Essay

Bayes and String Theory

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Abstract

What does probability theory tell us about the range of possibilities that a theorist can consider for answers to this problem? Prior to the experimental result he will have some estimate for the probability that string theory is a correct theory of quantum gravity and for the probability that supersymmetry will be observed at the LHC. There are no absolutely correct global values for these probabilities, they are a relative concept. But at the least any answer should be consistent with the laws of probability including Bayes Law. In this essay, I discuss what we really can say.

Key Words: Bayes, String Theory, gravity, supersymmetry, probability, LHC.

If Supersymmetry is found or excluded at the Large Hadron Collider, how will it affect your opinion on string theory as unification of gravity and particle physics? This is a hard question and opinions differ widely across the range of theorists, but at the least any answer should be consistent with the laws of probability including Bayes Law. What can we really say?

A staunch string theorist might want to respond as follows:

"I am confident about the relevance of superstring theory to the unification of gravity and the forces of elementary particles because it provides a unique way to accomplish this that is consistent in the perturbative limits (Amongst other reasons.) Unfortunately it does not have a unique solution for the vacuum and we have not yet found a principle for selecting the solution that applies to our universe. Because of this we cannot predict the low energy effective physics and we cannot even know if supersymmetry is an observable feature of physics at energy scales currently accessible. Therefore if supersymmetry is not observed at the TeV scale even after the LHC has explored all channels up to 14 TeV with high integrated luminosities, there is no reason for that to make me doubt string theory. On the other hand, if supersymmetry is observed I will be enormously encouraged. This is because there are good reasons to think that supersymmetry will be restored as an exact gauge symmetry at some higher scale, and gauged sypersymmetry inevitably includes gravity within some version of supergravity. There are further good reasons why supergravity is not likely to be fully consistent on its own and would necessarily be completed only as a limit of superstring theory. Therefore if supersymmetry is discovered by the LHC my confidence in string theory will be greatly improved."

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On hearing this, a string theory skeptic would surely be seen shaking his head vigorously. He would say:

"You cannot have it both ways! If you believe that the discovery of supersymmetry will confirm string theory then you must also accept that failure to discover it falsify string theory. Any link between the two must work equally in both directions. You are free to say that supersymmetry at the electro-weak scale is a theory completely Independent of string theory if you wish. In that case you are safe if suppersymmetry is not found but by the same rule the discovery of supersymmetry cannot be used to claim that superstring theory is right. If you prefer you can claim that superstring theory predicts supersymmetry (some string theorists do) but if that is your position you must also accept that excluding supersymmetry at the LHC will mean that string theory has failed. You can take a position in between but it must work equally in both directions."

The Tetrahedron of Possibilities

What does probability theory tell us about the range of possibilities that a theorist can consider for answers to this problem? Prior to the experimental result he will have some estimate for the probability that string theory is a correct theory of quantum gravity and for the probability that supersymmetry will be observed at the LHC. In my case I assign a probability of $P_{ST} = 0.9$ to the idea that string theory is correct and $P_{SUSY} = 0.7$ to the probability that SUSY will be seen at the LHC. These are my prior probabilities based on my knowledge and reasoning. You can have different values for your estimates because you know different things, but you can't argue with mine. There are no absolutely correct global values for these probabilities, they are a relative concept.

However, these two probabilities do not describe everything I need to know. There are four logical outcomes I need to consider altogether:

- P_1 = the probability that both string theory is correct and SUSY will be found
- P_2 = the probability that string theory is correct and SUSY will not be found
- P_3 = the probability that string theory is wrong and SUSY will be found
- P_4 = the probability that string theory is wrong and SUSY will not be found

You might try to tell me that there are other possibilities, such as that SUSY exists at higher energies or that string theory is somehow partly right, but I could define my conditions for correctness of string theory and for discovery of SUSY so that they are unambiguous. I will assume that has been done. This means that the four possible outcomes are mutually exclusive and exhaustive. We can conclude that $P_1 + P_2 + P_3 + P_4 = 1$. Of course the four probabilities must also be between 0 and 1. These conditions map out a three-dimensional tetrahedron in the four-dimensional space of the four probability variables with the four logical outcomes at each vertex. This is the tetrahedron of possible prior probabilities and any theorists prior assessment of the situation must be described by a single point within this tetrahedron.

So far I have only given two values that describe my own assessment so to pinpoint my complete position within the three-dimensional range I must give one more value. If I thought that string theory and SUSY at the weak scale were completely independent theories I could just multiply as follows:

$P_1 = P_{ST} .P_{SUSY} = 0.63$
$P_2 = P_{ST} .(1 - P_{SUSY}) = 0.27$
$P_3 = (1 - P_{ST}) .P_{SUSY} = 0.07$
$P_4 = (1 - P_{ST}) .(1 - P_{SUSY}) = 0.03$

The condition that the two theories are independent fall on a surface given by the equation $P_1 . P_4 = P_2 . P_3$ that neatly divides the tetrahedron in two.

As I already explained I do not think these two things are independent. I think that SUSY would strongly imply string theory. In other words I think that the probability of SUSY being found and string theory being wrong is much lower than the value of 0.07 for P_3 . In fact I estimate it to be something like $P_3 = 0.01$. I must still keep the other probabilities fixed so $P_1 + P_2 = P_{ST} = 0.9$ and $P_1 + P_3 = P_{SUSY} = 0.7$. This means that all my probabilities are now known

$P_1 = 0.69$
$P_2 = 0.21$
$P_3 = 0.01$
$P_4 = 0.09$

Notice that I did not get to fix P_1 separately from P_3. If I know how much the discovery of SUSY is going to affect my confidence in string theory then I also know how much the non-discovery of SUSY will affect it. It is starting to sound like the string theory skeptic could be right, but wait. Let's see what happens after the LHC has finished looking.

Suppose SUSY is now discovered, how does this affect my confidence? My posterior probabilities P'_2 and P'_4 both become zero and by the rules of conditional probabilities $P'_{ST} = P_1/P_{SUSY} = 0.69/0.7 = 0.986$. In other words my confidence in string theory will have jumped from 90% to 98.6%, quite a significant increase. But what happens if SUSY is found to be inaccessible to the LHC? In that case we end up with $P'_{ST}= P_2/(1-P_{SUSY}) = 0.21/0.3 = 0.7$. This means that my confidence in string theory will indeed be dented, but it is far from falsified. I should still consider string theory to have much better than level odds. So the skeptic is not right. The string theorist can argue that finding SUSY will be a good boost to string theory without it being falsified if SUSY is excluded, but the string theorists has to make a small concession too. His confidence in string theory has to be less if SUSY is not found.

Remember, I am not claiming that these probabilities are universally correct. They represent my assessment and I am not a fully fledged string theorist. Someone who has studied it more deeply may have a higher prior confidence in which case excluding SUSY will not make much difference at all to him even if he believes SUSY would strongly imply string theory.

References

1. http://blog.vixra.org/2012/06/12/bayes-and-string-theory/