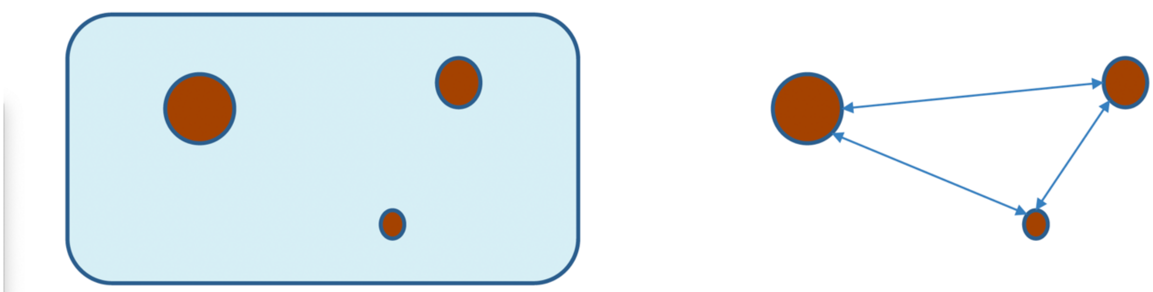
LECTURE 2 – MOTION, INERTIA, AND LET'S BEFRIEND NEWTON

******LITERATURE / EXAM QUESTIONS / QUESTIONS WHEN SUBMITTING SUMMARIES AT THE END/IF I DON'T SELECT YOUR QUESTION******

Substantivalist (Newton) **Relationalist (Leibniz)**



Substantivalism

- The problem of matter: For substantivalists, matter ontologically depends on spacetime (but not vice versa).

⇒ The existence of matter necessitates that of spacetime.

1- Start by finishing last lecture
2- Debate on substantivalism v. relationalism
3- Questions

Debate subs/relat: https://compass.onlinelibrary.wiley.com/doi/epdf/10.1111/phc3.12219

Relationalism v. Substantivalism debate

- RECORD THE DEBATE
- read intro/section 1 together (5 min)
- separate class in two: make sure physicists are equally divided
- one group studies sec. 2 and another section 3,4 (footnote 14)
  - how much time reading (15 min)
  - how much time organizing for debate
  - discussion among team to make sure argument is solid (15 min)

- debate rules: S - 3 min opening remarks
  R - 3 min opening remarks
  (~5 min)

(~20 min)

S - 5 min argument (choose someone)
R - 3 min reply
S - 2 min counter-reply

R - 5 min argument (choose someone)
S - 3 min reply
R - 2 min counter-reply

I take notes as we go.

(~25 min)

5 - 10 min to consider positioning changes and develop final remarks

S - 5 min final remarks

R - 5 min final remarks

!!! Read last sentence !!!

QUESTIONS FROM THE STUDENTS

1- **I had a hard time understanding the "does spacetime explain" paragraph, could you elaborate on this more in class?**
   a. Considering space as a substance was overkill to define motion as it also provides an unneeded definition of absolute rest, but positing Galilean spacetime seems to be exactly what's required to provide the background physics needs. Not directly detectable, but conceptually necessary. This moves shifts the perspective from rest/motion (same or not points over time) distinction in favour of inertial/non-inertial motion one (accord. to spacetime struc.).

      But this new distinction seems circular: 'motion is inertial iff it's one of the inertial-structure-preferred motions'. Granting that, then we can either say that we have to start somewhere anyways and take that to be the spacetime geometry itself (primitive), endorsing the substantivalist idea, or we take the definition at face-value without positing anything beyond it.

      The former attitude is called geometry-first approach and it takes the spacetime geometry to be irreducible. It considers that the world has the spacetime structure it has as a substantive fact about the world, and another substantive fact that this geometry meshes with the dynamics in the way it does, namely by having a preferred set of trajectories in spacetime that relates to the inertial structure. The existence of such trajectories (c.e.g., GR) constraints the types of laws of physics we can have, so that the spacetime geometry has explanatory power.

      The latter attitude coined dynamics-first approach takes these trajectories in spacetime to simply encode the existence of inertial motion, though their definition is self-contained as we saw: inertial frames are the ones in which force-free bodies move inertially, and the laws of physics are such that there are some frames, the inertial ones, w.r.t. which force-free bodies move in straight lines at constant speed. Spacetime has the geometry it has because of the laws of physics, not vice-versa. This approach sees spacetime much more like a mathematical tool **[realism v. instrumentalism].**

2- **Wallace states that absolute space is necessary for Newton's laws but cannot be measured. Given this paradox, how do contemporary physicists reconcile the idea of absolute space with the operationalism of modern physics?**
   a. That's exactly the point, many physicists are actually tacitly structural realists! And we also have seen last lecture the difficulty between separating observations from theory, so being an operationalist typically doesn't allow one to be straightforwardly dismissive about theoretical terms.

3- **In Wallace's conclusion, he argues for a 'dynamics-first' approach to understanding spacetime geometry. Could you elaborate on why this approach might be preferable over the 'geometry-first' perspective, particularly in the context of general relativity?**
   a. GR will come later, but one of its main cores already appeared at the Newtonian level. As Wallace discusses, even in Newtonian gravity it will be the matter distribution itself that will determine the gravitational potential anywhere in

space (through Newton's equations and Newton's gravity – so dynamics defining inertial structure). But if gravity is the thing now that is responsible for the inertial structure, and that is determined by the matter distribution, why do we need to talk about spacetime as a substance when everything seems to depend only on matter and its dynamics? But then, vacuum solutions. This also addresses another question from someone that was concerned if this view undermines the substantivalist view, but we saw during our debate how nuanced this discussion becomes.

WALLACE – CHAPTER 2: MOTION AND INERTIA

What does it mean for something to move?

Newton's first law (naïve form): An object on which no force acts that is at rest will remain at rest; or, if moving, will remain in motion at constant speed and in a straight line.

Newton's second law (naïve form): The acceleration of a body is proportional to the force acting on it.

The problem with these laws is that motion, rest, and acceleration seem to be absolute notions, instead of relative between different bodies. And even if it was relative, it could be that a body is at rest in relation to other body, but moving in relation to another one. Perhaps they should be thought in relation to Earth, but even the Earth is moving, and then we cannot use the Earth itself to talk about its relative motion. A final option could be using the distant, *fixed stars*, since the Earth seems to be moving in relation to them. But even then, people knew that these stars also move in relation to themselves. The issue is that there is no absolute *rest frame* to which the laws can refer to when discussing other bodies motion. Unless, we introduce *absolute space*: the thing that defines the rest frame, the unchanging reference against which motions can be defined.

To consider space as something separate from matter, a substance in itself is called *substantivalism*, which contrasts with *relationalism,* the view that all there is in the world is matter and space is simply encoding the relations between different bodies. Newton's laws seems to demand the existence of a rest frame as a *background* (just sits there) against which physics plays out, and if space takes on this role, it has to be absolute and ever-unchanging.

The relativity principle

But if the only thing we can observe seems to be the relative motions between bodies, how can we define the relative motion to an absolute rest frame? We cannot even see it, so how can we use it to detect motion in relation to it?

Carroll's explanation.

Thus, Newton's laws themselves do not allow us to detect the absolute velocity (in relation to an absolute rest frame), because the *relative motion of the bodies are unaffected by their overall velocity (in relation to the absolute rest frame)*. This is due to a *dynamical symmetry* of the theory, which in the case of Newtonian mechanics tells us that velocity boosts – transformations where all bodies are increased in speed by the same amount, in the same direction – do not change Newton's laws (similarly for position shifts). Therefore, Newton's laws tells us it is impossible, in principle, to detect whether or not something is moving with respect to absolute space.

Inertial Reference Frames

But if motion cannot be detected against the rest frame, how is that somehow part of physics? Perhaps it doesn't have to be, even for Newtonian mechanics. Let's consider a class of reference frames called *inertial* that are assumed to be moving at constant velocity as measured by the rest frame (absolute space). Any body at rest with respect to any of these frames will be moving inertially (straight line and constant speed), which given the principle of relativity, guarantees that they are not accelerating in relation to the rest frame.

But then, we know that physics can be done equally well in that case where we only consider relative motion in relation to inertial frames. So, the question is whether we could reformulate Newton's laws without making reference to an absolute rest frame. The laws are formulated in relation to a single rest frame, but inertial frames can have different inertial motion in relation to the rest frame, so we know that the reframed laws won't pick a single inertial frame (of which the rest frame would be one, even if simply defined to be inertially at rest against itself), but rather the whole class of inertial frames if this is meant to work. And then we can say:

Newton's first law (absolute-space version): An object on which no force acts will move in a straight line at constant speed relative to any inertial reference frame.

The concept of spacetime

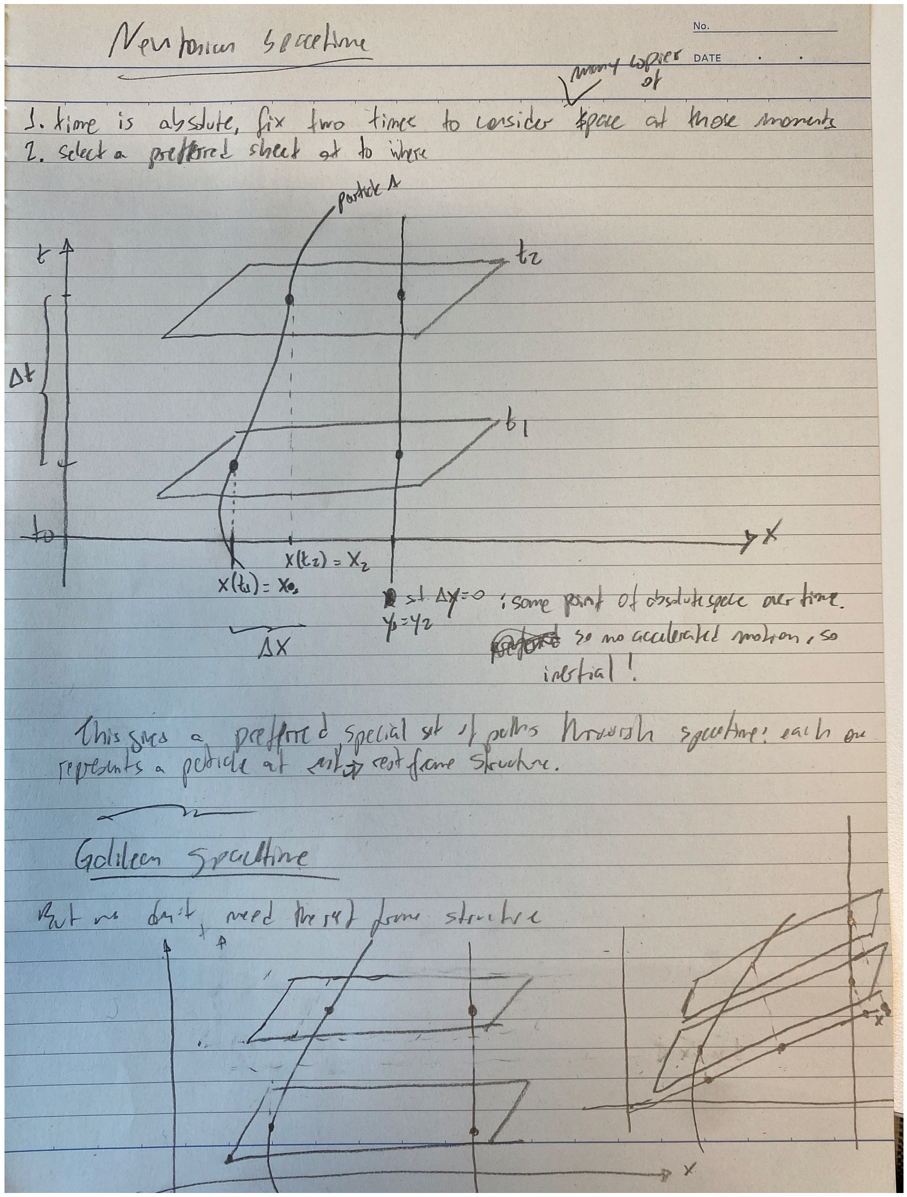
If no reference to absolute space, can we simply let go of these notions? Well, not so fast, as inertial frames are defined by having constant velocity relative to absolute space. Can't we just keep the notion despite not being observed? (Underdetermination, realism)

Fact is that this notion, together with absolute time, provides a lot of background structure seemingly required for physics:

1. Spatial geometry: Euclidean geometry in Newton's – not dynamical; distances
2. Rest-frame: defines rest and motion, enough to define absolute velocities
3. Temporal metric: absolute time determines elapsed time between events

But the principle of relativity tells us that we don't need this much structure, as basically we just need to be able to tell what's accelerating from what's not.

Putting the structure above together we can think of it in terms of spacetime, which combines space and time into a single geometrical structure. Spacetime points carry information about *where* something might be and *when* it might happen.



Does spacetime explain?

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But this new distinction seems circular: *'motion is inertial iff it's one of the inertial-structure-preferred motions*'. Granting that, then we can either say that we have to start somewhere anyways and take that to be the spacetime geometry itself (primitive), endorsing the substantivalist idea, or we take the definition at face-value without positing anything beyond it.

The former attitude is called *geometry-first* approach and it takes the spacetime geometry to be irreducible. It considers that the world has the spacetime structure it has as a substantive fact about the world, and another substantive fact that this geometry meshes with the dynamics in the way it does, namely by having having a preferred set of trajectories in spacetime that relates to the inertial structure. The existence of such trajectories (c.e.g., GR) constraints the types of laws of physics we can have, so that the spacetime geometry has explanatory power.

The latter attitude coined *dynamics-first* approach takes these trajectories in spacetime to simply *encode* the existence of inertial motion, though their definition is self-contained as we saw: inertial frames are the ones in which force-free bodies move inertially, and the laws of physics are such that there are some frames, the inertial ones, w.r.t. which force-free bodies move in straight lines at constant speed. *Spacetime has the geometry it has because of the laws of physics, not vice-versa*. This approach sees spacetime much more like a mathematical tool [connect with realist and instrumentalist discussion, and the nuance here].

But what if the inertial structure of the world is actually not just an inert background?

Inertia and Gravity

Astronauts: not zero-gravity! But *free fall*. Because gravity is actually universal: the acceleration it induces on a body is the same for small and large bodies (contrary to electrical forces, for instance). [EINSTEIN ELEVATOR] [inertial and gravitational mass cancel]

But this poses a puzzle for our understanding of inertia: if there is no way of detecting whether we are or not under the influence of some gravitational acceleration (given we observe objects to infer changes in the velocity), then our inertial structure from before seems to be asking more than what's needed in practice. As uniform velocity was undetectable, so are **uniform** *external gravitational forces.* Thus, perhaps we should formulate physics in a way that we do not need to distinguish between the absence or presence of an external gravitational field acting over a system. Meaning, Newton's laws should also hold for any frame that is *falling freely under gravity.*

This is a major shift in perspective:

1. It means an universal force is not a force at all, since they are defined by causing deviation from inertial motion, but now free motion under gravity is inertial motion. Thus, gravity instead is what defines inertial frames, while other forces tells us how objects accelerate relative to those inertial frames
2. It breaks the idea that inertial struc. Is background structure, since gravity is determined by the distribution of masses, and that is dynamical.
3. It tells us that inertial structure is *local,* instead of being defined for the whole Universe. The single collection of inertial frames is replaced by a patchwork, one for each little region of spacetime: rules for adjacent collections encoded in the spacetime curvature.

In light of this, the geometry-first approach can take the inertial structure as absolute, independent of gravity, but then essentially undetectable, while the dynamics-first one sees inertia as directly influenced by gravity, making spacetime geometry and inertia deeply interconnected.

CARROLL – CHAPTER 3: DYNAMICS

- Dynamics: change that obeys the equations of physics
- Within the Laplacian paradigm in classical mechanics, what matters to motion is knowing the position (3) and velocity (kinematics) of the object in question, which allows us to determine its acceleration using Newton's equation (dynamics), and that's enough to predict/retrodict the motion of the object
    - Crucially, shifts in the velocity and position are not relevant for the dynamics, leading to the same acceleration, but shifts in the acceleration change the dynamics of the system. **[Explain with drawings and formulas?]** Thus, position and velocity are already relative at the level of Newton's equations since their absolute values do not matter when determining the system's dynamical evolution. For position, that's easy to accept: we do not expect the laws of physics to change depending where we do our experiments! But we do not have the same intuition for the velocity, because tacitly we always assume it *in relation to* the Earth. On the other hand, when we are inside an airplane, except for the noise (and luckily the absence of turbulence), we feel as if we are still! The absence of a preferred location or an absolute measure of rest in the laws of physics is known as *Galilean Relativity.*
    - On the same token, that means that acceleration is absolute. And that's *zero*, which defines a special class of trajectories called *inertial*, meaning they are not undergoing any acceleration at all. Once again, whenever we are inside a train's cabin without looking outside, we know when the train starts accelerating.
- **The energy perspective:**
- **The spherical cow: the harmonic oscillator, approximating the potential, harmonic oscillator everywhere**

CARROLL CH 4 – SPACE

- **Dimension:** an independent direction in which things can move (orthogonality of rods in space)
- **Coordinates:** cartesian, spherical, coordinate invariance
- **Dimensions and forces:** lines of force (coulomb's)

Locality

What is special about space is that interactions are local in space, things (particles, fields, etc) need to be on the same point in SPACE (not with the same velocity/momentum, for instance!) to interact. That's the case despite how symmetric the dynamical equations (for instance, for a Harmonic oscillator, free theories, or even generically the Hamiltonian equations) are.

Action at a distance

Gravity -> fields permeating space
Plot of sun's gravitational field