Regarding how Quantum Theory can only be true if it is, at is foundation, probabilistic:

> "The problem is this: At first glance, wave-particle duality is not only mysterious but inconsistent in a blatant way. The inconsistency can be understood with a thought experiment. Imagine a burst of light from which a light wave ripples out through an ever-widening sphere in space. As the wave travels, it gets more attenuated, since the energy in it is getting spread over a wider and wider area. (That is why the farther you are from a light bulb, the fainter it appears.) Now, suppose a light-collecting device is set up, a box with a shutter-essentially, a camera. The farther away it is placed from the light burst, the less light it will collect. Suppose the light-collecting box is set up at a distance where it will collect exactly a thousandth of the light emitted in the burst. The inconsistency arises if the original burst contained, say, fifty particles of light. For then it appears that the light-collector must have collected 0.05 particles (a thousandth of fifty), which is impossible, since particles of light are indivisible. A wave, being continuous, can be infinitely attenuated or subdivided, whereas a particle cannot.
>
> "Quantum theory resolves this by saying that the light-collector, rather than collecting 0.05 particles, has a 0.05 probability of collecting one particle. More precisely, the average number of particles it will collect, if the same experiment is repeated many times, is 0.05. Wave-particle duality, which gave rise to quantum theory in the first place, forces us to accept that quantum physics is inherently probabilistic. Roughly speaking, in pre-quantum, classical physics, one calculated what actually happens, while in quantum physics one calculates the relative probabilities of various things happening." (Barr, p.3-4)

Things get even stranger, and it is clear why some people pine for the good old days when waves were waves and particles were particles. One of those people was Albert Einstein. He detested the idea that a fundamental theory should yield only probabilities. "God does not play dice!" he insisted. In Einstein's view, the need for probabilities simply showed that the theory was incomplete. History supported his claim, for in classical physics the use of probabilities always stemmed from incomplete information. For example, if one says that there is a 60 percent chance of a baseball hitting a glass window, it is only because one doesn't know the ball's direction and speed well enough. If one knew them better (and also knew the wind velocity and all other relevant variables), one could definitely say whether the ball would hit the window. For Einstein, the probabilities in quantum theory meant only that there were as-yet-unknown variables: hidden variables, as they are called. If these were known, then in principle everything could be predicted exactly, as in classical physics. (Barr, p.4)

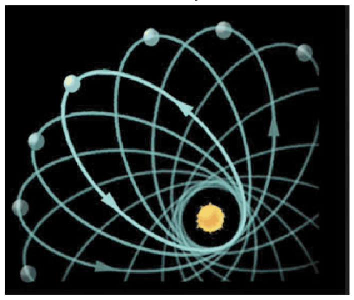
- **Statistical Model** – reveals patterns in a set of data, but gives no insight into the underlying mechanism causing the behavior.

    - **Ex:** Young Male Drivers (< 25 yrs.) have higher insurance rates.

    - **Ex:** Precession of Mercury's Orbit

Precession of the perihelion of Mercury http://physics.ucr.edu/~wudka/Physics7/Notes_www/node98.html

Figure 7.20: Artist's version of the precession of Mercury's orbit. Most of the effect is due to the pull from the other planets but there is a measurable effect due to the corrections to Newton's theory predicted by the General Theory of Relativity.



As seen from Earth the precession of Mercury's orbit is measured to be 5600 seconds of arc per century (one second of arc=1/3600 degrees). Newton's equations, taking into account all the effects from the other planets (as well as a very slight deformation of the sun due to its rotation) and the fact that the Earth is not an inertial frame of reference, predicts a precession of 5557 seconds of arc per century. There is a discrepancy of 43 seconds of arc per century.

This discrepancy cannot be accounted for using Newton's formalism. Many *ad-hoc* fixes were devised (such as assuming there was a certain amount of dust between the Sun and Mercury) but none were consistent with other observations (for example, no evidence of dust was found when the region between Mercury and the Sun was carefully scrutinized). In contrast, Einstein was able to *predict*, without any adjustments whatsoever, that the orbit of Mercury should precess by an extra 43 seconds of arc per century should the General Theory of Relativity be correct.

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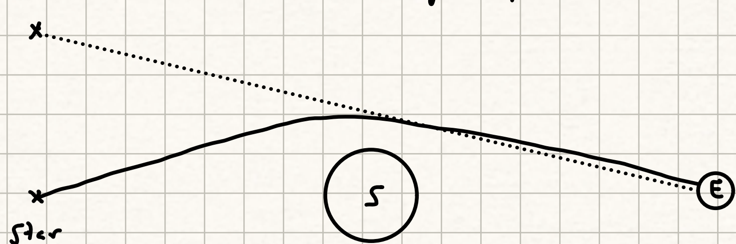
Next: Gravitational red-shift. **Up:** Tests of general relativity. **Previous:** Tests of general relativity.

Jose Wudka
9/24/1998

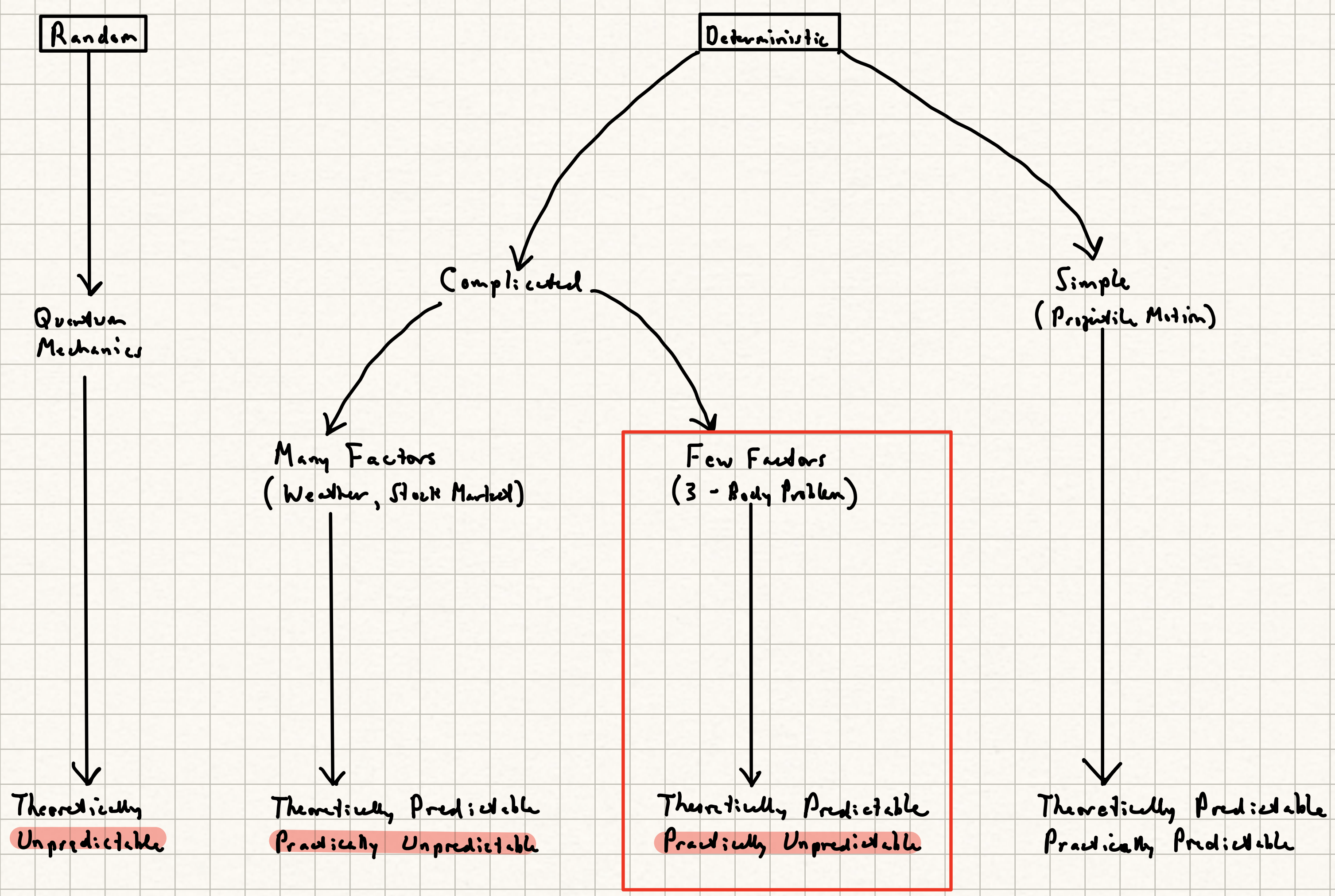
- **Theoretical Model** – are formulated from first principle (foundational observation of the universe; physical laws) and describe the evolution of a system from a given state. Give insight into the underlying mechanism causing the behavior.

    - **Ex:** Young Male Drivers – Why?: testosterone, social conditioning, frontal lobe development

    - **Ex:** Einstein's Theory of Relativity – gravity is the effect of mass warping space.

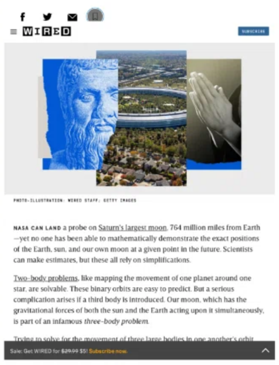


2. Conceptual Framework -



https://www.wired.com/story/technology-philosophy-three-city-problem/

NASA CAN LAND a probe on Saturn's largest moon, 764 million miles from Earth—yet no one has been able to mathematically demonstrate the exact positions of the Earth, sun, and our own moon at a given point in the future. Scientists can make estimates, but these all rely on simplifications.



Two-body problems, like mapping the movement of one planet around one star, are solvable. These binary orbits are easy to predict. But a serious complication arises if a third body is introduced. Our moon, which has the gravitational forces of both the sun and the Earth acting upon it simultaneously, is part of an infamous three-body problem.

Trying to solve for the movement of three large bodies in one another's orbit creates a circular logic. The calculations rely on the initial positions of the three bodies, but these initial positions are unknowable over time because the bodies always affect one another in unpredictable ways. In the 300 years since Isaac Newton outlined the dilemma in his Principia, diligent physicists have only been able to offer special-case solutions for restricted versions of the problem. "In a nonlinear system like the chaotic three-body problem," writes Caroline Delbert for Popular Mechanics, "all bets are off, and our intuitions are scrambled."

On the Difference Between Using Probabilities to Negotiate Incomplete Knowledge and Envisioning Probability at the Foundation of a Theory:

> Things get even stranger, and it is clear why some people pine for the good old days when waves were waves and particles were particles. One of those people was Albert Einstein. He detested the idea that a fundamental theory should yield only probabilities. "God does not play dice!" he insisted. In Einstein's view, the need for probabilities simply showed that the theory was incomplete. History supported his claim, for in classical physics the use of probabilities always stemmed from incomplete information. For example, if one says that there is a 60 percent chance of a baseball hitting a glass window, it is only because one doesn't know the ball's direction and speed well enough. If one knew them better (and also knew the wind velocity and all other relevant variables), one could definitely say whether the ball would hit the window. For Einstein, the probabilities in quantum theory meant only that there were as-yet-unknown variables: hidden variables, as they are called. If these were known, then in principle everything could be predicted exactly, as in classical physics. (Barr, p.4)

On Classical Physics as Deterministic:

> Classical physics was strictly deterministic, so that (as Laplace famously said) if the state of the physical world were completely specified at one instant, its whole future development would be exactly and uniquely determined. Whether a man lifts his arm or nods his head now would (in a world governed by classical physical laws) be an inevitable consequence of the state of the world a billion years ago. (Barr, p. 5)

Free Will?

On the Revolution of Chaos Theory:

"As one physicist put it: 'Relativity eliminated the Newtonian illusion of absolute space and time; quantum theory eliminated the Newtonian dream of a controllable measurement process; and chaos eliminates the Laplacian fantasy of deterministic predictability." Of the three, the revolution in chaos applies to the universe we see and touch, to objects at human scale. Everyday experience and real pictures of the world have become legitimate targets for inquiry. There has long been a feeling, not always expressed openly, that theoretical physics has strayed far from human intuition about the world. Whether this will prove to be fruitful heresy or just plain heresy, no one knows. But some of those who thought physics might be working its way into a corner now look to chaos as a way out.'" (Gleick, p.3)

On The Essence of Chaos Theory:

"You might argue that the reason for this unpredictability is that there are simply too many variables present in meteorological or economic systems. That is indeed true in these cases, but this is by no means the complete answer. One of the remarkable discoveries of twentieth-century mathematics is that very simple systems, even systems depending on only one variable, may behave just as unpredictably as the stock market, just as wildly as a turbulent waterfall, and just as violently as a hurricane. The culprit, the reason for this unpredictable behavior, has been called "chaos" by mathematicians." (Devaney, p. 2)

On the Relationship of Chaos Theory to the World on a Human Scale:

Gleick summed up the revolutionary effect of Yorke's paper: "Yorke had offered more than mathematical result. He had sent a message to physicists: Chaos is ubiquitous; it is stable; it is structured." (Yorke, p. 2)