Toward the Eco-Grid: A Harmoniously EVOLVED INTERCONNECTION ENVIRONMENT

Designed as a complex ecosystem, it balances the competing interests of its numerous species as its social, economic, and technological environments evolve.

By Hai Zhuge and Xiaoqing Shi

The Internet, along with its myriad resources and users, constitutes a vast artificial virtual environment that benefits all of human society. But both the general public and the research community may be unaware of its developmental trend toward disorder due to the exponential growth of the numbers and types of its resources and users. By way of analogy, this trend can be explained with the help of the second law of thermodynamics, which states that if we regard the environment as a closed system with constant volume and energy, then every change to the system increases its tendency toward entropy.

Web users are regularly dissatisfied with the Web's information services [5], and IT professionals worldwide look to establish new interconnection environments through, say, the Semantic Web, the Grid, and peer-to-peer and intelligent technologies [1, 2]. But these efforts neglect the problem of how to prevent the new environment from falling into its own future disorder, especially when some factors (such as resources and users) change dramatically.

The natural ecological environment is another vast and complex system that has evolved over billions of years. The health of any ecosystem depends on effective energy flow, material flow, and information flow cycles to maintain the dynamic balance of populations of species in the flow cycles by assimilating waste and being able to self-recover from damage. The harmonious characteristics of the natural ecological environment represent a new way for IT professionals to establish a future interconnection environment.

An Eco-Grid is an open worldwide interconnection environment

Illustration by Richard Downs

reflecting the characteristics of natural ecological environments. Its versatile resources and social roles coexist harmoniously yet evolve, provide appropriate on-demand services to one another, are transformed from one form to another, and communicate in terms of information, knowledge, and service flows through social and economic value chains. It maintains a reasonable rate of expansion of useful resources and assimilates waste resources in light of overall environmental capacity.

The Eco-Grid's development methodology incorporates relevant principles, rules, models, and methods involving ecology, biology, physics, economics, systems science, management science, and social science. It provides an experimental environment for investigating the economic and ecological management and social behavior of its millions of participants. It also introduces new requirements for upgrading the existing methodology used to develop the Web and the Grid.

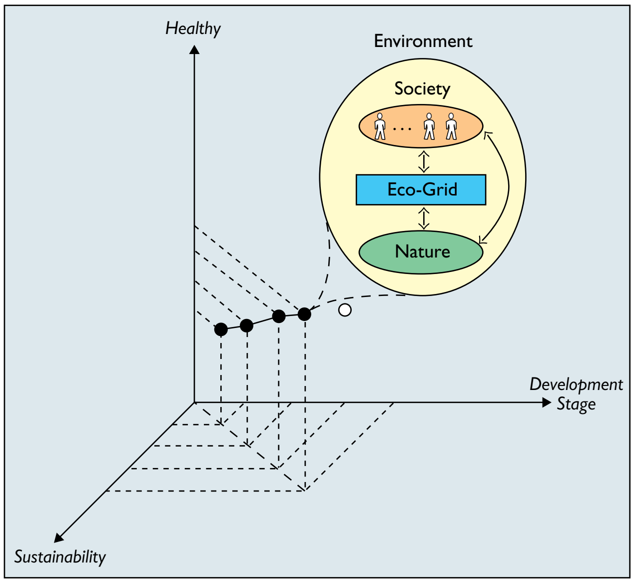

Figure 1. Harmonious evolution of the Eco-Grid.

The Eco-Grid's interconnection environment of resources and roles is itself a resource responsible for overall storage, communication, and management services. Humans interact with resources through roles, or the virtual mediation between them and the resources. Resources also interact with other resources through roles.

Each resource in the Eco-Grid belongs to an evolving species. The only way to generate a new resource is by inheriting the needed components from an existing resource. Different from the usual kind of inheritance in software, a species evolves according to its own version of natural selection, like the survival of the fittest in the natural environment. Differences are likely to exist among resources generated by inheriting from the same species at different times. This mechanism challenges existing software technology and methodology.

The rank, or status, of resources varies depending on their value to the overall community. Having low rank for some period of time or becoming out of date, resources are retired or allowed to die by the environment and thus lose the right to obtain and contribute services. Resources must provide better services in order to compete with one another to earn greater rank and ensure their survival. For example, as special resources, multiple interconnection environments might have to compete to provide better services to achieve greater rank during the evolutionary process. Any resource and any role have some right to choose the proper environment and service they want to obtain.

Just as the human body, human social networks, and the natural ecosystem [4] strive for some healthy form of existence, the Eco-Grid strives to be vigorous, well organized, resilient, adaptable, and inclusive in terms of the numbers and variety of species it allows to participate. Vigor and organization depend on whether the environment evolves harmoniously and maintains effective information-flow, knowledge-flow, and service-flow cycles; they also depend on whether resources are able to obtain appropriate services from other resources and provide their own services by participating in the flow cycles. This resilience and adaptability depend on whether relevant services are able to integrate quickly to provide appropriate on-demand services and adapt to the changing demand of the service process.

The Eco-Grid's principle parameters are time, space, flow, and structure, along with their relationships. Space involves the organization, management, and state of the resources. Structure involves the differences among resources, as well as the overall architecture of the environment and its resources. Behavior involves inheritance, evolution, and evaluation. Figure 1 indicates that the Eco-Grid co-evolves with nature and society through which different development stages request different criteria involving health and sustainability.

The Eco-Grid consists of resource communities, species, flow cycles, roles, and management services (see Figure 2). The resources generated by inheriting from the same species belong to one or even to several communities. Each resource involves four major parameters: age, rank, community, and status. Each species involves a life span and the ability to feed back to its resources and self-evaluate general ecosystem performance to dynamically adjust its features. Thus, resources generated by inheriting from the same species at different times may exhibit different features. A species records its own evolutionary changes (such as features) and the various logs (such as birthdays) of its resources for use in the self-repair process. Users enjoy the services of resources by participating in flow cycles via Eco-Grid roles.

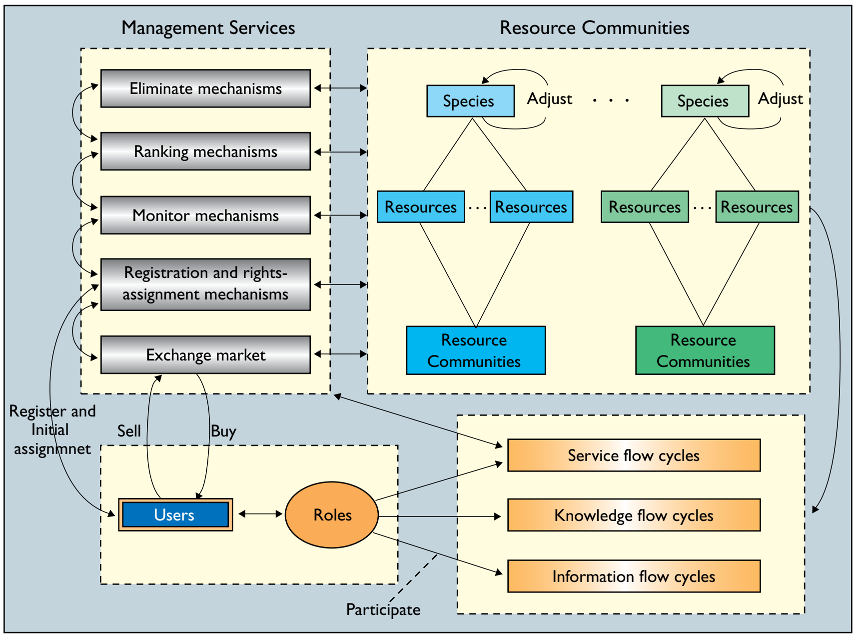

Figure 2. Eco-Grid architecture.

Eco-Grid management services are provided by several resource mechanisms:

Elimination. Responsible for searching for, assimilating, and removing low-status, illegal, useless, or dead resources;

Ranking. Ranks resources according to their contribution to the community, as reflected by the weights and amounts of time they participate in relevant flow cycles; high-ranking resources are granted more rights and greater priority for obtaining services, knowledge, and information;

Monitoring. Monitors the population, distribution, and status of resources and selectively employs resources (such as information, knowledge, and services) to optimize flow cycles so as to ensure effective cooperation; and

Registration and rights-assignment. Responsible for examining resources (and roles) and assigning initial sets of rights and privileges in order to obtain or provide services based on economic principles. A resource or role that wants to acquire more rights or improve its status needs to buy them from the built-in market in the same way shares are exchanged in a stock market. The party that risks its own investment to increase the capacity of the overall environment might thus be able to earn profits from its investment in the market; it might also lose its investment.

Controlling Evolution

The evolution of each species affects relevant energy, information, and resource flows, and thus affects the evolution and even the survival of other species. A change in the population of one species may affect the populations of other species. The Eco-Grid maintains harmonious and sustainable evolution of all species if the mechanisms anticipate and plan for the overall ecosystem's evolutionary trends.

The Eco-Grid incorporates various ecological, biological, and communication growth models (such as those involving population and scale-free networks) and benefits from achievements in the natural, health, and social sciences, as well as from Internet-based and other software technologies.

Eco-Grid researchers compute the dynamic scale distribution of the Eco-Grid's participating species and evolutionary trends by studying the effects of the positive and negative relationships among the different species, determining their birthrates and deathrates from these relationships, and investigating evolutionary trends.

Resources may grow, shrink, die, or even hibernate in complex ways. Simulation of natural evolutionary processes is one way they might obtain the experience they need to be able to develop methods for their evolutionary control within the Eco-Grid. We've carried out ecological simulations to explore the relationships among the increasing numbers of resources, the eliminated resources, the current resources, and the elimination ratios of resources during evolution based on a set of resource growth modes (such as exponential, sectioned function, polynomial, and logistics).

Figure 3 outlines the simulation results when any given set of resources increases in sectioned-function mode under the limitation of near-linear growth of capacity. In this mode, resources increase steadily during the first stage, sharply during the second stage, and near-linearly during the third stage, as shown in the upper-left-hand chart. The upper-right-hand chart compares the change in the eliminated number (ΔE) and the change in the generated number (ΔR) during a given time interval. Both curves go up sharply during the second stage when resources increase exponentially. ΔE decreases and ΔR holds steady at the third stage when resources increase near-linearly. The elimination ratio evolves in the form shown in the lower-right-hand chart, while the existing resources evolve in the way indicated in the lower-left-hand chart.

The elimination ratio includes three stages: the steadily increasing stage, the sharply increasing stage, and the near-linearly increasing stage, which keeps pace with increasing capacity. The change point between the second stage and the third stage reflects the capacity limitation and the possibility that the elimination rate exceeds the birthrate.

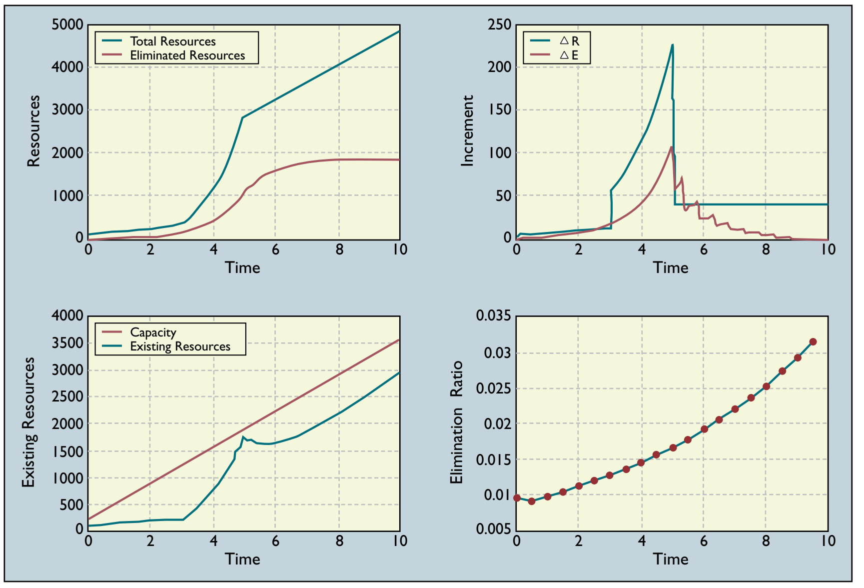

Figure 3. Evolution as resources grow in a sectioned function.

If Eco-Grid researchers would adapt and include more resource growth models (such as epidemic speed models and development models of disciplines), they could obtain multiple sets of curves to induce event-condition-action rules to enable the management mechanism to monitor and control the evolutionary process. For example, the elimination mechanism can determine the death criteria (such as rank and relative contribution to the community) according to the elimination ratio determined by the relevant growth model. Tracking the real-time evolution process and comparing it with the existing simulation curves, the monitor mechanism would know the status of the entire Eco-Grid environment.

Multiple coexisting interconnection environments within the Eco-Grid could also help support the reasonable expansion of its resources. For example, the Eco-Grid can learn from the current Web's growth and distribution models. Natural ecology offers many implications to help us further understand the evolution of artificial systems as we experiment with Eco-Grid evolution.

Resource Management

Resources are independent virtual organisms actively seeking out and working with relevant resources while providing appropriate on-demand services. The unified resource model concerns the design of species and the dynamic inheritance mechanism. A species consists of the inheritable portion (attributes and functions) and the internal detection and adjustment mechanisms that enable the evolution of the inheritable portion. A resource is allowed by the model to inherit from multiple species to form a new hybrid resource.

The Eco-Grid manages its resources as if they were organisms, ensuring their effectiveness at the macrocosm and microcosm scales:

Macrocosm (dynamic and autonomous clustering). Resources dynamically and autonomously cluster together depending on demand from other resources and participants for optimization, efficacy, efficiency, trust, and security to dynamically support computing, autonomy, and collaboration.

Microcosm (normal organization and semantic interconnection). The Eco-Grid resource management mechanism needs a set of normal forms and constraint axioms to be able to dynamically organize resources, include only useful resources satisfying demand from other resources and roles, guarantee the correctness and accuracy of resource operations on local and global views, and realize resource sharing. A dynamic, adaptive multilayered semantic link network can establish semantic interconnection for versatile resources. Resources interact with one another based on their mutual understanding at the representation semantic layer, logical semantic layer, process semantic layer, and parallel semantic layer, as well as some minimum amount of consistency of shared roles and resources between layers. Mapping from the semantic layer onto the low-level peer-to-peer network, the Eco-Grid organizes large-scale resources in an autonomous, semantically rich and scalable way.

The China Knowledge Grid Research Group in Beijing developed the Eco-Grid's knowledge flow model, as well as its soft-device model (a unified resource model), its semantic link network model, its resource space model, and relevant integrity constraint theory (see www.knowledgegrid.net). It also used the Eco-Grid method to design a scalable e-science environment called IMAGINEE-1 incorporating three harmoniously cooperating and evolving environments: research, development, and domain applications [5]. Ongoing work includes:

- Defining the criteria for evaluating the Eco-Grid's health and sustainability;
- Determining the effect of the development of human society and economy on the Eco-Grid;
- Developing a China regional natural ecological monitoring, simulation, and research environment based on the Eco-Grid method, model, and platform; and
- Exploring biological, economical, and social theory on the Eco-Grid.

Conclusion

The Eco-Grid reflects a multidisciplinary methodology incorporating various natural and social sciences. We've proposed its basic notions and methods, architecture, approach to evolution, and the resource organization and management methods needed to establish a harmonious interconnection environment. We hope our work inspires Internet researchers everywhere to rethink their own approaches to the next-generation Web, as well as to existing software technology and methodologies to improve the performance and sustainability of all kinds of information systems [4]. The Eco-Grid reaches beyond Jim Gray's dozen IT research goals [3] to challenge existing theory, technologies, and methodologies. C

References

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