A 4-Dimensionalist Top Level Ontology (TLO): Mereotopology and Space-Time

4-Dimensionalism in Large Scale Data Sharing and Integration
Newton Gateway to Mathematics

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Team effort: the BORO Team

http://www.borosolutions.net/who-we-are

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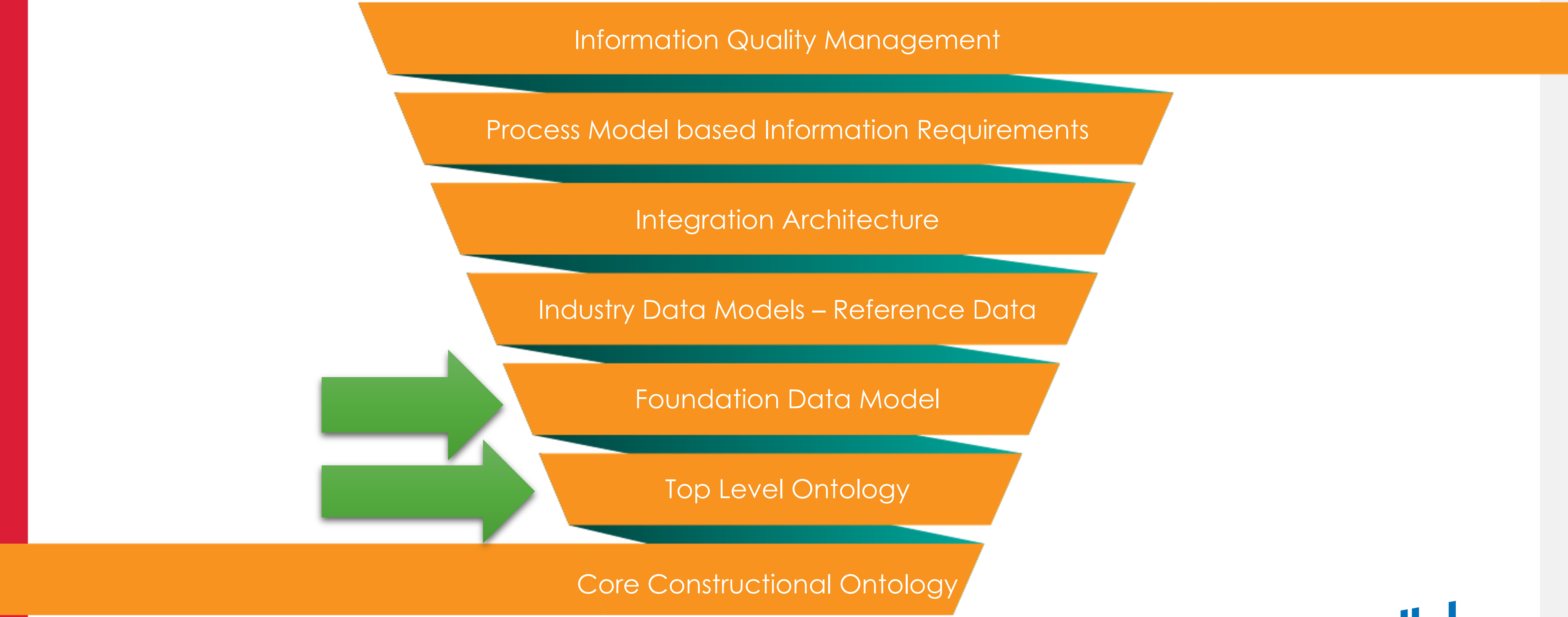
Where in the Seven Circles of Information Management



Preliminaries - overall approach

How, broadly speaking, do we develop the ontology?

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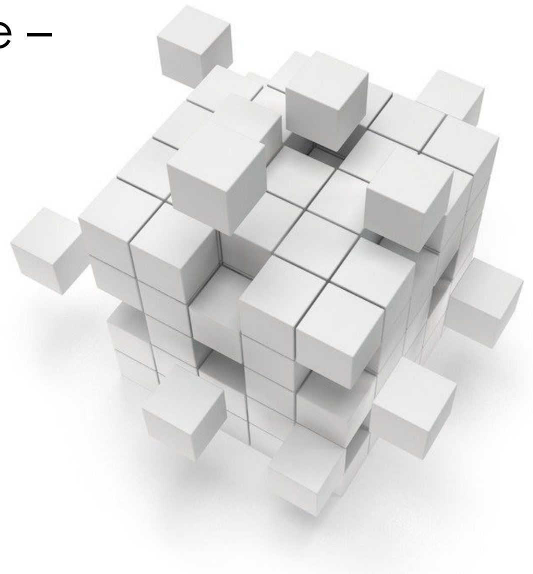
Target structure

A modular, component-based architecture – motivated by the usual reasons:

- complexity management
- understandability
- encapsulation
- simpler substitution/replacement
- recombinability
- expandability
- resilience



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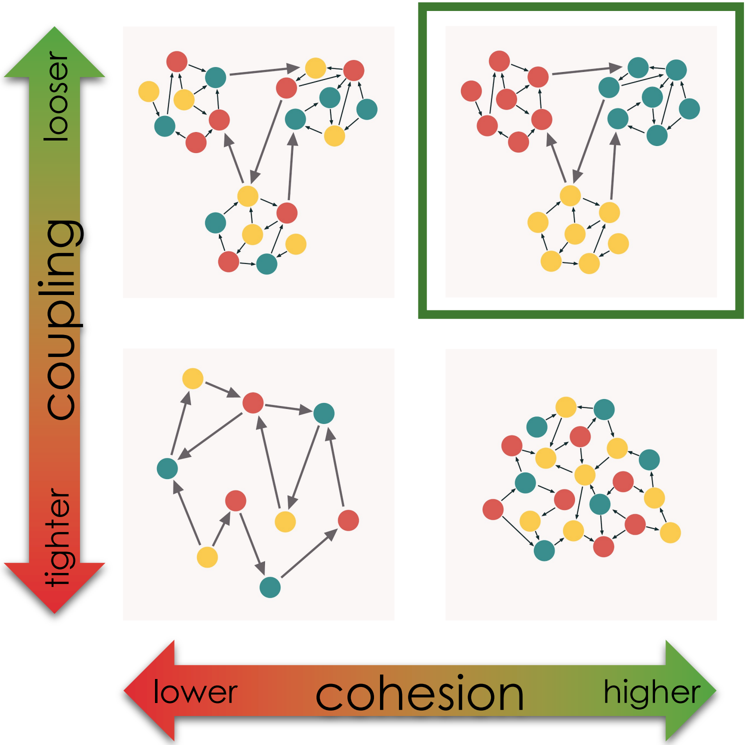
Modular: loosely coupled, highly cohesive modules

coupling
- about the relations between the modules

cohesion
- about the relations between the elements within the module



loose coupling, high cohesion aims for a structure where relations cluster inside the modules

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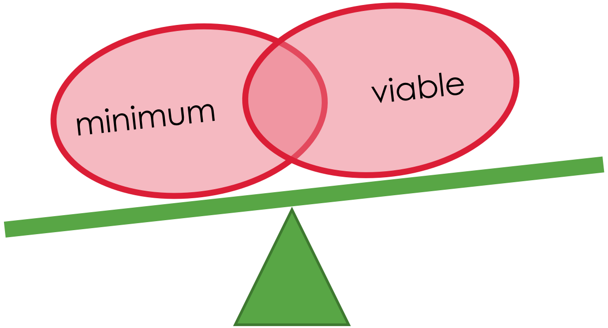
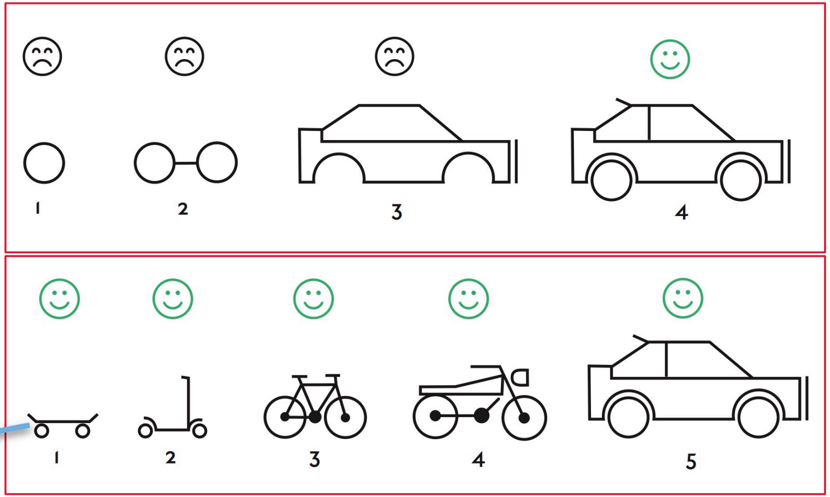
‘Agile’ development: an iterative, adaptive approach

At each stage, the ‘product’ needs to be:

- something useful and usable
- a step towards the target structure





mereotopology
and
space-time

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Situating 4D in ontological space

A requirement for space-time is central

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Reminder: 4D ontologies' choices

4D ontologies are maximally unifying

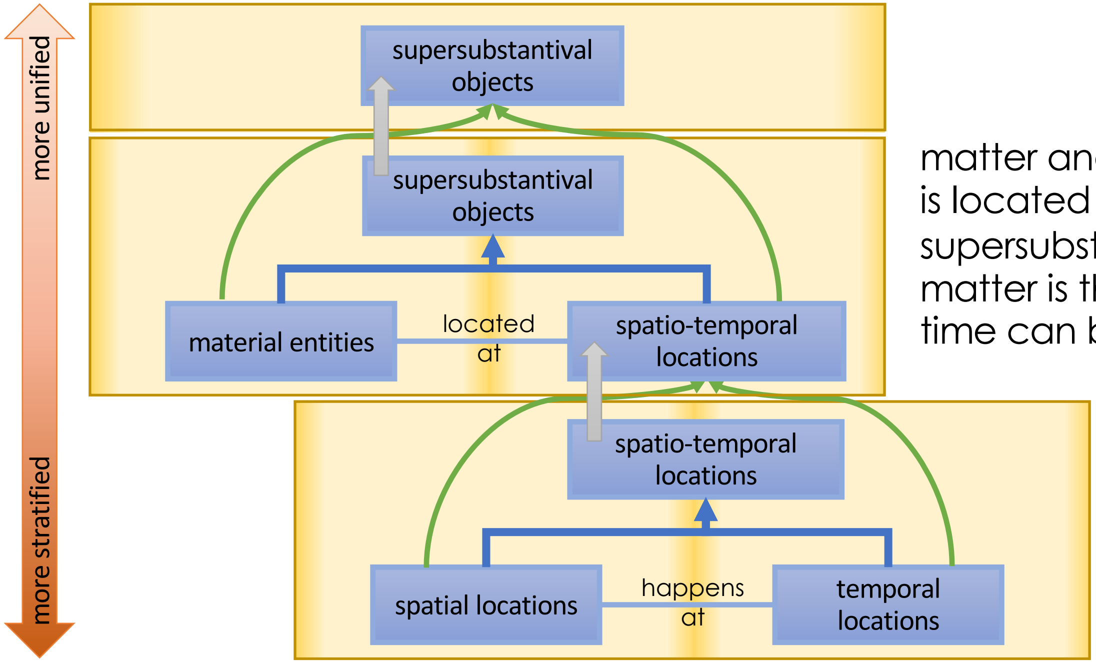
category	type	choice	4D Ontologies
horizontal aspect	**spacetime**	**unifying or separating**	**unifying**
	locations	**unifying or separating**	**unifying**
	properties	unifying or separating	unifying
	endurants	unifying or separating	unifying
	immaterial	unifying or separating	unifying

Motivation:

- the perceived benefits of parsimony and cost of separation
- the easy fit with plenitude

https://digitaltwinhub.co.uk/a-survey-of-top-level-ontologies/#a_survey_of_TLOs_contents

Two (of many) levels of unifying



matter and the space-time it is located in are unified as supersubstantival objects – matter is then a way space-time can be

locations in space and locations in time are unified as locations in space-time

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Broad modularisation context

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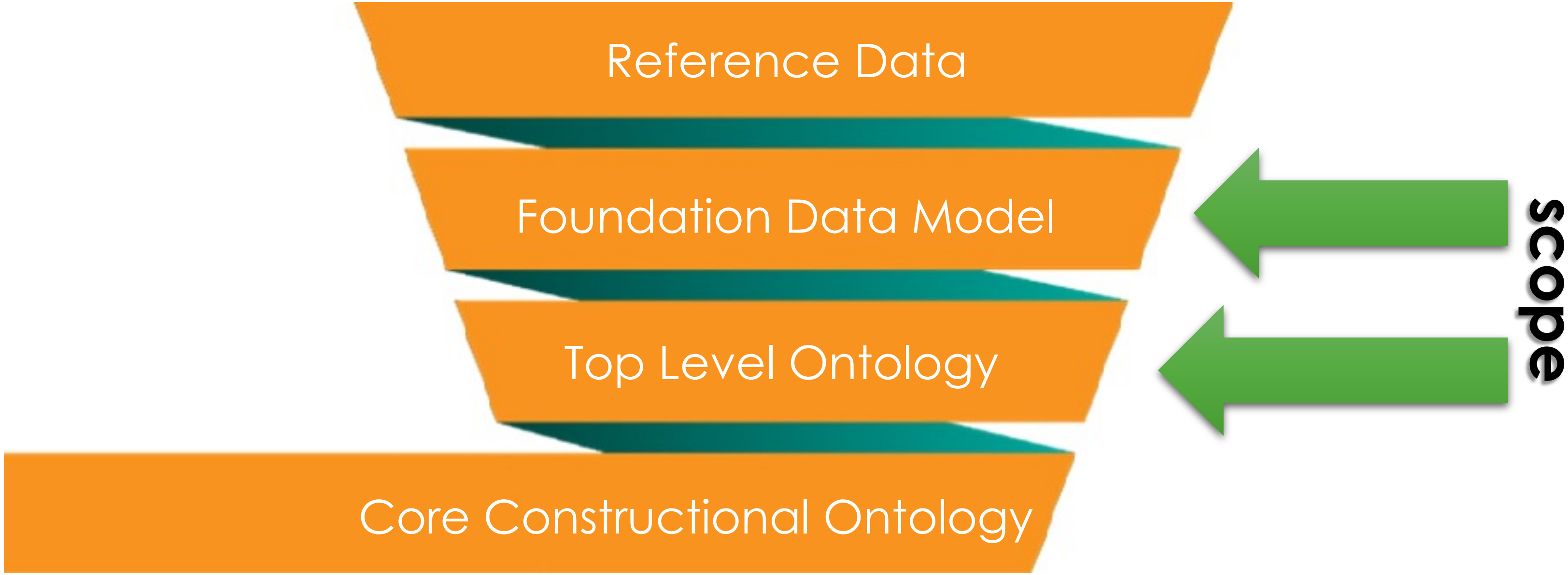
Data perspective: four coarse grained layers



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Basis: Core Constructional Ontology

Provides the ‘base’ for the whole ontology:

- object completeness – builds all the objects
- categorical completeness – establishes all the (ontological) categories of objects
- extensional identity criteria – establishes an extensional criteria of identity for the objects

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First iteration: scope

What should the scope of the first ‘MVP’ be?

Industry Data Model survey provides a context

https://digitaltwinhub.co.uk/a-survey-of-idms-and-rdls-intro/

A core set of standards and associated data

These cover 'geometry' from CAD and geographical perspective

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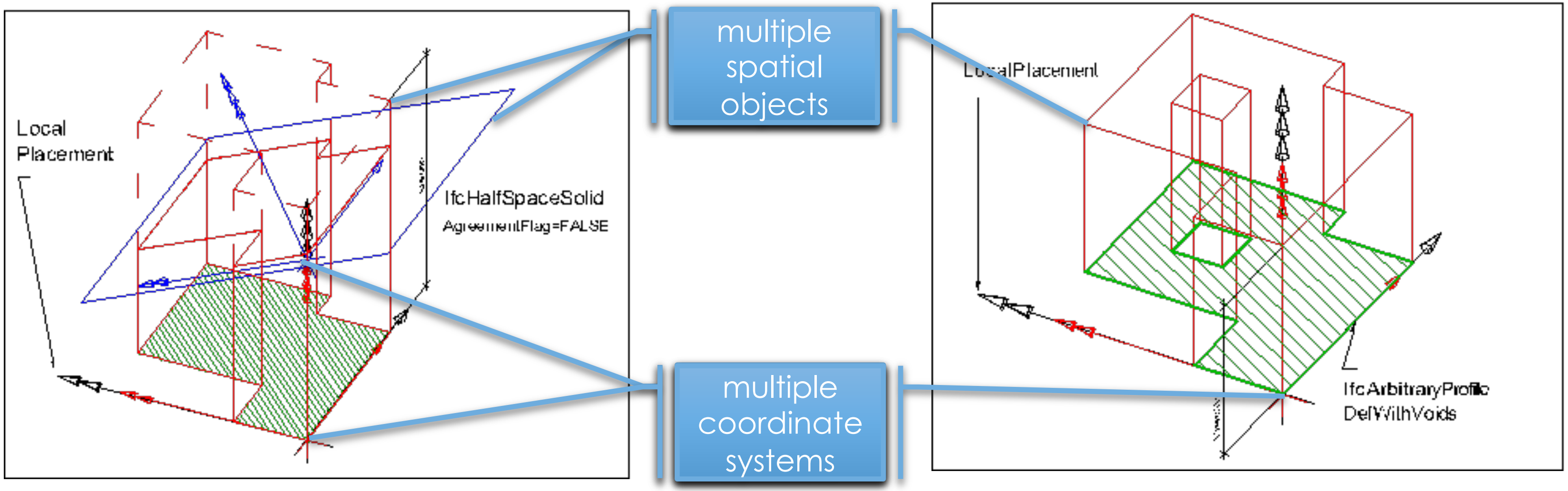
Geometry - CAD – examples from BuildingSMART



https://standards.buildingsmart.org/IFC/RELEASE/IFC2x/FINAL/HTML/ifcproductextension/lexical/ifcspace.html

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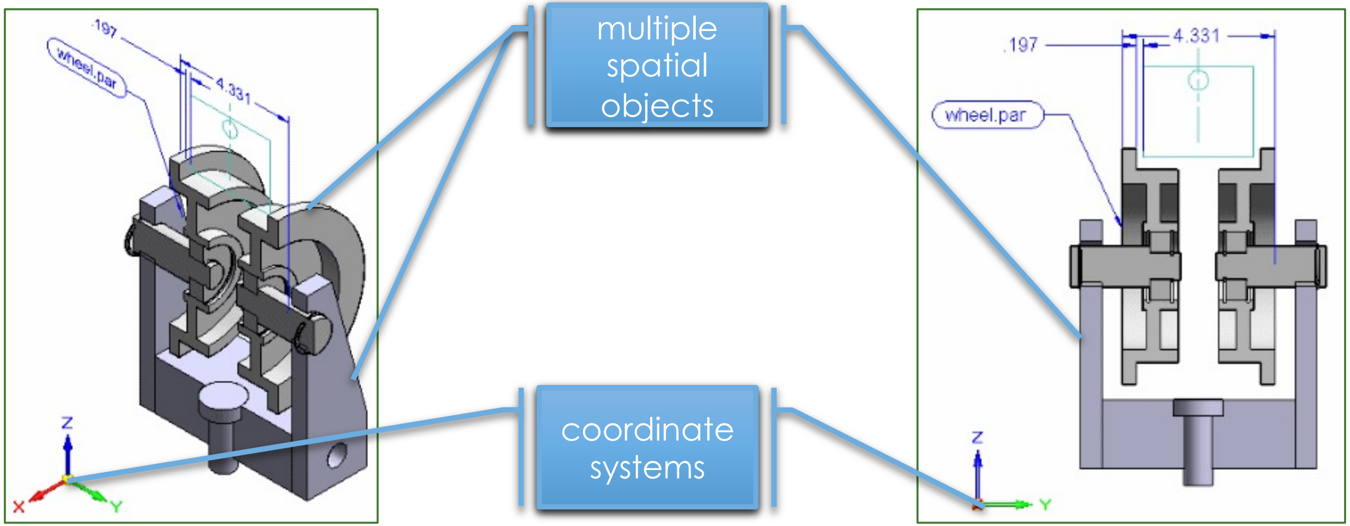
Geometry - CAD – examples from STEP (ISO 10303 Part 42)

ISO 10303
Part 42



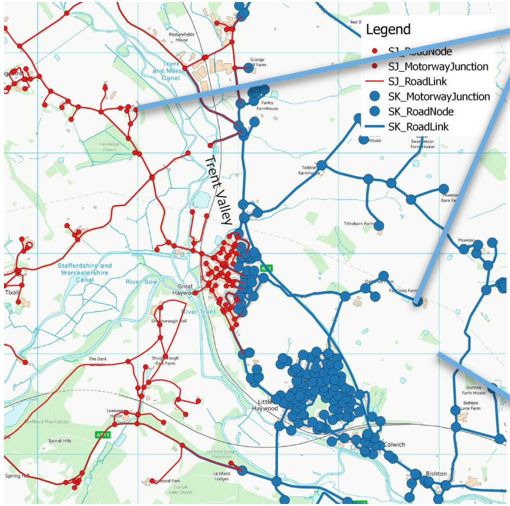
Geometry - Geography – examples from TC211/INSPIRE

ISO/TC 211

INSPIRE

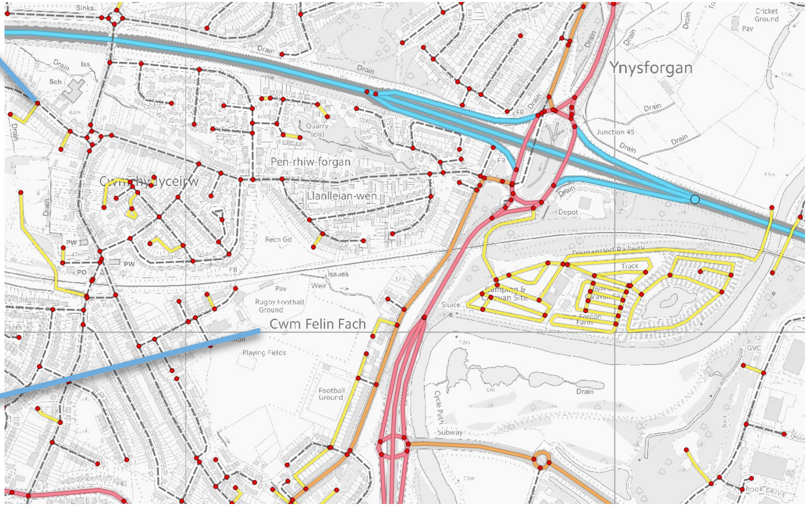
OS Open Roads

OS Open Names



multiple spatial objects

coordinate systems



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Two (three) clear candidates emerge

spatial objects	one, two or three (spatial) dimensional objects either eternal or recurring (at each snapshot) technically rigid, in the sense of no (or practically no) deformation over time
spatial locations	where the spatial objects are located • typically expressed as a (2/3D) coordinate system note: these have the same characteristics as spatial objects (eternal/recurring and rigid)
(names	*things, including the objects and locations have names)*

Current situation:

- space appears to be Euclidean
- no clear way of dealing with time (mostly, not even mentioned)
- no deep formalization

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Some examples

examples

places	spatial objects	geography geometry
roads	spatial objects	geography geometry
solids	spatial objects	CAD geometry
surfaces	spatial objects	CAD geometry
points	spatial objects	CAD geometry
Eastings and Northings	spatial locations	geography geometry
coordinates (2D and 3D)	spatial locations	CAD geometry

buildingSMART International

GeoSPARQL

ISO/TC 211

ISO 10303 Part 42

OS Open Names

INSPIRE

OS Open Roads

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Proposed scope: ‘space-time’

Proposed scope:

- a formalized spatio-temporal account of spatial objects and locations
    - hence named ‘space-time’

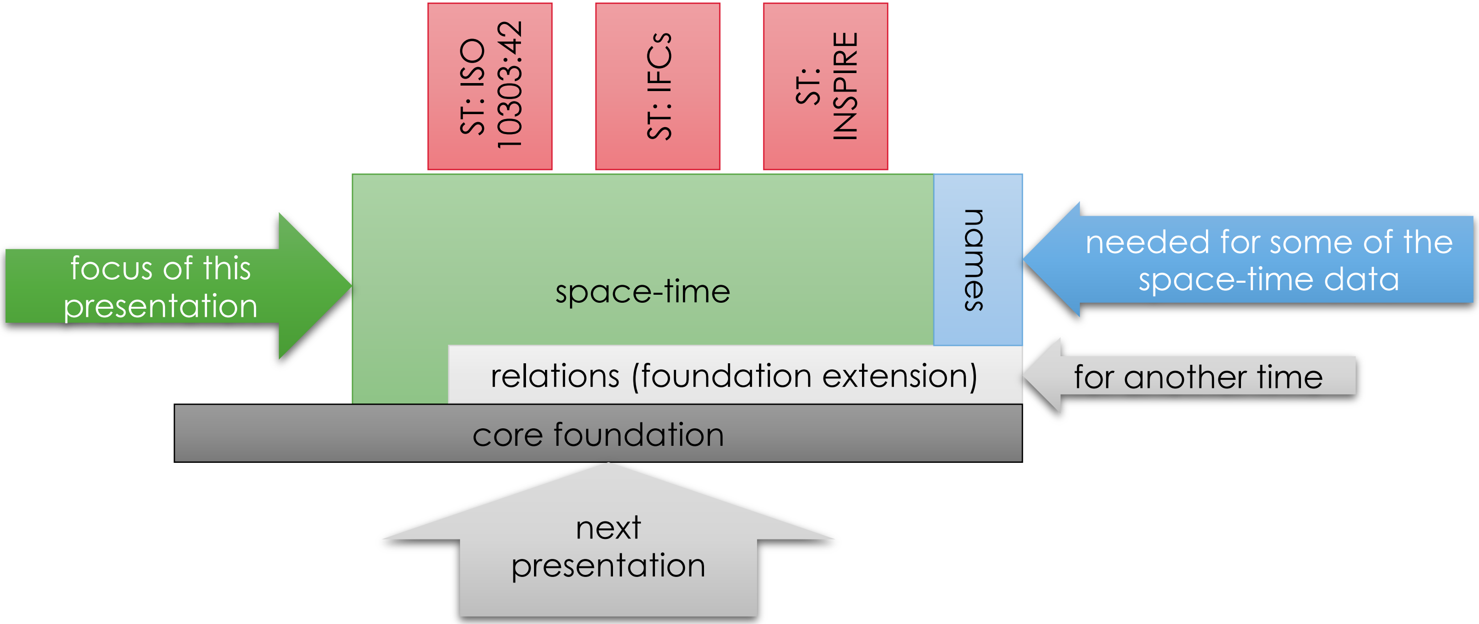
Spatio-temporal challenge:

1. provide a clear way of dealing with space-time, space and time
2. provide a deep formalization of this

Spatial challenge:

1. provide, an account of spatial objects and locations in space-time
    - there is a nexus of things needed for this, including:
        - rigid objects and being relatively at rest

The space-time 'module' in context



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Top-down and bottom-up approach

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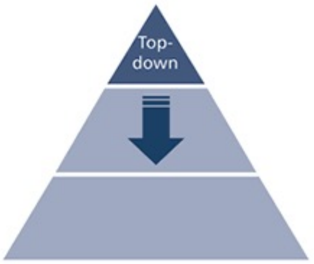
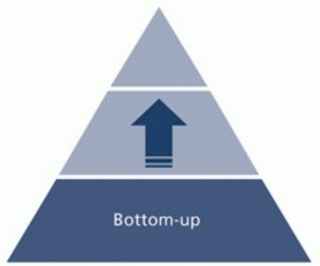
Approach – two workstreams

1. Top-down workstream:
   - (where top is the more general or abstract)
   - builds the formal ontological skeleton
   - discuss in following sections
2. Bottom-up workstream:
   - (where bottom is the more concrete)
   - data driven
   - mine an ontology from current industry standard schemas and data
     - Evidence-based Ontological Requirements Elicitation
       - also called: bCLEARer





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Two mutually supporting workstreams

The two workstreams validate and inform each other

- top-down workstream guides the bottom-up workstream
- bottom-up workstream validates the top-down workstream;
  - its completeness and fit
    - early de-risking

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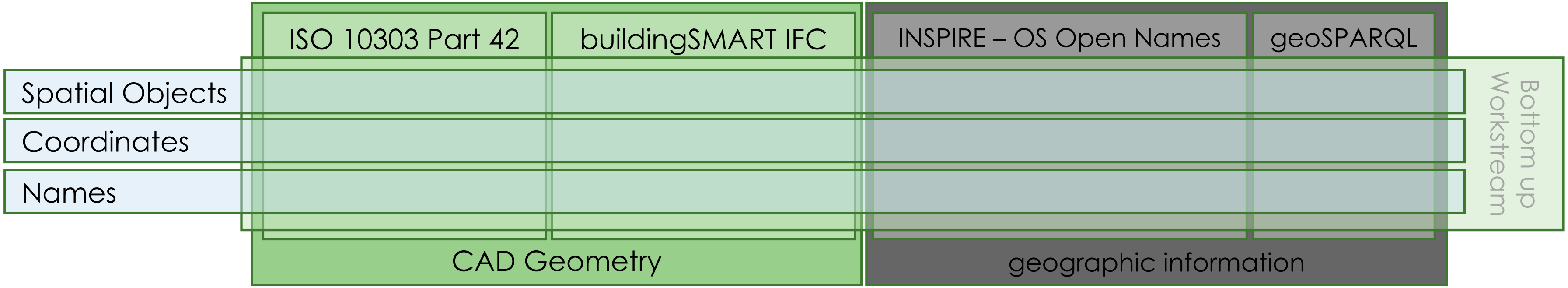
Bottom up workstream – breakdown - visualisation



NB: As noted earlier, coordinates are a form of spatial location

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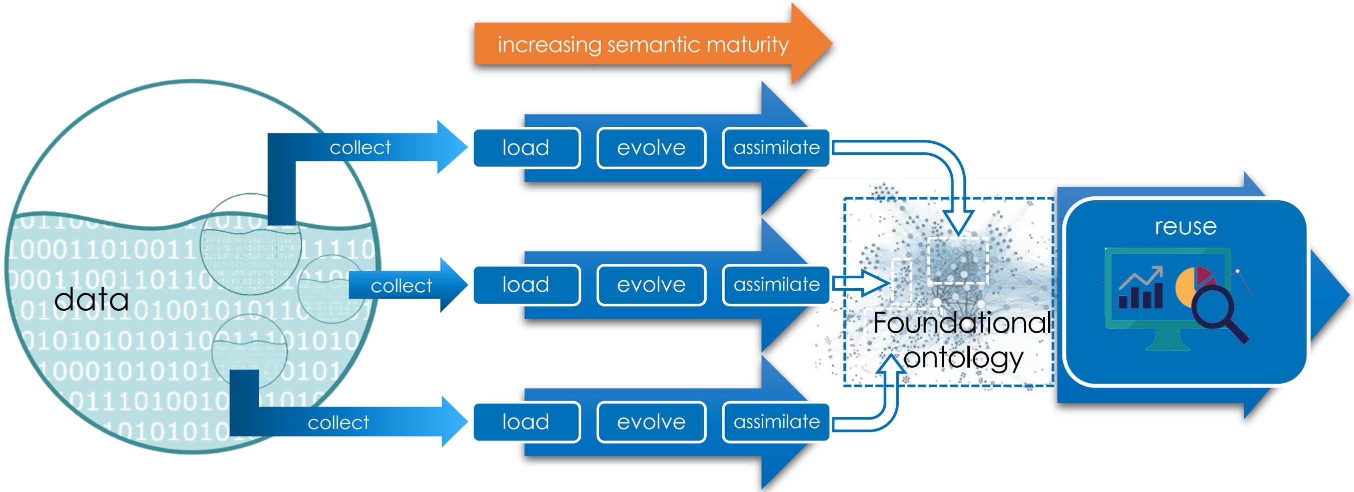
Bottom-up bCLEARer process: visualisation

A repeated sequence of processes: increasing semantic maturity



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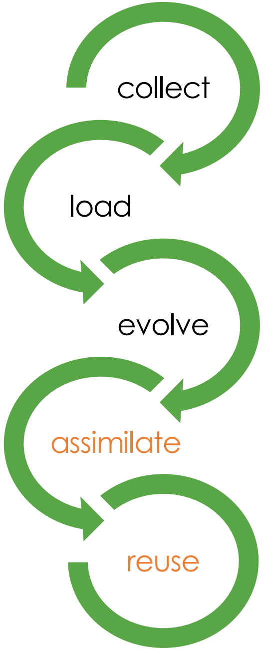
Bottom-up workstream – stages



b(e)	
Collect	collect the datasets in scope in order to establish the broad scope of the process – establishing a bCLEARer master dataset
Load	define the detailed scope by selecting from the Collect dataset the data in scope Translate the dataset into the cell-based format – the table paradigm
Evolve	reveal the underlying semantics of the Load Dataset – 'entification' – in an 'entified' dataset Mine the ontology from the 'entified' dataset – the Evolve ontology dataset
Assimilate	merge the Evolve ontology dataset into the full ontology model
Reuse	publish dataset in a format suitable for the reuse context

In-scope

Out-of-scope

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Space-time – top-down workstream

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Formalising space-time: some historical precedents

Opportunity to build upon previous work:

Year	Author	Title
1919	A. N. Whitehead	An enquiry concerning the principles of natural knowledge
1928	R. Carnap	The Logical Structure of the World
1936	B. Russell	On order in time
1939	J. H. Woodger	The Technique of Theory Construction
1981	P. Needham	Temporal Intervals and Temporal Order
1982	C. Lejewski	Ontology: What's Next?

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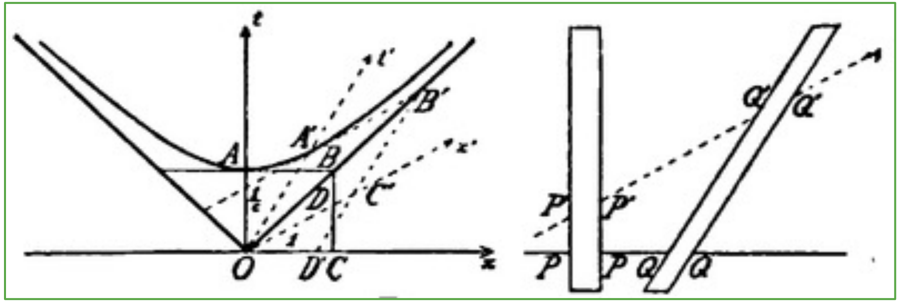
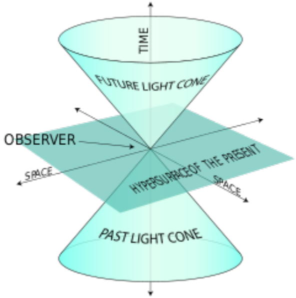
A recurring theme: worldlines: the first example

Illustration: Minkowski, Hermann (1909), "Raum und Zeit", Physikalische Zeitschrift, 10: 75–88





In Minkowski's formalization:

- the worldline is the path that a particle traces in 4-dimensional spacetime
- worldlines are primitive
- so 'points' are derived as the intersections of the worldlines

Worldlines: a logical (ontological) primitive

Selected examples

Year	Author	Title
1909	H. Minkowski	Raum und Zeit
1958	R. Carnap	Introduction to symbolic logic and its applications
1972	P. Suppes	Some open problem in the philosophy of space and time
2008	T. Benda	A formal construction of the spacetime manifold

"49. ASs OF SPACE-TIME: TOPOLOGY: 2. THE *Wlin*-SYSTEM
The present second form is called the *Wlin*-system. Its single *primitive sign is 'Wlin'*."
Rudolf Carnap (1958) Introduction to symbolic logic and its applications.

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Worldlines: a more physical primitive (selected examples)

Year	Author(s)	Title
1972	R. Penrose	Techniques of differential topology in relativity
1973	S.W. Hawking G. F. R. Ellis	The large scale structure of space-time
1976	S.W. Hawking A. R. King P. J. McCarthy	A new topology for curved space-time which incorporates the causal, differential, and conformal structures
1977	D. Malament	The class of continuous timelike curves determines the topology of spacetime

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Why worldlines?

Proposed 'space-time' scope:

- *a formalized spatio-temporal account of spatial objects and locations*

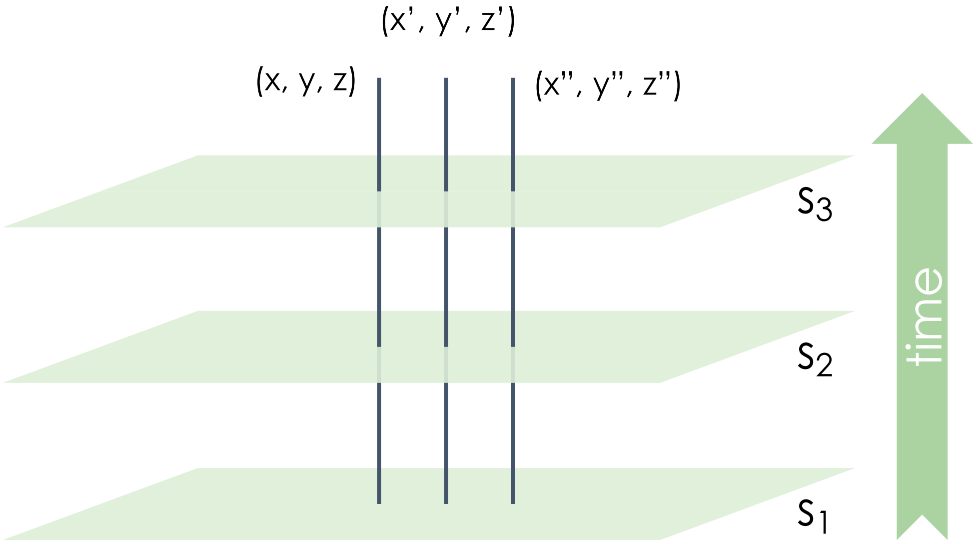
Worldlines handle the full span of the challenges

- we've noted that they have been used to characterise space-time
- we now show they do this in a way that also naturally characterizes rigid (that is, spatial) objects and their locations (and so also coordinate systems)

See:
DiSalle, Robert, "Space and Time: Inertial Frames", The Stanford Encyclopedia of Philosophy (Winter 2020 Edition), Edward N. Zalta (ed.),
Partridge, C.: An Information Model for Geospatial and Temporal Reference. 2011

Worldlines: the same 'spatial' place

Being in the same 'spatial' place is remaining on the same 'coordinate' reference worldline



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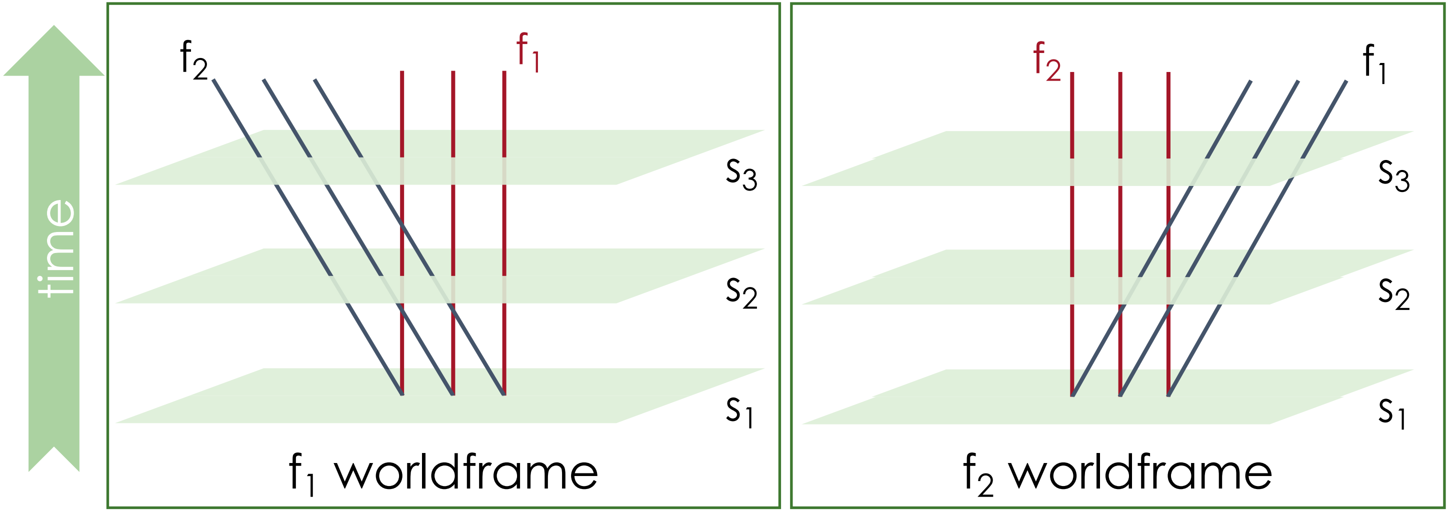
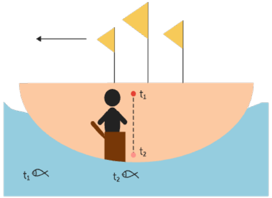
Worldlines: different reference worldframes

There are different reference worldframes and so different ‘same’ places
These reference frames are sets of ‘mutually at rest’ worldlines: worldframes





Galilean relativity

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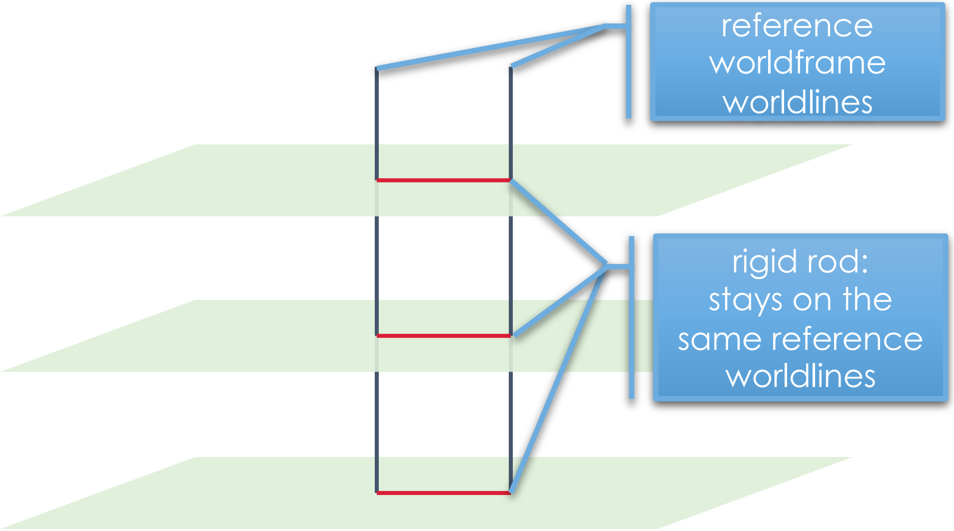
Worldframes: the same 'spatial' object

Being the same 'spatial' object (no spatial change – or deformation) involves one's parts staying on worldlines that are mutually at rest – equidistant – so in the same reference worldframe



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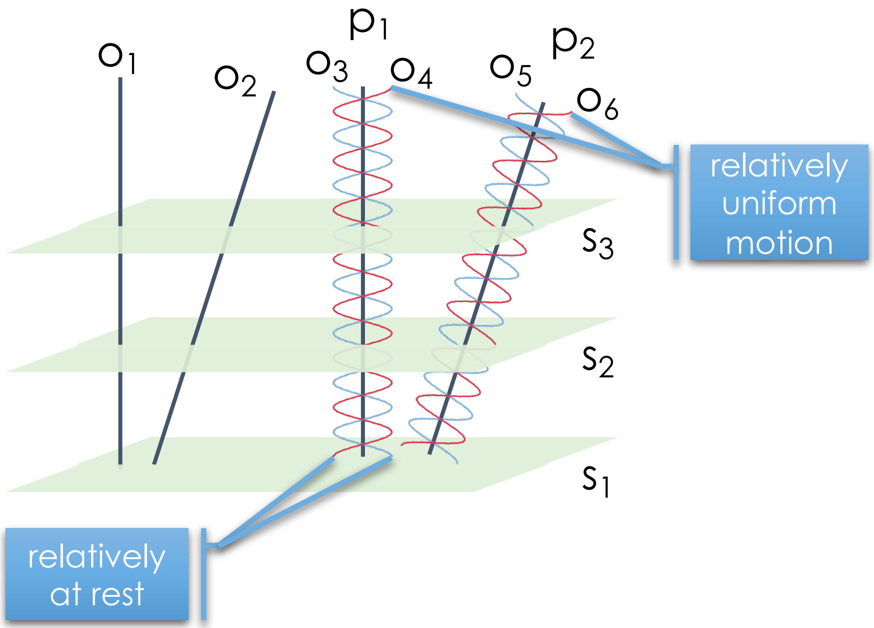
Worldlines: how many different reference worldframes

Each set of ‘mutually at rest’ worldlines marks out a (reference) worldframe

If the two curves circulating around p_1 (and correspondingly p_2) are correctly aligned, then they are also mutually at rest and so mark out a (reference) worldframe



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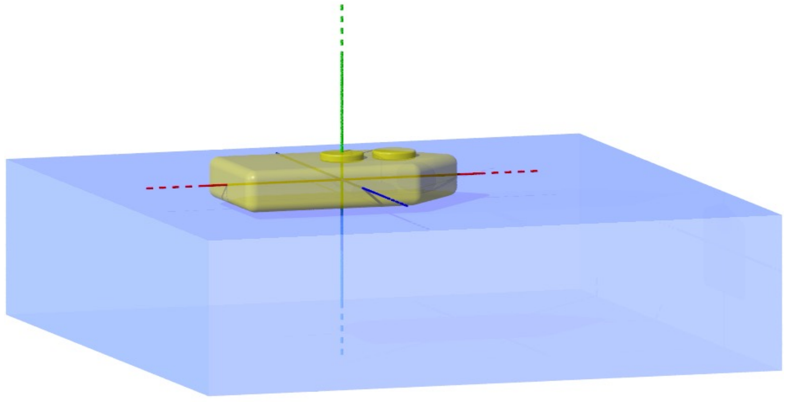
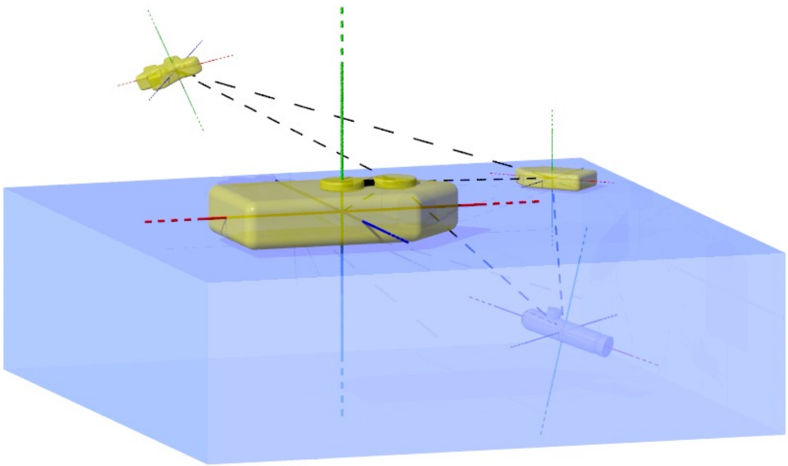
Requirements for multiple coordinate systems



Single Platform



Multi-Platform

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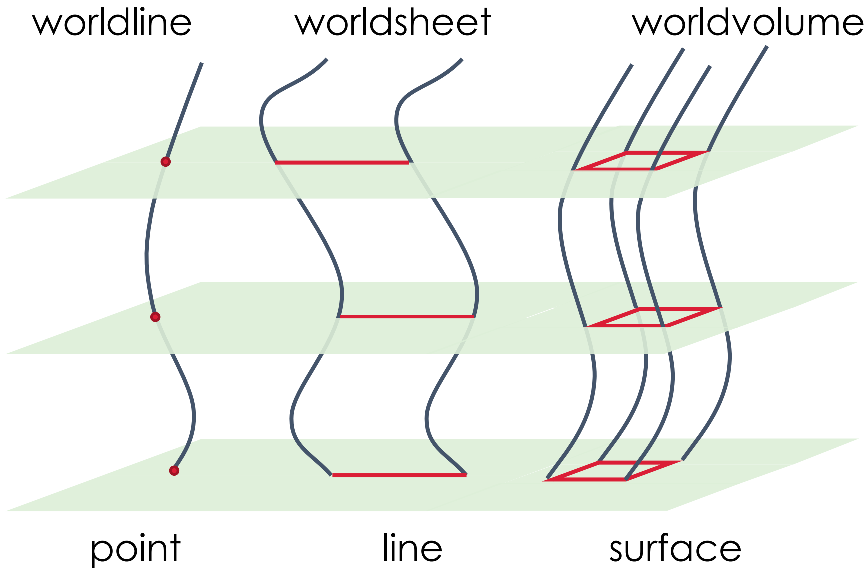
Tracing out higher-dimensional objects

Objects of higher dimension can trace out shapes in space-time



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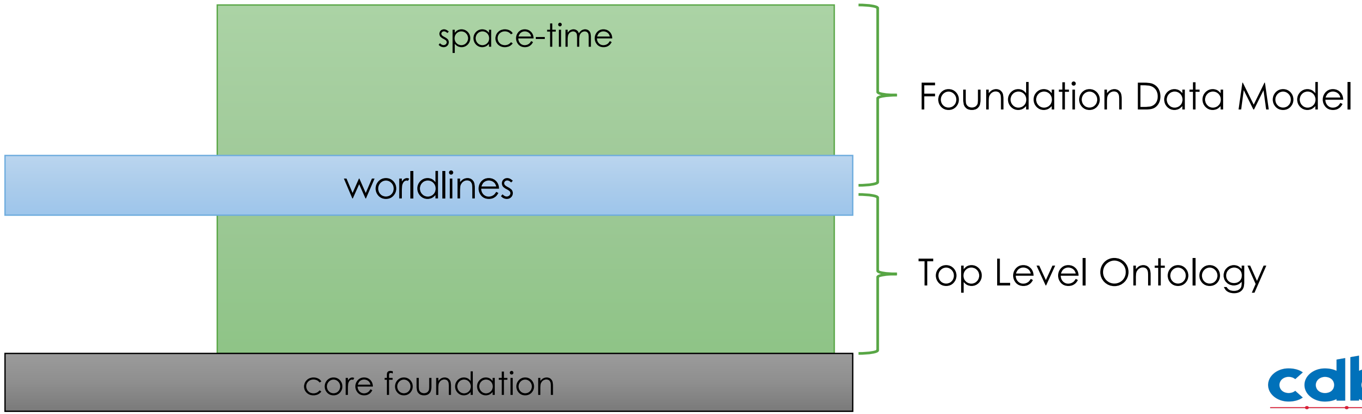
Decomposing the space-time 'module' using worldlines

From the perspective of the space-time 'module', there is an opportunity for horizontal slicing – modularization:

- a decomposition into two sub-components based upon the 7 circles:
    - from core to worldlines
    - from worldlines to spatial objects and locations



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Space-time: Foundation Data Model

from worldlines to spatial objects and locations

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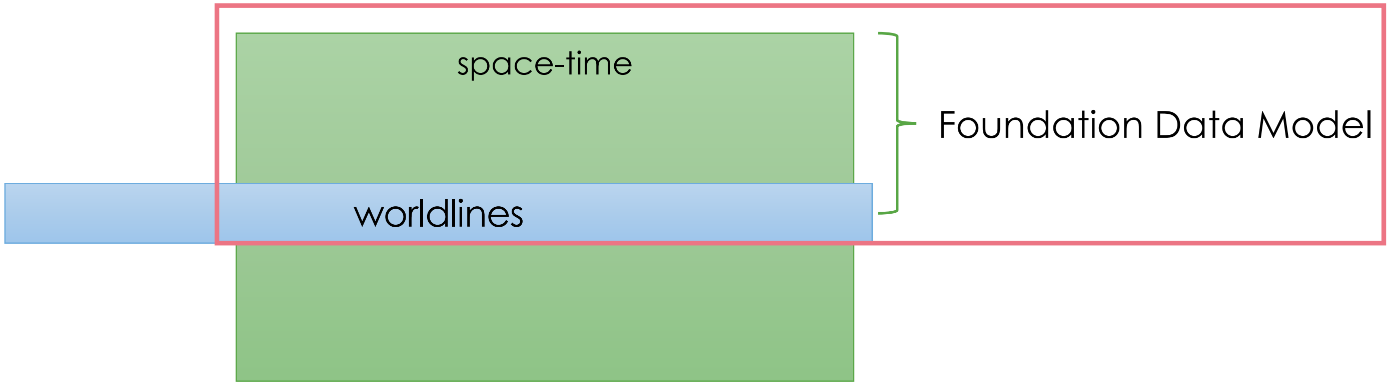
Space-time: foundation data model

from worldlines to spatial objects and locations



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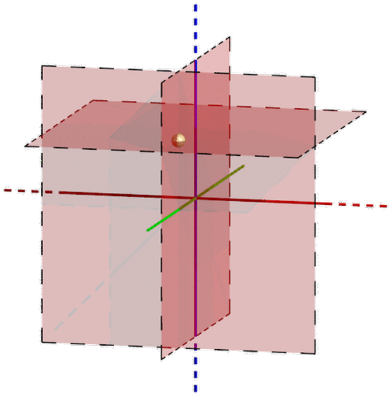
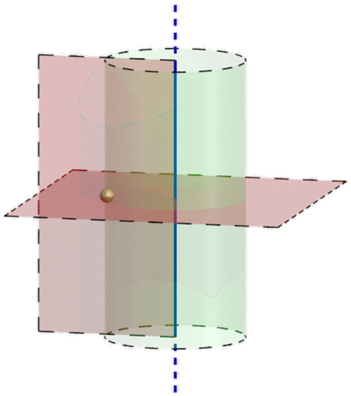
Visualising the coordinate systems (in 3D + time)

NB: coordinate systems AKA spatial locations

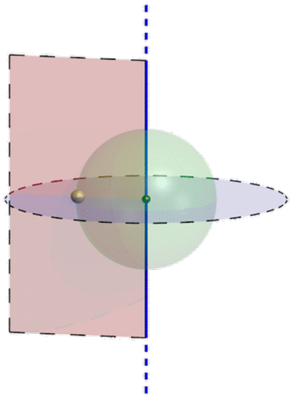
Coordinate systems are characterised in terms of surfaces – which intersect at points



Cartesian



Cylindrical



Spherical

intersecting surfaces uniquely identify a point

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Three common coordinate (point-labelling) systems

- Each decompose into three reusable components:
  - sets of co-oriented coordinate surfaces
- What distinguishes the systems is the types of the surface

Coordinate System	Surface Types
Cartesian	3 × planes
Spherical	sphere, cone and half-plane
Cylindrical	cylinder, half-plane and plane

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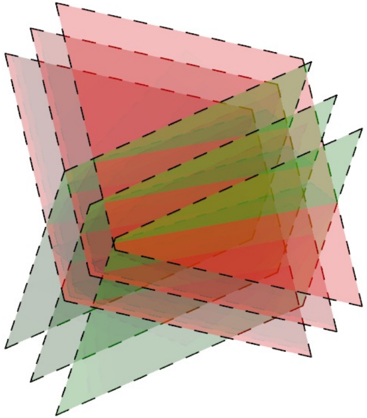
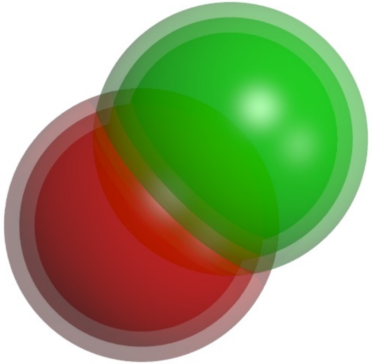
Visualising the types of sets of co-oriented surfaces

Note: the surfaces have an orientation only

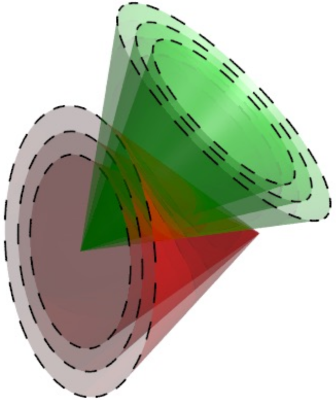
- no notion of axes or origin



Planes

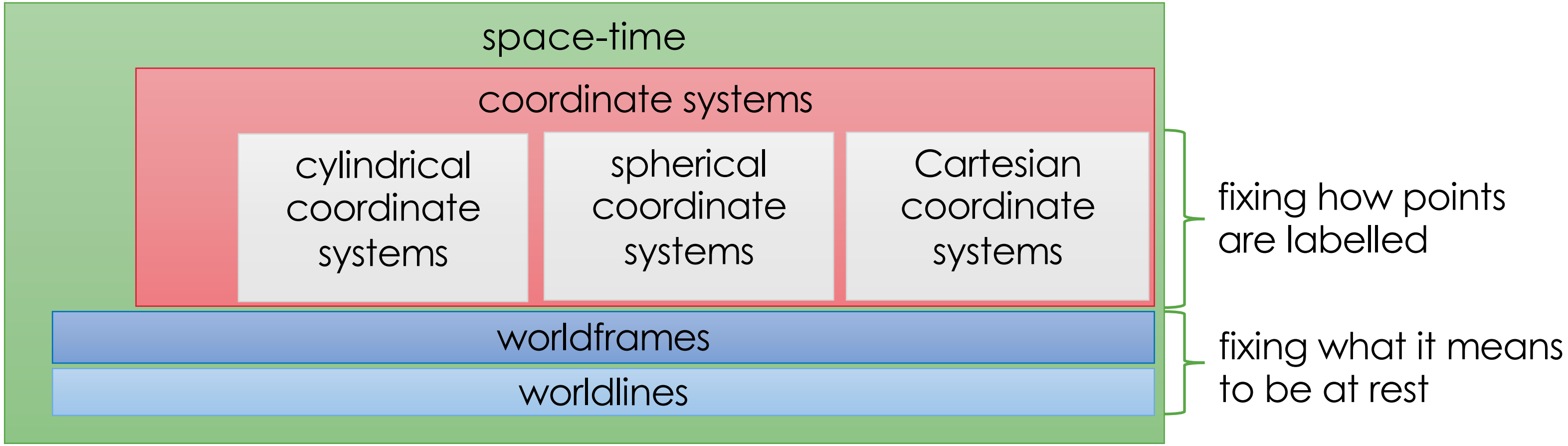


Spheres



Cones

Coordinate systems – built on worldframes



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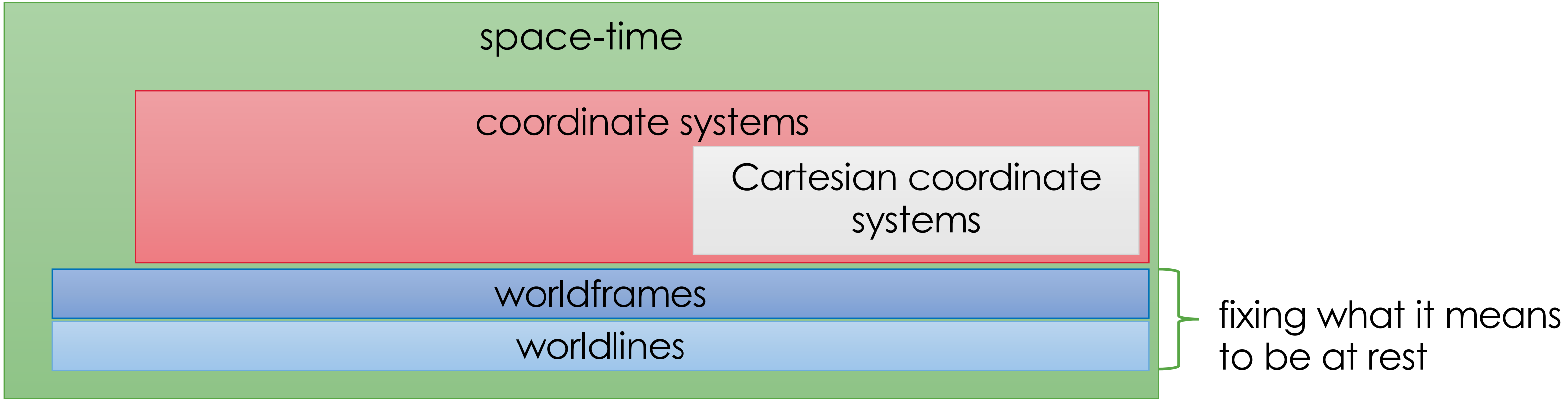
One example: cartesian coordinate systems



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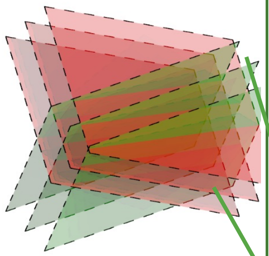
Cartesian coordinate systems: fix the dimensions



Planes

NB: dimension worldvolumes (sets of planes, in this case) can be derived from axes – but not vice versa

Cartesian coordinate systems

xyz-axes dimension worldvolumes triple

worldframes

worldlines

fixing the dimensions

fixing what it means to be at rest

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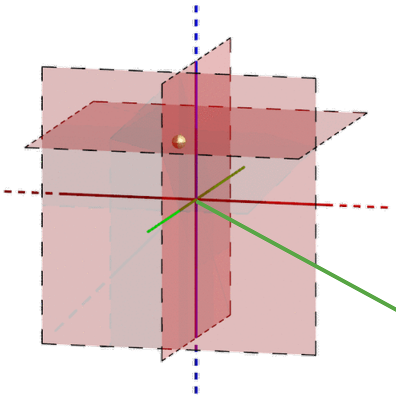
Cartesian coordinate systems: fix origin worldline



Cartesian

NB1: The visualisation is 3D – so the worldline is a 3D point
NB2: From the origin and dimension worldvolumes one can infer the axes

Cartesian coordinate systems

origin worldline	xyz-axes dimension worldvolumes triple

worldframes

worldlines

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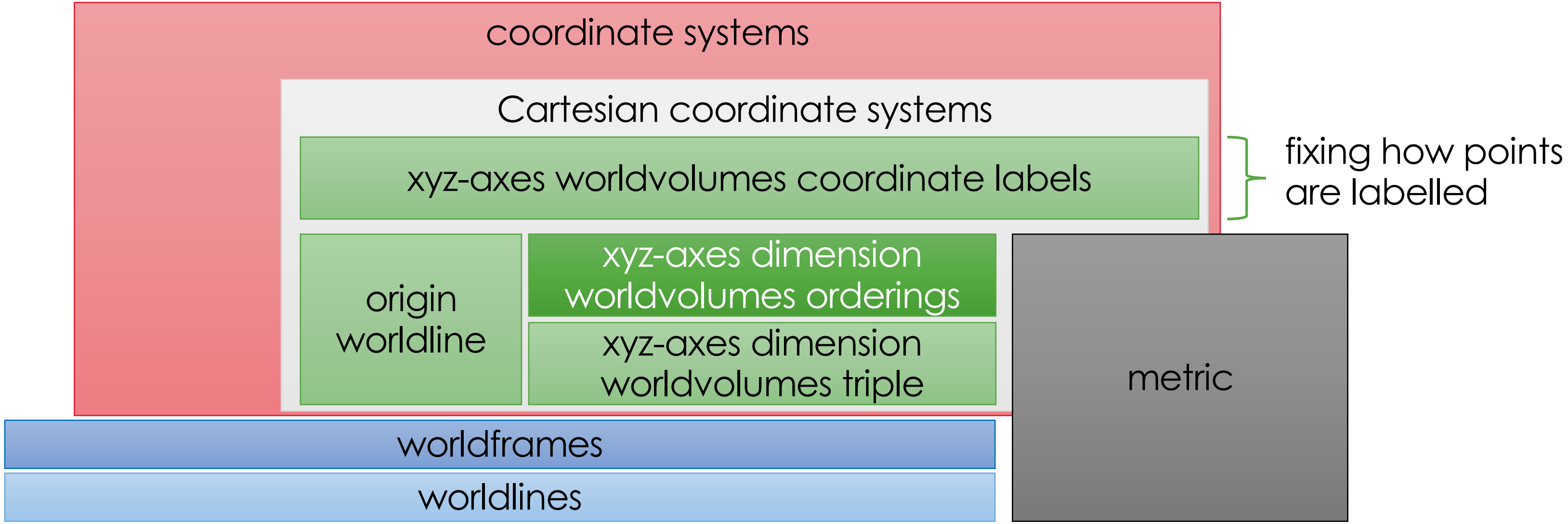
Cartesian coordinate system – components



See:
- Partridge, C.: An Information Model for Geospatial and Temporal Reference. 2011
- Partridge, C.: Geospatial and Temporal Reference – A Case Study Illustrating (Radical) Refactoring. ONTOBRAS-2013 6th Ontology Research Seminar in Brazil, 2013

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Common building process

Devised a common process, with variations, for building up the coordinate systems

Order	Stage	Description
1	Surface Orientation	selecting the set of co-oriented surfaces
2	Solid Ordering	building a mereological ordering for the surfaces – the process varies by surface
3	Ratio Scaling	in these three systems, shifting down one or two dimensions to distance and angle ratios
4	Unitising	selecting the unitised distance or angle ratios – based upon the selection of unit
5	Labelling	labelling the unit ratios

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See: Partridge, C., A. Mitchell, M. Loneragan, et al. (2019). "Coordinate Systems: Level Ascending Ontological Options". In: 2019 - MODELS-C. url:https://www.academia.edu/40354620.

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Space-time:
top-level-ontology

from core to worldlines

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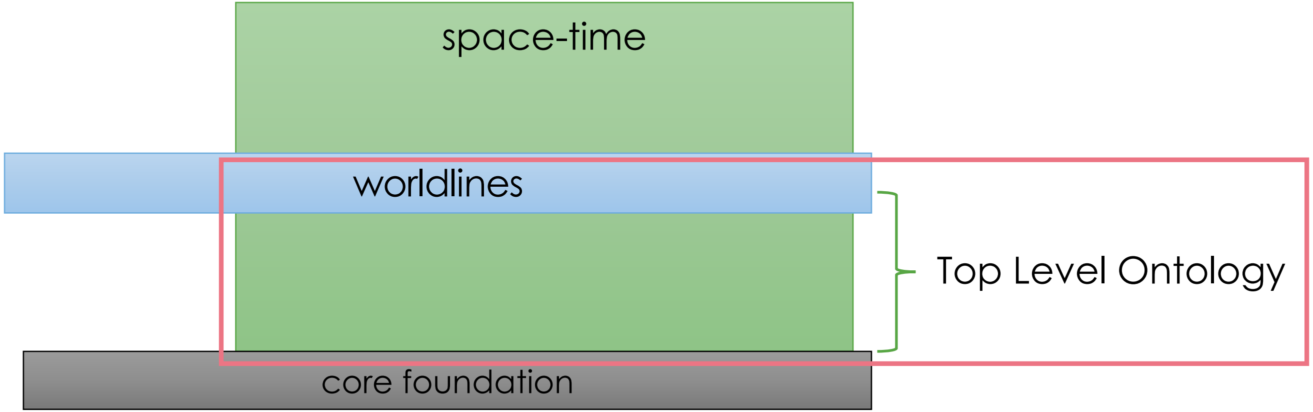
Space-time: top-level-ontology

from core to worldlines



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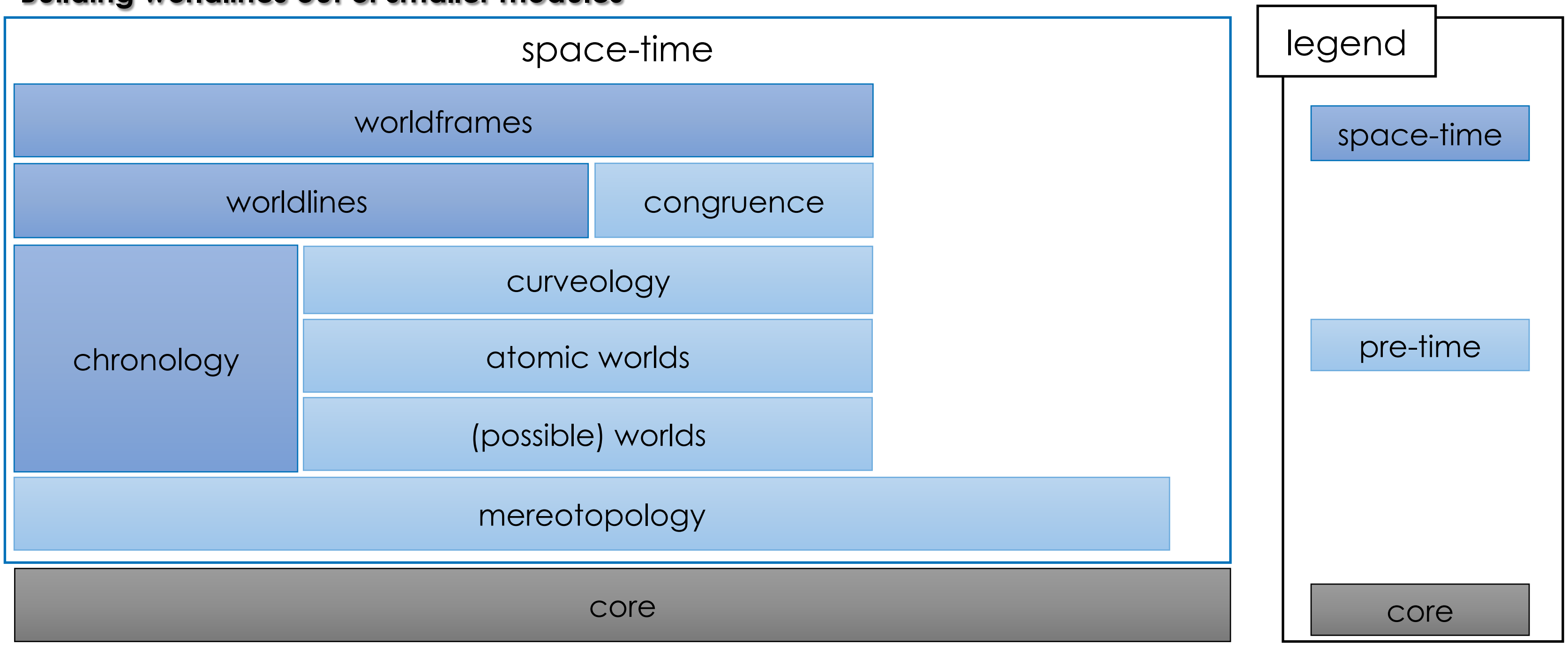
Modularising TLO Space-Time

Building worldlines out of smaller modules



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Questions

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