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indirect help [7]. Everyone can benefit from the community if every node can generously contribute knowledge. Encouraging unselfish cooperation is another strategy that helps a knowledge flow network reach its greatest effectiveness.

Special knowledge spirals and their effect in science. Distinguishing the following special knowledge flow spirals can help scientists explore knowledge evolution in research community development:

- A *rising* spiral has an increasing rate of citations over time. This implies a rising research group or community. In contrast, a *descending spiral* has a decreasing rate of citations. This implies a declining research group or community.
- A *rising and expanding spiral* is a rising spiral that includes an increasing number of authors over time. This implies a rising and expanding research group or community.
- A *falling and shrinking spiral* is a descending spiral that is losing authors. This implies a declining and shrinking group or community.
- An *authoritative* spiral requires that all its nodes remain authoritative. This implies an authoritative research group.
- An *original* spiral has at least one source node. This implies the presence of an initiator.
- A *downstream* spiral contains authors whose articles often cite others but are seldom cited by other researchers.

USING AND MANAGING KNOWLEDGE FLOW NETWORKS IN E-SCIENCE

Scientists need an ideal e-science environment to support research more effectively than the Web. Scientists only need to start the environment by uploading their articles, or start with a directory or online database of articles. Searching the citation network among Web pages and in digital libraries can reveal knowledge flows among authors. By extracting and mining from scientific data, activities, and documents of an area; analyzing the relationships between results to enrich a knowledge flow network; and tracing its evolution, an e-science environment can provide scientists with the following services:

- *Outline personal research roadmaps and depict the evolution of interest and knowledge.* This service helps scientists record and analyze personal research history and status. They can use this information to plan their research by looking at the distribution and evolution of their areas. The system can display users' personal knowledge flow networks by finding their citations and their coauthors' citations, classifying the articles involved by discipline and chronology, expressing the category semantics for advanced services, linking the categories with the citations, and revealing knowledge flows using the citation network.
- *Recommend a network of appropriate references.* This service can recommend references by retrieving documents from the Web and digital libraries, ranking them according to their citation rates and the roles of the authors, and tracing and analyzing their citation networks to show the references as a network rather than as a list. The network can be a hierarchy that enables people to zoom in and out of the research area.
- *Display closely related peers and their status.* This service can help scientists select peers by finding the dense cliques in knowledge flow networks by looking at the statistical results and distribution of authors, articles, and citations.
- *Automatically discover interest groups.* This service can discover global interest groups by finding two types of citation relationship. The first relationship is between authors who cited the same article, on the basis that authors who cite the same article have a shared interest. The second is authors who cited each other; the more articles the authors mutually cite, the more common interests they share. Mutual citation can be extended to be indirect: if there is a citation path in each direction between two articles, then the authors share common interest and knowledge.
- *Estimate the effectiveness of cooperative research.* This service can help a researcher find prospective partners by their current roles (source, authority, bee, hub, or novice).
- *Objectively and dynamically evaluate research.* Criteria such as the number of citations, the number of articles, and the impact factor for journals are