The fine tuning problem and the hierarchy problem

Suppose you calculate the following using a calculator..

$$2.343636 \times 3480.021 - 3.457626 - 3.449343 \times 2363.477587$$

Somewhat surprisingly, you will find that the answer is very close to zero, namely:

$$-0.000000019\cdots$$

In fact this is because I have delicately chosen the values in such a way that the final answer is very close to zero. In other words, if I had chosen a slightly different value for the first number, say 2.3436 instead of 2.343636, I would have gotten $-0.125\cdots$, a value not nearly as close.

You see here that a very slightly different value as input can destroy the closeness to zero as output. For such a case, we say that the values are "fine-tuned."

In theoretical particle physics, we encounter similar cases. For example, whatever it may mean, the observed cosmological constant of our universe is incredibly small compared to the values for the "input." We do not know why they are fine-tuned. Could this be a mere coincidence? Perhaps not, even though we are not sure; it is natural to suspect that a mechanism behind this should exist. The question of why the various constants in our universe seem to be fine-tuned is called the "fine-tuning problem" and is regarded as a serious problem by theoretical particle physicists. There is a fine-tuning problem in cosmology as well. In our later article "History of astronomy from the early 20th century to the early 21st century," we will briefly mention how Alan Guth proposed "inflation," the rapid accelerated expansion of universe in the very early universe, as a solution to the fine-tuning problem in cosmology.

Related to the fine-tuning problem is the hierarchy problem. One example of the hierarchy problems is the weakness of gravity. Gravity is very weak compared to other three forces (i.e. electromagnetic force, strong force, weak force) that are believed to exist in our universe. For example, it is 10^{32} times weaker than the weak force. In other words, there is a vast discrepancy, described as a hierarchy. One may ask then, "Where does this huge number 10^{32} come from? Why not a modest number like 2 or 3?" These are hard problems to answer, as physicists have found that the origin of the hierarchy lies in fine-tuning. For example, the strength of gravity is 10^{-32} times that of weak force. So, God needed to fine-tune his parameters to obtain a ratio as close to zero as 10^{-32}.

There have been several proposals to solve the hierarchy problem. To explain the weakness of gravity, in 1998, Arkani-hamed, Dimopoulos and Dvali suggested that the extra dimensions could be as big as a millimeter. (We will explain what the extra dimensions are in our article "Manifold.") However, critics of the proposal say that it doesn't solve the hierarchy problem but replaces it with another problem, namely, why the extra dimensions should be so big. In 1999, Randall and Sundrum proposed another model to solve the hierarchy problem. Their model uses the fact that you get only a modest number if you take the log of a very small number, i.e. a number close to zero.[1] For example, log of 10^{-9} is only -9, which may not be as modest as 2 or 3, but is way more modest than the original value. Along with the extra dimensions, both the ADD model and RS model are explained in detail in Randall's popular book "Warped Passages: Unraveling the Mysteries of the Universe's Hidden Dimensions."

Summary

- If a very slightly different value as input can destroy the closeness to zero as output, we say that the values are "fine-tuned."
- The question of why the various constants in our universe seem to be fine-tuned is called the "fine-tuning problem."
- The hierarchy problem, of which one example is the extreme weakness of gravity compared to other forces, is closely related to the "fine-tuning problem."

[1] If you do not know what log is, please read "Logarithm."