Higher-dimensional spatial information

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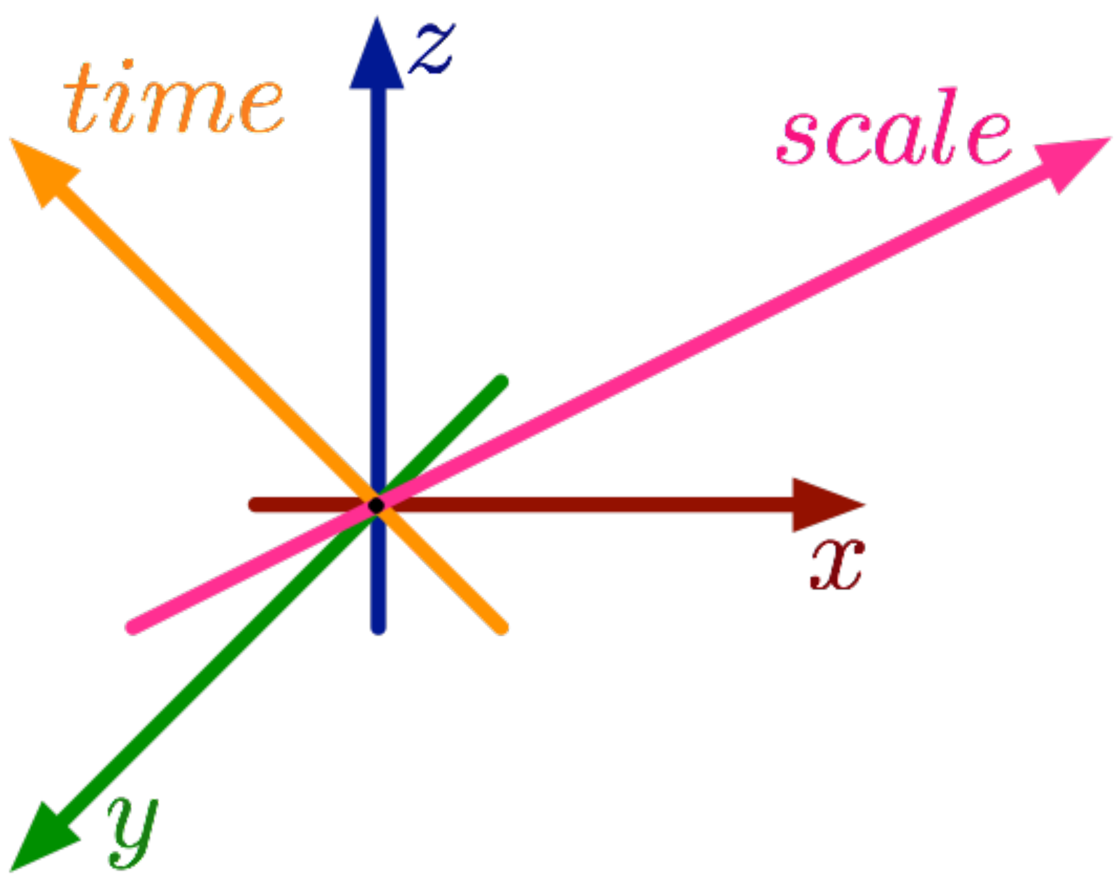
Introduction

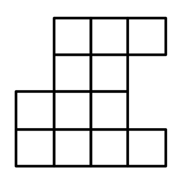
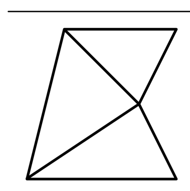
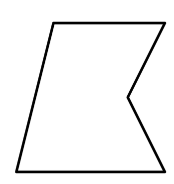
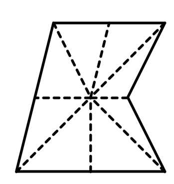
The integration into a GIS of new parametrisable characteristics such as a third spatial dimension, time, and scale has so far achieved by reusing and extending existing 2D data structures. 3D systems often mimic the third dimension by using a so-called 2.5D structure, or represent 3D objects only implicitly by their 2D boundary using a 2D data structure with no explicit 3D (volume to volume) topological relationships. Meanwhile, spatio-temporal GISs usually keep either multiple representations or a list of changes per object using 2D structures.



An interesting alternative to this is the representation of parametrisable characteristics as additional geometric dimensions, orthogonal to the spatial ones, such that real-world (0D-3D) entities are modelled as higher-dimensional objects embedded in higher-dimensional space.

Data models and structures for nD objects

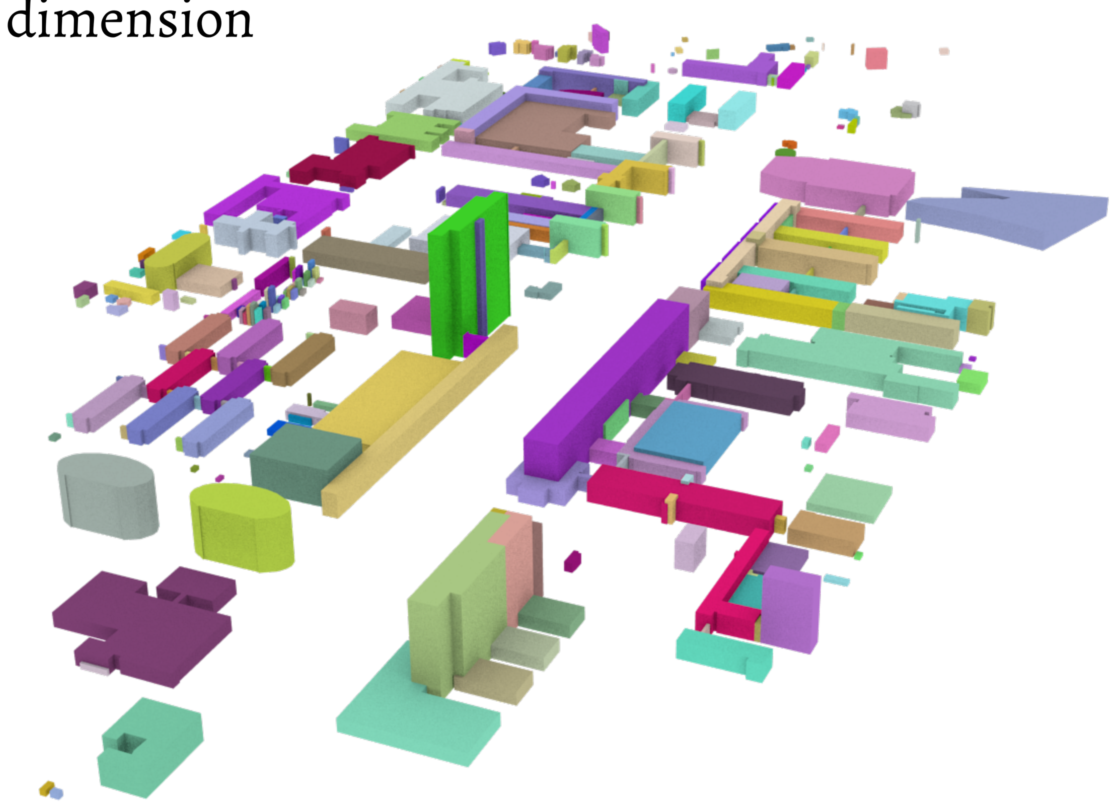
We are interested in structures that are capable of storing a well-defined and relatively broad class of objects of arbitrary dimension, embedded into Euclidean space of the same or higher dimension, attributes attached to such objects, and enough topological relationships between them to allow for quick traversal of the structure and simple operations, such as testing if two given objects are identical, adjacent or overlapping.

Model		Data structure	Description
	Decomposition models	Regular and semi-regular tessellations	Split a predefined region in a deterministic manner, then store the values of a path along the subdivision
		Hierarchical descriptions using trees	Subdivide space recursively with each node in a tree splitting it into a fixed number of parts
	Geometric simplicial complexes	Simplex-based data structure	Split objects into simplices, then store simplices + the adjacency relationships between them
	Cell complexes	Incidence graph	Store the cells of every dimension as primitives + the incidence relationships between them
		Nef polyhedra	Store the local pyramid (projection of the space) around a vertex to reduce the dimension by one
		Manifold data structures	Limit the number of incidence relationships to a fixed number (e.g. half-cell data structure)
	Ordered topological models	Generalised maps / cell-tuple	Purely combinatorial simplicial decomposition of a cell complex + storage with a simplex-based structure
		Combinatorial maps	The above but without decomposing edges and defining an orientation per edge
		Chains of maps	Generalised maps + an incidence graph for non-manifold situations

Algorithms to construct nD objects

Extrusion

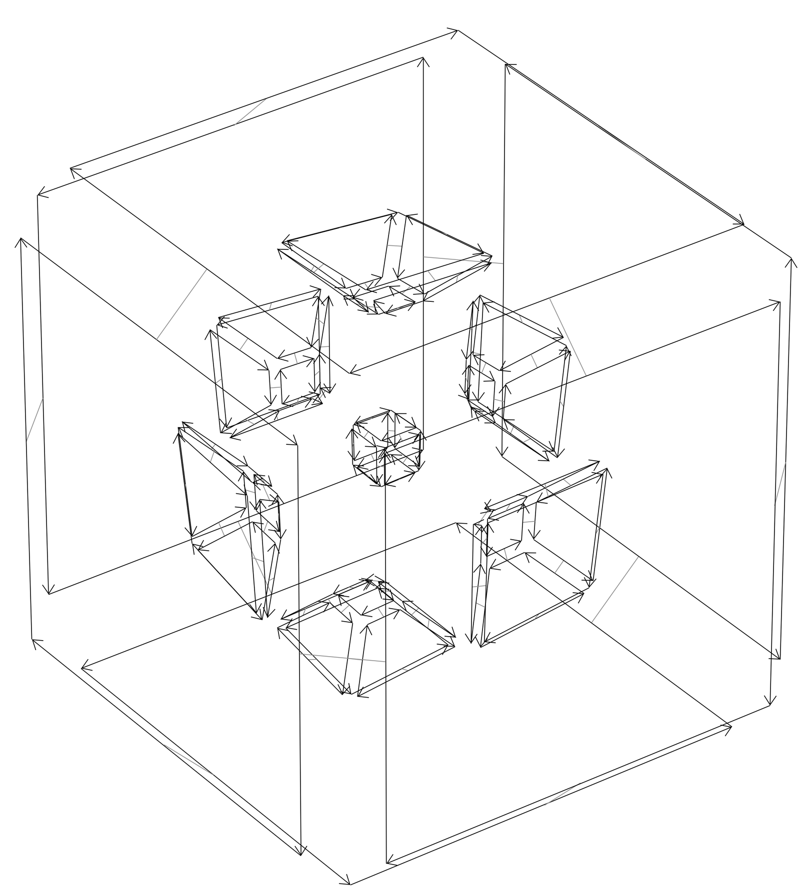
Extrude an (n-1)-dimensional space partition to an n-dimensional one by assigning to each (n-1)-cell one or more ranges along the n-th dimension



Using extrusion to generate higher-dimensional GIS datasets. Ken Arroyo Ohori and Hugo Ledoux. In Craig Knoblock, Peer Kröger, John Krumm, Markus Schneider and Peter Widmayer (eds.), *SIGSPATIAL'13: Proceedings of the 21st ACM SIGSPATIAL International Conference on Advances in Geographic Information Systems*, November 2013, pp. 398–401.

Incremental construction

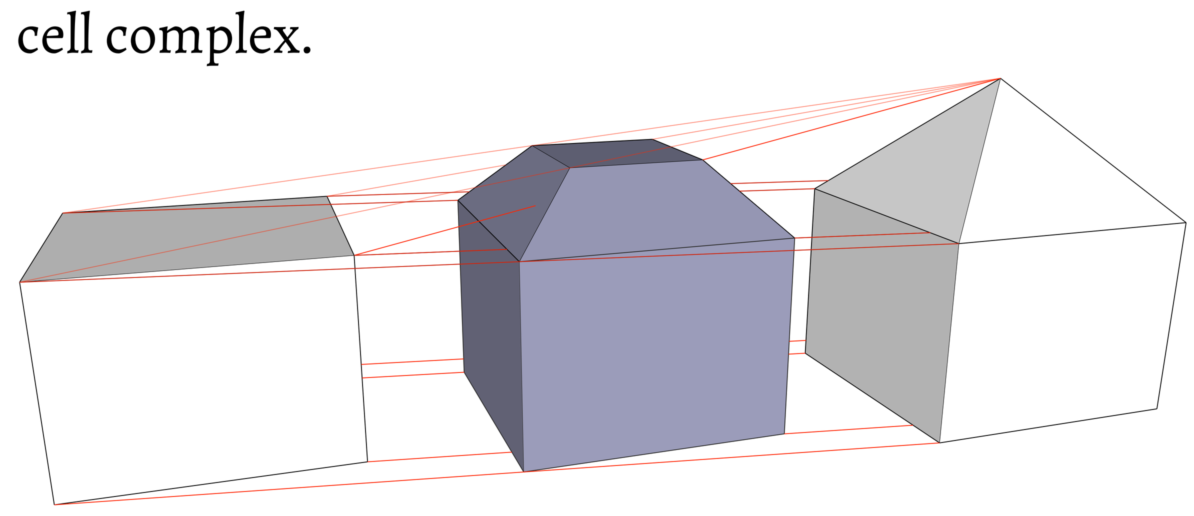
Construct objects incrementally from the lowest dimension (points) upwards, reusing common boundary cells whenever possible.



Constructing an n-dimensional cell complex from a soup of (n-1)-dimensional faces. Ken Arroyo Ohori, Guillaume Damiand and Hugo Ledoux. In Prosenjit Gupta and Christos Zaroliagis (eds.), *Applied Algorithms, ICAA 2014*, Volume 8321 of Lecture Notes in Computer Science, Springer International Publishing Switzerland, January 2014, pp. 37–48.

Linking LoDs

Connect a series of representations of the same up to (n-1)-dimensional object at different levels of detail in a consistent manner in an n-dimensional cell complex.



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