

An Observable World

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August 31, 2012

My effort here is not to modify quantum mechanics to make it consistent with my view of the world, but to modify my view of the world to make it consistent with quantum mechanics.

Carlo Rovelli [1]

1 The Communications System

Why does it make a difference, in quantum physics, whether something is observed?

In our current conceptual framework, it's hard to imagine a sensible answer. It gives us only two alternatives: either a thing is objectively real in itself, apart from any context in which it might be observed, or else it's just subjective, in someone's mind.

Now surely the physical world is objectively real – but that's not all it is. It's not only a vast body of observer-independent fact, but also a complex web of interactions that communicate those facts, making them observable from the viewpoints of countless local systems. This informational environment isn't happening in our heads; it's the aspect of the physical world that can actually be experienced, by a person or a measuring device or anything else.

This communications system isn't hypothetical – we know it exists, and we know it works, since it's the source of any information we can have about the world. But we generally take it for granted. In describing things objectively we focus on what they are in themselves, not the interaction-context that makes them observable.

We have excellent theories of all the components of this system, from an objective standpoint – the electromagnetic and gravitational fields, the many quantum fields through which particles interact. But we don't usually think of it as a functional system, or ask how these different interactions work together to define and communicate information. Objectively, we theorize about the world as though we could stand outside, and describe what's there from no particular viewpoint. So the question of how things are physically observable from particular viewpoints doesn't even come up.

The objective standpoint works fine, in classical physics. But quantum theory suggests that at bottom, things have determinate characteristics just to the extent that this information is empirically determined through interaction with other systems. If so, the ability of our world to communicate about itself may be something we need to understand. Instead of taking reality as just given in itself, we may need to reconceive it as the shared information-content that's constantly being communicated between local systems through interaction.

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Consider a rainbow.[2] A camera can record its circular array of colors, so it's not subjective. But it can only be seen from a certain angle, relative to the sun and the falling rain. If we describe the situation objectively, from no point of view, we have the sun and raindrops at their respective coordinates in space, and laws of optics that tell us how light bounces through raindrops. But there's no rainbow in the objective picture. It belongs to the physical world as seen from inside.

Even so, in classical physics, the rainbow is well explained by the objective picture. We can just insert an observer at a certain spot and calculate what he'll see. Adding the observer doesn't change the factual situation; it just limits the information being considered. That gives us the appearance of the rainbow.

Our current framework assumes this is always true, i.e. that all significant information is given in the objective reality of things, and what appears from any particular viewpoint is just a limited (and maybe distorted) part of that information. Yet both of our more fundamental theories – relativity and quantum mechanics – differ from classical physics precisely by taking the observer's viewpoint into account. In fact, this is almost the only thing these two theories have in common. And the quantum theory makes it very hard to maintain that the observer makes no difference to the situation.

So while the objective standpoint works very well for most purposes, a fundamental theory may also need to describe the physical environment from the standpoint of a participant. And I suggest that we may already have two well-developed theories of that do this, in relativity and quantum mechanics. Possibly the reason it's been so hard to grasp what these two theories are telling us about the world is just our assumption that they're theories of objective reality, like classical physics.

When we look at them that way, relativity and QM give us two completely different and nearly incompatible pictures of the underlying reality. And each of those pictures seems so different from the world we actually experience that we can hardly expect to understand them, except mathematically. But I think our situation might actually be just the reverse – that is, these theories may be hard to understand because what they're describing is the world we experience, and we haven't yet learned how to think about physics from the point of view we actually have.

This essay has two main goals – first, to attempt a very rough preliminary sketch of the communications system, just to give an idea of what might be involved in developing a clearer conception of it. I then want to address a couple of basic problems in relativity and QM that need clarification if we're going to approach them as theories of communication. I'm not proposing any modification of these theories – only trying to imagine what they might be telling us, if we look at them from a different viewpoint.

2 Exploring Measurement Contexts

So what does it take for me to see the world, physically? For one thing, each photon my eyes pick up contributes to a visual field made of many other photon-interactions. Together they give contrasting shades and colors of light, showing me the shapes and locations of things. No one interaction could convey such information; there has to be a local context consisting of other interactions.

Further, each photon can contribute only if it's absorbed by an electron in my retina. That changes the electron's orbit in the context of its interaction with an atomic nucleus, which changes the way the atom connects with other atoms in a molecule, which makes the molecule react differently with other

molecules – and so on. Interactions communicate because they make a difference in a context of other kinds of interactions, that also make a difference, in some other context.

We can begin to see why this question has hardly been explored. It's not that there's any big mystery about what makes things measurable; we know what's involved in each case. The problem is that measurements are inherently contextual. They can't be analyzed into simple, self-contained elements without losing sight of what makes them work.

In general, measuring any physical parameter requires a context in which the values of certain other parameters are known. So those must also be measurable, in other contexts, for which other kinds of measurements are needed. In practice, we count on certain background information being built into our equipment, such clocks and measuring-rods. But when we try to understand how that information gets determined, we're back in a tangle of interdependencies.

We can only measure distances in space or time because our clocks and rulers are made of atoms that have very special properties. Atoms have precisely uniform structures that define standard distances and frequencies. And, they combine to form stable, quasi-rigid molecules, to make up solid matter. Without such highly functional building-blocks, there would be no way to determine anything. And we know this functionality depends on the complex structure of atomic electron-shells, which depends on electromagnetic interaction as modified by several different quantum rules, as well as the still more complex interaction-laws that stabilize atomic nuclei.

So in short, if we try to explore the physical system that lets us observe and communicate information, we find ourselves in a jungle that may include all of physics. We find no well-defined basic elements, but a system where everything refers to something else. This is so different from the mathematical simplicity that physicists traditionally hope for in a fundamental theory, it's hardly surprising they haven't gone down this road. But I think this kind of inter-referential structure is just what's required, in principle, in any universe that supports observable phenomena.

The thing is, regardless of any objective reality we might imagine as the underlying cause of the phenomena we observe, any observable information has to be able to be defined and measured in terms of other observable information. Common sense tells us we can only measure something if it's really there, and has certain definite properties built into it. But whether or not there's any information built into the reality of things in themselves, the web of interaction still has to be able to define all the information it communicates in terms of other information it communicates. That's all any observer has access to.

So the structure of any observable world has to be something like the structure of a language, where the meanings of words get explained in other words. In our language, though, we can also explain many words by pointing to physical things they refer to. In the language of physical communication, there's nothing refer to beyond the language itself.

As another analogy, think about how your brain constructs a mental image of the world, by integrating the different kinds of information you get through sight, hearing, touch and balance. Each of these sensory systems constantly takes in new data and filters it, interpreting it in the context of data provided by the other senses. Together they maintain an evolving picture of what's going on around you, as the unconscious background of your conscious perception. So it takes a huge amount of complex low-level

processing to support the seemingly simple, stable, sensible view of the world you're seeing as you glance around.

What happens in the physics of communication could be similar to this. Many different channels of communication provide different kinds of information, making contexts for interpreting each other. A complex interplay of very different ways of interacting seems to be needed, at the atomic level, to support the simple, stable, determinate structure of the world at the level we actually observe.

3 The Present Moment in Spacetime

I'm suggesting that we need to look at the world in two distinct ways – both as a body of objective fact and also as a dynamic system that defines and communicates those facts between local systems. I'll try to show that both relativity and quantum theory have this dual aspect, and that in both cases the communications structure is what's fundamental.

In Einstein's original formulation, relativity was essentially a method of translating between the reference-frames of different observers. Where Newtonian physics located events in a universal framework of objective space and time, Einstein's innovation was to insist on defining space and time as actually measured from some point of view. In place of an external framework, these viewpoints were coordinated through the structure of light-speed communications between them, by assuming this velocity to be the same in all reference-frames.[3]

Then Minkowski reconceived the theory as describing the intrinsic geometry of spacetime, as an object in itself. When this opened the way to general relativity and the theory of gravity, the objective reality of spacetime seemed to supersede the observer's view. In fact, since space and time are completely different from the viewpoint of an actual observer, this internal viewpoint came to be seen as essentially wrong, in conflict with the underlying reality.

Now I want to show there's really no conflict here – the relativistic concept of spacetime is entirely in accord with our experience. Even though it can be useful to imagine spacetime as a thing in itself, it's also still the structure that coordinates different viewpoints through light-speed communication. But if we take the objective viewpoint as fundamental, we can easily miss what the theory actually shows us.

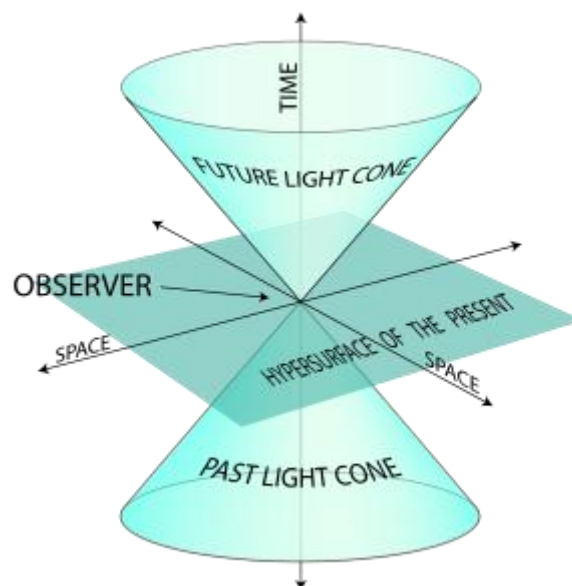
The conflict supposedly arises from our experience of the world as happening now, in present time. In classical physics, this was assumed to be part of objective reality – that is, it was taken for granted that certain events are happening simultaneously, right now, everywhere in the universe. But the first point Einstein made in his 1905 paper was that there's no objective definition of simultaneity. Observers in differently-moving reference-frames define different sets of events as happening at any point in time.

Given our current framework, if there's no objective, universal "now", then our experience of existing in the present moment must be subjective, an illusion somehow produced by consciousness. And this claim is frequently made.[4] It's said that in relativity, time is just another dimension of space; what physics describes is a static, 4-dimensional "block universe", where the future of the universe is already given, co-existing with everything in its past. In physical reality, you and I are 4-dimensional creatures who exist everywhere in our life-histories at once. This bizarre idea has some sensible opponents.[5] But surprisingly many physicists and philosophers take it as a proven fact, confirming that fundamental physics is completely at odds with our experience.

Yet any measuring instrument is subject to exactly the same time-constraints as we humans are. Space and time are not at all the same, physically – our environment is vast in space, but extremely narrow in time. A camera can see distant galaxies in all directions in space, but only at a particular instant in time; no instrument can see into the past or detect the future. It's true that if a galaxy is 5 million light-years away, then a camera sees it as it was 5 million years ago – but it can't be seen at any other point in time.

Now I think this is just what relativity is telling us about the present moment – not that it's happening in our minds, but that it's specific to our particular viewpoint in space.[6] The “now” I experience certainly doesn't include anything that may be going on simultaneously, 5 million light-years away. My present time here is related to the ongoing time in that distant galaxy in a different way – through the structure of light-speed communication.

To clarify, let's look at the familiar light-cone diagram –



This diagram actually illustrates two distinct spacetime geometries. The space of the diagram itself pictures an objective 4-dimensional “block universe”, with time on one axis and 3-dimensional space represented by the perpendicular plane. This “hypersurface of the present” is “now” as imagined in classical physics, as a set of simultaneous events happening throughout the universe. In a different reference-frame this plane would be tilted; a differently-moving observer would define a different set of events as happening at this moment.

But of course, none of these supposedly simultaneous events are actually present, from an observer's viewpoint. This spacelike hyperplane in the diagram has nothing to do with the “now” we experience. The space that's actually present for any observer is represented in the diagram by the dual light-cone.

The 3-dimensional space that's seen by the observer “now” lies on the surface of the lower cone. [7] This is the world that's physically present to him; the borderline between his past and future. What's inside the lower cone is for him past and gone, accessible only through the physical evidence it's left behind. Anything outside the lower light-cone hasn't yet happened, so far as he's concerned.

The upper light-cone is the space in which he's now present to others – the space into which he can communicate. And anything going on between the upper and lower cones is not part of his universe, right now – it can't affect him in any way, and he can't affect it. Later on in time, he'll be able to find out about things that were happening “at that moment” in other parts of the universe. Only then can the issue of “simultaneity” arise, in retrospect. At that point, his reconstruction of what happened on the earlier “hypersurface of the present” in the diagram will differ from the version given by observers in other reference-frames, since “at that moment” has no objective meaning for the universe as a whole.

So we have two distinct spacetime geometries here – the objective “block” spacetime of the diagram, and the ongoing spacetime of communication, from an observer's viewpoint. Mathematically, there's a simple relationship between them. In a 4-dimensional “block”, where time is just another dimension of space, the distance between two events is given by $(d^2 + ct^2)^{1/2}$, where d is the spatial distance between them, in a given reference-frame, and t is their distance from each other in time. But in relativistic geometry, the invariant spacetime interval is $(d^2 - ct^2)^{1/2}$.

The minus sign means that distances in space and distances in time cancel each other. It means there's no spacetime distance (a “null interval”) between the observer and any point on his light-cone. Every student of relativity knows this, but its meaning is rarely discussed. We're so used to thinking of the world objectively, as it's shown in the diagram, that the relativistic geometry seems “counter-intuitive”, impossible to envision. So the difference in sign often gets treated as a technicality – another weird aspect of physics we can only grasp mathematically, not in terms of our actual experience.

But this light-cone geometry is just the structure of space and time that we experience, from inside. When I look through a telescope at that galaxy, my “now” is connected through the light-speed web to a “now” 5 million years ago, 5 million light-years away. What's physically present to us is what's equally distant in space and in time. Even the very early universe is part of our present moment, here on Earth, though it's only present as something 13 billion light-years away from us in space.

Now it's much easier for us to imagine the universe as a “block”. And that's a useful way to think of it, as a big 4-dimensional box in which all events have their place, in objective universal history. In this view, light from a distant galaxy has to crawl along at a steady pace for millions of years, to reach us over all that distance. But in the spacetime view, light doesn't take any time to cross any distance in empty space. The “speed of light” isn't a velocity at which anything moves; it represents the way space and time are physically cross-connected.

This objective view is fine, if we don't take it literally. It's the view that Einstein had in mind when he introduced relativity, and it's hard to imagine teaching the theory without diagrams like the one above, with space and time on perpendicular axes. We just need to remember this isn't how space and time are physically connected, in spacetime. Forgetting that gives rise to specious “proofs” that the universe is a 4-dimensional block of fact, and “now” only happens in our heads.

Physically, we share our local present moment only with things that are present here with us – that is, near enough so there's no significant time-lag in our communicating back and forth, in real time. And since light-speed is very fast, on the scale at which we operate, we humans effectively share the same physical “now” with everyone on the planet. We all share a common boundary between our past and our future.

If we drew the light-cone diagram on a human time-scale, the cones would flatten out; they'd effectively coincide with the "hypersurface of the present" out to a range of many thousands of miles. Within this range, relativistic geometry coincides with our classical notions of space and time. But if I called a friend of mine on Mars by videophone, it would be obvious we don't share a common "now", at that distance. What I say to her in my present moment would be part of her present moment several minutes in my future. And she'd be part of my present moment as she was several minutes in her past.

This unfamiliar view is awkward to put into words, and in this brief space I'm not able to draw a clearer picture. To envision this kind of geometry objectively, from outside, we need to imagine something like a network of intersecting light-cones, connecting the different present-time viewpoints of different observers. But we don't really need to envision the cross-connected spacetime of the communications system, since we can all just look at it. This is just what we actually see, when we look up at the stars at night, where things that are equally far from us in space and in time are physically present.

4 How Measurements Happen

Like relativity, quantum mechanics first emerged as a theory of observables. Though it's always been controversial, the view of Bohr and Heisenberg was that QM gives only probabilities of measurement results. It doesn't describe any underlying reality, since if we interpret the equations that way, they show things as existing in a superposition of all their possible states, until a measurement is made. Even then the superposition "collapses" only for the parameters that are measured, and only to the degree of precision the measurement achieves. So quantum systems never have the kind of factual reality imagined in classical physics.

So we might well read QM as a theory of the observable world – and Carlo Rovelli took just that approach in his Relational Quantum Mechanics.[1] But I won't go into his very interesting paper here, since it concerns only the mathematical formalism of QM; he bypasses the issue of the physical context-structures that make information measurable.

Here we have a basic problem, though, because the mathematics of QM seems to tell us nothing about measurement. In fact, the equations tell us that when quantum systems interact, their superpositions don't collapse; instead, they get entangled in a combined system that still exists in all possible states. So again there seems to be a radical difference between physics and the world we observe. QM describes a statistical structure of possibilities, and what we observe is a structure of definite outcomes.

We might suppose something's missing from the equations, and that some interactions do create actual outcomes. As we've seen, many different interactions are involved in any measurement, so maybe certain ones are special. But if so, the equations are structured so it makes no difference to the theory's predictions which interaction does the job.

For that matter, we can collapse the superposition of a system without even interacting with it, if we can find out something about it indirectly, by observing other systems. Conversely, in "quantum eraser" experiments we can interact with a system to gain information, but then undo the measurement, by making the results inaccessible. Though the interaction occurred, the system remains in a superposition of states, so long as the information doesn't get out into the observable environment.

So in short, all experimental evidence indicates that no one event or one type of interaction makes a measurement. What counts is whether a physical context exists in which information is available to other systems. If we ask, to which other systems? – we get the same run-around. Say a physicist in the lab next door to me makes a measurement. Does the collapse happen when his instrument registers the result, or when he looks at his instrument, or when he stops by later to tell me the result? I can choose whichever I like; it makes no difference to the theory's predictions.

Now strange as it may seem, I think this actually makes sense. The problem is that we're looking for an objective description of how measurements happen, but there isn't one, because measurements aren't objective. They always depend on a particular physical context, and define information from a particular point of view. This is the basic point Rovelli made in the paper noted above: observable information only exists for a particular observer.

Equations give us relationships among parameters that are supposed to apply in every case, so they're inherently objective. In QM, when we write an equation to describe any given measurement set-up, it gives us only probabilities – because that's all you can say about the situation, without being part of it. I think QM is telling us that whenever we're in a context in which information becomes definable – where a particular outcome can make a difference, from our point of view – then a particular outcome always appears, as a random selection from the given possibilities. Where there's no context to which the outcome matters, there's no outcome.

And if there is such a context, the outcome exists for that context – not in the absolute. No objective transformation turns possibilities into facts, in an underlying reality. Outcomes can become objective facts to the extent that they get consistently communicated between different viewpoints, in a wider and wider range of contexts. So the communications system can support objective reality as a body of precise, universally agreed-upon fact, but only at a high enough level – where the interaction-web is densely woven, where the weave is complex enough to provide interrelated contexts to measure all the different kinds of information involved.

However this system may operate, it seems very different from our classical notions of how things happen in the physical world. But is it different from what we experience? In each present moment, we find ourselves in a situation where many things are possible, and some are more likely than others. As we interact with things around us, certain of these possibilities become new facts, and that revises the structure of what's possible, both for us and for the other things we're interacting with.

And these "facts" are only for us, in this moment. To be sure they're objectively real, we have to look twice, and communicate with others to confirm things look the same from other perspectives. So our human reality isn't just given – it's an evolving construct maintained by ongoing observation and conversation. Quantum theory may be telling us that physical reality is also an evolving construct, maintained not by human observers but by the interactive environment we observe.

5 Evolving Communication

I've tried to make it plausible that what our current theories describe is not after all radically different from the world we experience, and that by learning to conceptualize the world from inside, we might see more clearly what those theories are telling us. This approach raises difficult questions that I haven't dealt with here, and it promises no simple answers. But I'd like to suggest one more reason why this challenge may be worth taking up.

However it works, the environment we experience constantly reproduces the vast, complex body of information that we call objective reality, from moment to moment, by defining and communicating very small parts of this information between local systems. As you look around right now, this is what you're seeing. For this to happen, each local system needs a present context that makes the incoming data observable, so it can contribute to other contexts that make other information observable.

At least, this seems a reasonable way of imagining the world we experience. Whether or not there's an absolute reality underlying this web of communicated information, it's evidently able to define itself in terms of itself, over and over again in each moment, always with slight variations, from countless points of view. And it does this through a kind of random selection, subject to environmental constraints.

So it's conceivable that what we're looking at is an evolutionary process operating through a kind of natural selection, analogous to biological evolution. Instead of many organisms replicating themselves, reproducing their species, here we have many local systems contributing to the reproduction of their common environment, as a body of shared, self-defining information.

If we had more insight into what's required to make this environment work, we might be able to think of simpler systems that would be able to do this at a more primitive level, defining only a few parameters in terms of each other. We might be able to see how more complex communications could emerge within these simpler interaction-webs, and we might look for vestiges of these simpler stages in the complicated physics of our present universe.

Our current physics is after all not only complicated but extremely finely-tuned, to support observable phenomena. We can easily imagine other universes – based on physics exactly like ours, except for small differences in a few basic constants – in which no stable atoms would be able to form. Without atoms, as noted above, there would be no physical means of measuring anything. The laws of physics would be moot; none of the parameters we use to express them would even be definable.

So is our universe built the way it is just so we can observe it? We can always dismiss fine-tuning as a selection effect, since the only universe anyone could observe would have to be one that supports observers. But that tells us nothing, and we know evolution can be a powerful way of explaining finely-tuned complexity and diversity. So it may be worth considering whether the observable world may in fact be evolving around us in real time, as we watch.

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