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2D to 1D and 2D to 0D Geometry Generalization Based on the Straight Skeleton by the Dual-Half Edge Structure

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Abstract

Efficient vario-scale representation is important in Geographic Information Systems (GIS) and cartographic generalization, particularly when transitioning 2D features into 1D or 0D representations. Traditional approaches often introduce topological inconsistencies and abrupt transitions between scales. This paper presents a novel method for vario-scale representation by integrating the Straight Skeleton Network (SSN), Dual Half-Edge (DHE) structure, and Space-Scale Cube (SSC). The straight skeleton enables hierarchical polygon decomposition, ensuring smooth feature transitions across scales. The DHE structure maintains topological consistency, supports dynamic updates, and allows structured connectivity between spatial features. The SSC framework organizes these transformations within a volumetric model, ensuring seamless scale transitions. The proposed approach is tested on various polygonal configurations, demonstrating its effectiveness in preserving spatial coherence, feature continuity, and structural integrity. This research contributes to multi-scale GIS modeling, automated map generalization, and spatial data structuring.

1. Introduction

Efficient multi-scale representation of spatial data is a important challenge in Geographic Information Systems (GIS) and cartography. Traditional generalization methods often rely on discrete levels of detail, which can lead to abrupt transitions between scales and potential loss of topological consistency. Vario-scale representation has emerged as a solution by enabling continuous transformations of geographic features across different scales (Van Oosterom et al., 2014). However, existing methods struggle to maintain smooth transitions, particularly when generalizing 2D features into 1D or 0D representations. This research aims to enhance vario-scale representation by leveraging the Straight Skeleton Network (SSN) (Aichholzer et al., 1996), the Dual Half-Edge (DHE) structure, (Boguslawski, 2011) and the vario-scale Space Scale Cube (SSC) (Meijers and van Oosterom, 2011) to improve topological consistency and facilitate dynamic updates.

The straight skeleton is a geometric structure that provides an alternative to the medial axis for polygon decomposition (Aichholzer et al., 1996). It partitions a polygon into monotone sub-polygons, where each sub-polygon is defined such that any vertical or horizontal line intersects its boundary at most twice while preserving angular bisectors, making it well-suited for generalizing 2D features into simplified representations (Haunert and Sester, 2004). This approach has been successfully applied to multiple representation databases (MRDB) for generalization tasks such as area collapse and geometry type transitions (Haunert and Sester, 2004). Additionally, hierarchical analysis of polygon skeletons can enhance smooth transitions between scales (Wang, 2009).

To efficiently implement this approach, the DHE structure (Boguslawski and Gold, 2016) offers a robust topological data framework for navigating and updating spatial features. The DHE structure naturally encodes hierarchical relationships, making it particularly useful for constructing a tree-structure in a vario-scale environment (Gholami et al., 2024). Its duality connections allow for seamless adaptation of the SSC whenever the initial 2D feature is modified, supporting dynamic updates (Gholami et al., 2024).

The vario-scale SSC provides a volumetric representation of spatial features across different scales, enabling a seamless transition between levels of detail (Van Oosterom et al., 2014). By structuring scale transitions within a cube-based model, the SSC accounts for neighboring features, ensuring that spatial continuity is preserved throughout the generalization process (Van Oosterom et al., 2014). This aligns with recent research in building simplification using offset curves derived from the straight skeleton (Meijers, 2016), which demonstrates the potential of skeleton-based methods for structural generalization.

Building upon these advancements, this research integrates the straight skeleton, DHE structure, and vario-scale SSC into a unified vario-scale framework. This approach not only enables the generalization of 2D features into 1D and 0D representations, but also ensures smooth transitions through polygon hierarchy while supporting dynamic updates. By combining topological efficiency, volumetric modeling, and hierarchical decomposition, this research aims to enhance existing generalization techniques and provide a scalable and adaptive solution for continuous spatial representation.

In this paper, a multiscale representation of 2D features will be transformed into 1D or 0D using the straight skeleton. Subsequently, the polygon hierarchy and SSN will be utilized to implement the vario-scale SSC using the DHE structure.

A key question addressed in this paper is why the DHE structure is a suitable data structure for constructing the vario-scale SSC. In the following sections, we demonstrate how the DHE structure facilitates topological consistency, enables seamless scale transitions, and supports efficient navigation within the SSC framework.

1.1 Straight Skeleton Network

The SSN is the result of the straight skeleton, the straight skeleton is a geometric structure used to partition a polygon into monotone regions through an inward wavefront propagation process. Introduced by (Aichholzer et al., 1996) the straight skeleton differs from the medial axis, as it is composed only of straight-line segments, making it preferable for applications that require polygonal decomposition without curved edges. In Figure 1 the processes of the generating of the SSN is shown.

The straight skeleton S(*P*) of a simple polygon *P* (Figure 1a) is defined as the geometric structure formed by the angular bisectors of the polygon's edges during a shrinking process, where the polygon edges move inward at a uniform speed. The wavefront propagation continues until the polygon collapses entirely, producing the skeleton.

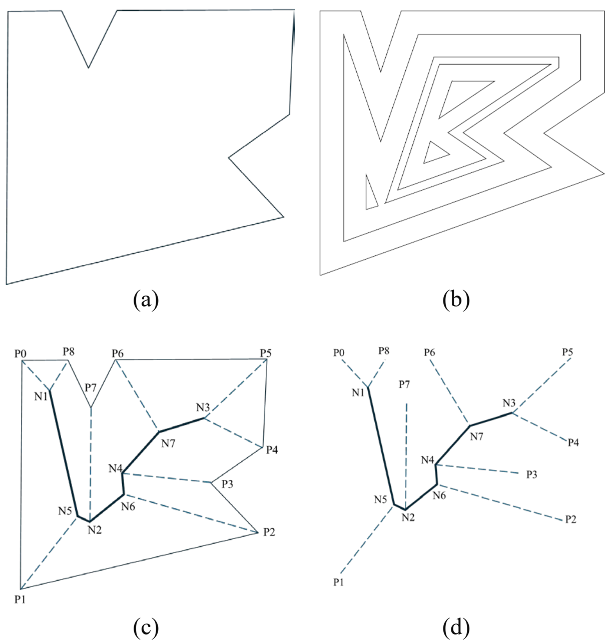

Figure 1. Generate the SSN: (a) the 2D feature (polygon *P*) (b) Shrinking the polygons (c) the SSN and the monotone polygons (d) The SSN of polygon *P*.

During this shrinking process, two key types of events occur (Huber, 2011):

- *Edge Event*: An edge shrinks to zero length, causing adjacent edges to become neighbors.
- *Split Event*: A reflex vertex (interior angle > 180°) collides with an opposite polygon edge, splitting the polygon into two parts.

The straight skeleton consists of arcs and nodes, which bisector pieces are called arcs, and their endpoints which are not vertices of *P* are called nodes (Aichholzer et al., 1996).

The process can be described as a recursive partitioning of the polygon, ultimately producing a hierarchy of nested polygons. The straight skeleton has several distinguishing features:

Tree Structure: Unlike the medial axis, which may include cycles, the straight skeleton forms a tree with *n* connected faces, *n - 2* nodes, and *2n - 3* arcs (Aichholzer et al., 1996).

Monotone Partitioning: Each face of the straight skeleton is monotone with respect to one of the polygon's original edges, making it useful in applications, such as roof modeling and terrain generation (Kenichi, 2019).

- *Lower Complexity than Medial Axis*: Since it avoids curved segments, the straight skeleton is often simpler to compute than the medial axis, which involves parabolic arcs (Huber, 2011).

The straight skeleton has been widely used in various computational geometry and applied fields, including:

Aichholzer et al. (1996) proposed a systematic approach for generating a polygonal roof over a given arrangement of ground walls by a straight skeleton.

Jiang et al. (2023) used straight skeleton in path planning and indoor navigation systems.

Haunert and Sester (2024) demonstrated that the straight skeleton can be an effective tool for automated map generalization, particularly in multiple representation databases, by progressively simplifying polygon structures, it allows for smooth scale transitions, making it valuable for GIS, cartography, and multi-scale mapping applications.

Sugihara (2011) introduced an automatic generation of 3D building models with straight skeleton based on building polygons (building footprints) on digital maps.

1.2 Dual Half-Edge Structure

The DHE structure is a 3D spatial data structure closely related to the radial-edge, facet-edge, and half-edge representations (Boguslawski, 2011). It is built upon the Augmented Quad-Edge (AQE) structure (Ledoux and Gold, 2007) providing an efficient framework for representing and processing topological relationships in 3D space. In this paper, we further explore the DHE structure as a foundation for implementing the vario-scale SSC.

The Dual Half-Edge (DHE) structure is built upon two interconnected components: the primal and dual graphs. In this framework, the primal structure captures the geometric representation of 3D objects, while the dual structure encodes topological relationships. This duality follows the principles of 3D Poincaré duality, where:

- A cell in the primal space corresponds to a single vertex in the dual space.
- A face in the primal is represented as a dual edge.
- A primal edge corresponds to a dual face.
- A vertex in the primal maps to a dual cell.

This relationship ensures a topologically consistent and efficient representation of 3D models.

One of the key strengths of DHE is its efficient navigation system, which is made possible by pointer-based connectivity between all structural elements. The Half-Edge (HE) concept is used to represent edges, where each edge is split into two directed half-edges for easier traversal. The DHE model supports five primary navigation operations (see Figure 2), which enable efficient topological queries, real-time modifications, and hierarchical spatial analysis in GIS, CAD, and 3D modeling applications.

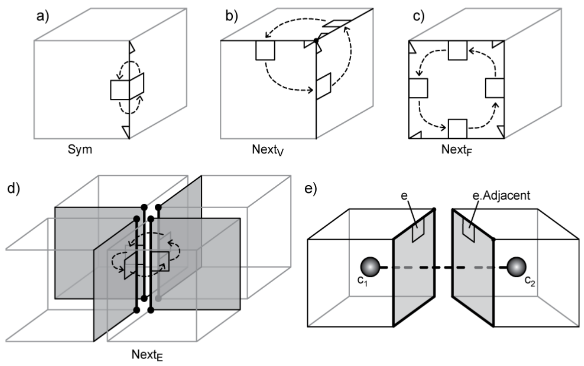

Figure 2. Navigational operators: a) *Sym* navigates from one half of an edge to the second one;
b) *NextV* navigates around a shared vertex; c) *NextF* navigates around a face; d) *NextE* navigates around a bundle of edges; (d) *Adjacent* navigates around the adjacent cell (Boguslawski, 2011).

1.3 The vario-scale Space Scale Cube

The vario-scale SSC (Meijers and van Oosterom, 2011) is constructed by extruding 2D polygonal features along the scale dimension, forming a continuous 3D space in which each polygonal region is represented as a polyhedral volume. This concept builds upon the tGAP (topological Generalized Area Partitioning) structure (Van Oosterom, 2005) and ensures that each slice taken from the cube at a specific scale remains a valid 2D planar partition. The SSC guarantees:

Topological Consistency: No overlaps or gaps exist between generalized representations.

Hierarchical Representation: Each higher-scale representation derives from its lower-scale counterpart through a sequence of generalization operations such as simplification, merging, and collapsing.

Smooth Generalization: Unlike traditional step-wise generalization, SSC allows for continuous transitions between different levels of detail, supporting smooth zoom functionality which the smooth SSC (Figure 3g) is introduced by (Van Oosterom and Meijers, 2011).

In Figure 3, the progress of the vario-scale SSC is shown. There are two types of vario-scale SSC: Classic SSC (introduced by Meijers and van Oosterom, 2011) and Smooth SSC (introduced by Van Oosterom and Meijers, 2011). In Classic SSC, discrete changes in representation cause a jump in visualization, making smooth zooming difficult due to the step-wise zoom-in/out process. In contrast, Smooth SSC enables seamless zooming, preventing visual artifacts caused by sudden generalization changes.

in this paper, the smooth SSC has been chosen for the vario-scale SSC model.

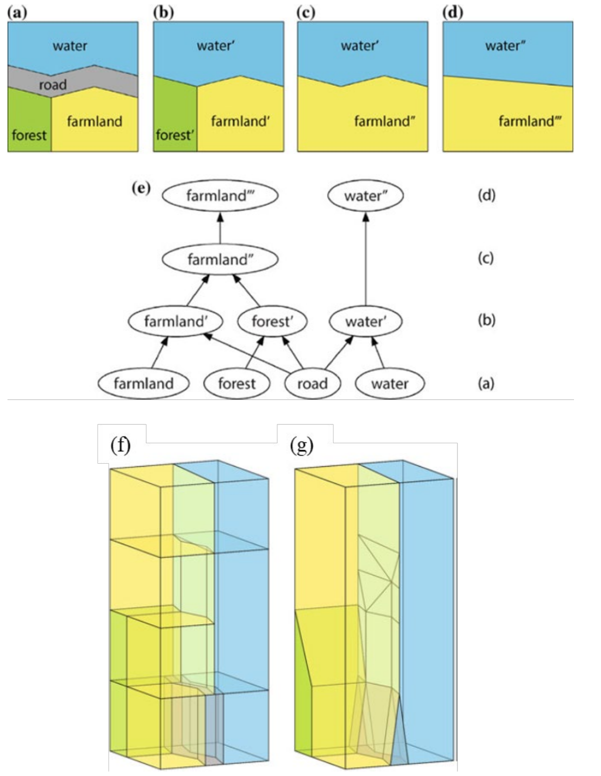

Figure 3. The vario-scale SSC: (a) Original map (b) Result of collapse (c) Result of merge (d) Result of simplify (e) Corresponding tGAP structure (f) Classic SSC (g) Smooth SSC (Van Oosterom et al., 2014).

2.The vario-scale representation

The proposed vario-scale representation for 2D feature to 1D and 0D feature map transition is shown in Figure 4.

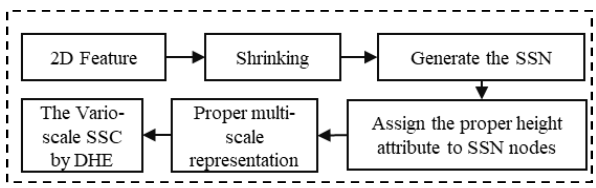

Figure 4. The proposed vario-scale representation.

Based on the approach introduced by Aichholzer et al. (1996), the SSN is generated by shrinking the 2D feature. By assigning the appropriate height attribute to the SSN nodes, a structured representation of the 3D SSN is formed.

This structure allows for the creation of a hierarchical model, where the highest height attribute represents a 1D or 0D feature, which by replacing the proper scale dimension to height attribute extending the skeleton edges, and considering a collapsing method for neighbor feature cases the proper multi-scale will be represented, then finally, the vario-scale SSC will be constructed by DHE to support smooth multi-scale transitions and to be a volumetric and topological vario-scale SSC.

2.1 Generate the SSN

The processes of 2D feature to 0D feature mapping based on the method proposed by Aichholzer et al. (1996) is shown in Figure 1. First, the polygon hierarchy by shrinking the polygons based on the split/edge events will be generated and then the 3D SSN will be created.

In this paper, we classify the nodes in the SSN (see Figure 1d) into two main categories:

1. *Polygon Nodes*: These correspond to the original vertices of the polygon (Figure 1a), denoted as $P_0, P_1, \ldots, P_8$.
2. *Skeleton Nodes*: These are event points formed during the wavefront propagation, denoted as $N_1, N_2, \ldots, N_7$. Skeleton nodes are further categorized into three types:
   - *Branch Nodes*: Points where three or more skeleton edges converge, created during a split event (e.g., N_2 and N_4).
   - *Edge Event Nodes*: Nodes formed when a polygon edge collapses to zero length, modifying the topology (e.g., N_1 and N_3).
   - *Leaf Nodes*: The terminal nodes of the skeleton tree, where no further propagation occurs. These nodes typically appear when the polygon fully collapses into a single point (e.g., N_5, N_6, and N_7).

Additionally, we classify the edges in the SSN into two types:

- *Ridge Edges*: Represented by dashed lines, these edges are connected to at least one polygon node.
- *Skeleton Edges*: Represented by solid lines, these edges are bounded by two skeleton nodes within the SSN.

Once the SSN is generated, the vario-scale SSC can be constructed using the DHE structure. This SSC enables a smooth transition between 2D features and their 1D or 0D representations. In the next section, we will describe how our proposed vario-scale representation effectively models these transformations.

2.2 Mapping the 2D feature to 1D feature

If the height attribute of all skeleton nodes is assigned a single Z-value ($Z_{top\text{-}layer}$ or Z_t) and the nodes are connected to form a line, the highest shape of the skeleton nodes will be a horizontal skeleton line parallel to the XY coordinate plane (Figure 5a). If the polygon □ is then connected to this skeleton line using ridge edges, a specific 3D SSC is created (Figure 5b).

In the multi-scale representation, where neighboring features surround the 2D feature, the straight skeleton edges must be extended based on collapsing methods. One such method is discussed by Haunert and Sester (2004). Therefore, when using the SSN for vario-scale representation, it must be adjusted according to the collapsing method and the influence of neighboring features.

The final vario-scale SSC for a single 2D feature (Figure 5d) closely resembles the 3D SSC of the straight skeleton (Figure 5b), except that in the vario-scale SSC, the top-scale 1D feature is an extension of the top Z-line. Additionally, instead of using the Z-dimension, the scale dimension is considered in the vario-scale SSC.

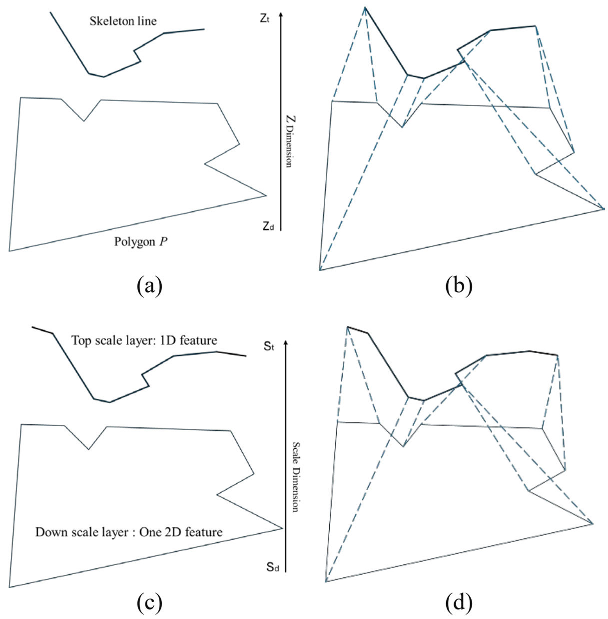

Figure 5. The vario-scale representation of one feature : (a) The top and down layers in height dimension, (b) The specific 3D SSC (c) Multi-scale representation: the top and down layers in scale dimension, (d) The vario-scale SSC representation.

In case of the M-2D features when one of the 2D feature is generelized with the straight skeleton, the collapsing features in top scale layer of multi-scale representation will be important, for example in Figure 6a, the 2D feature (polygon P) and N_1 (neighbour 1), N_2, N_3, and N_4 features with the SSN and partitioning polygons of the 2D feature is shown when we want to create the top scale layer in multi-scale representation, the features should be collapsed in shared extended skeleton edges, the question is how the collapsing will happen, to find a proper solution we consider to discuss it in our future researching, so far let's assume the collapsing method has been done like Figure 6b which the partitioning polygons are merged with neighbour features, subsequently, the skeleton edges should be extended with proper collapsing method and during this extension the ridge edges will be one of the, the final 1D feature is shown with a bolded line in Figure 6b, which the P_0N_1 and N_3P_4 lines are added to skeleton edges.

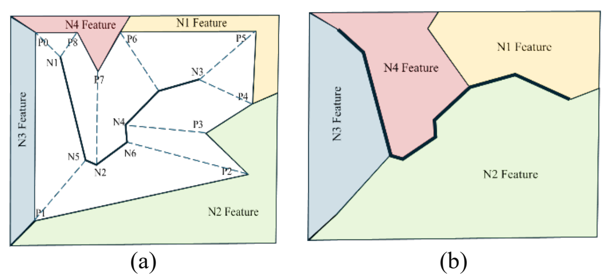

Figure 6. Multi-scale representation with neighbour features: (a) Down scale layer: The polygon P with corresponding SSN and partitioning polygons and neighbour features (b) Top scale layer: Collapsed neighbour features with an initial 2D feature shown Figure 3a, where the bolded line is the final 1D feature with neighbours.

In this paper the vario-scale SSC is constructed by DHE structure as discussed by Gholami et al. (2024), as shown in Figure 5b the

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vertical faces are non-planer, so to avoid it, in our future research we will consider constructing the 3D vario-scale model with vertical planer faces by considering of the Euler or Cardboard & Tape DHE operators.

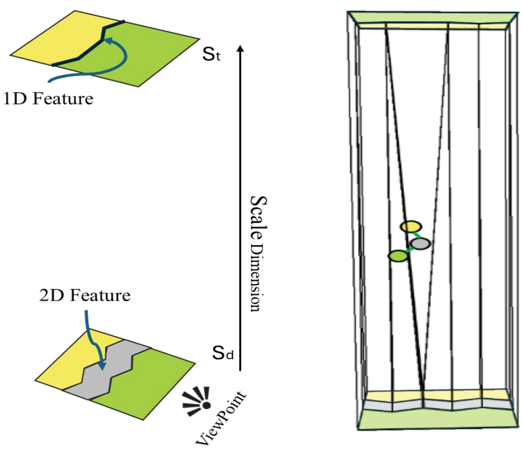
A key question in this paper is: Why choose the DHE structure? To answer this, we examine its potential for a simple vario-scale SSC model, as illustrated in Figure 7.

In the multi-scale representation (Figure 7a), the lower scale layer contains a 2D road feature alongside two neighboring features (land cover and forest). At the higher scale layer, the road object is generalized into a 1D feature, while the land cover and forest areas remain, collapsing the intermediate area.

Figure 7b demonstrates how the vario-scale SSC is constructed using the DHE structure, following the DHE construction operators proposed by Gholami et al. (2024). The DHE framework establishes a duality connection between the cell complexes, ensuring a structured representation. This duality, combined with the DHE navigational pointers (Figure 2), enables efficient cell-to-cell navigation, making it a volumetric and topological vario-scale SSC.

Additionally, the DHE structure supports adaptive updates through its adjacent face relationships. When a change occurs in one face within a cell complex, the neighboring cell complex is automatically updated. This feature is particularly valuable for our future research, where we aim to enhance road map transitions using the straight skeleton and polygon hierarchy. With DHE, these map transitions will automatically propagate to neighboring cell complexes, ensuring consistent and dynamic scale transformations.

Therefore, in this paper, we implement the vario-scale representation using the DHE structure to ensure a consistent and structured transition between scales.

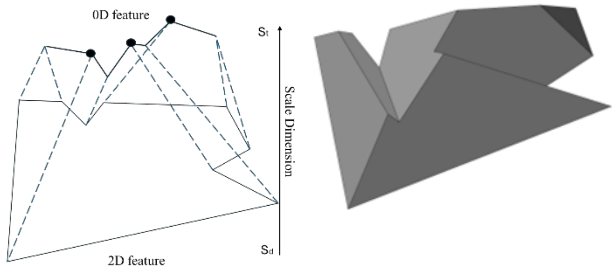


(a) (b)

Figure 7. One simple vario-scale SSC by DHE : (a) Multi-scale representation (b) Vario-scale SSC by DHE visualization from viewpoint, where three circles are dual vertices connected by dual edges.

2.3 Mapping the 2D feature to the 0D feature

If the highest point of the 3D SSN in the straight skeleton corresponds to one or more vertices, then this 3D SSN can be utilized as a 3D representation for the transition from 2D features to 0D features. By leveraging this approach, the vario-scale SSC can be effectively implemented. This map transition between different scale levels is governed by geometric transformations, ensuring a structured and continuous transition, driven by the properties of the straight skeleton. In Figure 8 mapping of the 2D feature to 0D feature is shown.



(a) (b)

Figure 8. Methodology process for mapping 2D feature to 0D (b) a 3D SSC by (Aichholzer et al., 1996)

Based on the 3D SSC, the top feature in the vario-scale representation can be either 1D or 0D. In the 0D case, the top scale level consists of one or more vertices, typically corresponding to leaf nodes, which are positioned at the highest scale level. In contrast, branch nodes are situated at lower scale levels than leaf nodes. Future research will further explore this hierarchical structure, along with the transition of neighbouring features. Additionally, future studies will focus on enhancing the map transition within the SSN to improve transformations between S_t ($S_{topfeature}$)and S_d ($S_{downfeature}$).

To construct the vario-scale SSC using the DHE structure for a 2D to 0D map transition, this paper considers a simplified vario-scale SSC model. To illustrate this, we examine a square feature (2D feature) surrounded by four neighbouring features, as shown in Figure 9a. After applying the straight skeleton and collapsing the structure, the top scale layer reduces to a 0D feature, with the surrounding features also collapsing accordingly.

In Figure 9b, the vario-scale SSC is constructed using the DHE structure. As shown, the duality connections between cell complexes create a volumetric and topologically consistent vario-scale SSC, ensuring structured and seamless scale transitions.

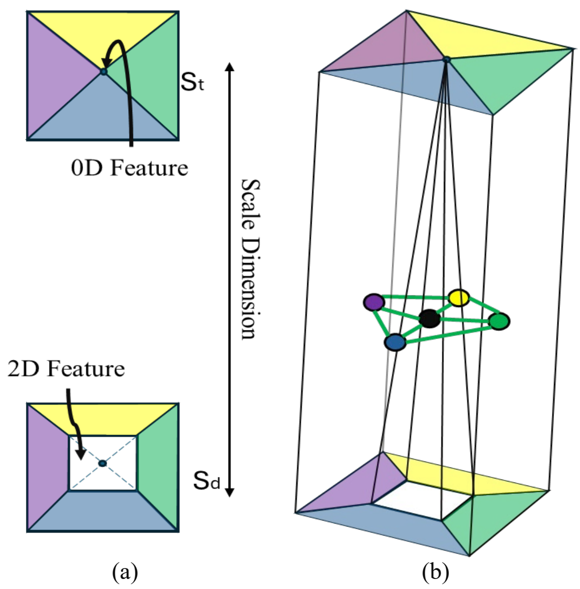


Figure 9. A simple vario-scale SSC for 2D to 0D: (a) Multi-scale representation with neighbour features: Downscale layer: The square feature with corresponding SSN and partitioning polygons and neighbour features, Top scale layer: Collapsed neighbour features, where the central vertex is a 0D feature with neighbours.

In our future research, we plan to implement and analyze a more complex vario-scale SSC, focusing on a polygon *P* with surrounding neighbor features in the context of a 2D to 0D map transition. Additionally, we will explore the scale assignment of the scale dimension and examine how this transition is structured and represented within the vario-scale SSC.

3. Summary and Future Research

This study introduces a structured approach to vario-scale representation, enabling the generalization of 2D features into 1D and 0D while preserving topological consistency and geometric integrity. The integration of the SSN, DHE structure and SSC offers a scalable and adaptable solution for hierarchical polygon decomposition and dynamic scale transformations.

The straight skeleton ensures a partitioning of polygons, preventing topological inconsistencies during scale transitions. The DHE structure provides a topological framework that maintains feature relationships and connectivity, facilitating real-time updates as spatial features evolve. Meanwhile, the SSC framework allows for a volumetric representation, ensuring structured, smooth transitions between different levels of detail.

Experimental results confirm that this methodology effectively handles multi-scale transformations, ensuring that neighbouring features remain spatially consistent.
Several directions for future research can further enhance the proposed vario-scale representation approach:

1. Scalability and Computational Optimization
   - Develop optimized algorithms to improve the efficiency of straight skeleton generation and DHE-based transformations, particularly for 2D to 0D map transition to have a gradual transition.
2. Machine Learning for Generalization
   - Investigate machine learning models to predict optimal feature transitions for automated multi-scale generalization.
3. Neighboring Feature Interactions
   - Extend the methodology to incorporate complex feature interactions, particularly in urban environments, ensuring better spatial adaptation across road networks, buildings, and natural features.
4. 3D Generalization and Extended Scale Transitions
   - Expand the straight skeleton and DHE structure applications to 3D generalization, allowing transformations between 3D, 2D, 1D and 0D features.

By addressing these aspects, future research can further improve the robustness, adaptability, and efficiency of vario-scale spatial representations, making them even more applicable to real-world GIS and cartographic applications.

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5. References

Aichholzer, O., Aurenhammer, F., Alberts, D., Gärtner, B., 1996. A Novel Type of Skeleton for Polygons, in: Maurer, H., Calude, C., Salomaa, A. (Eds.), J.UCS The Journal of Universal Computer Science. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 752–761. https://doi.org/10.1007/978-3-642-80350-5_65

Boguslawski, P., (2011). Modelling and analysing 3d building interiors with the dual half-edge data structure. University of South Wales (United Kingdom).

Boguslawski, P., Gold, C., 2016. The dual half-edge—A topological primal/dual data structure and construction operators for modelling and manipulating cell complexes. ISPRS Int. J. Geo-Inf. 5, 19.

Gholami, A., Boguslawski, P., Meijers, M., van Oosterom, P., 2024. Evaluation of the dual half-edge data structure for implementation of a vario-scale model. Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.-ISPRS Arch. 48, 25–32.

Haunert, J.-H., Sester, M., 2004. Using the straight skeleton for generalisation in a multiple representation environment, in: ICA Workshop on Generalisation and Multiple Representation, Leicester.

Huber, S., 2011. Computing straight skeletons and motorcycle graphs: theory and practice. Shaker.

Jiang, L., Li, J., Hu, Y., Pan, F., Zhu, J., Lei, B., Lin, R., 2023. A Voronoi path planning extracted from improved skeleton for dynamic environments. J. Mech. Sci. Technol. 37, 2019–2032. https://doi.org/10.1007/s12206-023-0338-4

Kenichi, S., 2019. Straight Skeleton Computation Optimized for Roof Model Generation. Václav Skala - UNION Agency. https://doi.org/10.24132/CSRN.2019.2901.1.12

Ledoux, H., Gold, C.M., 2007. Simultaneous storage of primal and dual three-dimensional subdivisions. Comput. Environ. Urban Syst., Topology and Spatial Databases 31, 393–408. https://doi.org/10.1016/j.compenvurbsys.2006.03.003

Meijers, B.M., van Oosterom, P.J.M., 2011. THE SPACE-SCALE CUBE: AN INTEGRATED MODEL FOR 2D

POLYGONAL AREAS AND SCALE. Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. XXXVIII-4-C21, 95–102. https://doi.org/10.5194/isprsarchives-XXXVIII-4-C21-95-2011

Meijers, M., 2016. Building simplification using offset curves obtained from the straight skeleton, in: Proceedings of the 19th ICA Workshop on Generalisation and Multiple Representation. Helsinki, Finland. pp. 1–18.

Sugihara, K., 2011. Automatic generation of 3-D building models by straight skeleton. https://doi.org/10.1145/2077378.2077408

Van Oosterom, P., Meijers, M., 2011. Towards a true vario-scale structure supporting smooth-zoom.

Van Oosterom, P., 2005. Variable-scale Topological Data Structures Suitable for Progressive Data Transfer: The GAP-face Tree and GAP-edge Forest. Cartogr. Geogr. Inf. Sci. 32, 331–346. https://doi.org/10.1559/152304005775194782

Van Oosterom, P., Meijers, M., Stoter, J., Šuba, R., 2014. Data Structures for Continuous Generalisation: tGAP and SSC, in: Burghardt, D., Duchêne, C., Mackaness, W. (Eds.), Abstracting Geographic Information in a Data Rich World, Lecture Notes in Geoinformation and Cartography. Springer International Publishing, Cham, pp. 83–117. https://doi.org/10.1007/978-3-319-00203-3_4

Wang, T., 2009. Extraction of optimal skeleton of polygon based on hierarchical analysis, in: Int. Archives of Photogrammetry, Remote Sensing, and Spatial Information Sciences. Citeseer, pp. 272–276.