Tangraphe: Interactive Exploration of Network Visualizations using Single Hand, Multi-touch Gestures

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ABSTRACT

Touch-based displays are becoming a popular medium for interacting with visualizations. Network visualizations are a frequently used class of visualizations across domains to explore entities and relationships between them. However, little work has been done in exploring the design of network visualizations and corresponding interactive tasks such as selection, browsing, and navigation on touch-based displays. Network visualizations on touch-based displays are usually implemented by porting the conventional pointer based interactions as-is to a touch environment and replacing the mouse cursor with a finger. However, this approach does not fully utilize the potential of naturalistic multi-touch gestures afforded by touch displays. We present a set of single hand, multi-touch gestures for interactive exploration of network visualizations and employ these in a prototype system, Tangraphe. We discuss the proposed interactions and how they facilitate a variety of commonly performed network visualization tasks including selection, navigation, adjacency-based exploration, and layout modification. We also discuss advantages of and potential extensions to the proposed set of one-handed interactions including leveraging the non-dominant hand for enhanced interaction, incorporation of additional input modalities, and integration with other devices.

CCS CONCEPTS

• **Human-centered computing → Gestural input**; *Graph drawings*;

KEYWORDS

Network Visualization; Multi-touch Interaction; Interaction Design

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1 INTRODUCTION

Network visualizations, often in the form of node-link diagrams are frequently used to explore and present data relationships in various domains including but not limited to social networks [10], business ecosystems [2], and biology [21], among others. Network visualization has been a topic of keen interest within the information visualization (InfoVis) research community and there exist numerous commercial, open-source, and free tools and systems for visual network exploration and analysis [2, 3, 10, 32]. The crucial role of interaction in information visualization is widely recognized [24, 38]. Interaction is critical to network visualizations as it allows users to better understand relational patterns between entities, discover entities with prominent structural characteristics, and identify clusters of interest [11].

An increasingly important research theme within the InfoVis community over the past few years has been that of designing visualization systems to run on devices with enhanced input modalities that go beyond the traditional mouse and keyboard [18]. Such interfaces, commonly referred to as post-WIMP interfaces, have explored a variety of input modalities including touch [5, 27], mid-air gestures [1, 17], and natural language [33], among others. While there are a growing number of visualization tools for post-WIMP interfaces, only a few of these tools support network visualizations, and exploring this design space remains an open challenge [12]. With touch displays becoming practically ubiquitous and the increasing computational capacity of smaller portable devices such as phones and tablets, it is important that visualization systems exist that allow users to explore their data using network visualizations on touch-based devices in a natural and fluid manner [6].

In this paper, we present a set of single hand, multi-touch gestures that can let users interactively explore networks and perform various operations including selection, navigation, and basic layout modification. We employ the proposed gestures in a prototype network visualization tool, Tangraphe, and describe how the tool supports interactive network exploration through a usage scenario. Our work contributes to the growing number of touch-based visualization systems, and more specifically, to the interaction design space of network visualizations (particularly node-link diagrams) on touch devices. Finally, we discuss potential extensions to the proposed set of interactions including incorporation of additional modalities and integration with other devices.

2 RELATED WORK

As stated earlier, networks have been extensively studied within the InfoVis community, as summarized in [11, 36]. Motivated by the importance of understanding tasks in visualization research, various researchers have proposed different task taxonomies for network visualizations [19, 25, 29]. In our work, we seek to support a variety of tasks listed by these taxonomies through lower-level operations such as selections, navigation, and layout modification.

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We particularly focus on supporting topology- and browsing-based tasks with respect to Lee et al.'s taxonomy [18] as these have been shown to be a representative sample of some of the most common and core tasks during visual exploration of networks.

Given the widespread adoption of direct manipulation as an interaction technique on WIMP interfaces, touch-based input has almost naturally been the common choice for designing InfoVis systems on post-WIMP interfaces. Researchers have explored InfoVis systems on touchscreen devices ranging from watches [13, 31] to tablets [5, 26, 27] to large displays including tabletops [23, 35] and wall mounted displays [20, 40], discussing both individual and collaborative scenarios [1, 15, 35]. Such efforts have shown that existing WIMP-based visualization systems cannot simply be "ported" to these new devices and often require significant changes in the interaction style even for basic tasks such as selection [28].

With respect to network visualizations on post-WIMP interfaces, among the early work was Frisch et al.'s [7] investigation of how people edit node-link diagrams using pen and touch on tabletop surfaces. Cordeil et al. [4] investigated the relative advantages of immersive technologies like CAVE-style environments and low-cost head-mounted displays (HMDs) for collaborative analysis of network connectivity. More recently, Kister et al. [16] presented GraSp, a system that leverages proximally aware mobile devices to facilitate network exploration and analysis on large wall displays. Most related to our work is the work by Schmidt et al. [30] who propose a set of multi-touch gestures specifically focusing on edge interactions for node-link diagrams to enable operations such as selections and edge congestion. However, in our work, we support selections of both nodes and edges, and also provide some explicit gestures for simple node-based layout modification operations. More importantly, the gestures in our case are limited to a single hand, allowing users to employ their non-dominant hands for other tasks such as holding the device in the case of tablets or to leverage a second device such as a smartwatch or a phone to get additional details based on interactions with their dominant hand.

3 INTERACTION TECHNIQUES AND PROTOTYPE

In this section, we first present the various interaction techniques we support for common operations performed during visual network exploration. We then describe our prototype system, Tangraphe, which employs these interaction techniques. Finally, we demonstrate how the interaction techniques can be used for visual network exploration through a usage scenario. We also provide a supplementary video showcasing these interactions [1].

3.1 Supported Interactions

In our design, we focused on node-link diagrams as these are one of the most common representations for network data. Further, we wanted to design a set of interactions that could work across touch devices of different sizes. Correspondingly, we constrained our design space to single hand gestures as in the case of devices like tablets, the non-dominant hand is often required to hold the device itself [27, 37, 39]. While designing the interactions, we sought to leverage gestures that were familiar to users based on their prior experiences with touch devices and network visualizations, and yet, were distinguishable from each other.

We focus on exploring interaction techniques for four core groups of operations that are commonly required when performing common network visualization tasks such as topology- and browsing-based tasks [19]. These groups include *(1) selection*, *(2) adjacency-based exploration*, *(3) navigation*, and *(4) layout modification*. Below we describe the set of multi-touch, single-handed interaction techniques we support for each of these groups of operations.

Selection

Selecting an individual node or link, or a particular sub-network is one of the most common operations in any network visualization tool. Further, adjacency-based tasks, a subcategory of topology-based tasks [19] are extremely common with network visualizations. Consequently, in addition to selection of individual nodes, we also provide gestures to select a specific node and its first-degree network. Selection of nodes and links are supported as follows:

- *Selecting individual nodes.* Single tap on a node selects it. Nodes can be added to the selection by tapping on them individually.
- *Selecting an individual link or a group of links.* A single finger swipe across a link selects the link. A swipe across multiple links selects all of them (Figure 1B).
- *Selecting a node and its first-degree network.* A long press on a node selects the node, its links, and its neighboring nodes (nodes directly connected to the selected node).
- *Selecting a sub-network.* A three-finger gesture can be used to draw a free-form selection area (a lasso). All nodes and links enclosed within the selection area are selected (Figure 1C).

Following all selection operations, a radial context menu (Figure 1A) appears at the end of the selection gesture. The context menu appears at the location where the gesture ended, and it allows the user to perform a set of common actions such as removing the selected nodes and links. The actions in the context menu are dynamically presented based on the contents of the selection.

The contents of a selection can contain only nodes, only links, or both nodes and links. In cases where both nodes and links are selected, the context menu provides options to winnow in on the selection by only selecting nodes, or only selecting links. Similarly, when only links, or only nodes are selected the context menu allows swapping selections between links and nodes, and vice versa. For example, in the case of a single swipe gesture to select edges, users get an option in the context menu to select (exclusively or in addition to the links) all the nodes corresponding to the selected links. Similarly, in the case of a three-finger gesture to select a sub-graph, the context menu can be used to select only the nodes or links.

Adjacency-based Exploration

Network visualization tools often enable different strategies for exploration including top-down and bottom-up. In top-down exploration, users look at the entire network and then drill down into more focused sub-networks. By contrast, with bottom-up exploration, users begin with a focused sub-network (or even a single node) and then expand outwards to see the bigger picture. A common approach for network visualization tools to support both of these strategies is providing an expand/collapse feature where

[1] Link to supplementary video: https://goo.gl/pdNUJd

nodes can be "expanded" to add their neighbors to the visualization or "collapsed" to remove neighbors from the visualization. Expand/collapse of nodes is supported in the following ways:

- Double tapping a node expands or collapses the node depending on the state of the node (expanded or collapsed).
- Whenever one or more node(s) are selected via any of the previously described gestures, expand/collapse options are provided via the context-menu (Figure 1A).

Navigation

Even small- or medium-sized networks with tens or a few hundred nodes can become difficult to fit in the available screen space depending on the device. Correspondingly, navigation operations such as pan and zoom are critical to allow users to look at specific sections of the network at a time and navigate to different regions. Pan and zoom are supported as follows:

- *Zoom.* A conventional two-finger pinch gesture is used to zoom in or out of the network.
- *Pan.* A two-finger drag is used for panning.

Our design rationale for choosing a two-finger drag as opposed to the conventional one-finger drag for pan was twofold. First, the single finger drag for pan would conflict with the link selection gesture (Figure 1B). The single finger swipe maps well to link selection because it is similar to the single finger tap to select a node. Along these lines, the second reason was that we wanted to maximize commonalities between gestures for operations within the same category (e.g., node and link *selection*, zoom and pan for *navigation*). Accordingly, since zooming requires two fingers, we use two fingers for panning too.

Layout Modification

Node-link diagrams are often rendered using network layout algorithms such as a force-directed layout [14], circular layout [8], etc. These layouts automatically compute node positions based on various aesthetic and structural properties. However, during exploration, users may want to reorganize the layout in a way that better maps to their mental models and helps them explore the network more freely. For example, users may wish to create a separate cluster of a sub-network to explore it further. Basic layout modifications are supported in two ways, as described below:

- *Pinning/Unpinning Nodes.* A node can be dragged with a single finger. Releasing the dragged node pins it, and it is no longer re-positioned by the layout algorithm. A pinned node can be unpinned using the context menu or by "shaking" a node using a single finger flick gesture similar to the TouchStrumming gesture presented by Schmidth et al. [30].
- *Attracting/Repelling Neighbors.* Oftentimes, based on the layout algorithm, nodes can be rendered at relatively distant positions even though they are directly connected to each other. Especially in cases where a user cannot see the entire graph and has to zoom into smaller regions, this distance can be even more difficult to cope with while inspecting a node's neighborhood. Instead of dragging nodes individually, when a node has been long-pressed, a five-finger pinch gesture can be used to pull/push (or attract/repel) the selected node's first-degree connections (Figure 1D). This adjusts the neighboring nodes' positions similar to the "Bring & Go" topology-based network interaction technique [22].

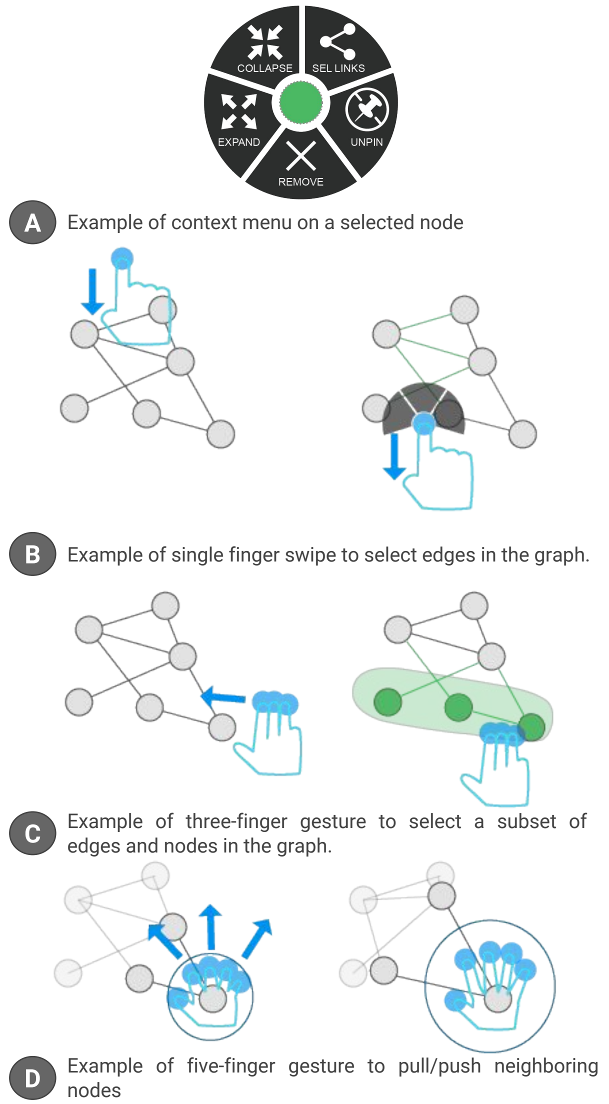


Figure 1: Examples of multi-touch interactions and selection context menu. Selected nodes and edges are colored green.

3.2 Tangraphe

System Overview. We employed the aforementioned interaction techniques in a network visualization tool, Tangraphe. Figure 2 shows Tangraphe's user interface that consists of two primary components: the visualization canvas (Figure 2A) and the details panel (Figure 2B) that shows details of selected nodes and links. Tangraphe uses a force-directed layout to determine the initial positions of nodes. Nodes are represented as circles and links as straight lines between them. By default, nodes that are added to the canvas are in a "collapsed" state and have a blue fill. When a node is expanded, the fill is changed to light blue. When nodes or links are selected, they are colored green.

Usage Scenario. To provide a better sense of how the described interaction techniques enable visual network exploration, we now describe a hypothetical usage scenario of Tangraphe being used on a vertically mounted touch display. Imagine Sam, a government contractor who has a dataset of hundreds of international organizations and alliances them. Sam is interested in understanding relationships between various organizations in general and identifying sub-networks that may be interesting for further analysis. To begin his analysis, Sam loads a subset of the network containing only North American and European companies into Tangraphe as he is more aware of companies from those continents.

To look at the available list of alliances, Sam casually swipes through the network using a single finger swipe gesture. This selects most of the links on screen and presents their details such as alliance title, date, summary, etc. Sam then starts glancing through their details and a cross country alliance between *NASA* and *BP Chemicals International* pertaining to the development of a liquid resin system catches his attention. To focus on NASA and its partners further, Sam locates the NASA node and drags it to the open area at the bottom right corner of the canvas to pin it there. Sam then long presses the NASA node and uses the five-finger pinch gesture to bring NASA's connections closer to the node (Figure 3A). Using the two-finger pan gesture, Sam brings NASA and its two partners in the current network, *BP Chemicals International* and *Chemische Werke Huls AG* to the center of the canvas.

Sam then double taps NASA to expand it and see if there are other companies it is connected to outside North America and Europe. This brings in two other companies, *Tosoh Corp* from Japan and *Chemical Fabrics Corp* from India and also adds several links between these companies and the three previously existing companies. To see if there are any other nodes that these five companies are connected to, Sam uses the three-finger gesture to draw a selection area around the nodes and expands them using the context menu (Figure 3B). This does not add any new nodes or links. Sam notes this cluster as a potentially interesting network to analyze further and starts reading about alliances in the sub-network using the single swipe link selection gesture.

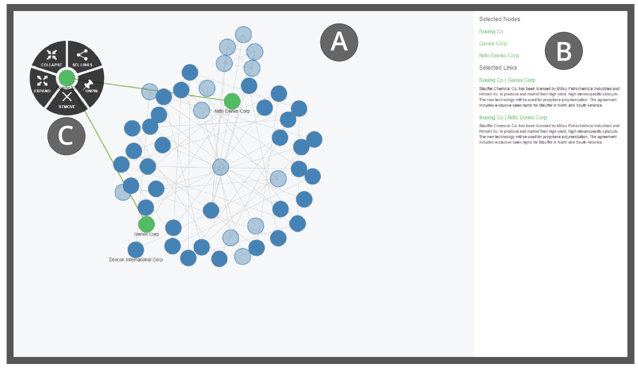
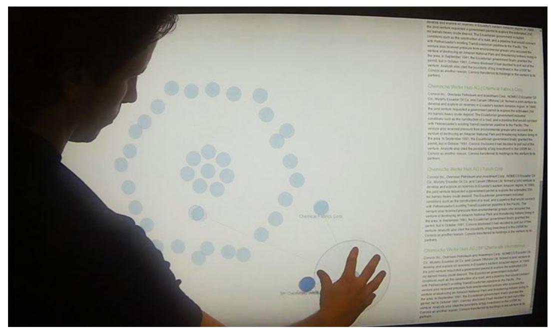
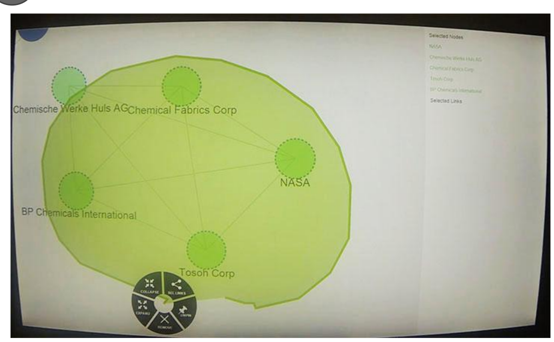


Figure 2: Tangraphe User Interface. (a) Visualization canvas, (b) Details panel and (c) Radial context menu



A Isolating the NASA network with five-finger pinch gesture.



B Selecting the NASA sub-network with a three-finger swpie.

Figure 3: Exploring alliance network with Tangraphe.

4 FUTURE WORK

Our current suite of interactions support a variety of common operations such as selection, navigation, adjacency-based exploration, and layout modifications and enable a range of network visualization tasks. However, remain several areas for improvement and exploration of future work. First, our current interaction set is based on reviewing prior work, our own experimentation, and some informal testing with fellow researchers. However, conducting observational studies and formal evaluations to measure the learnability and usability of the supported gestures and more importantly how well they facilitate visual analysis and exploration tasks is important to improve and build upon our current work.

One line of future work involves allowing users to leverage their non-dominant hand for complementary tasks. For instance, consider cases where users are interacting with the network on a relatively large display as in the usage scenario described above. Since only one hand is required for performing the gestures, as shown by recent work of Horak et al. [13], the non-dominant hand can be used to host a second smaller device such as a smartwatch and enable a more fluid, interactive experience [6]. Context menus play an important role in our current prototype. However, new devices such as Microsoft's Surface dial present the opportunity to explore new user interface techniques where the non-dominant hand can be used to navigate content menus and be used for other operations like generalized selection [9, 28]. Another open area for exploration is that of incorporating additional input modalities. For instance, recent work by Srinivasan and Stasko [34] explored how touch- and speech-based multimodal input can be used to facilitate visual network exploration and analysis. Especially in the case of devices like tablets where the users' non-dominant hands are typically pre-occupied, exploring how speech input could be used to complement the presented touch gestures is another avenue for future exploration.

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