Phil. 4400
Notes #11: Absolute Space

I. The traditional dispute: Two conceptions of space + time

- *The Relational Conception of Space:* All that exists are spatial relations between bodies.
- *The Substantival Conception of Space:* Space exists independently of bodies. Bodies merely 'occupy' space.
- *The Relational Conception of Time:* There are only temporal relations between events.
- *The Substantival Conception of Time:* Time exists independently of events. Events merely 'occupy' time.
- "bodies": Material objects.
- "substance": Something that 'exists independently'; everything else that exists depends on substances. Also: ultimate subjects of predicates; not predicated of anything. Hence the term "substantival conception of space."
- *Note:* Please do not confuse "the relational theory of space" with the theory of relativity, which will be discussed in a later class.

II. Related concepts

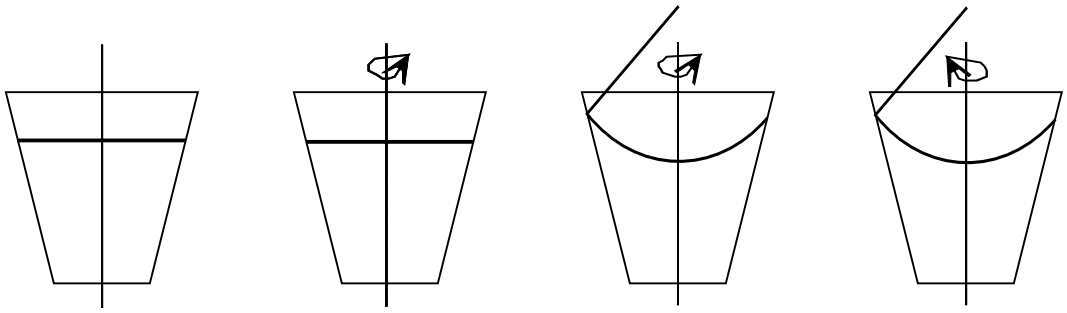
- ***Location:***
  - For absolutists: The part of space a body occupies. A statement of location has the form *x*O*y*, where *x* is a body and *y* is a part (a region or point) of space.
  - For relationists: A body's spatial relation to other bodies. A statement of location has the form *x*R*y*, where *x* and *y* are both bodies. R is a spatial relation, e.g. "inside", "next to", etc.
  - Similar points apply to 'location' in time.
- ***Duration of an event:***
  - For absolutists: The measure of the region of time the event occupies.
  - For relationists: A relationship between the beginning of the event (which is itself a small event) and the end of the event. Or, alternately: the number of cycles of a clock that pass during the event (hence, a relationship between the event and some other process).
- ***Motion:***
  - *Absolute motion:* change in the part of space a body occupies, over time.
  - *Relative motion:* change in the spatial relations between bodies. *Or:* the difference in the absolute motions of two bodies.
  - Note: Substantivalists believed in absolute motion; relationists believed in only relative motion, for obvious reasons. Thus, traditional substantivalists were also *absolutists.*
  - Example: Suppose you walk at 5 mph on the deck of a ship. The ship is moving at 20 mph in the ocean. Finally, the earth is moving at 1000 mph *in space*. All these motions are in the same direction. Then your *absolute motion* is 1025 mph (the sum of these motions).
  - *Question:* Is absolute motion "motion relative to absolute space"? No; that tries to define absolute motion in terms of relative motion. Relative motion is "difference in absolute motions."

III. Measurement

• We measure the *size* of a body by comparing it with another, *rigid* body (a body that doesn't change its own size).
  • For absolutists: This means it does not change the amount of space it takes up.
  • For relationists: It retains the same "bigger than"/"smaller than" relations to a lot of other bodies.
• Similarly, we measure the *duration* of an event by comparing it with a *uniform* motion/process (a process that continues at a constant speed).
  • For absolutists: It does not change the amount of absolute time that each cycle takes up.
  • For relationists: It keeps a constant relationship (keeps synchronized) with lots of other processes.

IV. Newton's Bucket

• A bucket of water is suspended from a rope. The bucket is turned around several times, twisting the rope up.



Stage		Relative motion of water w/ respect to bucket	Surface of water
1.	Before releasing bucket.	0	Flat
2.	Bucket is released, starts spinning as rope unwinds.	←	Flat
3.	Water picks up motion of the bucket, starts 'spinning with the bucket.'	0	Concave
4.	Rope has twisted up in the other direction, starts unwinding again. Bucket spins in the opposite direction from stage 2.	→	Concave

• *Newtonian account of the events:*
  • *Newton's First Law:* Bodies at (absolute) rest tend to remain at rest, and bodies in (absolute) motion tend to remain in motion in a straight line, unless compelled to change their state by forces impressed on them.
  • 'Centrifugal forces' appear for rotating bodies: The 'force' pushing towards the outside of the

circle is really just the tendency to continue in a straight line.
- Centrifugal force exists in stage 3, 4, because the water is rotating absolutely.

• *Relationist cannot explain this.*
- Newton's first law is malformed, according to them: there is no such thing as absolute motion in a straight line.
- Suppose you substitute "relative motion": "Bodies in relative motion tend to remain in relative motion in a straight line unless compelled to change their state by forces impressed on them." *Problem:* This is false.
- The relative motions in stages 1 and 3 are the same (0), but there is centrifugal force in stage 3, not in stage 1. Why?
- The relative motions in 2 and 4 are the same (in opposite directions, but that shouldn't matter), but there is centrifugal force in 2 but not in 4. Why?
- The centrifugal force is completely unrelated to the *relative* motions. It can only be explained by the absolute motion of the water.

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Notes #12: Positivism & Relativity

Claim:

Whether 2 events are simultaneous is relative to a reference frame.
- Contemplate how radical this claim is.

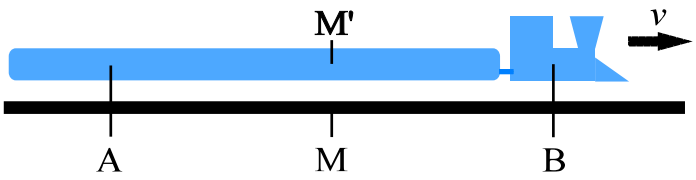
Outline of the Argument

1. ***Def. of simultaneity:*** *x* is simultaneous with *y* iff: An observer placed at the midpoint between *x* and *y* would see *x* and *y* at the same time.
2. Observers in different states of motion (but both at the same point in space) could differ on whether they saw *x* and *y* at the same time.
3. Therefore, *x* and *y* could be simultaneous *for* one observer (or one reference-frame) and not for another.

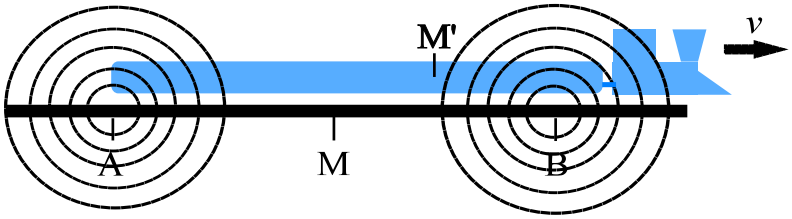
Defense of the Definition

- Verificationism: The meaning of a statement is determined by its method of verification.
  - Corollary: the meaning of a predicate is determined by the method of determining whether it applies to a thing.
  - Corollary: the meaning of a predicate must specify the method of verifying its application *in every case* in which it can be applied.
    (Implicit rationale: This is the only way to avoid unverifiable statements, given compositionality of meaning?)
- The suggested def. satisfies this criterion.
- *Objection*: The def. assumes that the light travels at the same speed from *x* to the observer, as it does from *y* to the observer.
  - *Reply*: This isn't an assumption, but a "stipulation which I can make of my own freewill." [How can he think this? Understand how this results from verificationism.]
- What's wrong with this definition: *x* is simultaneous with *y* iff *x* and *y* happen at the same time.
  - Answer: No obvious method of verification for distant events.

Why this Leads to Relativity of Simultaneity



- We have:
  - A train moving with velocity *v* with respect to a railway embankment.
  - Events A and B happen at the railway embankment (and right next to people who are on the train as it passes).
  - Point M on the embankment is halfway between the points *on the embankment* where A and B happened.
  - Point M' on the train is halfway between the points *on the train* adjacent to where A and B happened.
- The train moves to the right as the light from A and B travels towards observers at M and M':



  - Light rays emanate from A and B.
  - M receives the light from A and B simultaneously
  - M' must receive the light from B before the light from A.
  - Hence, *for M*, A and B are simultaneous; *for M'*, B is before A.

Criticism

- An alternative def. of simultaneity:

  x and *y* are simultaneous iff they happen at the same time.

  - Einstein could not object to the expression "at the same time," since it appears in *his own* definition.
  - This def. lets "simultaneous" keep the same meaning for events with different spatial relations to each other.
  - It also avoids the counter-intuitive result of relativity of simultaneity.

- Verificationism has previously been criticized.

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Notes #13: Special Relativity

Spacetime:

- Two concepts of a space:
  - *Physical space:* the space you are moving around in.
  - *Mathematical space:* a set of things ('points') that have certain mathematical properties. Basically, they have relations to each other that enable them to be arranged along one or more dimensions. *Ex.:* logical space, the color space, the IQ-height space, various spaces in statistics. Physical space is also a mathematical space.
- Another *mathematical* space:
  Spacetime: the 4-dimensional 'space' in which the points are ordered quadruples giving (physical) spatial and temporal coordinates. Spacetime is a mathematical space; it includes physical space.
- Learn to enjoy spacetime diagrams.

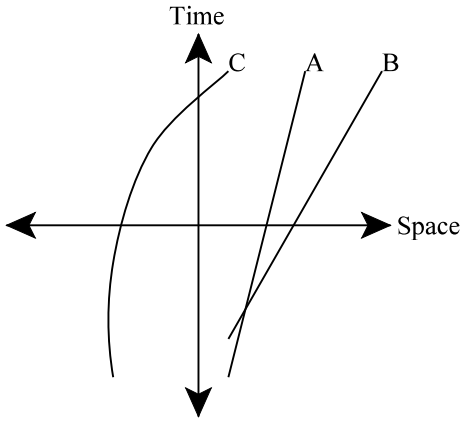

Figure 1. Spacetime. We suppress two spatial dimensions to make it possible to draw on a flat piece of paper. Vertical axis is time; horizontal axis is space. Line A represents an object moving to the right. B is an object moving *faster* to the right. C is an object *accelerating*.

What is the Special Theory of Relativity (STR)?

- It is a theory of the structure of spacetime.

Newtonian spacetime:

- Shortest path between 2 points is a straight line. Distance between points:
  $D^2 = \triangle t^2 + \triangle x^2 + \triangle y^2 + \triangle z^2$
- Distinguishes:
  Straight lines / curved lines
  Vertical lines / slanted lines
- Spatial & temporal coordinates are separable. Spatial and temporal distances both objective.
- No speed limit.
- See figure 1.

Minkowski spacetime:

- Shortest path *not* a straight line (but the path of a light ray). The invariant spacetime interval:
  $I^2 = (c\triangle t)^2 - \triangle x^2 - \triangle y^2 - \triangle z^2$
  Note the minus signs!
- Distinguishes:
  Straight lines / curved lines

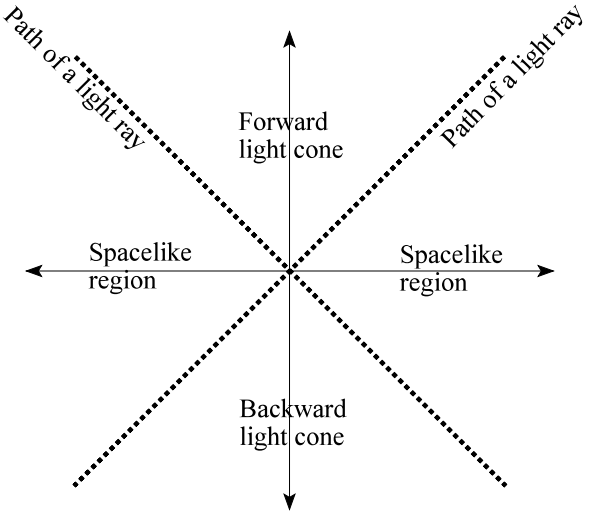

Figure 2. Minkowski spacetime. For any given spacetime point, there is a set of points that would be connected to it by a light pulse sent out in all directions: this set of points is the *forward light cone*. Similarly, there's a backward light cone. Outside the light cones are the points at 'spacelike separation.'

- Space & time are inseparable. Spacetime intervals are objective, but how they divide into spatial and temporal components is not.
  - There are multiple equally acceptable specifications of the time axis.
  - Hence, no absolute simultaneity.
- Has an objective 'light cone structure' (any given point has a forward & backward light cone). Which s-t points are in the light cone is invariant.
- See figure 2.

Famous features of STR:

- All inertial reference frames are equally good.
- The speed of light (c) is constant; i.e., every r.f. must agree on whether a thing is traveling at c.
- All of the following are 'relative':
  - Velocity of an object (if below c)
  - Length of an object
  - Time-order of two (spacelike) events
  - Shape of an object
  - Mass of an object
  - Duration of an event
- Nothing can travel faster than c. Why:
  - The putative 'stages' of the spacteime worm of such an object would be *spacelike* related to each other.
  - There is no objective time order to spacelike separated events.
  - Also, it would require infinite energy.

About relative vs. absolute quantities:

- 'Relative' quantities are those which differ between reference frames. They are not in objective reality; they are convention-dependent.
- 'Absolute' quantities are *invariant* ones: i.e., all rf's agree on them. They are in objective reality.

Common misunderstandings:

- STR is not the relational theory of space.
- STR does *not* say "objects shrink (gain mass, etc.) when they go faster." (Understand why that's wrong!) What do these equations mean:

$$L = L_0\sqrt{1-\frac{v^2}{c^2}} \qquad T = \frac{T_0}{\sqrt{1-\frac{v^2}{c^2}}} \qquad m = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}$$

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Notes #14: Alternative to Special Relativity

I. The Lorentz Ether Theory

- LET uses the same equations, with different interpretation:

$$L = L_0\sqrt{1-\frac{v^2}{c^2}} \qquad T = \frac{T_0}{\sqrt{1-\frac{v^2}{c^2}}}$$

- Interpretation: These are *real, dynamical effects* of motion through the ether (or absolute space), unlike in relativity.
  - Absolute motion (or motion relative to the ether) causes objects to shrink (really!).
  - Absolute motion causes internal movement & other processes to slow down.
  - Absolute motion causes things to gain mass.
  - Marklin favors ether; Tooley favors absolute space
- This theory is empirically equivalent to STR.
  - See why length contraction, time dilation are not measurable
  - LET & STR just place different interpretations on the same equations.
  - Why light ray will appear to have a *round-trip* velocity *c*, for any observer: see Appendix.
- Trivia: The LET is the original source of these equations, which is why they're called "the Lorentz transformations."

II. Objections to LET

A. The Argument from Authority

1. Physicists say STR is true.
2. Physicists are smart.
3. Therefore, STR is true.

B. The Positivist Argument

1. If LET, then there are undetectable facts, unmeasurable quantities (which could be named).
2. This is impossible.
3. So LET is false.

C. The Simplicity Argument

1. LET has more spacetime structure than STR.
2. So LET is more complex than STR.
3. Ceteris paribus, simpler theories are more likely to be true.
4. So, ceteris paribus, STR is more likely than LET.

D. The "We got here first" Argument

1. New theories must have novel predictions to be justified.
2. LET has no novel predictions.
3. So LET is unjustified.

E. LET is Ad Hoc, Physically Weird

- Why would objects shrink in the direction of motion through the ether?
- Partial answer: The forces that determine the distances between particles are electromagnetic. The ether is what transmits electromagnetic effects.

F. The Conspiracy of Silence Objection

1. It is impossible to detect absolute motion.
2. On LET, this is an improbable "conspiracy of silence."
3. So this is evidence against LET.

Tooley's Response to the Conspiracy of Silence:

a. (1) is true only if (and only because): It is impossible to measure the 1-way velocity of light.
b. If it is impossible to measure the 1-way velocity of light, then this is an improbable "conspiracy of silence" *regardless* of whether LET or STR holds.
c. So the same conspiracy of silence holds on either theory.
d. So this isn't a reason to prefer STR over LET.

Why (a) is true:

- Suppose O is moving at absolute velocity v. O sends a light ray in the direction of his movement.
  Absolute speed of light: c
  Speed relative to O: $c - v$
  Apparent speed, after Lorentz transformation: $c^2 / (c + v)$. *Calculations:*
  - Given the length contraction, a distance D will *appear* as $[D / (1\text{-}v^2/c^2)^{1/2}]$.
  - Given time dilation, a time T will *appear* as $T(1\text{-}v^2/c^2)^{1/2}$.
  - So a velocity $V=D/T$ will appear as

$$\frac{(D/\sqrt{1-v^2/c^2})}{(T\sqrt{1-v^2/c^2})} = \frac{D}{T(1-v^2/c^2)} = \frac{V}{(1-v^2/c^2)} = \frac{Vc^2}{c^2-v^2}$$

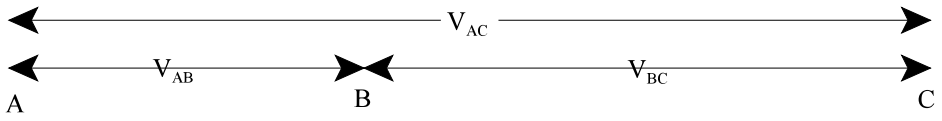
  - So the relative velocity of the light ray, $(c - v)$, will appear as

$$\frac{(c-v)c^2}{c^2-v^2} = \frac{(c-v)c^2}{(c+v)(c-v)} = \frac{c^2}{(c+v)}$$

- Now suppose O sends a light ray in the opposite direction:
  Absolute speed of light: c
  Speed relative to O: $c + v$
  Apparent speed, after Lorentz transformation: $c^2 / (c - v)$
  - Calculation here exactly parallel to that above.

III. Advantages of LET

1. The following propositions seem intuitively obvious:
   - Waves require a medium. (There can't be a wave with nothing that waves.)
   - The size, shape, and mass of objects are objective properties of those objects (not convention-dependent, and not relationships to other objects. An object has only one length (shape, mass) at any given time.
   - The Galilean Law of the Addition of Velocities: If A, B, and C are all moving along a single dimension, the velocity of A with respect to B is V_{AB}, the velocity of B with respect to C is V_{BC}, and the velocity of A with respect to C is V_{AC}, then $V_{AB} + V_{BC} = V_{AC}$.



   - Time is distinct from space. Time is not just like another spatial dimension.
   - Events have an objective time-order.
   - There's such a thing as "everything that exists (or is taking place) *now*" (and it's not convention-dependent). Something can be happening now, even if it's not here.
   - Space (the same space) continues to exist through time.

2. STR is incompatible with all the propositions in (1). LET is compatible with all of them.

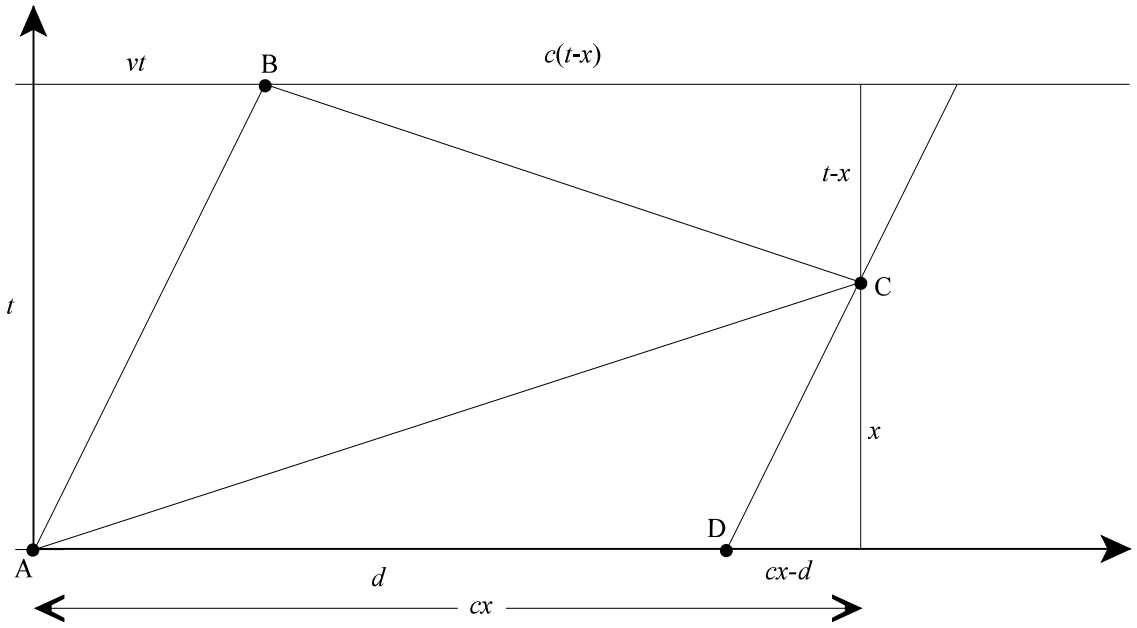
3. STR provides no *reason* for denying these propositions.
   a. The empirical evidence is equally compatible with LET.
   b. There are no other arguments against them either. Scientists who adopted STR never even considered them.

4. So, LET is better than STR.

Appendix: Why the round-trip velocity of light appears to be *c*

Scenario: An observer at A is moving to the right with (absolute) velocity *v*. He sends a light ray to bounce off a mirror at point C and come back to him. The round trip takes a time *t*. (See diagram.)

Question: What will this observer take the round-trip velocity of light to be?



Observations:

- The true velocity of the light is *c*. The light will take some amount of time (call it "*x*") to get to the mirror. It will take a smaller amount of time (*t* - *x*) to get back to the observer, since he's moving to the right.
- The real distance traveled by the light to get from A to C is *cx* (velocity times time = distance).
- Similarly, the real distance traveled by the light to get from C to B is *c*(*t* - *x*).
- Let *d* be the length of the path that the observer *thinks* the light is traveling between A and C. Since he thinks he's stationary, he thinks point D on the diagram is directly below point C, so he thinks AD is the distance traveled. And he thinks the return trip is the same length.

Plan:

- First we'll find the actual length *d* of the segment AD.
- Then we apply the Lorentz length-contraction formula to figure out how long AD will *appear* to the observer.
- Then we'll apply the Lorentz time-dilation formula to figure out how long the time interval *t* will *appear* to the observer.
- Then we'll divide what the observer takes the total distance to be (that's twice what he takes the length of AD to be) by what he takes the total time to be. The desired result is *c*, that is, that the observer will measure the round-trip speed of the light to be *c*, its real speed (despite all the deceptions he's subject to).

Solution:

$$\frac{cx-d}{x} = \frac{vt}{t} \qquad (similar\ triangles) \qquad \text{(Equation 1)}$$

$$cx = vt + c(t-x) \qquad \text{(Equation 2)}$$

$$x = \frac{vt+ct}{2c} \qquad (rearranging\ equation\ 2) \qquad \text{(Equation 3)}$$

$$d = x(c-v) \qquad (rearranging\ equation\ 1) \qquad \text{(Equation 4)}$$

$$d = \frac{vt+ct}{2c}(c-v) = \frac{t}{2c}(c^2-v^2) \qquad (substituting\ Eq.\ 3\ into\ Eq.\ 4\ +\ simplifying) \qquad \text{(Eq .5)}$$

Since we want the round trip, we're actually considering 2*d*, so:

$$2d = \frac{t}{c}(c^2-v^2) \qquad \text{(Eq. 6)}$$

Applying the Lorentz length contraction, this distance will *appear* as:

$$Apparent\ distance = \frac{t}{c}(c^2-v^2)\times\frac{1}{\sqrt{1-v^2/c^2}} \qquad \text{(Eq. 7)}$$

Applying the Lorentz time dilation, the time will appear as:

$$Apparent\ time = t\sqrt{1-v^2/c^2} \qquad \text{(Eq. 8)}$$

Finally, dividing Eq. 7 by Eq. 8, we get the apparent velocity of the light ray:

$$Apparent\ velocity = \frac{\frac{t}{c}(c^2-v^2)\times\frac{1}{\sqrt{1-v^2/c^2}}}{t\sqrt{1-v^2/c^2}} = \frac{1}{c}(c^2-v^2)\times\frac{1}{1-v^2/c^2}$$

$$= \frac{1}{c}(c^2-v^2)\times\frac{c^2}{(c^2-v^2)} = c$$

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Notes #15: Non-Euclidean Geometry & General Relativity

I. About Pure Geometry

- Three kinds of geometry:
  ("Parallel" lines: Lines that do not cross.)
  a) *Elliptical geometry* : through a given point outside a given line, there are no parallel lines.
  b) *Hyperbolic geometry* : through a given point outside a given line, there are infinitely many parallel lines.
  c) *Euclidean geometry* : through a given point outside a given line, there is exactly one parallel line. (This is the "axiom of parallels.")
- Two kinds of geometry:
  Pure geometry is a word game with made up, stipulative definitions and rules. No connection to reality needed.
  Applied geometry is the application of a geometrical system to some thing in the world.

a) A model of elliptical geometry: The "plane" is the surface of a sphere. The "straight lines" are great circles.

- Features of this geometry:
  1) No parallel lines.
  2) The interior angles of a triangle will be more than 180°.
  3) C/d of a circle $< \pi$.
- Note: Again, "line", "triangle", etc. are *not* used in the ordinary English sense of the words.
- This surface has "positive curvature".
- This proves: Elliptical geometry is consistent.
- Why is it called "elliptical": it can be modeled on the surface of an "ellipsoid".

b) A model of hyperbolic geometry: The "plane" is a saddle surface (surface of a hyperboloid). "Straight lines" are geodesics.

- Features of this geometry:
  1) Many parallel lines.
  2) The interior angles of a triangle will be less than 180°.
  3) C/d of a circle $> \pi$.
- This surface has "negative curvature".
- This proves: Hyperbolic geometry is consistent.

- *Note* : Two senses of "curvature": a) Physical curvature
  b) Mathematical "curvature"

II. About general relativity

- Spacetime as a mathematical space. (Note: Lots of things are "spaces" in the mathematical sense, although they have nothing special to do with physical space.)
- Points as ordered quadruples. (event locations)
- Newton's spacetime: Euclidean.
- Einstein's theory:
  1. Concentrations of mass/energy alter the geometry of spacetime, "curving" spacetime. Note:

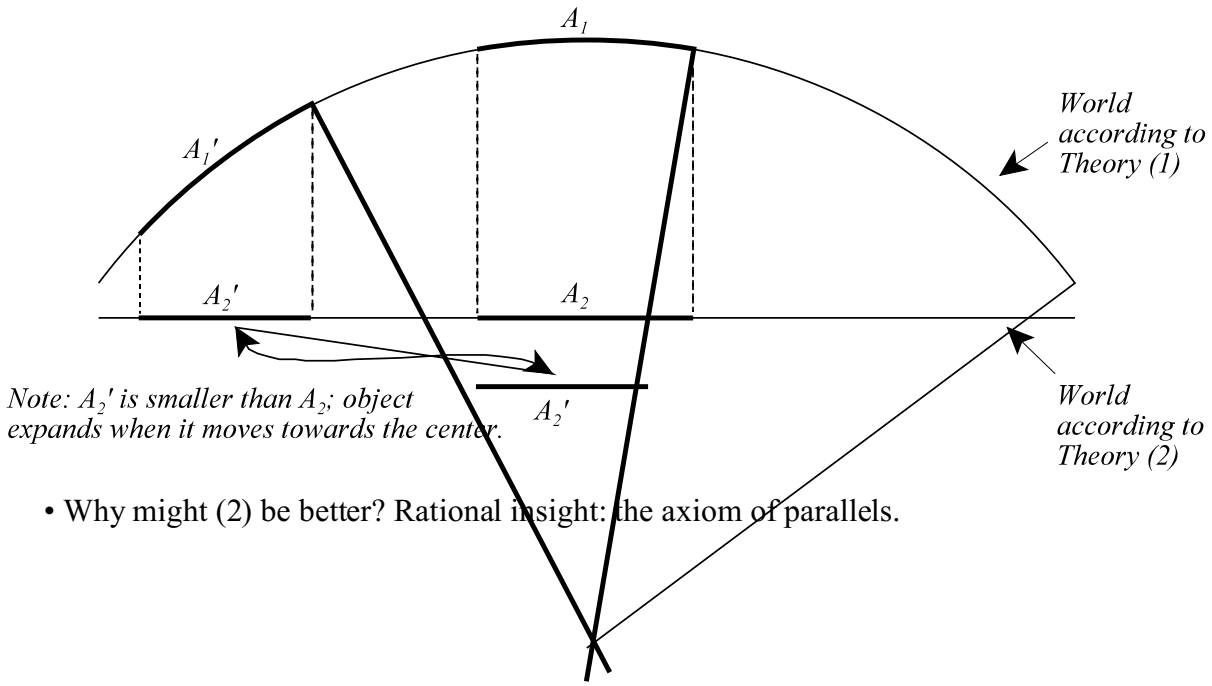
a) *Spacetime*, not *space*
b) It is not *physically* curved. It is curved in the mathematical sense.

2. Objects travel straight lines through spacetime when not acted on by forces. Gravitational 'force' is replaced by spacetime curvature.
3. Light always traces straight lines through spacetime.

• Empirical evidence:
a) the bending of light around the sun
b) gravitational red shift
c) advance of the perihelion of Mercury

III. Two alternative interpretations (Carnap's example)

• You have two people occupying a 2-dimensional world (see diagram below).
Theory 1 : You have rigid (fixed size & shape) rods moving on a curved surface.
Theory 2 : Rods affected by universal forces, on a flat surface.
  • 'Universal forces': Forces that distort everything in the same way and cannot be shielded against.
  • A heuristic for seeing the relation between the theories: Imagine the theory-1-world above the theory-2-world, and a light shining directly down from above. In (2), objects expand or contract to be the size of the 'shadow' of the objects in theory (1).
• Note that they get the same empirical predictions. (See why.)
  • You cannot directly measure distortions made by universal forces.
  • They have *effects* indiscernible (by observation) to those of the noneuclidean geometry.
• Which theory is better?
  • Einstein: (1) is better.
  • Carnap: (1) and (2) are the same theory.
  • BonJour: (2) is better.



• Why might (2) be better? Rational insight: the axiom of parallels.

Phil. 4400
Notes #16: Simultaneous Causation

Two views of causation:

Sequential: Causes immediately precede their direct effects.
Simultaneous: Causes occur at the same time as their direct effects.

Common sense examples of simultaneous causation

- Lifting a pencil.
- A ball on a cushion.
- *Objection:* at the micro-physical level, there is a slight time delay.

Simultaneous causation in physics

- Two examples:
  Newton's Second Law: $\mathbf{F} = m\mathbf{a}$
  The Lorentz equation: $\mathbf{F} = q\mathbf{E} + q\mathbf{v}\times\mathbf{B}$
- The basic causal laws of physics are *differential equations*. Understanding this:
  - The effect is typically a *rate of change*.
  - The rate of change exists at exactly the time of the cause.
  - Differential equations do *not* require instantaneous events or "infinitesimal" changes.
    The temporally-extended change event (effect) occurs during the same *interval* as its temporally-extended cause.

The problem of temporally extended causal processes

Hume's objection:
1. If all direct causation is simultaneous, there are no temporally extended causal processes.
2. There are temporally extended causal processes.
3. So not all direct causation is simultaneous. At least some is sequential.

Hume's view of the structure of time:
- The discrete conception:
  a) Time is made up out of indivisible parts.
  b) For each such part (moment), there is a next moment following it.
- Hume accepts the principle of *no action at a temporal distance*.
- Conclusion: To have extended causal processes, effects must occur at *the next* instant in time.

(This is valid.)

In the continuous structure of time:
- There is no smallest (non-zero) temporal interval.
- There's no next point in time after any other point. (Time is "dense".)
- How temporally extended causal processes result:
  - Laws specify a relation between the *current configuration* of a system and the *rate of change* of one or more aspects of its configuration.
  - Integrate rate of change over finite interval → finite change.

- Note: extended change is a logical consequence of the view.

The Principle of Reciprocity

Objection:

1. Example: two balls collide, ball A causes ball B to gain momentum.
2. If cause & effect are simultaneous, then momentum conservation is violated.
3. This is impossible.
4. So cause & effect are non-simultaneous.

Reply:

- Change in momentum is a continuous process, not a discrete event.
- The rates of change are simultaneous.
- Actually, the *sequential* view violates momentum conservation: if the effect is latter than the cause, then there is a time when total momentum is lower than at the beginning.

Objection:

1. Example:
   A ball is lowered onto a cushion. Ball exerts force F, causing compression of cushion, which causes an upward force on the ball, which causes a reaction force R from the ball.
2. If causes & effects are simultaneous, then when the ball exerts force F, it exerts force F+R.
3. This is impossible.
4. So the causes & effects are not simultaneous.

Reply:

- Compression of cushion is not instantaneous. (Instantaneous force has 0 effect.)
- Compression is a continuous process.
- The force-exerting and cushion-compressing events occur over the same time interval.
- Rate of change of the ball's downward force = the rate of change of the cushion's upward force due to compression.

Distinguishing causes & effects

Why we believe forces cause accelerations, not vice versa:

1. Intuitive notion of 'force'.
2. Asymmetry of determination:
   Laws determine function: configuration → forces → acceleration
   Do not determine function: acceleration → forces → configuration

Phil. 4400
Review, Unit 3

Know these concepts:
Relational theory of space
Substantival conception of space
  interpretation of position, absolute motion, & relative motion.
Newton's 1st Law
Centrifugal force
Simultaneity, Einstein's def.
spacelike separation
forward light cone
backward light cone
Galilean law of the addition of velocities
Euclidean geometry, incl.
  Axiom of parallels
Elliptical geometry, including
  Its axiom of parallels
  How to model it
  Effect on angles of a triangle
  Its curvature
Hyperbolic geometry, incl.
  Its axiom of parallels
  How to model it
  Effect on angles of a triangle
  Its curvature
Curvature of a surface

Know these theories:
Special Relativity, including:
  The invariant interval
  What is relative, what is absolute
  The speed limit
  Interpretation of Lorentz equations
  View of simultaneity
Lorentz Ether Theory, including:
  Interpretation of Lorentz equations
  Its view of spacetime & what is absolute
  Why Lorentz contractions are unobservable
  Why our absolute speed is undetectable
General relativity, basic principles of it
Universal forces theory (alternative to GR)
  What the universal forces do
  The geometry of the theory
  Carnap's view of it
  BonJour's view of it
Simultaneous conception of causation, incl.:
  Its view of time
  What the immediate effects are
  Why there are temporally extended causal processes
  Correct understanding of derivatives
Sequential conception of causation, incl.:
  Its view of time
  When direct effects occur

Know these arguments:
Einstein's argument against absolute simultaneity
Conspiracy of silence objection
  Incl., what's the "conspiracy"
Tooley's response to Conspiracy-of-Silence
  Incl., the other "conspiracy" T discusses
Some reasons for preferring LET over STR
Argument for simultaneous causation, incl.,
  No action at a temporal distance

Know these examples:
Newton's bucket & what it shows
Some examples of simultaneous causation