My research aims to understand, predict, and enhance human behavior in networks by developing techniques in data science, data mining, network analysis, machine learning, and natural language processing. Information as well as humans are organized in networks. Interacting with these networks is part of our daily lives: we talk to friends in our social network; we find information by navigating the Web; we spread viruses over networks of interacting people; and we form opinions by listening to others and to the media. Thus, human behavior in networks poses important research problems with practical applications of high impact: analyses of online behavior lead to billions of dollars in ad revenue; understanding users’ information-seeking behavior helps improve websites and search engines; modeling interpersonal interactions is crucial for containing the spread of diseases; and understanding how opinions form lets us counteract propaganda and misinformation. My research aims to solve such pressing problems, and this statement focuses on my work on two important human network behaviors: navigation and language.

In order to make use of the information and resources around us, we constantly explore, disentangle, and navigate networks. Network navigation is a fundamental human behavior, and has been a focus of my research. Since it is hard to obtain navigation traces labeled with the exact goal the navigator had in mind, I designed a novel method for collecting such traces via a human-computation game, which has been played over 100,000 times and has led to a better understanding of how people navigate networks. I also extended my methods to traces collected “in the wild,” which has, e.g., resulted in an algorithm for detecting important missing hyperlinks by mining raw web server logs. I successfully applied it to terabytes of Wikipedia’s server logs, and turned it into a tool to be rolled out to millions of Wikipedia users. Whether we talk, text, gossip, sing a song, or write a research statement, we always use language to transmit information in our social network. Hence, language is another human network behavior, and the interplay of language and networks another focus of my work. For instance, I have formulated a probabilistic graphical model for sentiment prediction that, by using both text and network, clearly outperforms text-only and network-only versions. I have also shed light on the relationship between the language of individuals and that of the communities they are part of, by analyzing 10 years of longitudinal text data from social networking sites, resulting in methods for predicting early on how long a member will stay in a community. As another example, my team and I developed an automated method that leverages textual as well as network-based signals to detect fake articles (“hoaxes”) in Wikipedia with superhuman accuracy.

Throughout my research, I take an end-to-end approach, from (1) innovative ways to generate and collect data to (2) principled analysis and modeling to (3) algorithms and large-scale implementations that can be incorporated into production systems. I believe the combination of these elements will help improve the tools we use, our understanding of ourselves, and, ultimately, our lives.

NETWORK NAVIGATION

Whether we do a literature search, look for a long-lost friend on Facebook, ask a stranger on the bus for directions, or browse the Web, we always navigate a network. Although network navigation is ubiquitous, we know little about it. To better understand and model this fundamental human behavior, I devised a creative method for collecting navigation traces labeled with the navigator’s exact goal, by inventing and implementing Wikispeedia [4], a human-computation game where participants are asked to navigate between two given Wikipedia articles in as few clicks as possible. This is a challenging task, given that

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1 Citation numbers reference the numbered publication list in my CV.
participants have no prior knowledge of the connectivity of the underlying hyperlink network and must rely exclusively on their commonsense intuitions (Fig. 1).

The game is fun to play and has produced over 100,000 traces to date. Analyzing them has led us to a better scientific understanding of human navigation in networks. I found that humans excel at finding short paths, requiring in the median only one more click than the optimum (4 vs. 3 clicks). In a detailed study of navigation strategies [8], I described the anatomy of typical human navigation traces. The most basic pattern consists of first navigating to a central, high-degree hub node, and then zooming in on the target by traversing nodes that are increasingly more related to it. Interestingly, the strategies I discovered apply not only to the online world: the general importance of my findings was highlighted by research groups from Cambridge and Regensburg, who built on my work to reason about human navigation in the physical world as well.

Building on the above results, I have developed algorithms for measuring semantic relatedness based directly on human intuition [4], learning to navigate automatically [9], and predicting the targets of human paths from only the first few clicks [8]. These are important building blocks for designing more intuitively navigable information spaces and tools to help people find information.

Ultimately, I want to understand how people interact with information. To this end, it is important to also study human navigation “in the wild,” rather than in the controlled game scenario. I started to do so by analyzing Wikipedia’s full web server logs, where every access to any Wikipedia article is recorded.

As a first step, my team and I approached the well-established problem of missing-link detection from a fresh angle [18]. Previous methods were purely based on graph structure and did not account for how users navigate. Further, since generating millions of link suggestions would overwhelm the editors who usually need to add or verify links manually, we should account for humans in the loop. Hence, we define link placement under resource constraints as the combinatorial optimization problem of selecting the best limited-size subset of links to add (where candidates are generated from human navigation traces), and solve it efficiently by exploiting submodularity, a diminishing-returns property. The algorithm uses a vast number of traces collected from humans, who in turn used their vast knowledge to navigate an intricate network. This combination of human and machine intelligence is a recurring theme in my research. We processed nearly 10 billion traces extracted from Wikipedia’s raw server logs, and built a tool for adding missing links that is about to be released to millions of users.

This project is the result of a strong and productive partnership with the Wikimedia Foundation. Through this collaboration, which I started and am leading as a Wikimedia Research Fellow, I am actively involved in shaping Wikimedia’s agenda. While this has already resulted in significant real-world impact (e.g., our tool for adding missing links, and another tool for finding and creating missing articles [19]), I see many promising ways forward: How can we use navigation traces to improve networks beyond adding missing links? Can we use them to detect missing pages, rank existing pages by importance, or optimize the order of contents on a page? Can we harness traces from different language versions of Wikipedia to learn about cultural differences? Can we improve one language version based on traces from another?

Users navigating a website, such as Wikipedia, have diverse goals: some want to quickly look up a definition, others to acquire profound knowledge; some want to dive into the depth of a topic, others to explore its breadth; some require work-related information, others are browsing just for fun. I want to understand these intentions better, and organize them in a principled taxonomy of human navigation. I anticipate that such a theory of navigational intentions will have many useful practical applications, such as statistical...
models for automatically recognizing user needs in real time and actively supporting them. Concretely, I will build models to detect that a user wants to learn about a certain topic, and react by proposing a curriculum of content to read, with the goal of guiding the user towards a step-by-step understanding of the topic. Indeed, such curricula could themselves be mined from navigation traces, e.g., by analyzing the evolution of users’ reading patterns over longer periods of time (weeks, months, or even years). Educators are already using Wikispeedia and similar games as a learning tool and to encourage deeper attention in children, and I believe we can turn network navigation into an even more effective learning paradigm by using empirical data from navigation traces.

I will also investigate how users mix navigating with query-based search. What are the tradeoffs? What is the optimal switching policy? I believe answering these questions will ultimately lead to hybrid search-and-browse engines to support human information seeking more naturally. I can build on significant experience working with search queries from internships with Yahoo! [3], Microsoft [12, 13], and Google [16].

**LANGUAGE AND NETWORKS**

As humans, we are nodes in a social network, and we use language to send information to other nodes. So language is a network behavior, and social aspects of language play an important role in my research.

A good example of my approach to modeling language in its social context is given by my work on interpersonal evaluations [23], which are prevalent in all kinds of discourse and important for establishing reputations, building social bonds, and shaping public opinion. Previous approaches to person-to-person sentiment analysis can be roughly divided into two camps: On the one hand, natural language processing has typically framed the problem as text classification, while disregarding social network signals. On the other hand, social science has developed network-based theories that reason about triads of nodes. For instance, structural balance theory makes predictions such as, “The friend of my friend is my friend,” “The friend of my enemy is my enemy,” etc.

Voicing an opinion is inherently a social act, so clearly both text and social context play a role. Hence, I modeled person-to-person sentiment prediction as a combinatorial optimization problem with the hybrid objective of inferring edge signs that are in tune with predictions from the text alone, and that at the same time form triads in tune with social theory (Fig. 2). I proved that solving this problem exactly is NP-hard, and formulated a continuous relaxation as a hinge-loss Markov random field, which is amenable to an efficient exact solution, with the additional benefit that the model parameters can be learned in a supervised manner. My model outperforms text-only and network-only versions on two very different datasets involving community-level decision-making: Wikipe-dia admship elections and U.S. Congressional speeches. Further, when textual features are weak, the model learns to give them less weight and to rely on network features instead, and vice versa.

Some utterances can be understood only when social context is accounted for—e.g., sarcastic speakers say the opposite of what they mean—and I believe that, moving forward, our method of combining text and network will be a promising starting point for handling non-literal language such as sarcasm and humor. Currently, these are major barriers in text mining and human–computer interaction: e.g., understanding sarcasm will enable more accurate classification of product reviews, and humor is crucial for more natural human–computer interfaces. I am particularly interested in computational aspects of humor. In an ongoing collaboration with Microsoft Research, I built Unfun.me, a human-computation game for collecting an aligned corpus of humorous and very similar serious phrases, which can be used to learn common semantic

![Figure 2: Benefits of combining text and network for sentiment prediction: Structural balance theory favors triads with 0 or 2 negative ties, which helps recognize sarcasm as positive (left) and handle sparse data (right); clear positive signal of “Love u!” lets us infer third edge to also be positive.](image)
transformations involved in humor creation. For the future, I envision a human-computation framework building on these foundations where humans and algorithms collaborate to create humor.

Our opinions are influenced not only by the people around us, but also heavily by the media. Understanding the media’s role in society is crucial for keeping society healthy. Hence, I plan to perform large-scale analyses of media networks and their language to answer such questions as, What dynamics govern the relation between people’s demand for, and the media’s supply of, information? How do the news drive public opinion? What is the relation between social and mainstream media, and how has it evolved over time? We have been collecting 40 terabytes (and growing) of news, blogs, tweets, etc., over the last 6 years—an ideal dataset for studying these questions. In a first project, I am currently investigating reactions in news and Twitter to the deaths of 40,000 notable people, which has revealed common patterns; e.g., the most famous artists tend to gain, and the most famous politicians to lose, popularity with death.

Information spreads fast on networks and reaches a global audience. Useful information can benefit many, but false information can do much harm; so automatically detecting misinformation is an important research problem. In the case of Wikipedia—a main source of information for many—my collaborators and I found that humans can correctly distinguish between legitimate articles and fabricated hoax articles only 66% of the time [20]. A classifier trained on surface features, such as article length and adherence to Wikipedia style guidelines, does no better than random on the same test set; but digging below the surface, we found that hoaxes are less tightly embedded into the rest of the article network as well as the editor network, and that giving the classifier access to network-based features boosts performance to 86%. That is, network features make the difference between random and superhuman performance. Faking the content of an article is easy; faking its status in the network is not. I look forward to continuing this research: What motivates users to mislead others? What kinds of fake fact are most easily believed? How is misinformation to be phrased and presented to successfully fool others? How can we most effectively counteract it?

Language is not a fixed construct; rather, it constantly evolves as it flows through the network of its speakers. To track linguistic change at both the individual and the community level, my colleagues and I analyzed 10 years’ worth of user contributions on two social networking sites. We developed an information-theoretic framework for quantifying a user’s distance from the community’s overall language at any point in time, and discovered that users go through a characteristic linguistic life cycle: when young on the site, they first align their still malleable language with the present community norms; but later on, as their personal language congeals, they stop adapting to the ever-changing norms. This leads to robust signals to predict a user’s total life time in a community from only a few initial posts. This work [11] won the WWW’13 best-paper award and has been included in the curricula of several universities, e.g., Cambridge, Columbia, Cornell, Michigan, and Stanford. While being of theoretical significance for sociolinguistics, it also has major practical implications: in ongoing work, we apply our approach to corporate email and find that it predicts if an employee will leave the company soon—and if they will do so voluntarily or involuntarily.

We humans organize our knowledge as well as our social selves into complex networks. These networks become useful to us only once we interact with them, through behaviors such as navigating, exploring, and communicating. Hence, the study of human behavior in networks constitutes an important research area. Through my work I have already made contributions to this area, and am excited to continue my agenda. I am convinced that maximum benefit will be achieved by grafting onto my firm computational roots the expertise and methods from other disciplines. Hence, I have collaborated with experts beyond computer science, such as linguists and health scientists, and am looking forward to expanding this interdisciplinary platform by reaching out to biologists, epidemiologists, political scientists, cognitive scientists, and others.