Radial network visualization - Linking spatial and non-spatial networks in a connected circular layout

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Abstract

The integration of spatial and non-spatial entities within a single visualization remains challenging. Map-based approaches preserve geographic context but may require arbitrary placement of non-spatial elements, while network layouts may obscure spatial relationships, and multiple views can increase cognitive load. We present a coherent visualization concept that integrates spatial and non-spatial entities from different networks in a single view. The approach uses a radial layout centered on a map, where spatial entities retain their positions and non-spatial entities are arranged along a circular boundary. Relationships are represented as circular arcs on concentric layers, with markers indicating connections, thereby reducing overlap and improving readability. Interactive prototypes implemented in D3.js demonstrate variations in layout, interaction, and data complexity. The results show that radial, map-based network visualizations can support the integrated analysis of spatial and non-spatial relationships while preserving both geographic context and network structure.

CCS Concepts

• ***Human-centered computing*** → *Visualization design and evaluation methods; Information visualization;*

1. Introduction

Relationships between entities are commonly visualized as networks with varying complexity. Standard layouts such as force-directed or hierarchical approaches are widely used. In many applications, both spatial and non-spatial entities must be represented together. While spatial entities can be placed on maps, integrating non-spatial entities is challenging. Arbitrary placement on the map may distort spatial perception, whereas separating views requires transitions that can hinder interpretation [TAA*21; BB25]. In both cases, combining spatial and non-spatial networks in a single coherent visualization remains problematic. This issue arises in multiple scenarios, including relationships between built entities and networks, between different infrastructure networks, and between physical and intangible networks. To address this, we propose a visualization concept that integrates spatial and non-spatial entities from one or more networks and represents their relationships within a unified layout.

2. State of the art

Network visualization supports the analysis of complex relational data across domains, e.g., geography. Approaches aim to balance readability, aesthetics, and analytical accuracy [BCG*25; vKS*11]. For non-spatial networks, classical layouts such as force-directed and hierarchical methods remain prevalent due to their ability to reveal structure and clusters [vKS*11]. Heuristic improvements enhance readability, especially for large datasets [BRSG07]. Spatial and multidimensional visualizations extend these approaches by integrating geographic or attribute-based information [BNT*24]. Recent work emphasizes hybrid and interactive techniques for exploring large, multi-layered networks [FAM23]. A central challenge is visual clutter caused by overlapping nodes and edges. Techniques such as BioFabric address this by replacing node–link diagrams with structured layouts, enabling scalable pattern analysis. BioFabric is a network visualization technique in which nodes are depicted as parallel horizontal lines and edges as vertical connections between them, minimizing overlap by assigning each node a dedicated row [Lon12; FDH*24; NMSL19]. However, such approaches require substantial space and are less suited for static displays. Radial and circular layouts can reduce overlap and emphasize structure through arc-based representations [LS09]. Related approaches, such as geophylogenies, combine maps with hierarchical structures and linking elements [EHM*21; KKS*25; Pre25]. Circular variants further improve readability by reducing edge crossings [PSD*22; vDSS25]. For spatially constrained networks, overlap is often unavoidable as data size increases. Position adjustments are limited when geographic accuracy must be preserved, sometimes requiring data reduction [KBH25]. Boundary labeling places related information along a circular perimeter and links it to spatial locations via leaders [BTGH22; GAH23; ZB19]. Our approach builds on these ideas by combining a central map with a circular boundary and leader-based connections, enabling a coherent visualization of spatial and non-spatial entities within a single structured representation.

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3. Methods

A circular layout is used to integrate spatial context and network structure, although the approach is not limited to this shape. Despite being less space-efficient on rectangular displays, circular layouts improve readability by supporting continuous, unbroken connections. The design is inspired by circular geophylogeny visualizations [vDSS25; PSD*22] and incorporates concepts from BioFabric, where nodes are effectively represented through structured connections [FDH*24; Lon12; NMSL19]. The visualization organizes all elements around a global center, which acts as the visual origin [1] (Fig. 1). A bounded spatial region, typically represented by a map, contains all spatial nodes and defines the geographic frame of reference. Its maximum extent determines the outer boundary for layout and routing. Spatial nodes are placed according to their coordinates, while non-spatial nodes are arranged along a circular boundary and evenly distributed, forming an inner ring that conveys their network affiliation [2]. From all nodes, radial leader lines extend outward and encode connectivity through markers that indicate the presence, number, and type of relationships [3]. Connections are drawn as continuous curves combining radial segments and circular arcs centered on the global origin. To structure these connections and reduce overlap, multiple concentric routing layers are used, with each connection assigned to an appropriate layer. This layered routing enables clear separation of relationships while preserving continuity. The circular arcs support detailed analysis of inter-entity relationships, while the layered arrangement minimizes visual clutter. Crossings without connections remain identifiable due to missing markers [4], and isolated nodes are recognizable by the absence of markers along their leaders [5]. Overall, the method combines spatial embedding and abstract network representation within a consistent radial geometry, enabling simultaneous geographic orientation and structural analysis.

4. Results

The visualization concept was prototypically implemented in D3.js and explored through multiple design variants, differing in interaction, layout, and data complexity. The approach was further developed into an interactive, user-guided visualization to assess its applicability. A thematic case study was used to demonstrate the concept, focusing on the relationships between national road construction, power plants, and international connections in Switzerland during the economic boom (1960–1990). The visualization integrates spatial and non-spatial entities from the energy, transport, and foreign countries networks, with additional geometry to represent infrastructure such as roads and power lines. The interactive implementation enables exploration of connections by highlighting nodes and their relationships. For example, selecting a transport node reveals its links to entities in other networks and supports detailed analysis of connection types through the routed arcs and associated visual encodings.

5. Discussion

The proposed radial network visualization enables a coherent representation of spatial and non-spatial entities and is primarily suited for exploratory analysis. In its current form, it is not well suited for static use and benefits from interactive implementation. Limitations include suboptimal arc arrangement and node placement, which can lead to visual clutter. The method currently scales only to small networks (approximately 20 nodes), and overlaps within the spatial map are not addressed, requiring established cartographic solutions. Despite these limitations, the approach demonstrates that spatial and non-spatial networks can be integrated into a single, structured visualization. Spatial and non-spatial nodes remain clearly distinguishable, while their relationships are preserved. The use of separate routing layers and connection markers reduces ambiguity between overlaps and actual relationships. Additionally, connectivity patterns, within and across networks, can be quickly identified. Future work should focus on improved layout optimization (see e.g. Next Steps - Zoom), enhanced interaction (e.g., zooming), and user studies to evaluate usability, learning, and applicability across domains and larger network sizes.

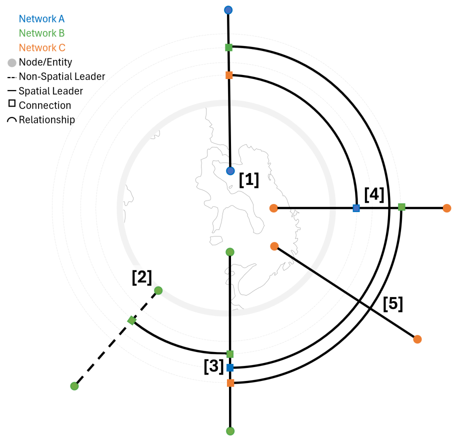

Figure 1: *Example illustration of the radial network visualization concept with three different networks and the possible entity types (nodes and leaders) and connection types (arcs).*

6. Conclusion

We present an approach for visualizing spatial and non-spatial entities and networks inside one visualization based on a combination of a radial layout and a map. The feasibility and the potential of this visualization was demonstrated on an architectural use case of the interplay of the national highway construction and power plants. Further research is needed to test the full potential of this visualization.

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Sample data and implemented prototypes can be found here: `https://fhnw-igeo.github.io/BilderCHInfra/`.

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