CatNet: Catallactic Mechanisms for Service Control and Resource Allocation in Large Scale Application-Layer Networks*

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Abstract

The aim of the CatNet *project is to combine economic and computer science research to provide new coordination mechanisms for large-scale application-layer networks. The ability of a free-market economy to balance and satisfy the con¤icting needs of millions of human agents recommends it as a decentralized organizational principle.* CatNet *will evaluate a decentralized mechanism for resource allocation in computer networks, which is based on the economic paradigm of the Catallaxy. The technical realization of the paradigm builds on software agents which buy and sell network services and resources. This concept is applied both to initial service deployment and service access and to provisioning during the network's lifecycle.*

1. Service Control and Resource Allocation in Application-Layer Networks

Application-layer networks are software architectures that allow provisioning of services requiring a huge amount of resources by connecting large numbers of individual computers for information search and retrieval, parallel processing or data storage [5]. Application-layer networks are needed to set up multicast services for global audiences, to provide services for storing large-scale data sets, and to allow the execution of parallel applications requiring tera¤ops of processing power. However, such large-scale decentralized distributed systems face fundamental problems of usage. The over-usage of shared resources for example, known as the "tragedy of commons" or "free-riding behavior" [1], soon leads to the network's collapse. In order to keep application-layer networks operational, service control and resource allocation mechanisms are required.

Service control and resource allocation is realized in existing operational large-scale distributed systems mostly by employing a centralized coordinator object. This centralized approach has several drawbacks. A £rst prerequisite for a central coordination object to work properly is that the environment must not change between the beginning and the end of the computation process. This is possible when the whole system changes its state in discrete timeslots. Application-layer networks, however, are very dynamic and fast changing systems: service demands and node connectivity changes are very frequent, and new services are created and composed continuously. Dynamic application layer networks need a continuously updating coordination mechanism, which re¤ects the changes in the environment. A second related property is that the coordinator should have global knowledge on the state of the network. This is mostly achieved by calculating the time steps such that actual status information from all nodes arrives safely at the coordination instance. However, if the diameter of the network is too large, this approach leads to long latency times for the nodes. Third, a centralized coordinator is part of the problem that decentralized application-layer networks are trying to solve. As bids and offers have to route through the network to the single instance which collects global knowledge and computes the resource allocation, the distribution and deployment of services throughout the network is counteracted. This is currently not a problem while the control information is small compared to the allocation data itself, but may increase when the principle is applied to more and more application areas.

2. The Catallaxy Paradigm

The Catallaxy coordination approach [4] is a coordination mechanism for systems of autonomous decentralized software devices based on constant negotiation and price signaling. The research builds on efforts from distributed

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arti£cial intelligence and agent-based computational economics with the aim of developing new technical solutions for coordinating decentralized multiagent systems. This market coordination approach is designed to exhibit self-regulating coordination patterns and leads to a co-evolution of software agent strategies. The software agents are able to learn via a decentralized evolutionary algorithm, and their constant revision of strategies leads to a stabilization of prices throughout the system. The resulting patterns are comparable to those witnessed in human market negotiation experiments. Earlier work in the context of computer science has used economic principles for resource allocation in operating systems, packet routing in computer networks, and load balancing in distributed computer systems [3]. These approaches rely on using a centralized auctioneer and the explicit calculation of an equilibrium price as a valid implementation of the mechanism. A successful implementation of the Catallaxy paradigm for distributed resource allocation mechanism promises the advantage of a more ¤exible structure and inherent parallel processing compared to a centralized, auctioneer-based approach. The research question is to assess whether it is possible to achieve coherent coordination in application-layer networks from the sel£sh pursuit of utility-maximizing agents, without a centralized coordinator.

3. The *CatNet* Project

The project goals of *CatNet* are to evaluate the Catallaxy paradigm for decentralized operation of application-layer networks in comparison to a baseline centralized system. The overall success criterion for the evaluation of a control mechanism is ”maximum social welfare”, which is the sum of all utilities of the participating nodes. This criterion balances both costs and revenue related to the nodes and allows comparing different variants of the Catallaxy and baseline implementations. Social welfare maximizing solutions are a subset of ”Pareto-ef£cient” ones; once the sum of the payoffs is maximized, an agent’s payoff can increase only if another agent’s payoff decreases. As this property also holds for local optima of the solution space, ”social welfare” is considered to be the main evaluation parameter. The resource allocation ef£ciency of an agent adds to the revenue, while communication cost, measured as the ratio of data to control bandwidth consumption, adds to the costs. Increasing performance and decreasing communication in the whole network thus directly computes to relatively maximized social welfare. This evaluation will be carried out through simulations using the *Javasim* network simulator [6]. *Javasim* is a discrete event simulator targeted at networking research that provides substantial support for simulation of real network topologies and application layer services; it very accurately simulates communication events, i.e. data and control messages among application network instances.

The technical realization of the coordination mechanism accomplished service control from the initial lifecycle of the service through deployment mechanisms. Deployment is the mechanism through which control is exercised in real world situations for creation of distributed systems such as teams, towns, or armies. Its computer systems equivalent [2] allows for the creation and control of new services in application-layer networks by the implementation of resource discovery, service speci£cations, resource mapping and service composition mechanisms. Deployment is also catallactic: sel£sh service deployers compete for existing destinations, and sel£sh resource providers compete for provisioning of new services. During the runtime of the network, software agents in the network nodes buy and sell network services using a heuristic and adaptive negotiation strategy. Changes in prices for certain services re¤ect changes in the supply and demand situation, which are propagated throughout the network. Upon receiving this information, both client and service provider agents will adapt their strategies about where to buy and sell, and thus continuously change the state of the network. The project will de£ne a software agent framework for coordination and coherent resource allocation throughout the whole network. It de£nes mandatory norms and rules for all nodes in the network to provide immediate feedback and to propagate subsequent action to counterbalance undesired effects. The de£nition of individual agent strategies by the node owners is then possible, without the need for a central designer instance.

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