**Spacetime**

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*For other uses of this term, see* [*Spacetime (disambiguation)*](https://en.wikipedia.org/wiki/Spacetime_%28disambiguation%29)*.*

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In [physics](https://en.wikipedia.org/wiki/Physics), **spacetime** (also **space–time**, **space time** or **space–time continuum**) is any [mathematical model](https://en.wikipedia.org/wiki/Mathematical_model) that combines [space](https://en.wikipedia.org/wiki/Space) and [time](https://en.wikipedia.org/wiki/Time_in_physics) into a single interwoven [continuum](https://en.wikipedia.org/wiki/Continuum_%28theory%29). The spacetime of our [universe](https://en.wikipedia.org/wiki/Universe) is usually interpreted from a [Euclidean space](https://en.wikipedia.org/wiki/Euclidean_space) perspective, which regards space as consisting of [three dimensions](https://en.wikipedia.org/wiki/Three-dimensional_space), and time as consisting of [one dimension](https://en.wikipedia.org/wiki/One_dimension), the "[fourth dimension](https://en.wikipedia.org/wiki/Four-dimensional_space)". By combining space and time into a single [manifold](https://en.wikipedia.org/wiki/Manifold) called [Minkowski space](https://en.wikipedia.org/wiki/Minkowski_space), physicists have significantly simplified a large number of [physical theories](https://en.wikipedia.org/wiki/Theoretical_physics), as well as described in a more uniform way the workings of the universe at both the [super galactic](https://en.wikipedia.org/wiki/Physical_cosmology) and [subatomic](https://en.wikipedia.org/wiki/Quantum_mechanics) levels.

**Explanation**

In non-relativistic [classical mechanics](https://en.wikipedia.org/wiki/Classical_mechanics), the use of Euclidean space instead of spacetime is appropriate, because time is treated as universal with a constant rate of passage that is independent of the state of [motion](https://en.wikipedia.org/wiki/Motion_%28physics%29) of an [observer.](https://en.wikipedia.org/wiki/Observer_%28special_relativity%29) In [relativistic](https://en.wikipedia.org/wiki/Theory_of_relativity) contexts, time cannot be separated from the three dimensions of space, because the observed rate at which [time](https://en.wikipedia.org/wiki/Time) passes for an object depends on the object's [velocity](https://en.wikipedia.org/wiki/Velocity) relative to the observer and also on the strength of [gravitational fields](https://en.wikipedia.org/wiki/Gravitational_fields), which can slow the passage of time for an object as seen by an observer outside the field.

In [cosmology](https://en.wikipedia.org/wiki/Cosmology), the concept of spacetime combines space and time to a single abstract [universe](https://en.wikipedia.org/wiki/Universe). Mathematically it is a [manifold](https://en.wikipedia.org/wiki/Manifold) consisting of "events" which are described by some type of [coordinate system](https://en.wikipedia.org/wiki/Coordinate_system). Typically **three spatial dimensions** (length, width, height), and one **temporal dimension** ([time](https://en.wikipedia.org/wiki/Time)) are required. Dimensions are independent components of a coordinate grid needed to locate a point in a certain defined "space". For example, on the globe the [latitude](https://en.wikipedia.org/wiki/Latitude) and [longitude](https://en.wikipedia.org/wiki/Longitude) are two independent coordinates which together uniquely determine a location. In spacetime, a coordinate grid that spans the 3+1 dimensions locates [events](https://en.wikipedia.org/wiki/Event_%28relativity%29) (rather than just points in space), i.e., time is added as another dimension to the coordinate grid. This way the coordinates specify *where* and *when* events occur. However, the unified nature of spacetime and the freedom of coordinate choice it allows imply that to express the temporal coordinate in one coordinate system requires both temporal and spatial coordinates in another coordinate system. Unlike in normal spatial coordinates, there are still restrictions for how measurements can be made spatially and temporally (see [Spacetime intervals](https://en.wikipedia.org/wiki/Spacetime#Spacetime_intervals#Spacetime_intervals)). These restrictions correspond roughly to a [particular mathematical model](https://en.wikipedia.org/wiki/Lorentzian_manifold#Lorentzian_manifold) which differs from Euclidean space in its manifest [symmetry](https://en.wikipedia.org/wiki/Symmetry).

Until the beginning of the 20th century, time was believed to be independent of motion, progressing at a fixed rate in all [reference frames](https://en.wikipedia.org/wiki/Frame_of_reference); however, [later experiments](https://en.wikipedia.org/wiki/Time_dilation#Experimental_confirmation) revealed that time slows at higher speeds of the reference frame relative to another reference frame. Such slowing, called [time dilation](https://en.wikipedia.org/wiki/Time_dilation), is explained in [special relativity](https://en.wikipedia.org/wiki/Special_relativity) theory. Many experiments have confirmed time dilation, such as the relativistic [decay](https://en.wikipedia.org/wiki/Particle_decay) of [muons](https://en.wikipedia.org/wiki/Muon) from [cosmic ray](https://en.wikipedia.org/wiki/Cosmic_ray) showers and the slowing of [atomic clocks](https://en.wikipedia.org/wiki/Atomic_clock) aboard a [Space Shuttle](https://en.wikipedia.org/wiki/Space_Shuttle) relative to synchronized Earth-bound inertial clocks. The duration of time can therefore vary according to events and [reference frames](https://en.wikipedia.org/wiki/Frame_of_reference).

When dimensions are understood as mere components of the grid system, rather than physical attributes of space, it is easier to understand the alternate dimensional views as being simply the result of [coordinate transformations](https://en.wikipedia.org/wiki/Coordinate_transformation).

The term *spacetime* has taken on a generalized meaning beyond treating spacetime events with the normal 3+1 dimensions. It is really the combination of space and time. Other proposed spacetime theories include additional dimensions—normally [spatial](https://en.wikipedia.org/wiki/Three-dimensional_space) but there exist some speculative theories that include additional temporal dimensions and even some that include dimensions that are neither temporal nor spatial (e.g., [superspace](https://en.wikipedia.org/wiki/Superspace)). How many dimensions are needed to describe the universe is still an open question. Speculative theories such as [string theory](https://en.wikipedia.org/wiki/String_theory) predict 10 or 26 dimensions (with [M-theory](https://en.wikipedia.org/wiki/M-theory) predicting 11 dimensions: 10 spatial and 1 temporal), but the existence of more than four dimensions would only appear to make a difference at the [subatomic](https://en.wikipedia.org/wiki/Subatomic) level.

**Spacetime in literature**

[Incas](https://en.wikipedia.org/wiki/Incas) regarded space and time as a single concept, referred to as [***pacha***](https://en.wikipedia.org/wiki/Pacha_%28Inca_mythology%29) ([Quechua](https://en.wikipedia.org/wiki/Quechua_language): *pacha*, [Aymara](https://en.wikipedia.org/wiki/Aymara_language): *pacha*). The peoples of the [Andes](https://en.wikipedia.org/wiki/Andes) maintain a similar understanding.

[Arthur Schopenhauer](https://en.wikipedia.org/wiki/Arthur_Schopenhauer) wrote in §18 of [*On the Fourfold Root of the Principle of Sufficient Reason*](https://en.wikipedia.org/wiki/On_the_Fourfold_Root_of_the_Principle_of_Sufficient_Reason) (1813): "the representation of coexistence is impossible in Time alone; it depends, for its completion, upon the representation of Space; because, in mere Time, all things follow one another, and in mere Space all things are side by side; it is accordingly only by the combination of Time and Space that the representation of coexistence arises".

The idea of a unified spacetime is stated by [Edgar Allan Poe](https://en.wikipedia.org/wiki/Edgar_Allan_Poe) in his essay on cosmology titled [*Eureka*](https://en.wikipedia.org/wiki/Eureka_%28Edgar_Allan_Poe%29) (1848) that "Space and duration are one". In 1895, in his novel [*The Time Machine*](https://en.wikipedia.org/wiki/The_Time_Machine), [H. G. Wells](https://en.wikipedia.org/wiki/H._G._Wells) wrote, "There is no difference between time and any of the three dimensions of space except that our consciousness moves along it", and that "any real body must have extension in four directions: it must have Length, Breadth, Thickness, and Duration".

[Marcel Proust](https://en.wikipedia.org/wiki/Marcel_Proust), in his novel [*Swann's Way*](https://en.wikipedia.org/wiki/In_Search_of_Lost_Time) (published 1913), describes the village church of his childhood's Combray as "a building which occupied, so to speak, four dimensions of space—the name of the fourth being Time".

**Mathematical concept**

In [Encyclopedie](https://en.wikipedia.org/wiki/Encyclopedie) under the term *dimension* [Jean le Rond d'Alembert](https://en.wikipedia.org/wiki/Jean_le_Rond_d%27Alembert) speculated that duration (time) might be considered a fourth dimension if the idea was not too novel.

Another early venture was by [Joseph Louis Lagrange](https://en.wikipedia.org/wiki/Joseph_Louis_Lagrange) in his *Theory of Analytic Functions* (1797, 1813). He said, "One may view mechanics as a geometry of four dimensions, and mechanical analysis as an extension of geometric analysis".

The ancient idea of the [cosmos](https://en.wikipedia.org/wiki/Cosmos) gradually was described mathematically with [differential equations](https://en.wikipedia.org/wiki/Differential_equation), [differential geometry](https://en.wikipedia.org/wiki/Differential_geometry), and [abstract algebra](https://en.wikipedia.org/wiki/Abstract_algebra). These mathematical articulations blossomed in the nineteenth century as electrical technology stimulated men like [Michael Faraday](https://en.wikipedia.org/wiki/Michael_Faraday) and [James Clerk Maxwell](https://en.wikipedia.org/wiki/James_Clerk_Maxwell) to describe the reciprocal relations of electric and magnetic fields. Daniel Siegel phrased Maxwell's role in relativity as follows:

[...] the idea of the propagation of forces at the velocity of light through the electromagnetic field as described by Maxwell's equations—rather than [instantaneously at a distance](https://en.wikipedia.org/wiki/Action_at_a_distance)—formed the necessary basis for relativity theory.

Maxwell used vortex models in his papers on  [Physical Lines of Force](https://en.wikipedia.org/wiki/On_Physical_Lines_of_Force), but ultimately gave up on any substance but the electromagnetic field. [Pierre Duhem](https://en.wikipedia.org/wiki/Pierre_Duhem) wrote:

[Maxwell] was not able to create the theory that he envisaged except by giving up the use of any model, and by extending by means of analogy the abstract system of electrodynamics to [displacement currents](https://en.wikipedia.org/wiki/Displacement_current).

In Siegel's estimation, "this very abstract view of the electromagnetic fields, involving no visualizable picture of what is going on out there in the field, is Maxwell's legacy." Describing the behavior of [electric fields](https://en.wikipedia.org/wiki/Electric_field) and [magnetic fields](https://en.wikipedia.org/wiki/Magnetic_field) led Maxwell to view the combination as an [electromagnetic field](https://en.wikipedia.org/wiki/Electromagnetic_field). These fields have a value at every point of spacetime. It is the intermingling of electric and magnetic manifestations, described by [Maxwell's equations](https://en.wikipedia.org/wiki/Maxwell%27s_equations), that give spacetime its structure. In particular, the rate of motion of an observer determines the electric and magnetic profiles of the electromagnetic field. The propagation of the field is determined by the [electromagnetic wave equation](https://en.wikipedia.org/wiki/Electromagnetic_wave_equation), which requires spacetime for description.

Spacetime was described as an [affine space](https://en.wikipedia.org/wiki/Affine_space) with [quadratic form](https://en.wikipedia.org/wiki/Quadratic_form) in [Minkowski space](https://en.wikipedia.org/wiki/Minkowski_space) of 1908. In his 1914 [textbook](https://en.wikipedia.org/wiki/Textbook) *The Theory of Relativity*, [Ludwik Silberstein](https://en.wikipedia.org/wiki/Ludwik_Silberstein) used [biquaternions](https://en.wikipedia.org/wiki/Biquaternion) to represent events in Minkowski space. He also exhibited the [Lorentz transformations](https://en.wikipedia.org/wiki/Lorentz_transformation) between observers of differing velocities as biquaternion mappings. Biquaternions were described in 1853 by [W. R. Hamilton](https://en.wikipedia.org/wiki/W._R._Hamilton), so while the physical interpretation was new, the mathematics was well known in English literature, making relativity an instance of applied mathematics.

The first inkling of [general relativity](https://en.wikipedia.org/wiki/General_relativity) in spacetime was articulated by [W. K. Clifford](https://en.wikipedia.org/wiki/William_Kingdon_Clifford#Premonition_of_relativity). Description of the effect of gravitation on space and time was found to be most easily visualized as a "warp" or stretching in the geometrical fabric of space and time, in a smooth and continuous way that changed smoothly from point-to-point along the spacetime fabric. In 1947 [James Jeans](https://en.wikipedia.org/wiki/James_Jeans) provided a concise summary of the development of spacetime theory in his book *The Growth of Physical Science*.

**Basic concepts**

The basic elements of spacetime are events. In any given spacetime, an event is a unique position at a unique time. Because events are spacetime points, an example of an event in classical relativistic physics is , the location of an elementary (point-like) particle at a particular time. A spacetime itself can be viewed as the union of all events in the same way that a line is the union of all of its points, formally organized into a [manifold](https://en.wikipedia.org/wiki/Manifold), a space which can be described at small scales using coordinate systems.

A spacetime is independent of any observer. However, in describing physical phenomena (which occur at certain moments of time in a given region of space), each observer chooses a convenient metrical [coordinate system](https://en.wikipedia.org/wiki/Coordinate_system). Events are specified by four [real numbers](https://en.wikipedia.org/wiki/Real_numbers) in any such coordinate system. The trajectories of elementary (point-like) particles through space and time are thus a continuum of events called the [world line](https://en.wikipedia.org/wiki/World_line) of the particle. Extended or composite objects (consisting of many elementary particles) are thus a union of many world lines twisted together by virtue of their interactions through spacetime into a "world-braid".

However, in physics, it is common to treat an extended object as a "particle" or "field" with its own unique (e.g., center of mass) position at any given time, so that the world line of a particle or light beam is the path that this particle or beam takes in the spacetime and represents the history of the particle or beam. The world line of the orbit of the Earth (in such a description) is depicted in two spatial dimensions *x* and *y* (the plane of the Earth's orbit) and a time dimension orthogonal to *x* and *y*. The orbit of the Earth is an [ellipse](https://en.wikipedia.org/wiki/Ellipse) in space alone, but its world line is a [helix](https://en.wikipedia.org/wiki/Helix) in spacetime.

The unification of space and time is exemplified by the common practice of selecting a metric (the measure that specifies the [interval](https://en.wikipedia.org/wiki/Interval_%28mathematics%29) between two events in spacetime) such that all four dimensions are measured in terms of [units](https://en.wikipedia.org/wiki/Units_of_measurement) of distance: representing an event as (in the Lorentz metric) or (in the original Minkowski metric) where is the [speed of light](https://en.wikipedia.org/wiki/Speed_of_light). The metrical descriptions of [Minkowski Space](https://en.wikipedia.org/wiki/Minkowski_Space) and spacelike, light like, and timelike intervals given below follow this convention, as do the conventional formulations of the [Lorentz transformation](https://en.wikipedia.org/wiki/Lorentz_transformation).

**Spacetime intervals in flat space**

In a [Euclidean space](https://en.wikipedia.org/wiki/Euclidean_space), the separation between two points is measured by the distance between the two points. The distance is purely spatial, and is always positive. In spacetime, the [displacement four-vector](https://en.wikipedia.org/wiki/Four-vector#Four-position) Δ*R* is given by the space [displacement vector](https://en.wikipedia.org/wiki/Displacement_vector) Δ*r* and the time difference Δ*t* between the events. The *spacetime interval*, also called *invariant interval*, between the two events, *s*2, is defined as:

(spacetime interval),

where *c* is the speed of light. The choice of signs for above follows the [space-like convention (−+++)](https://en.wikipedia.org/wiki/Sign_convention#Relativity).Spacetime intervals may be classified into three distinct types, based on whether the temporal separation () or the spatial separation () of the two events is greater: time-like, light-like or space-like.

Certain types of [world lines](https://en.wikipedia.org/wiki/World_line) are called [geodesics](https://en.wikipedia.org/wiki/Geodesic) of the spacetime – straight lines in the case of Minkowski space and their closest equivalent in the curved spacetime of general relativity. In the case of purely time-like paths, geodesics are (locally) the paths of greatest separation (spacetime interval) as measured along the path between two events, whereas in Euclidean space and Riemannian manifolds, geodesics are paths of shortest distance between two points. The concept of geodesics becomes central in [general relativity](https://en.wikipedia.org/wiki/General_relativity), since geodesic motion may be thought of as "pure motion" ([inertial motion](https://en.wikipedia.org/wiki/Fictitious_force)) in spacetime, that is, free from any external influences.

**Time-like interval**

For two events separated by a time-like interval, enough time passes between them that there could be a cause–effect relationship between the two events. For a particle traveling through space at less than the speed of light, any two events which occur to or by the particle must be separated by a time-like interval. Event pairs with time-like separation define a negative spacetime interval () and may be said to occur in each other's future or past. There exists a [reference frame](https://en.wikipedia.org/wiki/Frame_of_reference) such that the two events are observed to occur in the same spatial location, but there is no reference frame in which the two events can occur at the same time.

The measure of a time-like spacetime interval is described by the [proper time interval](https://en.wikipedia.org/wiki/Proper_time_interval), :

(proper time interval).

The proper time interval would be measured by an observer with a clock traveling between the two events in an [inertial](https://en.wikipedia.org/wiki/Inertial) reference frame, when the observer's path intersects each event as that event occurs. (The proper time interval defines a [real number](https://en.wikipedia.org/wiki/Real_number), since the interior of the square root is positive.)

**Light-like interval**

In a light-like interval, the spatial distance between two events is exactly balanced by the time between the two events. The events define a spacetime interval of zero (). Light-like intervals are also known as "null" intervals.

Events which occur to or are initiated by a [photon](https://en.wikipedia.org/wiki/Photon) along its path (i.e., while traveling at , the speed of light) all have light-like separation. Given one event, all those events which follow at light-like intervals define the propagation of a [light cone](https://en.wikipedia.org/wiki/Light_cone), and all the events which preceded from a light-like interval define a second (graphically inverted, which is to say "*pastward*") light cone.

**Space-like interval**

When a space-like interval separates two events, not enough time passes between their occurrences for there to exist a [causal](https://en.wikipedia.org/wiki/Causal) relationship crossing the spatial distance between the two events at the speed of light or slower. Generally, the events are considered not to occur in each other's future or past. There exists a [reference frame](https://en.wikipedia.org/wiki/Frame_of_reference) such that the two events are observed to occur at the same time, but there is no reference frame in which the two events can occur in the same spatial location.

For these space-like event pairs with a positive spacetime interval (), the measurement of space-like separation is the [proper distance](https://en.wikipedia.org/wiki/Proper_distance), :

(proper distance).

Like the proper time of time-like intervals, the proper distance of space-like spacetime intervals is a real number value.

**Interval as area**

The interval has been presented as the [area](https://en.wikipedia.org/wiki/Area) of an oriented [rectangle](https://en.wikipedia.org/wiki/Rectangle) formed by two events and [isotropic lines](https://en.wikipedia.org/wiki/Isotropic_line) through them. Time-like or space-like separations correspond to oppositely [oriented](https://en.wikipedia.org/wiki/Orientation_%28vector_space%29) rectangles, one type considered to have rectangles of negative area. The case of two events separated by light corresponds to the rectangle degenerating to the segment between the events and zero area. The transformations leaving interval-length invariant are the area-preserving [squeeze mappings](https://en.wikipedia.org/wiki/Squeeze_mapping).

The parameters traditionally used rely on quadrature of the hyperbola, which is the [natural logarithm](https://en.wikipedia.org/wiki/Natural_logarithm). This transcendental function is essential in mathematical analysis as its inverse unites [circular functions](https://en.wikipedia.org/wiki/Circular_function) and [hyperbolic functions](https://en.wikipedia.org/wiki/Hyperbolic_function): The [exponential function](https://en.wikipedia.org/wiki/Exponential_function), e*t*, *t* a real number, used in the [hyperbola](https://en.wikipedia.org/wiki/Hyperbola) (e*t*, e–*t* ), generates [hyperbolic sectors](https://en.wikipedia.org/wiki/Hyperbolic_sector) and the [hyperbolic angle](https://en.wikipedia.org/wiki/Hyperbolic_angle) parameter. The functions cosh and sinh, used with [rapidity](https://en.wikipedia.org/wiki/Rapidity) as hyperbolic angle, provide the common representation of squeeze in the form or as the [split-complex unit](https://en.wikipedia.org/wiki/Split-complex_number)

**Mathematics of spacetimes**

For physical reasons, a spacetime continuum is mathematically defined as a four-dimensional, smooth, connected [Lorentzian manifold](https://en.wikipedia.org/wiki/Lorentzian_manifold) . This means the smooth [Lorentz metric](https://en.wikipedia.org/wiki/Lorentz_metric) has [signature](https://en.wikipedia.org/wiki/Metric_signature) . The metric determines the geometry of spacetime, as well as determining the [geodesics](https://en.wikipedia.org/wiki/Geodesic) of particles and light beams. About each point (event) on this manifold, [coordinate charts](https://en.wikipedia.org/wiki/Coordinate_charts) are used to represent observers in reference frames. Usually, Cartesian coordinates are used. Moreover, for simplicity's sake, units of measurement are usually chosen such that the speed of light is equal to 1.

A reference frame (observer) can be identified with one of these coordinate charts; any such observer can describe any event . Another reference frame may be identified by a second coordinate chart about . Two observers (one in each reference frame) may describe the same event but obtain different descriptions.

Usually, many overlapping coordinate charts are needed to cover a manifold. Given two coordinate charts, one containing (representing an observer) and another containing (representing another observer), the intersection of the charts represents the region of spacetime in which both observers can measure physical quantities and hence compare results. The relation between the two sets of measurements is given by a [non-singular](https://en.wikipedia.org/wiki/Non-singular) coordinate transformation on this intersection. The idea of coordinate charts as local observers who can perform measurements in their vicinity also makes good physical sense, as this is how one actually collects physical data—locally.

For example, two observers, one of whom is on Earth, but the other one who is on a fast rocket to Jupiter, may observe a comet crashing into Jupiter (this is the event ). In general, they will disagree about the exact location and timing of this impact, i.e., they will have different 4-tuples (as they are using different coordinate systems). Although their kinematic descriptions will differ, dynamical (physical) laws, such as momentum conservation and the first law of thermodynamics, will still hold. In fact, relativity theory requires more than this in the sense that it stipulates these (and all other physical) laws must take the same form in all coordinate systems. This introduces [tensors](https://en.wikipedia.org/wiki/Tensors) into relativity, by which all physical quantities are represented.

Geodesics are said to be time-like, null, or space-like if the tangent vector to one point of the geodesic is of this nature. Paths of particles and light beams in spacetime are represented by time-like and null (light-like) geodesics, respectively.

**Topology**

Main article: [Spacetime topology](https://en.wikipedia.org/wiki/Spacetime_topology)

The assumptions contained in the definition of a spacetime are usually justified by the following considerations.

The [connectedness](https://en.wikipedia.org/wiki/Connectedness) assumption serves two main purposes. First, different observers making measurements (represented by coordinate charts) should be able to compare their observations on the non-empty intersection of the charts. If the connectedness assumption were dropped, this would not be possible. Second, for a manifold, the properties of connectedness and path-connectedness are equivalent, and one requires the existence of paths (in particular, [geodesics](https://en.wikipedia.org/wiki/Geodesic)) in the spacetime to represent the motion of particles and radiation.

Every spacetime is [paracompact](https://en.wikipedia.org/wiki/Paracompact). This property, allied with the smoothness of the spacetime, gives rise to a smooth [linear connection](https://en.wikipedia.org/wiki/Connection_%28principal_bundle%29), an important structure in general relativity. Some important theorems on constructing spacetimes from compact and non-compact manifolds include the following:

* A [compact](https://en.wikipedia.org/wiki/Compact_space) manifold can be turned into a spacetime if, and only if, its [Euler characteristic](https://en.wikipedia.org/wiki/Euler_characteristic) is 0. (Proof idea: the existence of a Lorentzian metric is shown to be equivalent to the existence of a nonvanishing vector field.)
* Any non-compact 4-manifold can be turned into a spacetime.

**Spacetime symmetries**

Main article: [Spacetime symmetries](https://en.wikipedia.org/wiki/Spacetime_symmetries)

Often in relativity, spacetimes that have some form of symmetry are studied. As well as helping to classify spacetimes, these symmetries usually serve as a simplifying assumption in specialized work. Some of the most popular ones include:

* Axisymmetric spacetimes
* [Spherically symmetric spacetimes](https://en.wikipedia.org/wiki/Spherically_symmetric_spacetime)
* [Static spacetimes](https://en.wikipedia.org/wiki/Static_spacetime)
* [Stationary spacetimes](https://en.wikipedia.org/wiki/Stationary_spacetime)

**Causal structure**

Main article: [Causal structure](https://en.wikipedia.org/wiki/Causal_structure)

*See also:* [*Causality (physics)*](https://en.wikipedia.org/wiki/Causality_%28physics%29) *and* [*Causality*](https://en.wikipedia.org/wiki/Causality)

The causal structure of a spacetime describes causal relationships between pairs of points in the spacetime based on the existence of certain types of curves joining the points.

**Spacetime in special relativity**

Main article: [Minkowski space](https://en.wikipedia.org/wiki/Minkowski_space)

The geometry of spacetime in special relativity is described by the [Minkowski metric](https://en.wikipedia.org/wiki/Minkowski_metric) on R4. This spacetime is called Minkowski space. The Minkowski metric is usually denoted by and can be written as a four-by-four matrix:

where the [Landau–Lifshitz space-like convention](https://en.wikipedia.org/wiki/Sign_convention#Relativity) is being used. A basic assumption of relativity is that coordinate transformations must leave spacetime intervals invariant. Intervals are [invariant](https://en.wikipedia.org/wiki/Lorentz_invariance) under [Lorentz transformations](https://en.wikipedia.org/wiki/Lorentz_transformation). This invariance property leads to the use of [four-vectors](https://en.wikipedia.org/wiki/Four-vector) (and other tensors) in describing physics.

Strictly speaking, one can also consider events in Newtonian physics as a single spacetime. This is [Galilean–Newtonian relativity](https://en.wikipedia.org/wiki/Galilean%E2%80%93Newtonian_relativity), and the coordinate systems are related by [Galilean transformations](https://en.wikipedia.org/wiki/Galilean_transformation). However, since these preserve spatial and temporal distances independently, such a spacetime can be decomposed into spatial coordinates plus temporal coordinates, which is not possible in the general case.

**Spacetime in general relativity**

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| [**General relativity**](https://en.wikipedia.org/wiki/General_relativity) |
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| * + [Introduction](https://en.wikipedia.org/wiki/Introduction_to_general_relativity)
	+ [History](https://en.wikipedia.org/wiki/History_of_general_relativity)
* [Mathematical formulation](https://en.wikipedia.org/wiki/Mathematics_of_general_relativity)
	+ [Resources](https://en.wikipedia.org/wiki/General_relativity_resources)
	+ [Tests](https://en.wikipedia.org/wiki/Tests_of_general_relativity)
 |
| **Phenomena**

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| --- |
| * [Kepler problem](https://en.wikipedia.org/wiki/Two-body_problem_in_general_relativity)
* [Gravitational lensing](https://en.wikipedia.org/wiki/Gravitational_lens)
* [Gravitational waves](https://en.wikipedia.org/wiki/Gravitational_wave)
* [Frame-dragging](https://en.wikipedia.org/wiki/Frame-dragging)
* [Geodetic effect](https://en.wikipedia.org/wiki/Geodetic_effect)
* [Event horizon](https://en.wikipedia.org/wiki/Event_horizon)
* [Singularity](https://en.wikipedia.org/wiki/Gravitational_singularity)
* [Black hole](https://en.wikipedia.org/wiki/Black_hole)
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| ***Spacetime*** |
| * [Spacetime diagrams](https://en.wikipedia.org/wiki/Spacetime_diagrams)
* [Minkowski spacetime](https://en.wikipedia.org/wiki/Minkowski_spacetime)
* [Wormhole](https://en.wikipedia.org/wiki/Wormhole)
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| * Equations
* Formalisms

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| *Equations* |
| * [Linearized gravity](https://en.wikipedia.org/wiki/Linearized_gravity)
* [Einstein field equations](https://en.wikipedia.org/wiki/Einstein_field_equations)
* [Friedmann](https://en.wikipedia.org/wiki/Friedmann_equations)
* [Geodesics](https://en.wikipedia.org/wiki/Geodesics_in_general_relativity)
* [Mathisson–Papapetrou–Dixon](https://en.wikipedia.org/wiki/Mathisson%E2%80%93Papapetrou%E2%80%93Dixon_equations)
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| *Formalisms* |
| * [ADM](https://en.wikipedia.org/wiki/ADM_formalism)
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| *Advanced theory* |
| * [Kaluza–Klein theory](https://en.wikipedia.org/wiki/Kaluza%E2%80%93Klein_theory)
* [Quantum gravity](https://en.wikipedia.org/wiki/Quantum_gravity)
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In [general relativity](https://en.wikipedia.org/wiki/General_relativity), it is assumed that spacetime is curved by the presence of matter (energy), this curvature being represented by the [Riemann tensor](https://en.wikipedia.org/wiki/Riemann_tensor). In [special relativity](https://en.wikipedia.org/wiki/Special_relativity), the Riemann tensor is identically zero, and so this concept of "non-curvedness" is sometimes expressed by the statement *Minkowski spacetime is flat.*

The earlier discussed notions of time-like, light-like and space-like intervals in special relativity can similarly be used to classify one-dimensional [curves](https://en.wikipedia.org/wiki/Causal_structure#Curves) through curved spacetime. A time-like curve can be understood as one where the interval between any two [infinitesimally](https://en.wikipedia.org/wiki/Infinitesimal) close events on the curve is time-like, and likewise for light-like and space-like curves. Technically the three types of curves are usually defined in terms of whether the [tangent vector](https://en.wikipedia.org/wiki/Causal_structure#Tangent_vectors) at each point on the curve is time-like, light-like or space-like. The [world line](https://en.wikipedia.org/wiki/World_line) of a slower-than-light object will always be a time-like curve, the world line of a massless particle such as a photon will be a light-like curve, and a space-like curve could be the world line of a hypothetical [tachyon](https://en.wikipedia.org/wiki/Tachyon). In the local neighborhood of any event, time-like curves that pass through the event will remain inside that event's past and future [light cones](https://en.wikipedia.org/wiki/Light_cone), light-like curves that pass through the event will be on the surface of the light cones, and space-like curves that pass through the event will be outside the light cones. One can also define the notion of a three-dimensional "spacelike hypersurface", a continuous three-dimensional "slice" through the four-dimensional property with the property that every curve that is contained entirely within this hypersurface is a space-like curve.

Many spacetime continua have physical interpretations which most physicists would consider bizarre or unsettling. For example, a [compact](https://en.wikipedia.org/wiki/Compact_space) spacetime has [closed timelike curves](https://en.wikipedia.org/wiki/Closed_timelike_curve), which violate our usual ideas of causality (that is, future events could affect past ones). For this reason, mathematical physicists usually consider only restricted subsets of all the possible spacetimes. One way to do this is to study "realistic" solutions of the equations of general relativity. Another way is to add some additional "physically reasonable" but still fairly general geometric restrictions and try to prove interesting things about the resulting spacetimes. The latter approach has led to some important results, most notably the [Penrose–Hawking singularity theorems](https://en.wikipedia.org/wiki/Penrose%E2%80%93Hawking_singularity_theorems).

**Quantized spacetime**

Main article: [Quantum spacetime](https://en.wikipedia.org/wiki/Quantum_spacetime)

In general relativity, spacetime is assumed to be smooth and continuous—and not just in the mathematical sense. In the theory of [quantum mechanics](https://en.wikipedia.org/wiki/Quantum_mechanics), there is an inherent discreteness present in physics. In attempting to reconcile these two theories, it is sometimes postulated that spacetime should be quantized at the very smallest scales. Current theory is focused on the nature of spacetime at the [Planck scale](https://en.wikipedia.org/wiki/Planck_scale). [Causal sets](https://en.wikipedia.org/wiki/Causal_sets), [loop quantum gravity](https://en.wikipedia.org/wiki/Loop_quantum_gravity), [string theory](https://en.wikipedia.org/wiki/String_theory), [causal dynamical triangulation](https://en.wikipedia.org/wiki/Causal_dynamical_triangulation), and [black hole thermodynamics](https://en.wikipedia.org/wiki/Black_hole_thermodynamics) all predict a [quantized](https://en.wikipedia.org/wiki/Quantization_%28physics%29) spacetime with agreement on the order of magnitude. [Loop quantum gravity](https://en.wikipedia.org/wiki/Loop_quantum_gravity) makes precise predictions about the geometry of spacetime at the Planck scale.

**See also**

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|  | [***Time portal***](https://en.wikipedia.org/wiki/Portal%3ATime) |
|  | [***Physics portal***](https://en.wikipedia.org/wiki/Portal%3APhysics) |
|  | [***Cosmology portal***](https://en.wikipedia.org/wiki/Portal%3ACosmology) |
|  | [***Space portal***](https://en.wikipedia.org/wiki/Portal%3ASpace) |

* [Anthropic principle § Applications of the principle §§ Spacetime](https://en.wikipedia.org/wiki/Anthropic_principle#Spacetime)
* [Basic introduction to the mathematics of curved spacetime](https://en.wikipedia.org/wiki/Basic_introduction_to_the_mathematics_of_curved_spacetime)
* [Four-vector](https://en.wikipedia.org/wiki/Four-vector)
* [Frame-dragging](https://en.wikipedia.org/wiki/Frame-dragging)
* [Global spacetime structure](https://en.wikipedia.org/wiki/Global_spacetime_structure)
* [Hole argument](https://en.wikipedia.org/wiki/Hole_argument)
* [List of mathematical topics in relativity](https://en.wikipedia.org/wiki/List_of_mathematical_topics_in_relativity)
* [Local spacetime structure](https://en.wikipedia.org/wiki/Local_spacetime_structure)
* [Lorentz invariance](https://en.wikipedia.org/wiki/Lorentz_invariance)
* [Manifold](https://en.wikipedia.org/wiki/Manifold)
* [Mathematics of general relativity](https://en.wikipedia.org/wiki/Mathematics_of_general_relativity)
* [Metric space](https://en.wikipedia.org/wiki/Metric_space)
* [Philosophy of space and time](https://en.wikipedia.org/wiki/Philosophy_of_space_and_time)
* [Relativity of simultaneity](https://en.wikipedia.org/wiki/Relativity_of_simultaneity)
* [Strip photography](https://en.wikipedia.org/wiki/Strip_photography)
* [World manifold](https://en.wikipedia.org/wiki/World_manifold)

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* [Seven](https://en.wikipedia.org/wiki/Seven-dimensional_space)
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