Philosophy 232 Presentation Notes
philosophy of physics on Cartwright

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1 Some physics

1.1 How do theoretical physicists ground their job?

Whenever you hear someone is doing physics, this person is most definitely working on some form of the following question: "given some information about a system of interest, what will it be doing later? Or, it could be some variations like "what was it doing earlier? what was a part of it doing earlier?" This entire subject of physics, although soundingly difficult, could be simply summarized as the studies of **time evolution**. Physicists care about how a system is changing with a parameter called time.

Well? Okay, but what is this time thing we are dealing with? Unfortunately, no one yet has an entirely persuasive answer from the first principle to this fundamental question physicists and philosophers are bound to answer. However, we can still abstract some properties from what we commonly call time. It seems like time is infinitely continuous in an ordered way. That is, we can't rearrange the order of time frames as we wish. In our abstract toolbox - mathematics, the same set of objects called the real numbers have the same properties. Since we are also treating time as an independent variable, we have some freedom to model it as we wish - the set of real numbers on a number line.

Now, what are the specifics? What is the thing we are investigating that is dependent on time? How do we characterize/quantify such a system? Physicists start by defining the **configuration** of the system we try to describe. Configuration is a fancy word which basically means "what the system looks like at some specific time." Notice that configuration should generally be a function of time. (for mathematically advanced people, a configuration should be a map from a real parameter time t to a complete configuration Q, such that $Q(t) : \mathcal{R} \rightarrow \mathcal{Q}$)

Suppose we pull a bunch of configurations from a bunch of different adjacent time. In that case, we should be able to form a set of configurations $Q_1, Q_2, ..., Q_N$. We can select arbitrarily many number of configurations for a desired description of the system. Calling the starting time of this set to be t_0, its corresponding state should be $Q(t_0)$. Therefore, to describe the time evolution of some system, all we need to do is to find the function f such that

$$Q(t) = f(t, Q(t_0))$$

<u>Some caveats</u>: we made a few assumptions in the above process.

1. time is infinitely continuous, meaning the difference between two times could be made arbitrarily small.
2. the configuration Q contains absolutely every variable that affects the system's time evolution.
3. time evolution is deterministic, smooth, and invertible.

ALL of these assumptions turn out to be only correct under some conditions. First, it turns out that time cannot be separated into arbitrarily small chunks. The smallest we can do is called the Planck time (5.39×10^{-44}sec), but it is negligible on an everyday scale unless you study quantum gravity. Second, we can only be confident in knowing a system's full configuration if we suppose some **isolated system**, where we have all variables that could have the system inside such system. For the third, it used to be the case that things were deterministic, until the birth of Quantum Mechanics.

As good physicists, although they aren't true, we still take them to be true most of the time. With the analysis and assumption we made above, there is a mathematical theorem that guarantees the **existence of the equation of motion**, which we could use to determine the time evolution of configuration of any system. *For the mental wellness of my readers, I will omit the proof here:) See the "some proof" section for the proof.*

The three most important issues from the above formulation could be summarized as the **problem of interpretation, dynamics, and calculation**, respectively. The problem of interpretation arises when we identify a real and observable physics system into the variables that affects this system. The problem of dynamics concerns obtaining a mathematical form of the function $f(t, Q(0))$ above that describes the time evolution. And the problem of calculation, well, is just the problem of calculation and solving the equations.

Cartwright's essay focuses on the intersection of the **problem of interpretation and dynamics**.

1.2 Some laws in Cartwright

The universal law of gravitation is proposed by Newton in his *Principia Mathematica* in 1687. The law takes the following mathematical form

$$\boxed{F_g = \frac{Gm_1m_2}{r^2}\hat{r}}$$

Here G is the gravitation constant, m_1, m_2 are the masses of two subjects in kg, r is the distance between the subjects. This law, therefore, describes the gravitational force between any two massive (meaning the body has mass, not that it's big:) bodies as a function of their distance apart.

What is the weird-looking $\hat{r}$ with a hat? In physics, it is called the unit vector, and it does nothing other than given the direction of the force.

A really similar law Cartwright used in her paper is the **Coulomb's law**, which has the form

$$\boxed{F_c = \frac{kq_1q_2}{r^2}\hat{r}}$$

Here k is the Coulomb's constant, q_1, q_2 are the charges of two particles. This law describes the electric force between any charged bodies as a function of their distance apart.

2 Some philosophy

2.1 Cartwright and RZ on superposition of different force - not facts!

We see the above two laws are paradigm cases of **isolated systems**, where we only have two bodies whose motion is governed by either mass OR charge. What happens when we deal with a real case for a massive body with charge? Neither one of them gives the correct prediction. Based off that, Cartwright argues that these fundamental laws of physics don't describe true facts about reality, as none of them gives a full description of the configuration. If we explicitly add the restriction of the type of system (e.g. only charge affects the system), Cartwright still can argue that it is not a very useful law, as it now can only be applied to a TINY subset of all real-world problems. All other applications of these laws are false.

However, physicists will have their well-deserved revenge and say it's a question too easy - just take the significant contribution!

$$F_{\text{resultant}} = \frac{Gm_1m_2}{r^2}\hat{r} + \frac{kq_1q_2}{r^2}\hat{r}$$

If there are two variables, namely masses and charges, we just use them both! This result undoubtedly gives the correct resultant force both mathematically and empirically. Moreover, the only good measurement for a theory is its **correspondence to the empirical verification**. As a defense for the theorists, there can never be a 100% confirmation from experiments to theories. Whenever there is an experiment, there are its associated errors, which are precisely due to the isolation problem we mentioned before. We could never have 100% pure water, or 100% accuracy on a generated spectra, so we can never have 100% confirmation of any theory. In a sense, a theory only needs to be *close enough* to the result within the experimental error to be correct. In the real world (i.e. not a philosopher's world:) when we calculate the force between two electrons, we only need to worry about the Coulomb contribution, simply because electrical force is MUCH stronger than the gravitational force. Let's run an actual calculation using actual data between two electrons and setting $r = 1\text{m}$

$$\begin{aligned} F_{\text{gravitation}} &= \frac{Gm_1m_2}{r^2}\hat{r} = 6.67 \times 10^{-11} \times (9.1 \times 10^{-31})^2 = 5.52 \times 10^{-71}\text{N} \\ F_{\text{electric}} &= \frac{kq_1q_2}{r^2}\hat{r} = 8.98 \times 10^{9}(\times 1.6 \times 10^{-19}) = 2.29 \times 10^{-28}\text{N} \end{aligned}$$

Since we are talking about an elementary particle, both forces are tiny. However, we notice that F_g is MUCH smaller than F_e to an order of 10^{43}. That means if we add these two forces together, every calculator would return the value of just F_e. That also means this error cannot be detected by ANY experiment. As far as my uneducated mind concerns, no experimental apparatus on this planet could measure forces of that magnitude. Therefore, we might as well ignore gravitational force when dealing with charges at this magnitude.

I should mention that these kinds of approximations are a HUGE and necessary part of modern physics. As the equations get more and more complex, the **problem of calculation** becomes much harder than throwing balls off the Pisa tower. The majority of the times physicists find their equation to be just analytically unsolvable. Until this very day, the only exact solution we have for a quantum system is the hydrogen atom. On these occasions, approximation methods represented by neglecting non-influential variables, truncating series, and numerical methods are our only hope of decoding these equations. It is an intrinsic limit of mathematics, or should I say the limit of us:)

2.2 Cartwright and RZ on vector addition - causal powers

Cartwright could then argue that there are also so many cases where the comparison isn't negligible, and in these cases, the laws of physics clearly do not describe the facts. We could have three massive bodies exerting forces on each other. In this case, one of the three bodies gets exerted two gravitational forces by the other two bodies, but there is only one "observable" force, and that is the resultant vector after adding two vectors together.
VECTOR DIAGRAM ICI: sorry for my LaTeXconverter issue, please imagine three planets and the forces among them...
Cartwright describes such addition as the causal powers that bodies have. She offers Lewis Creary's account that the result comes out true because they "correctly describe the influences produced, the vector addition law then combines the separate influences for the correct prediction." Although this formulation does not describe the facts, it provides a much better explanation of the composition of causes, therefore, serves a much better role of explanation - it is part of their explanatory role to not tell the truth.

Cartwright is definitely right that fundamental laws don't describe the truth. However, it does not really create any problem for physicists. This is my two cents on the paper: all of us have occasions in our lives when you know someone is absolutely right, but it doesn't matter. (just like when people say you should come to a full stop at any stop sign, but all of us just tap on the break metaphorically) One point is what we just mentioned - lots of the times we are justified in applying approximations due to empirical and calculation limits. If no experiment could reach infinite precision, so shouldn't our theory. Second, and it is a part that Cartwright misses, is that fundamental laws are supposed to be used in combination with proved validity of superposition or unifying laws. Superposition and unifying laws justify our usage of fundamental laws for many-body problems. Fundamental laws of physics and their superposition argument should be one entity. Using fundamental laws while ignoring its superposition property is analogues to constructing a philosophical argument with premises and no logic.

The fact that fundamental laws are descriptive is a necessary outcome of **reductionism**. Going back to the formulation of theoretical physics, we need an **isolated system** with correctly identified variables to produce the descriptive equations. In this complex world we live in, there are **too many variables** that we have no idea if they contribute to the time evolution of any objects. The best shot we have is to **create and exploit simple models**, whether through

Gedanken experiment or actual experiment, to eliminate as many variables as we can to obtain a ***ceteris paribus*** case, so long as just one variable is operating. Once we have a well-established *ceteris paribus* theory for the basic cases (two bodies, two charges, etc), if we can prove the **validity of superposition** (or more general cases - unifying theories) mathematically and empirically, we can the **generalize** the simple relationship to more complex phenomena. In the process of generalization, problems occur. We then repeat this same process of reductionism again to establish and generalize another simple model. fyi: This indirectly supports Karl Popper's **conjecture and refutation** model of science.

As for the **facticity view** (which is an essential topic in the essay we didn't focus on), it is almost never the case in physics except in the beginning. (Earth on the back of a giant turtle - I meant it:) Physicists started to find causality at the level of our daily life, but the overwhelming amount of variables called out **reductionism**. As scenarios we investigate get increasingly individualized, it becomes less and less descriptive, but the structure in which a phenomenon is caused becomes increasingly clear, with its peak at classical field theory and analytic mechanics...until we meet the quantum world. The introduction of indeterminism and the imaginary number i makes the law entirely non-descriptive, but we also notice no matter how abstract the laws of physics become, it should still generate the correct outcome in the **ceteris paribus** (or approximation) sense. We might as well imagine the laws of physics at the current stage as a Blackbox which takes an input and spits out an outcome.

Here is the Schödinger Equation because why not:)

$$\hat{\mathcal{H}}\,|\psi(t)\rangle = i\hbar\,\frac{\partial|\psi(t)\rangle}{\partial t}$$

Please don't worry if you have no idea what this equation means. All I want to show here is: the equation that governs every motion in the quantum world contains the imaginary number $i \equiv \sqrt{-1}$. In this case, we shouldn't even bother to think if the law of physics should describe real facts. Instead, we should really think about whether the laws of physics could be non-physical!

3 Some proof: appendix

Here we prove the existence of the equation of motion. (reference: Trevor Scheopner's *Notes on Theoretical Physics*) Recall the time evolution equation:

$$Q(t) = f(t, Q(t_0))$$

where Q is the configuration and f is a function that takes initial condition and time to evolve in time.

As a principled and disciplined physicist, we assume ANY function to be differentiable, namely Q, f in our case. Differentiate both sides:

$$\frac{dQ(t)}{dt} = \frac{\partial f(t, Q(t_0))}{\partial t}$$

Due to the assumption that time is smoothly invertible, we reasonably (are we?:) assume an inverse transformation f^{-1} that could take the evolved configuration back to the initial condition $Q(0)$, such that

$$f^{-1}(t, Q(t)) = Q(t_0)$$

Substitute the above to the differential equation above:

$$\frac{dQ(t)}{dt} = \frac{\partial f(t, f^{-1}(t, Q(t)))}{\partial t}$$

We see that RHS is now a function of t and $Q(t)$ independent of any initial condition. If we define the right hand side to be a new function (formally defined as the velocity field):

$$V(t, Q(t)) \equiv \frac{\partial f(t, f^{-1}(t, Q(t)))}{\partial t}$$

We conclude

$$\frac{dQ(t)}{dt} = V(t, Q(t))$$

We have the equation of motion that is now independent of initial conditions. $Q.E.D$