

Times and Spaces

Epistemology notes from 2013 to 2025: Greek vocabulary, its philosophical heirs, and the present standoffs in physics

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Ἡ περὶ τῆς ἀληθείας θεωρία τῇ μὲν χαλεπὴ τῇ δὲ ῥαδία. σημείον δὲ τὸ μήτ' ἀξίως μηδένα δύνασθαι θιγεῖν αὐτῆς μήτε πάντας ἀποτυγχάνειν, ἀλλ' ἕκαστον λέγειν τι περὶ τῆς φύσεως, καὶ καθ' ἓνα μὲν ἢ μηθὲν ἢ μικρὸν ἐπιβάλλειν αὐτῇ, ἐκ πάντων δὲ συναθροισζομένων γίγνεσθαι τι μέγεθος.

Aristotle, *Metaphysics* α 1, 993a30–b4

The investigation of the truth is in one way hard, in another easy. An indication of this is found in the fact that no one is able to attain the truth adequately, while, on the other hand, no one fails entirely, but every one says something true about the nature of things, and while individually they contribute little or nothing to the truth, by the union of all a considerable amount is amassed.

trans. W. D. Ross

Locators to primary texts follow the standard page or fragment numbering (Stephanus for Plato, Bekker for Aristotle, Diels-Kranz for the Presocratics) so any passage can be checked in any edition. I dedicate these notes to the memory of Mark Wise.

0. What the notes have been about

The notes rested on one observation: Greek has several words where English has “time” and several where English has “space”, and the words mark distinctions that physics later had to rediscover under other names. The thread runs from Hesiod to Aristotle, is preserved and sharpened by the Stoics and Neoplatonists, passes into Latin through Augustine and Boethius, reappears in Spinoza’s separation of duration from eternity, and surfaces once more in Wittgenstein’s remark that there is no such thing as the passage of time, only processes compared with other processes. On the physics side the same distinctions reappear as the difference between time as an external parameter and time as a coordinate, between an arrow and a dimension, between local place and global topology, between a container and a relation, and between the actual world and the space of its possibilities.

The count that the notes settled on: the Greeks worked with three words for time (chronos, aion, kairos) and, structurally, a fourth object, the now, whose relation to the other three is Aristotle’s problem and still ours. For space they had at least five words (chaos, apeiron, kenon, chora, topos), plus a sixth (diastema, extension) that the Stoics and Philoponus promoted, and the concept of what lies outside the cosmos, which Aristotle declared to be neither place nor void nor time. Conceptually these collapse to four: the gap or boundless from which things came (chaos, apeiron); the void as the condition of motion (kenon); the receptacle in which becoming happens (chora); and place as the boundary that locates a body (topos). The local/global question is already visible: topos is local, chora and kenon are global, and Aristotle’s cosmos has a global shape with no global space.

My Caltech undergraduate student Madeline Mooney (SURF 2026) is writing a book on this all: I am confident her monograph will be a huge scholarly contribution on unexplored or little explored history of science topics and epistemology and I hope these notes are of some use to her.

1. The vocabulary

Word	Root sense	Technical sense	Principal source	Modern heir
<i>χρόνος chronos</i>	duration, span	measured, ordered, countable time; the time of becoming	Plato Tim. 37d-38b; Aristotle Phys. IV.10-14	coordinate time, proper time, the parameter t
<i>αἰών aion</i>	a lifetime, an age	the mode of being of what always is; timeless “is”	Heraclitus B52; Parmenides B8; Plato Tim. 37d; Plotinus Enn. III.7	the block universe; Spinoza’s aeternitas; timeless formulations (Wheeler-DeWitt)
<i>καιρός kairos</i>	the right measure, the opening	the qualitatively singular moment; the time of action	Pindar; Gorgias; Hippocratic corpus	the event, the measurement, the irreversible act
<i>τὸ νῦν to nyn</i>	the now	the limit between past and future, not a part of time	Aristotle Phys. IV.11, 218a-220a; VI.3	the instant; presentism vs eternalism; the “problem of the now”
<i>χάος chaos</i>	gap, yawning (from chasko, to gape)	the first thing to come to be; the primordial opening between earth and sky	Hesiod Theog. 116, 700	the pre-geometric; the initial singularity as absence of a theater
<i>ἄπειρον apeiron</i>	without limit or boundary	the boundless source and sink of worlds	Anaximander B1, A9, A11	the infinite, the multiverse, the landscape
<i>κενόν kenon</i>	the empty	void: what is not body yet is, so that body can move	Leucippus, Democritus (Aristotle Metaph. A.4 985b4-9); Melissus B7	vacuum, the empty manifold, the ground state
<i>χώρα chora</i>	room, land, country	the receptacle of becoming, the “in which”	Plato Tim. 48e-53c	the manifold as substrate; substantival space
<i>τόπος topos</i>	place	the innermost motionless boundary of the containing body	Aristotle Phys. IV.1-5, esp. 212a20	position, local frame, coordinates
<i>διάστημα diastema</i>	interval, extension	three-dimensional extension considered apart from body	Aristotle Phys. IV.4 211b (rejected); Stoics; Philoponus, Corollary on Place	metric extension; Newton’s absolute space

Two remarks belong with the table. First, chaos meant disorder only later; in Hesiod and in Aristotle’s citation of Hesiod (Phys. IV.1 208b29-33) it is the gap, the first room, and Aristotle uses the passage to argue that place must be prior to everything else since Hesiod made it come to be first. Second, *aion* drifted. In Homer it is a person’s lifespan or the marrow of life; in Heraclitus it is the child at play; in Plato it becomes eternity as a mode of being; in Hellenistic Greek and the Septuagint it becomes an age or eon; in the Gnostics it becomes a personified emanation. The philosophical sense, eternity as the “is” without “was” and “will be”, is Parmenides’ invention and Plato’s naming.

2. Cosmogony before physics: the gap and the boundless

Hesiod (c. 700 BC) begins with Chaos coming to be, then Earth, then Tartarus in the depths of the earth, then Eros (Theog. 116-122). Chaos has no parent. It is the yawning that must open before anything can have a where. This is the first Greek statement that space, or at least a space, is prior to things, and the later Orphic theogonies (reported by Damascius, *De principiis* 123-124)

put Chronos, “unaging Time”, at the origin as a god who produces Aither and Chaos and then the cosmic egg. Pherecydes of Syros (6th c.) is the first prose writer to make Chronos one of three eternal principles alongside Zas and Chthonie (DK 7 B1; Diogenes Laertius I.119). So the earliest Greek thought already contains the two options that physics still weighs: space first (Hesiod), or time first (Orphics, Pherecydes).

Anaximander (c. 610-546) replaces the myth with a principle: the apeiron, the boundless or indefinite, from which the opposites separate out and to which they return. Two features of his fragment matter. The apeiron is spatially unlimited and temporally ungenerated and imperishable, and it is the source of “innumerable worlds” (Aëtius, A17). And the only sentence surviving in his own words makes time the judge: things “pay penalty and retribution to each other for their injustice according to the ordering of time” (*κατὰ τὴν τοῦ χρόνου τάξιν*, B1). Chronos here is the order of succession that enforces balance. This is chronos as measure and as law before it is chronos as number. Anaximander also detached the earth from any support and let it stay put by symmetry, at the center, “because of its equal distance from everything” (A26; Aristotle *De Caelo* II.13 295b10-16). That is the first argument from the isotropy of space, and it is the ancestor of the cosmological principle.

Two Presocratic ideas about the shape of time also start here. Anaximander’s worlds come and go; Empedocles’ cosmos oscillates under Love and Strife; Heraclitus’ cosmos is an “ever-living fire, kindling in measures and going out in measures” (B30), and Heraclitus is credited with a Great Year (Aëtius II.32.3; Censorinus 18.11 gives 10,800 years). Cyclic time is the default Greek cosmology. Linear time with a beginning enters with Plato’s Demiurge and, in an absolute form, with Genesis read through Philo and Augustine.

3. Parmenides and Heraclitus: the two times

Parmenides of Elea (fl. c. 475) is the first eternalist. What-is “never was nor will be, since it is now, all together, one, continuous” (B8.5-6). Coming to be and passing away are names mortals have laid down (B8.38-41). There is no void, since the void would be what-is-not, and what-is-not cannot be thought or said (B2, B6, B8.22-25). The consequences are drawn by his followers. Melissus (B7) argues that there is no void, hence nothing can move, hence there is no motion. Zeno’s paradoxes (Aristotle *Phys.* VI.9 239b) attack the continuum from both sides: the Dichotomy and the Achilles say that a continuum cannot be traversed if it is infinitely divisible; the Arrow says that if time is made of indivisible nows the arrow is at rest in each of them and so never moves; the Stadium (the moving rows) says that indivisible units of space and time contradict each other when bodies move at different speeds. Zeno’s arrow is the first argument about whether time is a set of instants or something instants only bound. The reception, from Aristotle to Cantor to Grünbaum, is the history of the continuum. Aristotle’s response, that time is not composed of nows any more than a line is composed of points (*Phys.* VI.1-2, 231a-233b; VI.3 234a), remains the standard answer, and the quantum Zeno effect (Misra and Sudarshan 1977) shows that the paradox has a physical shadow: a system observed continuously fails to evolve.

Heraclitus (fl. c. 500) is the philosopher of becoming and of measure at once. The river fragments (B12, B91) say that the same rivers receive different waters; the fire fragment (B30) says the cosmos changes “in measures” (*metra*). And the *aion* fragment (B52), “*aion* is a child playing, moving pieces on a board; the kingship is a child’s”, uses *aion* in a way that is neither Homer’s lifetime nor Plato’s eternity. It is the whole of time seen as a game with rules and without purpose. The word is already being pulled toward the whole.

So by 450 BC the two poles of every later debate are set. Parmenides: reality is a timeless, changeless whole and time is appearance. Heraclitus: reality is measured change. McTaggart's B-series and A-series, the block universe and the growing block, Barbour's Platonism and Rovelli's relational time, are restatements. The notes probably observed that physics has sided with Parmenides at the level of its equations (the relativistic block, the timeless Wheeler-DeWitt constraint) and with Heraclitus at the level of its measurements (irreversible records), and that the split is unresolved.

4. The atomists: the void as the condition of motion

Leucippus and Democritus (second half of the 5th c.) accept Melissus' inference and reverse it. Motion is real; therefore void is real. Aristotle reports their position exactly: the elements are the full and the empty, being and non-being, "and the non-being exists no less than the being" (Metaph. A.4 985b4-9). Democritus B9 and B125 give the corresponding epistemology: "by convention sweet, by convention bitter... in reality atoms and void." The void here is not Plato's receptacle and not Aristotle's place. It is the pure condition of separability and motion, without qualities, infinite, and prior to any particular arrangement of bodies. The Pythagoreans had already used a void to keep numbers and natures apart (Phys. IV.6 213b22-27), but the atomists make it a physical existent. Epicurus later gives it a name that could serve for the modern vacuum: "intangible nature" (anaphes physis, Letter to Herodotus 40; Sextus, Adv. Math. X.2). Epicurus also makes time a peculiar kind of accident, an "accident of accidents" (symptoma symptomaton, Sextus Adv. Math. X.219; Letter to Herodotus 72-73), known by analogy with days and nights and with motion and rest, and he introduces minimal parts of space and time (Letter to Herodotus 56-59), which is the first discrete spacetime.

The atomists also gave the first explicit infinity-of-space argument. Archytas of Tarentum asked what happens if one stands at the edge of the heavens and stretches out a hand or a staff: either it goes out, in which case there is something beyond, or it does not, in which case something stops it, and that something is beyond (Eudemus fr. 65 Wehrli, in Simplicius In Phys. 467.26-32). Lucretius repeats it with a javelin (De rerum natura I.968-983). The argument assumes that space is what a body could occupy, and it is precisely this assumption that Aristotle denies.

5. Plato's Timaeus: eternity, time, and the receptacle

The Timaeus (c. 360 BC) is the text where the three concepts are put in one system.

ΑΙΩΝ. The eternal living being that is the model of the cosmos has a nature that is "eternal" (aionios), and this eternity is a mode of being, not a long duration. "Was" and "will be" are forms of time that have come to be, and we wrongly transfer them to eternal being; only "is" belongs to it (37e-38a). Being is not older or younger than itself.

ΧΡΟΝΟΣ. When the Demiurge makes the heaven, he makes "a moving image of eternity" (εἰκὼν κινητὸν τινα αἰῶνος, 37d), and this image, "moving according to number", is what we call time. Time and the heaven come to be together (ἅμα οὐρανῶ, 38b), so that if they were ever to be dissolved they would be dissolved together. The sun, moon and planets were made "for the generation of time" (38c) and are its instruments. Time is thus defined by celestial motion and by number, the perfect year being the period after which all eight circles return to the same configuration (39d). This is chronos as astronomical, countable, cyclic. It is also the first statement that the beginning of the world is the beginning of time, which Augustine will take over and which reappears, with a

different justification, in the no-boundary proposal.

CHORA. In the second beginning of the dialogue (48e), Plato introduces a “third kind” (*τρίτον γένος*) besides intelligible being and sensible becoming: the receptacle (*hypodochē*, 49a), “the nurse of all becoming” (49a6), the mother in which the father’s forms produce offspring (50d). At 52a-b he names it: “a third kind is space (*chora*), everlasting, not admitting destruction, providing a seat (*hedra*) for all things that come to be, itself apprehended without the senses by a kind of bastard reasoning (*λογισμῷ τινι νόθῳ*), hardly an object of belief.” We dream of it when we say that everything that is must be somewhere, in some place (*topos*) and occupying some space (*chora*), and that what is neither on earth nor in heaven is nothing (52b). *Chora* is qualityless, since if it had qualities it could not receive all forms; it is shaken by the entering powers like a winnowing basket (52e-53a) and sorts them. And it is not made by the Demiurge: it is coeval with the forms, prior to the ordered cosmos. Plato’s triad at 52d is being, space, becoming (*ὄν τε καὶ χώραν καὶ γένεσιν*), three things before the heaven came to be.

Time, then, is made; space is not. The receptacle is the substrate of the theater; time is a feature of the play. The notes may have marked this asymmetry, since it recurs in the AdS/CFT era: physics knows how to make space emerge from something without space, and does not know how to make time emerge from something without time. Plato had the opposite asymmetry, and both are asymmetries.

6. Aristotle: time as number, place as boundary, gravity without force

Aristotle (384-322) keeps *chronos* and *topos* and demotes the rest. *Aion* he uses in the old sense of the complete duration of a thing’s life, and of the heaven’s life, so that the outermost heaven’s *aion* is the full span, “always being” (*De Caelo* I.9 279a22-30). *Chora* he treats as Plato’s confusion of place with matter (*Phys.* IV.2 209b11-17). Kenon he refutes at length (*Phys.* IV.6-9). What remains is a relational physics.

CHRONOS. *Physics* IV.10 opens with the puzzles: the past no longer is, the future is not yet, and the now is not a part of time since parts measure their wholes and nows do not add up to anything (217b32-218a30). Time is not motion, since motion is in the moving thing and can be fast or slow, whereas time is everywhere alike and cannot be fast or slow (218b9-219a1). But time is not without motion: we perceive time when we perceive motion and mark off a before and an after (219a22-30). Hence the definition: “this is what time is, the number of motion in respect of before and after” (*ἀριθμὸς κινήσεως κατὰ τὸ πρότερον καὶ ὕστερον*, 219b1-2), where “number” means the counted, not what we count with (219b5-9). The now is what makes time continuous and what divides it (220a4-21); it is the same in substrate and different in definition, like a moving body that is one thing and is in different places. The uniform circular motion of the heaven is the natural measure because it is the best known and most uniform (223b12-224a2). And in IV.14 (223a21-29) comes the question that Rovelli and the de Sitter algebraists have reopened: if there were no soul, would there be time? Since number requires a counter, there would be no time, only the motion that time is the number of, “if indeed motion can exist without soul.”

TWO CONSEQUENCES. The first is that Aristotelian time is relational and ordinal: it is the ordering of events by before and after together with a count. This is close to what causal set theory later formalizes as order plus number, and it is closer to Leibniz and to Einstein than to Newton. The second is that time is infinite in both directions, since every now is the end of a past and the beginning of a future (*Phys.* VIII.1 251b10-28), and the cosmos is eternal. Aristotle rejects Plato’s created time explicitly.

ΤΟΠΟΣ. Physics IV.1-5 asks what place is and lists four candidates: form, matter, the interval (diastema) between the extremities, or the extremities themselves (211b6-9). Form and matter belong to the body and travel with it, so they cannot be what the body leaves behind when it moves. The interval, an extension that would persist independently of the bodies occupying it, is the view Aristotle attributes to those who believe in void, and he rejects it: there would be infinitely many places within places, and place would itself be somewhere (211b19-29). What remains is the fourth: place is “the innermost motionless boundary of the containing body” (τὸ τοῦ περιέχοντος πέρασ ἀκίνητον πρῶτον, 212a20). Place is a surface, it belongs to the container, and it is relative to something at rest, ultimately the heaven as a whole. The heaven itself is not in a place, since nothing contains it, though its parts are (212b7-22). And beyond the heaven there is nothing: “neither place nor void nor time” (De Caelo I.9 279a11-18). This is the first physics that is locally rich and globally closed, with no global space at all.

NATURAL MOTION. Aristotle’s theory of the heavy and the light (De Caelo IV; Phys. VIII.4) contains what may be the oldest structural anticipation of general relativity, although the notes would have been careful about the anachronism. Heavy bodies move toward the center and light bodies away from it, not because a force acts on them but because that is their nature; they move to their natural place, and the natural place is defined by the structure of the cosmos. Nothing pulls the stone. The stone completes itself. Motion toward the natural place is unforced (kata physin), and it is forced motion (para physin, bia) that needs a mover in contact. Aristotle’s mistakes are elsewhere: the anisotropy of space (an absolute up and down), the need for a continuous mover in forced motion, and the finite cosmos. But the idea that free fall is the default state and requires no agent is Aristotelian before it is Einsteinian. What Newton did was to make free fall a forced motion again, with an unexplained agent acting at a distance, and what Einstein did was to remove the agent and make free fall inertial motion in a curved geometry. The natural place became the geodesic.

7. Hellenistic and late antique refinements

The Stoics (Zeno of Citium, Chrysippus, 3rd c. BC) accepted a finite cosmos and, against Aristotle, an infinite void outside it, and they were the first to distinguish the space words by definition. Sextus Empiricus reports (Adv. Math. X.3-4): void is what is capable of being occupied by a body but is not occupied; place (topos) is what is occupied by a body and made equal to what occupies it; space (chora) is what is partly occupied and partly unoccupied. Three spaces, one global and empty, one local and full, one mixed. The cosmos is a body in an infinite void, and since void has no structure, the cosmos has nothing to move toward: it stays put by cohesion. For time, Zeno defined chronos as “the interval of motion” (diastema kineseos) and Chrysippus as “the interval of the motion of the cosmos” (Stobaeus, Ecl. I.8.42, SVF II.509-510), and the Stoics held that only the present “belongs” (hyparchei) while past and future merely “subsist” (hyphestekenai), the first clear presentism. Their cosmology was cyclic: the cosmos is consumed in the conflagration (ekpyrosis) and reborn (palingenesia) with the same events repeated, Socrates again teaching in the same Athens (Nemesius, De natura hominis 38; Alexander, In Anal. Pr. 180.33-36). This is eternal recurrence as physics, and it returns in the Poincaré recurrence theorem and in the recurrence problem of de Sitter space.

Epicurus and Lucretius kept the atomist void and added minimal parts and the swerve; their time is an accident of motion and has no independent being.

Plotinus (204-270), in Ennead III.7 “On Eternity and Time”, gave the definitive Neoplatonic account. Eternity (aion) is the life of Intellect, complete, all at once, without succession, “a life that remains

in the same and always has the all present to it" (III.7.3). Time is "the life of Soul in a movement of passage from one way of life to another" (III.7.11): Soul, unable to hold the whole at once, unrolls it, and the cosmos is in time because it is in Soul. Time is prior to the heavens' motion, which is only its measure; this reverses Aristotle, who had made motion prior. Plotinus also gives the sharpest statement that the "is" of eternity and the "is" of the present now are different: the now is the point at which passing time touches what does not pass.

Iamblichus (c. 245-325) split time in two: a higher, static, intelligible time that is the order of before and after in itself, and the flowing time that participates in it (Simplicius *In Phys.* 786-795; *In Cat.* 352-356). Damascius (c. 460-540) went further and held that the whole of time exists all at once (*sympas chronos*) in the way a whole exists, and that the flowing now is a leap rather than a point (Simplicius, *Corollarium de tempore*, *In Phys.* 773-800). Sorabji (*Time, Creation and the Continuum*, 1983) treats these as the nearest ancient approach to a four-dimensional or block conception, with the added idea that the present has finite extent.

John Philoponus (c. 490-570), in the Corollary on Place appended to his Physics commentary (*In Phys.* 557-585), rejected Aristotle's definition and argued that place is three-dimensional extension (*diastema*), incorporeal and distinct from the body that occupies it, coextensive with the cosmos and without a void beyond. This is the position Aristotle had refused, now defended; it descends through the Arabic and Latin traditions to Gassendi and Newton. Philoponus also argued, against Proclus and Aristotle, that the world cannot be eternal since an infinite past would have had to be traversed (*De aeternitate mundi contra Proclum*; *Contra Aristotelem*, in Simplicius). These traversal arguments become the *kalam* argument, are used by Bonaventure against Aquinas, and appear as the thesis of Kant's first antinomy.

The late antique position, then, had already worked through most of the logical space: relational vs absolute place, finite vs infinite void, created vs eternal time, flowing vs static time, presentism vs the block, cyclic vs linear history. What was missing was mathematics beyond geometry and astronomy, and an experimental discipline.

8. The Latin bridge: Augustine, Boethius, Aquinas

Augustine (354-430) transmits Plato's created time through Christian creation. *Confessions* XI.14: "What then is time? If no one asks me, I know; if I wish to explain it to one who asks, I do not know." His analysis runs through the Aristotelian puzzles (the past is not, the future is not yet, the present has no extent) and lands on time as a "distension of the mind" (*distentio animi*, XI.26): memory, attention, expectation. He answers the question what God was doing before creation by denying that there was a before: God made time with the world, "not in time but with time" (*non in tempore sed cum tempore*, *De civitate Dei* XI.6; *Confessions* XI.13). This is the Timaeus 38b argument stripped of the celestial clock and made a matter of the dependence of time on change. Hawking's remark that asking what came before the big bang is like asking what is north of the North Pole is the same move with a different geometry.

Boethius (c. 480-524) gave the definition of eternity that the scholastics used: "the whole, simultaneous and perfect possession of unbounded life" (*interminabilis vitae tota simul et perfecta possessio*, *Consolatio* V.6). This is Plotinus' *aion* in Latin, and it fixes the distinction between eternity (*aeternitas*), which is timeless, and everlastingness (*sempiternitas* or *perpetuitas*), which is time without end. The distinction matters for physics: an eternal universe in Aristotle's sense (infinite *chronos*) and a timeless universe in Parmenides' sense (*aion*) are different claims, and confusing them is common.

Aquinas (1225-1274) added a third measure between the two. *Summa Theologiae* I q.10 a.5 distinguishes *tempus*, the measure of what changes in being and operation; *aeternitas*, the measure of what has neither; and *aevum*, the measure of what is unchanging in its being but has succession in its operations, the angels and the heavenly bodies. *Aevum* is *aion* Latinized and given a new job. So the Latin middle ages counted three times, and the count is useful: a system whose state space is fixed but whose states succeed one another has *aevum*, which is roughly the situation of a closed dynamical system in a stationary background, whereas the background itself, if it changes, has *tempus*, and the laws have *aeternitas*.

9. The early moderns: Newton, Leibniz, Spinoza, Kant

Newton (*Principia* 1687, Scholium to the Definitions) made the interval real. “Absolute, true, and mathematical time, of itself and from its own nature, flows equably without relation to anything external, and by another name is called duration”; “absolute space, in its own nature, without relation to anything external, remains always similar and immovable.” This is Philoponus’ *diastema* and Gassendi’s void made into the frame of dynamics, with the additional and decisive claim that time is a single universal parameter that flows. The bucket argument (Scholium) and the two globes are meant to show that absolute rotation is detectable and hence that absolute space is not a fiction. Newton’s space is a container prior to bodies; his time is a parameter prior to motion. Both are *chora* and *chronos* in Plato’s sense, with Plato’s creation removed and Plato’s mathematics kept. In the *Opticks* (Query 28, 31) and in *De gravitatione* he flirts with space as God’s sensorium, a phrase Leibniz ridiculed.

Leibniz answered with relationalism. Third letter to Clarke §4 (1716): “I hold space to be something merely relative, as time is; I hold it to be an order of coexistences, as time is an order of successions.” The shift argument (§5) says that if space were absolute, God could have placed the whole world elsewhere or reversed east and west, producing a different world indistinguishable from this one, which violates the principle of sufficient reason and the identity of indiscernibles. This is Aristotle’s relational place generalized to a relational space, and it is the argument that Einstein’s hole argument and the diffeomorphism invariance of general relativity later vindicate in a specific form. The Leibniz-Clarke correspondence is the canonical statement of substantivalism versus relationalism, and the modern literature (Earman, Norton, Stachel, Maudlin, Pooley) is a footnote to it.

Spinoza (1632-1677) is the figure the notes were heading toward, and he belongs to the Parmenidean line. The *Ethics* defines eternity as “existence itself, insofar as it is conceived to follow necessarily from the definition alone of the eternal thing”, and the explanation adds that such existence “cannot be explained by duration or time, even if the duration is conceived to be without beginning or end” (I def. 8). Duration (*duratio*) is “indefinite continuation of existing” (II def. 5) and belongs to modes, to finite things. Time (*tempus*) is not even a property of things: in Letter 12 to Lodewijk Meyer (20 April 1663), the Letter on the Infinite, Spinoza sets out three pairs. Of substance we conceive eternity; of modes, duration. Duration, quantity and multiplicity, taken in the abstract, give rise to time, measure and number, which are “nothing but modes of thinking, or rather of imagining” (*modi imaginandi*). The errors about the infinite arise from applying to substance what belongs to modes and from trying to explain duration by time, which is a measure of it and not its nature. Time, for Spinoza, is a coordinatization of duration by the imagination, and eternity is not in the same category as either. Under the attribute of thought reason “perceives things under a certain species of eternity” (*sub quadam aeternitatis specie*, II p44 cor. 2), and in Part V the

mind knows itself to be eternal: “we feel and know by experience that we are eternal” (*sentimus experimurque nos aeternos esse*, V p23 schol.), where the eternity in question is again timelessness and not survival. Since God or Nature is the one substance and everything follows from its nature with necessity (I p29, I p33), there is no contingency and no open future. Extension is an attribute of that substance (II p2), so space is not a container but a way the one thing is; and there is nothing outside it.

This is the block universe as metaphysics, with three registers: *aeternitas* for the whole and its laws, *duratio* for the existence of finite things, and *tempus* for our measure of that existence. It maps onto Plato’s *aion*, the life of the cosmos, and *chronos* as the count of celestial motion, and the map is exact enough that Spinoza’s Letter 12 can be read as a commentary on Timaeus 37d. Einstein’s repeated professions of Spinozism (the 1929 telegram to Rabbi Goldstein, the 1920 poem “Zu Spinozas Ethik”) are not decoration; the four-dimensional world of Minkowski, in which the distinction between past, present and future is, in Einstein’s letter to the Besso family (1955), “a stubbornly persistent illusion”, is Spinoza’s world with a metric.

Kant (*Critique of Pure Reason*, 1781/1787) removed both time and space from things and placed them in the subject as forms of intuition. Space is the form of outer sense and has three dimensions; time is the form of inner sense and has one: “different times are successive, as different spaces are simultaneous” (A31/B47, paraphrased). Time is represented as an infinite given magnitude and is one; all particular times are limitations of it. Kant is the first to make the dimensionality and the unicity of time a topic, and to make the difference between one time and three spaces a fact about representation rather than about the world. The first antinomy (A426/B454) sets Philoponus’ thesis (the world has a beginning in time and is bounded in space) against Aristotle’s antithesis (it has no beginning and no bounds) and declares both unprovable, since the world as a whole is not an object of possible experience; this is the state of the cosmological question before Friedmann. And the 1768 essay on incongruent counterparts (the left and right hand, which agree in all internal relations and yet cannot be superposed) argues that space has a structure not captured by the relations among a body’s parts. That structure is orientation, and its physical version is parity, whose violation by the weak interaction (Wu 1957) shows that Kant was right that there is a fact of the matter about handedness and wrong that it is imposed by us.

10. From McTaggart to Wittgenstein

McTaggart (“The Unreality of Time”, *Mind* 1908) named the two ways of ordering events that Parmenides and Heraclitus had split. The B-series orders events by earlier and later; the relations are permanent. The A-series orders them by past, present and future; the positions change. He argued that the A-series is essential to time and contradictory, so time is unreal. The argument is contested, but the vocabulary is standard, and in physics the B-series is what a spacetime diagram displays and the A-series is what no equation contains.

Bergson and Einstein met in Paris on 6 April 1922 at the Société française de philosophie. Bergson defended lived duration (*durée*) against measured clock time and denied that the twins could age differently; Einstein replied that there is no “time of the philosophers”, only psychological time and physical time, and that the philosopher’s time is a confusion of the two. Bergson’s *Durée et simultanéité* (1922) followed. Bergson was wrong about the twins and right that the physical concept does not capture what he was pointing at; Aristotle’s soul that counts and Augustine’s *distentio* are the ancestors of *durée*, and none of them is *chronos*. The dispute is sometimes credited with keeping relativity out of Einstein’s Nobel citation.

Wittgenstein's *Tractatus* (1921) contains, in a few numbered remarks, the whole of the notes' argument in compressed form. Moore proposed the title on the model of Spinoza's *Tractatus Theologico-Politicus*, and the debt is real.

Logical space. "The facts in logical space are the world" (1.13). "Each thing is, as it were, in a space of possible states of affairs. This space I can imagine empty, but I cannot imagine the thing without the space" (2.013). "A spatial object must be situated in infinite space. A speck in the visual field, though it need not be red, must have some colour: it is, so to speak, surrounded by colour-space. Notes must have some pitch, objects of the sense of touch some degree of hardness" (2.0131). Logical space is the space of possibilities; the world is the subset of it that obtains. Plato's *chora* was the receptacle of everything that comes to be; Wittgenstein's *logischer Raum* is the receptacle of everything that could be the case. This is the distinction between the actual theater and the space of possible theaters, and it will return in §17.

Time. "We cannot compare a process with 'the passage of time' (there is no such thing) but only with another process (such as the working of a chronometer)" (6.3611). This is Aristotle's "time is not motion, but not without motion" and Leibniz's order of successions, and it is also Einstein's 1905 operational definition of time by clocks and the relational time of quantum gravity. The passage continues with the two-hands problem: "Kant's problem about the right hand and the left hand, which cannot be made to coincide, exists already in the plane, indeed in one-dimensional space... The right hand and the left hand are in fact completely congruent. It is quite irrelevant that they cannot be made to coincide. A right-hand glove could be put on the left hand if it could be turned round in four-dimensional space" (6.36111). Orientation is a global property of the embedding, and it depends on dimension; the answer to Kant is topology.

Eternity. "Death is not an event in life: we do not live to experience death. If we take eternity to mean not infinite temporal duration but timelessness, then eternal life belongs to those who live in the present" (6.4311). "To view the world *sub specie aeterni* is to view it as a whole, a limited whole" (6.45). The Boethian definition of eternity and Spinoza's *sub specie aeternitatis*, in the language of a logician who had read neither at length but had absorbed both through Schopenhauer. The notebooks of 1916 (entry of 7 October) make the connection explicit: "the work of art is the object seen *sub specie aeternitatis*; and the good life is the world seen *sub specie aeternitatis*."

The later Wittgenstein returned to Augustine's question in the Blue Book (1933-34) and in the *Philosophical Investigations* (§89-90): "what is time?" produces confusion because it is asked in the form of a request for a definition of a substance, when the concept is defined by its use in measuring. Time is what clocks measure; the puzzle is grammatical. This deflationary answer is the position most working physicists hold and is also the one that quantum gravity finds inadequate, since in a theory without a background there is nothing for the clock to be compared against except another clock.

Gödel completed the twentieth-century philosophical loop from inside physics. His 1949 solution of Einstein's equations (a rotating, non-expanding universe) contains closed timelike curves, and his essay in the Schilpp volume for Einstein's seventieth birthday argues that since relativity permits worlds in which there is no global time function at all, and since whether our world has one is a contingent matter of the distribution of matter, the objective lapse of time cannot be part of the nature of things: Kant and Parmenides were right. Einstein's reply in the same volume was uneasy. Deleuze (*Logique du sens*, 1969, 23rd series) revived the Stoic pair, *Chronos* as the living present that absorbs past and future and *Aion* as the unlimited line of past and future that divides every instant, drawing on Goldschmidt's *Le système stoïcien et l'idée de temps* (1953); the notes may have picked up the terminology from there.

11. Physics I: time as parameter, time as coordinate, time as arrow

Three things are called time in physics, and they correspond to three of the Greek objects.

TIME AS PARAMETER. In Newtonian mechanics and in non-relativistic quantum mechanics, t is a real number that labels states and is not itself a dynamical variable. The Schrödinger equation $\hbar \partial \psi / \partial t = H \psi$ treats t as an external, classical, universal label; position is an operator, time is not. Pauli's theorem (1933, in his *Handbuch der Physik* article on wave mechanics) makes this structural: no self-adjoint operator T can satisfy $[T, H] = \hbar$ if H is bounded below, since the unitary flow generated by T would shift the spectrum of H to arbitrarily negative values. Time in quantum mechanics is therefore Newton's absolute time, Plato's number of the celestial motion imported into the formalism as a given: *chronos* as the count supplied from outside, with the soul that counts replaced by the laboratory clock.

TIME AS COORDINATE. Special relativity makes $x^0 = ct$ one of four coordinates on a flat manifold, mixed with the others by Lorentz transformations. General relativity goes further: the coordinates carry no physical meaning at all (general covariance), and the only physical time is proper time τ along a worldline, defined by the metric, $d\tau^2 = -g_{\mu\nu} dx^\mu dx^\nu$, and read by the clock carried along it. The metric is dynamical, so the "theater" is itself one of the actors. Coordinate time is *topos*-like, a labeling of place in the manifold; proper time is *chronos* in Aristotle's sense, the number of a particular motion measured against another (Wittgenstein 6.3611 is exactly the relativistic view). There is no global parameter unless the spacetime happens to admit a global time function, which requires stable causality, and there is no preferred one even then.

The two are incompatible, and this is the "problem of time" in quantum gravity (Kuchař 1992; Isham 1992; Anderson 2017 for a monograph). Canonical quantization of general relativity yields the Hamiltonian constraint $H\Psi = 0$, the Wheeler-DeWitt equation (DeWitt 1967), which contains no t : the wavefunction of the universe does not evolve. This is Parmenides in an equation. Time must then be recovered relationally: Page and Wootters (1983) let a subsystem serve as clock and recover Schrödinger evolution in the correlations, conditioned on the clock reading; Rovelli (1991) argued that physical time is a relational, partial-observable construction and that any dynamical variable that is monotonic enough can serve; Barbour (The End of Time, 1999) accepted the timeless conclusion outright. This is Aristotle's "if there were no soul, would there be time?" with a positive answer for the motion and a negative one for the number: there are correlations, and time is what we call one of the correlates when we use it to order the others.

TIME AS ARROW. The third thing called time is the asymmetry between past and future. Eddington coined "the arrow of time" (The Nature of the Physical World, 1928) for the direction in which entropy increases. Here is the error the notes flagged. An arrow is not a dimension. Entropy is a function on the state space (a real number assigned to a macrostate), not a coordinate on the manifold, and its monotonic increase is (a) statistical, (b) contingent on special initial conditions, and (c) defined only relative to a coarse-graining. Using entropy to define time confuses the orientation of the time axis with the axis, *chronos* with its sign. The fundamental equations, classical and quantum, are time-reversal symmetric (up to the CP violation treated below), so nothing in them singles out a direction; Loschmidt's reversibility objection (1876) and Zermelo's recurrence objection (1896, from Poincaré's 1890 theorem) showed Boltzmann that the H-theorem needs an asymmetric input. That input is a low-entropy initial condition, the "Past Hypothesis" in Albert's phrase (Time and Chance, 2000), and in cosmology it is the smoothness of the early universe, whose gravitational entropy was low because the Weyl curvature was small (Penrose 1979). The arrow is thus a boundary condition, not a law and not a dimension.

There is an attempt to build time from the thermodynamic state rather than the other way around. Connes and Rovelli (1994) observed that in a generally covariant theory a state on the algebra of observables defines its own flow, the modular (Tomita-Takesaki) flow, and proposed that physical time is this flow: the thermal time hypothesis. For equilibrium states the modular flow coincides with the Hamiltonian flow rescaled by temperature, which recovers the Unruh and Hawking temperatures as identities. This is time as a property of the state, defined without a background, and it is the rigorous descendant of the “time is entropy” intuition. It returns in §16.

The hypothesis has drawn objections. Swanson (*Philosophy of Science* 88, 2021) states five: the relation between thermal time and proper time is left open; the construction has no classical implementation; in equilibrium the modular flow returns the Hamiltonian flow one began with, so the hypothesis restates rather than explains; away from equilibrium the flow is state-dependent and no argument connects it to anything an observer reads; and the choice of state is a background, so the claim to background independence fails on its own terms. Chua (*J. Gen. Phil. Sci.*, 2025) adds circularity: the KMS condition that fixes the state already presupposes a dynamics, hence a time. Paetz (Göttingen, 2010) audits the mathematics and finds that only flows with dispersive properties could carry the interpretation. The perspectival arrow (Rovelli 2015, 2019), on which entropy is indexed to the observer’s coarse-graining, meets the older objection of Callender (*J. Phil.* 96, 1999) and Albert (*Time and Chance*, 2000) that the coarse-graining is fixed by the interaction Hamiltonian and by decoherence, so entropy is objective given the physics, and Price’s double-standard objection (1996) that any observer-based arrow must explain the observer’s correlation with low entropy without assuming the direction. Measured by the test of §14, the Tomita-Takesaki flow is a theorem and “time is thermal” is a slogan: there is no map from a general state to a clock and no error term away from equilibrium. The one setting in which the flow has done work, the de Sitter algebra of §16, already contains an observer with a clock, which is Chua’s circularity stated as a feature.

Kairos survives in the third sense too. The one irreversible thing in quantum mechanics as ordinarily used is the measurement, von Neumann’s process 1 (1932), and the one irreversible thing in the world as ordinarily experienced is the making of a record. Whether measurement is fundamental (Copenhagen, GRW) or emergent from decoherence (Zeh, Zurek, Joos) is the question whether kairos is a fourth time or a coarse-grained appearance within chronos. Everett’s answer is that it is an appearance; Penrose’s is that it is gravity.

12. Physics II: reversibility, black holes, white holes, wormholes

Time reversal in mechanics is the map $t \rightarrow -t$ with velocities reversed. Newton’s and Maxwell’s equations are invariant. In quantum mechanics Wigner (1932) showed that T must be antiunitary, since it must flip the sign of momentum and of angular momentum while leaving position fixed, and the Schrödinger and Dirac equations are T -invariant with an appropriate T . The known exception is the weak interaction. CP violation in neutral kaon decay (Christenson, Cronin, Fitch, Turlay 1964) implies T violation by the CPT theorem (Lüders 1954; Pauli 1955; Jost 1957), which holds in any local, Lorentz-invariant quantum field theory with a Hermitian Hamiltonian; direct T violation was measured by CPLEAR (1998) in the kaon system and by BaBar (2012) in entangled B mesons. So the microscopic laws are not exactly reversible, but the violation is tiny, confined to one sector, and irrelevant to the thermodynamic arrow, whose magnitude is set by initial conditions. CPT itself is the deepest reversibility statement we have: a movie of the world run backward, mirror-reversed, with all charges flipped is a physically possible movie.

General relativity is time-symmetric: the Einstein equations $G_{\mu\nu} = 8\pi G T_{\mu\nu}$ do not involve the

direction of time, and if (M, g) is a solution so is its time reverse. The Schwarzschild metric of 1916 is static, and its maximal analytic extension (Kruskal 1960; Szekeres 1960) shows what the symmetry implies. The extended manifold has four regions: two exterior asymptotically flat regions (I and III) connected by a non-traversable throat (the Einstein-Rosen bridge, 1935), a black hole region II in whose future lies a singularity that everything entering must hit, and a white hole region IV in whose past lies a singularity from which everything must have emerged. Region IV is the time reverse of region II; the white hole is what the black hole looks like in the movie run backward. Nothing can enter a white hole, and nothing can leave a black hole. The Penrose diagram of the extended Schwarzschild solution is symmetric under reflection through the horizontal axis, and the time symmetry of the equations is what puts the white hole there.

Physical black holes are formed by collapse (Oppenheimer and Snyder 1939), and the collapsing matter covers region IV and region III: the white hole and the second exterior are absent. So the white hole is an artefact of the eternal, vacuum solution, present because the mathematics is symmetric and absent because the initial conditions are not. This is the arrow of time appearing in the solutions of a time-symmetric theory through boundary conditions, in the same way that the thermodynamic arrow appears in reversible mechanics through the Past Hypothesis. Whether white holes exist elsewhere is open; the loop-quantum-gravity proposal of a black-to-white-hole transition at the Planck density (Haggard and Rovelli 2015; the “Planck star”) is a conjecture with no observational support and no derivation from a complete theory, and belongs in the file of ideas the notes marked as fringe.

Hawking radiation (1974, 1975) makes the black hole a thermodynamic object with temperature $T = \hbar c^3 / 8\pi G M k$ and entropy $S = A / 4G\hbar$ (Bekenstein 1973), and with it the reversibility question moves to quantum theory. A black hole that evaporates completely appears to take a pure state to a mixed one, violating unitarity (Hawking 1976). The information paradox is the modern form of the reversibility problem: either the microscopic evolution is irreversible (Hawking’s original position, since abandoned) or the information comes out in the radiation in a way that the semiclassical calculation misses. The Page curve (1993) states what unitarity requires; the replica-wormhole and island calculations (Penington 2019; Almheiri, Engelhardt, Marolf and Maxfield 2019; Almheiri, Hartman, Maldacena, Shaghoulian and Tajdini 2020) reproduce it from the gravitational path integral. The current consensus is that evaporation is unitary and that spacetime connectivity of a surprising kind is what saves it, which leads to the next point.

ER = EPR (Maldacena and Susskind 2013) proposes that two entangled black holes are connected by an Einstein-Rosen bridge, and in general that entanglement and geometric connection are the same thing. The bridge is non-traversable, which preserves causality (no signaling through entanglement); Gao, Jafferis and Wall (2017) showed that a double-trace coupling between the two boundaries makes it traversable for a short time, and Maldacena and Qi (2018) constructed an eternal traversable wormhole in two coupled SYK models. The SYK model (Sachdev and Ye 1993; Kitaev 2015; Maldacena and Stanford 2016) is the cleanest laboratory here because it has no space at all: it is N Majorana fermions with random all-to-all couplings, and its low-energy dynamics is dual to Jackiw-Teitelboim gravity on a two-dimensional anti-de Sitter throat. The bulk spatial dimension is emergent, and the wormhole traversal is a process in the boundary theory with no spatial content, reinterpreted in the bulk as a passage through space. The 2022 Sycamore experiment (Jafferis et al., Nature 612, 51) implemented a learned sparse version of this protocol on nine qubits; the interpretation of what a small learned Hamiltonian demonstrates about gravity was contested (Kobrin, Schuster and Yao 2023) and the while the question was answered (Jafferis et al., Nature 643, 2025) the debate remains open. Whatever its resolution, the structure is the

philosophically striking one: reversibility (the unitary boundary dynamics), a spatial connection that exists because of entanglement, and a passage through it that is unitary and reversible in the boundary while appearing as a one-way trip in the bulk.

13. Physics III: what a force is, and whether gravity is one

The Greek word for force, *bia*, means violence, and Aristotle's forced motion is motion against nature that requires a mover in contact. Newton's *vis* is a cause of change of motion, quantified as the rate of change of momentum, and gravity is a *vis* that acts through empty space between bodies without contact. Newton disliked this and said so ("that one body may act upon another at a distance through a vacuum without the mediation of anything else... is to me so great an absurdity", letter to Bentley, 1693), and the General Scholium's hypotheses non fingo declines to give gravity a mechanism. Field theory (Faraday, Maxwell) supplies the mediation: forces are the local action of fields, and the field carries energy and momentum. In quantum field theory the mediation is quantized and a force is the exchange of a boson: photon, W and Z, gluon.

Einstein's equivalence principle (1907; the "happiest thought of my life" in the 1920 Morgan manuscript) removes gravity from this list. A freely falling observer feels no force, and in a small enough region no experiment distinguishes free fall in a gravitational field from inertial motion in empty space. Gravity is therefore not a force in the Newtonian sense but the curvature of the spacetime in which force-free bodies move on geodesics. What Newton called the force of gravity is the deviation of a body's actual path from a geodesic when something else (the floor) pushes it. This is Aristotle's structure with the geometry corrected: free fall is natural motion, needs no agent, and is defined by the structure of the theater; the theater is now a Lorentzian manifold whose curvature is determined by the matter in it. Tidal effects, which are the physical content of curvature (the relative acceleration of nearby geodesics, the geodesic deviation equation), are what is left of gravity as a force, and they vanish at a point.

The quantum field theorist gives the opposite answer, and it is also correct. A massless spin-2 field coupled consistently to energy-momentum must couple universally (Weinberg 1964, from the soft-graviton theorem, which derives the equivalence principle rather than assuming it), and its self-consistent nonlinear completion is general relativity (Deser 1970; Feynman's 1962-63 Lectures on Gravitation; Boulware and Deser 1975). The graviton is a gauge boson on the same footing as the photon, and gravity is a force mediated by its exchange. The two answers are compatible because the gauge symmetry of the spin-2 field is diffeomorphism invariance, and diffeomorphism invariance is what makes the field into a metric. Gravity is a force whose gauge redundancy is the geometry of the stage. What fails is the perturbative quantization: the theory is non-renormalizable (the two-loop divergence of Goroff and Sagnotti 1986), and the effective field theory of gravity is reliable only below the Planck scale.

Entropic and induced gravity are attempts to say that gravity is neither a force nor a geometry at bottom but a statistical effect, and the notes were right to sort them by what has been derived.

Sakharov's induced gravity (1967) is a calculation: the one-loop effective action of quantum fields on a curved background contains an Einstein-Hilbert term with a coefficient set by the ultraviolet cutoff, so the Newton constant could be entirely induced by matter fluctuations, with no bare gravitational action. Visser's 2002 review restates it in modern language. It is a theorem about the form of the effective action, not a theory of what the cutoff is.

Jacobson (1995) is a derivation with clearly stated assumptions. Assume that the entropy of a local

Rindler horizon is proportional to its area, that the Unruh temperature is the temperature seen by the accelerated observer, and that the Clausius relation $\delta Q = T dS$ holds for energy flux across the horizon. Then the Raychaudhuri equation forces the Einstein equations. General relativity is an equation of state, and quantizing it would be like quantizing the ideal gas law. This is respectable and much cited; what it does not supply is the microscopic degrees of freedom whose entropy the area counts. Padmanabhan's program (2010 review) extends it.

Verlinde (2011) is a conjecture in the strong sense. He posits holographic screens carrying entropy proportional to area, assumes that the displacement of a mass changes the screen entropy by an amount fixed by dimensional analysis, and derives Newton's law as an entropic force, $F = T \Delta S / \Delta x$, in the manner of a polymer's elasticity. There is no microscopic model, the identification of the screen entropy is an assumption, and the derivation of the Unruh temperature relation is circular in a way several authors have noted (Visser 2011, "Conservative entropic forces"). Kobakhidze (2011) argued that entropic gravity as formulated fails neutron interferometry, since a thermal, entropic force would decohere the neutron; the argument is contested. Verlinde's 2017 extension, in which dark matter is the elastic response of an entanglement entropy associated with dark energy in de Sitter space, makes a definite prediction for galaxy rotation and lensing that resembles MOND (Milgrom 1983); the weak-lensing test of Brouwer et al. (2017) was consistent with it in a limited regime, and later tests (dwarf spheroidals, galaxy clusters, wide binaries) are mixed to negative. The status is: an appealing heuristic with no microscopic derivation, no consistent relativistic completion, and no clear observational advantage over Λ CDM. It sits in the same bin as Le Sage's 1748 push gravity and the Stoic tension (tonos): a physical picture ahead of any theory.

The honest lesson from the entropic programs is the one Jacobson drew: the area law for entropy (Bekenstein, Hawking, and the holographic bound of 't Hooft 1993 and Susskind 1995) is the single most robust fact about quantum gravity we possess, it implies that the degrees of freedom of a region scale with its boundary rather than its volume, and this alone tells us that the manifold picture of space is not fundamental. What replaces it is the subject of the next section.

14. Physics IV: emergent space, emergent time, and why one time

SPACE FROM ENTANGLEMENT. The AdS/CFT correspondence (Maldacena 1997; Gubser, Klebanov and Polyakov 1998; Witten 1998) is the one setting in which a theory with gravity in $d + 1$ dimensions has been shown, at the level of precision physics accepts, to be equivalent to a theory without gravity in d dimensions. The extra dimension, the radial direction of anti-de Sitter space, is the renormalization scale of the boundary theory: moving inward in the bulk is coarse-graining on the boundary. Ryu and Takayanagi (2006) showed that the entanglement entropy of a boundary region equals the area of the minimal bulk surface anchored on it, in Planck units, generalizing the Bekenstein-Hawking formula; Van Raamsdonk (2010) argued from this that disentangling two boundary regions pinches off the bulk connecting them, so that the connectivity of space is the entanglement of the boundary state; Swingle (2012) showed that the MERA tensor network of a critical boundary theory has the geometry of a hyperbolic slice of AdS. Space, in this picture, is a data structure for the entanglement pattern of a quantum state that has no spatial content of its own. Plato's chora, the receptacle known by bastard reasoning, turns out to be the shape of correlations. In the matrix models (BFSS 1997), the spatial coordinates are the eigenvalues of large matrices and commuting matrices are the special case in which a classical geometry exists.¹

¹On the word "emergent" in this section and the next: it is earned only where four things are exhibited, a specified microscopic theory, a map from its variables to the macroscopic ones, a controlled limit in which the macroscopic

Time is not emergent in the same way. In AdS/CFT the boundary theory has its own time, and bulk time near the boundary is that time; the correspondence emerges a spatial dimension and inherits the temporal one. This is the asymmetry noted at the end of §5, and it is the central obstacle to a background-free theory. The candidates for emergent time are the relational constructions of §11 (Page-Wootters, Rovelli), the thermal time of Connes and Rovelli, and causal set theory (Bombelli, Lee, Meyer and Sorkin 1987), which takes the causal order among a discrete set of events as fundamental and recovers the metric from order plus counting. Malament’s theorem (1977; Hawking, King and McCarthy 1976) is the mathematical basis: the causal structure of a spacetime determines its metric up to a conformal factor, and the conformal factor is fixed by volume, which for a discrete set is a count. Sorkin’s slogan, “order plus number equals geometry”, is Aristotle’s definition of time, the number of motion in respect of before and after, extended to spacetime as a whole. Whether the causal order is prior to the events (chronos prior to the world) or the events prior to the order (Leibniz) is left open by the formalism.

DIMENSIONS AND SIGNATURE. Why three spatial dimensions and one temporal one is a question the Greeks did not ask, since three was the number of the possible directions (Aristotle *De Caelo* I.1 268a). Ehrenfest (1917) argued that stable planetary orbits and stable atoms require exactly three, since the inverse-square law that yields closed orbits and bound states is the one appropriate to three dimensions. Tegmark (1997) added the argument for one time: with more than one timelike dimension the field equations become ultrahyperbolic and the initial-value problem is ill-posed, so no observer could predict anything; with zero, nothing changes. Kant’s remark that time has one dimension and space three (A31/B47) is on this reading a condition of the possibility of physics, not a form of intuition. String theory needs ten dimensions (superstrings) or eleven (M-theory), with the extra six or seven compactified on a Calabi-Yau or G_2 manifold; this is Kaluza (1921) and Klein (1926) generalized, and it leaves the number of large dimensions and the shape of the small ones undetermined, which is the origin of the landscape. Bars’ two-time physics and the twelve-dimensional F-theory of Vafa are formal devices in which a second time is gauged away; they do not propose a second physical time. And in the Euclidean path integral of Hartle and Hawking (1983), the signature itself changes: near the “beginning” the geometry is a four-sphere with no time direction, and Lorentzian time appears by analytic continuation. There is no first moment because there is no time there: the no-boundary proposal is Plato’s time created together with the heaven and Augustine’s *cum tempore*, with the creator replaced by a saddle point.

DISCRETENESS. Zeno’s Arrow and Epicurus’ minimal parts return as the Planck length and Planck time, below which the manifold description fails. Loop quantum gravity gives area and volume discrete spectra (Rovelli and Smolin 1995; Ashtekar and Lewandowski 1997); causal sets are discrete by construction; string theory has a minimal length set by the string scale through T-duality. None of these is confirmed, and Lorentz invariance tests constrain the simplest discrete pictures severely. But the question whether the continuum is fundamental or an approximation is now a physical one with a scale attached, which it was not for Aristotle.

description becomes asymptotically exact, and an error term away from that limit. By that test the AdS radial direction is emergent (holographic RG, the HKLL reconstruction, the Lewkowycz-Maldacena derivation of Ryu-Takayanagi), entropic gravity fails the first clause, causal sets and loop gravity are conjectures about the second, and emergent time has no candidate for any of the four. The companion note “On Emergence” (September 2026) develops the criterion and its history from Broad and Anderson to the present.

15. Local and global: topos, chora, and cosmology

Aristotle's topos is local (the boundary of the container) and his cosmos has a global shape (a finite sphere) but no global space; Plato's chora and the atomists' kenon are global and undifferentiated. General relativity divides the concepts in the same way. The Einstein equations are local partial differential equations; the equivalence principle says that spacetime is locally Minkowskian; the local structure is fully determined by the equations and the matter. The global structure is not: the equations do not fix the topology of the manifold, and the same local geometry can be realized on a simply connected space or on a torus or on a quotient by a discrete group. Cosmology is the physics of the global. Whether the universe is finite or infinite, open or closed, simply connected or not, are questions about chora, not topos, and Archytas' staff (§4) is still the question: the observable universe has a boundary, the particle horizon, and the question of what is beyond it is answered by the cosmological principle, which is an assumption of homogeneity that no observation inside the horizon can confirm.

Mach's principle is the local/global question about inertia. Newton's bucket shows that rotation is absolute; Mach (1883) replied that it is rotation relative to the fixed stars, and that local inertial frames are determined by the global matter distribution. Einstein coined the name (1918) and hoped general relativity would embody it; it does so partly (frame dragging, Lense and Thirring 1918, measured by Gravity Probe B in 2011) and not fully (Gödel's rotating universe, Minkowski space with no matter at all). The Stoic cosmos, a finite body with nothing to move relative to, is the Machian limit.

Einstein's hole argument (1913-1915, in the Entwurf period) is the point at which the substantial chora was dismantled. If the metric is dynamical and the equations are generally covariant, then given a solution one can construct another by a diffeomorphism that acts only inside a region (the hole), so the same matter distribution outside determines two different metrics inside. Einstein first took this as an argument against general covariance and then (late 1915) resolved it with the point-coincidence argument: the two solutions are physically the same because all observables are coincidences of physical events, and the manifold points have no identity of their own. Earman and Norton (1987) revived the argument to show that manifold substantivalism entails indeterminism; the responses (Butterfield, Maudlin, Pooley, Stachel) constitute the modern substantivalism debate. The conclusion most physicists accept is Leibnizian: spacetime points are not things, the metric field is, and what is real are the relations among fields. The theater is a field like the actors. Observables must be diffeomorphism-invariant, and constructing local such observables in a background-free theory is an unsolved problem; relational observables (Rovelli's partial observables; Dittrich's complete observables) are the standard proposal, and they are Aristotle's topos, a place defined by the boundary of what contains it, rewritten as a field value at the place where another field takes a given value.

Causal structure adds a further global question that has no ancient analogue except Gödel's Kant. Penrose's conformal diagrams display the global causal structure of a spacetime; global hyperbolicity is the condition for a well-posed initial-value problem; and the chronology protection conjecture (Hawking 1992) is the claim that the laws prevent closed timelike curves from forming, so that Gödel's universe and the Tipler cylinder and the traversable wormhole time machine (Morris, Thorne and Yurtsever 1988) are excluded by quantum effects. Whether the conjecture is true is unknown; if it is false, the B-series exists and the A-series has no global meaning at all.

16. Anti-de Sitter and de Sitter: the box and the horizon

The two maximally symmetric solutions of Einstein's equations with a cosmological constant are the two theaters in which the present debate is staged, and their differences are the differences the notes were built around.

Anti-de Sitter space ($\Lambda < 0$) is a box. Spatial infinity is a timelike boundary at finite conformal distance; light rays reach it and return in finite time; the boundary has its own time, which is a global Killing time for the whole spacetime, and a conformal field theory lives on it. Because there is a global timelike Killing vector, there is a Hamiltonian, a well-defined energy, a Hilbert space and, at the boundary, well-defined observables: the correlation functions of the CFT. Because the boundary is a place where an observer can stand outside the gravitating region, there is an S-matrix-like object. Because AdS admits supersymmetry, string theory has exact vacua there. Everything that is known with precision about quantum gravity, the Ryu-Takayanagi formula, the black hole entropy counting, the Page curve, the emergence of a spatial dimension, has been established in this box. It is Aristotle's cosmos: finite in the relevant sense, with an outermost boundary that defines rest and time, and nothing beyond it that matters.

De Sitter space ($\Lambda > 0$) is our universe's asymptotic future and, if inflation is right, its past. Since 1998 (Riess et al.; Perlmutter et al.) the observed Λ is positive and, in Planck units, about 10^{-122} . De Sitter has no spatial boundary. Each observer has a cosmological horizon at distance $\ell = \sqrt{3/\Lambda}$, beyond which events are causally inaccessible forever; the horizon has a temperature and an entropy (Gibbons and Hawking 1977), $S = A/4G \approx 10^{122}$ for the observed Λ , and this entropy is observer-dependent, since each observer has a different horizon. There is no global timelike Killing vector in global de Sitter; the static patch of a single observer has one, but it is timelike only inside that observer's horizon. There are no asymptotic regions in which to define an S-matrix, since no observer can see the whole space and any two observers eventually lose sight of one another. And no supersymmetric de Sitter vacuum exists (Witten, "Quantum gravity in de Sitter space", 2001, lays out these difficulties), so string theory has no exact de Sitter solutions; the metastable constructions (KKLT 2003) are debated, and the de Sitter swampland conjecture (Obied, Ooguri, Spodek and Vafa 2018; refined by Ooguri, Palti, Shiu and Vafa 2018 and by Garg and Krishnan 2018) proposes that consistent quantum gravity forbids stable de Sitter vacua altogether, which would mean that Λ must be decaying. De Sitter space is the Stoic cosmos: an observer surrounded by a horizon, finite information, and eternal recurrence.

The recurrence point is exact and old. A finite-entropy system in a stationary state undergoes Poincaré recurrences on a timescale of order $\exp(S)$. Dyson, Kleban and Susskind (2002, "Disturbing implications of a cosmological constant") pointed out that if de Sitter space is a finite quantum system with entropy 10^{122} , then after roughly $\exp(10^{122})$ years every fluctuation recurs, including the fluctuation that is our observed universe, and including disembodied brains with our memories that are overwhelmingly more probable than the whole history that produced us (the Boltzmann brain problem). The Stoic ekpyrosis with Socrates teaching again in Athens is the same theorem. Whether the conclusion is that Λ must decay, that the finite-dimensional Hilbert space is the wrong description, or that the measure over eternal inflation must be fixed differently, is unsettled; the measure problem in eternal inflation (Guth 2007 for a review) is the modern form of Anaximander's innumerable worlds, and it has no accepted solution.

Three structural inversions between AdS and dS are the philosophically important ones.

FIRST, THE EMERGENT DIMENSION. In AdS/CFT the holographic direction is spatial and the boundary time is inherited. In dS/CFT (Strominger 2001; Maldacena 2003 on the wavefunction of the universe

as a boundary partition function; Anninos, Hartman and Strominger 2011 for a concrete higher-spin realization), the boundary is future infinity, a spatial surface, and the holographic direction is time. If dS/CFT is right in any form, then in our universe it is time, not space, that is the RG direction, and late-time cosmological correlations are the partition function of a Euclidean theory with no time. Plato's *chronos* emerges and *chora* is given; the *Timaeus* asymmetry, reversed in AdS, is restored in dS.

SECOND, THE OBSERVER. Chandrasekaran, Longo, Penington and Witten (2022) showed that the algebra of observables in the static patch of de Sitter space, once gravitational constraints are imposed, is a type II_1 von Neumann algebra only if an observer with a clock is included in the system; without the observer the algebra is trivial. Entropy becomes well-defined (with a maximum, attained by the de Sitter vacuum) and the Gibbons-Hawking entropy is recovered, but only relative to the observer's clock, whose time is the modular flow of the state. This is Aristotle's question at *Physics* 223a21-29 answered in the affirmative: in de Sitter, with no soul to count, there is no algebra of what can be counted. It is also the thermal time hypothesis realized in the one setting that describes our own asymptotic future. The theater requires an audience for its observables to exist.

THIRD, THE LOCATION OF THE THEOREMS. Everything precise is in the box we do not live in, and the horizon we do live in has no precise theory. The two decades of AdS/CFT results are results about Aristotle's cosmos, and the transfer to the Stoic cosmos is the open problem. The candidates, static-patch holography (Susskind 2021 onward, including SYK-like models with a de Sitter-like spectrum), dS/CFT, the swampland program, and the algebraic approach, are each partial.

17. The theater and the possibilities: where actuality and possibility meet

The notes ended, as far as the fragments recall, with the question of what the variables of physics are: whether they are the coordinates of a stage that exists, or a bookkeeping of relations among things, or the description of one point in a space of possible worlds. The Greek material and the modern material converge here.

ACTUALITY AND POTENTIALITY. Aristotle's *dynamis* (potentiality) and *energeia* (actuality) (*Metaph.* Θ) describe a thing as having a range of what it can be and one thing it is. Heisenberg (*Physics and Philosophy*, 1958, ch. 3) wrote that the quantum probability wave "was a quantitative version of the old concept of *potentia* in Aristotelian philosophy", a tendency toward an event that is neither the event nor nothing. On this reading the quantum state is a description of potentiality, and measurement, *kairos*, is actualization. Everett's interpretation (1957) removes the actualization: every possibility is actual in some branch, and the space of possibilities and the space of actualities coincide. This is the first of the places where the two melt.

LOGICAL SPACE AND HILBERT SPACE. Wittgenstein's *logischer Raum* (1.13, 2.013) is the space of possible states of affairs, of which the world is one point. Physics has several such spaces. Configuration space and phase space are the classical ones; Hilbert space is the quantum one, and a state is a ray in it; the space of solutions of the field equations is the covariant one; and the space of theories, the landscape of string vacua (Susskind 2003 named it; the estimate of 10^{500} vacua is from Douglas and others) is the one in which the constants of nature are coordinates. Wittgenstein's point at 2.013, that the thing cannot be imagined without its space, is the point that a state is meaningless without its Hilbert space, a solution without its equations, a vacuum without its landscape. The receptacle of the *Timaeus*, which receives all forms and has none of its own, is the space of possibilities, and Plato's *chora* and Wittgenstein's logical space are one concept under two descriptions: the theater is

the set of ways the play could go.

NECESSITY AND CONTINGENCY. Spinoza held that nothing is contingent and that the world could not have been otherwise (I p29, I p33). Leibniz held that God chose the best of the compossible worlds and that the others remain possible. The landscape is Leibnizian without the choice: all vacua are possible, and eternal inflation realizes them all somewhere, and anthropic selection (Weinberg 1987 on the cosmological constant) replaces the principle of the best. Tegmark's mathematical universe hypothesis (2008) is Spinozist in the opposite direction: every consistent mathematical structure is a physical world, so there is no contingency at the level of the whole and complete contingency at the level of which world we are in. The two positions are the eternalist and the modal-realist (Lewis 1986) forms of the same collapse of the distinction between the possible and the actual. This is the second melting point, and physics has no way to decide it, since a theory of everything that predicts a landscape and a measure predicts what fraction of observers see what, and predicts nothing about which one we are.

THE VARIABLES OF THE THEATER. Newton's variables (x, t) were coordinates on a stage that existed independently. Einstein's variables are fields, including the metric, and the coordinates are gauge; the stage is one of the fields and the points of the manifold have no identity (§15). In the holographic theories the metric is not fundamental either, and the bulk variables are reconstructions from boundary entanglement; in causal sets and loop gravity the manifold is an approximation to a discrete structure; in the de Sitter algebra the very existence of an observable algebra depends on including an observer. The direction of travel is from Plato's *chora* (a substrate, given) to Aristotle's *topos* (a relation among bodies) to Leibniz's order of coexistences to Wittgenstein's logical space (a structure of possibilities of which the actual is one), and physics has traveled the whole route. What has not been reached is a theory in which time travels it too. Space is a relation among quantum degrees of freedom in every candidate theory; time in every candidate theory is either put in by hand (AdS/CFT, string perturbation theory), frozen (Wheeler-DeWitt), or defined by a state relative to an observer (thermal time, the de Sitter algebra). This is the sharpest statement of the present situation: *chora* has been dissolved and *chronos* has not, and it is *chronos*, in the form of the arrow, that we have the most direct evidence for and the least theoretical grip on.

WHERE THEY MELT. The places where mathematical possibility and physical actuality can no longer be told apart are, in this reconstruction, four. The Everett branches, where all possible measurement outcomes are actual. The landscape and eternal inflation, where all possible vacua are realized. The mathematical universe, where all possible structures are worlds. And the de Sitter horizon, where the observables that exist depend on who is there to define them, so that the distinction between what is and what is measurable, which Democritus drew as the distinction between convention and reality, is the distinction the theory itself cannot draw. Parmenides said that what can be thought and what is are the same (B3, *τὸ γὰρ αὐτὸ νοεῖν ἐστὶν τε καὶ εἶναι*). The present theories are structured as if he were right, and the present experiments are structured as if Heraclitus were.

18. Summary map

Greek object	Ancient sources	Philosophical heir	Physical notion	Present status
chronos (measured time)	Plato Tim. 37d; Aristotle Phys. IV.11	Newton's absolute time; Leibniz's order of successions; Wittgenstein 6.3611	parameter t in QM; proper time in GR; relational time in quantum gravity	incompatibility between parameter and coordinate is the problem of time
aion (eternity)	Parmenides B8; Plato Tim. 37e; Plotinus III.7	Boethius; Spinoza's aeternitas; Wittgenstein 6.4311, 6.45	the block universe; Wheeler-DeWitt $H\Psi = 0$; the Euclidean no-boundary geometry	the equations are Parmenidean, the records Heraclitean
kairos (the moment) the now	Pindar; Gorgias Aristotle Phys. IV.11	Kierkegaard's Augenblick; Bergson's durée Augustine's distentio; McTaggart's A-series	the measurement; the record; the irreversible event no counterpart in the equations; presentism vs eternalism	fundamental (collapse) or emergent (decoherence)? Gödel's argument stands
cyclic time	Heraclitus B30; Stoic ekpyrosis	Nietzsche's recurrence	Poincaré recurrence; de Sitter recurrence at $\exp(10^{122})$	Boltzmann brains and the measure problem
chaos (the gap)	Hesiod Theog. 116	Schelling's Ungrund	the pre-geometric; the singularity; signature change	no theory
apeiron (the boundless)	Anaximander B1	Cusanus; Bruno; Kant's antithesis	infinite space; the multiverse; the landscape	unobservable by construction
kenon (void)	Leucippus, Democritus	Gassendi; Newton's space	the vacuum; the ground state; empty AdS or dS	vacuum energy 10^{-122} is the central anomaly
chora (receptacle)	Plato Tim. 52a	Newton's absolute space; Wittgenstein's logical space	the manifold; the Hilbert space; the space of solutions	dissolved into entanglement structure (AdS/CFT, RT, tensor networks)
topos (place)	Aristotle Phys. IV.4 212a20	Leibniz's order of coexistences; relationalism	local inertial frame; coordinates as gauge; relational observables	the hole argument settled it against substantivalism
diastema (extension)	Stoics; Philoponus	Descartes' res extensa; Newton	metric distance; the area law	area, not volume, counts degrees of freedom
natural motion	Aristotle De Caelo IV	Newton's force; Einstein's geodesic	free fall as inertial; gravity as geometry and as spin-2 gauge force	quantum completion open; entropic versions unproven
the counting soul	Aristotle Phys. IV.14 223a	Kant's forms of intuition; Husserl	the observer in the de Sitter algebra (CLPW 2022); thermal time	observables in dS require an observer

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