Realising the Foundations of a Higher Dimensional GIS: A Study of Higher Dimensional Spatial Data Models, Data Structures and Operations

Ken Arroyo Ohori

What will I do?

- Realise data models, data structures and operations for higher dimensional (> 3) spatial data.

- Take advantage of the extensive research done in computer science and computer graphics. Apply it to GIS data, which is special.

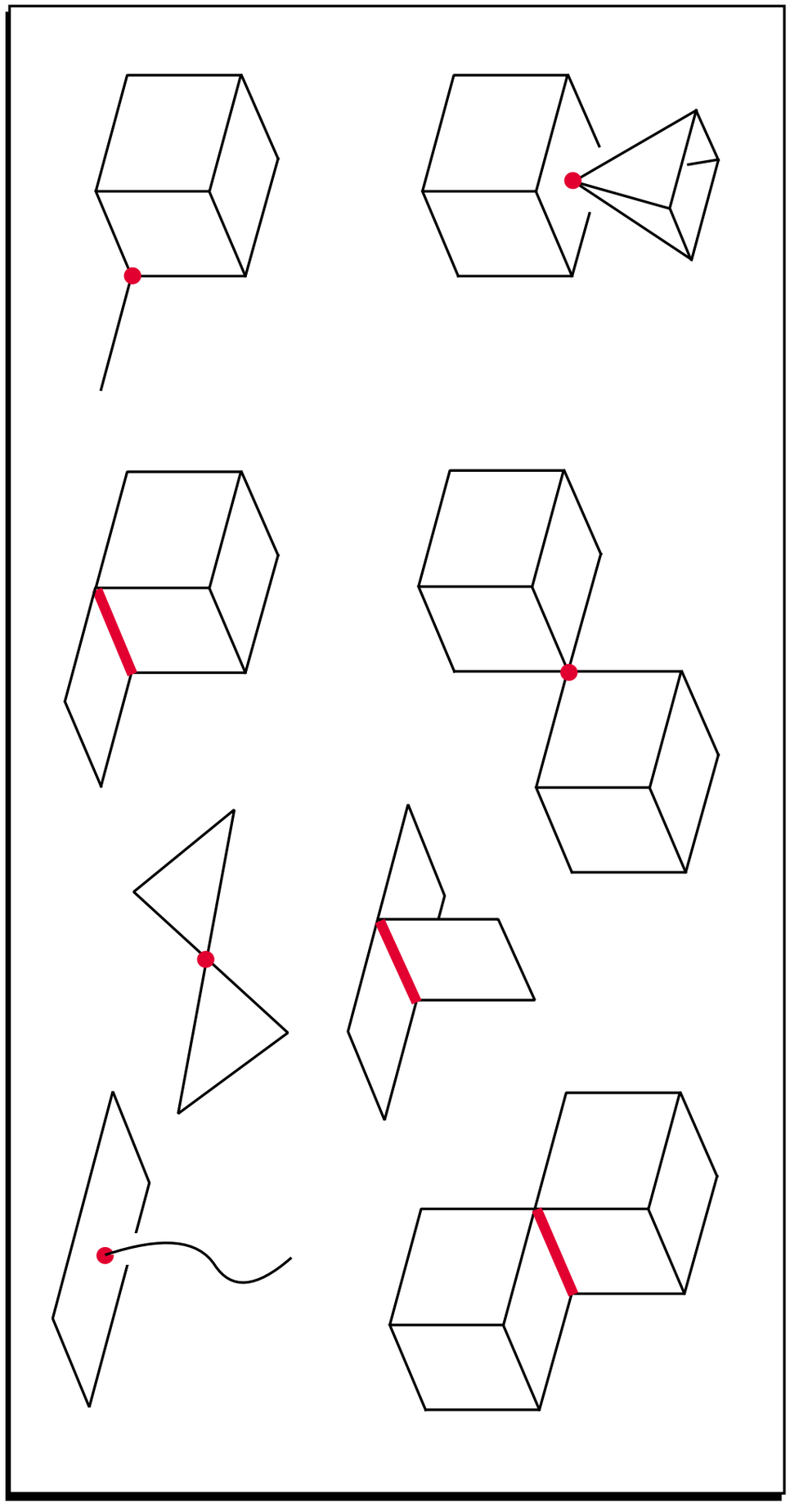
- The motivation: integration of other (non spatial) dimensions and treat them as spatial (e.g. time, scale, feature spaces)

2D/3D modelling in GIS

- Top-down approach
- Data models are based on standards
    - By standard bodies: ISO 19107, GML, CityGML, ...
    - By developers or the industry: KML, Shapefiles, ...
- Data structures are ad hoc
- Operations are well defined, based on users' needs

Limitations of models in GIS

- Limited to 2D/3D
- Lack of a formal (mathematical) definition
- Implementations diverge from standards
- Different implementations yield different results

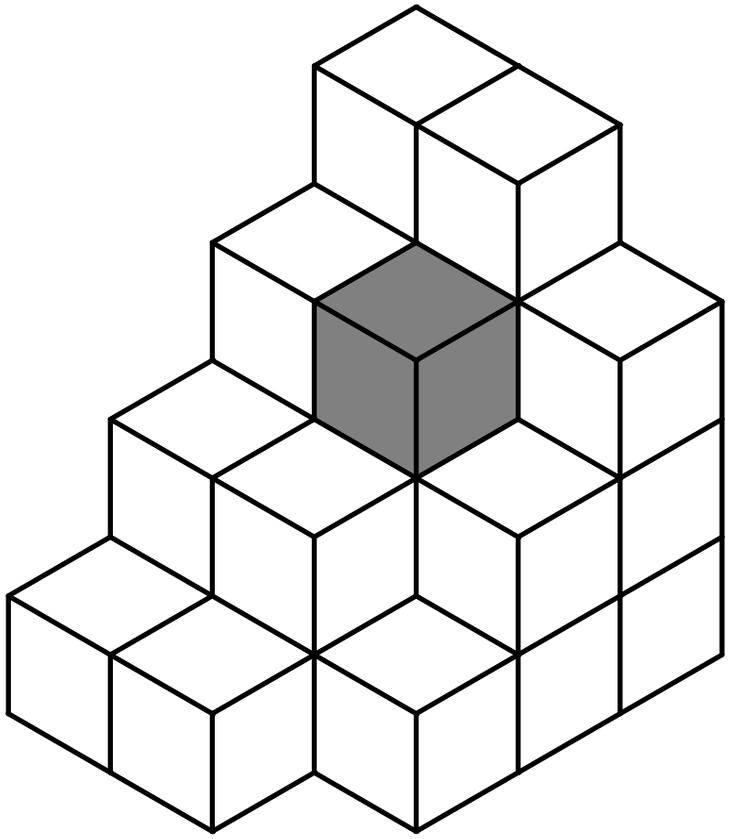


Models in computer science and computer graphics

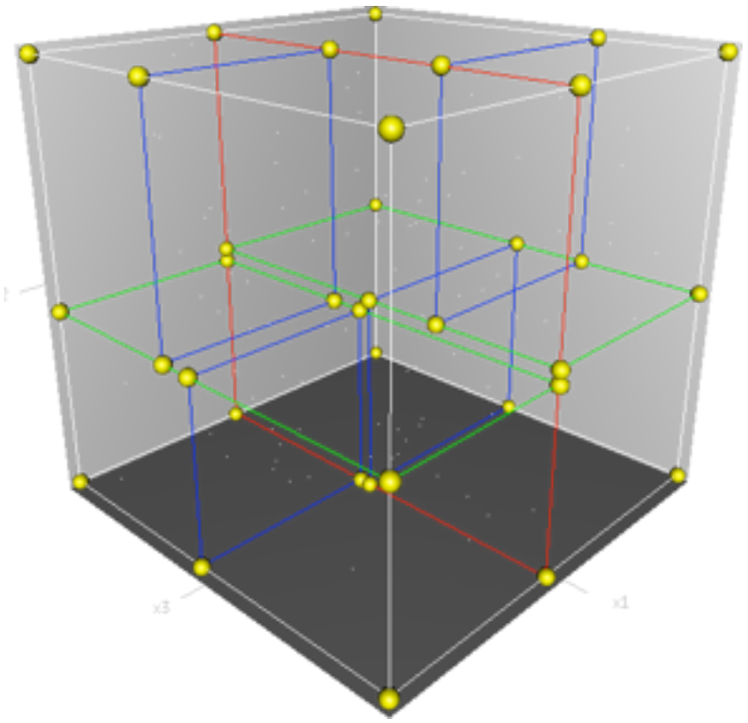
- Bottom-up approach
- Data models defined mathematically (e.g. point set topology)
- Data structures defined mathematically (e.g. algebraic topology and combinatorics)
- Operations are ad hoc

Data models in CS/CG

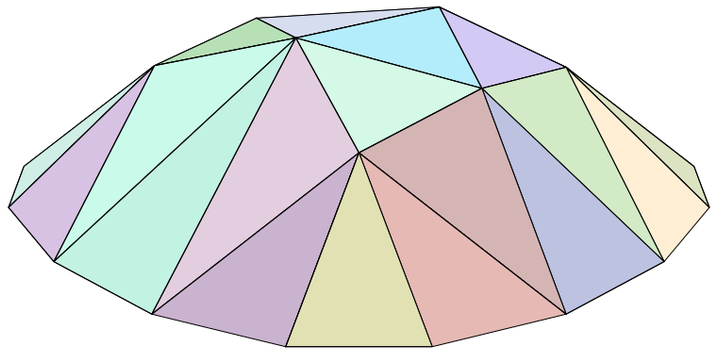
- Decomposition models
- Constructive models
- Boundary models

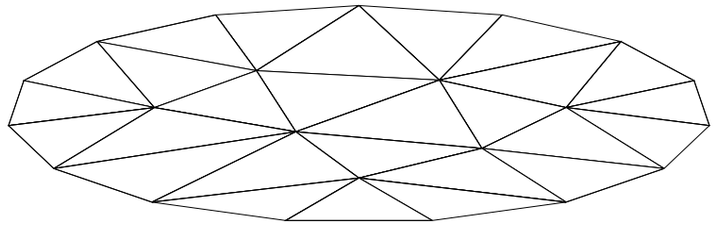


rasters

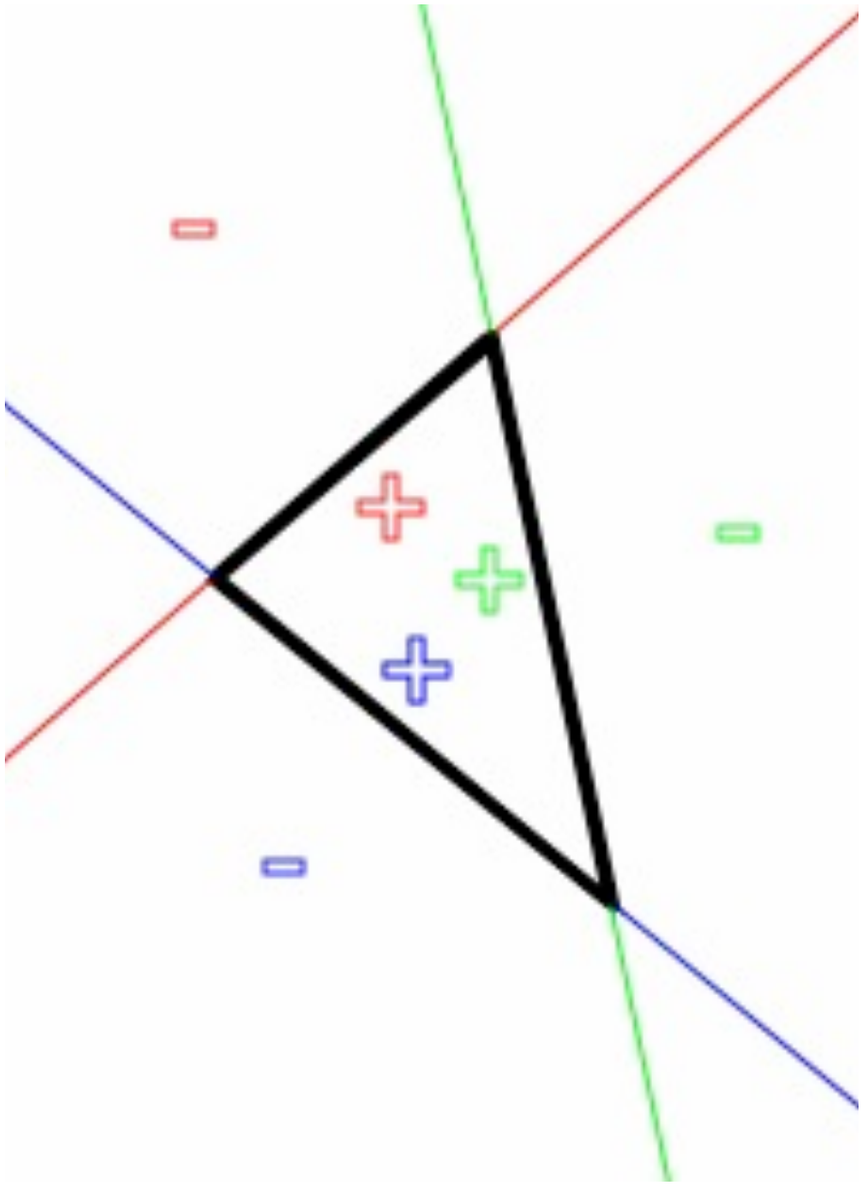


space subdivision

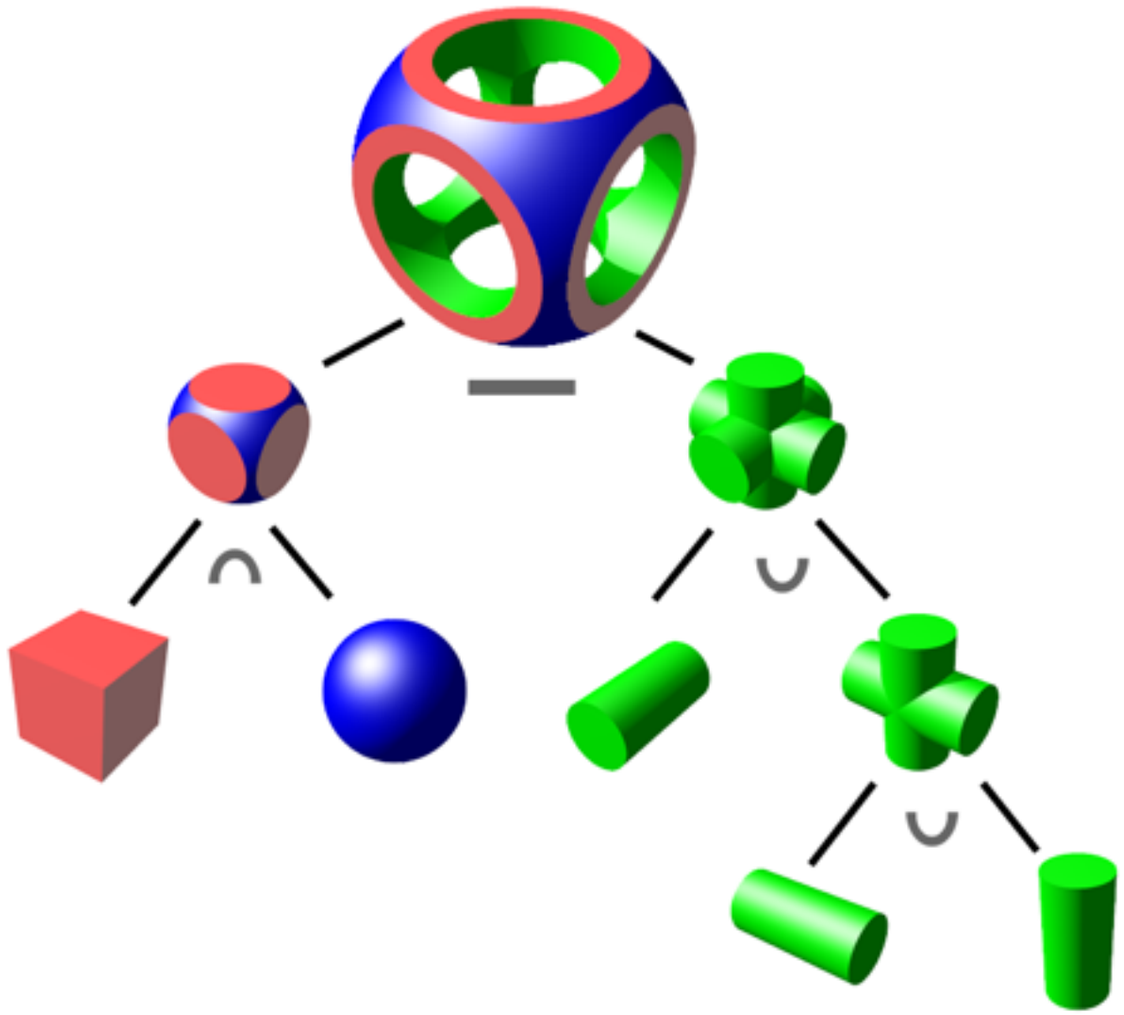




cell decomposition

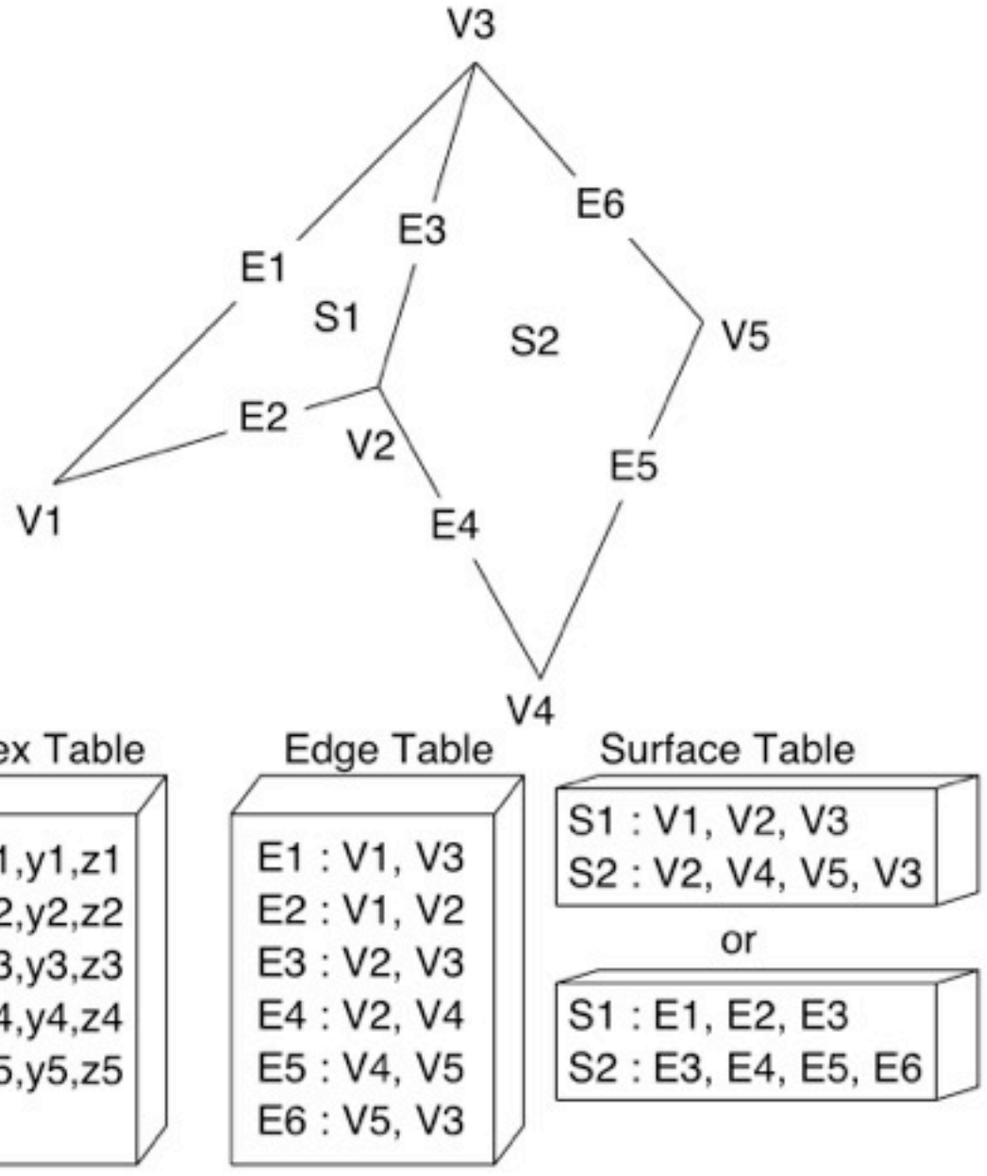


half-space

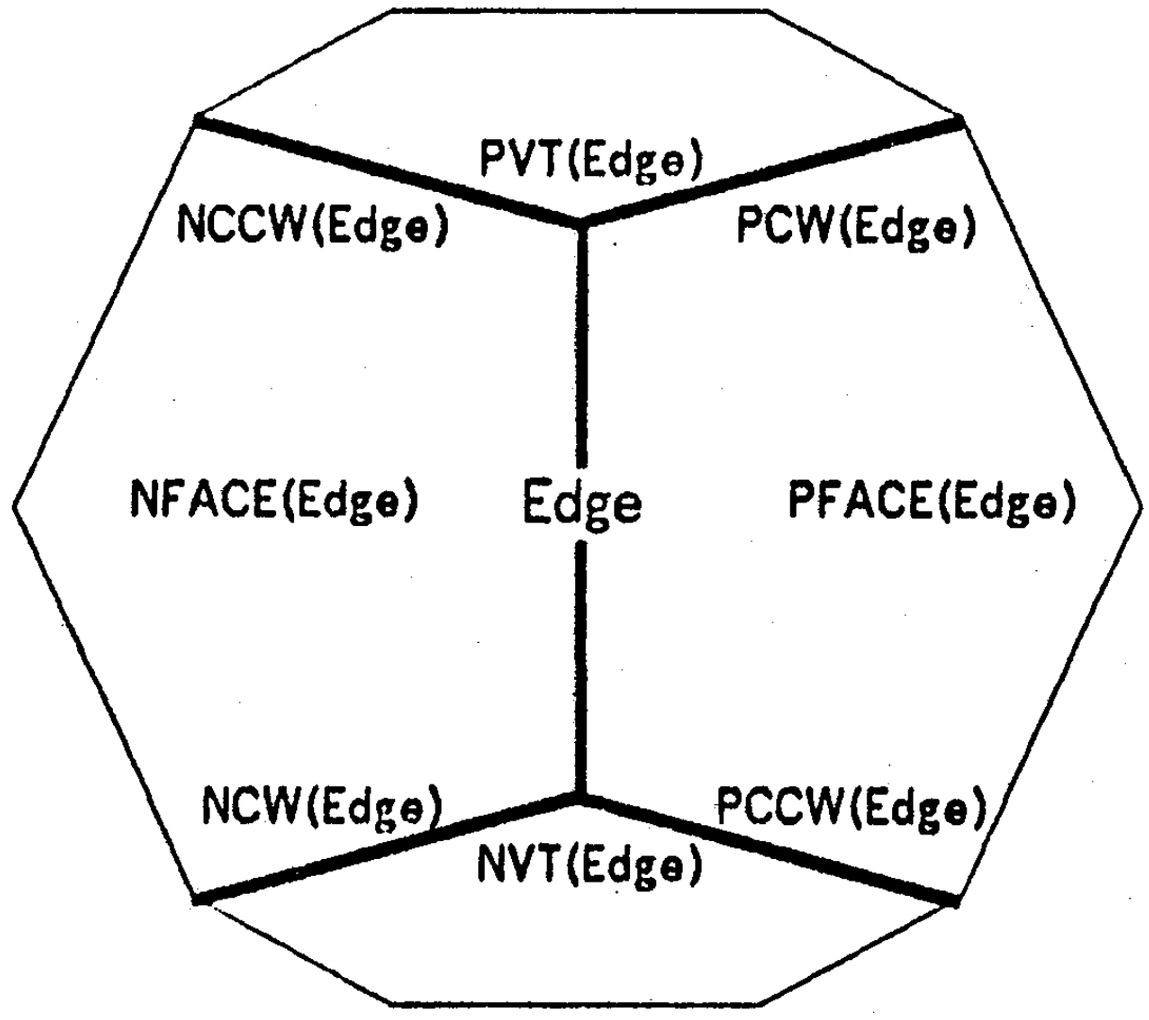


CSG

Constructive models



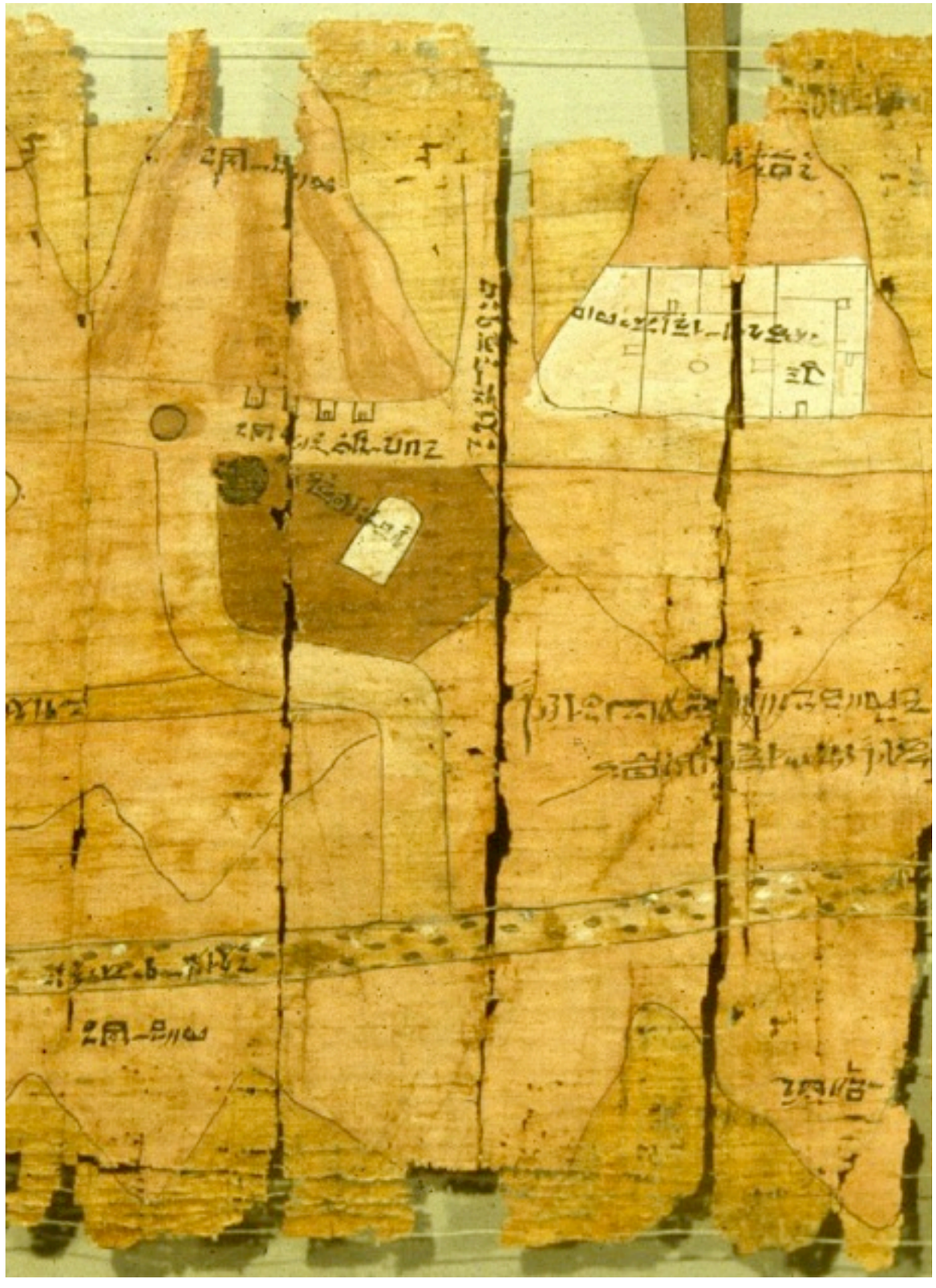
incidence models



ordered topological models

Boundary based models are best

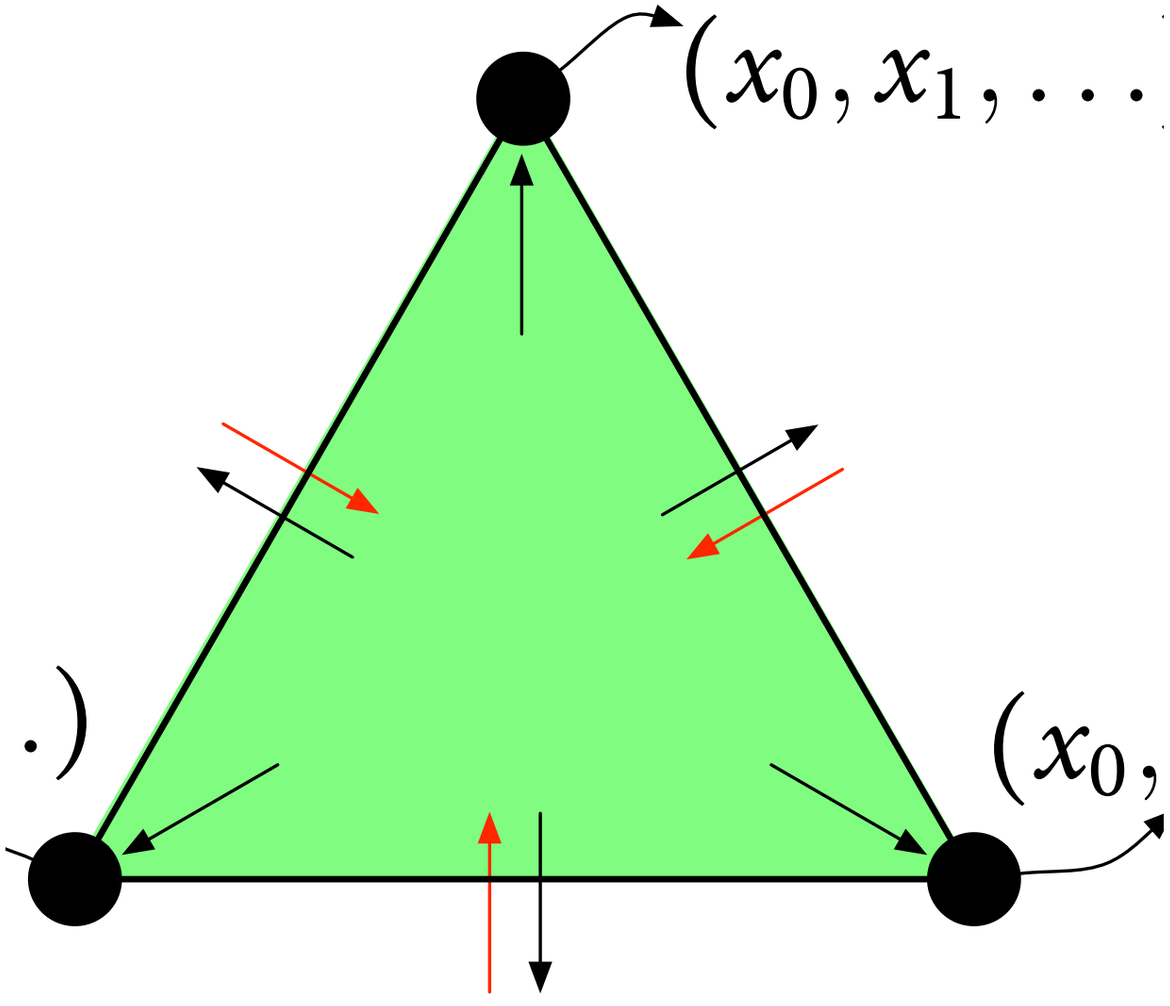
- No need to make data conform to a particular shape (decomposition models)
- Easy to append information to vertices, edges, faces, ...
- Efficient storage
- Good for visualisation
- Options for *n*-D: simplices, polytopes, intermediate

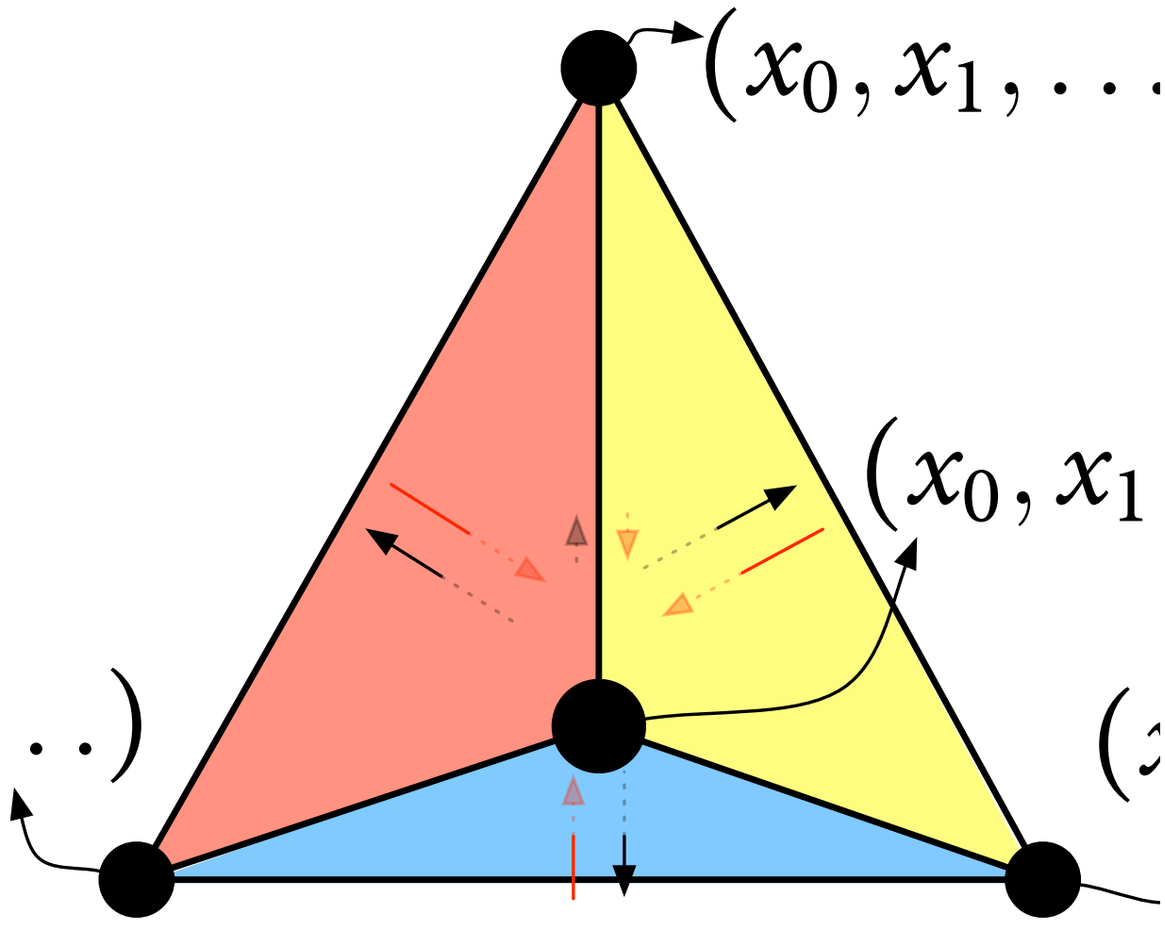


An intuitive representation

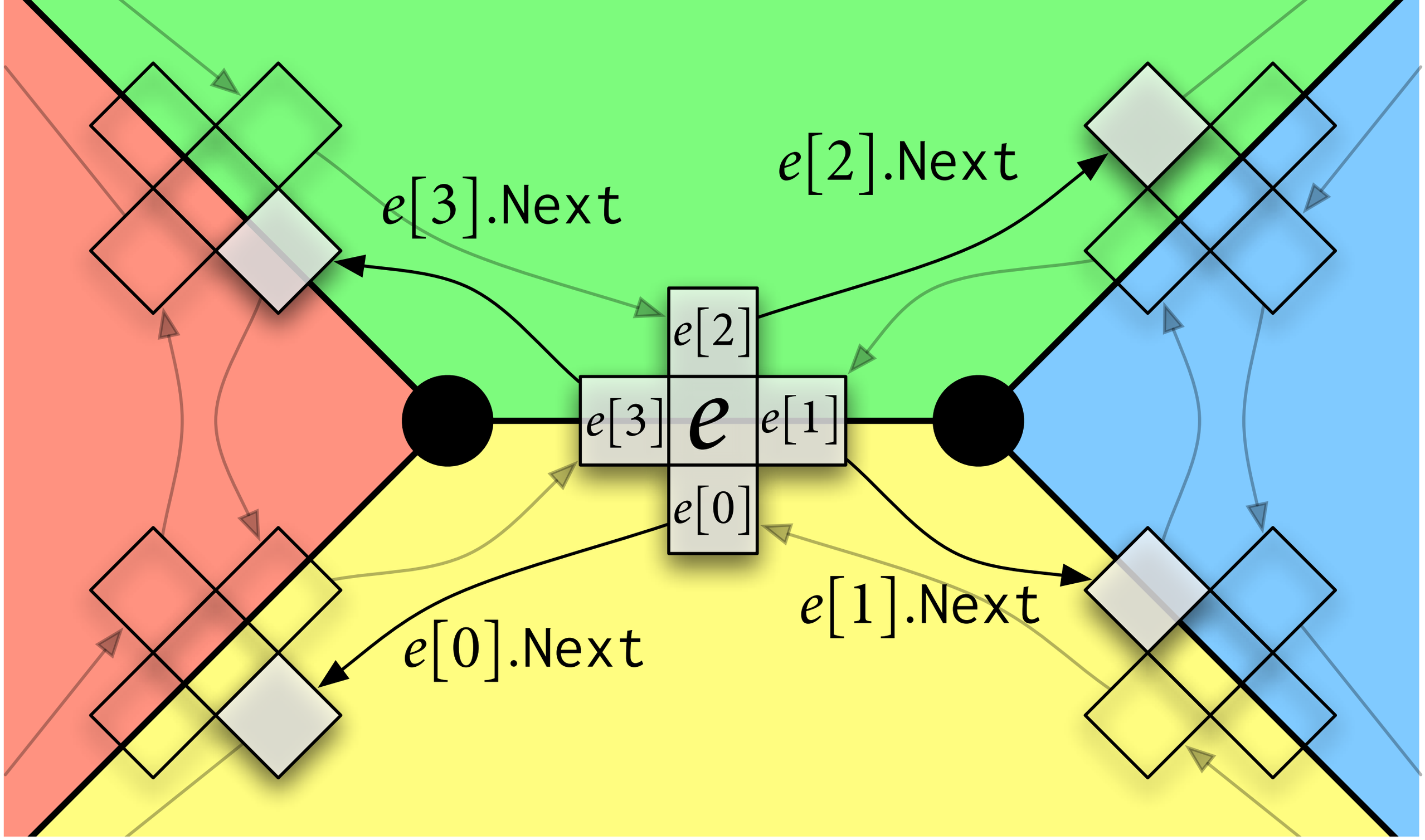
Data structures in CS/CG

- Fit for *n*-D:
    - Simplex based (incidence model)
    - Quad-edge, facet-edge and cell-tuple (and half-edge)
    - G-maps: from combinatorial maps and v-maps

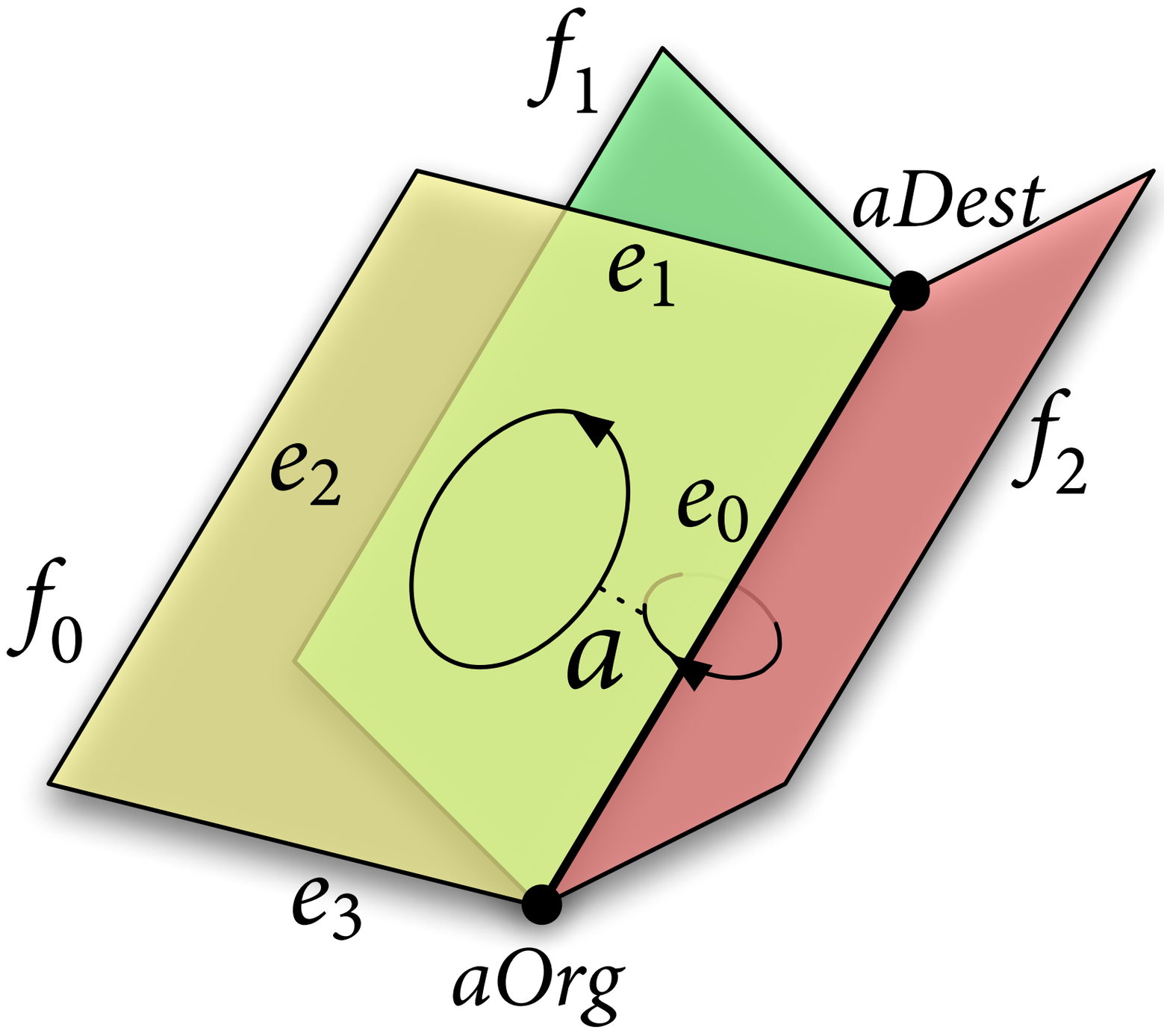




n-simplices

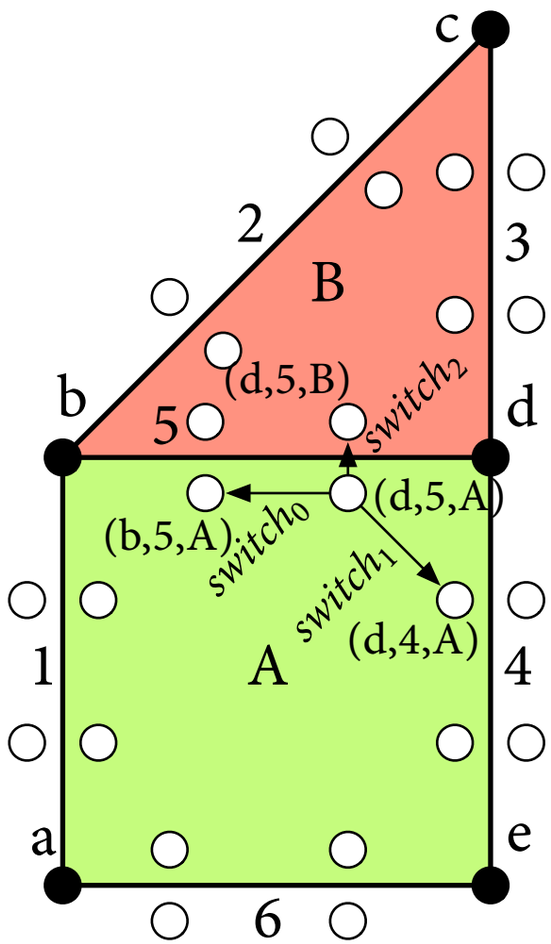


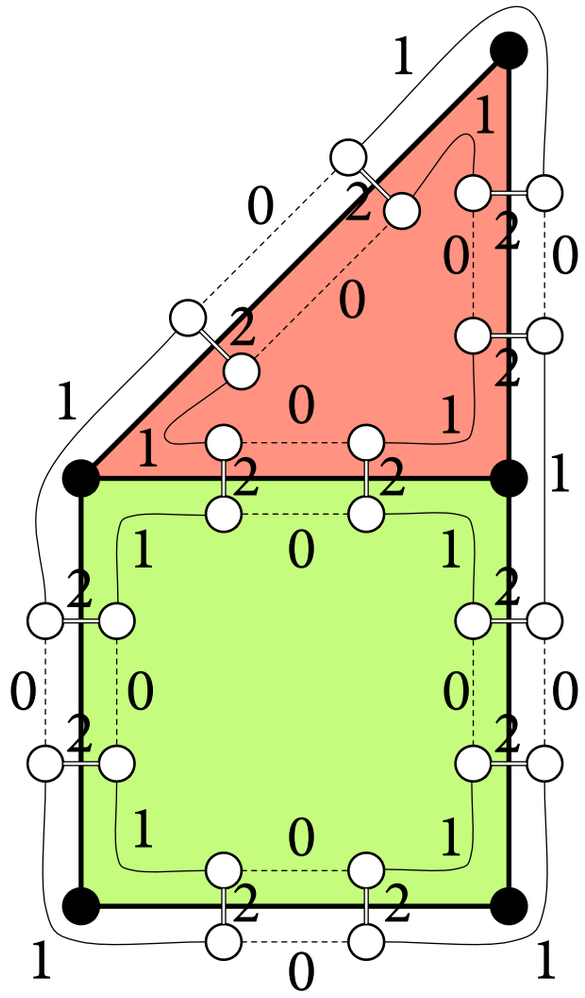
Quad-edge, facet-edge and cell-tuple

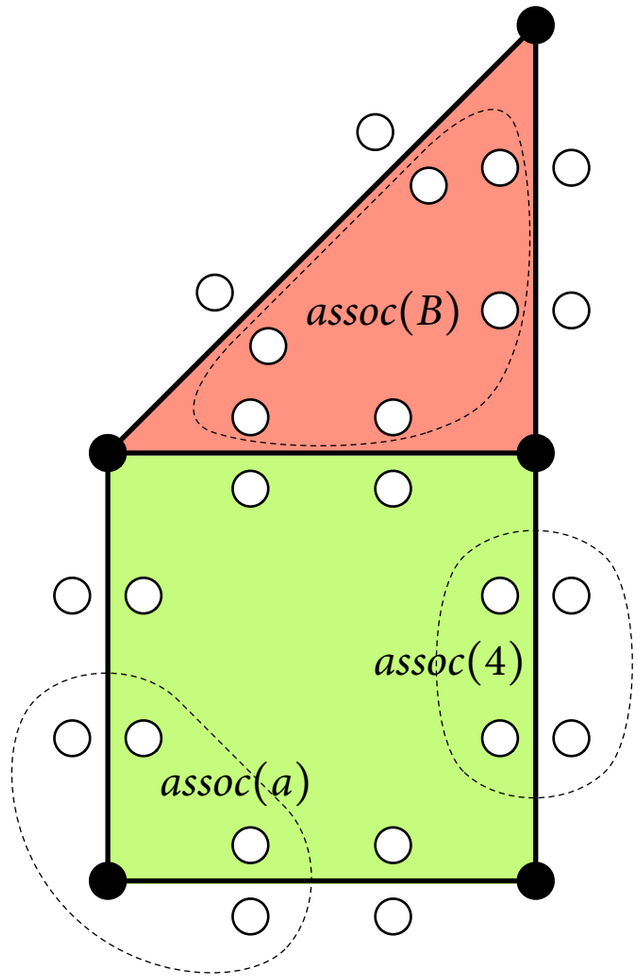


Quad-edge, facet-edge and cell-tuple

Facet-edge

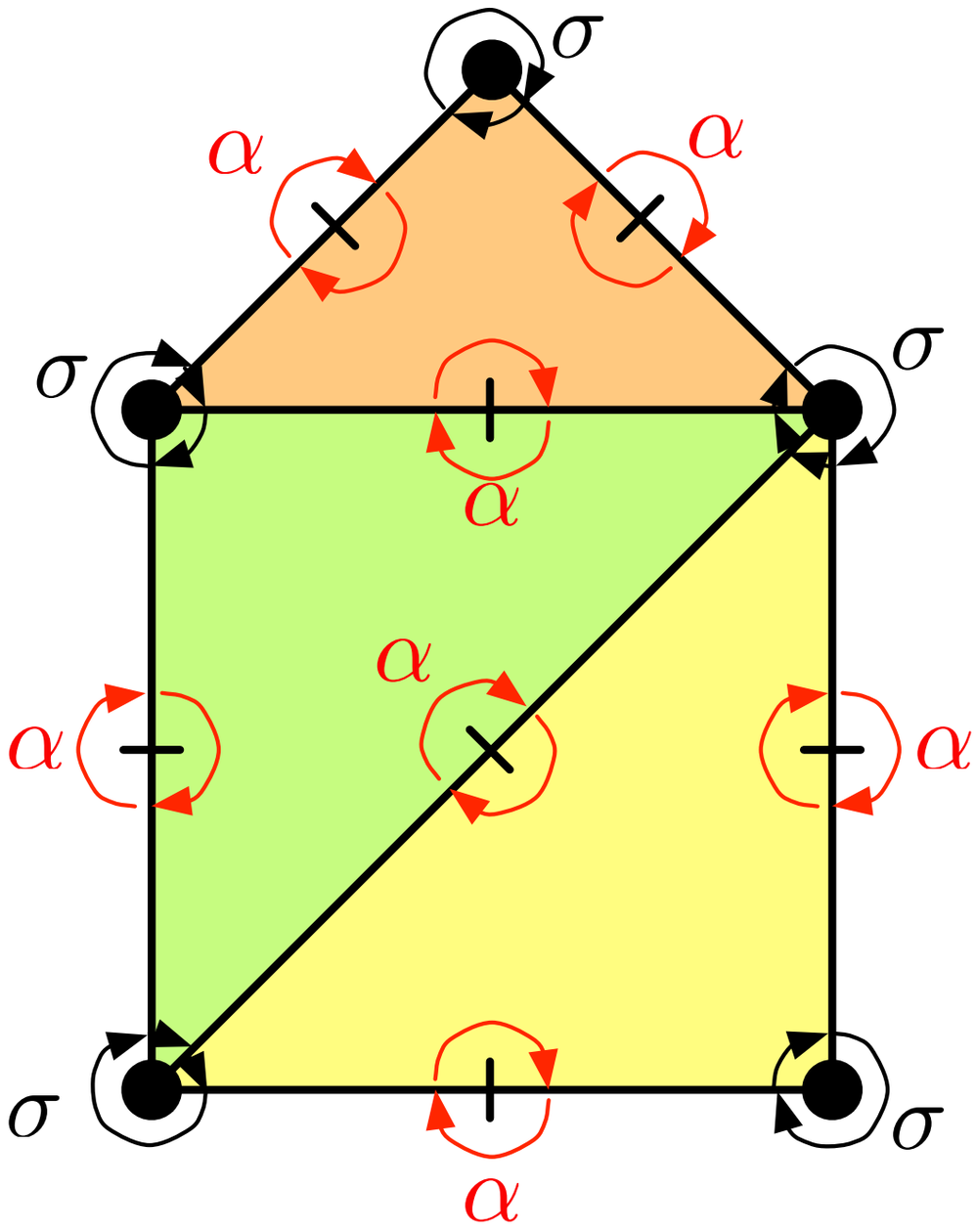


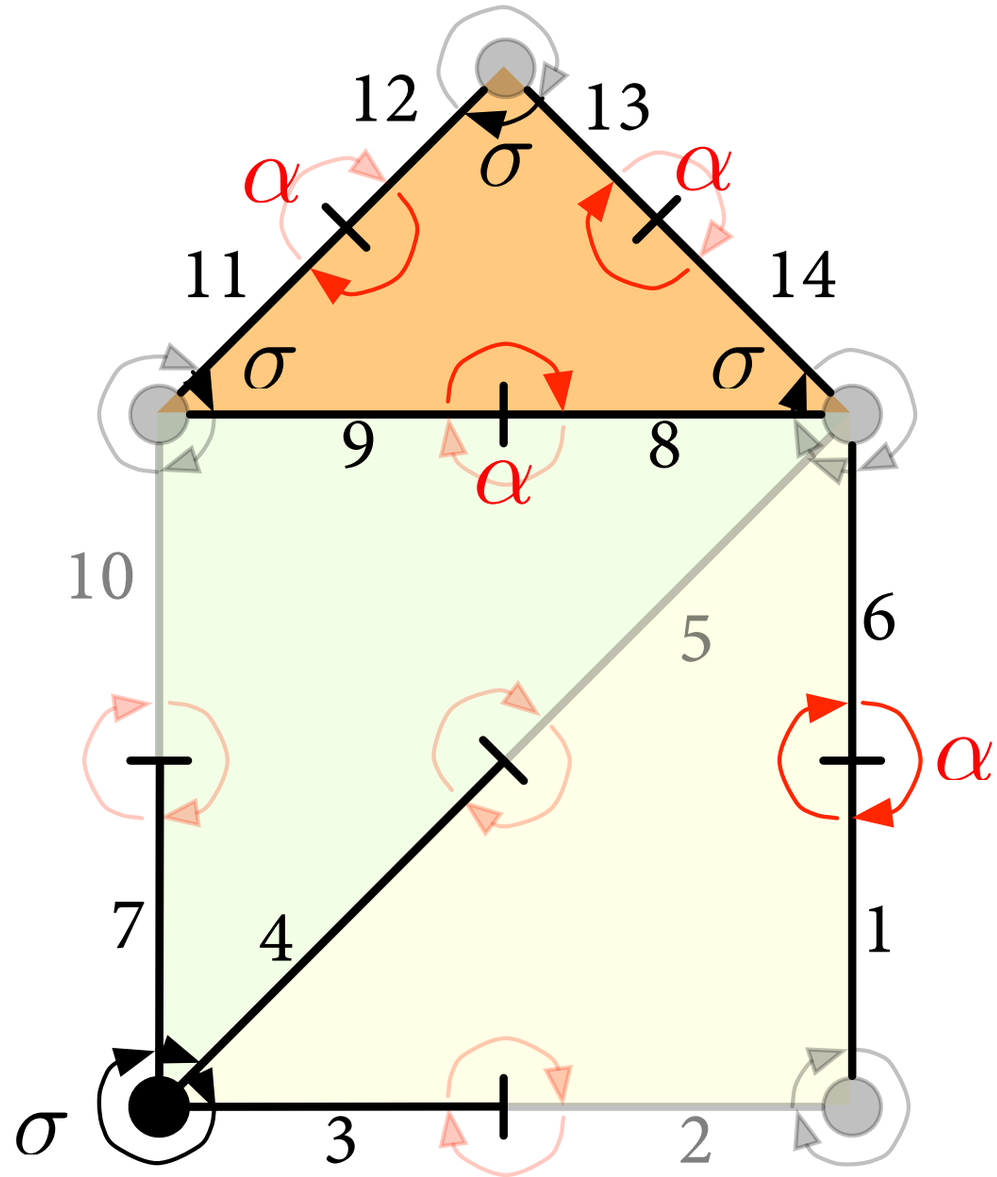




Quad-edge, facet-edge and cell-tuple

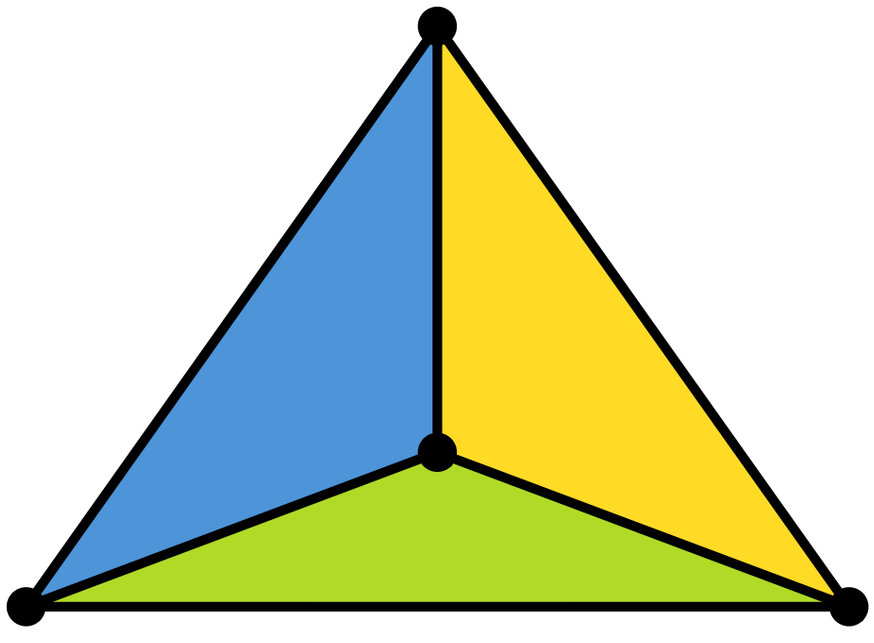
Cell-tuple

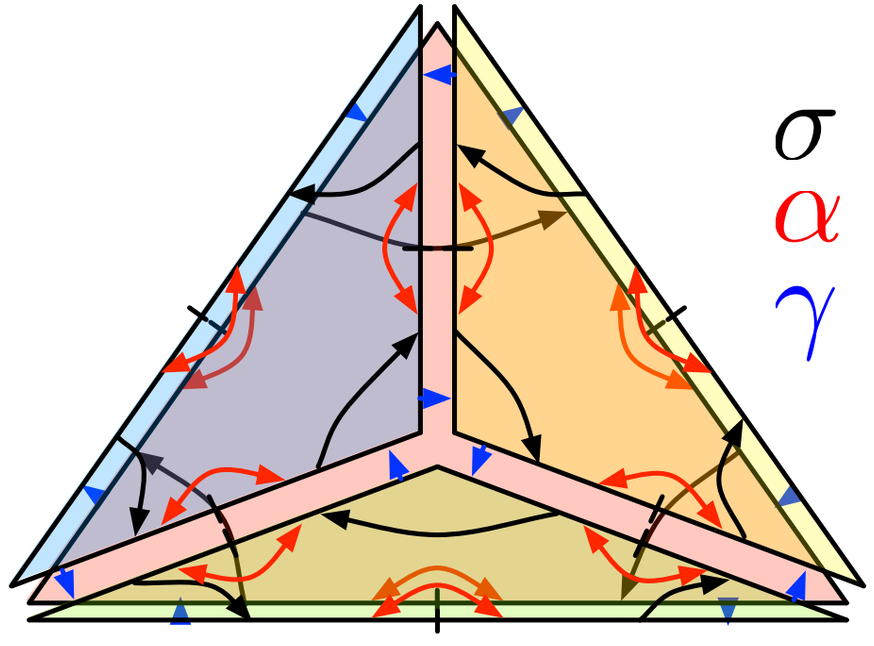


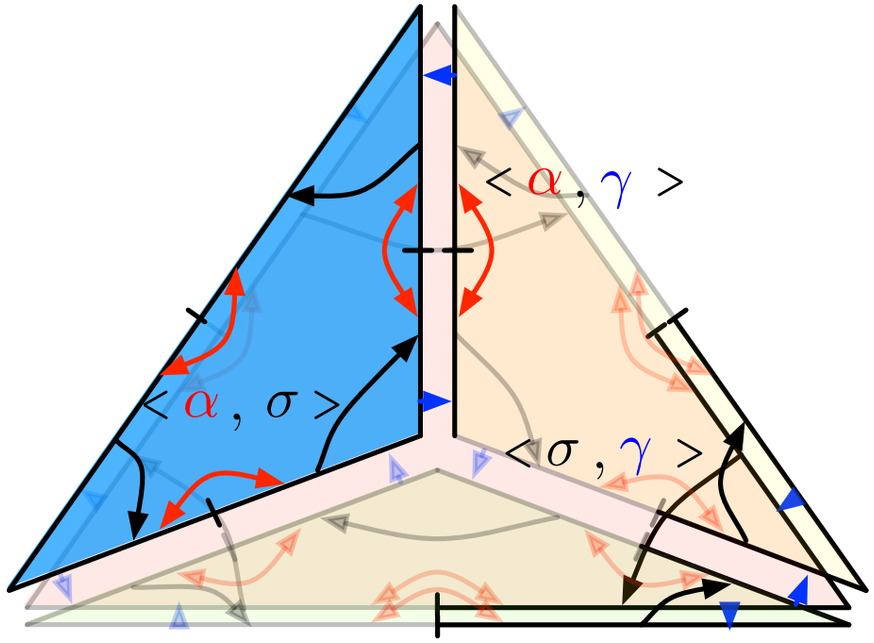


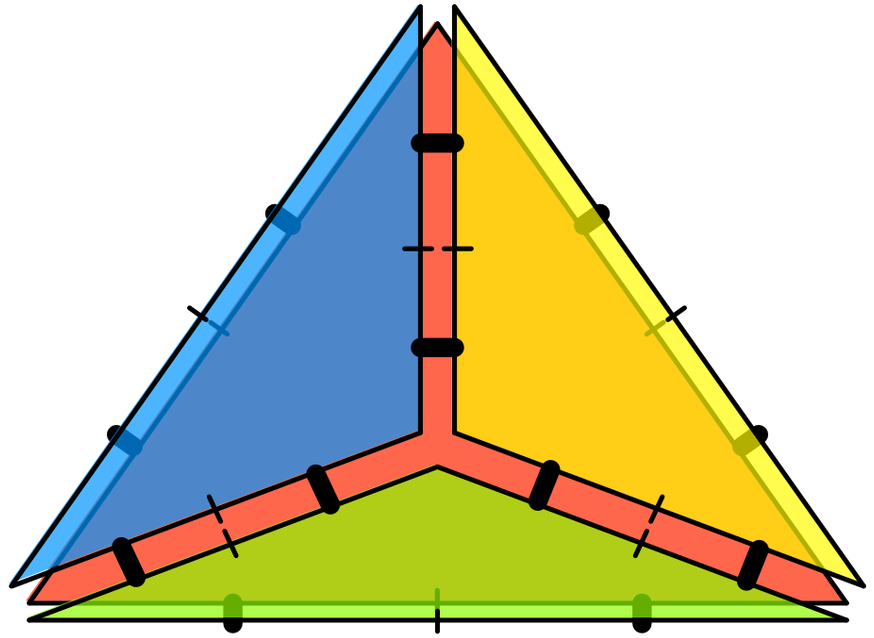
G-maps

Combinatorial maps

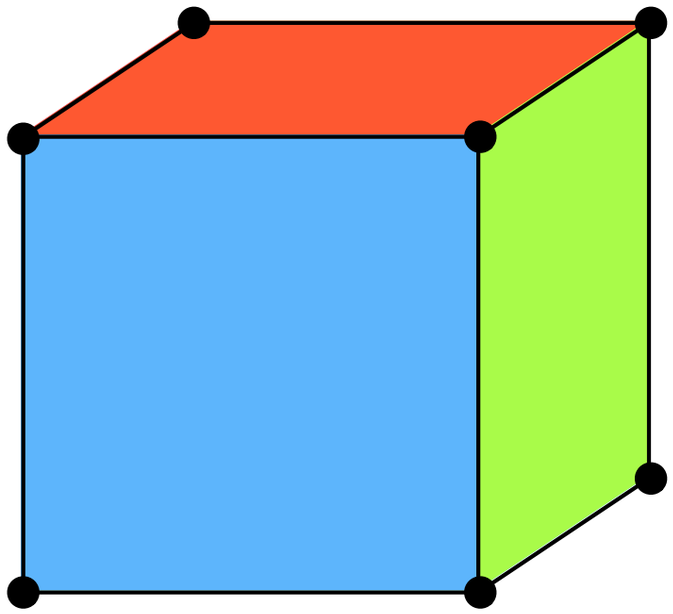


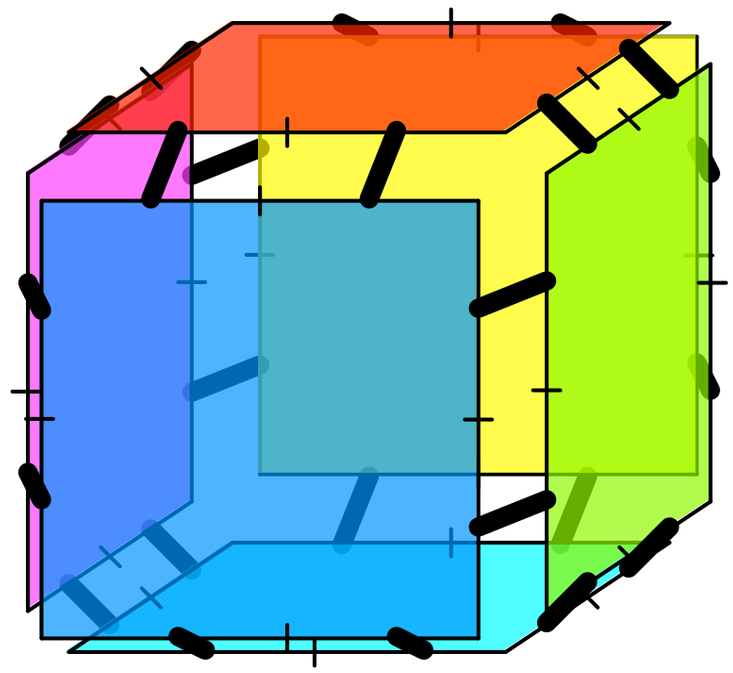


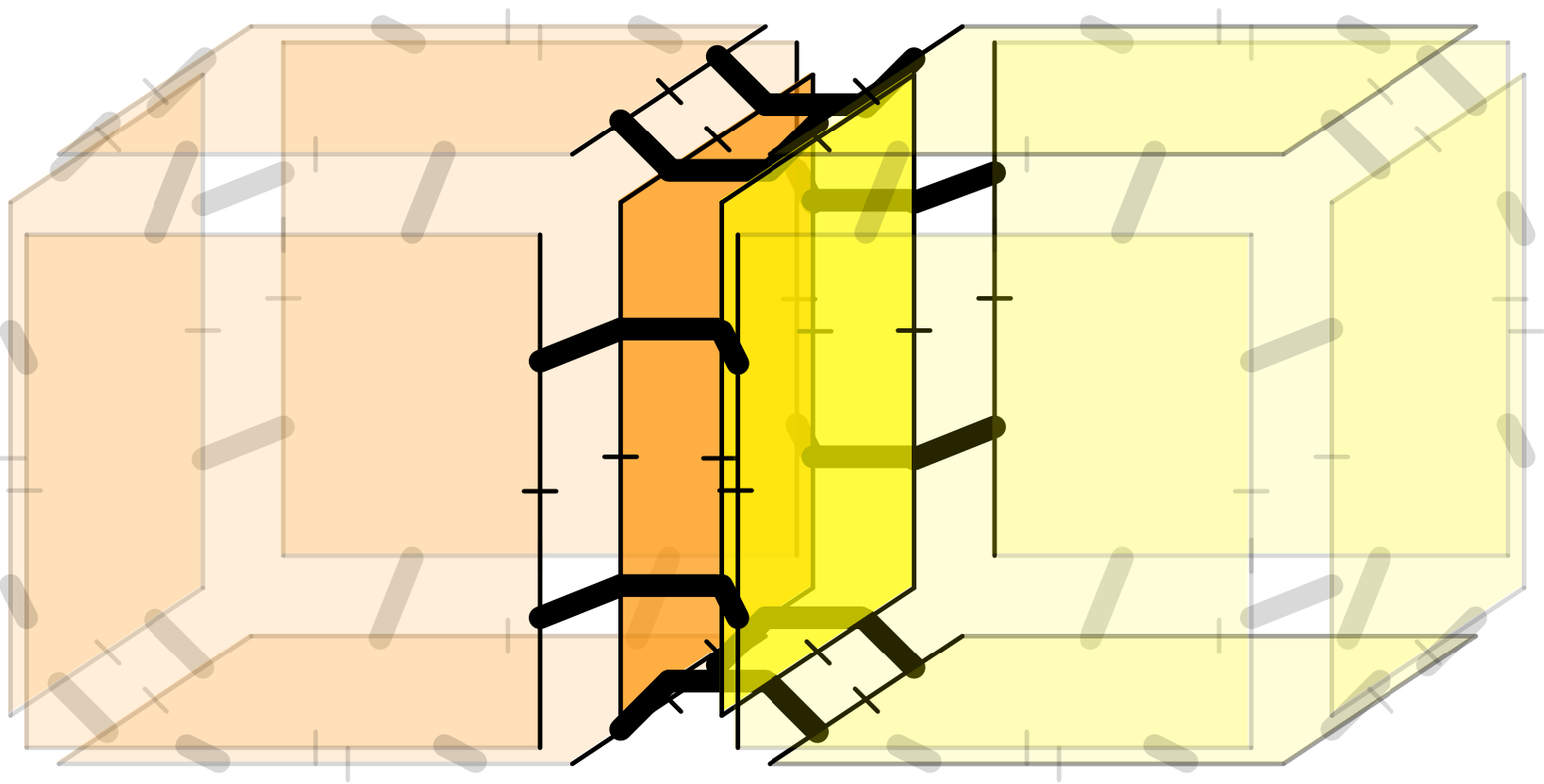




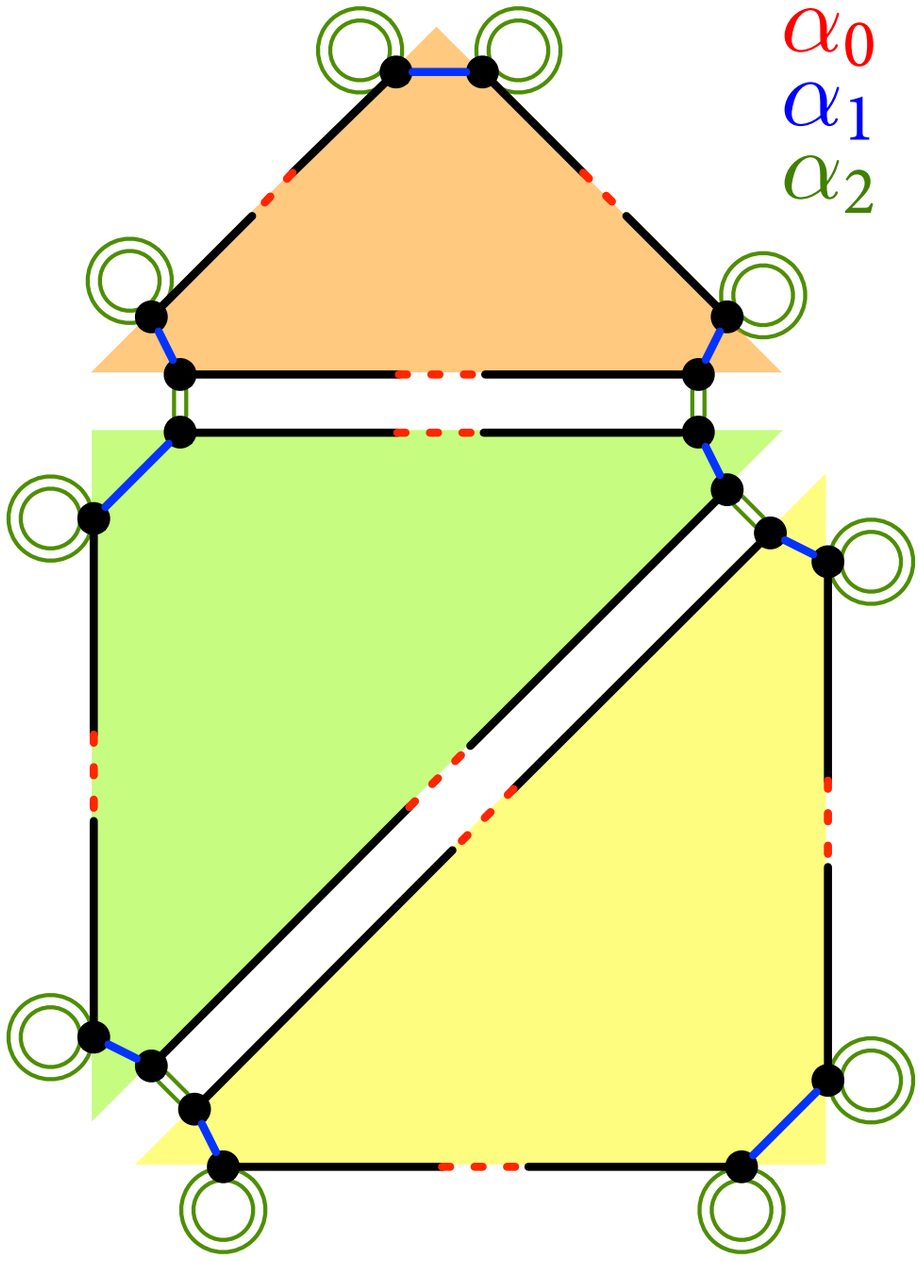
G-maps | V-maps

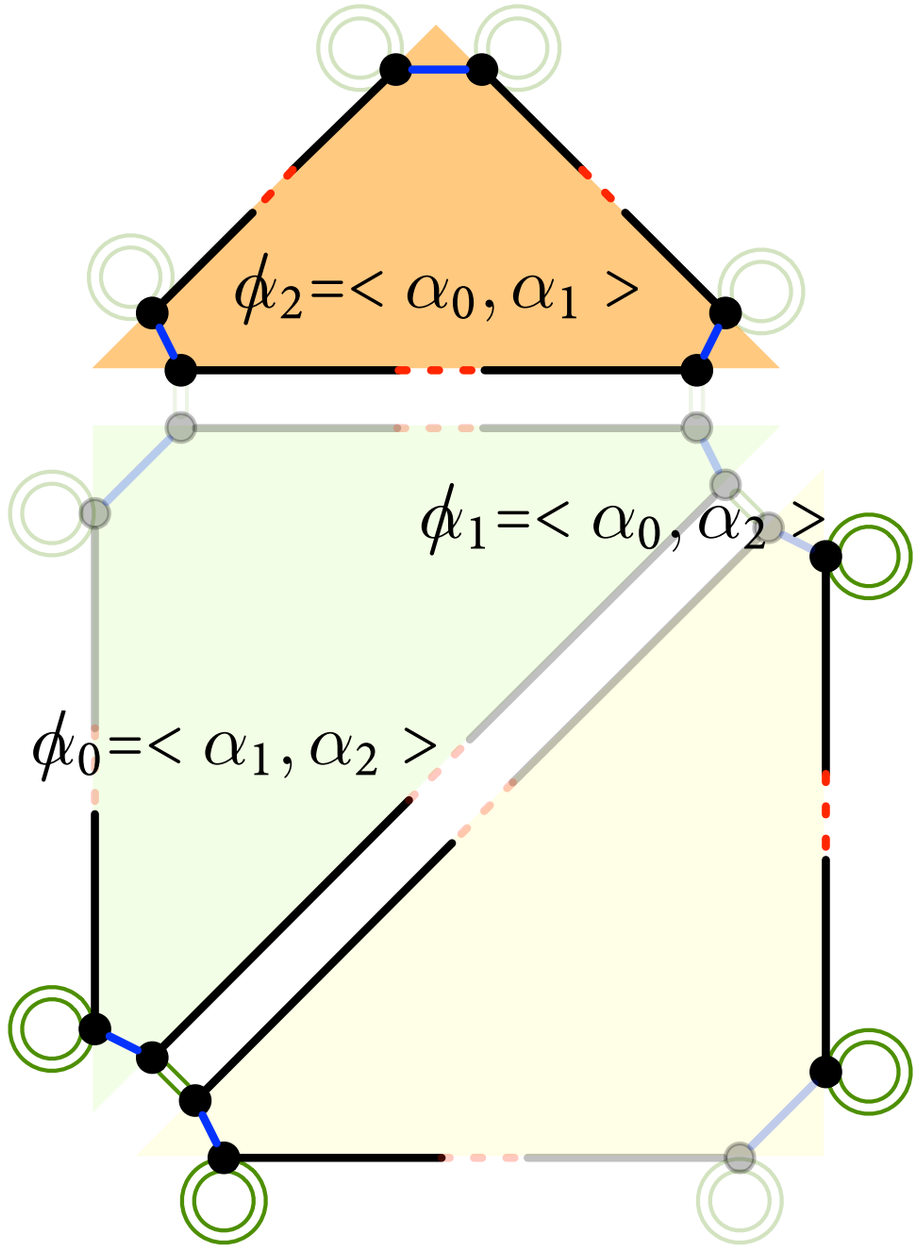




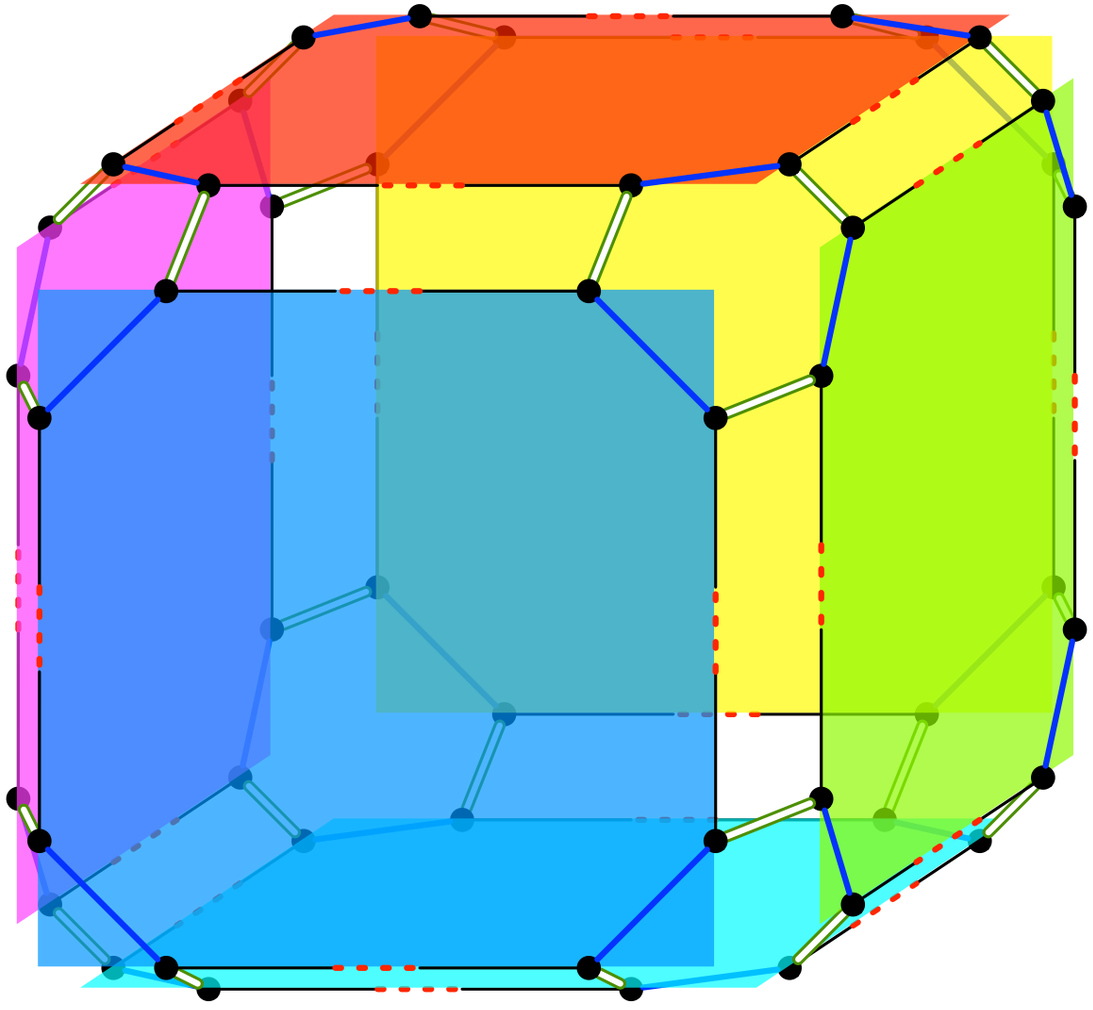


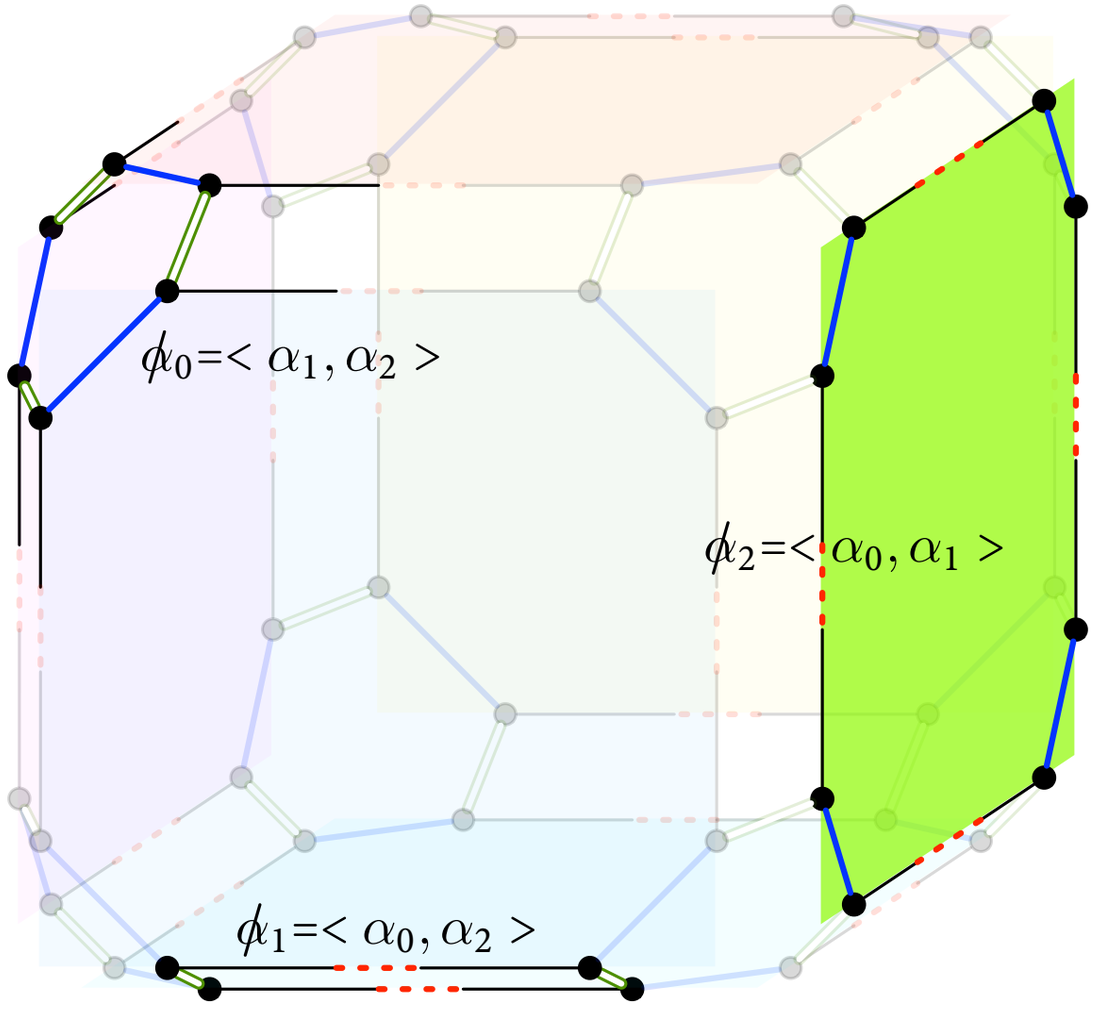
G-maps | V-maps


α_0
α_1
α_2


$\phi_2 = < \alpha_0, \alpha_1 >$
$\phi_1 = < \alpha_0, \alpha_2 >$
$\phi_0 = < \alpha_1, \alpha_2 >$

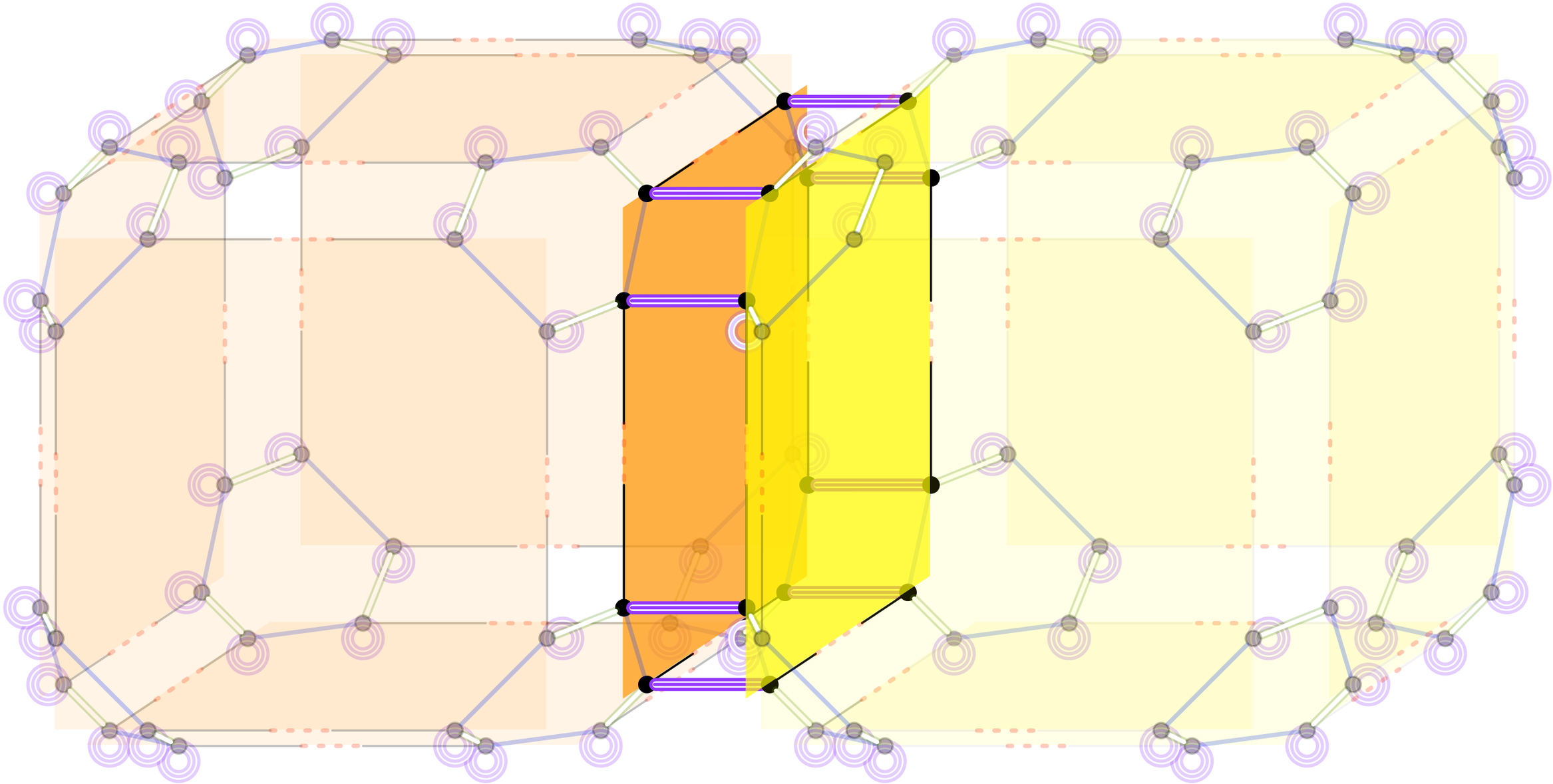
G-maps | 2D





G-maps

3D



G-maps | 3D

What I'll do

"The realisation of a data model, data structure and the basic algorithms required for the operations in a higher dimensional Geographic Information System"

- Study data models and data structures available
- Find out the specific needs of GIS (operations)
- Realisation: creation, implementation, testing
- Visualisation

Phase	Time period	Activities
1	June-October 2011	Initial (broad) literature review Basic implementation of G-maps for GIS data Initial work on a 3D visualiser Research proposal
2	November 2011-February 2012	Continued literature review Define the needed *n*-d operations Article about bridging computer science/GIS Implement more high-level operations on G-maps Obtain *n*-d data sets Loading and viewing 3D data in visualiser
3	2012	Focused literature review Test other data structures Comparison of *n*-d data structures Article about *n*-d data structures Connect *n*-d data structure and visualiser Loading and storing *n*-d data
4	2013	*n*-d operations for GIS data Investigate database implementation Definition of the data structure to use Visualisation of *n*-d data
5	2014	Formalisation of the developed ideas
6	2015	Work on dissertation Prepare for PhD defence

Time planning

What I’ve done

- Literature study
- Implementation of G-maps in arbitrary dimensions
- Visualiser