Cf. § 8 (A239, B244) of Husserl's 3rd Logical Investigation. The ideas in this work, which reveal a remarkable topological sophistication, have unfortunately remained unexploited by Husserl's successors.

discontinuity we follow the topological approach outlined by Thom. Suppose that W is the spatio-temporal extension of a given phenomenon. As a portion of space-time, W is of course a topological space with the usual topology. Suppose further that the different qualities which fill W are expressed by degrees of $\underline{n}$ distinct intensive magnitudes q_1, q_2, ... , q_n, each a function of points w å W. The $q_i(w)$ are then sensible qualities (colour, texture, temperature, reflectance, etc.), but considered physically,[14] as immanent to the objects themselves and as associated with a certain possibility of measuring.

A point w is called *regular* if all $q_i(w)$ are continuous in a neighbourhood of w. Let R be the set of regular points of W. R contains a neighbourhood of every one of its points, and hence it is an open set of W. Let K be the complementary set of R relative to W. K is the closed set of what we can call the non-regular or *singular* points of W. Clearly, w is a singular point if and only if there is at least one quality q_i which is discontinuous at w. We shall call K the *morphology* of the phenomenon that fills W. K is the system of qualitative discontinuities which sets this phenomenon into relief and makes it salient as a phenomenon. Consider, for example, the morphological organization of a leaf, of a crack in a window-pane, of a dog, or of the photograph of a dog.

Ad iii: In order, now, to accord physical content to the definition, we must find some way to conceive a morphology K as a manifestation of physical properties internal to whatever underlies or causes the phenomenon in question. Condensing a lot of physical detail into a small space,[15] we can say that the instantaneous states of a physical system *qua* physical are, when taken individually, *transient*: they are too fleeting to be observable. There are however circumstances in which there arise effectively observable states of a system: this occurs for example where trajectories manifest asymptotic behaviour, or where there is sufficiently rapid oscillation between one stable endpoint and another. Such effectively observable states, the states into which the system repeatedly falls, or into which it tends to fall, are for obvious reasons called the *attractors* of the system. Consider, for example, an oscillating electric circuit. From any initial state the system after some time reaches the stable oscillatory state and so its trajectory is attracted by this state.

Return, now, to our phenomenon of the spotted dog having substrate S, spatio-temporal extension W and morphology K. Choose a non-singular w å W. The internal state of the substrate S at w can be physically described in terms of some attractor A_w. And the $q_i(w)$ are intensive quantities associated with A_w. To explain

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[14]. Of course certain simplifications are involved here. Thus colour might be accounted for in terms of three distinct qualities: hue, saturation and brightness. Similarly there is no single property of reflectance, which is a macroscopic approximation of a more fine-grained system on the quantum level of a range of properties having to do with the emission-absorption spectra of the atoms constituting the substrate.

[15]. Some of this detail is provided in our paper “Physics and the Phenomenal World”, in preparation. [Now published in R. Poli and P. M. Simons, eds., *Formal Ontology*, Dordrecht/Boston/Lancaster: Kluwer, 1997, 233–254.]

the qualitative discontinuities of the $q_i(w)$, we now let w_o å K be some singular point of W. The idea is that in moving through points w å W the attractor A_w becomes unstable when we cross w_o and is replaced by another attractor B_w. Similarly we can explain what happens at the exterior apparent contours of things by saying that when we cross such a contour the attractor A_w disappears entirely.

In macroscopical physics, there are many examples of such phenomena of transition of the internal state of a system. They are known as *critical phenomena*. A typical example is that of phase transitions in thermodynamics, where a system undergoes a sudden change of thermodynamical phase (for example from solid to liquid or from liquid to gas, from a magnetic to a non-magnetic phase). Such changes occur when a parameter such as temperature crosses a critical value. In this example the qualities $q_i(w)$ are the thermodynamical phases. The behaviour of the underlying physical system is unobservable. What we experience as salient, and what we possess words to describe, is the qualitative discontinuity which is the phase transition.

There are many other critical phenomena: for example shock waves in acoustics, transition to turbulence in hydrodynamics, buckling in elasticity theory, etc. All such phenomena are salient in our perceptual experience. They and their like are the physical support of the qualitative organization of the world of everyday experience.

A Theory of the Commonsense World

We claim that one can succeed in this way in solving the problem (in principle, at least) of relating physics and the qualitative world from the point of view of the mathematics of morphologies. Of course our treatment of qualitative discontinuities, too, does not yield a description of the qualitative world as some monolithic bedrock of reality. In this sense it is at the same distance from an ontology in the strict sense as are classical mechanics, quantum mechanics, etc. For our theory deals after all not with objects (qualities, etc.) in the world, but rather with products of mathematical reconstruction. The difference, however, is that this reconstruction turns out to allow on its own terms a mimicking of just those central features of the Aristotelian commonsensical ontology that were so fatefully abandoned by Galileo and his successors. That is, it offers not only a theory of qualities, but also, in the long run, a theory of substance, of change or process, of typicality, species and categorization, and so on – or in other words an entire theory of the commonsensical world.

But does this theory constitute a science in the strict and proper sense? Certainly it is not predictive in the usual (causal) sense; but then the aim of the qualitative ontology is not the aim of standard physics. The approach does lead to prediction, but only in the sense that it leads to the possibility of our explicating mathematical constraints for different sorts of empirical morphologies. This is a ‘prediction’ of exactly the same sort as the predictions to the effect that if you have, for example, a crystal, or the envelope of a virus, or a snowflake, or honeycomb, or an ornamentation of the Alhambra of Granada, then the symmetry of the structure is necessarily one of the ‘Platonic’ symmetries which is allowed by geometry. There exist theorems which make the same type of structural predictions for the possible morphologies K. These predictions can be interpreted as abstract mathematical constraints upon the universe of morphological phenomena.

Qualitative Ontology and the Science of Cognition

We have seen how a theory of the commonsense world can be rooted in the physics of the material substrates. But in order to have a plausible theory of the qualitative world we clearly need in addition a psychological-cognitive theory of perception and an account of the link between this theory and the substrate theory, or between perceiver and object of perception. How is the perceiving subject involved in the perceptual explication and cognitive interpretation of the qualitative structure of the commonsensical world? As far as qualities such as colour is concerned, we already dispose of considerable work on these problems and we know something about the steps which lead from physics to the mind.

We have first of all, at the microlevel, the absorption-emission spectra of the atoms making up the substrate. At the macrolevel we have the reflectance of the object, which gives rise in its turn to transmission of light of certain wavelengths. At the level of the retina, the light excites the cones and the information (pattern of wavelengths) it bears is processed by these transducers, which is to say it is transformed into neuronal information (frequencies of neuron-firings codifying the wavelengths). This gets processed further on its way to the visual cortex, where there occurs the registering of a sensible quality of colour. Through all these steps something is preserved, and from our present point of view it is clear that at least part of what is preserved can be very well explained via the concept of qualitative discontinuity. For this is a concept which applies equally to qualities as realized physically and as apprehended in patterns of sensation in the mind. Wave optics explains (in a highly non-trivial manner) how the very special type of information which concerns qualitative discontinuities can come to be encoded in light (that is to say how singularities can be propagated by light). And the theory of visual perception (for example as propounded by David Marr) clarifies the perceptive endowment which allows us as cognitive systems to detect and to process this information. Briefly we can say that qualitative discontinuities on the side of the object are qualitatively salient for the subject because the concept of qualitative discontinuity is at one and the same time an objective and a subjective concept.

The interest of the point of view of Marr and his successors is that it reconciles two apparently antagonistic approaches: the information-processing point of view, and the ecological point of view of J. J. Gibson, *et al.* In the classical cognitivist paradigm (as exemplified by Fodor, Pylyshyn, *et al.*), information processing is essentially reduced to the operations of calculation on symbolic mental representations. These operations are essentially syntactic: the cognitivists focus exclusively on algorithms and neuronal implementations thereof; they leave no room for any link between the cognitive system and those objective, stable features of the qualitative world which we have placed at the centre of our concerns. If, however, one wants to introduce such objective structures of the environment into one's account of perception and cognition, as the ecologists do, then one is committed to making such structures constrain the information-processing devices.

Marr explains that what Gibson considered as the ‘extraction’ (pick-up) of invariants from the environment can be understood as a form of information processing capable of being explicated in computational terms. But a computational theory in Marr's sense must not only focus on algorithms and neuronal implementations; it must in addition comprehend each algorithm in relation to the type of object-derived information which it processes. But then, because the algorithms employed are determined by objective properties of the environment, it follows that we have a means of reconciling the syntactic status of the algorithms with an ecological semantics. Methodological solipsism is hereby overcome, and the world is once more made safe for qualitative experience.