GraphTiles: A Visual Interface Supporting Browsing and Imprecise Mobile Search

Figure 1. Comparing *GraphTiles* with IMDb's mobile website. (a) and (b): The MPM(Movie-person-movie) *QueryType*; (c) and (d): the PMP(Person-movie-person) *QueryType*.

ABSTRACT

Although mobiles are generating a rapidly increasing proportion of search queries, search interfaces have not changed significantly to accommodate mobile constraints. Imprecise search, which exists in the no-man's land between specific fact-finding and general browsing, is especially challenging in the mobile setting, when input is difficult and distractions complicate recall. We examined the prevalence of these mobile search use cases in a two-week diary study, finding that imprecise and general search accounted for the large majority of difficulty with search. Hypothesizing that the ability to view a link neighborhood around the search result could be quite helpful in these cases, we designed *GraphTiles*, a visual interface for mobile search that exploits the structured entity relationships present in a significant portion of online datasets (e.g. IMDb [2] and LinkedIn [3]). In an experimental evaluation, users found performed imprecise searches more quickly with *GraphTiles* than with a standard mobile site.

Author Keywords

Mobile search, fact-finding, browsing, entity-relationship, imprecise search.

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION

According to recent reports, mobile search will soon surpass desktop search as measured by both queries and ad revenue [23][6]. Despite this growing importance, Cui and Roto [12] and Church and Oliver [11] find that current mobile search interfaces lead users to seek only information that is fairly specific (e.g. fact-finding) or quite general (e.g. browsing). Both types of information are easy to retrieve with queries, and easy to find in search results.

Ideally mobile users should not have to limit themselves in this way, and indeed often they do not, either because they try and fail to do so, or because of their pressing need for the information. Then their lack of knowledge about the information they seek and the limited query capability of the mobile interface [16] can force them to repeatedly reformulate their queries, and explore results extensively. For example, a user may seek a specific actor. If she cannot remember the name of the actor (in which case she would directly search by name)

or she might instead search for an actor who worked with the actor they seek.

As Lee *et al.* [19] point out, this "no man's land" of *imprecise* search (neither very general nor very specific) is more common than we might think, and some search engines have begun offering partial solutions. Search suggestions offer to complete keyword sets automatically in real time, helping users form better queries. Google's Knowledge Graph displays related facts from databases, making results easier to navigate. Yet neither solution is complete.

We believe that we can improve imprecise mobile search further by exploiting the entity-relationship structure in many online information sources to give mobile users a better overview of their results. Such sources might include movies and crew in IMDb [2], songs and artists in Pandora [4], and friends in Facebook [1]. These overviews reduce cognitive load through recognition, allow navigation of search results by attributes rather than only keyword [15], and guide users in reformulating queries that are typical of imprecise search.

In this paper, we present *GraphTiles*, a visual search interface designed help mobile users perform imprecise and general searches. The interface displays an incomplete portion of the local entity-relationship neighborhood: a thumbnail of the current page alone in the left column, some pages one link away in the middle column, and other pages two links away in the right column. To see the complete neighborhood, users can scroll the central and right columns vertically. While this layout implies many links, it does not indicate exactly where the links are between the second and third columns. Users can reveal these locations by selecting a page thumbnail from these columns, triggering an *interactive reordering* that highlights pages linked to the selection and places them onscreen or nearly so. Users can restore the original (better known) order by deselecting the page.

CONTRIBUTIONS

The main contributions of this paper are:

- In a two-week diary study, we learned that most of the difficulty mobile search users experienced occurred during imprecise or general (browsing) searches.

- We designed the 'GraphTiles' system, supporting imprecise and general searches on mobile devices.

- In a controlled experiment, demonstrated that users were able to perform imprecise searches more quickly with GraphTiles than with a standard mobile website.

RELATED WORK

One way of thinking about GraphTiles is that it exploits knowledge of information locality to improve search. Similarly, other mobile search tools often take advantage of user context such as location and time to provide a localized experience. Lymberopoulos *et al.* apply a data-driven approach where local search model at different levels of location granularity (e.g. city, state, country) are combined together to improve click prediction accuracy in the search results [20]. *FindAll* is a local mobile search engine that lets users search and retrieve web pages, even in the absence of connectivity. The premise for their work is that mobile users often search for web pages that they have previously visited, known as re-finding. *FindAll* estimates the benefits of local search, by learning the re-finding behavior of users [8]. *Hapori*, a local mobile search tool, not only takes into account location in the search query but richer context such as the time, weather and the activity of the user [18]. Amini *et al.* present Trajectory-Aware Search (TAS) that predicts the user's destination based on location data from the current trip and shows search results near the predicted location [7]. SocialSearchBrowser incorporates social networking capabilities with key mobile contexts to improve the search and information discovery experience of mobile users [10].

GraphTiles is essentially a visualization of and search interface for the local entity-relationship graph. There has been little work specifically addressing mobile visualization [9], and to our knowledge, no work on mobile visualization for search. Karstens [17] proposes node-link diagrams of hierarchies arranged around a rectangle to make efficient use of display space. He displayed nearly 1000 nodes, each represented with a very small circle. Hao and Zhang [14] propose a space-filling sunburst display of hierarchies. Their larger nodes are easier to interact with, but their graphs are much smaller. Pattath *et al.* [21] visualize general graphs numbering just a few dozen nodes using node-link diagrams. Finally, in work most closely related to our own, Da Lozzo *et al.* [13] use node-link diagrams centered around a specific node, again with very small nodes. To recognize mobile constraints, GraphTiles limits visualization to a graph neighborhood as do Da Lozzo *et al.*, but like Hao and Zhang, it displays many links implicitly.

DIARY STUDY

We wanted to understand how often people perform *imprecise* searches in regular use, and how much of an influence those searches have on difficulty. To capture mobile users outside of the lab, we opted for a two-week diary study, in which participants record their own behavior [22].

Imprecise searches can be characterized by at least one of two properties [19]:

1. Users iteratively refine multiple queries to find relevant information due to difficulty formulating an exact query.
2. Users have difficulty navigating through their search results to find the answer they are looking for, leading to multiple link following.

Accordingly we formulated the following definition of *imprecise* search, as measured by our diary study: *more than one query was required, or three or more links were followed in results*. However, we found one ambiguous case: one query and at least three followed links might be imprecise search, with a user arriving directly at a confusing set of search results and hunting around; or they might be general browsing search, with a user quickly finding a broad swath of interesting information, and slowly exploring it. Disambiguation might require knowing how rapidly users followed their links. Unfortunately, this sort of timing information is not reliable

Category	Number of Searches	Percentage	Query Examples
Precise and Easy	425	49	"lakes around raleigh" "data mining companies in the US" "lenovo a580 review"
Precise and Difficult	61	7	"Where can I buy beautiful ruins at lowest price?" "home remedy for cat diarrhea" "how to transfer when taking a grey hound"
Imprecise/General and Easy	174	20	"labrador dog breeder" "flights to west coast" "halloween costumes "
Imprecise/General and Difficult	208	24	"salmon recipes" "name of movie with actors chang and bling" "bathroom vanity mirror, bathroom mirror"

Table 1. 4 categories of mobile searches in the diary study, their frequency of occurrence and examples.

in diary studies. We therefore settled for grouping imprecise with general searches in our design.

We now describe the participant profile, web diary tool, and study procedure of our diary study.

Participants

We recruited 32 participants (21 college students, 8 software professionals, 2 office secretaries, and 1 school teacher) through online mailing lists and flyers. Their ages ranged between 18 and 62, with 17 being male and 15 female. All had normal or corrected-normal vision. They were required to have a mobile device capable of search, and to be regular users of that functionality. 14 participants had iOS, 11 had Android, and 7 had Windows phones.

Procedure

We provided each participant with a diary booklet to keep a history of their online searches. We asked them to record at least two searches per day in order to fill out a 25-page booklet over the two week period. We met each participant after a week in order to check their diaries and data, answer any questions, and help them improve their feedback. During the meeting, we audio-recorded the dialog to archive quotes and feedback. After the second week, we collected the booklets. Participants were either compensated $9 or earned class credit. Each participant was assigned a unique ID to maintain their anonymity. If a participant completed a booklet before two weeks were over, we gave them a new one to fill out. We informed participants that they could terminate the experiment at any time, and that they should only divulge information that they were comfortable sharing. We also mentioned that we may publish anonymized quotes from their diaries.

The booklet contained 25 pages and each page included the questions listed below. If participants were not able to find an appropriate answer, they provided an explanation. We asked the participants to write down these details as soon as possible after they performed a search.

These were the questions on each page of the diary that participants answered as soon as they performed a search.

1. Date
2. Time
3. Duration of search task
4. What app or website did you access
5. What were you searching for?
6. Did you find what you were searching for at all? YES/NO
7. If you did find your information, please continue by filling in the blanks with numbers: I performed _ searches to find my information. I followed _ links after leaving the search results page.
8. Rate the difficulty of finding your information from 1–5 with 5 being very difficult. Add text to explain if you like.

Results

During the course of the diary study, we collected 868 search entries with an average of 27 entries per person. 9% of searches (33 out of 868) failed, not providing users with the information they sought. Participants performed an average of 1.2 searches ($median = 1, min = 1, max = 5$) and followed 2.5 links ($median = 2, min = 0, max = 39$) to find their information. Participants rated search difficulty at an average of 1.9 ($median = 2, \sigma = 1$).

We categorized searches by type and difficulty. Searches were imprecise or general (browsing) when they employed more than one query or three or more links clicked in results. Otherwise, the searches were precise (fact finding). Searches were too hard when they failed, users rated them difficult (4 or 5 on the scale), or they required more than 2 minutes of searching. Otherwise, searches were easy.

Using these two categories, were were able to bin the searches into four combined groups. 49 % of the queries were precise and easy, 7 % were precise and difficult, 20 % were imprecise or general and easy, and 24 % were imprecise or general and difficult.

Some of the comments by the study participants on why they found imprecise or general searches to be difficult, include: *"could not come with the right descriptors for the mirror to find the one I had seen in the store"*, *"had to navigate lots of links to find something useful"* , *"had a hard time finding the right video of the musician as I didn't remember his name"*, *"could not come up with the right search terms to find a book by a particular author and did not remember the author".* Table 1 shows various corresponding examples.

Although search was usually successful, it was difficult about a third of the time (31%), especially when search was more imprecise or general. In fact these searches formed the large majority of the difficulties users were having. Further, roughly one third of imprecise and general searches sought information from datasets organized by entity relationships, such as movies and crews (`www.imdb.com`) or recipe ingredients and dishes (`allrecipes.com`). (This number may be significantly larger, because many participants only recorded their search tool, not the information they sought).

In sum, we believe the large majority of problem searches could have benefited from a tool that helped users navigate through the information neighborhoods typical of imprecise and general search, and that a good starting point for such a tool would be exploiting the structure available in many datasets.

THE GRAPHTILES INTERFACE

We designed *GraphTiles* to help mobile search users handle the most challenging use case identified by our diary study: general or imprecise search. With general search, users browse and cast a wide net. We expected a tool providing a good overview of search results to help them find the most interesting results. With imprecise search, users have difficulty characterizing their search, typically reformulating their queries and exploring intermediate results to hone in on and find reminders of what they seek. Again we expected a visual overview to aid users. GraphTiles exploits the structure available in many online datasets to produce this overview.

With *GraphTiles* (Figure 1 (a),(c)), we assume that users will employ search to find a locality of concern around a central node (e.g. for IMDb, "near John Wayne"), represented by a thumbnail alone in the left column. Distance in the GraphTiles layout from this central node reflects relational distance from the center (e.g. for IMDb, degrees of working separation from John Wayne), with the middle column on link away, and the right column two links away. To see the complete two link neighborhood, users can scroll the central and right columns vertically. We display links largely implicitly: every node in the middle column has an implied link to the central node, and every node in the right column is reachable from the middle column. To represent links between the middle and right columns we support both explicit link display, and interactive reordering. Explicit links appear only when both linked nodes are currently displayed. With reordering, when users select a thumbnail from these columns, GraphTiles highlights thumbnails linked to the selection and reorders to place them onscreen or nearly so. Users can restore the previous order by deselected the thumbnail. When necessary, users can drag a non-central node to the left to change the central node.

We considered a circular (or rectangular) layout to make better use of the blank space in the left column, with a scroll around the central node rather than along it, but discarded it so that we could provide a glimpse of a larger two-link neighborhood. A circular layout with a two-link neighborhood would require much smaller nodes (difficult to touch with a finger tip), and would fit poorly in rectangular mobile displays. Representing within column links explicitly can be confusing, so for such cases we rely on interactive reordering alone (see (c) in Figure 2, depicting data from the Seattle Band Map [5]).

EXPERIMENT: COMPARISON TO IMDB'S MOBILE SITE

To test the value of GraphTiles in imprecise search, we performed an experiment comparing it to a standard mobile interface to a well known structured online dataset: IMDb. An imprecise search making use of IMDb is often similar to this: a user wants to recommend a movie to a friend, but cannot remember the name of that movie, nor the name of any actors in that movie. This makes using standard search interfaces somewhat difficult. They do however know that one of the actors in the movie they want to recommend was also in a different movie they can name. They navigate from movie to actor to movie. We focused on answering imprecise queries of that nature.

Figure 1 shows a comparison of the visuals used in *GraphTiles* and IMDb's mobile website (`http://m.imdb.com`) to answer movie-person-movie(MPM) queries of this type, as well as person-movie-person(PMP) *QueryTypes*. We expected that *GraphTiles* would allow users to find answers to imprecise queries more quickly than IMDb's web app.

Method

Our experiment had 20 participants, all of them employees at a large corporate research center. We obtained informed consent from the participants, and asked them to read the instructions for the experiment. We then familiarized them with the task using 8 training datasets, two for each combination of link *interface* and *QueryType*. Participants were free to ask verbal questions during training. Each participant performed 120 information seeking tasks, each using a different graph neighborhood in the IMDb database, with median size of 115 nodes. On average, they completed all their tasks in one hour.

We used a fully crossed within subjects 2×2 design. As participants performed the tasks, we systematically altered two variables. *Interface*, or the tool used to access the IMDb information, had two levels: *GraphTiles* and the IMDb web app. *QueryType* had two levels: a movie-person-movie (MPM) query or a person-movie-person (PMP) query. If *QueryType* was MPM, we asked participants to find the person who worked in two given movies. In this case, the central node at the left of the visualization was always a movie. If *QueryType* was PMP, we asked participants to find the movie on which two given people collaborated. In this case, the central node at the left of the visualization was always a person. To answer the question, participants used a phone to scroll in the right column to find the second person's node, and then scroll in the middle column to find the movie connecting the two people, and select it.

GraphTiles displayed link lines and used interactive reordering. Every participant performed 30 trials with each of the $2 \times 2 = 4$ experimental treatments. We grouped trials by *Interface* into two blocks of 60 trials each. Thus participants performed all trials with the current Interface before moving on to the next. To combat the effects of fatigue and learning, we used complete counterbalancing across participants: half

of them performed the *GraphTiles* block first, the other half the web app block first. Within each of these blocks, we randomly ordered the levels of *QueryType*. We randomized the order of graph neighborhoods without replacement, so that each participant saw each neighborhood exactly once.

Apparatus

We implemented *GraphTiles* on three Samsung SGH-i917 phones running Windows Phone 7.5, with an AMOLED display and a full capacitive touch screen. The monitor used to display questions was a 1920×1200 pixel Dell 24". Participants interacted with the visualization on a phone by scrolling with a swipe gesture or selecting nodes with a long tap.

We obtained our IMDb graph neighborhoods using the official IMDb API (`http://www.imdb.com/interfaces`), obtaining a large cross section of its database (approximately 3GB in size). We then randomly selected 60 nodes within the IMDb graph describing well known actors (supporting PMP queries), and 60 nodes describing well known movies (supporting MPM queries). We then sampled the two-link neighborhood around each actor (PMP) node by adding the top movies linked to it as indicated by IMDb's own API call; and then for each of those top movies, adding its top actors, again as indicated by IMDb's API call. We created two-link neighborhoods around movie (MPM) nodes similarly. The number of top movies returned by IMDb's API was generally much lower than the number of top actors.

Results and Discussion

All participants performed all trials correctly, so we report only completion times here. We tested significance using a two-factor repeated measures ANOVA. Only the two single variable effects were significant; they did not interact.

When using *GraphTiles*, participants were significantly ($F(1, 19) = 2291.833$, $p < 0.001$) faster than when using the IMDb web app. Average completion time with *Graph-Tiles* was 18.2s ($\sigma = 5.27$), while with IMDb web app, it was 31.5s (SD 5.26).

Although its effect was significant ($F(1, 19) = 11.27$, $p < 0.005$), *QueryType*'s effect was not meaningful. The difference in completion times when participants looked for movies rather than persons was 0.6s: (25.0s for movies, 24.4s for persons). The likely explanation for this effect was the consistent differences in MPM vs. PMP neighborhoods.

Results in fact exceeded our expectations, with *GraphTiles* users almost twice as fast as IMDb web app users. It should be said that *GraphTiles* was designed specifically for imprecise queries; IMDb is a more general tool. What remains to be seen is whether or not a single interface can support both precise and imprecise queries well.

CONCLUSION AND FUTURE WORK

As mobile devices become the dominant form of computing, mobile search will become increasingly important. In this paper we described *GraphTiles*, a new search interface specifically designed to general browsing and imprecise search. In a diary study, these types of search proved to be the focus of most user difficulty with mobile search. In an experimental evaluation, accessing the IMDb graph for imprecise search with *GraphTiles* was nearly twice as fast as with the existing IMDb mobile web app.

GraphTiles could use design improvements to maintain visual continuity. When users change the central node, they can quickly become disoriented. Our current implementation is quite visual and relies on thumbnail images. *GraphTiles* will need improvement for more textual search domains. We also plan to evaluate *GraphTiles* on other devices such as tablets, where we might display larger neighborhoods.

Future experiments might study how well *GraphTiles* supports specific *as well as* imprecise and general queries.

REFERENCES

1. Facebook. `http://wwwfacebook.com`.

2. Internet movie database (imdb). `http://www.imdb.com`.

3. Linkedin. `http://www.linkedin.com`.

4. Pandora. `http://www.pandora.com`.

5. The Seattle Band Map. `http://www.seattlebandmap.com`.

6. Mobile search will surpass desktop in 2015. *eMarketer* (2014).

7. Amini, S., Brush, A., Krumm, J., Teevan, J., and Karlson, A. Trajectory-aware mobile search. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '12, ACM (New York, NY, USA, 2012), 2561–2564.

8. Balasubramanian, A., Balasubramanian, N., Huston, S. J., Metzler, D., and Wetherall, D. J. Findall: A local search engine for mobile phones. In *Proceedings of the 8th International Conference on Emerging Networking Experiments and Technologies*, CoNEXT '12, ACM (New York, NY, USA, 2012), 277–288.

9. Chittaro, L. Visualizing information on mobile devices. *Computer 39*, 3 (2006), 40–45.

10. Church, K., Neumann, J., Cherubini, M., and Oliver, N. Socialsearchbrowser: A novel mobile search and information discovery tool. In *Proceedings of the 15th International Conference on Intelligent User Interfaces*, IUI '10, ACM (New York, NY, USA, 2010), 101–110.

11. Church, K., and Oliver, N. Understanding mobile web and mobile search use in today's dynamic mobile landscape. In *Proceedings of the 13th International Conference on Human Computer Interaction with Mobile Devices and Services*, MobileHCI '11, ACM (New York, NY, USA, 2011), 67–76.

12. Cui, Y., and Roto, V. How people use the web on mobile devices. In *Proceedings of the 17th international conference on World Wide Web*, WWW '08, ACM (New York, NY, USA, 2008), 905–914.

13. Da Lozzo, G., Di Battista, G., and Ingrassia, F. Drawing graphs on a smartphone. 153–164. 10.1007/978-3-642-18469-7-14.

(a) Band and artist relationship

(b) Band relationship

(c) Interactive reordering with dimmed image when not related.

Figure 2. Applying *GraphTiles* to Seattle's music band data.

14. Hao, J., and Zhang, K. A mobile interface for hierarchical information visualization and navigation. In *Consumer Electronics, 2007. ISCE 2007. IEEE International Symposium on*, IEEE (2007), 1–7.

15. Hearst, M., Elliott, A., English, J., Sinha, R., Swearingen, K., and Yee, K.-P. Finding the flow in web site search. *Commun. ACM 45*, 9 (Sept. 2002), 42–49.

16. Kamvar, M., Kellar, M., Patel, R., and Xu, Y. Computers and iphones and mobile phones, oh my!: A logs-based comparison of search users on different devices. In *Proceedings of the 18th International Conference on World Wide Web*, WWW '09, ACM (New York, NY, USA, 2009), 801–810.

17. Karstens, B. Visualization of complex structures on mobile handhelds. In *In Proceedings of International Workshop on Mobile Computing* (2003), 17–18.

18. Lane, N. D., Lymberopoulos, D., Zhao, F., and Campbell, A. T. Hapori: Context-based local search for mobile phones using community behavioral modeling and similarity. In *Proceedings of the 12th ACM International Conference on Ubiquitous Computing*, Ubicomp '10, ACM (New York, NY, USA, 2010), 109–118.

19. Lee, U., Kang, H., Yi, E., Yi, M., and Kantola, J. Understanding mobile q&a usage: an exploratory study. In *SIGCHI '12: ACM SIGCHI Conference on Human Factors in Computing Systems* (2012), 3215–3224.

20. Lymberopoulos, D., Zhao, P., Konig, C., Berberich, K., and Liu, J. Location-aware click prediction in mobile local search. In *Proceedings of the 20th ACM International Conference on Information and Knowledge Management*, CIKM '11, ACM (New York, NY, USA, 2011), 413–422.

21. Pattath, A., Ebert, D. S., May, R. A., Collins, T. F., and Pike, W. Real-time scalable visual analysis on mobile devices. R. Creutzburg and J. H. Takala, Eds., vol. 6821, SPIE (2008), 682102.

22. Sohn, T., Li, K. A., Griswold, W. G., and Hollan, J. D. A diary study of mobile information needs. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '08, ACM (New York, NY, USA, 2008), 433–442.

23. Sterling, G. Matt cutts: Google mobile queries may surpass pc search this year. *Search Engine Land* (2014).