One „Time" is Not Enough

Essay written for the FQXi contest on the Nature of Time

Introduction

 We expect too much of time. The word applies to one of the dimensions, a coordinate of spacetime. Spacetime is a complex physical concept. It is a four dimensional geometry, an abstract mathematical theory, which is interpreted by Relativity in terms of experiments. That mapping, called semantics by Carnap's school, is the content of a physical theory. For example, a geodetic is interpreted as the path of a light beam traversing two points.

    In the interests of clear communication, this semantical mapping should be one-to-one. One mathematical symbol should correspond to one, and only one, physical concept, unless careful analysis shows that the two concepts are identical, or at least compatible.

What is the other meaning of the word "time"? We do not really have a special word for it. We treat it as an obvious function, and this may lead to confusion. A good name might be "universal evolution parameter." By calling it "time," a concept we think we know, or at least assume exists, we are actually avoiding the question of its existence. Systems change, we can say they evolve, but that does not necessarily mean they evolve in time.

A few examples

 They may. The system of N classical particles does evolve in time. Such a system has a state at any given time, and a universal time common to all particles. In this case the "universal evolution parameter" does exist and can be made identical with time. However, let's consider a more complex case, a set of N interacting relativistic particles. To keep it as simple as possible, let's just consider pair interactions between the particles, mediated by light. We can use the semi-classical terminology Einstein used for the derivation of black body radiation in equilibrium with harmonic oscillators [1]. Particles interact through the exchange of photons.

  Using the terminology of Relativity, we have a set of events confined to a section of spacetime. The particles are moving and their momenta are changing whenever a photon is emitted or absorbed. If we think about these changes in terms of the transactional interpretation [2] of Quantum mechanics, we know that these changes happen in pairs: One particle emits a photon and the other particle absorbs a photon. The distance between these events is zero; the relativistic distance of the two events involved in a transaction is zero. Therefore, changes of momentum can be seen as collisions, and we can consider the system as a hard core event gas. We cannot say that the state of the gas is evolving with time, or in time. Time already has a role as a fourth component of each event. There may be no common or universal time in which the events or transactions can be sorted and ordered.

 Each particle may have a local clock and may count the cycles of some local process and call that local time. We can consider particles which are more complex, not just dipole molecules. Particles do not have to be elementary. They may each have local frames of reference in time and space. Each particle has an associated light cone. The changes which happen outside of one particular light cone are more remote those in the cone. Thus, the transactions form a partially

ordered set. But ordering does not guarantee the existence of a parameter, of a real number, which would tell us that one transaction happened before another. To say that system evolves "in time" or "with time," would mean we assume the existence of such a parameter.

Subjective probabilities

Let's consider even more complex systems: I am now at the origin of one of these frames of reference. Here 'I' means an observer, one of many possible observers. We can actually consider very complex particles, each having of E10 cells, with each cell made of E10 atoms, and intelligent enough to be able to reason about their environment. These complex particles, let's call them subjects, get information about the outside when one "their" atoms or molecules absorbs a photon. They measure and manipulate their environment by sending out photons. They learn to synchronize their clocks according to Einstein's prescription and learn something about the outside particles. Their knowledge of the outside world is incomplete, as new particles with unknown properties enter their respective light cones. In addition, there may by spontaneous emissions, which occur at random, without a cause.

While these subjects can imagine the system in a semi-classical way, as a set of particles, they can only describe it in terms of probabilities. These, of course, are subjective probabilities. Like the word "time," the label "probability" is used for different physical concepts, not only in Quantum mechanics, but in classical statistical physics as well. To avoid confusion, we will only use the term "probability" in one narrow meaning.

Let's illustrate this narrow meaning with an example: I go to Las Vegas and play Black Jack. I count cards. Those are my measurements. I have made some assumptions about the game, about the number of tens in the deck, but my information about the deck is incomplete. I can only estimate the probability that the next card, which I, or my fellow player will draw, will be a ten. Each time I see a card go by, I adjust my incomplete picture of the world. I recalculate the probabilities and I assign them to the outside events. If I play, count, and calculate well enough, I survive, and may continue to play next day or with the next deck.

As long as I do not confuse my picture of the world, my assigned probabilities, with an undefined concept called „the state of the system," or even „the state of the system at time t," I will have no problem. I will not encounter any paradoxes. In the card game analogy, I do not see others' hands, and I do not know what probabilities they have assigned to the events which they will encounter in their futures.

If we accept this narrower definition of probability, then there is no „Wigner's friend paradox." If one of the players were Wigner, and his friend told him about the hand of another player, that would not create a problem. The probabilities we all have are subjective, and tied to our frames of reference. Wigner could accept the advice, and recalculate the probabilities, or he could consider this a bluff, and disregard the „information." That would depend on the degree of trust, on the psychology of the players. Players are systems too complex to be predictable. Instead dealing with psychology, we will return to the question of how the system changes when simple particles exchange photons.

Evolution parameter

Each transaction involves a pair of spacetime events, or points in spacetime. In

special cases, in macroscopic situations, we can see that the observers are
cylinder-shaped clusters of atoms in spacetime. These structures, the observers,
construct images which are imperfect and incomplete pictures of both their
internal structure and of the outside world. In some cases, they may be able to
construct from shared data a real-number-valued parameter. Such a universal
evolution parameter may allow them to decompose the section of the spacetime
containing the event gas, into a sequence of „states," each state corresponding to
each value of the „universal evolution parameter." They will not, however, succeed
in all cases.

We have argued that the concept „a state of the system at time t" is not always
meaningful. Only when the sequence of „states," each associated with an „evolution
parameter" exists, can this „universal evolution parameter"   be made equal to
„time."

An example of such a special case is a system of N classical particles. The state
of the system is given by the phases of the particles: q(i), p(i) with i,j   =
1,2, ... N. The interaction of the particles (let's consider just one kind) can
be described by an interaction potential f(q(i) – q(j)). At each instance of
"time" (here, time is the same concept as the evolution parameter) the momenta p(i)
are updated by forces acting between all the pairs i,j.

In the more general, relativistic case, the interaction potential is replaced by
the interaction action S(p(i), q(i), t(i), p(j),q(j), t(j)) . The inter-action
defines the probability that a photon was exchanged between particles i and j.
There is no given ordering of the transactions. Instead of a „state of the system"
and „time", we have a set of event pairs, of transactions. Each such event has
space coordinates and a time coordinate.

Proof by contradiction.

  We will now show that indeed there are cases when this event gas cannot be
decomposed into a common "time" and a sequence of "states of the systém." We will
carry the proof by contradiction. We will assume that decomposition is possible,
and show the contradiction. Specifically, we postulate the objective reality of
the particles. We postulate that all interactions are local, which means confined
to their respective light cones. Then by the reasoning of the Bell theorem [3], we
obtain predictions which conflict with observations. Therefore, the assumption we
made was incorrect. Therefore, in these types of systems, there is no consistent
physical concept which can be described as "the state of the system at the time t."
 QED

Recapitulation

The line of reasoning presented here could be called "The Hidden Assumption
Interpretation of Quantum Mechanics." The assumption is called hidden, but not
because it is hard to see. At the beginning of most of physics expositions, we
often find a statement such as: " ... the state of the system at any one time is
sufficient to determine its future and past evolution in time..." e.g. in [4], page
1.

   What is hidden, what is hard to see, is the fact that this is an assumption. If
that assumption is accepted, then the Bell theorem can be applied to the physical
system and predicts values which conflict with experiment. That is often taken as
evidence that experimental facts, axioms of objective reality, and locality,
conflict. However, we do not have to accept this hidden assumption. If we want to

keep the postulates of objective reality and locality, then we have to abandon
that assumption. We may have to construct a „parameter of evolution"
in which systems do evolve.

References

1) Black Body Radiation.
        http://www.egglescliffe.org.uk/physics/astronomy/blackbody/bbody.html

2) The Transactional Interpretation of QM.
        http://www.npl.washington.edu/TI/

3) Bell theorem
        http://plato.stanford.edu/entries/bell-theorem/

4) What if Time Really Exists?
        http://fqxi.org/community/forum/topic/318