On Line Markets for Distributed Object Services: the MAJIC system

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Abstract

We describe a general-purpose architecture for applying economic mechanisms for resource allocation in distributed systems. Such economic mechanisms are required in settings such as the Internet, where resources belong to different owners. Our architecture is built above standard distributed-object frameworks, and provides a "market" for arbitrary distributed object resources. We first describe the abstract elements and properties of an architecture that can be applied over essentially any distributed object-based platform. We then describe the MAJIC[1] system that we have implemented over Suns' Jini platform. A key novel aspect of our system is that it handles multiple parameters in the allocation and in the specification of utilities and costs for each distributed service. We provide both theoretical and experimental results showing the following three key properties of this system: (1) Efficient resource allocation. (2) Motivation for resource owners to share them with others. (3) Load balancing.

1 Introduction

1.1 Motivation

The following concept may be viewed as the holy grail of "Internet Computing": Every user connected to the Internet should have complete access to all resources available anywhere on the Internet. The user should be presented with an illusion of a single centrally organized "global computer". The main challenge of computer engineering, in this context, is to design the protocols, algorithms, paradigms, and systems that achieve this illusion by using the aggregation of the physical computers, communication links, and other resources that are available on the Internet.

Ideally, such systems would optimally allocate all available resources across the Internet. There are indeed a wide variety of such resources: computational resources (such as CPU time, or file servers), information resources (Databases, video), communication resources (links, QoS), services (help-desk, access to specialized algorithms), hardware (printers, cameras), and more. A dream suite of protocols and algorithms for the Internet would allow all these resources, as well as others, to be optimally and transparently allocated across the Internet.

There are clearly many aspects that need to be addressed on the way to this "holy grail", and many of these aspects have received much attention in the literature. In this paper we concentrate on the interplay and synergy between two key paradigms that address different aspects of this challenge: the distributed objects paradigm for basic technological interoperability and the economic paradigm for motivating resource sharing by different users or organizations.

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[1] **M**ultiparameter **A**uctions for **JI**ni **C**omponents

1.2 Distributed Objects Paradigm

In recent years the paradigm of distributed object services is becoming the basic backbone of communication and cooperation between components of a distributed system. In a distributed object framework, computers on a network encapsulate their shareable resources (services) in well defined procedural interfaces. Other computers then use these resources by performing remote procedure calls (RPC), or in an OOP terminology, remote method invocations (RMI) on them. In its pure object-oriented variant this paradigm is the basis of most modern commercial distributed platforms: CORBA [5, 32], Microsoft's DCOM [6], Java's RMI [38]. Taking a wider perspective, web servers follow this paradigm on the level of web pages (static or dynamic), and with standards such as XML [53, 52] and protocols such as SOAP [44], a true web-like infrastructure for distributed processing that follows this paradigm emerges. Indeed many authors have proposed variants and implementations of this vision under names such as "Web of Objects", "Distributed Objects Everywhere", etc [36, 51, 45, 14, 3].

1.3 Economic Paradigms for Resources Sharing

A major difficulty in achieving efficient sharing of resources across the Internet is the obvious fact that the different computers and resources belong to different organizations. An Internet-wide resource sharing system must provide motivation for the owners of resources to share them with others. Any such motivation leads to some kind of economic system, and in its simplest form involves payments for services. Such economic systems for distributed allocation of computing resources have been applied to CPU time [9, 50, 49, 48, 29, 37] , communication [22, 43, 40, 21], and other resources [23, 16, 41, 48], and have received much theoretical interest lately [22, 27, 10, 35, 17, 42, 30, 31]. Such systems pursue two complementary goals: that participants are indeed motivated to share these resources with others and that the resources are indeed allocated well.

1.4 This Paper

We first propose a general architecture for augmenting a distributed-object system with payments, and a market-based mechanism for allocating resources. We then describe a system of this sort, the MAJIC system, that we have implemented over Sun's Jini infrastructure. More details are available in the MAJIC web site [24]. This architecture allows, for the first time, applying the ideas of economic-based cooperation to the full spectrum of resources available on the Internet: CPU time, file servers, Databases, online entertainment, communication bandwidth, algorithms, printers and other hardware, etc. Moreover, this is done in a way that is easily inter-operable with the current leading technologies. We provide both general arguments (and mathematical proofs) showing that such an augmented system would indeed function well, and specific experimental results from MAJIC, supporting these findings. This architecture provides, for the first time, an economy based general-purpose infrastructure for all kind of resources, compared with earlier similar systems, which were dedicated to one kind of resource. A key novel aspect of our architecture is that it allows multiple parameters in specifying utilities and costs for each service request and handles these parameters in an efficient and non-trivial way.

It is clear that any system that achieves serious resource sharing over the Internet must address both the issue of technical inter-component communication and the issue of motivating selfish entities to share their resources. We believe that systems built along the principles laid here answer both issues in an integrated, inter-operable, and efficient way and could provide a general-purpose architecture that allows true efficient resource sharing on the Internet!

2 A blueprint for a market of distributed object services

2.1 Basic idea

The starting point of our architecture is simple: each object that provides a service may attach a "price-tag" to it. When another object wishes to use a particular type of service, it calls a central "service market place" that functions as the object request broker. The market performs a "reverse auction" for this service, where all available objects (service providers) that provide a service of this type can participate. The provider that charges the lowest price wins, and gets to service the request for the agreed-upon price.

A simple example that we will use throughout the paper is a printing service. Our starting point assumes that printers provide the service of printing a page by providing the simple remote method: *printer.print(page)*. Each printer has a price for this service: *printer.getPrice()*. A computer that wants to print a page on a printer that does not belong to him gets the reference to the cheapest printer from the "printing market" and can then print on this printer: *market.getPrinter().print(page)*.

Several basic issues need to be addressed before this can be made into a workable system, and we describe the major ones.

2.2 Parameterized Services

Looking at the previous printing example, one is immediately concerned with the differences between different printers and printing jobs. In reality many parameters distinguish one print job from another: number of pages, page size, printer's location, printing speed, print quality, etc. Clearly any serious system that handles printing services must be aware of these differences. More generally, distributed object services receive input parameters - it is quite clear that the price requested for a service must be tightly related to these parameters. Additionally, inter-changeable distributed service providers are still not totally equivalent in many of their parameters (such as their quality, virtual location or their speed).

This is not a simple issue to tackle when one attempts to produce a "market" for these services. Ignoring the parameters in the market will simply make any type of efficiency in resource allocation impossible. Taking all the parameters into account in the definition of the "market" will lead to a logically separate market for each request and for each service provider, eliminating competition and thus any flexibility in allocations. The solution is clearly to work within a single market, but take parameters into account during resource assignment.

In our system each *service type* specifies the set of parameters of the service, defining the *parameter space* of the service. Each service provider can supply the service in some specified subset of the parameter space. Back to our example, a certain printer may only be able to print on "A4" or "letter" page sizes, but not on "A3" size, while another may also offer "A3" size. Similarly, a printer will usually only supply the printing service at a certain physical location or with a certain time delay (depending on its current load). Each service request may be in a single point of the parameter space ("I need A4 pages"), or may be satisfied with a whole subset of the parameter space ("A4 or letter is fine"), possibly with preferences among the different possibilities.

In economic terms, each point in the parameter space of a service type is a separate product type. The products that correspond to different points in the parameter space of a single service type are *partial substitutes* to each other - both for service providers and for service requesters. The challenge we face (and solve below) is to organize a single market for all these products, while handling the partial substitution in an economically efficient way.

2.3 Sellers' Quote and Buyers' Utility

Our economic system is based on a common currency in which all participants can express their economic preferences. Thus we assume that each service provider - *seller* - has a certain internal cost for supplying the service at each point of the parameter space that can be provided by him. Similarly, each service requester - *buyer* - has a certain economic benefit from receiving the service, a benefit that may depend on the parameters. Denote by P the parameter space of a certain service type, our economic model of participants is given by the following two functions: (1) Sellers' *cost* function: $c_S : P \rightarrow R^+$. For a point $p \in P$, $c_S(p)$ specifies seller S's internal cost for supplying the service with parameters p. I.e., he would like to provide this service with these parameters if he is paid more than $c_S(p)$, and would not agree to provide the service for a lower price. We take the convention that if S cannot provide the service with parameters p at all then $c_S(p) = \infty$. (2) Buyers' *utility* function: $u_B : P \rightarrow R^+$. For a point $p \in P$, $u_B(p)$ specifies buyer B's benefit from receiving the service with parameters p. I.e., he would like to receive this service with these parameters if he pays less than $u_B(p)$, and would not agree to buy the service for a higher price. We take the convention that if the service with parameters p is not acceptable at all to him, then $u_B(p) = 0$.

In our system, each seller sends to the market a function corresponding to his cost function – called the *quote* function $q_S : P \rightarrow R^+$. For a point $p \in P$, $q_S(p)$

specifies his "quote" for the service with parameters p – i.e. the amount of money he demands for providing the service with these parameters. The quote function q_S is essentially a catalog specifying a price for each choice of parameters that can be supplied by S. Informally speaking, the quote function q_S of a seller should correspond tightly to his cost function c_S. This however cannot be guaranteed at this point as a seller will likely send to the market a quote function aimed for maximizing his profits - not aimed at any particular correspondence with his cost function. We will return to this point below. The system allow sellers to modify their quote functions occasionally, taking into account changes in status.

When a buyer requests a service he sends to the market a representation of his *utility* function. The market matches this buyer with the seller that fits him best. The abstract process that takes place is that the market creates an agent for the buyer based on his *utility* function. This agent is presented with the catalogs (*quote* functions) of all sellers, and chooses the best seller and parameters. The details of this process are explained in section 2.4.

The representation of the *quote* and *utility* functions as objects may be given by specifying the formulas that define them as a function of the different parameter values or may be given by opaque distributed objects that encapsulate these functions. The choice of representation will usually depend on the service type and has consequences in how the system can function.

2.4 The Market Mechanism

As mentioned, the market holds the current quotes from all sellers $\{q_S\}$, and when it receives a request from a buyer - specified by the buyer's utility function u_B – it attempts matching this request to the best seller and choosing the best parameter values. The optimization criteria is the *surplus*: $surplus_{B,S}(p) = u_B(p) - q_S(p)$. For a given supplier S, the parameters p are chosen as to maximize this surplus: $p^*_{B,S} = \arg\max_p\{surplus_{B,S}(p)\}$. In case this search over the parameter space is computationally feasible (this depends on the representations of the parameter space and the quote and utility functions), the buyers' agent can directly find these optimal parameters. Otherwise, the system allows each buyer to supply a "parameter search engine" that attempts finding these parameters, given a quote function (encapsulated by an object) as input. We expect this mechanism to be computationally efficient either because of the simplicity of the parameter space, or because of the low dimensional size. However, when searching in complex parameter space, we expect the buyer's search engine to find a close approximation in reasonable time.

The optimal supplier is chosen as to optimize the surplus under the optimal parameters: $S^* = \arg\max_s\{surplus_{B,S}(p^*_{B,S})\}$. At this point the buyers' agent must check that this surplus is indeed positive: $surplus_{B,S^*}(p^*_{B,S^*}) > 0$. Otherwise, the buyer is not willing to pay as much as the optimal seller is asking, and the service request should be canceled. As analyzed theoretically in section 4, and demonstrated experimentally in section 5, this agent-based allocation produces efficient allocations in terms of reported utilities and quotes.

Once the optimal $S^*$and $p^*$are found, the market may in principle fix any payment d in the range $q_{S^*}(p^*) \leq d \leq u_B(p^*)$. Any price in this range will be acceptable both to the buyer and to the seller. The simplest choice would be to use the quote function as the price: the buyer must pay the seller the amount of $q_{S^*}(p^*)$. This is certainly the usual choice in commerce as it corresponds to the catalog price of the chosen product. In terms of auction theory, this corresponds to a first price auction [34, 26].

We suggest also a different choice of payment, generalizing Vickrey's second price auction [47]. The motivation for this payment rule is to motivate sellers to send the market a quote that is equal to their cost function $q_S = c_S$ – a property known as incentive compatibility. This is extremely important due to the fact that otherwise the assignment does *not* optimize the allocation according to the true costs but rather according to the quotes. Indeed the previously mentioned payment rule motivates sellers to announce a quote that is higher than their costs – thus potentially leading to a wrong choice of seller. For general background on this topic see [15, 4, 25], and for specific discussion in the context of computation resources see [30, 28, 39, 46].

The payment rule we suggest is as follows. Let S^2 be the second best choice for supplier: $S^2 = S^2_B = \arg\max_{S \neq S^*_B}\{surplus_{B,S}(p^*_{B,S})\}$. The surplus with supplier S^2 is less or equal to the surplus with supplier S^*. This payment method mandates that the buyer only gets the surplus of S^2, while the optimal seller gets the difference between the two surpluses. Thus the payment to supplier S^* is given by: $d = u_B({p^*}_{B,S^*}) - surplus_{B,S^2}({p^*}_{B,S^2})$. The main theoretical result we show, using the standard game-theoretic models of rational behavior, is that this payment method results in incentive compatibility, and thus all rational sellers indeed quote their true costs leading to efficiency of allocations in the system.

2.5 Load Balancing as a By Product

As described above, this type of system ensures optimal allocation of each request to the service provider that is best for it. In cases that requests do not conflict with each other, this implies that the system obtains optimal global performance. This is clearly not the usual case! The whole point of allocation in distributed systems is handling the conflicts – different requests should normally be split between the available servers. Going back to our printing example, not everyone can gain access to the best and cheapest printer – this would likely cause a bottleneck there. Indeed, perhaps the most basic requirement from a distributed system is that of load balance: the load should be reasonably split between available servers.

A key observation is that economic-based systems can provide this load balancing – if designed correctly. Specifically, when one considers the underlying reason why load balancing is usually desired, it seems that the reason is simply that users want their requests to be served quickly. Putting this into economic terms, users' utilities depend on the time until their request is serviced. This is rarely formalized, but may be easily formalized if service-time is a parameter in the parameter space of the service type – as it is in our system. E.g., a request may specify a firm deadline by setting the utility to be zero if the service-time is greater than the required deadline. Similarly, gentler penalties for tardiness may be applied by tailoring the utility function's dependence on time. Suppliers, on the other hand, must make sure that their quotes do indeed reflect their current capabilities in terms of service-time and must modify them when their load changes.

Load balancing emerges automatically once the quotes of the different suppliers do indeed reflect their actual service-time capabilities. As a certain service supplier gets more requests assigned to it, it must raise the service-time promised in his quotes. This will automatically cause time-sensitive requests to be allocated to other service suppliers – those with lower loads. Requests that are less sensitive to service-time and more sensitive to other parameters that are optimized by a loaded supplier may still be assigned to it. This form of load balancing strikes a balance between optimized matching of service parameters and reducing the service-time in a way that is *locally* perfect: exactly according to the specification of the service request.

This local optimization does not necessarily imply global optimal balance of load: an assignment of a certain supplier to one request may result in a heavy penalty for the next request. Indeed, any formalization of optimal global allocation is computationally intractable (NP-complete) [11], and moreover, cannot be done in an online mode – servicing requests as they come [8]. Yet, we supply theoretical evidence as well as experimental results, suggesting that load balance emerges.

3 The MAJIC system: Multi-parameter Auctions for JIni Components

The MAJIC system is built on top of the Sun's Jini platform, while implementing the basic architecture described above. We chose the Jini platform since it is a simple yet powerful distributed object system with open source. Moreover, Jini's object-broker mechanism – the lookup service – turned out to be easily adapted to our purposes. In addition, Jini uses Java's code mobility capabilities, which in our case allows transfer of utility functions and quote functions encapsulated in objects.

3.1 Jini overview

The $Jini^{TM}$ system is a distributed systems technology released by Sun Microsystems in 1999. The Jini technology enables all types of digital devices to work together in a community, without extensive planning or installation. It is built on top of the Java environment [18] and the RMI mechanism [38]. Detailed specifications and explanations regarding the Jini system can be found in [1, 7]; on-line documentation can be found in [19, 20]. We now describe only the bare essentials that are directly required for our purposes.

The Jini technology infrastructure provides mechanisms for devices, services, and users to join and detach spontaneously from a network, and be visible and available to those who wants to use it. Each Jini system is built around one or more *lookup services*. A *lookup service* is a service that maintains a list of known services and provides the ability to search and find services via the *lookup* protocol. When a service is booted on to the network, it uses the *discovery* protocol to find the local lookup service. The service then registers its proxy object (a Java object) with the lookup service using the *join* protocol. When a client program queries the lookup service for a particular service (using the *lookup* protocol), the lookup service returns the appropriate service proxy (or a set of service proxies) to the client. Then, the client can invoke methods of the chosen service using the proxy. The invocation can be done either locally or remotely (using Java *RMI* protocol). Figure 1 illustrates the system normal flow.

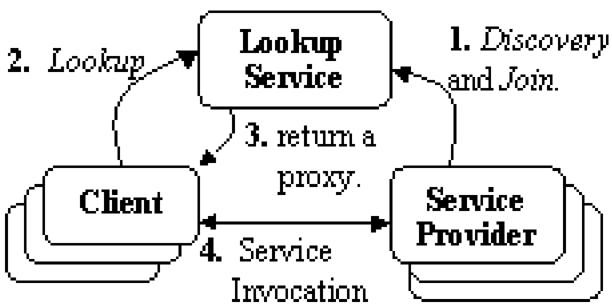


Figure 1 - Jini protocols flow

We use two other Jini concepts inside MAJIC; the first is the *leasing* mechanism ([7] ch. 10), which provides Jini its self-healing nature. This mechanism is a timed-based resource reservation: if a service fails or stops (either intentionally or unintentionally) without "cleaning up" after itself, its leases will eventually expire and the service will be deleted. The second concept is the service attribute set ([7] ch. 7), a flexible way for services to annotate their proxy objects with information describing the service; thus helping clients to find their required services.

3.2 MAJIC Architecture overview

The MAJIC architecture is based on the general blueprint described above applied to Jini platform. The main considerations were to preserve interoperability and the programming paradigms of the original Jini platform, while providing maximal flexibility. In addition, the market mechanisms should have minimal effect on the performance of the system.

3.2.1 Service Types

Each service type in our architecture is implemented as a *Jini service* that additionally implements the *Economy Service Interface* (ESI). Each service type has a well known set of parameters that defines the *parameter space*. The parameters are partitioned into *seller parameters*, those that are totally fixed by each seller, and *buyer parameters* which can be chosen by each buyer. Each service type defines a Service Contract class (a subclass of the abstract SC class described below) for sellers and a Buyer Valuation class (a subclass of the abstract BV class described below) for buyers.

3.2.2 The market

The *market* is implemented as an extension (subclass) of Jini's *lookup service* that uses economic mechanisms to perform efficient allocation. When service providers (sellers) *join* the market, they submit their *quote* wrapped in a *Seller Contract* (SC) object, passed as one of the *service attributes*. Whenever a buyer performs a *lookup* using the market, the buyer submits his *utility* function and its *parameter search engine*, both wrapped in a *Buyer Valuation* (BV) object. This is used by the market to create a buyer agent that performs the economic search for the optimal seller and parameters. Finally, the market returns a proxy to the optimal seller as the result of the lookup request. Additionally, a *Final Contract* object encapsulating the closed deal is created and sent to the buyer and to the seller. We have implemented two distinct markets, corresponding to the two payment methods described in the blueprint (first or second price).

3.2.3 The seller

The seller is a Jini service provider (thus additionally implementing the ESI interface). When joining a market, the seller should submit its *quote* function encapsulated in the SC object. Note that the quote function may be implemented as an arbitrary Java method; the method's code is actually transferred to the market. In addition to the quote function, the SC object also includes the fixed values of all seller parameters as well some timing-control information to be described below. Using the ESI interface, the seller receives online notifications of all *Final Contracts* (described below) and must be able to update and resubmit its SC object to the market. When the seller is actually invoked by a buyer using a previously obtained proxy, it must verify the validity of the corresponding FC.

3.2.4 The buyer

The buyer is a simple Jini client that in a lookup request sends the market its BV object. The BV object encapsulates both the *utility* function and the *parameter search engine* that finds the best values for the *buyer parameters* (accessed through a *getBuyerParameters()* method*).* Both of these may be implemented as arbitrary Java methods whose code is transferred to the market and used as the buyers' agent. The parameter search engine may use well-known structure information regarding the parameter space of a particular service type, or may perform an exhaustive search of the parameter space.

3.2.5 Final contract

The *Final Contract (FC)* is a sealed contract that represents a closed deal between a buyer and a seller; it is constructed by the market and contains the following: a unique identifier, the SC, the chosen *Buyer Parameters* (BP), and the payment details. The FC should, in principle, be digitally signed by the market (this is not currently implemented) and is to be used as the basis for the actual electronic fund transfers.

3.2.6 Time-control mechanisms

Two mechanisms are supplied for ensuring that sellers' time-dependent quotes are used only if they are up to date. Every SC that is submitted to the market allows specifying a maximum number of contracts that may be created according to this SC. Whenever the maximum is reached, the market removes this seller from its list of service providers. Sellers with time-dependent quotes can specify a low maximum and then must periodically update their SC prior to this maximum being reached. In addition, each FC contains a lease control object (LCO) that ensures sellers that their services will be invoked by buyers within a predefined time interval. When the lease expires, the service proxy can no longer be used and an exception is raised.

3.3 Summary - flow of events

The System behaves as follows:

1. Economically enhanced lookup service is put in place and economic parameters for a service type are defined.
2. The seller (service provider) creates a well defined contract (SC) that describes its economic parameters.
3. The seller joins the market and submits its SC within its attribute list.
4. When the buyer (client) searches for an appropriate service, it creates a valuation object (BV) and sends it to the lookup service.
5. The market (lookup service) finds the best seller according to the buyer valuation object (e.g. finds a seller that maximize the surplus of the buyer) and computes the payments that should be transferred.
6. The market constructs an FC object, representing the deal, and sends it to both buyer and the chosen seller.
7. The buyer receives the optimal seller's proxy and the FC*,* and invokes the service via retrieved proxy.
8. The seller may update his quote function.

3.4 Participants obligations

There are some implicit contracts (commitments and obligations) between all entities (players). The most significant assumption is that the market is *trustable* and *accepted* by all sides.

The market can assign buyers to a seller, as long as its SC is *valid*. The SC is *valid* as long as the service is registered at the lookup service and the seller hasn't supplied the maximum number of contracts mentioned in his SC. The seller must provide the service according to the parameters published in the FC, as long as the FC is *valid (*the FC lease hasn't expired). The seller is required to change all necessary parameters inside its SC whenever relevant (time dependent parameters). The buyer can execute the service during the lease duration, defined in the FC. Both seller and buyer accept the payment details described inside the FC.

4 Theoretical Analysis

We describe a theoretical model that analyze our multiparameter market system.

4.1 The Model

The Model is based on two types of players: a buyer and a seller, and a market place. Denote by P the parameter space of a certain service type.
Each Seller S, has:

1. A private *cost* function: $c_S : P \rightarrow R^+$. If S cannot provide the service with parameters p, then $c_S(p) = \infty$.
2. A public *quote* function $q_S : P \rightarrow R^+$. This function is sent to the market.

Each Buyer B, has two functions that are coupled together:

1. A *utility* function: $u_B : P \rightarrow R^+$. If the service with parameters p is not acceptable at all to him, then $u_B(p) = 0$.
2. A function $g_B : Q \rightarrow P$, where Q is the space of all possible *quote* functions. This function acts as the *parameter search engine* that finds appropriate parameters, given a *quote* function.

See section 2.3 for explanations.
Definition 1. g_B is called *optimal* if $\forall q_S,\ g_B(q_S) \in \arg\max_{p \in P}\{u_B(p) - q_S(p)\}$. I.e., g_B finds the parameters that maximize the buyer *surplus.*

4.1.1 The assignment mechanism

The market holds the current *quotes* from all sellers $\{q_S\}$, and when it receives a request from a buyer B, (u_B, g_B), it attempts matching this request to the best seller and choosing the best parameter values. The optimization criteria is the *surplus.* For a given supplier S, the parameters p are chosen by the buyer's *parameter search engine:* $p^*_{B,S} = g_B(q_S)$. The optimal seller is chosen as to optimize the surplus under these parameters: $S^* = \arg\max_s\{surplus_{B,S}(p^*_{B,S})\}$. If $surplus_{B,S^*} \leq 0$ then the request is denied. Otherwise, the market fixes a payment d_{B,S^*} according to one of the following payment methods:

- *first price*: $d_{B,S^*} = q_{S^*}(p^*_{B,S^*})$
- *second price*:
  let $S^2 = \arg\max_{s \neq S^*}\{surplus_{B,S}\}$.
  $d_{B,S^*} = u_B(p^*_{B,S^*}) - surplus_{B,S^2}(p^*_{B,S^2})$
  If $surplus_{B,S^2} \leq 0$ or S^2 does not exist then $d_{B,S^*} = u_B(p^*_{B,S^*})$.

Finally, the market outputs the assignment $B \longleftrightarrow S^*$ and the payment d_{B,S^*}.

We assume the following: (1) Several sellers have registered at the market and can alter their *quote* functions at any moment. (2) Buyers arrive to the market online and immediately receive a seller assignment.

4.2 Incentive Compatibility

Our analysis uses game theoretic notions that are standard in the field of mechanism design (see [25, 33]).
Definition 2. (seller gain) For a fixed buyer (u_B, g_B) the gain of seller S is

$$gain_S(q_S, q_{-S}) = \begin{cases} d_{B,S} - c_S(p) & B\, gets\, S\, with\, p \\ 0 & otherwise \end{cases}$$

where q_{-S} is a vector of the quotes of all other sellers.
Definition 3. (Dominant strategy) A strategy (*quote*) q_S of seller S is called *dominant* if for every other declared quote $\widehat{q_S}$ and for every declarations of all other players q_{-S} , $gain_S(q_S, q_{-S}) \geq gain_S(\widehat{q_S}, q_{-S})$.
Definition 4. (Incentive Compatibility) A market mechanism will be called *incentive compatible* if declaring the true cost function ($q_S = c_S$) is a dominant strategy for all sellers.
Note: We do not discuss in this paper incentive compatibility for buyers as it is known that this can not be achieved concurrently with incentive compatibility of sellers as known from the analysis of bilateral trade [25].

Theorem 4.1. *Assume that (1) the assignment of services does not cause changes in any c_S and (2) g_B is optimal for all buyers, then the second price MAJIC mechanism is incentive compatible.*

Proof. The proof is easily concluded by the following lemma. It can also be verified that the second price MAJIC mechanism is a VCG mechanism [47] and thus the incentive compatibility follows. □

Remark. According to [31], when g_B is not optimal, the VCG mechanism is not incentive compatible. Nevertheless, there are methods that achieve feasible approximation to incentive compatibility; such methods are described in [31].

Lemma 4.2. *Under assumptions of theorem 4.1,* $\forall u_B \forall \widehat{q_S} \forall q_{-S} \;\; gain_S(c_S, q_{-S}) \geq gain_S(\widehat{q_S}, q_{-S})$.

Proof. Postponed to Appendix A. □

4.3 Allocation Efficiency

Definition 5. The total welfare achieved by the market is $\sum_{B\, gets\, S\, with\, p.} (u_B(p) - c_S(p))$.

Theorem. *Assume that (1) for all sellers* $q_S = c_S$*; (2) for each buyer* g_B *is optimal; (3) the assignment of services does not cause changes in any* c_S*. Then, for every sequence of service requests the total welfare is optimized by the market's allocation.*

Proof. (sketch) The assumptions above implies that for each arriving buyer, B, the market maximizes the *surplus, which is* $u_B(p) - c_S(p)$. Hence, the theorem immediately follows. □

4.4 Load balancing

We can show that the load balancing achieved by this economic-based model is good in many situations. Specifically, if all service suppliers are identical, then we would expect for almost uniform allocation of work among the suppliers.

Theorem 4.3. *Assume that (1) All the service providers are identical; (2) All buyers place a positive utility on faster service-time; (3) All quotes are correctly updated to reflect to the service suppliers true load. Then, the allocation obtained by the market achieves a makespan (last completion time of a service) that is within a factor of 2 w.r.t. the optimal allocation.*

Proof. Note that these assumptions implies the *identical machines* model and the allocation mechanism becomes the greedy algorithm [12] (assigning the next task to the machine with the current minimum load). This algorithm is 2-competitive w.r.t. the makespan [13]. □

It is shown in [2] that no algorithm can achieve a better competitive ratio. As usual, and as demonstrated by our experiments, typical behavior is much better and applies in a wider class of situations.

5 Experimental results

We have performed several kinds of tests on the MAJIC system: the system performance overhead, the load balancing effect, and the resource allocation efficiency in the MAJIC system. We have created two types of services and corresponding clients: a trivial service, called Simple, and a complex one, called Printer. The simple service has a single parameter (price) and the corresponding client has a fixed utility function. The printer service has several parameters: price per page, service-time (the time that the client request can be served), quality and speed. The service-time parameter varies with time to achieve simulation of time dependent services.

5.1 Testing environment description

We have built a network based testing environment that enables us to execute services and clients on several machines simultaneously. The entities (lookup service, services and clients) and their parameters can be externally configured. We have used a single machine (PIII-600 processor, 128KB RAM, WinNT 4.0 OS) for invoking the lookup service and the service providers, and another machine (PIII-600 processor, 2GB RAM, Linux OS) for invoking the clients. The machines were connected by LAN (Ethernet 10Mb/s).

The flow of events of each test was as follows: (1) Activating a specific type of *lookup service*. (2) Activating the required service providers. (3) Activating the clients with configurable time interval between their invocations. (4) The clients initiate the *lookup* protocol and eventually invoke the given service.

5.2 Results

5.2.1 System performance

The performance of the system has been measured by the *lookup* protocol response time, since it is the most significant difference between the Jini and the MAJIC systems. This is measured at the buyer side and contains the lookup search time and the network latency.

Fig 2 and Fig 3 show the differences between the various systems in low load (500 milli-seconds time interval) and high load (no time interval between clients) scenarios respectively. The tests have been performed using 1000 clients and variable number of "simple" services. The main purpose of this test is to examine the MAJIC system overhead due to the market mechanism (including the parameter search engine) and the additional message (FC) that is being sent to the chosen seller after every assignment. We should emphasis that the additional overhead is only for the *lookup service* itself, which is normally insignificant compared to invocations of services. From these figures, we see indeed that the MAJIC overhead is not prohibitive: in the low load case, we observed a 50% MAJIC overhead, while in the high load case we observed only 15% overhead. The difference between the two cases can be explained by the fact that in the high load scenario most of the *lookup* time is spent on waiting for entering the lookup service and therefore the MAJIC overhead is less significant.

Figure 3: Lookup response time in high load scenario

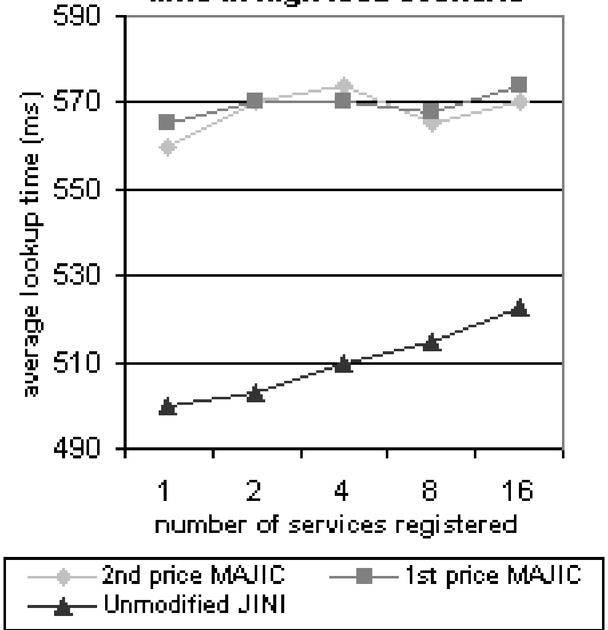
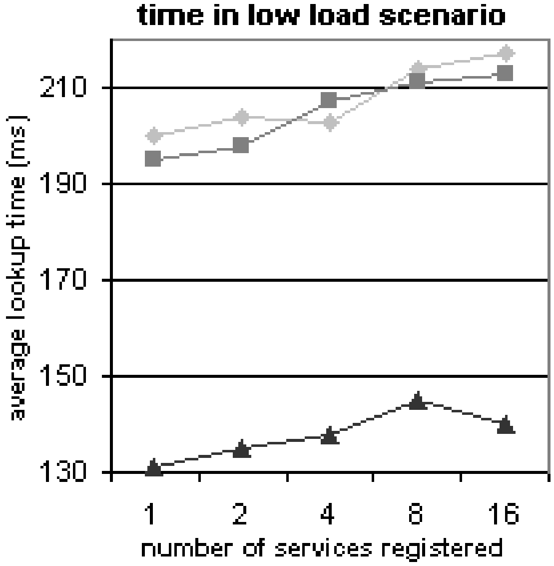


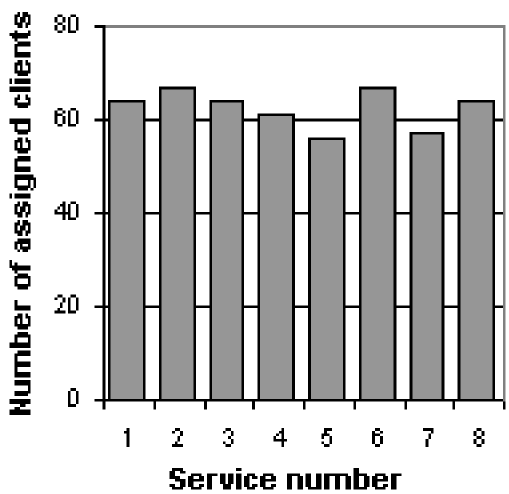
Figure 2: Lookup response time in low load scenario



5.2.2 Load balancing

The load balancing tests have been performed on 8 printer services with 500 clients (500ms time interval between clients invocations). The services were identical in all parameters. Each seller's service-time was constantly updated to reflect its current load. Each buyer had a 60 ms job duration and a *utility* function: $u_B = 120 - 0.05 \cdot service - time$. Fig 4. shows the assignments of clients to services by the MAJIC system (for example, service number 1 was assigned to 64 clients). The average number of clients assigned to a service is 62.5, moreover, the maximal deviation from the average is 10%. Pure online algorithms geared to load balancing, which are 2-competitive, show similar results [13].

Figure 4: Load balancing in the MAJIC system



5.2.3 Resource allocation efficiency

In order to demonstrate resource allocation efficiency, we chose to perform tests on the quality attribute of a printer service. We have designed a system that contains printer services with different printing qualities. In this system, each buyer had a particular preference for a printing quality. We expected from the MAJIC system to assign buyers with preference for higher quality to high quality printers and vice versa. We have used 3 printer services with the following qualities: High (quality=150, price=15), Medium (quality=100, price=10) and Low (quality=50, price=5). Note that as quality decreases the printing price decreases as well. Each buyer has a parameter, f_q , which is a continuous quality factor that is chosen uniformly in the range of [0,1]. This factor represents the buyer's preference for printing quality. We activated 100 clients using the following utility function: $u_B = 40 + f_q \cdot quality$. As f_q increases, the buyer utility grows faster with quality. Thus, we expect that as the quality factor gets higher, the client will tend to be assigned to higher quality printer, although it charges higher price. In Fig 5, we show buyers assignments on the described services with respect to their quality . As we can see, buyer with higher quality factor is assigned to higher quality service. For example, the buyer with $f_q = 0.8$ is assigned to the High quality service.

In addition, we have tested the same scenario when the printer service-time had also been taken into consideration: $u_B = 100 + f_q \cdot quality - 0.25 \cdot service\_time$. As we can see in Fig 6, the service-time parameter caused a load balancing effect; when one of the services was loaded, the clients that were supposed to be assigned to this service have been assigned to an adjacent service instead. We observe that even when the system manifests load balancing, the clients' quality preferences still effect the assignments.

Fig 5:
Assignment by quality

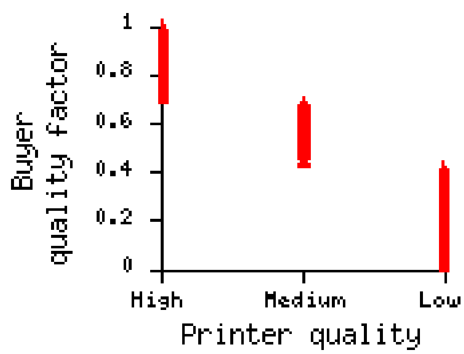
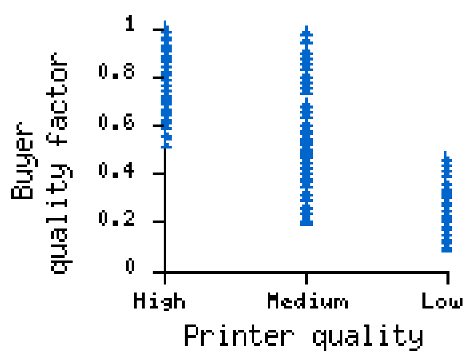


Fig 6:
Assignment by
quality and load



6 Conclusions

We have introduced a blueprint infrastructure for performing on line auctions for computer services over distributed object systems; we implemented such a system on top of Sun's Jini system. We have presented both theoretical and initial empirical studies, which show the efficiency of such systems. Two major aspects of our architecture (i.e., providing an economy based general-purpose infrastructure for all kind of resources and handling a multiparameter space in a non trival way) distinguishes our work from previous related systems, which were dedicated to one kind of resource or application.

Using a specific service type over significant population would be a major trial for this system. This way, we can examine some parameters of the MAJIC system: the system efficiency, possible implementations of *parameters search engines*, integration with existing security environments, etc.

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Appendix A. Proof of lemma 4.2

Lemma. *4.2 Under assumptions of theorem 4.1,* $\forall u_B \forall \widehat{q_S} \forall q_{-S} \;\; gain_S(c_S, q_{-S}) \geq gain_S(\widehat{q_S}, q_{-S})$

Proof. Let l_1, l_2 be two of the sellers registered in the market; let b_0 be the buyer who joins in a certain time. W.l.o.g. let l_1 be the seller which has been assigned to buyer b_0 and l_2 be the seller with the second best surplus (thus $surplus_{b_0,l_1} \geq surplus_{b_0,l_2}$). Let $p_1, p_2 \in P$ be the chosen goods of l_1, l_2 respectively (for example $g_{b_0}(q_{l_1}) = p_1$). These goods maximize the buyer *surplus* from sellers l_1, l_2 , since g_B is optimal.

We can obtain the following:

$$d_{b_0,l_1} = u_{b_0}(p_1) - surplus_{b_0,l_2} \;; \quad d_{b_0,l_1} \geq q_{l_1}(p_1).$$

Since the seller is rational, the declaration must be $q_{l_1}(p_1) \geq c_{l_1}(p_1)$. The upper bound of the seller gain must be $gain_{l_1}^{max}(q_{l_1}, q_{-l_1}) = u_{b_0}(p_1) - [u_{b_0}(p_2) - q_{l_2}(p_2)] - c_{l_1}(p_1)$. Whenever $q_{l_1} = c_{l_1}$ the maximal gain is reached because seller l_1 got the assignment. When $\widehat{q_{l_1}}(p_1) > c_{l_1}(p_1)$ we consider two possible options:

1. the buyer b_0 prefers the same good (i.e., p_1). In this case either l_1 wins and get the same gain as before or l_2 wins and $gain_{l_1}(\widehat{q_{l_1}}, q_{-l_1}) = 0$.

2. the buyer prefers another good, $\widehat{p_1}$. In this case we will show that $gain_{l_1}^{max}(q_{l_1}, q_{-l_1}) \geq gain_{l_1}^{max}(\widehat{q_{l_1}}, q_{-l_1})$. If l_1 would declare the truth than p_1 will be the chosen good; therefore

$$u_{b_0}(p_1) - q_{l_1}(p_1) \geq u_{b_0}(\widehat{p_1}) - \widehat{q_{l_1}}(\widehat{p_1}) \implies$$

$$u_{b_0}(p_1) - S_{b_0,l_2} - q_{l_1}(p_1) \geq u_{b_0}(\widehat{p_1}) - S_{b_0,l_2} - \widehat{q_{l_1}}(\widehat{p_1})$$

(denote that $S = surplus$) and these are the required gains.

Seller l_2 has $gain_{l_2}(q_{l_2}, q_{-l_2}) = 0$; the best good that l_2 can offer is p_2, since g_{b_0} is optimal. The only case that should be considered is a false declaration: $\widehat{q_{l_2}}(p_2) < c_{l_2}(p_2)$. This can easily change the assignment (l_2 can win) but also causes $gain_{l_2}$ be negative: $c_{l_2}(p_2) \geq u_{b_0}(p_2) - surplus_{b_0,l_1} \geq \widehat{q_{l_2}}(p_2)$. Therefore, the lemma holds. □