Evolution of the Laws that Deal with the Utilization of Information Networks

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Abstract
Three Laws are used to explain how the potential value of a network increases as the network expands: Sarnoff's Law, Metcalf's Law, and Reed's Law. How accurately do these laws predict the actual value of information networks? We will take a closer look at the application of the laws to information networks and derive corollaries based upon which we shall propose certain attributes that will increase the value of an information network much more profoundly than the number of nodes, which is the primary concern of the laws mentioned above.

1. Introduction

Value or Utility is a measure of the satisfaction gained from the consumption of a "package" of goods and services. Today, three Laws are used to explain how the potential value of a network increases: Sarnoff’s law, Metcalf’s law [1], and Reed’s law [2]. As Reed puts it: “There are at least three categories of value that networks can provide: the linear value of services that are aimed at individual users, the "square" value from facilitating transactions, and exponential value from facilitating group affiliations. The dominant value in a typical network tends to shift from one category to another as the scale of the network increases.” (figure 1).

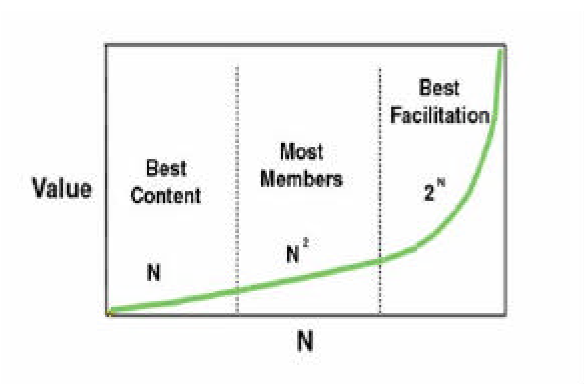

Figure 1) Three famous laws concerning value of networks.

The advent of such generalized laws has had profound effects on the perceived value of information networks and the strategies undertaken to increase the value of such networks [3].

How accurately do these laws predict the actual value of information networks? In this paper we will take a closer look at the application of the laws to information networks and derive corollaries based upon which we shall propose certain attributes that will increase the value of an information network much more profoundly than the number of nodes, which is the primary concern of the laws mentioned above.

We will first review the laws and discuss some observation with regards to them and the assumptions they make in order to have a better perspective over how the laws can be interpreted in real world networks. We will then proceed to define “information networks” and consider the application of the three laws to this class of networks.

Sarnoff’s law

The value of the network grows with the number of nodes:

$V(n) \sim n$

In the real world n is limited by the following:

- Cost of access: In the cellular phone networks, for example, the cost of the handset and the monthly subscription fee are barriers to adoption.
- Perceived value of access: In the example above, many people buy cell phones for safety reasons (e.g., being able to call for emergency).
- Perceived ease of access: Many people do not enable WAP services on their cell phones because it is assumed to be hard to use.

Metcalf’s law

The total value of a network where each node can reach every other node grows with the square of the number of nodes:

$V(n) \sim n^2$

In many cases, for each user on such a network, a maximum a nodes are accessible at any given time. This may be a limitation on the user's part, or as a consequence of the network layout and cost of navigation[1], both of which are not proportional to n when n is sufficiently large. In these cases, the total value of the network is computed as:

$V(n) \sim na \sim n$ (Sarnoff's law)

Reed's Law

The value of the Group Forming (GF) network grows exponentially to the number of users:

$V(n) \sim 2^n$

This law is based on the fact that certain configurations (i.e., groupings) of node connections in a network yield a higher value than others. A Group Forming network resembles a network with smart nodes that, on-demand, form into such configurations. Reed mentions social networks as the catalyst. If we take the Internet as an example, if we replace a passive web page with an active human representative that forms and utilizes links with other human represented nodes depending on information demand at hand, Reed's law predicts exponential growth in the potential value of the network by achieving relevant network groupings. E-bay could be considered as an example of this phenomenon.

This, of course, is quite a controversial law, predicting that the addition of a single user to a GF network, can potentially double the value of the whole network. Observations such as the following show that the actual value of such networks may not always yield such promising value[2]:

- Reed's law counts the number of possible unique groups that can be formed in a GF network of n nodes. Will a new group always increase the value of the network? In most networks, forming new groups of value is difficult for large n. We have no reason to assume that the number of groups that are valuable is a function of n. It is quite possible that in many situations the maximum possible number of valuable groups is much less than n for large n.
- Finding existing groups of value may be difficult, making it difficult for a new member of the network to join groups of value, thus increasing the value of the network as a whole[3]. The maximum number of valuable groups a user can join is not necessarily a function of n.

2. Information Networks

Using the World Wide Web as our guiding example, we shall define an information network as a network with nodes that have one or more of the following content or behavior:

- Raw information: It is assumed that there is at least one node on the network, for which the access of this raw information has potential value.
- Transactional (e.g., e-commerce, banking): Information content on the network is manipulated using transactional nodes. Such manipulations are deemed valuable to some nodes on the network.
- Computational (e.g., calculator): Processing that does not necessarily effect the information content of the network, but is valuable to some nodes on the network.
- Navigational information (e.g., classifications): Navigational information help nodes on the network access information content, transactional or computational nodes on the network.
- User (e.g., human, bots): Derive value from a network by consuming information content, creating or transacting on existing information content, or processing information.

In the example of the World Wide Web, currently access to nodes is quite primitive and access is facilitated at the location of the service node. An analogy here is driving an early model of a car: In the early days access was facilitated at the physical

[1] Of course this logic does not hold in the case of mass broadcasts such as spam, but it is debatable as to how spam affects the value of a network.

[2] Reed does discuss the effect of supply and demand on the three laws, assuming that Money and attention resources scale linearly with n. He does not, however, consider the number of possible valuable groups as discussed here.

[3] Reed's law also assumes that a user joining a group results in two groups, one without the user, and one now with the new user. In reality, this is not how we calculate the number of valuable groups and usually joining a group does not create a new group in addition to the one before the user joined.

location of a device. To honk the horn you actually squeezed the horn itself. To start the car you would get out, go to the front of the car, and use a handle to rotate the pistons in the cylinders. In the case of the Web, a user needs to navigate to where the information or service resides in order to utilize it. There seems to be a need for reversing this paradigm, and bring the service to the user.

A user node is said to have acquired utility knowledge of a node when it learns to locate and utilize the node.

3. The Role of Knowledge

Due to the cost of acquisition of utility knowledge, the full benefits of the ever-expanding network of content, services, and applications available to a user remains dormant, and does not conform to the value curves described in the Three Laws.

We propose the following perspective to complement the laws mentioned in the last section:

The value of a network grows as a function of the number of nodes for which access and/or utility knowledge has been acquired, not the number of nodes.

In other words the number of nodes that exist in a network, for which no knowledge is acquired, has no relevance to the actual value of the network. This, of course, is another way of stating that raw information is always a cost unless it is transformed into knowledge. The potential value of a network can only be achieved once knowledge is acquired for all nodes in the network, but there is a cost associated with this knowledge acquisition process. This cost can be measured in processing power and speed, cost of access, and usability.

If k is used to denote the number of nodes for which utility knowledge has been acquired[4], the three laws can now be rewritten more accurately for information networks:

$V(n) \sim k$ (Sarnoff)
$V(n) \sim k^2$ (Metcalf)
$V(n) \sim 2^k$ (Reed)

[4] k is an oversimplification as it is denoting the acquisition of knowledge as a binary notion when in reality such knowledge acquisition per node is more of a fuzzy membership function.

Currently, for large n, k seems to be much less than n.

4. The Usability Angle

The cost of accessing information on a network is proportional to the cost of mapping the user's model (human or machine) to the actual network.

The above statements attempt to explain the cost of complexity of a network and the concept of "value" referred to in the three laws, as a function of a certain mapping between a user's model and the reality of a network. Knowledge is acquired through a mapping function between an internal model of intent on the part of the user, and the network nodes and topology. Value is therefore measured relative to the user's knowledge, and not as an abstract existence. This perspective states that in the absence of a perfect mapping, there is a cost to be paid to access nodes in a network.

The value of a network is in its effective use. The cost of using a network is proportional to the size and complexity of the network, but this cost is measured against the user's knowledge of the network: the more unfamiliar the user, the more costly the use. Knowledge of a network can therefore be defined as the cost of mapping the user's model of the network to the actual network. An example of this is the mental model that a human user has for a certain classification hierarchy, which may not necessarily map with the actual model as implemented in a content hierarchy.

Technology can and should be used to facilitate the transformation of information to knowledge. A faster database is worthless if the information content cannot efficiently be transformed into knowledge. If each node in a network actively works to conform to the mapping the user expects, the mapping cost can be dramatically decreased, increasing the value.

Knowledge Networks

If each node in a network reacts to usage with the goal to conform to the mapping the user expects, the mapping cost can be reduced, increasing the value of the network. We shall refer to such networks as Knowledge Networks. The ultimate incarnation of such systems would allow minimization of the cost of conforming to predefined, rigid, and complex network configurations, by taking the burden of the mapping off of the user's shoulders and distributing it over the network nodes.

Each node in such a network is represented by an agent, responsible for mapping user requests, formulated based on the user's model, to the ontology encapsulated in that node. If the mapping cannot be performed, in other words, if the agent determines that it alone is not capable of offering value to the user, it should collaborate with neighboring nodes that may.

In an information network, we shall call nodes represented by such agents as active ontologies.

Knowledge networks can be built by striking a usable balance between:

- facilitating the input of the user intent and translating it to the network configuration, and,
- using context to predict what the user intent will be and to present it to the user in a usable manner.

Another aspect of a knowledge network is the navigational cost. Users of conventional networks always pay a cost of navigation in order to access a node, even if the user has perfect knowledge of the network configuration. This cost can be reduced in a knowledge network if the network nodes propagate the user intent throughout the network, giving all nodes a chance to contribute to the delivery of value to the user. This is assuming that all network nodes are capable of aggregating value contributed by other nodes, and of delivering it to the user.

As an example, let's say a human user would like to see a picture she knows is sold by an e-commerce site, and she is at the home page of the site. Even if she knows where exactly to find the picture, she would have to navigate to it by clicking through the pages and getting to the web page (i.e., network node) containing the picture. If we replace the company web site with a knowledge network of active ontologies representing the information and functionality of each web page, and if we give the user a means to express her intent, say a text box where she can type in what she needs, then, upon entering her request, all active ontologies in this network would collaborate to understand, and facilitate this request. Also, the result of her request, i.e., the picture, should be presentable at the node she is at.

In this example, a search box feature would simulate this behavior by indexing web site content and facilitating navigation to pages containing the desired content. In many cases, however, utilizing a search box requires specialized knowledge as to how to formulate the search and how to navigate through the resulting hits, therefore the user is still taking steps to map her internal model (intent) to the network. Search engines also do little in facilitating transactions.

An Agent-Oriented Approach

A number of agent-based approaches are being proposed recently that show promise in creating the basis for true knowledge networks [4] [5] [6]. The Adaptive Agent oriented Software Architecture (AAOSA), is an agent-based infrastructure, which uses an adaptable, user-centric approach to rapidly construct an accurate representation of the user's task model, as well as the mapping from this to a specific application's functionality and interfaces [7]. An AAOSA agent network looks like a static network of nodes, but each node can be activated regardless of the distance from the entry node, and based on utility.

AAOSA builds upon the generative nature of knowledge, utilizing a user's existing knowledge (i.e., intent) to enable acquisition of knowledge, as opposed to information, over computerized networks.

An agent may be able to break a problem into sub-problems, and ask other agents to help solve them. Therefore, agents have communication capabilities and an inter-agent communication language (ACL). In order to ensure localization, reusability, dynamic addition and removal of agents to networks, and distributability, the registration of agents is localized to the agents themselves, or within limited domains (i.e., agent sub-networks).

Figure 2 shows the internals of a cross section of an agent-oriented system for a home entertainment and broadcasting system. Users will be able to enter the network and query it from any node, establishing the context of their request.

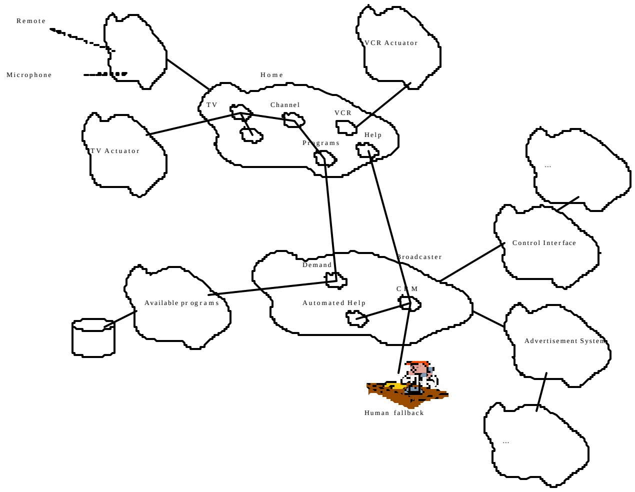

Figure 2) Example of an actual agent-oriented system for home entertainment.

A sub-network is a subset of a network of existing agents in a system. An outsider module, which may itself be an AAOSA agent, decides when to start a session. It goes on to pose problems to a sub-network. Agents providing a solution or parts of a solution also assert their relevance to deal with follow-up problems. If an agent determines irrelevance, it reroutes the request to its immediate up-chain within the path established by the session. This mechanism guarantees the traversal of the agent network to locate agents responsible for solving a problem, even though the entry point for posing the problem can be any agent in the network.
A time-out or depth of propagation is used to ensure a response by the network within a reasonable time frame. For information networks of the scale of the Web, search bots should be paired with the active ontology agents to help identify relevant user entry points by indexing the network under a generalized classification hierarchy.

Figure 3 shows a schematic of an AAOSA agent. The most basic capability of an AAOSA agent is to provide services to outside service requests. The service request-processing unit processes service requests, which may be local objects internal to the agent. The problem-solving unit is responsible for solving problems posed to it from outside the agent. This unit is more customized to the specifics of the problem domain than other modules in an AAOSA-agent and the actual processing of the problem may lead to internal service requests or service requests to other AAOSA-agents. The problem-solving unit may have a conceptual level knowledge of immediate down-chains. In other words, the problem-solving unit may be aware of what the agent's down-chains represent and what they may be able to do. The problem-solving unit includes a problem solving logic, and two sub-units for problem and solution composition. The problem-solving logic used by the agent to process problems is an object that may be modified through service requests.

In the process of solving the problem at hand, the problem-solving unit may come across problems of its own, which are formed and prepared for down-chain submission in the problem-composition unit. Using the problem-solving logic, the agent may choose to decompose a problem into sub-problems, some of which may also be handed down-chain. In the solution-composition unit solutions received from down-chain agents are considered, filtered, and composed into the solution to be provided by the agent. The problem-delivery unit is responsible for posing a problem to down-chain agents and is triggered by the problem-solving unit. This unit includes a mechanism to identify down-chains. The solution-receiver unit communicates with down-chains in order to receive their solutions to problems posed to them by the agent, and hands these solutions over to the solution-composition unit. The solution-delivery unit hands a solution or set of solutions up to the initial problem poser. Each solution is paired with a relevance object, which includes a confidence in the solution, along with the scope, or subset of the problem addressed by this solution. Relevance assignment is also handled in the problem-solving unit. If an agent determines irrelevance to solve a problem, it may reroute it to its session up-chain.

An agent, being somewhat higher level and more dependable than an object, requires elaborate failure recovery mechanisms built into it. An agent should be able to solve problems in spite of changes to the agent network, unpredictability of the problems, or when there are no responses or slow responses to problems posed down-chain.

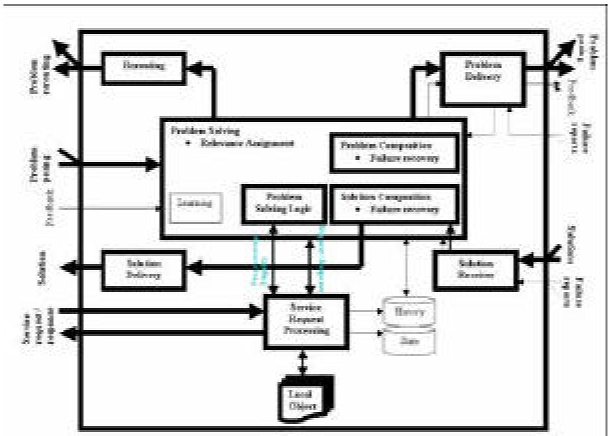

Figure 3) A DPS-Agent. Optional capabilities are drawn using thin lines, arrows and borders.

This architecture lends itself well to capabilities such as distributability and learning and users should have the option of incorporating and utilizing them in their implementations.

5. Actual Deployments

AAOSA has been deployed at Salesforce.com as their Wireless Edition (www.wireless.salesforce.com). Regardless of what modality or device the Salesforce.com user prefers, AAOSA takes their query, makes transactions against Salesforce.com on behalf of the user, and presents the user with the results of their query, in an intuitive, useful manner. Since deployment, the AAOSA-NLI for Sales Force Automation has enjoyed a strong uptake. In the first 120 days since the announcement of the service more than 300 companies signed up for use of the system. The success-rate of the system has been consistently above 90%, and more than 95% of the queries have been within the functional scope of the system capabilities. The average use per user of the system in the first few weeks of deployment was around 5.2 hits per week. Trends show a steady growth in usage and subscriptions since deployment.

6. Conclusion

The Three Laws mentioned in this paper all imply optimal communication and navigational efficiency for the described network effects to work. For example, a Group Forming network made up of people who all speak different languages will collectively produce little value. In order to achieve the potential value promised by the Three Laws, nodes in the value network -- be they human, applications, or information content -- must possess a shared communication/information model, and there is a cost to acquiring this knowledge.

Today, certain agent-oriented technologies provide a glimpse into how systems can minimize the mapping cost mentioned above.

6. References

[1] G. Gilder, "George Gilder's Telecosm: Metcalfe's Law and Legacy," Forbes ASAP, September 13, 1993. (http://www.seas.upenn.edu/~gaj1/metgg.html)

[2] D. P. Reed, That Sneaky Exponential—Beyond Metcalfe's Law to the Power of Community Building, 1999. (http://www.reed.com/Papers/GFN/reedslaw.html)

[3] H. Rheingold, Smart Mobs: The Next Social Revolution, Perseus Publishing; October 15, 2002.

[4] R. J. Bayardo, Jr., W. Bohrer, R. Brice, A. Cichocki, J. Fowler, A. Helal, V. Kashyap T. Ksiezyk, G. Martin, M. Nodine, M. Rashid, M. Rusinkiewicz, R. Shea, InfoSleuth: Agent-Based Semantic Integration of Information in Open and Dynamic Environments, Proceedings of the ACM SIGMOD International Conference on Management of Data, 1997.

[5] Snehal Thakkar, Craig A. Knoblock, Jose-Luis Ambite, and Cyrus Shahabi, Dynamically Composing Web Services from On-line Sources, In Proceeding of 2002 AAAI Workshop on Intelligent Service Integration, Edmonton, Alberta, Canada, pp. 1-7, July 2002.

[6] Genesereth, M. R., Keller, A. M. and Duschka, O. M. 1997. Infomaster: An Information Integration System. In Proceedings of ACM SIGMOD-97

[7] Hodjat B., Amamiya M., Introducing the Adaptive Agent Oriented Software Architecture and its Application in Natural Language User Interfaces, IJCAI Work-shop on Distributed Constraint Reasoning held at IJCAI'2001, pp.109-122, Seattle, 2001.