Towards Self-Organizing Peer-to-Peer Web Search

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The peer-to-peer (P2P) computing paradigm is an intriguing alternative to Google-style search engines for querying and ranking Web content. In a network with many thousands or millions of peers the storage and access load requirements per peer are much lighter than for a centralized Google-like server farm; thus more powerful techniques from information retrieval, statistical learning, computational linguistics, and ontological reasoning can be employed on each peer’s local search engine for boosting the quality of search results [1, 2, 10–12, 26]. In addition, peers can dynamically collaborate on advanced and particularly difficult queries. Moreover, a peer-to-peer setting is ideally suited to capture local user behavior, like query logs and click streams, and disseminate and aggregate this information in the network, at the discretion of the corresponding user, in order to incorporate richer cognitive models.

The DELIS project is aiming at a P2P system where each peer has a full-fledged Web search engine, including a crawler and an index manager. The crawler may be thematically focused or crawl results may be postprocessed so that the local index contents reflects the corresponding user’s interest profile. With such a highly specialized and personalized “power search engine” most queries should be executed locally, but once in a while the user may not be satisfied with the local results and would then want to contact other peers. A “good” peer to which the user’s query should be forwarded would have thematically relevant index contents, which could be measured by statistical notions of similarity between peers [3, 4]. Both query routing and the formation of “statistically semantic” overlay networks could greatly benefit from collective human inputs in addition to standard statistics about terms, links, etc.: knowing the bookmarks and query logs of thousands of users would be a great resource to build on [8, 14]. Note that this notion of Web search includes ranked retrieval and thus is fundamentally much more difficult than Gnutella-style file sharing or simple key lookups via distributed hash tables (DHTs) [24]. Further note that,

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although query routing in P2P Web search resembles earlier work on metasearch engines and distributed information retrieval [17, 18], it is much more challenging because of the large scale and the high dynamics of the envisioned P2P system with thousands or millions of computers and users. Finally, the P2P setting poses great challenges also for network-efficient top-k query processing [25, 16], decentralized and other advanced forms of link analysis [6, 7, 13, 14, 21], distributed gathering and dissemination of statistics about data, load, and user behavior [16, 19, 20], and the creation of self-organizing overlay networks [9, 15, 22, 23, 27].

A system architecture for the envisioned solution is currently prototyped, as an experimental platform within the DELIS project, under the name Minerva [5]. This system has all the characteristics and poses the challenges of a complex system. The autonomy of peers and the diversity of different behavioral patterns can be understood only by analyzing and controlling the system at different levels, ranging from the underlying physical network and the virtual overlay network layers to the level of intelligent search, query routing, and collaboration strategies of the individual peers. For cost-efficient solutions it is crucial to consider benefit and cost factors at all levels. Finally, a deep understanding mandates studying such complex systems at different scales in terms of time and space, for example, the short-term interactions of a peer with its immediate neighborhood, triggered by query routing and query execution, on one hand, and the long-term, long-range evolution of the entire system, to organize itself into effective and robust semantic overlay structures, on the other hand.

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