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Are We There Yet?
A Roadmap of Network Visualization From Surveys to Task Taxonomies

Velitchko Filipov, Alessio Arleo, Silvia Miksch

TU Wien

CVAST

Outline

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Introduction

Roadmap & Disciplines

Task Taxonomies & Coverage

Discussion & Results

Open Challenges & Summary

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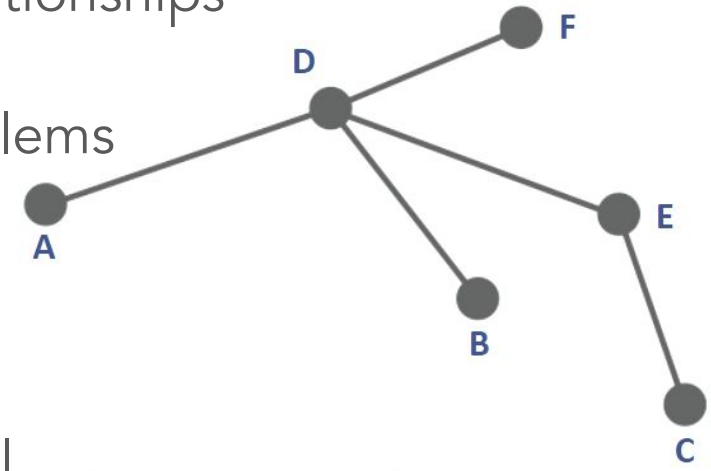
Introduction

Networks are a set of data points and relationships

Abstract structure that models many problems

Have a wide range of applications

Network visualization provides meaningful representations of such data



V = {A, B, C, D, E, F}
E = { (A, D); (D, B); (D, E); (D, F); (E, C) }

Background

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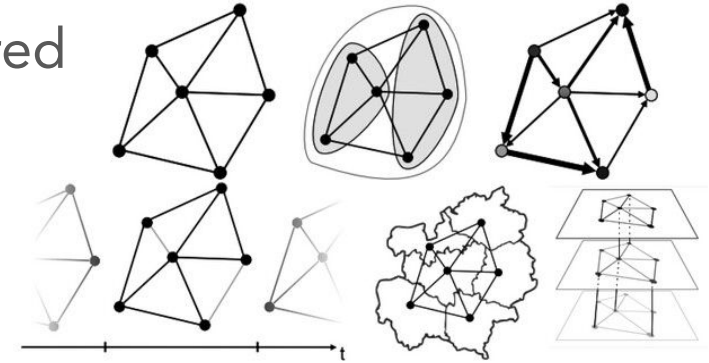
Network visualization is expanding and pursuing challenging topics

e.g., Dynamic, Multi-variate, Large, Geospatial networks

Research in these various topics is scattered

Classifications are often inconsistent

Lack of task taxonomies for most topics



Hadlak et al., "A survey of multi-faceted graph visualization.", 2015.

Motivation

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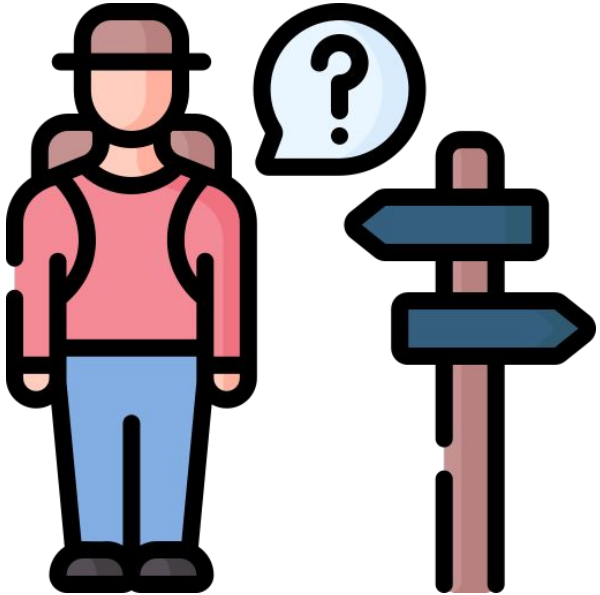
Can be overwhelming

Overview easily lost

How can I contribute?



Motivation

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Difficult to answer questions like:

- “What has already been done?”
- “What areas are yet to be explored?”

Our Goal

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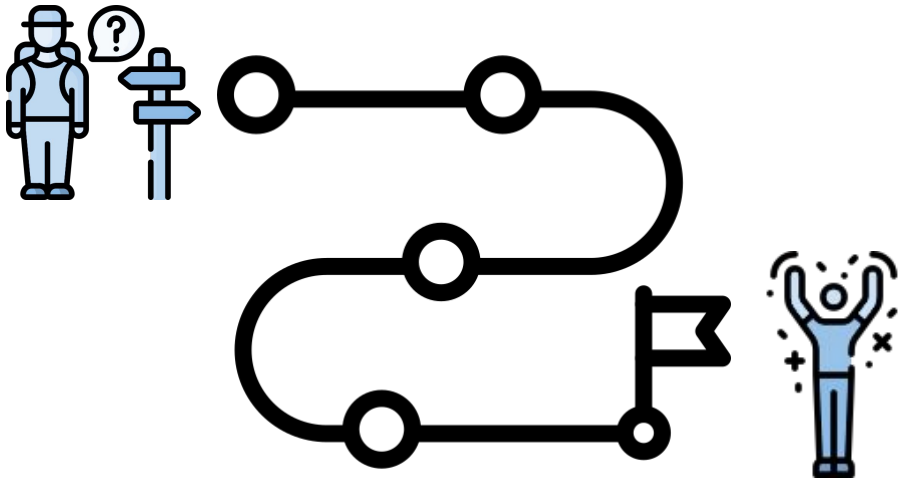
Provide a roadmap detailing the research directions in network visualization and relationships between them



Methodology

Following PRISMA statement [Page et al., 2021]

Multiple refinement cycles

Forward and reverse lookup (citing or cited by)

Keywords:

(*Survey* | *STAR* | *Taxonomy* | *Design Space*) & ((*Graph* | *Network*) *Viz.*)

Page et al., "The PRISMA 2020 Statement: An updated guideline for reporting systematic reviews", 2021

Methodology

Publication venue	Count
TVCG	9
CGF	9
EuroVis	3
VIS	2
Information Visualization	3
AVI	2
Other	15

Total of 43 papers included

- From an initial set of 152 papers
- Filtered according to inclusion criteria
- Window of interest 2000-2021

Methodology

Survey inclusion criteria (SC):

SC1: Is a systematic review of literature about a specific branch of network visualization

SC2: Focus is on network visualization **not** algorithmic and graph theoretical contributions

Methodology

Task taxonomy inclusion criteria (TC):

TC1: Has a categorization of tasks for a specific network visualization type

TC2: Is obtained empirically or by extending/adapting previous ones

TC3: Is formally evaluated and proved effective

Methodology

Discipline inclusion criteria (DC):

DC1: Should have at least one survey dedicated to it

DC2: Data type should have unique characteristics alongside networked nature

Related Work

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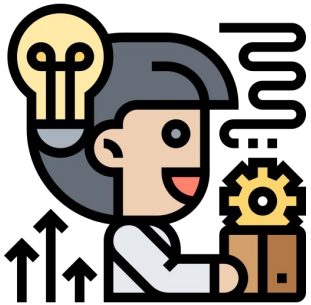
We were inspired by the idea of a meta-survey



Meta Survey on InfoVis Surveys [McNabb et al., 2017]

86 surveys from InfoVis literature

Meta Survey on Text Visualization [Alharbi et al., 2018]

13 surveys from text analysis and visualization

Meta Survey on Interpretation of ML [Chatzimparmpas et al., 2020]

18 surveys from ML about interpretability and explainability

McNabb et al., "Survey of Surveys: Mapping the landscape of survey papers in information visualization", 2017
Alharbi et al., "SoS TextVis: A survey of surveys on text visualization", 2018
Chatzimparmas et al., "A survey of surveys on the use of visualization for interpreting machine learning models", 2020

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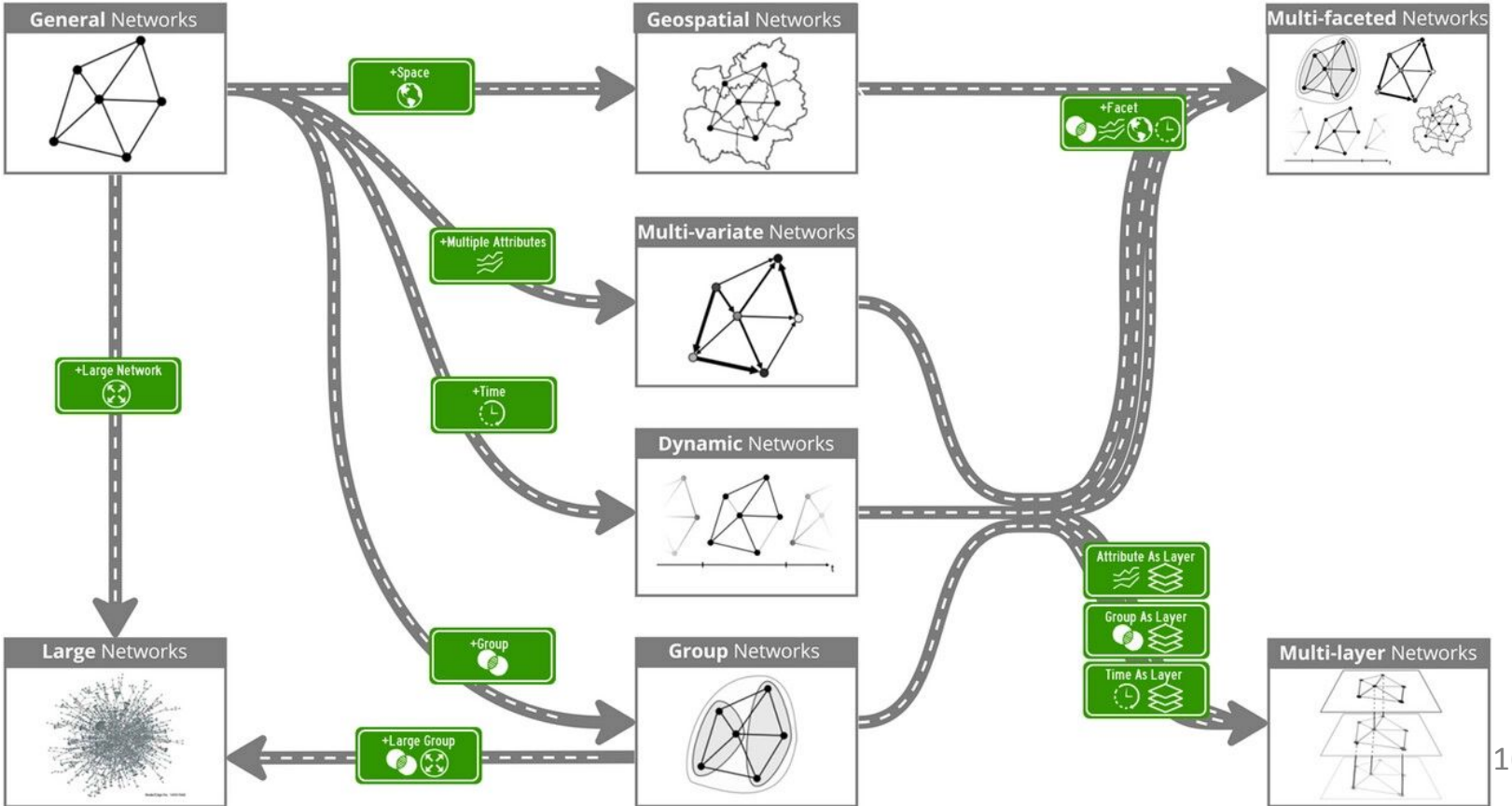
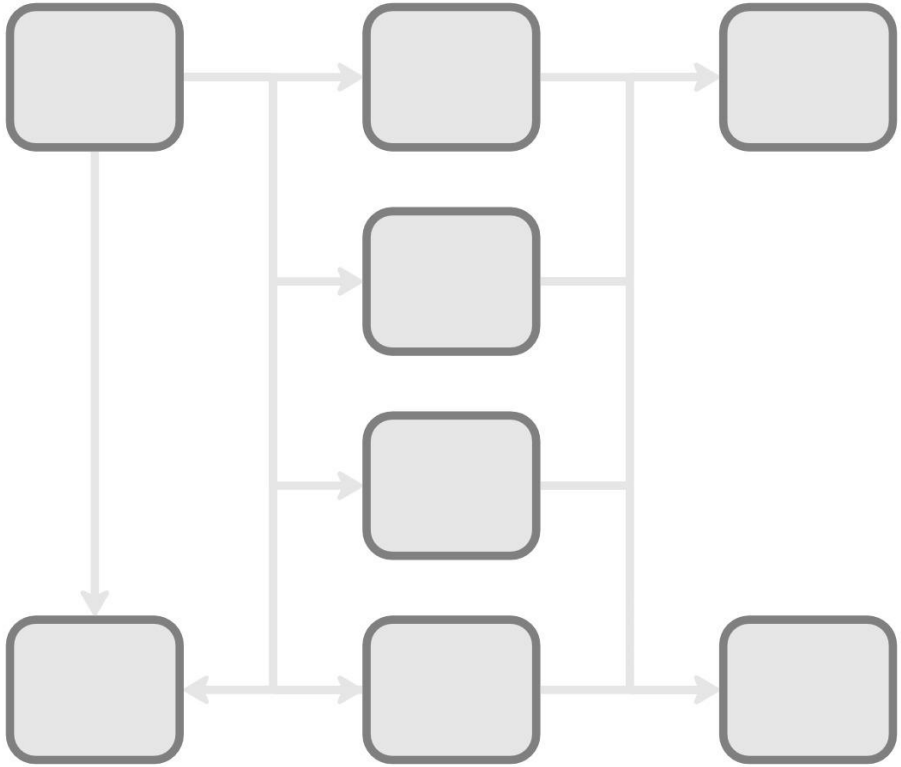
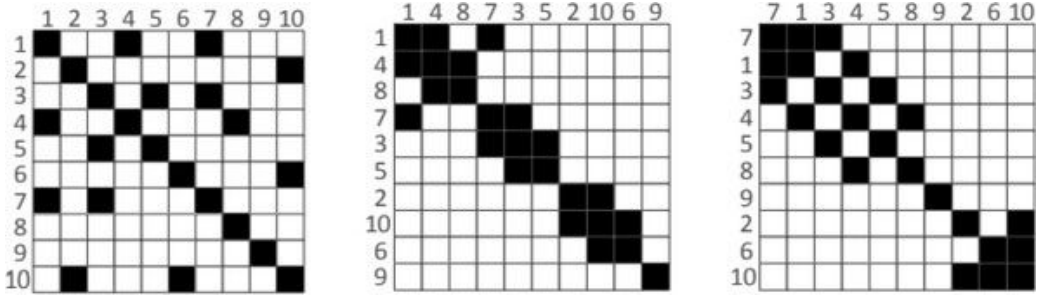
The Roadmap


General Networks
+Space
Geospatial Networks
+Facet
Multi-faceted Networks
+Multiple Attributes
Multi-variate Networks
+Large Network
+Time
Dynamic Networks
Attribute As Layer
Group As Layer
Time As Layer
Large Networks
+Group
Group Networks
Multi-layer Networks
+Large Group

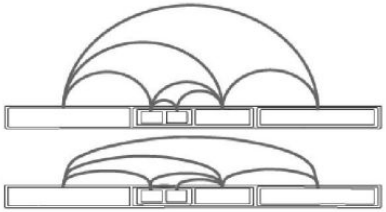
Disciplines



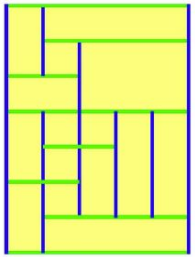
General Network Visualization



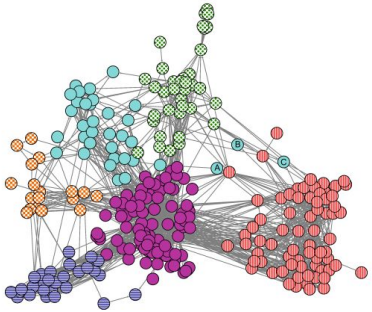
Behirsch et al., "Matrix reordering methods for table and network visualization", 2016



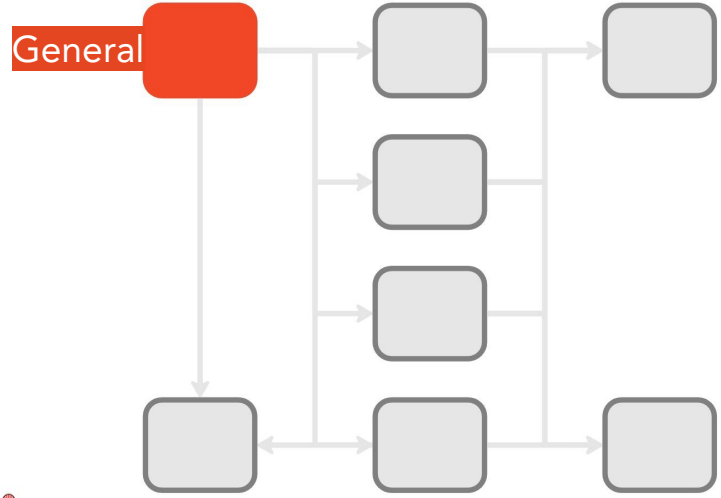
Neumann et al., "ArcTrees: Visualizing Relations in Hierarchical Data", 2005



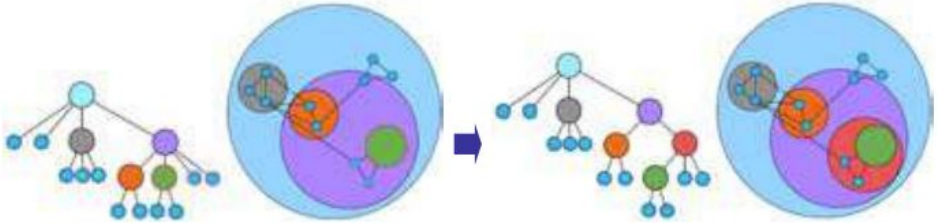
Battista et al., "Graph Drawing Algorithms for the Visualization of Graphs", 1999



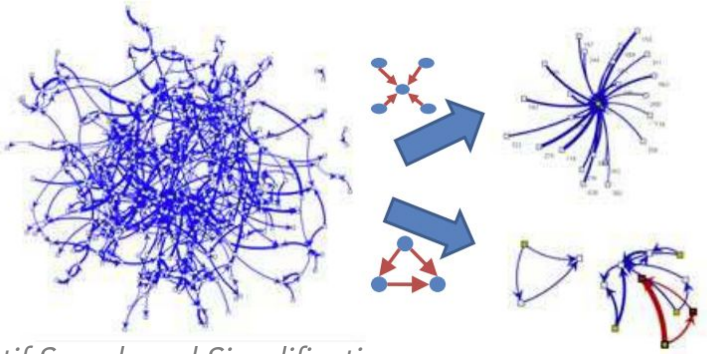
Gibson et al., "A survey of two-dimensional graph layout techniques for information visualisation", 2013



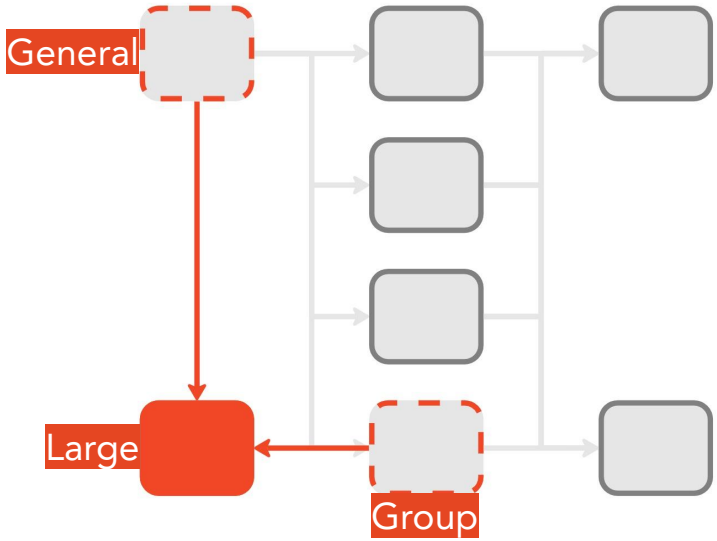
Large Network Visualization



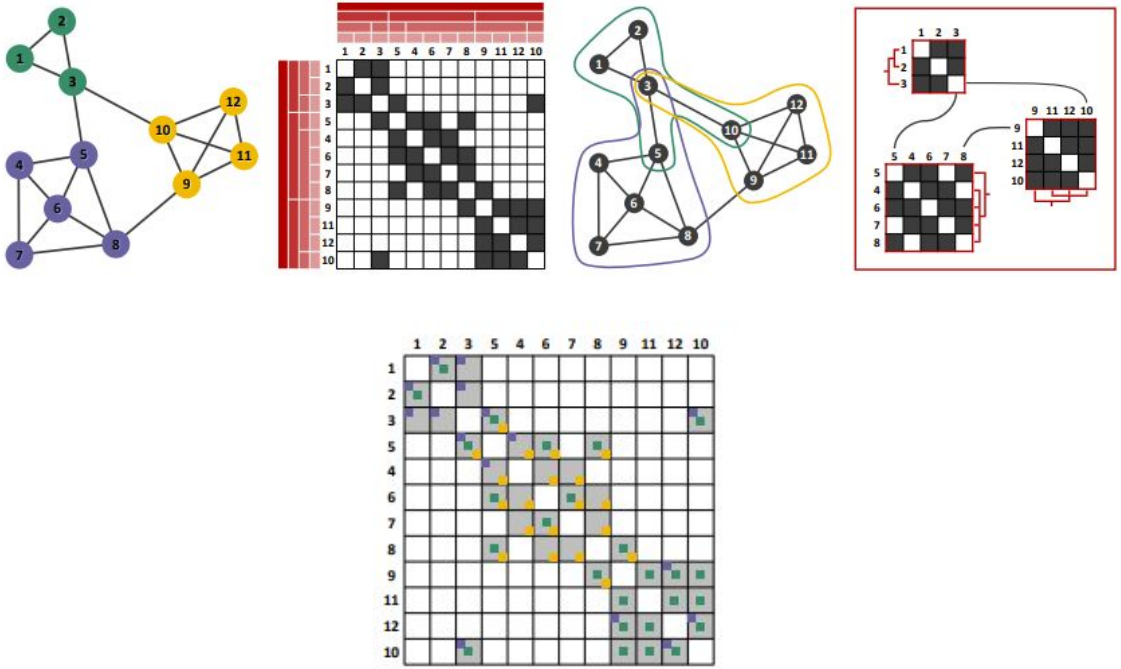
Aggregating nodes
Archambault et al., "Steerable exploration of graph hierarchy space", 2008

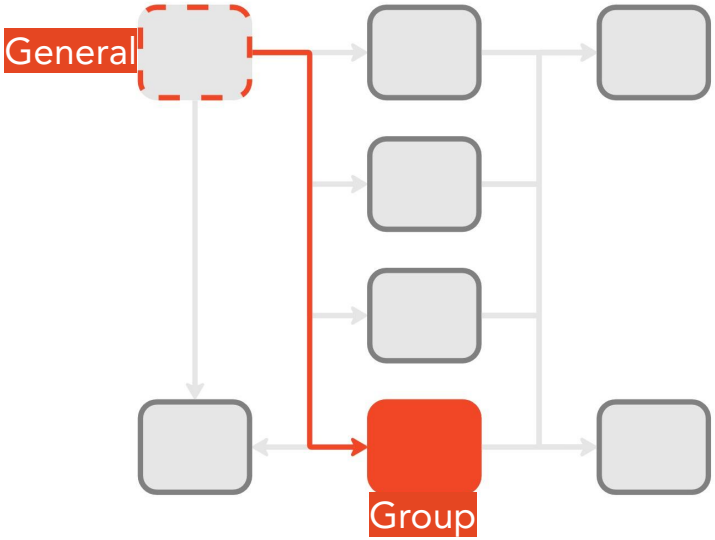


Graph Motif Search and Simplification
von Landesberger et al., "A system for interactive visual analysis of large graphs using motifs in graph editing and aggregation", 2009



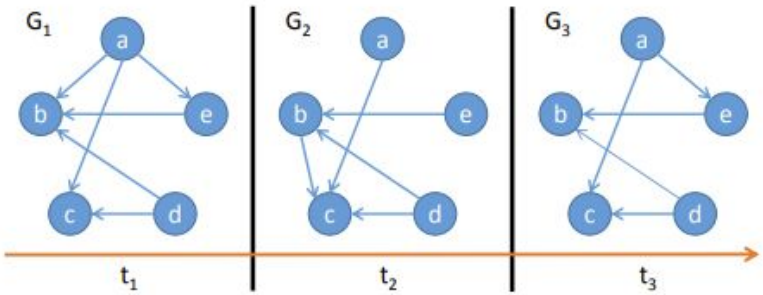
Group Network Visualization



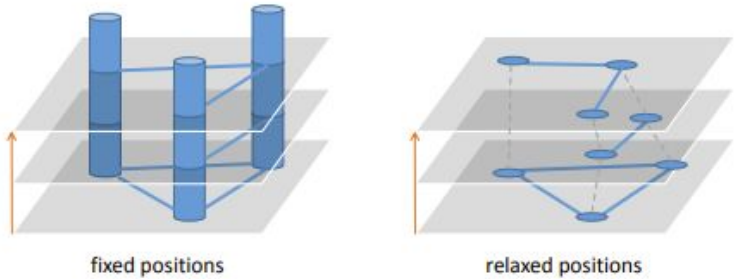


Vehlow et al., "Visualizing fuzzy overlapping communities in networks", 2013

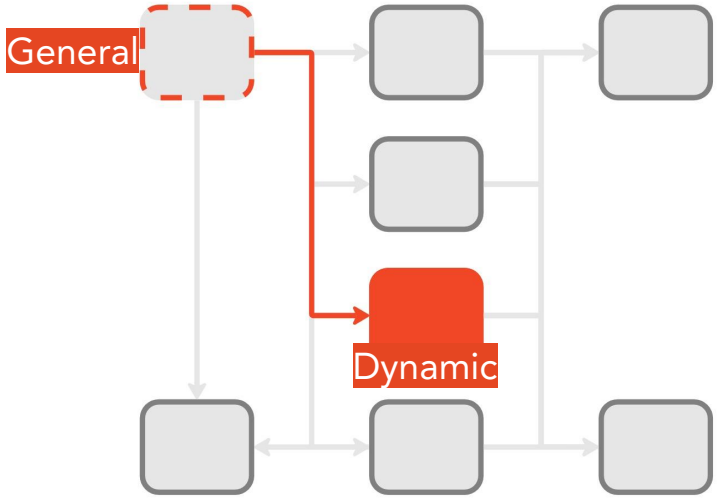
Dynamic Network Visualization



Juxtaposition

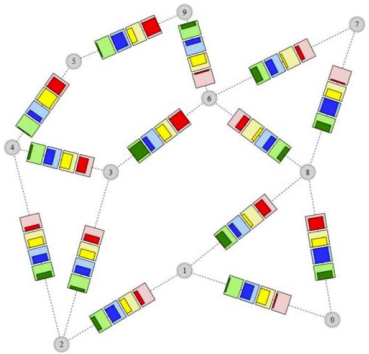


Superimposition

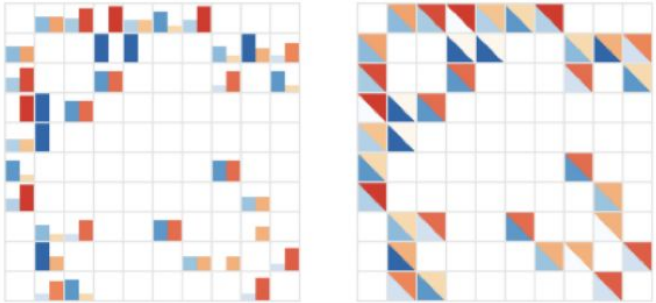


Beck et al., "A Taxonomy and Survey of Dynamic Graph Visualization", 2017

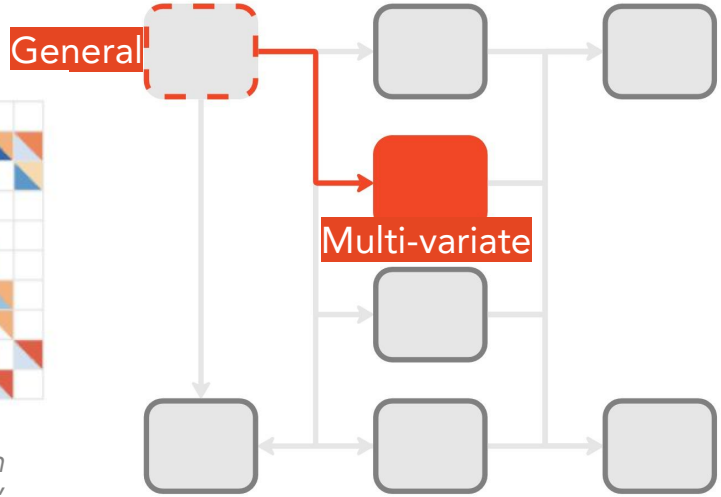
Multi-variate Network Visualization



Schöffel et al., "A User Study on Multivariate Edge Visualizations for Graph-Based Visual Analysis Tasks", 2016



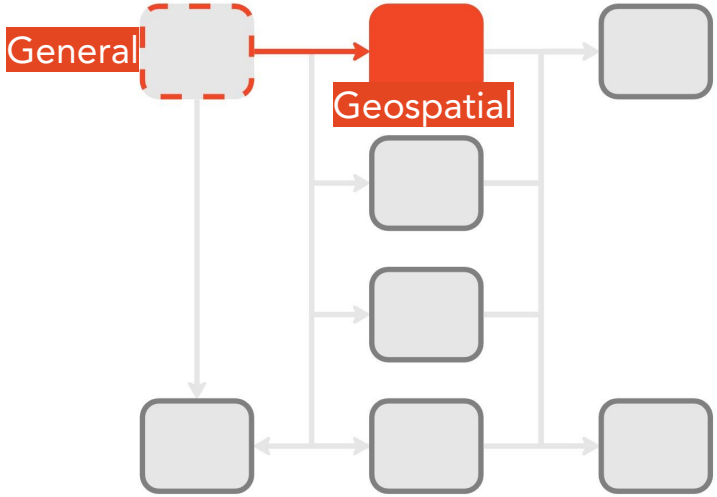
Alper et al., "Weighted graph comparison techniques for brain connectivity analysis", 2013

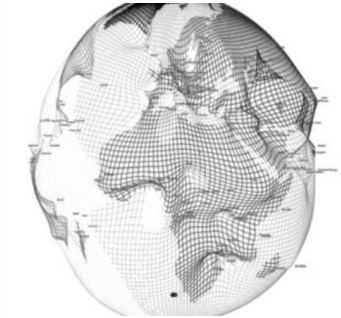


Geospatial Network Visualization

Sun, "A spatial one-to-many flow layout algorithm using triangulation, approximate Steiner trees, and path smoothing", 2019

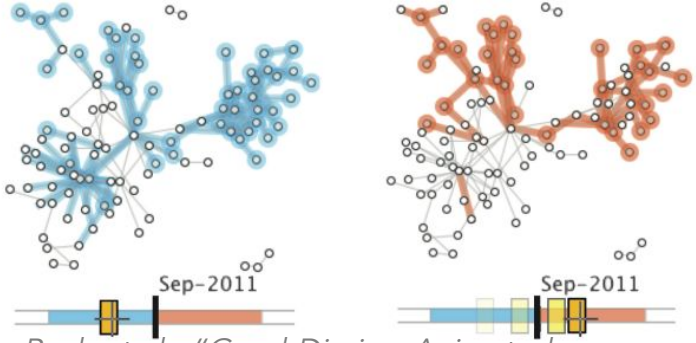
Lambert et al., "Winding Roads: Routing edges into bundles", 2010



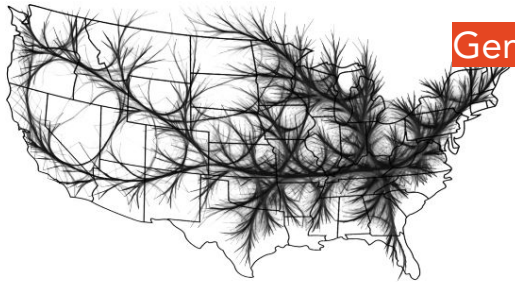


Alper et al., "Dynamic visualization of geographic networks using surface deformations with constraints", 2007

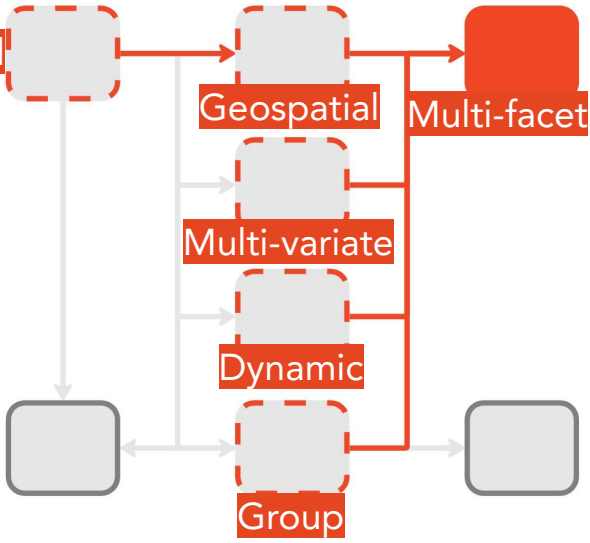
Multi-faceted Network Visualization

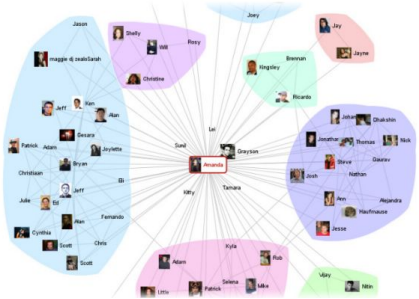


Bach et al., "GraphDiaries: Animated transitions and temporal navigation for dynamic networks", 2014

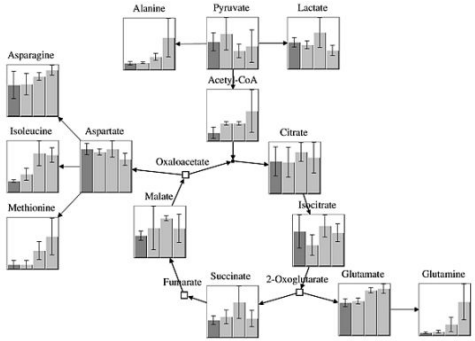


Hurter et al., "Graph bundling by kernel density estimation", 2012



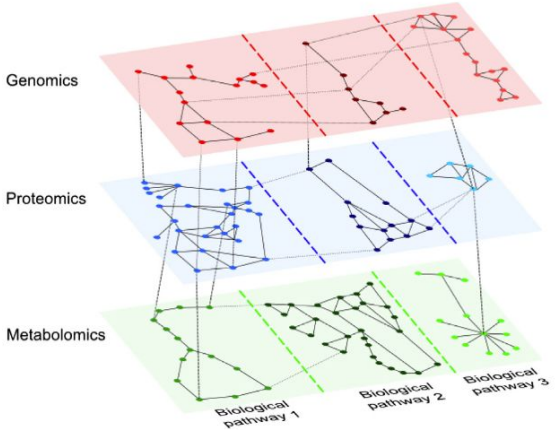


Heer et al., "Vizster: Visualizing online social networks", 2005

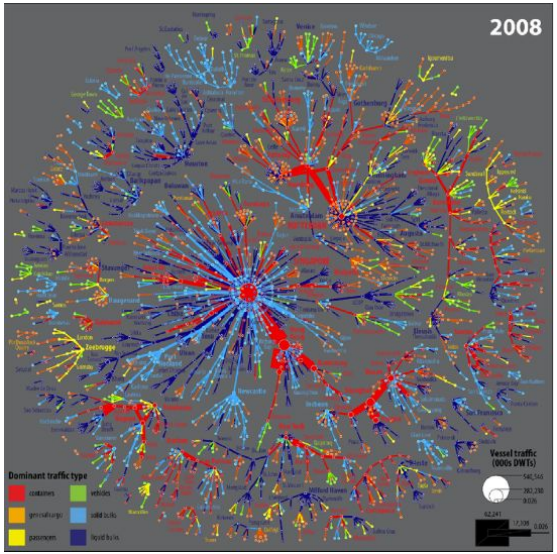


Borisjuk et al., "Integrating data from biological experiments into metabolic networks with the DBE information system", 2005

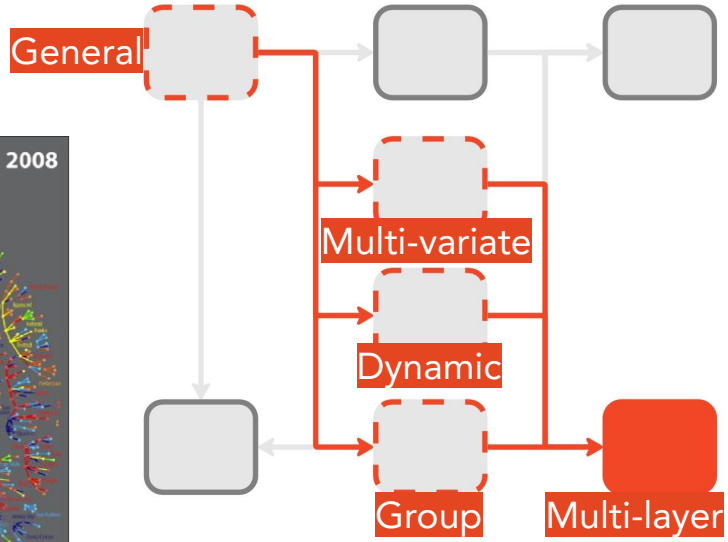
Multi-layer Network Visualization



McGee et al., "The state of the art in multilayer network visualization.", 2019



Ducruet et al., "Multilayer dynamics of complex spatial networks: The case of global maritime flows (1977–2008)", 2017



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Task Taxonomies

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Taxonomies are *lagging* behind survey literature

Majority of disciplines **lack** a dedicated task taxonomy

No **clear relationship** between existing taxonomies

We categorize these based on their **support** and **tasks**

Task Taxonomies

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Coverage refers to the existence of a taxonomy for a specific discipline

Specialized: specific to the target discipline and fully supports task for that data type

Supports comparing approaches for standard tasks

Generalized: more abstract tasks covering a broader range of data types

Can be extended/adapted for network disciplines that lack one

Generalized → Specialized

Adrienko & Adrienko, 2006 — *For dynamic network visualization* → Kerracher et al., 2015

\+

Graph data 

Lee et al., 2006

\+

Valiati et al., 2006 — *For multi-variate network visualization* → Pretorius et al., 2014

Adrienko & Adrienko, "Exploratory Analysis of Spatial and Temporal Data: A Systematic Approach.", 2006
Valiati et al., " A taxonomy of tasks for guiding the evaluation of multidimensional visualizations.", 2006
Lee et al., "Task taxonomy for graph visualization.", 2006
Kerracher et al., "A task taxonomy for temporal graph visualisation.", 2015
Pretorius et al., "Tasks for Multivariate Network Analysis.", 2014

No Support

Disciplines that lack a dedicated task taxonomy for their data type:

Large [von Landesberger et al., 2011]

Geospatial [Schöttler et al., 2021]

Multi-faceted [Hadlak et al., 2015]

Multi-layer [McGee et al., 2019]

von Landesberger et al., "Visual analysis of large graphs: State-of-the-art and future research challenges.", 2011
Schöttler et al., " Visualizing and interacting with geospatial networks: A survey and design space.", 2021
Hadlak et al., "A survey of multi-faceted graph visualization.", 2015
McGee et al., "Visual analysis of large graphs: State-of-the-art and future research challenges.", 2019

Task Taxonomies Overview

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Coverage Overview

 Generalized Support

 Specialized Support

 No Support

General	Large	Group	Dynamic	Multi-variate	Geospatial	Multi-faceted	Multi-layer
							
							

Constructing Taxonomies

Geospatial Network Visualization Taxonomy?

Lee et al., 2006

+

Roth, 2013

Specialized Task Taxonomy for Geospatial Network Visualization

Graph analysis tasks

Geovisualization tasks

Lee et al., "Task taxonomy for graph visualization.", 2006
Roth, "An empirically-derived taxonomy of interaction primitives for interactive cartography and geovisualization.", 2013

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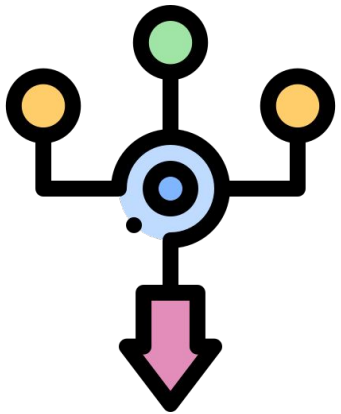
Results - Surveys

We found inconsistencies in terminology and classifications

This motivated us to establish a common dictionary across disciplines

Our consolidation has 6 higher-level groups



Consolidation

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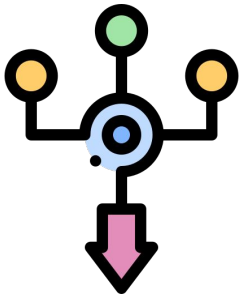
- Facet Composition
- Network Representation
- Entity Encoding
- Dimensionality
- Layout
- Aesthetic Criteria



Terminology		General	Large	Multi-faceted	Group	Dynamic	Multi-variate	Geospatial	Multi-layer
Facet Composition	Superimposition			[HSS15]	[VBW17]	[KKC14], [BBDW17], [BDA+17]		[Rod05], [SYPB21]	[KAB+14], [XLSP17], [MGM+19]
	Juxtaposition	[GK10], [LHT17]	[vLKS+11]	[HSS15]	[VBW17]	[MMB05], [KKC14], [BBDW17], [BDA+17]	[AAK+14], [NMSL19]	[SYPB21]	[KAB+14], [XLSP17], [MGM+19]
	Animation	[GK10], [LHT17]	[vLKS+11]	[HSS15]		[MMB05], [KKC14], [SL17], [BBDW17], [BDA+17]	[AAK+14]		[MGM+19]
	Timeline		[vLKS+11]	[HSS15]		[SL17], [BBDW17], [BDA+17]	[AAK+14]		
	Integration	[GK10], [CGZ+19]				[SL17], [BBDW17]	[KPW14], [NMSL19]	[SYPB21]	[MGM+19]
	Nesting			[HSS15]		[KKC14]		[SYPB21]	
	Embedding				[VBW17]	[KKC14]			
	Overloading	[GK10]		[HSS15]		[KKC14]	[NMSL19]		
	Multiple Views	[GK10], [CGZ+19]	[PAKC15]	[HSS15]	[VBW17]		[KPW14], [AAK+14], [NMSL19]	[Rod05]	[KAB+14], [MGM+19]
Network Representation	Node-Link	[HMM00], [SS06], [BRSG07], [GK10], [Kob12], [GFV13], [ZXYQ13], [WNF16], [LHT17], [CGZ+19], [CS20]	[vLKS+11], [PAKC15]	[HSS15]	[SHS10], [VBW17]	[MMB05], [KKC14], [SL17], [BBDW17], [BDA+17]	[KPW14], [AAK+14], [NMSL19]	[Rod05], [Wol07], [SYPB21]	[KAB+14], [XLSP17], [MGM+19]
	Matrix	[SS06], [GK10], [BBHR+16], [CGZ+19]	[vLKS+11], [PAKC15]	[HSS15]	[VBW17]	[KKC14], [SL17], [BBDW17], [BDA+17]	[AAK+14], [NMSL19]	[SYPB21]	[KAB+14], [XLSP17], [MGM+19]
	List	[GK10]				[SL17], [BBDW17]			
	Space-filling	[HMM00], [SS06], [GK10], [WNF16], [CGZ+19]	[vLKS+11]	[HSS15]	[SHS10]	[KKC14]	[NMSL19]		
	Hybrid	[WNF16], [CGZ+19]	[vLKS+11], [PAKC15]	[HSS15]	[VBW17]	[KKC14], [BBDW17]	[KPW14], [NMSL19]	[SYPB21]	[MGM+19]
	Alternative	[ZXYQ13], [LHT17], [CGZ+19]	[vLKS+11]			[KKC14], [BDA+17]	[AAK+14], [NMSL19]	[SYPB21]	[MGM+19]
Entity Encoding	Node	[HMM00], [SS06], [GK10], [WNF16], [CGZ+19]	[vLKS+11], [PAKC15]	[HSS15]	[SHS10], [VBW17]	[KKC14], [BBDW17], [BDA+17]	[KPW14], [NMSL19]	[SYPB21]	[KAB+14], [XLSP17]
	Link	[HMM00], [SS06], [GK10], [ZXYQ13], [WNF16], [LHT17], [CGZ+19]	[vLKS+11], [PAKC15]	[HSS15]	[SHS10], [VBW17]	[KKC14], [BBDW17], [BDA+17]	[NMSL19]	[Wol07], [SYPB21]	
	Network	[HMM00], [SS06], [GK10], [BBHR+16], [LHT17], [CGZ+19], [CS20]	[vLKS+11], [PAKC15]	[HSS15]	[SHS10], [VBW17]	[MMB05], [KKC14], [BBDW17], [BDA+17]	[NMSL19]	[SYPB21]	[KAB+14]
Dimensionality	1D	[GK10], [CGZ+19]			[VBW17]			[SYPB21]	[MGM+19]
	2D	[HMM00], [SS06], [BRSG07], [GK10], [Kob12], [GFV13], [BBHR+16], [WNF16], [LHT17], [CGZ+19], [CS20]	[vLKS+11], [PAKC15]	[HSS15]	[SHS10], [VBW17]	[MMB05], [KKC14], [SL17], [BBDW17]	[KPW14], [AAK+14], [NMSL19]	[Rod05], [Wol07], [SYPB21]	[KAB+14], [XLSP17], [MGM+19]
	2.5D	[SS06]		[HSS15]		[KKC14], [BBDW17]			[MGM+19]
	3D	[HMM00], [SS06], [GK10], [LHT17], [CGZ+19]	[vLKS+11]	[HSS15]	[SHS10], [VBW17]	[KKC14], [BBDW17], [BDA+17]	[AAK+14]	[Rod05], [SYPB21]	[KAB+14], [XLSP17], [MGM+19]
Layout	Energy-based	[HMM00], [SS06], [BRSG07], [GK10], [Kob12], [GFV13], [ZXYQ13], [WNF16], [CGZ+19], [CS20]	[vLKS+11], [PAKC15]	[HSS15]	[VBW17]	[MMB05], [SL17], [BBDW17]	[AAK+14], [NMSL19]	[Rod05], [Wol07]	[XLSP17], [MGM+19]
	Heuristic	[ZXYQ13], [BRSG07], [Kob12], [BBHR+16], [CS20]			[VBW17]		[AAK+14]	[Wol07]	
	Embedding (DR)	[GFV13], [BBHR+16], [CGZ+19], [CS20]	[vLKS+11]				[AAK+14]		[XLSP17]
	Tabular	[GK10], [BBHR+16]							
	Geometrical	[HMM00], [SS06], [GK10], [Kob12], [WNF16]	[vLKS+11], [PAKC15]	[HSS15]	[SHS10]	[SL17], [BBDW17]	[NMSL19]	[Rod05]	[MGM+19]
	Special-purpose	[HMM00], [SS06], [BRSG07], [GFV13], [ZXYQ13], [LHT17], [CGZ+19]	[vLKS+11], [PAKC15]	[HSS15]	[VBW17]	[MMB05], [SL17], [BBDW17]	[AAK+14], [NMSL19]	[Rod05], [Wol07]	[XLSP17], [MGM+19]
Aesthetic Criteria	Nodes	[HMM00], [BRSG07], [GFV13], [WNF16], [CS20]	[vLKS+11]		[SHS10]	[BBDW17]		[Wol07]	
	Links	[HMM00], [BRSG07], [GFV13], [WNF16], [CS20]	[vLKS+11]			[BBDW17]		[Wol07]	
	Mental Map	[Kob12]	[vLKS+11]					[Rod05]	
	Network	[HMM00], [BRSG07], [Kob12], [GFV13], [WNF16], [CS20]	[vLKS+11]					[Wol07]	

(see paper for definitions)

Consolidation

Facet Composition

Network Representation

Entity Encoding

Dimensionality

Layout

Aesthetic Criteria

Superimposition
Juxtaposition
Animation
Timeline
Integration
Nesting
Embedding
Overloading
Multiple View

Javed & Elmqvist, "Exploring the design space of composite visualization", 2012
Gleicher et al., "Visual comparison for information visualization", 2011

(see paper for definitions)

Consolidation

EUROVIS Leipzig 2023

Facet Composition

Network Representation

Entity Encoding

Dimensionality

Layout

Aesthetic Criteria

Superimposition

Juxtaposition

Animation

Timeline

Integration

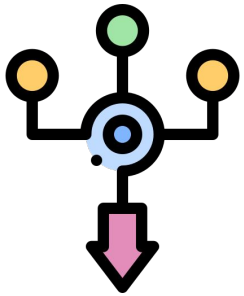
Nesting

Embedding

Overloading

Multiple View

“small multiples”
“multiple time slices”
“static flip books”



“Juxtaposition”

Consolidation

EUROVIS Leipzig 2023

Facet Composition
Network Representation
Entity Encoding
Dimensionality
Layout
Aesthetic Criteria

Energy-based
Heuristic
Embedding/Dimensionality Reduction
Tabular
Geometrical
Special-purpose

(see paper for definitions)

Consolidation

Facet Composition

Network Representation

Entity Encoding

Dimensionality

Layout

Aesthetic Criteria

Energy-based

Heuristic

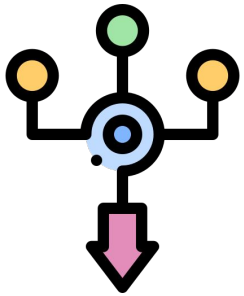
Embedding/Dimensio

Tabular

Geometrical

Special-purpose

"force-directed layout"
"spring layout"
"spring-embedder"
"spring-electrical layout"



"Energy-based"

(see paper for definitions)

Consolidation

Resulted in a *heatmap* (most and least popular concepts)

General network visualization most popular

- 2-D, node-link, energy-based layouts most discussed

Dynamic network visualization second most popular

- Juxtaposition and animation most used for temporal facet
- Balance between node-link and matrix based approaches
- Energy-based layouts most widely used

Consolidation

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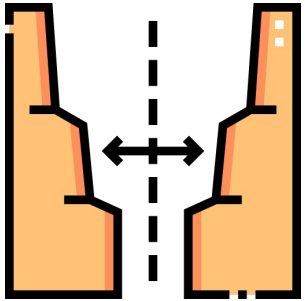
Resulted in a *heatmap* (**most** and **least** popular concepts)

Aesthetic criteria not commonly researched outside of dynamic and general network visualization

Possibly different aesthetic criteria for multi-variate, multi-layer, multi-faceted, and group network visualization?

Consolidation



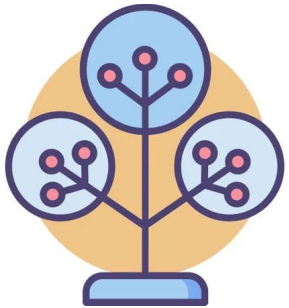
Interesting gaps

Matrices not experimented with as much as other techniques

Hybrid & Alternative visualization techniques scarcely explored

Uncertainty in networks is discussed a lot but under-investigated

Results - Taxonomies



How do the different task classifications relate?

Derived a classification of tasks from literature

Connected individual tasks and considered overlaps

Three main categories influenced by Amar et al.

- Topology
- Analytic Activity
- Facet

Amar et al., "Low-level components of analytic activity in information visualization.", 2005

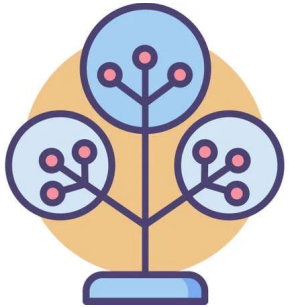
Consolidation

Topology tasks extensively covered

Operational tasks not widely explored

Operations that do not achieve a result in analysis

Time, Space, and Group facets scarcely explored as specific tasks



Topology				Analytic Activity			Facet			
Nodes	Links	Sub-networks	Networks	Operational	Analytical	Cognitive	Time	Space	Multi-variate	Group
7	7	6	5	1	7	4	3	0	5	2

7-6 5-4 3-0

Outline

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Introduction

Roadmap & Disciplines

Task Taxonomies & Coverage

Discussion & Results

Open Challenges & Summary

Ongoing Challenges

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Novel Visualization Metaphors

Size, heterogeneity, and dimensionality of networks is ever-increasing

New and alternative visualization techniques for networks have been discussed as open challenges across multiple surveys

Ongoing Challenges

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Evaluation Methodologies

Some disciplines lack specialized taxonomies

- Hindering formal evaluations/comparisons

Network visualization is increasing in complexity

- Traditional performance metrics may not be the best
- Focus on cognitive aspects, perception, and engagement

Ongoing Challenges

Interaction Techniques

Highlighted as interesting from numerous surveys

No classification or survey on interaction techniques for network visualization

Interactions to support human-assisted analysis

- Combining domain expert and automated analysis

Ongoing Challenges

Collaborative Analysis

Has big potential moving forward

Facilitating understanding and communication among collaborators

Gaining deeper insights leveraging collective intelligence

Working together synchronously or asynchronously

Conclusion

Q: *“Are we there yet?”*

A: *“No, not really.”*

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Thank you!

Contact:
Velitchko Filipov
velitchko.filipov@tuwien.ac.at

Our paper

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Questions and Discussion

Open forum for questions and discussion

meta-survey of network visualization

Taxonomies Coverage

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Low-level tasks for InfoVis [Amar et al., 2005]

Exploratory analysis of spatio-temporal data [Adrienko & Adrienko, 2006]

Multi-level typology of abstract visualization tasks [Brehmer & Munzner, 2013]

High-level multi-dimensional visualization analysis tasks [Valiati et al., 2006]

Tasks for interactive cartography and geovisualization [Roth, 2013]

General Network Visualization [Lee et al., 2006; Pandey et al., 2021]

Group Structure Visualization [Saket et al., 2014]

Dynamic Network Visualization [Ahn et al., 2016; Bach et al., 2014; Kerracher et al., 2015]

Multi-variate Network Visualization [Pretorius et al., 2014]

Amar et al., "Low-level components of analytic activity in information visualization.", 2005
Adrienko & Adrienko, "Exploratory Analysis of Spatial and Temporal Data: A Systematic Approach.", 2006
Brehmer & Munzner, "A multi-level typology of abstract visualization tasks.", 2013
Valiati et al., " A taxonomy of tasks for guiding the evaluation of multidimensional visualizations.", 2006
Roth, "An empirically-derived taxonomy of interaction primitives for interactive cartography and geovisualization.", 2003

Lee et al., "Task taxonomy for graph visualization.", 2006
Pandey et al., "A state-of-the-art survey of tasks for tree design and evaluation with a curated task dataset.", 2021
Saket et al., "Group-level graph visualization taxonomy." 2014
Ahn et al., "A task taxonomy for network evolution analysis." 2016
Bach et al, "GraphDiaries: Animated transitions and temporal navigation for dynamic networks.", 2014
Kerracher et al., "A task taxonomy for temporal graph visualisation.", 2015
Pretorius et al., "Tasks for Multivariate Network Analysis.", 2014

Generalized Support

Low-level tasks for InfoVis

[Amar et al., 2005]

Tasks for exploratory analysis of spatio-temporal data

[Adrienko & Adrienko, 2006]

Multi-level typology of abstract visualization tasks

[Brehmer & Munzner, 2013]

High-level multi-dimensional visualization analysis tasks

[Valiati et al., 2006]

Tasks for interactive cartography and geovisualization

[Roth, 2013]

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Specialized Support

General Network Visualization

[Lee et al., 2006; Pandey et al., 2021]

Group Structure Visualization

[Saket et al., 2014]

Dynamic Network Visualization

[Ahn et al., 2016; Bach et al., 2014; Kerracher et al., 2015]

Multi-variate Network Visualization

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