A Conversation about Entanglement – a Science Fictive Dialogue

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Today quantum mechanics is state-of-the-art in physics, accepted by everybody and with an abundance of practical applications in physics, chemistry, medicine, etc. But in the beginning of 20th century many of the consequences derived from its mathematical basis were hard to swallow by the scientific community. Even Albert Einstein protested against some of these consequences which contradicted the concept of causality as a foundation of so-called classical physics. Einstein had himself expanded or gone beyond this concept in his theories of relativity. But these theories could still be seen as generalizations of the classical concepts and as a very elegant completion of the "Newtonian" physics.

Quantum mechanics, on the other hand, was a much more dramatic revolution of basic principles, with Niels Bohr as a pioneer. Bohr's and Einstein's discussions on this matter have become famous, mainly because Einstein derived some spectacular intellectual experiments from the mathematical basis of quantum mechanics which implied observable phenomena which, according to Einstein, were "impossible". Einstein's trump card was that these phenomena not just contradicted well-known physics, but also apparently ordinary logic. But Bohr insisted. Long after the death of both the experiment, to the surprise of most of the scientific community, was realized, and turned out definitively to Bohr's side.

To explain this experiment, and other ones, always confirming Bohr's revolutionary thinking, is not so easy. There are good reasons that even Albert Einstein did not accept it. And to explain the mathematical basis is of course far beyond what is possible in the present exposition. However, we are so lucky that Einstein's objections basically were not technical, in their essence, but logical. And logic is, in its essence, the property of everybody. So perhaps it can be explained in a non-technical way, after all.

Because this is a question of the logic of relations between phenomena, the phenomena in themselves are not so important and may be changed from originally elementary particles to e.g. people, despite real people are not behaving like elementary particles, although we don't quite know why. And the technical equipment can also be changed to more ordinary settings, so long as the logical structure of the scenario is the same.

This is the background for the following piece of "science fiction".

Two CEO's from some small companies in software business are participating in a seminar on programming and now they meet in the evening in the bar. They know each other from their study time and from other seminars. Carl is working in Copenhagen, the Danish capital, and Anders is working in Aarhus, the second largest city in Denmark, some 150 km west of Copenhagen as the

crow flies. The seminar is held in Odense, the third largest Danish city, somewhere in between the other two.

After the professional sessions during the day it is time for small talk:

Anders: *Funny, I have in fact a new employee, Anna Nicolaisen, who lives just around the corner and every day is commuting all the way to Aarhus.*

Carl: *What a coincidence, I have a new employee, Curt Nicolaisen, who also lives somewhere in Odense and every day is commuting to Copenhagen. Nicolaisen is not a very common family name. They could even happen to be a couple, but Curt never mentioned that.*

Anders: *Neither did Anna, so I am in doubt. She is not talking much, but answers briefly when asked, and she obviously does not like directly being questioned about her private life.*

Carl: *It is the same with Curt. He is smart, but very shy also, so I don't like to ask him. But now I have become curious. How could we find out? I know that his official address for some reason is his cousin's, also in Odense. So we can't use that information.*

Anders: *I guess they are in fact a couple living together but want to hide that, and I guess that, as shy as they are, they are much more together than separate. Perhaps we could ask them about some innocent facts from their daily life and see if there is some sort of coincidence or co-ordination.*

Carl: *Good idea! What if we for a period ask them if they watched TV last night or not, that is what everybody in the company do already.*

Anders: *Yes, but you can't ask the same question every day. That is too conspicuous. You must have at least one more question. What about asking if they ate at home or went out for dinner?*

Carl: *Perhaps that is too private, but we can try. But you can't ask two questions, that would also be too conspicuous, and asking one question is already stressing these shy people. I propose we change between asking if they watched TV and if they ate at home.*

Anders: *OK! But if we co-ordinate our questions there is a risk that they tell each other what they were asked about when coming home in the evening, and then the cat is out of the bag, and we will get no answers any more.*

Carl: *OK! Then let us every morning, independent of each other, toss up for what we ask about, e.g. heads for the TV-question and tails for the dinner-question. Then we are sure there is no system in our questions to make them suspicious.*

Anders: *Good idea! My chance to ask a little casual is at our morning briefing from 8 to 8:10, best in the very beginning before people get seated.*

Carl: *Exactly the same in Copenhagen. So let us put the questions simultaneously at 8 sharp to both.*

Anders: *I suggest we do it the next 40 working days, write down our questions and the answers, and then meet and compare our lists.*

Carl: *Agree!*

Anders: *In fact I have a meeting in Copenhagen Friday just after the 40 days. Then we could meet in the evening and compare our lists.*

Carl: *Fine!*

Friday after the 40 days they meet again at some trendy café in central Copenhagen and compare their lists. They have followed their agreed plan strictly, and both Anna and Curt had answered their boss every time, although with low voice and nothing but "yes" or "no", and looking away. More questions were obviously not welcome and had certainly not been answered.

Anders and Carl have been lucky when tossing their coins. Exactly 10 times have both asked about TV and 10 times both about dinner. Another 10 times has Anders asked about TV and Carl about dinner, and finally 10 times has Carl asked about TV and Anders about dinner. It also turns up that both Anne and Curt half of the times they are being asked about TV say "yes" and half of the times say "no". The same with the dinner questions, both say half of the time "yes" and half of the time "no". A little strange with this regularity, but in no way impossible. Perhaps Anna and Curt, each or together, have a system of every second day watching TV and every second day eat out. Or perhaps they are also tossing coins to decide what they should do, each or together, if they at all are doing things together which can't be told from these counts, so far.

The interesting thing for Anders and Carl is, of course, if Anna and Curt are also ***agreeing*** in the 20 cases when they are answering the same questions. And it turns up that they are, in fact. When both are asked the TV-question they either both say "yes" or both say "no". And when both are asked the dinner-question they also either both say "yes" or "no". So Anders and Carl conclude that Anna and Curt must have been together at least these 20 days and done the same every time, and when these days have been chosen by chance there is very hard statistical evidence that Anna and Curt are always together and really are a couple, whether they really did the same all days or if they just agreed what to say when arriving to Odense, which must be just as hard evidence for their alliance as if they are just telling the truth.

Carl: *Well, then we can conclude that Anna and Curt really are a couple.*

Anders: *Yes, quite sure! But still there is something very strange about their answers. I had a look also at what they answered the 20 days we happened to ask different questions, and a very peculiar pattern appeared, which I can't explain. The 10 days when I in Aarhus asked Anna about dinner and you in Copenhagen asked Curt about TV, they always both said "yes" to both questions or "no" to both questions. They never answered differently. But all the other 10 days when I asked Anna about TV and you asked Curt about dinner, they never gave the same answer, but always answered differently, although changing over half of the times. How is that possible, if they are telling the truth?*

Carl: *Why should that be impossible?*

Anders: *Let us imagine that they one day watched TV and ate home, and that they always tell the truth. If we both asked about TV, they should answer "yes" and "yes". If we both asked about dinner, they should also answer "yes" and "yes". If I asked about dinner, and you asked about TV, they should still answer "yes" and "yes". But if I asked about TV and you about dinner, one of them had to tell the truth and answer "yes", and the other one had to lie and answer "no" according to the patterns we observed. And it is the same problem with other combinations of what they in fact did. I checked them out also, and there will always be situations in which one of them has to lie to produce the pattern we observed.*

Carl: *OK, I see that it is impossible then, that they always tell the truth, given our pattern of observations. But that does not make the pattern impossible if Anna and Curt before leaving Odense just agree of what to answer each, whether they are asked about one or the other of the questions. In this case the truth does not matter.*

Anders: *I agree that the truth does not matter here, and further, what we are testing is their alliance, and not their trustworthiness. My problem is that I can't imagine how any agreement or any rule, however elaborate, can help them to produce the pattern we observed. I tested the possibilities out with paper and pencil, and there always were combinations where one of them had to know what question was asked to the other one to know what she or he should answer to her or his own question. But how can they know what question is asked to the other one when it is a result of tossing coins 150 km away? And you know that if anybody is taken with a mobile phone during the morning briefing, he or she is sacked on the spot. And how should they be able in any case when just in front of the boss?*

Carl: *Well, apparently they still know, after all. Perhaps it is some kind of telepathy. Or perhaps, when they got married, they really became "one flesh" as you know.*

Anders: *Now you are joking.*

Carl: *Not quite. There is more in the world than we learned in the physics lectures, I believe. And here I think we in fact have an example of telepathy. What Anna is answering in Aarhus depends on what I am asking in Copenhagen. We just agreed on that, didn't we?*

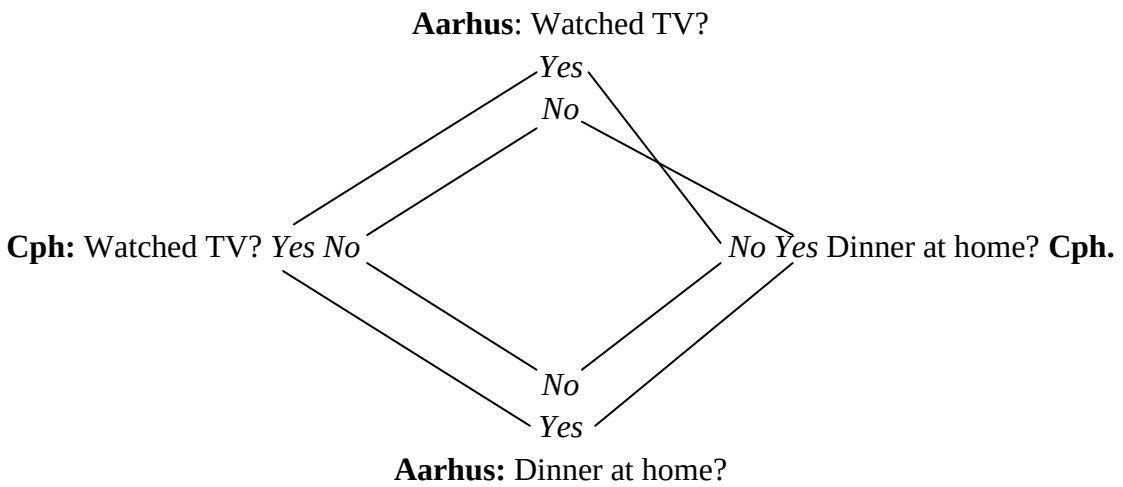
Anders: *Yes.*

Carl: *Well, and you receive Anna's answer. Consequently, is what you receive dependent on what I am asking, and the coupling between Curt and Anna is functioning as a communication channel between you and me. By choosing myself what to ask, instead of tossing coins, I could in this way send a message to you, in a sort of Morse code, or as a 01-string, as we know from the programming course. I communicate to Curt. Curt communicates to Anna. Anna communicates to you. Hence, I communicate to you. I know my elementary logic!*

Anders: *I am sure you do. But perhaps it is not quite applicable here. Let us imagine that I in Aarhus ask Anna if she watched TV, and that she answers "yes". What can I then conclude? If you asked the same question to Curt he must also have answered "yes". If you asked about dinner he must have said "no", because in this case they always answer differently. But how can I know which of the questions you asked? It is the same in all the three other possible combinations of question and answer in Aarhus. The answer I get from Anna is influenced by her knowledge of what you asked in Copenhagen, but I get no information about it, before we meet afterwards and compare what happened. I accept your premises that there is a coupling between your and Curt's behavior, between Curt's and Anna's, and between Anna's and mine. But it seems that you can't "chain" these couplings in the normal way.*

Carl: *If the couplings are following the rules for causality, it should be possible to chain them. As we learned in the logic course, causality is "transitive". If* a *causes* b*, and* b *causes* c*, then* a *causes* c*. You remember that?*

Anders: *Well, then the couplings are not following laws of causality. They are simply not causal. And that is also the explanation why they can't be links in a communication channel, carrying information as part of a transmission system. Do you remember my friend Niels who is in the Physics Department at Aarhus University, working with what they call quantum optics? They are trying to build a quantum computer, and he promised that my company would be one of the first to receive a prototype for testing when it is running. He showed me a diagram with couplings between possible "states" of particles in some famous experiments, and that reminds me of what we are talking of here. I think I can use it to analyze our problem. Give me a piece of paper from your note block and your ball pen, and five minutes. Then I will show you something!*



Carl: *Nice diagram! But what does it mean?*

Anders: *It shows all the pair-wise connections between answers received the same time in Aarhus and Copenhagen, which we found when we compared our lists.*

Carl: *Beautiful! Fine overview! But there is some inconsistency in the diagram. All the connections can't be valid at the same time, because then every one of the answers is connected to its own*

opposite answer, which means that if you should say "yes" it follows by following the connections that you should at the same time say "no", and vice versa. The diagram is "twisted" like this funny Möbius strip you can make with paper, scissors and some glue.

Anders: *Agree, except that you twice said "at the same time". Only one of the pair-wise relations is realized at any time. The other ones are just "potential", so there will never appear any contradictions in reality, I mean in what is actually happening. But when we look at the whole set of possible outcomes of our questioning, I agree that all answers are indirectly connected to their own opposites. I think that is also what Niels was talking about when he explained that as long as you don't force an observation on the states in the quantum computer they are "co-existing" with their opposites.*

Carl: *So this "twist" is the reason that the relations can only be "chained" as "potentialities" and not in the "real" world, and therefore are not behaving as causality, because they are not "transitive" as you said?*

Anders: *Exactly! Anna and Curt are deeply dependent on each other, as we saw, and we have hard evidence that they in fact are a couple. But the link is not causal.*

Carl: *I think you are right. But now I can't take in any more of that today. Let's have a beer.*

Anders: *I will pay if you can answer this. There are three closed doors and behind one of them is a brand new car and behind another is a goat …*

Carl: *Stop it, please! I will pay.*

Here we leave the two friends and hope they have a nice evening in the bar. Of course this scenario could not take place in reality. People have never been observed to be entangled in the same way as small particles as e.g. photons and electrons, although we don't quite know why. But pairs of small particles connected by a common origin, e.g. a common "mother particle", being sort of "twins", behave in fact this way, or in a way which is logically equivalent to our example. In some way the one particle "knows" what is measured on the other one, because its reaction to measurement is in fact depending on it, even if their distance is several kilometers and even if a causal interaction is excluded, because it in that case should be faster than the speed of light.

Interaction, as we use to understand it, determined by the ***form*** of matter, its properties, is in fact excluded in entanglement. What is happening is rather that the two particles due to their common origin as ***matter***, i.e. as ***individuality*** beyond properties, are not separate, but rather, as Carl joked, are "one flesh", so to say a ***shared*** individuality. A little hard to understand, because we are not used to it since Galilei and Newton, but apparently true anyway.

What is happening, when the twisted logical structure in the system of potential relations, mapped in Anders' diagram, is being observed, is that it is forced to join the structure of the "actual" world (a little misleading often called the macroscopic world) which is "non-twisted". This can, however, not be accomplished as a continuous transformation, because the structure of the two systems are

not topologically equivalent. You can’t change a Möbius strip into an ordinary non-twisted paper-ring without using scissors and glue. There have to be a rupture, a discontinuity.

But all physical laws are continuous, and you can’t continuously map structures with different topology on each other. There is a rescue, however. You can connect the two structures with an intermediate continuous probability-function, allocating probability measures to the ruptures, or “collapses” in physicist slang. And this is in fact what is done, and the reason that we can’t avoid probability or chance in quantum mechanics, although not in quantum mechanics itself as isolated, but every time we make observations of a quantum mechanical system.

It sounds a little “Platonic” in this way to let mathematical necessity dictate reality. But if mathematics on the other side is not autonomous, but a picture of some logic in reality, or in our access to reality, it is easier to accept.