# Multi-touch Graph-Based Interaction for Knowledge Discovery on Mobile Devices: State-of-the-Art and Future Challenges

Andreas Holzinger[1], Bernhard Ofner[1], and Matthias Dehmer[2]

[1] Research Unit Human-Computer Interaction, Institute for Medical Informatics,
Statistics & Documentation, Medical University Graz, Austria
{a.holzinger,b.ofner}@hci4all.at

[2] Department of Computer Science, Universität der Bundeswehr München
Neubiberg, Germany
matthias.dehmer@unibw.de

**Abstract** Graph-based knowledge representation is a hot topic for some years and still has a lot of research potential, particularly in the advancement in the application of graph-theory for creating benefits in the biomedical domain. Graphs are most powerful tools to map structures within a given data set and to recognize relationships between specific data objects. Many advantages of graph-based data structures can be found in the applicability of methods from network analysis, topology and data mining (e.g. small-world phenomenon, cluster analysis). In this paper we present the state-of-the-art in graph-based approaches for multi-touch interaction on mobile devices and we highlight some open problems to stimulate further research and future developments. This is particularly important in the medical domain, as a conceptual graph analysis may provide novel insights on hidden patterns in data, hence support interactive knowledge discovery.

**Keywords:** Graph Based Interaction, Graph Theory, Graph-based Data Mining, Multi-Touch, Interactive Node-Link Graph Visualization.

## 1 Introduction and Motivation

Graphs and Graph-Theory [1] are powerful tools to map data structures and to find novel connections between single data objects [2,3]. The inferred graphs can be further analyzed by using graph-theoretical and statistical techniques [4]. A mapping of already existing and in medical practice approved *knowledge spaces* as a conceptual graph and the subsequent visual and graph-theoretical analysis may bring novel insights on hidden patterns in the data, which exactly is the goal of knowledge discovery [5]. Another benefit of the graph-based data structure is in the applicability of methods from network topology and network analysis and data mining, e.g. small-world phenomenon [6,7], and cluster analysis [8,9]. The main contribution of this paper is a blend of graph-theory and multi-touch

A. Holzinger, I. Jurisica (Eds.): Knowledge Discovery and Data Mining, LNCS 8401, pp. 241–254, 2014.

interaction to stimulate further research; these ideas follows exactly the HCI-KDD approach of bringing together "the best of two worlds" [10]; both concepts applied together can offer enormous benefits for practical applications.

This paper is organized as follows: In section 2 we provide a short glossary to ensure a common understanding; in section 3 we discuss the state-of-the-art in multi-touch interaction, multi-touch gesture primitives, and multi-touch graph interaction. In section 4 we present the state-of-the-art in node-link graphs and interactive node-link graph visualization. In section 5 we provide an example of an empirically proved biomedical knowledge space and in section 6 we discuss some open problems in order to stimulate further research; we conclude the paper with a short future outlook.

## 2 Glossary and Key Terms

*Network:* Synonym for a graph, which can be defined as an ordered or unordered pair $(N, E)$ of a set $N$ of nodes and a set $E$ of edges [3]. Engineers often mention: Data + Graph = Network, or call at least directed graphs as networks; however, in theory, there is no difference between a graph and a network.

*Undirected Graph:* each edge is an unordered pair of nodes, i.e., $E \subseteq \{(x, y)|x, y \in N\}$ [1].

*Directed Graph:* each edge is an ordered pair, i.e., $E \subseteq \{(x, y)|x, y \in N\}$, and the edge $(x, y)$ is distinct from the edge $(y, x)$ [1].

*Relative Neighbourhood Graphs (RNG):* introduced by Toussaint (1980) [11], they capture the proximity between points by connecting nearby points with a graph edge; the various possible notions of "nearby" lead to a variety of related graphs.

*Sphere-of-Influence Graph (SIG(V)):* Let $C_p$ be the circle centered on $p$ with radius equal to the distance to a nearest neighbour of $p$. SIG(V) has node set $V$ and an edge $(p, q)$ iff $C_p$ and $C_q$ intersect in at least two points.

*Multi-touch:* refers to the abilities of a touch-screen [12], to recognize the presence of two or more points of contact. This plural-point awareness is often used to implement advanced functionalities such as pinch to zoom or activating certain subroutines attached to predefined multi-touch gestures [13].

*Graph Mining:* is the application of graph-based methods to structural data sets [14], a survey on graph mining can be found here [15].

*Pattern Discovery:* subsumes a plethora of data mining and machine learning methods to detect complex patterns in data sets [16]; applications thereof are, for instance, subgraph graph mining [14] and string matching [17].

*Frequent Subgraph Mining:* is a major challenge of graph mining and relates to determine all frequent subgraphs of a given class of graphs. Their occurrence should be according to a specified threshold [14].

*Small World Networks:* are generated based on certain rules with high clustering coefficient [3, 18] but the distances among the vertices are rather short in average, hence they are somewhat similar to random networks and they have been found in several classes of biological networks, see [19].

*Cluster Analysis Problem:* refers to partitioning a collection of $n$ points in some fixed-dimensional space into $m < n$ groups that are "natural" in some sense ($m \ll n$) [8, 9].

*Cyclicity:* Graph property measuring structural complexity, introduced by Bonchev et al. [20].

*Branching:* a precise definition of the concept of branching still remains a challenge [21, 22], but several indices have been suggested to measure branching in trees, including the Bonchev-Trinajstić index [23] and the Wiener index [24].

## 3 State-of-the-Art I: From Multi-touch Interaction to Multi-touch Graph Interaction

### 3.1 Multi-touch Interaction

Multi-touch input is a classic topic in Human–Computer Interaction and an active area of research with a history of several decades [13], [25].

Touch screens put the fingers in touch with the content in computer screens, consequently are considered as the most natural of all input devices [12]. The most obvious advantage of touch screens is that the input device is also the output device. Enhancing the advantages of the touch paradigm even more, multi-touch input can sense the degree of contact in a continuous manner along with the amount and location of a number of simultaneous points of contact [13]. A good introduction into multi-touch technologies can be found at the Natural User Interface Group, an open source HCI community [26].

Inspired by studies on human-short term memory requirements during keyboard operation by Alden et al. (1972) [27], Mehta et al. (1982) [28] laid the foundations for the triumph of multi-touch technologies, which today dominate the input technology of smartphones and tablets, and their success is also related to the renaissance in stylus-based input technologies [29].

Several studies have shown that multi-touch can be beneficial for interaction [30], [31], [32], and can particularly be useful for applications in the biomedical domain [33], [34], [35], [36].

However, this area is still a not well covered research area, e.g. a search for title="multi-touch interaction" on the Web of Science (WoS) resulted in only 13 hits, topic ="multi-touch interaction" brought still only 47 results (as of April, 19, 2014). The most recent work is "A Fast and Robust Fingertips Tracking Algorithm for Vision-Based Multi-touch Interaction" by [37]. The oldest paper is on "Flowfield and beyond: Applying pressure-sensitive multi-point touchpad interaction" by [38], and the most cited (17 references as of April, 19, 2014) is "ThinSight: Versatile Multi-touch Sensing for Thin Form-factor Displays" by [39].

Most relevant for our paper are the recent advances in the development of multi-touch *gesture sets*. There is a lot of research available on sketch recognition and free-hand gesture recognition, see e.g. [40], [41], [42], [43], [44], but there are only few works on the construction of gesture sets for multi-touch applications: Wu et al. (2006) [45] identify the creation of multi-touch gesture sets as a relevant problem, and provide guidelines to build effective sets, and a more recent work is [46], a very recent work is [47].

### 3.2 Multi-touch Gesture Primitives

Kammer et al. [48] defined the basic information supplied for gesture recognition as coordinates on a two-dimensional surface, and proposed strategies for formalization of gestural interaction on multi-touch surfaces. The resulting Gesture Formalization For Multi-Touch language (GeForMT) attempts to describe continued contacts by introducing five language elements:

1. the Pose Function, which describes the shape of the recognized contact on the touch device,
2. Atomic Gestures, such as `MOVE`, `POINT`, `DEPOINT`, `LINE`, `CIRCLE`
3. Composition Operators,
4. the Focus of the gesture,
5. and Area Constraints, which describe the relative movement of atomic gestures.

The basic multi-touch gestures, common across all different devices, are shown in Fig. 1, ranging form simple tapping to the more complex rotation gesture [49].

1. *Tap*: A single tap is recognized by quickly touching the device (`POINT`) and immediately releasing the finger (`DEPOINT`); typically used to press an input control or select an item.
2. *Double/Multi Tap*: Repeated taps and releases with a single finger (`1F`).
3. *Tap and Hold*: Defined as touching and holding (`HOLD`) the multi-touch surface. Also referred to as "Press and Hold" or "Long Press".
4. *Two/Multi Finger Tap*: A single touch down with two (`2F`) or more fingers.
5. *Drag*: The drag gesture is defined as touching down and moving the finger in an arbitrary direction, whilst keeping contact with the touch device. Stopping the movement and releasing the dragged object ends the gesture. Dragging is typically used for scrolling and panning.

6. *Two/Multi Finger Drag*: Drag gesture executed with multiple fingers.
7. *Flick*: A drag gesture which adds momentum by releasing the moved object before stopping the finger movement; generally used for faster scrolling and panning.
8. *Pinch*: The pinch gesture is recognized by touching down with two fingers, usually thumb and index finger, and either close (`JOIN`) or open (`SPREAD`) both fingers without releasing the touch device. The gesture ends once both fingers are stopped and released. "Pinch open" and "Pinch close" gestures are usually paired with the zoom function.
9. *Rotate*: Defined as touching down with two fingers and performing a clockwise or counter-clockwise rotation with both fingers, stopping the movement and releasing both fingers.

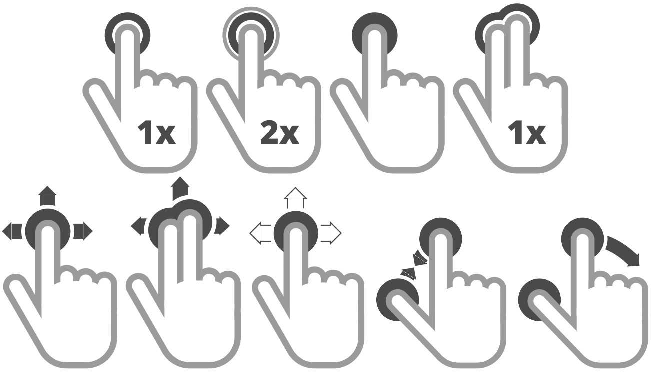

**Fig. 1.** Multi-touch Interaction Primitives: Tap – Double Tap – Tap and Hold – Two Finger Tap; Drag – Double Finger Drag – Flick – Pinch – Rotate

### 3.3 Multi-touch Graph Interaction

A search for TI="multi-touch graph interaction" as well as TS="multi-touch graph interaction" on the WoS resulted in 0 hits. Even TI="touch graph interaction" (and TS as well) did not return any results. The Google search allintitle: "Multi-touch Graph Interaction" resulted in exactly one hit – a paper by [50] presented at the 2010 ACM International Conference on Interactive Tabletops and Surfaces, which received so far 18 citations as of April, 2, 2014.

Schmidt et al. [50] focus in their paper on redesigning node-link graph exploration interfaces for use with multi-touch input.

## 4 State-of-the-Art II: From Node-Link Graphs to Interactive Node-Link Graph Visualization

### 4.1 Node-Link Graphs

**Node-link graphs** are critical in many domains and raise specific interaction challenges; for example:

1. congestion of nodes and links [51],
2. crossing of links [52], and
3. overview and detail [53].

The use of multi-touch input to address these challenges is a hot and promising research issue, because the increase in available contact points may support more significant edge detangling.

**Multi-point input** has been shown to enable better collaborative analysis [54]. By applying multi-touch capabilities to graph manipulations one can extend the possibilities of graph interaction through combinations of simple actions.

### 4.2 Interactive Node-Link Graph Visualization

There is not much work available on Interactive node-link Graph Visualization: Graph layouts have been often applied, but because of the scale and complexity of real world data, these layouts tend to be dense and often contain difficult to read edge configurations [55].

Much previous work on graph layouts has focused on algorithmic approaches for the creation of readable layouts and on issues such as edge crossings and bends in layout aesthetics [56, 57].

There are only a few interactive approaches which try to mitigate problems such as edge congestion include zoom and local magnification techniques [55,58–60]. These approaches **tend to work on the graph as a whole or focus on the nodes**, despite the fact that edges had been identified as one of the central aesthetic issues.

Recent interaction advances that deal directly with edges in connected diagrams include Wong et al.'s EdgeLens [51] and EdgePlucking [61], Holten's edge bundling [62] and Moscovich et al.'s link-based navigation techniques [63]. EdgeLens and EdgePlucking aim to reduce edge congestion by interactively moving and bending edges while preserving the location of nodes; in edge bundling, adjacent edges are bent and grouped into bundles, in order to reduce visual clutter in node-link diagrams. While the former approaches provide techniques to clarify the graph structure, Moscovich et al. focus on content-aware navigation in large networks.

## 5 Example of an Empirically Proved Biomedical Knowledge Space

Our experiences with a large data set clearly showed the advantages of graph-based data structures for the representation of medical information content. The graph is derived from a standard quick reference guide for emergency doctors and paramedics in the German speaking area; tested in the field, and constantly improved for 20 years: The handbook "Medikamente und Richtwerte in der Notfallmedizin" [64] (German for Drugs and Guideline Values in Emergency Medicine, currently available in the 11th edition accompanies every German-speaking emergency doctor as well as many paramedics and nurses. It has been sold 58,000 times in the German-speaking area. The 92-pages handbook (size: 8 x 13 cm) contains a comprehensive list of emergency drugs and proper dosage information. Additionally, important information for many emergency situations is included. The data includes more than 100 essential drugs for emergency medicine, together with instructions on application and dosage depending on the patient condition, complemented by additional guidelines, algorithms, calculations of medical scores, and unit conversion tables of common values. However, due to the traditional list-based interaction style, the interaction is limited to a certain extent. Collecting all relevant information may require multiple switches between pages and chapters, and knowledge about the entire content of the booklet. In consequence to the alphabetical listing of drugs by active agents, certain tasks, like finding all drugs with common indications, proved to be inefficient and time consuming.

Modeling relationships between drugs, patient conditions, guidelines, scores and medical algorithms as a graph (cf. Fig. 2) gives valuable insight into the structure of the data set.

Each drug is associated with details about its active agent and pharmacological group; brand name, strengths, doses and routes of administration of different products; indications and contraindication, as well as additional remarks on application. Consequently, a single drug itself can be represented as connected concepts. Shared concepts create links between multiple drugs with medical relevance, and provide a basis for content-aware navigation.

The interconnection of two drugs, namely adrenaline and dobutamine, is shown in Fig. 3. The left-hand side illustrates the main three types of relations inducing medical relevance; shared indications, shared contra-indications and shared pharmacological groups. Different node colors are used to distinguish between types of nodes such as active agents, pharmacological groups, applications, dosages, indications and contra-indications. The right-hand side highlights the connection of adrenaline and dobutamine by a shared indication.

Links to and between clinical guidelines, tables and calculations of medical scores, algorithms and other medical documents, follow the same principle. On the contrast to a list-based interaction style, these connections can be used for identification and visualization of relevant medical documents, to reorganize the presentation of the medical content and to provide a fast and reliable contextual navigation.

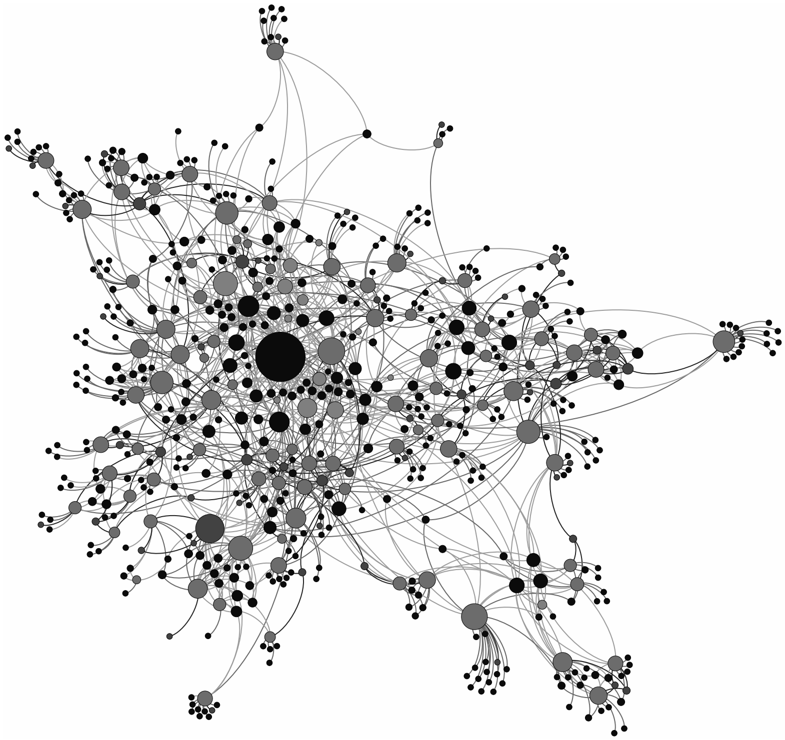

**Fig. 2.** Graph of the medical data set showing the relationship between drugs, guidelines, medical scores and algorithms

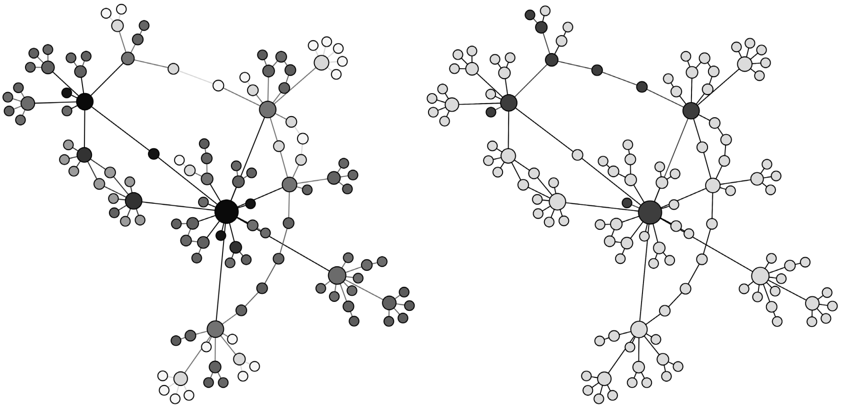

**Fig. 3.** Interconnection between two drugs, "Adrenaline" and "Dobutamine"; connections to and between clinical guidelines, tables and calculations of medical scores, algorithms and other medical documents, follow the same principle

## 6 Open Problems

Still unsolved problems include:

*Problem 1.* What is the maximum number of edges of an RNG in $\mathbb{R}^3$? It is known that it has at most $O(n^{\frac{4}{3}})$ edges, but no supra-linear lower bound is known.

*Problem 2.* That the SIG has at most $15n$ edges in the plane follows from a theorem of Erdös & Panwitz [65], but the best lower bound is $9n$. It is also known that the SIG has a linear number of edges in any fixed dimension [66], and bounds on the expected number of edges are known [67], but again tight results are not available.

*Problem 3.* What is the structural interpretation of graph measures [19, 68]? Graph measures are mappings which maps graphs to the reals. Thus, they can be understood as graph complexity measures [19, 68–70]. Investigating their structural interpretation relates to understand what kind of structural complexity they detect. Cyclicity, branching and linearity (path-like) are examples theoreof.

*Problem 4.* Multi-touch graph-based interaction requires to visualize large networks meaningfully. So far, there has been a lack of interest to develop efficient software beyond the available commercial software.

*Problem 5.* Can we generate unique fingerprints of multi-touch interaction graphs? Similar work but in the context of structural chemistry has already been performed by Dehmer et al. [71, 72].

*Problem 6.* Which structural properties possess the multi-touch interaction graphs? This calls for investigating graph classes beyond small world and random networks.

*Problem 7.* Which known graph classes are appropriate to model multi-touch interaction graphs properly? For instance, small world networks or special hypergraphs seem to be applicable. What kind of structural properties do the multi-touch interaction graphs have?

*Problem 8.* Are multi-touch interaction graphs structurally similar to other graphs (from known graph classes)? This calls for a comparison of graph classes and their structural characteristics.

*Problem 9.* Which graph measures are suitable to determine the complexity of multi-touch interaction graphs? Does this lead to any meaningful classification based on their topology?

*Problem 10.* What is interesting? Where to start the interaction with the graph?

## 7 Conclusion and Future Outlook

The explosive growth of complexity of networks have overwhelmed conventional visualization methods and future research should focus on developing more robust and efficient temporally aware clustering algorithms for dynamic graphs, i.e. good clustering will produce layouts that meet general criteria, such as cluster colocation and short average edge length, as well as minimize node motion between time steps [73].

Attacking aforementioned open problems, introduces several exciting and unique challenges. As an example, extensive investigation of structural properties of multi-touch interaction graphs, using large sets of generated graphs, seems to be an ideal starting point in addressing multiple unsolved problems. A comparison of these graph measures might give insightful conclusions, and might lead to a distinct characterization of multi-touch interaction graphs (problems 5 and 6). By further investigation of these structural characteristics, one could identify existing graph classes which are suitable to model multi-touch interaction, or reveal the need for a distinct graph class (problems 7 and 8). This requires an exhaustive comparison of known graph classes and their structural properties, as well as their limitations.

As mentioned above, the complexity of multi-touch interaction graphs should be investigated by using numerical graph invariants [19]. By using some distinct graph invariants such as graph entropy, distance measures and degree-based measures, one could determine their characteristic distributions and compare them with other graphs. This leads us to the question whether the structure of multi-touch interaction graphs is really different, i.e., whether these graphs have a different characteristic compared to others.

**Acknowledgments.** The authors are grateful for many fruitful, lively and enjoyable discussions with the hci4all.at Team at the Institutes meetings.

## References

1. Harary, F.: Structural models, An introduction to the theory of directed graphs. Wiley (1965)
2. Strogatz, S.H.: Exploring complex networks. Nature 410(6825), 268–276 (2001)
3. Dorogovtsev, S., Mendes, J.: Evolution of networks: From biological nets to the Internet and WWW. Oxford University Press (2003)
4. Dehmer, M., Emmert-Streib, F., Mehler, A.: Towards an Information Theory of Complex Networks: Statistical Methods and Applications. Birkhaeuser Boston (2011)
5. Holzinger, A., Dehmer, M., Jurisica, I.: Knowledge discovery and interactive data mining in bioinformatics - state-of-the-art, future challenges and research directions. BMC Bioinformatics 15(suppl. 6), 11 (2014)
6. Barabasi, A.L., Albert, R.: Emergence of scaling in random networks. Science 286(5439), 509–512 (1999)
7. Kleinberg, J.: Navigation in a small world. Nature 406(6798), 845–845 (2000)

8. Koontz, W., Narendra, P., Fukunaga, K.: A graph-theoretic approach to nonparametric cluster analysis. IEEE Transactions on Computers 100(9), 936–944 (1976)
9. Wittkop, T., Emig, D., Truss, A., Albrecht, M., Boecker, S., Baumbach, J.: Comprehensive cluster analysis with transitivity clustering. Nature Protocols 6(3), 285–295 (2011)
10. Holzinger, A.: Human computer interaction & knowledge discovery (hci-kdd): What is the benefit of bringing those two fields to work together? In: Cuzzocrea, A., Kittl, C., Simos, D.E., Weippl, E., Xu, L. (eds.) CD-ARES 2013. LNCS, vol. 8127, pp. 319–328. Springer, Heidelberg (2013)
11. Toussaint, G.T.: The relative neighbourhood graph of a finite planar set. Pattern Recognition 12(4), 261–268 (1980)
12. Holzinger, A.: Finger instead of mouse: Touch screens as a means of enhancing universal access. In: Carbonell, N., Stephanidis, C. (eds.) UI4ALL 2002. LNCS, vol. 2615, pp. 387–397. Springer, Heidelberg (2003)
13. Lee, S., Buxton, W., Smith, K.: A multi-touch three dimensional touch-sensitive tablet. In: ACM SIGCHI Bulletin, vol. 16, pp. 21–25. ACM (1985)
14. Cook, D., Holder, L.B.: Mining Graph Data. Wiley Interscience (2007)
15. Chakrabarti, D., Faloutsos, C.: Graph mining: Laws, generators, and algorithms. ACM Computing Surveys (CSUR) 38(1), 2 (2006)
16. Duda, R.O., Hart, P.E., Stork, D.G.: Pattern Classification. Wiley, New York (2001)
17. Gusfield, D.: Algorithms on Strings, Trees, and Sequences: Computer Science and Computational Biology. Cambridge University Press (1997)
18. Watts, D.J., Strogatz, S.H.: Collective dynamics of ‘small-world’ networks. Nature 393, 440–442 (1998)
19. Emmert-Streib, F., Dehmer, M.: Networks for systems biology: Conceptual connection of data and function. IET Systems Biology 5, 185–207 (2011)
20. Bonchev, D., Mekenyan, O., Trinajstić, N.: Topological characterization of cyclic structures. International Journal of Quantum Chemistry 17(5), 845–893 (1980)
21. Schutte, M., Dehmer, M.: Large-scale analysis of structural branching measures. Journal of Mathematical Chemistry 52(3), 805–819 (2014)
22. Kirby, E.C.: Sensitivity of topological indexes to methyl group branching in octanes and azulenes, or what does a topological index index? Journal of Chemical Information and Computer Sciences 34(5), 1030–1035 (1994)
23. Bonchev, D., Trinajstić, N.: Information theory, distance matrix, and molecular branching. The Journal of Chemical Physics 67(10), 4517–4533 (1977)
24. Wiener, H.: Structural determination of paraffin boiling points. J. Am. Chem. Soc. 69(1), 17–20 (1947)
25. Buxton, B.: A touching story: A personal perspective on the history of touch interfaces past and future. In: SID Symposium, vol. 41, pp. 444–448. Wiley (2010)
26. Cetin, G., Bedi, R.: Multi-touch Technologies. NUIgroup.com (2009)
27. Alden, D.G., Daniels, R.W., Kanarick, A.F.: Keyboard design and operation: A review of the major issues. Human Factors: The Journal of the Human Factors and Ergonomics Society 14(4), 275–293 (1972)
28. Mehta, N., Smith, K., Holmes, F.: Feature extraction as a tool for computer input. In: IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP 1982), vol. 7, pp. 818–820. IEEE (1982)
29. Holzinger, A., Searle, G., Peischl, B., Debevc, M.: An answer to “Who needs a stylus?” on handwriting recognition on mobile devices. In: Obaidat, M.S., Sevillano, J.L., Filipe, J. (eds.) ICETE 2011. CCIS, vol. 314, pp. 156–167. Springer, Heidelberg (2012)

30. Moscovich, T.: Multi-touch interaction. In: Conference on Human Factors in Computing Systems: CHI 2006 Extended Abstracts on Human Factors in Computing Systems, vol. 22, pp. 1775–1778 (2006)
31. Wang, F., Ren, X.S.: Empirical evaluation for finger input properties in multi-touch interaction. In: Greenberg, S., Hudson, S.E., Hinkley, K., RingelMorris, M., Olsen, D.R. (eds.) Proceedings of the 27th Annual Chi Conference on Human Factors in Computing Systems, pp. 1063–1072. Assoc Computing Machinery (2009)
32. Park, W., Han, S.H.: Intuitive multi-touch gestures for mobile web browsers. Interacting With Computers 25(5), 335–350 (2013)
33. Holzinger, A., Höller, M., Schedlbauer, M., Urlesberger, B.: An investigation of finger versus stylus input in medical scenarios. In: Luzar-Stiffler, V., Dobric, V.H., Bekic, Z. (eds.) ITI 2008: 30th International Conference on Information Technology Interfaces, pp. 433–438. IEEE (2008)
34. Crisan, S., Tarnovan, I.G., Tebrean, B., Crisan, T.E.: Optical multi-touch system for patient monitoring and medical data analysis. In: Vlad, S., Ciupa, R., Nicu, A.I. (eds.) MEDITECH 2009. IFMBE Proceedings, vol. 26, pp. 279–282. Springer, Heidelberg (2009)
35. Lundstrom, C., Rydell, T., Forsell, C., Persson, A., Ynnerman, A.: Multi-touch table system for medical visualization: Application to orthopedic surgery planning. IEEE Transactions on Visualization and Computer Graphics 17(12), 1775–1784 (2011)
36. Crisan, S., Tarnovan, I.G.: Optimization of a multi-touch sensing device for biomedical applications. In: Vlaicu, A., Brad, S. (eds.) Interdisciplinary Research in Engineering: Steps Towards Breakthrough Innovation for Sustainable Development. Advanced Engineering Forum, vol. 8-9, pp. 545–552. Trans Tech Publications Ltd, Stafa-Zurich (2013)
37. Xie, Q.Q., Liang, G.Y., Tang, C., Wu, X.Y.: A fast and robust fingertips tracking algorithm for vision-based multi-touch interaction. In: 10th IEEE International Conference on Control and Automation (ICCA), pp. 1346–1351 (2013)
38. Chen, T.T.H., Fels, S., Min, S.S.: Flowfield and beyond: applying pressure-sensitive multi-point touchpad interaction. In: Proceedings of 2003 International Conference on Multimedia and Expo., ICME 2003, vol. 1, pp. 49–52 (July 2003)
39. Hodges, S., Izadi, S., Butler, A., Rrustemi, A., Buxton, B.: Thinsight: Versatile multi-touch sensing for thin form-factor displays. In: Proceedings of the 20th Annual ACM Symposium on User Interface Software and Technology, UIST 2007, pp. 259–268. ACM (2007)
40. Baudel, T., Beaudouinlafon, M.: Charade - remote control of objects using free-hand gestures. Communications of the ACM 36(7), 28–35 (1993)
41. Long Jr., A.C., Landay, J.A., Rowe, L.A.: Implications for a gesture design tool. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, pp. 40–47. ACM (1999)
42. Alvarado, C., Davis, R.: Sketchread: A multi-domain sketch recognition engine. In: Proceedings of the 17th Annual ACM Symposium on User Interface Software and Technology, pp. 23–32. ACM (2004)
43. Paulson, B., Hammond, T.: Paleosketch: Accurate primitive sketch recognition and beautification. In: Proceedings of the 13th International Conference on Intelligent user Interfaces, pp. 1–10. ACM (2008)
44. Fernández-Pacheco, D., Albert, F., Aleixos, N., Conesa, J.: A new paradigm based on agents applied to free-hand sketch recognition. Expert Systems with Applications 39(8), 7181–7195 (2012)

45. Wu, M., Shen, C., Ryall, K., Forlines, C., Balakrishnan, R.: Gesture registration, relaxation, and reuse for multi-point direct-touch surfaces. In: First IEEE International Workshop on Horizontal Interactive Human-Computer Systems, TableTop 2006. IEEE (2006)
46. Wobbrock, J.O., Morris, M.R., Wilson, A.D.: User-defined gestures for surface computing. In: Greenberg, S., Hudson, S.E., Hinkley, K., RingelMorris, M., Olsen, D.R. (eds.) CHI2009: Proceedings of the 27th Annual Conference on Human Factors in Computing Systems, pp. 1083–1092. Assoc Computing Machinery (2009)
47. Park, W., Han, S.H.: An analytical approach to creating multitouch gesture vocabularies in mobile devices: A case study for mobile web browsing gestures. International Journal of Human-Computer Interaction 30(2), 126–141
48. Kammer, D., Wojdziak, J., Keck, M., Groh, R., Taranko, S.: Towards a formalization of multi-touch gestures. In: ACM International Conference on Interactive Tabletops and Surfaces, ITS 2010, pp. 49–58. ACM (2010)
49. Hoggan, E., Williamson, J., Oulasvirta, A., Nacenta, M., Kristensson, P.O., Lehtiö, A.: Multi-touch rotation gestures: Performance and ergonomics. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, CHI 2013, pp. 3047–3050. ACM, New York (2013)
50. Schmidt, S., Nacenta, M., Dachselt, R., Carpendale, S.: A set of multi-touch graph interaction techniques. In: ACM International Conference on Interactive Tabletops and Surfaces, pp. 113–116. ACM (2010)
51. Wong, N., Carpendale, S., Greenberg, S.: Edgelens: An interactive method for managing edge congestion in graphs. In: IEEE Symposium on Information Visualization, INFOVIS 2003, pp. 51–58. IEEE (October 2003)
52. Purchase, H.C., Carrington, D., Allder, J.: Evaluating graph drawing aesthetics: Defining and exploring a new empirical research area. Computer Graphics and Multimedia, 145–178 (2004)
53. Cockburn, A., Karlson, A., Bederson, B.B.: A review of overview plus detail, zooming, and focus plus context interfaces. ACM Computing Surveys, 41–1 (2008)
54. Isenberg, P., Carpendale, S., Bezerianos, A., Henry, N., Fekete, J.D.: Coconuttrix: Collaborative retrofitting for information visualization. IEEE Computer Graphics and Applications 29(5), 44–57 (2009)
55. Herman, I., Melanon, G., Marshall, M.: Graph visualization and navigation in information visualization: A survey. IEEE Transactions on Visualization and Computer Graphics 6(1), 24–43 (2000)
56. Tollis, I., Eades, P., Di Battista, G., Tollis, L.: Graph drawing: Algorithms for the visualization of graphs, vol. 1. Prentice-Hall, New York (1998)
57. Purchase, H.C.: Which aesthetic has the greatest effect on human understanding? In: DiBattista, G. (ed.) GD 1997. LNCS, vol. 1353, pp. 248–261. Springer, Heidelberg (1997)
58. Bederson, B.B., Hollan, J.D.: Pad++: A zooming graphical interface for exploring alternate interface physics. In: Proceedings of the 7th Annual ACM Symposium on User Interface Software and Technology, pp. 17–26. ACM (1994)
59. Sarkar, M., Brown, M.H.: Graphical fisheye views of graphs. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, pp. 83–91. ACM (1992)
60. Purchase, H.C.: Metrics for graph drawing aesthetics. Journal of Visual Languages & Computing 13(5), 501–516 (2002)
61. Wong, N., Carpendale, S.: Supporting interactive graph exploration with edge plucking. In: Proceedings of SPIE, vol. 6495, pp. 235–246 (2007)

62. Holten, D.: Hierarchical edge bundles: Visualization of adjacency relations in hierarchical data. IEEE Transactions on Visualization and Computer Graphics 12(5), 741–748 (2006)
63. Moscovich, T., Chevalier, F., Henry, N., Pietriga, E., Fekete, J.: Topology-aware navigation in large networks. In: Proceedings of the 27th International Conference on Human Factors in Computing Systems, pp. 2319–2328. ACM (2009)
64. Müller, R.: Medikamente und Richtwerte in der Notfallmedizin, 11th edn. Ralf Müller Verlag, Graz (2012)
65. Soss, M.A.: On the size of the euclidean sphere of influence graph. In: Proceedings Eleventh Canadian Conference on Computational Geometry, pp. 43–46 (1999)
66. Guibas, L., Pach, J., Sharir, M.: Sphere-of-influence graphs in higher dimensions. Intuitive Geometry 63, 131–137 (1994)
67. Dwyer, R.A.: The expected size of the sphere-of-influence graph. Computational Geometry 5(3), 155–164 (1995)
68. Dehmer, M.: Information theory of networks. Symmetry 3, 767–779 (2012)
69. Mowshowitz, A.: Entropy and the complexity of the graphs I: An index of the relative complexity of a graph. Bull. Math. Biophys. 30, 175–204 (1968)
70. Holzinger, A., Ofner, B., Stocker, C., Calero Valdez, A., Schaar, A.K., Ziefle, M., Dehmer, M.: On graph entropy measures for knowledge discovery from publication network data. In: Cuzzocrea, A., Kittl, C., Simos, D.E., Weippl, E., Xu, L. (eds.) CD-ARES 2013. LNCS, vol. 8127, pp. 354–362. Springer, Heidelberg (2013)
71. Dehmer, M., Grabner, M., Varmuza, K.: Information indices with high discriminative power for graphs. PLoS ONE 7, e31214 (2012)
72. Dehmer, M., Grabner, M., Mowshowitz, A., Emmert-Streib, F.: An efficient heuristic approach to detecting graph isomorphism based on combinations of highly discriminating invariants. Advances in Computational Mathematics (2012)
73. Ma, K.L., Muelder, C.W.: Large-scale graph visualization and analytics. Computer 46(7), 39–46 (2013)