The Basics of 4-Dimensionalism and the Role it Can Take in Supporting Large Scale Data Integration

4-Dimensionalism in Large Scale Data Sharing and Integration

Dr Matthew West OBE

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30 years with Shell

- Originally a Chemical Engineer
- Doing digital twins in the 1970's
- 30+ years in information management
- Information Quality
- Data Modelling for data integration
- Master and Reference Data
- Projects include PIPPIN, Shearwater and Downstream One

Cofounder of Information Junction 2008

- Consultant with the Centre for the Protection of National Infrastructure 2017
- Technical Lead National Digital Twin programme 2020

25+ years in standards development

- Founding Chair of EPISTLE
- ISO 15926, ISO 18876, ISO 10303, ISO 8000
- ISO TC 184/SC4 Policy and Planning Committee,
- Member BSI-AMT/4
- UK Expert for ISO-IEC 21838 – Top Level Ontologies

Author of "Developing High Quality Data Models"

Trustee – Ontolog Forum

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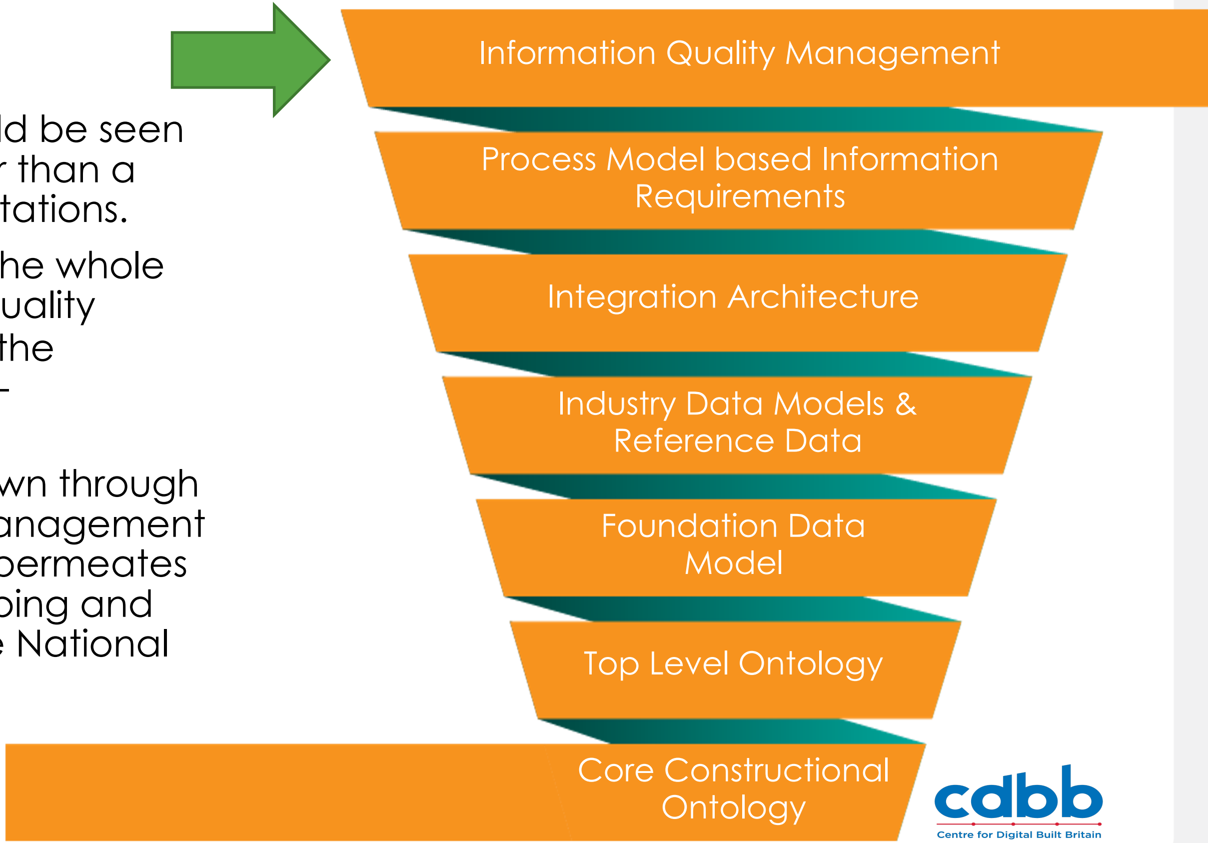
Introduction

- The presentations today should be seen as an integrated whole rather than a collection of separate presentations.
- This one is an introduction to the whole and covers the Information Quality Management angle which is the motivation for our interest in 4-Dimensionalism
- Later presentations will go down through the 7 circles of information management shown here showing how 4D permeates what we are doing in developing and using 4-Dimensionalism on the National Digital Twin programme.



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4-Dimensionalism Background

The original 3D position

As with many things, started with the Ancient Greeks – and lasted over a millennia.

Author	Document	Comment
Aristotle	On the Heavens	a solid has magnitude "in three ways and beyond these there is no other magnitude because the three are all."
	Physics [IV, 1]	in the context of motion, there are six "dimensions", dividing each of the three into two opposites, "up and down, before and behind, right and left," these terms being taken relatively.
Simplicius	Simplicii in Aristotelis De Caelo Connnentaria	notes "it is possible to take only three lines that are mutually perpendicular, two by which the plane is defined and a third measuring depth so that if there were any other distance after the third it would ne entirely without measure and without definition."
John Wallis	Treatise of Algebra (1685)	"For Length, Breadth and Thickness, take up the whole of Space. Nor can our Fansie imagine how there should be a Fourth Local Dimension beyond these Three."

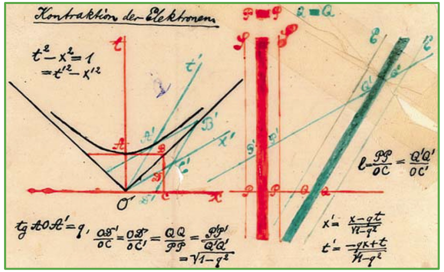
Early appearances

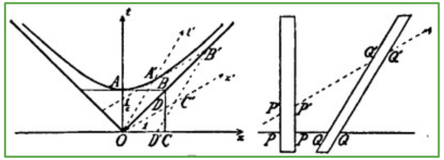
Year	Author	Document	Comment
1754	D'Alembert	Encyclopedie Art. "Dimension	"… one may however look upon duration as a fourth dimension, and that the product of time and solidity is in a way a product of four dimensions
1788	Joseph-Louis Lagrange	Mécanique analytique	mechanics operating in a four-dimensional space — three dimensions of space, and one of time.
1827	A. F. Möbius	Der barycentrische Calcul	a fourth dimension would allow a three-dimensional form to be rotated onto its mirror-image
1854	Georg Friedrich Bernhard Riemann	On the hypotheses which underlie geometry	formalized higher-dimensional spaces
1880	Charles Howard Hinton	What is the Fourth Dimension?"	Explained what a "four-dimensional cube" is.

Cajori, Florian (1926). "Origins of Fourth Dimension Concepts" (PDF). The American Mathematical Monthly. 33 (8): 397–406.

Origin of (geometric) four-dimensionalism

"Space and Time" address at 80th Assembly of German Natural Scientists and Physicians on 21 September 1908:





"The views of space and time which I wish to lay before you have sprung from the soil of experimental physics, and therein lies their strength. They are radical. Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality."

Hermann Minkowski

A brief history of the developments in four dimensionalism: Selected major publications - I

The first half of the 20th century

Year	Author	Publications
1920	A. N. Whitehead	The Concept of Nature. Cambridge University Press, Cambridge.
1923	C. D. Broad	Scientific Thought. Harcourt, New York.
1927	B. Russell	The Analysis of Matter. Allen & Unwin, London.
1928	R Carnap	Der logische Aufbau der Welt. Weltkreis-Verlag, Berlin.
1928	H. Reichenbach	Philosophie der Raum-Zeit-Lehre, Walter de Gruyter, Berlin and Leipzig.
1937	J. Woodger	The axiomatic method in biology. Cambridge 1937

A brief history of the developments in four dimensionalism: Selected major publications - II

The second half of the 20th Century

Year	Author	Publications
1951	N. Goodman	Goodman, N., 1951. The Structure of Appearance. Harvard University Press, Cambridge (MA).
1950	W.V.O. Quine	Methods of Logic. Holt, Rinehart & Winston, New York.
1955	Taylor	Spatial and temporal analogues and the concept of identity. The Journal of Philosophy, 52: 599–612.
1955	J. J. C. Smart	Spatialising time. Mind, 64: 239–241.
1967	H. Putnam	Time and physical geometry, Journal of Philosophy 64 (8):240-247.
1971	D. K. Lewis	Counterparts of persons and their bodies. The Journal of Philosophy, 68: 203–211.
1972	J. J. C. Smart	Space-time and individuals. In Rudner, R. S. and Scheffler, I., eds., Logic and Art
1976	H. W. Noonan	The four-dimensional world. Analysis, 37: 32–39.
1980	H. W. Noonan	Objects and Identity. An Examination of the Relative Identity Thesis and Its Consequences. Nijhoff
1986	D. K. Lewis	On the Plurality of Worlds. Blackwell, Oxford.
1980	D. M. Armstrong	Identity through time. In van Inwagen, P., ed., Time and Cause.
1982	D. Robinson	Re-identifying matter. The Philosophical Review, 91: 317–341.
1984	M. Heller	Temporal parts of four dimensional objects. Philosophical Studies, 46: 323–33
1990	M. Heller	The Ontology of Physical Objects: Four-dimensional Hunks of Matter. Cambri
1990	P. van Inwagen	Four-Dimensional Objects, Noûs, 24: 245–55.
1993	M. Heller	Varieties of Four Dimensionalism, Australasian Journal of Philosophy, 71: 47–5
1991	R. Le Poidevin	Change, Cause and Contradiction. A Defence of the Tenseless Theory of Time. Macmillan, London.
1993	M. Jubien	Ontology, Modality, and the Fallacy of Reference. Cambridge University Press, Cambridge.

The 21st Century texts on four dimensionalism are too numerous to list here.

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What is 4-Dimensionalism?

Hint: It is not just adding time to 3D, or even acknowledging special relativity

In ontology it is a series of commitments that characterize a Top Level Ontology

What is an ontology?

There are many definitions, but my favourite is:

theory of what exists

i.e. the things that exist and the rules that govern them

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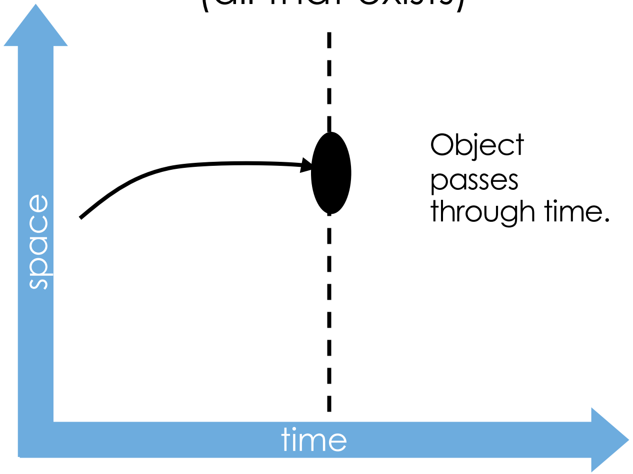
3D

The present

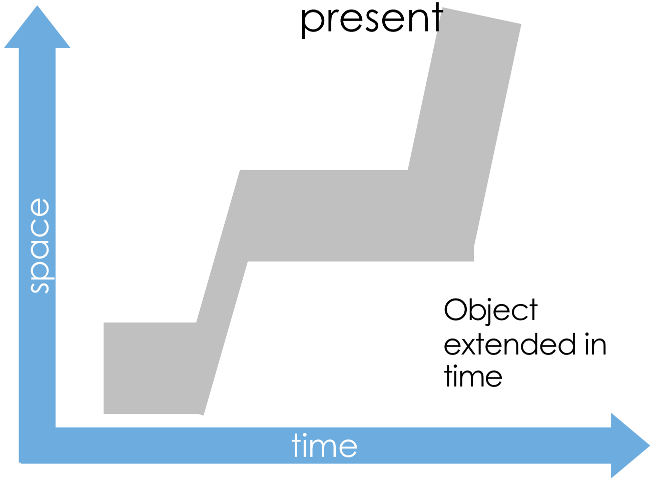
(all that exists)



1. Physical objects do not have temporal parts.
2. Different physical objects may coincide (non-extensional).

4D + Extensionalism

The past and the future exist as well as the present



1. Individuals extend in time as well as space and have both temporal parts and spatial parts.
2. When two individuals have the same spatio-temporal extent they are the same thing (extensionalism).

A framework for assessing an ontology's architectural choices

31 ontological choices

37 top ontologies shortlisted and assessed

Appendix E: Summary of Framework Assessment Matrix Results

category	vertical aspect								
type	parent-arity		transitivity	boundedness			stratification	formal generation	
relation	type-instance	super-sub-type	super-sub-type	type-instance			type-instance	whole-part	
characteristic				downwards	fixed finite levels	number of fixed levels		fusion	compler
choice	single or unconstrained	single or unconstrained	yes or no	bounded or unbounded	fixed or not-fixed	[a number]	stratified or unstratified	yes or no	yes or n
BFO	unconstrained	single	yes	bounded	fixed	2	stratified	no	no
BORO	unconstrained	unconstrained	yes	bounded	not-fixed	not applicable	unstratified	yes	yes
YAMATO	not assessed	single	yes	bounded	fixed	2	stratified	yes	yes
HQDM	unconstrained	unconstrained	yes	bounded	not-fixed	not applicable	unstratified	yes	yes
IDEAS	unconstrained	unconstrained	yes	bounded	not-fixed	not applicable	unstratified	yes	yes
ISO 15926-2	unconstrained	unconstrained	yes	bounded	not-fixed	not applicable	unstratified	yes	yes
UFO	unconstrained	unconstrained	yes	bounded	not-fixed	not applicable	stratified	no	no
GFO	unconstrained	single	yes	bounded	not-fixed	not applicable	unstratified	yes	yes
KR Ontology	not yet assessed	unconstrained	yes	not yet	not	not assessed	not assessed	not	not asse
DOLCE	unconstrained	single	yes						
ConML+CHARM	unconstrained	single	yes						
CIDOC (ISO 21127:2014)	unconstrained ?	unconstrained	yes						

The ontological choices shape the architecture of the ontology

https://www.repository.cam.ac.uk/handle/1810/313452

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

Stratification: 4D Ontologies' choices

Some choices multiply entities, others reduce them.
One thing that characterizes 4D Ontologies is that they are (from the framework perspective) maximally unifying.

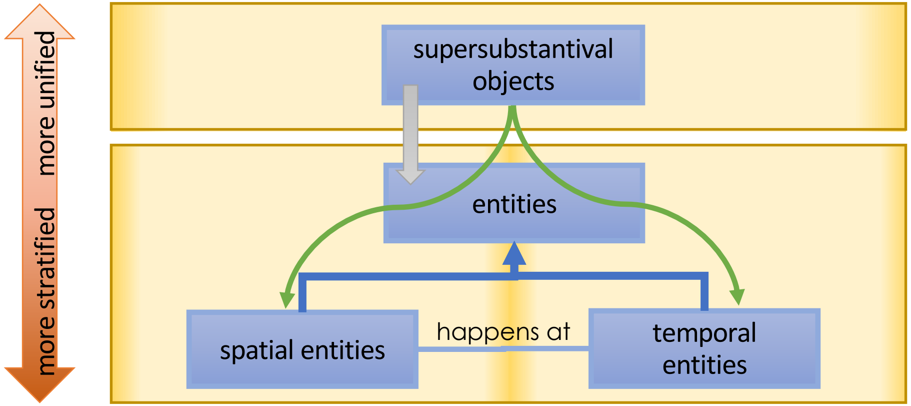
category	type	choice	4D Ontologies
Stratification	space-time	unifying or separating	unifying
	locations-objects	unifying or separating	unifying
	properties-objects	unifying or separating	unifying
	endurants-occurents	unifying or separating	unifying
	immaterial-material	unifying or separating	unifying

Motivation:

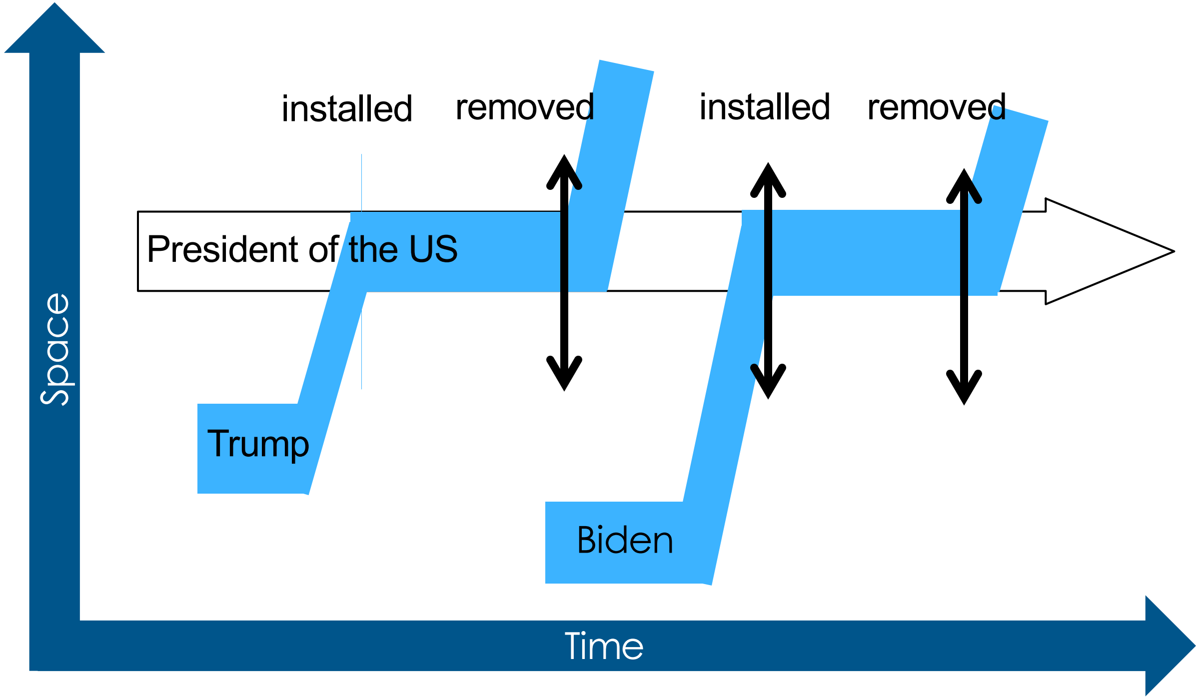
- the presumed benefits of parsimony and cost of separation.
- Nothing is lost in ability to support information requirements.

Stratification: visualizing unifying and separating

A key 4D choice is unifying space and time

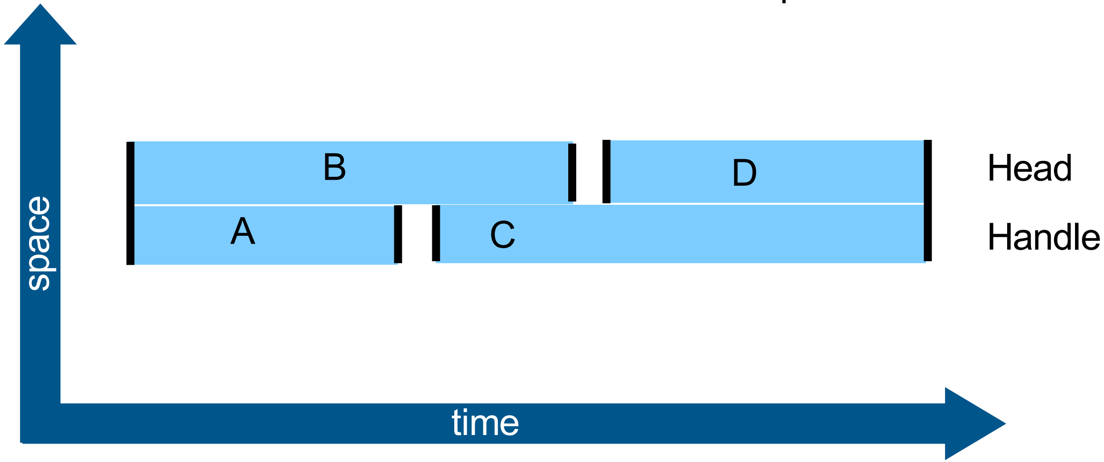


The President of the United States in 4D



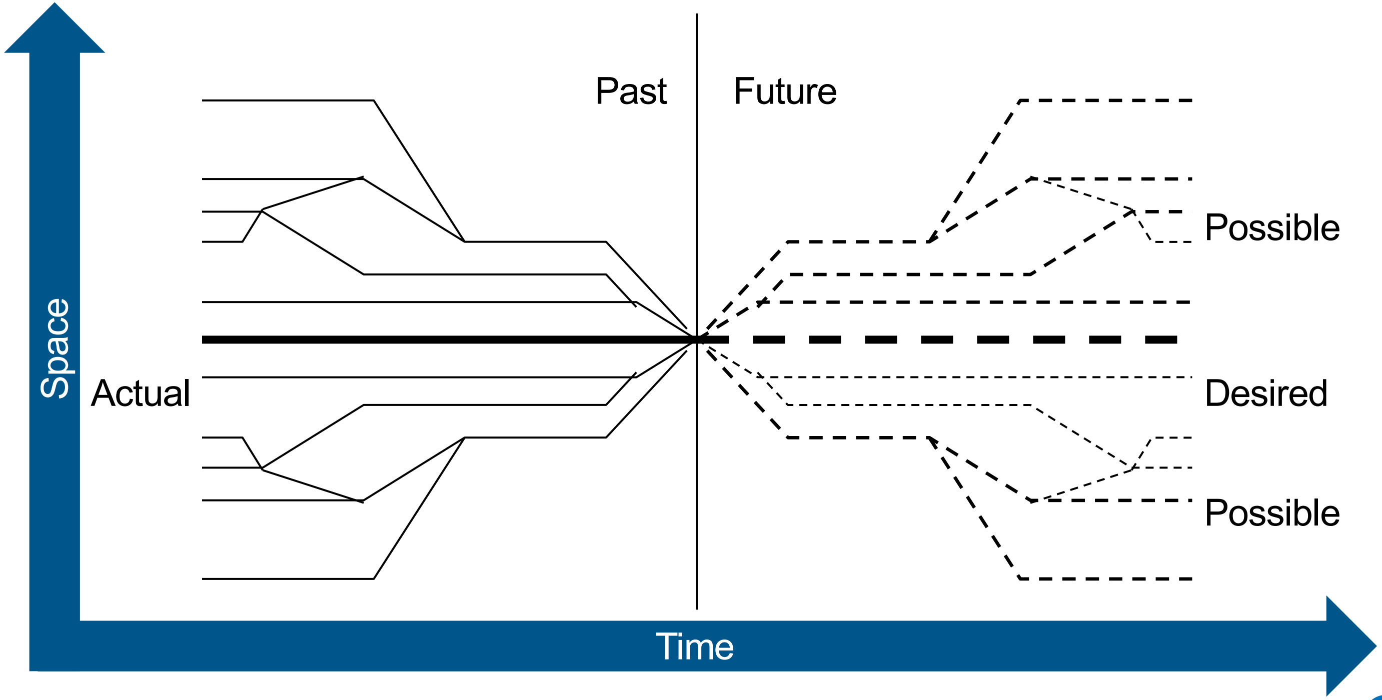
Trigger's broom

The Ship of Theseus is the posh version of this.

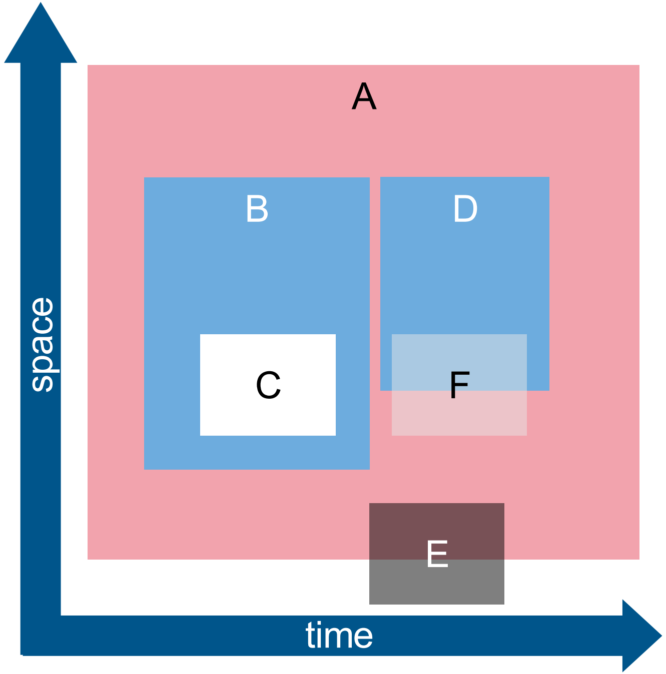


the identity of ordinary physical objects: they survive the changing of some, but not all their parts simultaneously

Possible Worlds

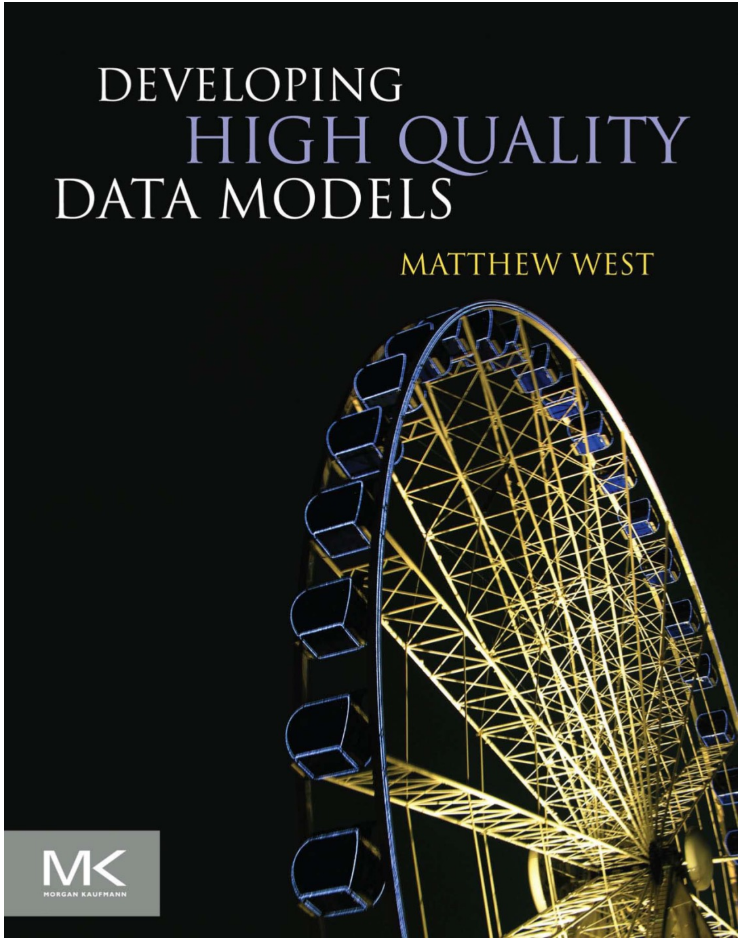


The 4D whole/part relationship (mereology)



- Nothing is a (proper) part of itself.
- If B is a part of A, then A is not a part of B (asymmetry).
- If B is a part of A and C is a part of B, then C is a part of A (transitivity).
- If A has parts (is not atomic – in the original, i.e. not physics, sense of the word) then it has at least two non-overlapping parts (e.g. B and D in Figure 11-1)
- If there is a part of E that is not a part of A, then E is not a part of A.
- In the sum of overlapping parts like D and F, any overlapping parts only count once.
- If a part of F is a part of D then D and F overlap.
- For any set of spatio-temporal extents, e.g. {B, D} there exists their mereological sum B+D.
- There are versions of mereology (the study of wholes and parts) where spatio-temporal extents are (improper) parts of themselves. I will stay with the more everyday understanding of being a part.

General Extensional Mereology just works for 4D



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Why are we interested in 4-Dimensionalism?

Hint: the reasons are pragmatic as much as theoretical

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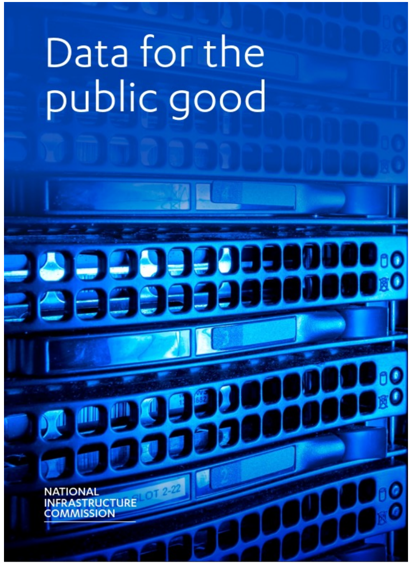
The National Digital Twin Programme

Data for the public good recommendations



2017

The National Digital Twin Programme

- Is led by the **Centre for Digital Built Britain**, with the mission of:
  - **delivering an Information Management Framework**, enabling secure data sharing and effective information management
  - **enabling the National Digital Twin**, an ecosystem of connected digital twins that will deliver better outcomes from our built environment
  - **aligning** industry, academia and Government on this agenda.

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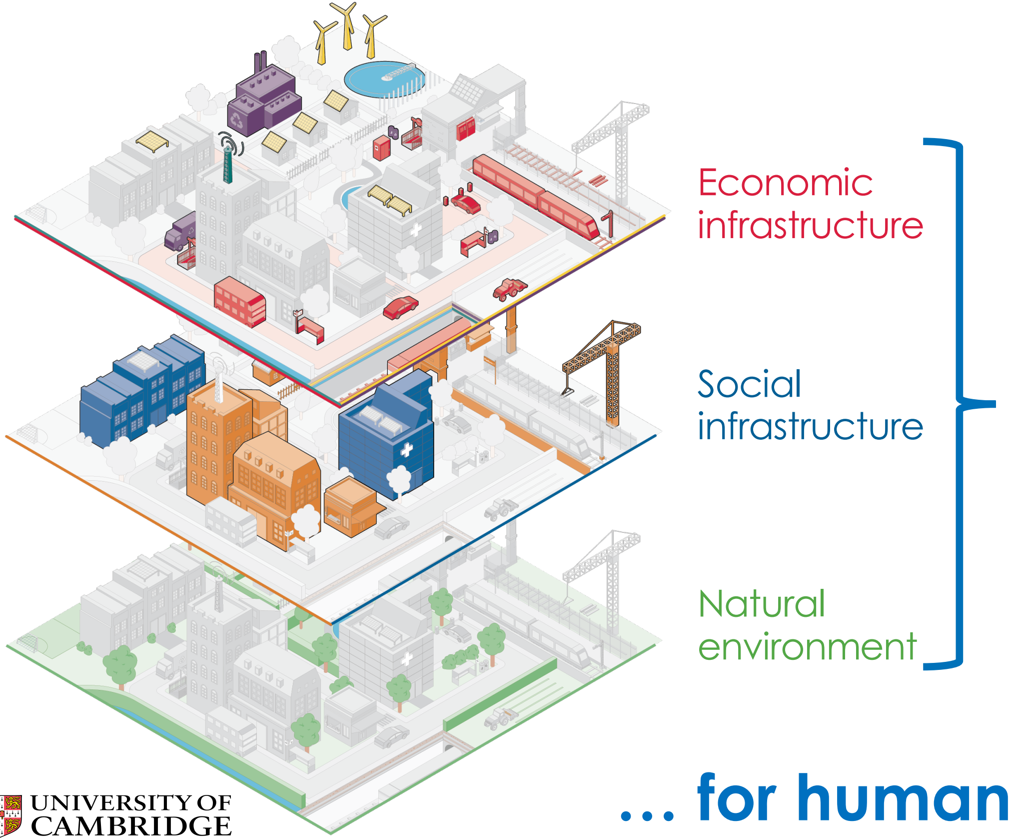
The Built Environment: A system of systems …



Built environment

… for human flourishing

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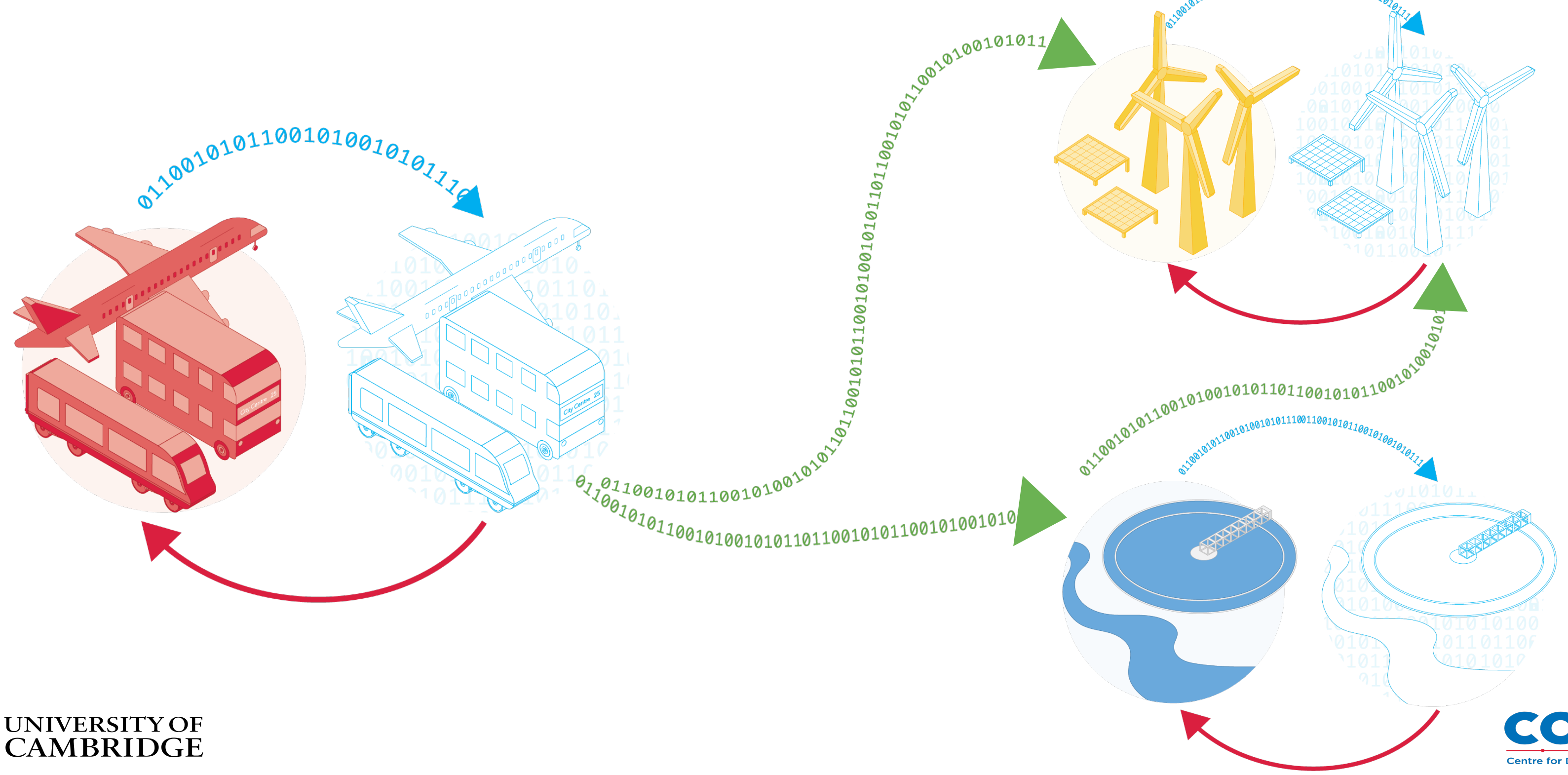
The National Digital Twin

An ecosystem of connected digital twins



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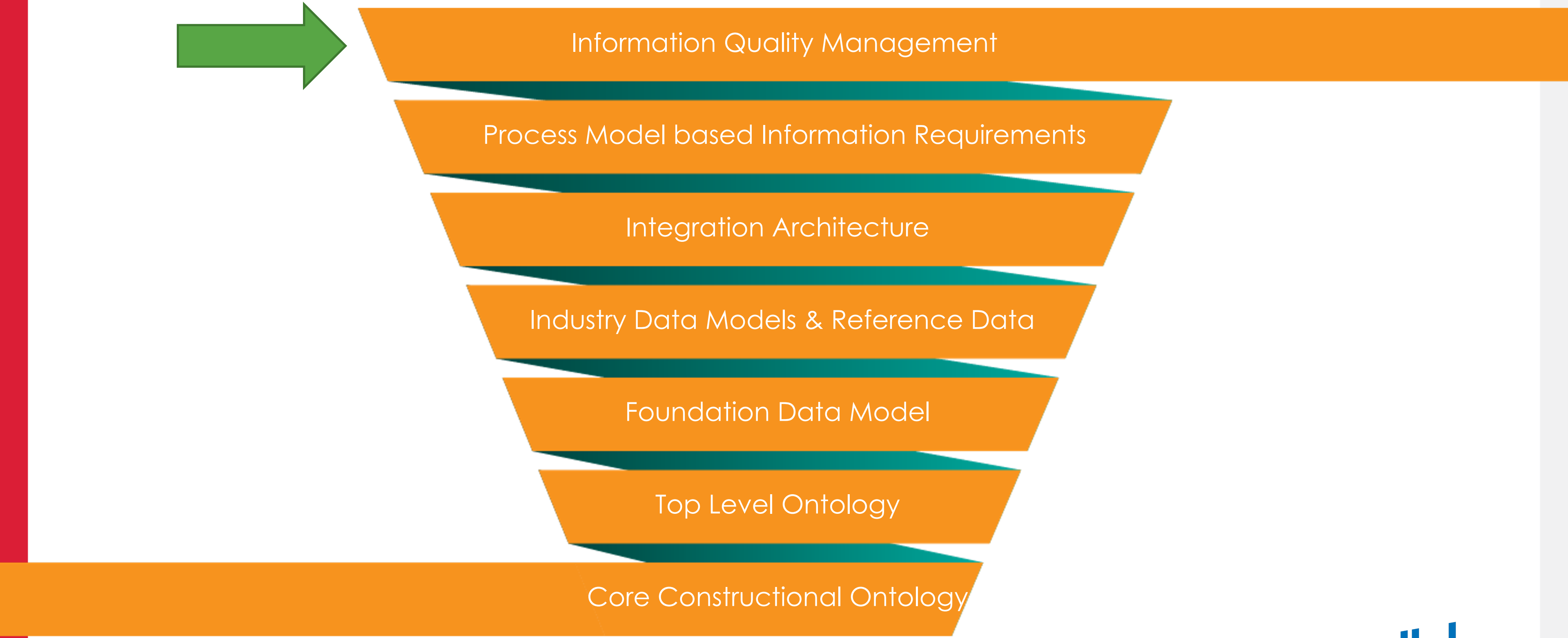
The Seven Circles of Information Management



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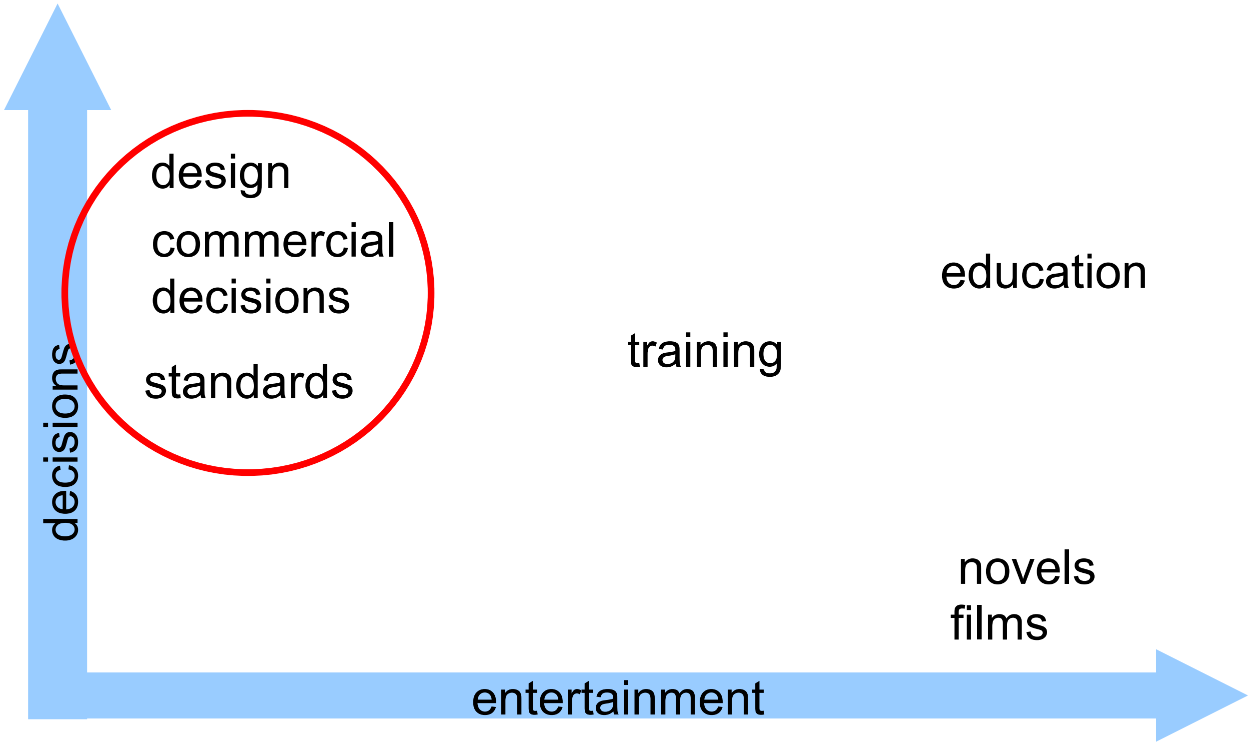
What is information used for?



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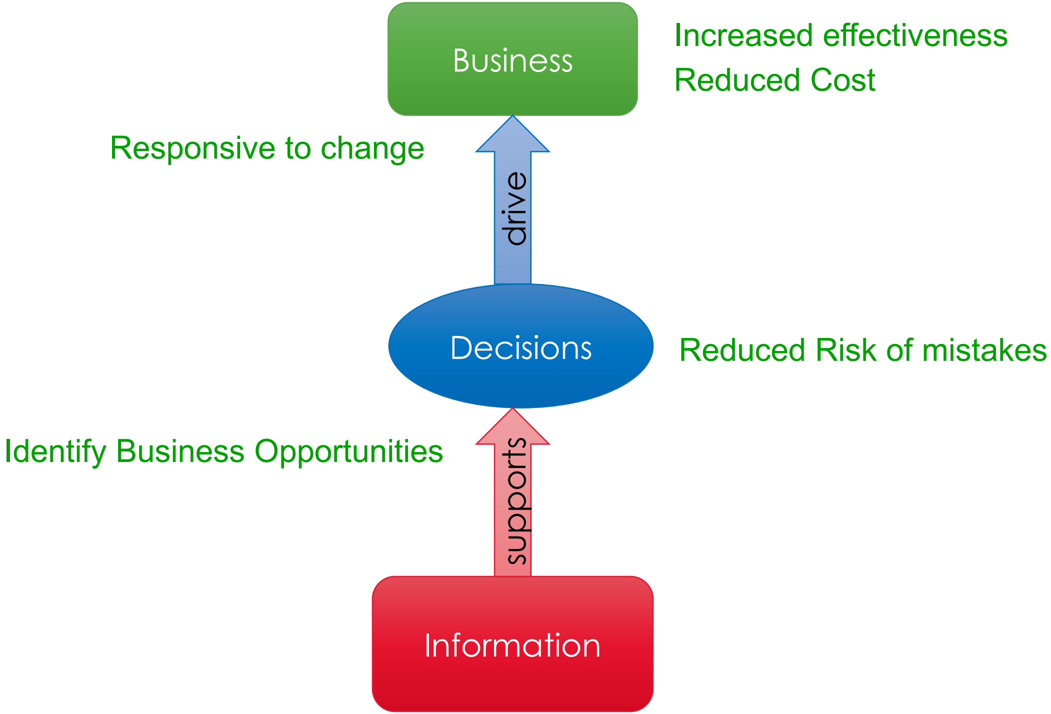
Why bother with Information?



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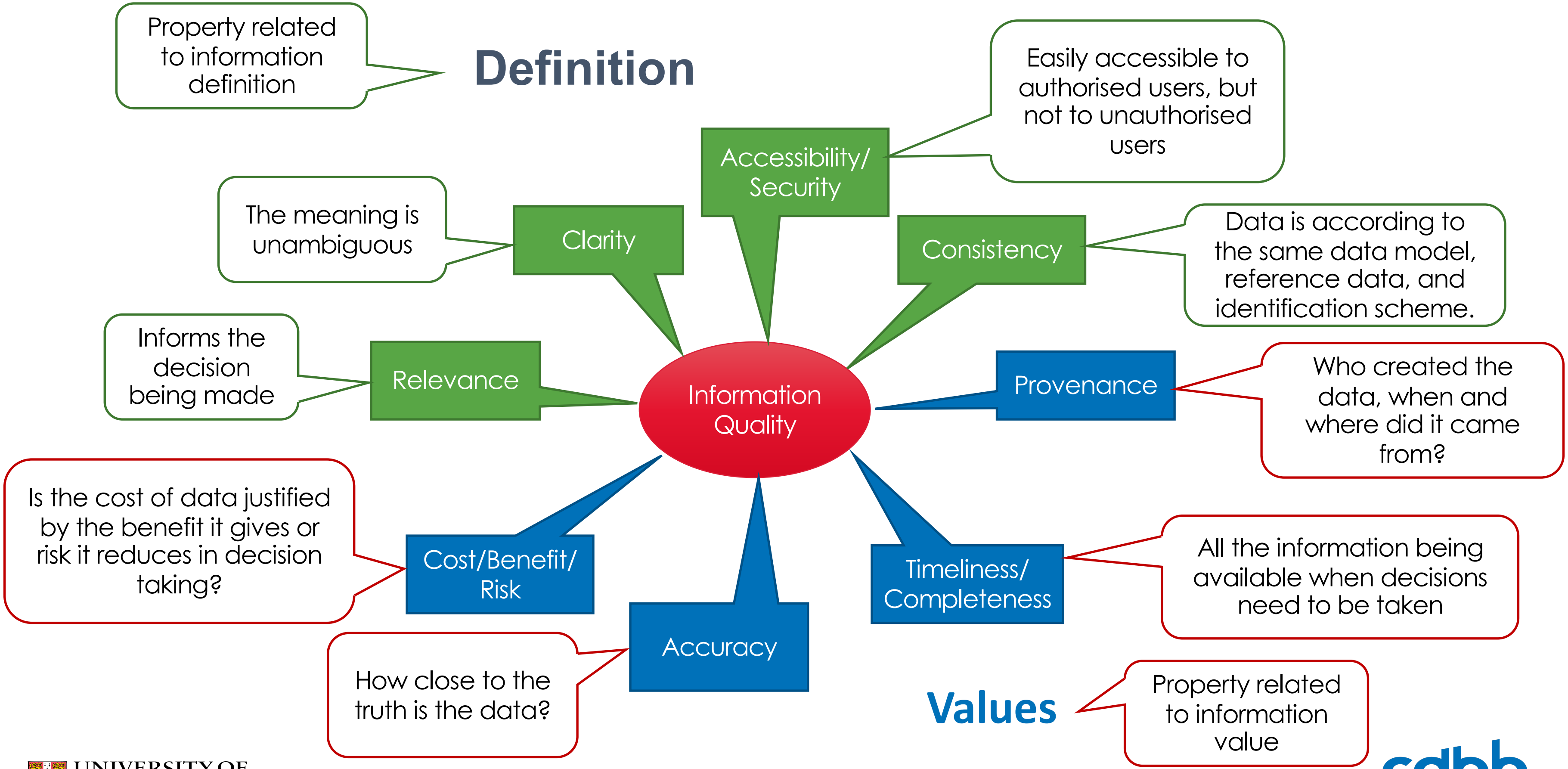

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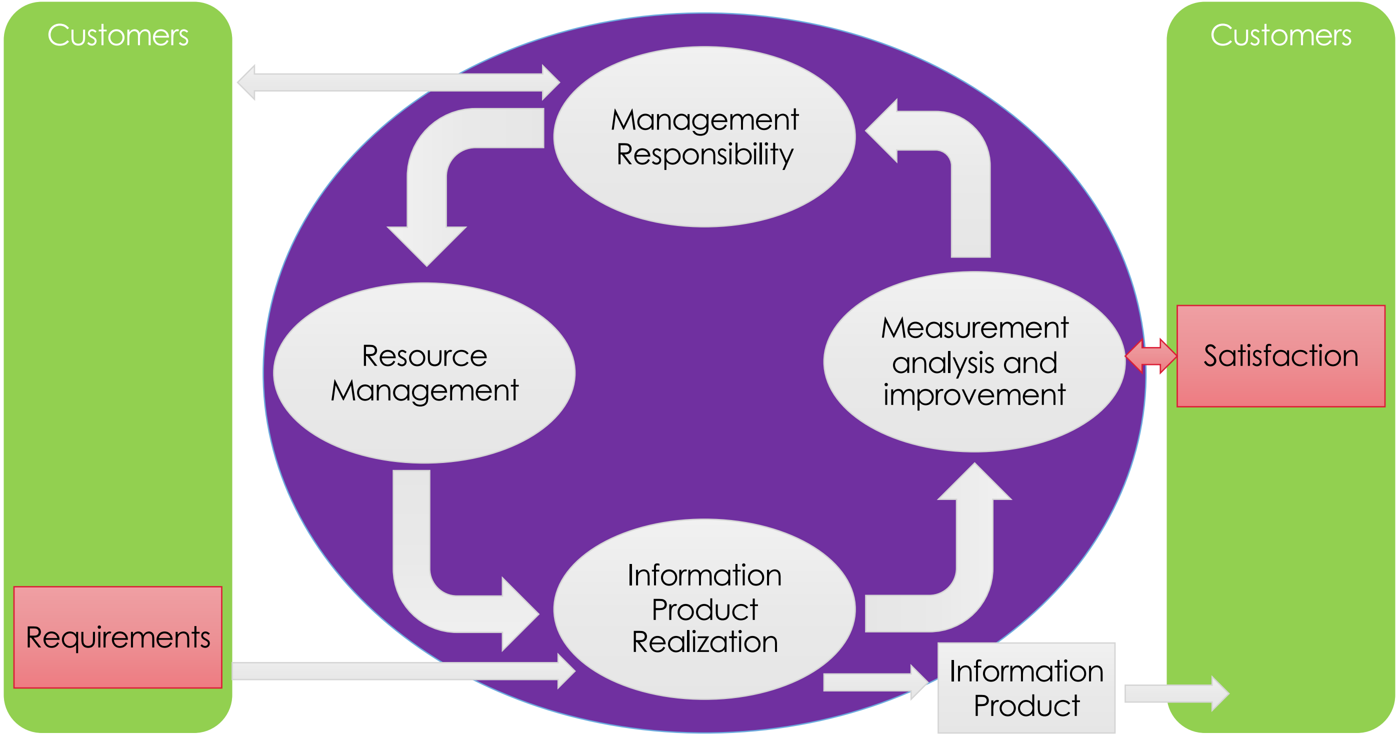
Process Based Quality Management System (ISO 9001)



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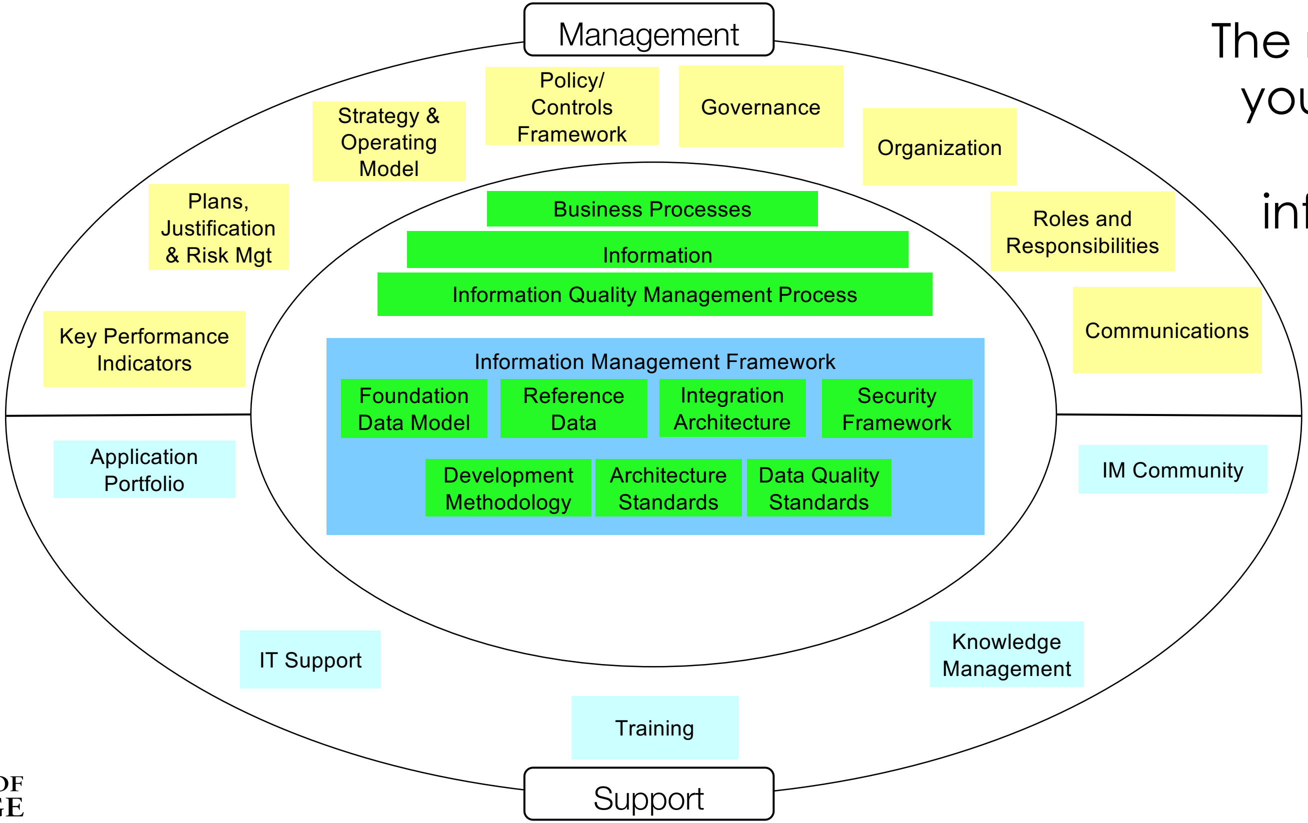
Information Management Landscape



The resources you need to manage information

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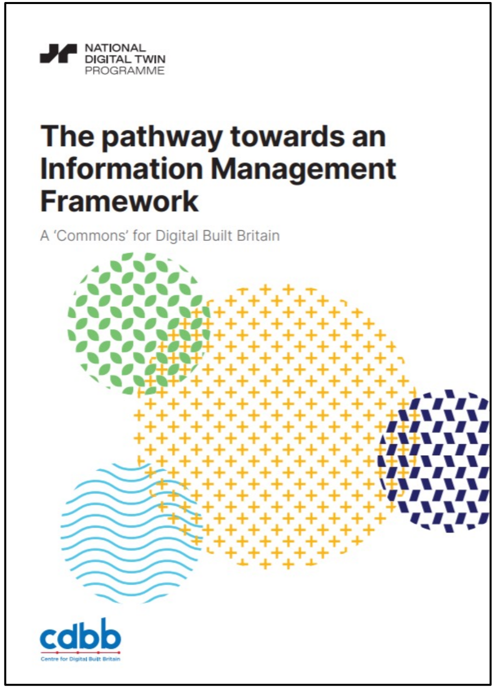
The pathway towards an Information Management Framework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The pathway towards an Information Management Framework

A 'Commons' for Digital Built Britain

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https://www.cdbb.cam.ac.uk/news/pathway-towards-IMF

1. **Foundation Data Model** – A high level definition of the structure and meaning of data to enable the consistent sharing of data across Digital Twins and the ecosystems they support.

2. **Reference Data Library** – the particular set of classes and the properties we will want to use to describe our digital twins

3. **Integration Architecture** – the protocols that will enable the managed sharing of data

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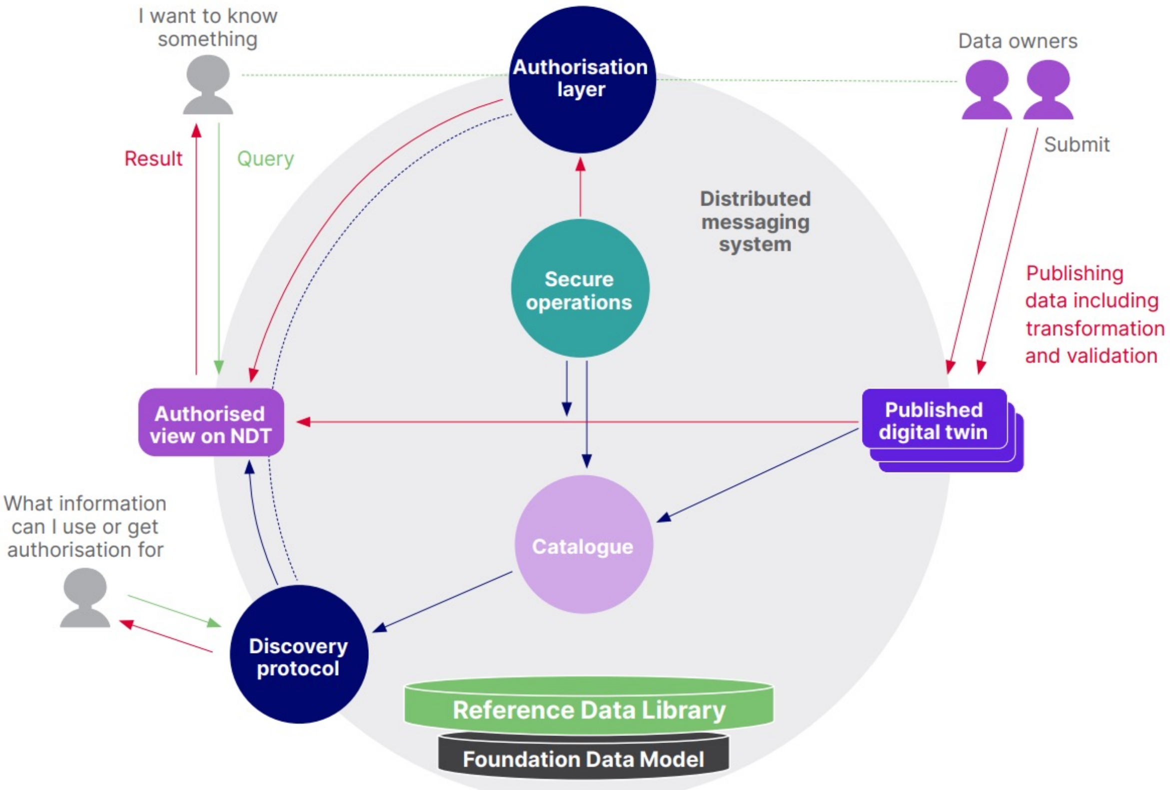
A National Digital Twin enabled by the IMF



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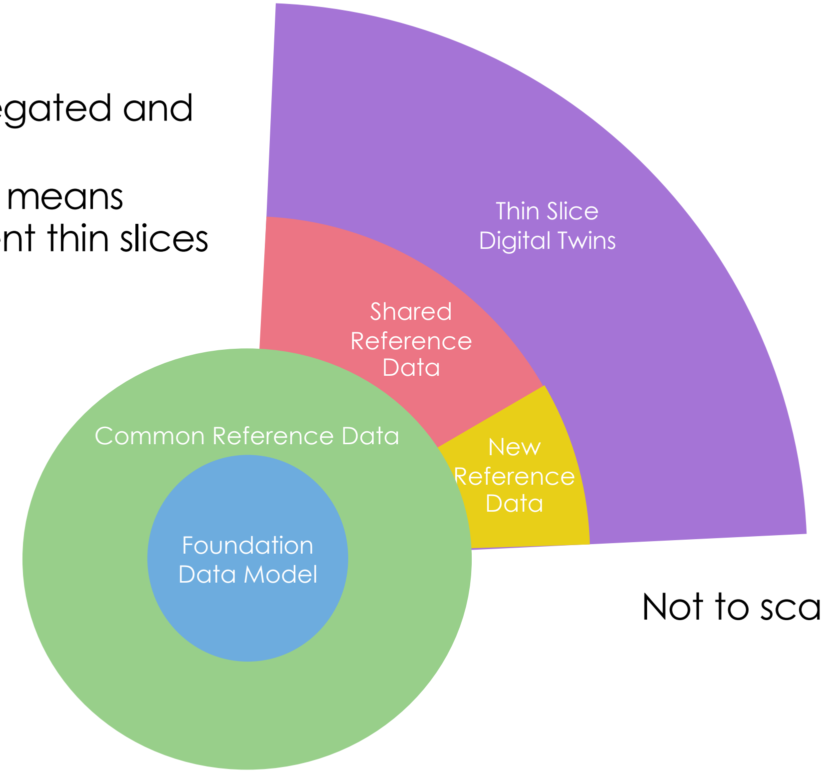
What a thin slice looks like

- Thin slices can be aggregated and compared.
- Shared Reference Data means Digital Twins from different thin slices can be combined.



Not to scale

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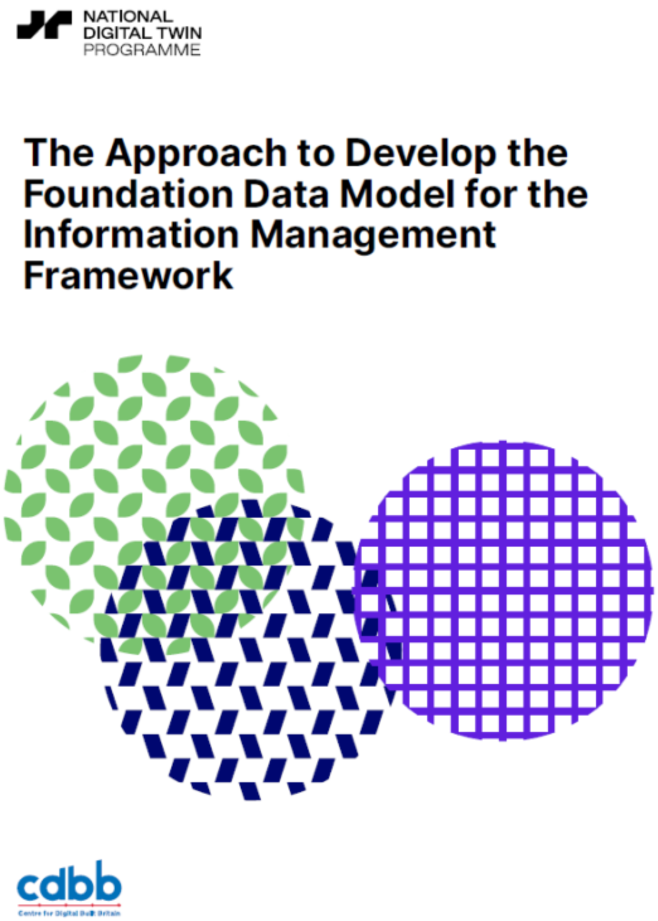
Approach to the FDM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The Approach to Develop the Foundation Data Model for the Information Management Framework

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Requirements for a Top Level Ontology

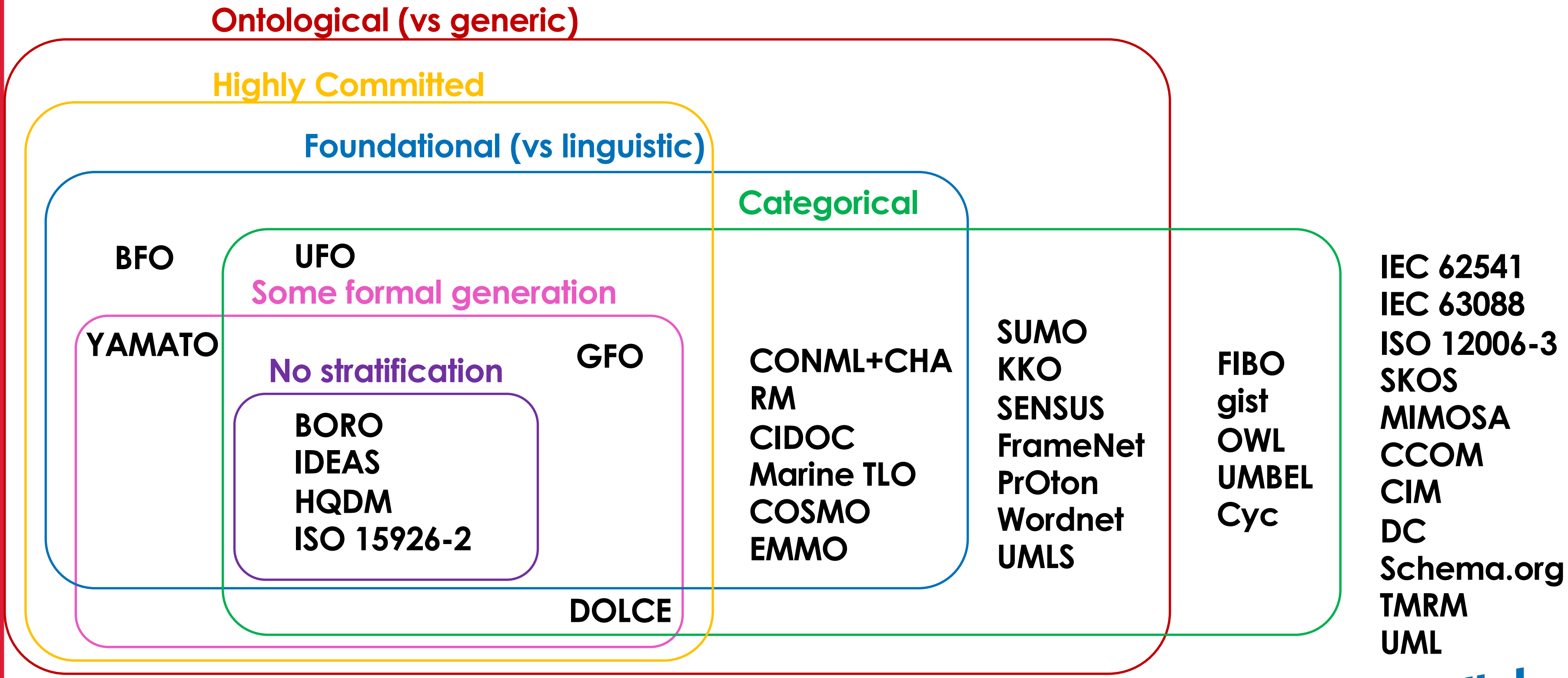
Pragmatic Requirements

- Rooted in science and engineering
- Extensible
- Stable
- Capable of consistent extension by different teams

Ontological consequence

- Principled and rigorous
- Ontological and
- Highly Committed
- Rooted in science and engineering – i.e. rooted in reality
- Foundational
- Comprehensive scope
- Categorical
- As simple as possible but no simpler
- Generative - some elements automatically inferred
- Non-stratified – choosing not to divide entities where this is an option

An Euler diagram of Top-Level Ontologies



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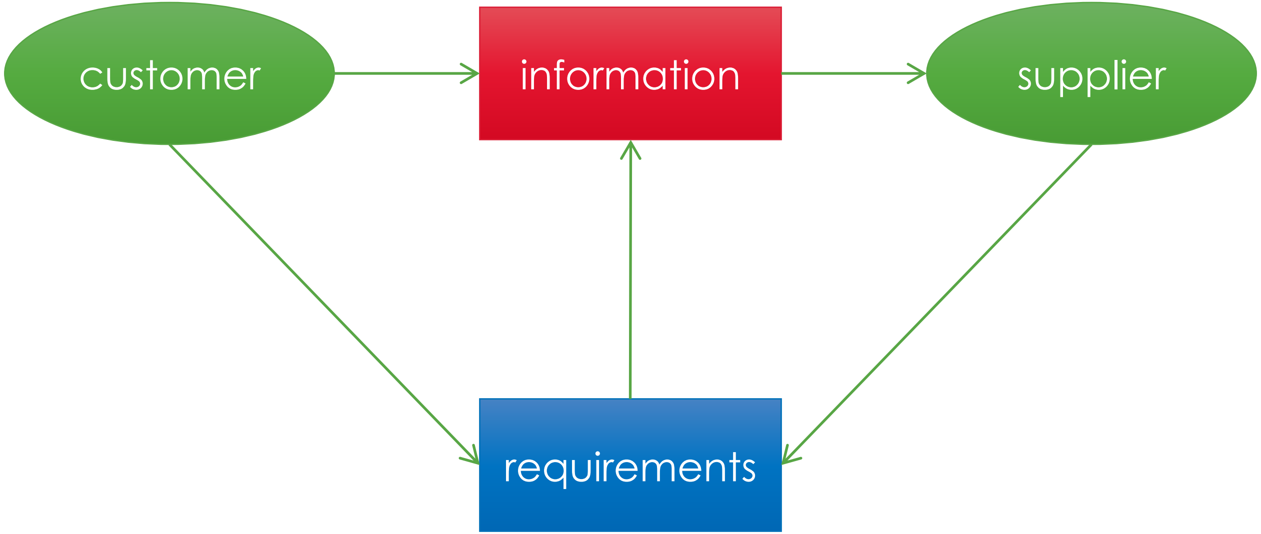
Information Quality



Quality is meeting **agreed** requirements

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Questions?

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