Fallout from Newton

Themes

Philosophical fallout from Newton

Induction

Causality and determinism

Chaos

Next homework due next Thursday

Newton and Philosophy

- Newton saw himself as an empiricist. "I do not entertain hypotheses," meant that he did not want to spend time on ideas (*e.g.*, what is the "true nature" of things) that are not rooted in observation.

  "Whatever is not deduced from the phenomena is to be called an hypothesis; and hypotheses, whether metaphysical or physical, whether of occult quantities or mechanical, have no place in experimental philosophy. In this philosophy particular propositions are inferred from the phenomena and afterwards rendered general by induction." (*Principia*, book II)

- Can ANYTHING be "deduced from the phenomena"?

- At least that was his self-image. In practice, he spent more time on theological speculations and alchemy than on physics, and within physics his theory of light (particles undergoing alternating fits of easy and hard refractability) was exactly the sort of speculation he claimed to eschew.

- How do Newton's views on space and time fit with his philosophical rules?

Newton's four rules of reasoning in natural philosophy (*Principia,* Book III)

- Simplicity. "We are to admit no more causes of natural things than such as are both true and sufficient to explain their appearances."
  - So that issue is settled?
- Induction. "The qualities of bodies ... which are found to belong to all bodies within the reach of our experiments, are to be esteemed the universal qualities of all bodies whatsoever."
  - *Which* qualities?
  - To what extent can induction be justified? To what extent do discoveries made by induction represent "reality"?
- Uniformity. "To the same natural effects we must, as far as possible, assign the same causes."
  - In some sense, a combination of simplicity and induction.
- Empiricism. "In experimental philosophy we are to look upon propositions collected by general induction from phenomena as accurately or very nearly true, notwithstanding any contrary hypotheses that may be imagined, till such time as other phenomena occur, by which they may either be made more accurate, or liable to exceptions."
  - But which hypotheses are the same, and which are contrary?

Grue and Bleen

Consider emeralds. All emeralds thus far have been green. Hence, we have good reason to believe that all emeralds are green.

Nelson Goodman claims that we could look at the uniformity of the color of all known emeralds and reach the conclusion that all emeralds are `grue.' Grue is a new predicate introduced by Goodman. It describes things which look green before some time (let's say the year 2015) and look blue subsequently. (Bleen has an obvious analogous meaning.) So someone using more conventional adjectives who looks at a grue object before 2015 will call it green, and after 2015 will call it blue.

- How can you decide if emeralds are green or grue?
- Goodman claims: `to say that valid predictions are those based on past regularities, without being able to say which regularities, is thus quite pointless. Regularities are where you find them and you can find them anywhere. Hume's failure to recognize and deal with this problem has been shared by his most recent successors.'

(In Goodman, Problems and Project (Bobbs-Merill, Indianapolis, 1972), p. 388).

Determinism

- Suppose one knew the force laws (i.e., how to calculate F in a given situation). Then if one knew the motions of all objects at any moment, one would, **in principle**, know the entire past and future. In Newtonian physics, events are inevitable.
  - "Let us imagine an Intelligence who would know at a given instant of time all ... forces ... and positions ... and that this Intelligence would be capable of ... mathematical analysis. ... Nothing would be uncertain. ... The past and the future would be present to its eyes." (Laplace)
- But Laplace acknowledged (contrary to caricatures):
  - "Geometry provides a weak outline of this Intelligence … man will remain infinitely far removed from it." (Laplace)
- Newtonian determinism fed into a Deistic religious stance:
  The "intelligence" could be treated as God, perhaps as one somehow involved in the initial setting of a clockwork universe, but not as one intervening to disrupt the inevitable lawful workings of the machine.

Causality

- The laws would give the hypothetical "Intelligence" a way to calculate what the results would have been if conditions had been different. So a definition of causation that starts "if things had been different, then… " would be meaningful.

- <u>In the absence of such laws, what does it mean to say that "A caused B“?</u>

- On the other hand, if there is complete causation, how can you isolate one event and ask what would have been different if only that event were different? Wasn't that event (e.g. an umpire's bad call) just as inevitable as anything else?

- For the more metaphysically inclined:
  – If there is determinism, then how can there be free will?
  There are no choices to make.
  – If there is no determinism, how can there be any will, free or otherwise?
  – (The nice thing about teaching this course rather than a metaphysics course is that I do not have to follow up on such questions.)

Generalizations?

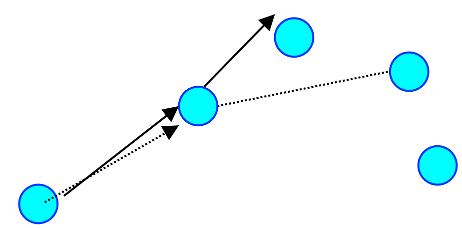
The stunning successes of physics (especially for astronomy) led to attempts to adopt its principles in other fields. Some of these confused the type of principles that described how things are with the type of rules that societies *ought* to adopt.

- Chemistry and biology: mechanistic, causal theories were sought, and, to a large extent, slowly found.
- Sociology (Auguste Comte). There should be some set of rules, based on generalization from observation, which describe the mysteries of why societies act the way they do.
- Economics (e.g. Adam Smith). The machine is supposed to work by letting a few simple principles play out, rather than by a hodge-podge of particular rules.
- Politics (many people, *e.g.*, Thomas Jefferson). Rather than have different rules for a myriad of different qualitative types of people (ranks of nobles, etc.) there should be some simple universal rules.
  - Which would not, of course, prevent the less 'massive' people from orbiting the more 'massive' ones.
  - Anything important should be written in a style imitating Newton imitating Euclid. "We hold these truths to be self evident…"

Is Newton's universe deterministic in practice?

(Let's worry only about gravity- the question would be even messier with forces for which there's no exact universal law.)

- The motion of three gravitating bodies cannot be calculated exactly. The only way to predict the motion is to do it, or simulate it, i.e. make a numerical computation of the behavior, breaking time into little intervals over which the positions and hence forces are given approximately by the results of the preceding calculation.
- Chaotic behavior limits one's predictions to the logarithm of one's computing power. The log of 10^{100} is 100. That's why we don't know next week's weather. The solar system itself appears to be weakly chaotic. Imagine a friction-free pool table, following very simple collision rules. It's not hard to see that small initial errors grow rapidly into extreme unpredictability. A small uncertainty in the direction of on ball leads to a bigger uncertainty in its direction after a collision. The uncertainties just keep multiplying, so that you soon cannot even predict which collisions occur.



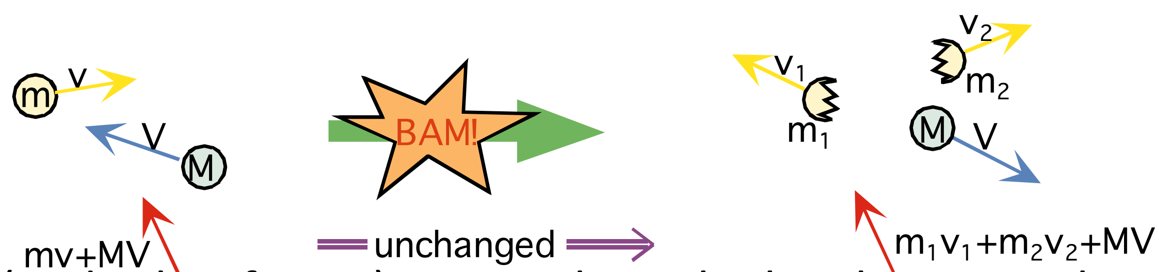
- Chaotic behavior precludes repeatability on long time scales.
- So, how does one *verify* that a system is deterministic?
- Is computability an essential feature of determinism?

Conservation Laws (reminder)

you CAN predict a few things even in complicated systems

Newtonian physics contains conserved quantities. “Conserved” means that the total value does not change with time.

- N’s 3rd law gives us:
  - Linear momentum. The momentum of an object is its mass times its VECTOR velocity.



- The rule that gravity (and other forces) points along the line between the objects gives:
  - Angular momentum. This is a measure of an object’s motion around some point. (It turns out that for planetary orbits, this conservation law is just the equal-areas per equal-times law.)

- Other conserved quantities (not known by Newton):
  - Electric charge. discovered by Faraday, in the 19th century.
  - Energy. (More below)

Energy

- Energy conservation is more difficult to observe than momentum, because energy can exist in various subtle forms. (So can momentum, but in many cases it stays in the form of nice visible motions.)

- For pure gravity sum up every $mv^2/2$ and every $-GmM/r$:
  - It's conserved!
  - Call $mv^2/2$ kinetic energy
  - Call $-GmM/r$ potential energy
- Generalize potential energy to include other forces e.g., springs have more potential energy when they're stretched or compressed.
- chemical energy, "heat", …….
- The history of heat illustrates how the interpretation of data is colored by one's theoretical framework. In the 18th century, heat was thought to be a distinct fluid, the caloric. (Lavoisier) The temperature of an object depended on the amount of caloric it contained, like the height of water in a container depends on the amount of fluid it contains. Just as water flows from higher to lower, heat would flow from hotter to colder regions.

More on energy

- Count Rumford's cannon-boring experiment (1798) was the first blow against caloric theory, because he could generate a seemingly unlimited amount of heat with his drills. However, at the time, this was seen as elucidating the properties of the caloric, not refuting its existence. (Objects do contain a seemingly infinite amount of electrical charge, i.e. much greater than the amount transferred in ordinary electrical processes, so this isn't a dumb idea.)
- Carnot's study of heat engine efficiency in 1824 was still done entirely within the caloric theory. The early development of efficient steam engines by Watt and others used caloric analysis.
- Each such practical success leaves a deeper impression that the theory must be basically right.
- In the 1840s Joule explicitly demonstrated the transformation between *mechanical energy* and heat. With this, it became possible to consider that energy is actually conserved, when *all* its forms are taken into account.
- The caloric theory was internally consistent, and worked well for a range of phenomena. After Joule, etc., caloric theory would need special rules for conversion of caloric to and from energy forms. It became messier than the modern picture, for which "heat" is just ordinary kinetic and potential energy associated with myriad microscopic modes.

Testing theories

(see Feynman on energy conservation)

- Energy is the sum of a bunch of terms. Not all of them are obvious. Suppose energy conservation appears to be violated. Should we throw out the law or look for another term?
- The usual response is that since it has worked so well for so long, the first thing to do is look for a new term. If the search is fruitless, after a while it will be time to consider a new theory.
  - E.g.: In the study of nuclear processes, some of them (b-decay) seemed to violate conservation of energy (1930's). (Actually, the same events which seemed to violate conservation of energy also seemed to violate conservation of angular momentum and of momentum. Was that worse or better for conservation laws than the violation of just one law?)
    To preserve the law, Fermi proposed the existence of neutrinos ("little neutral ones"). It took 20 years, but they were finally discovered in 1955.
- What would it mean to "discover" these particles?
  - How do you know they're there?
  - If you had no conservation law, would the particle be observed?
- One value of a theoretical framework is that it points to new phenomena to look for. One measure of a good framework is its ability to point to ones that actually exist.

- **How long does one continue to look before abandoning the old theory?**