flows along a semantic link network by such models as knowledge dissemination and query routing. Changing the semantic link network will influence the efficiency of query routing. The knowledge dissemination model resembles the spread of infectious diseases. Changing the semantic link network will influence the knowledge flowing through it.

Unlike data and control flows in workflows, which are predefined or adapted according to activities and changes, knowledge flows are behind the interaction among team members and come with activity-level cooperation. They work on knowledge-level cooperation.

Knowledge flows fuse frequently when used, and their contents are not predictable. Effectively managing knowledge flows within a team can lead to effective team knowledge management and eventually raise the effectiveness of teamwork. Coordinating and fusing knowledge flows, data flows, and control flows, and integrating knowledge flows and workflows, are powerful means for making teamwork effective.

Knowledge flow in future interconnection environments. Computing professionals are striving to develop new computing and interconnection platforms to provide more advanced services [3, 4]. The future interconnection environment will be a large-scale human-machine environment where the physical world, mental world, and digital virtual world will interact and evolve cooperatively [12]. Knowledge flow will be the major engine of its evolution. Various knowledge flow networks interact with each other and evolve continuously to constitute the dynamic overlay of the autonomous knowledge grid environment [10].

The development of science depends on scientists and on their recording and sharing ideas. The future interconnection environment will synergize data flows, control flows, and knowledge flows to support appropriate on-demand service flows [11, 12], from which knowledge flow networks will create a live knowledge space that develops independently of machines. Interacting with scientists and their records, this environment will evolve in a novel way to help the development of science.

Conclusion

Exploring the universe and human society are great challenges of 21st century science. This article explores the dynamic nature of knowledge, the power to promote and influence the development of human society, and the future interconnection environment. It describes an important approach to automatically discovering knowledge flow networks within scientific documents and activities. Such networks embody an autonomous knowledge grid, which supports individual and cooperative scientific research, helps investigate the evolution of knowledge and disciplines, and assists in planning for scientific research development. Using the rules of knowledge flow makes teamwork more effective and innovative, not only in an e-science environment but also in team management, as knowledge flow networking can generate knowledge during operation. However, many other scientific and technological issues relevant to knowledge flow, including human, philosophical, psychological, cognitive, economical, social, and management issues, are yet to be resolved, and are a major challenge to scientists. C

References

1. Adamic, L.A. and Huberman, B.A. Power-law distribution of the World Wide Web. *Science, 287,* 24 (2000), 2115.
2. Barabási, A.L. and Albert, R. Emergence of scaling in random networks. *Science, 286* (1999), 509–512.
3. Berners-Lee, T., Hendler, J., and Lassila, O. Semantic Web. *Sci. Am. 284,* 5 (2001), 34–43.
4. Foster, I. Service-oriented science. *Science 308,* 5723 (2005), 814–817.
5. Katerattanakul, P., Han, B., and Hong, S. Objective quality ranking of computing journals. *Commun. ACM 46,* 10 (2003), 111–114.
6. Kleinberg, J. and Lawrence, S. The structure of the Web. *Science 294,* 30 (2001), 1849–1850.
7. Nowak, M.A. and Sigmund, K. Evolution of indirect reciprocity. *Nature 427,* 27 (2005), 1291–1298.
8. Oida, K. The birth and death process of hypercycle spirals. *Artificial Life VIII,* R.K. Standish, M.A. Bedau, and H.A. Abbass, Eds. MIT Press, New York, 2002.
9. Redner, S. How popular is your paper? An empirical study of the citation distribution. *Eur. Phys. J.* B4 (1998), 131–134.
10. Zhuge, H. *The Knowledge Grid.* World Scientific Publishing Co. Singapore, 2004.
11. Zhuge, H. Exploring an epidemic in an e-science environment. *Commun. ACM 48,* 9 (Sept. 2005), 109–114.
12. Zhuge, H. The future interconnection environment. *IEEE Comput. 38,* 4 (2005), 27–33.

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