# The power of distributed software agents

by Lance Dean Kind

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Computer Science
Montana State University
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Abstract:
As the Internet continues to grow, a more efficient method than those currently used is needed for knowledge sharing. This method must be flexible and powerful enough to solve the following problems: Heterogenous Communication, Peer to Peer Processing, Exchange of Information, and Information Routing.

Research has shown that distributed software agents are capable of surmounting these distributed computing problems. Agents are looked at in general with specific examples illustrated with KQML agents. Agents, RPCs, and distributed databases are compared to see how they solve or do not solve these problems. It was discovered that agents can solve these problems to an extent which RPCs and distributed databases cannot.

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## ABSTRACT

As the Internet continues to grow, a more efficient method than those currently used is needed for knowledge sharing. This method must be flexible and powerful enough to solve the following problems:

Heterogenous Communication,
Peer to Peer Processing,
Exchange of Information, and
Information Routing.

Research has shown that distributed software agents are capable of surmounting these distributed computing problems. Agents are looked at in general with specific examples illustrated with KQML agents. Agents, RPCs, and distributed databases are compared to see how they solve or do not solve these problems. It was discovered that agents can solve these problems to an extent which RPCs and distributed databases cannot.

# CHAPTER 1 INTRODUCTION

With the increased popularity of the Internet, organizations have been trying to find effective ways to communicate between different sites worldwide. At this time information is being disseminated through the network but not always in a user friendly manner; the user must often learn to use cryptic software like ftp and telnet. What is needed is some common method of sharing knowledge which can take advantage of network structures.. This common method must be flexible enough and robust enough to surmount the following problems:

1) Heterogenous Communication: This is due to the fact that there are a wide variety of platforms and operating systems in operation on the Internet.
2) Peer to Peer Processing: The client server paradigm is limiting in cases where asynchronous transactions are an advantage.
3) Exchange of Information: Flexibility is needed so that all types of information can be represented and shared.
4) Information Routing: Routing is an important and often overlooked problem; if one cannot find the pertinent information, then the information is as good as useless.

Research has shown that not only can distributed software agents solve these problems; but they often do it better than other methods of distributed computing such as RPCs and distributed databases.

## What is an Agent?

Three definitions of an agent supplied by a wordprocessor (Excellence!) are:

1) one by which work is accomplished or an end effected;

2) one who acts for another; and

3) one who keeps secret watch to obtain information.

The first two definitions are the spirit of why one would want to have a software agent. The last one could be facilitated by a software agent, but is unethical.

M. Genesereth and S. Ketchpel define a software agent as:

4) "software 'components' that communicate with their peers by exchanging messages in an expressive agent communication language." [4]

This definition implies that not only should an agent be able to perform definitions one through three, an agent should communicate with other software agents. All four of these definitions imply a behavioral condition for agenthood; i.e. if a piece of software exchanges messages in an agent communication language then it is an agent.

Discussions about how agents can solve the four problems brought up in the introduction will be organized in the following manner: CHAPTER 2 HETEROGENOUS COMMUNICATION; CHAPTER 3 PEER TO PEER PROCESSING; CHAPTER 4 EXCHANGE OF INFORMATION; and CHAPTER 5 INFORMATION ROUTING.

# CHAPTER 2 HETEROGENOUS COMMUNICATION

If effortless information sharing is to be achieved, heterogenous communication is a requirement. A solution should be able to support multiple protocols including: TCP/IP, SMTP, and HTTP since these are the most prolific protocols running on the Internet.

## Agent Communication

Agents can use many different communication protocols to connect to the Internet. KAPI (KQML APplication Interface) was chosen for implementing KQML (Knowledge Query Manipulation Language) software agents, for this thesis work, due to the wealth of communication protocols it supports [15]. Being able to support many of these low level transport protocols is only part of the problem. In order for different agents to have the ability to talk to each other across different low level transport protocols, a common high level protocol is needed. This high level protocol is called the agent communication language (ACL). Different agents need to have a common ACL to allow interagent communication. KQML, one such ACL, has been used in a variety of projects funded by DARPA, the Air Force, and the Navy. (See Reference section). Because of KQML's flexibility and popularity, KQML agents were implemented for the research shown in this thesis.

KQML

KQML is a speech act based ACL; the KQML transport was built to model human speech [3]. KQML messages are performatives which contain keywords and their expressions [1, 2, 6, 11,13]. See Table 1. (A detailed discussion on

Table 1 KQML String Syntax in EBNF

```
<performative> ::= (<performative_name> {<whitespace> :<keyword>
                    <whitespace> <expression>}* )
<performative_name> ::= <word>
<keyword> ::= <word>
<expression> ::= <word> | <quotation> | <string> |
                 ({<word> {<whitespace> <expression>}*} | <performative> )
<word> ::= <character><character>*
```

KQML syntax and semantics is given in [1])

The KQML specification states that it is not a requirement to implement all 41 of the performatives listed in order to be KQML compliant. In fact, implementors may create more performatives for their own purposes if they find the reserved KQML performatives lacking. The performatives mentioned in the specification are reserved; if used, they must follow the specification requirements in order to be KQML compliant. Each performative has keywords which have certain values stored in their expression field as defined in the KQML specification [1].

Experimental agent implementations for this thesis work consist of two agents: one agent acts as a server which performs lookups in a database of merchandise (a catalog) of some fictional business; the other agent acts as a

client which accepts input from a user who is interested in searching and pricing some item. Table 2 shows five KQML performatives which were implemented; S

Table 2 Implemented KQML Performatives

| <performative_name> ::= ask-if \| ask-about \|tell \| deny \| error | |
|---|---|
| Performative Name | Meaning |
| ask-if | S wants to know if the sentence is in R's VKB |
| ask-about | S want all relevant sentences in R's VKB |
| tell | the sentence in S's VKB |
| deny | the embedded performative does not apply to S |
| error | S considers R's earlier message to be malformed. |

is the sending agent and R is the receiving agent. As requests for item descriptions, and prices of items are sent to the merchandising agent (MAG), it performs operations upon its catalog (database) and returns a performative (tell, or deny) which reflects what the MAG has discovered in its database (DB) .

## Other Methods of Distributed Computing

Agents compare favorably to other ways of creating distributed applications. The pros and cons are discussed below.

### RPCs

RPCs support only one transport mechanism: TCP/IP. This is only a slight disadvantage since most machines, which are capable of network access, have TCP/IP. The primary disadvantage is that different vendors have their own systems of implementing RPCs. If an application is written using Sun RPCs, a DCE RPC application will not be able to communicate with it. This is because RPCs operate on a lower level than agents; binary data is marshaled into a form for transport, and then delivered to the network, and then to the remote machine. The marshaled form (called an interface definition language or IDL) is different between RPC standards.

RPCs are implementation dependent while KQML does not try to force a specific implementation. KQML is concerned with interagent communication; not with data representation or transport. However, since RPCs are closer to the hardware and operate on a level closer to the transport protocol, they typically have higher performance for applications where computational speed is important.

Unlike RPC's, agents are often machine and operating system independent. Additionally, KQML is ASCII based so architectural characteristics (like big endian versus little endian) are not significant and no data marshalling is needed. The drawback to ASCII representation is that data is likely to require more space and network bandwidth than a binary.

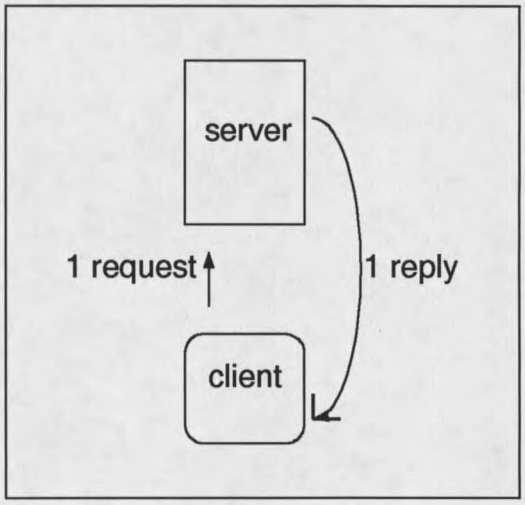
Distributed Databases

Distributed databases (DDB) allow data to be searched and retrieved from remote sites. Portions of the DB may be physically stored at different sites to allow load sharing. Some DDB use RPCs to perform operations on data. However much like RPCs, each DDB implementation only communicates with DDB of the same implementation. Different DDBs may be able to share data after some type of conversion process is applied.

# CHAPTER 3 PEER TO PEER PROCESSING

The client server model is the predominate model of software interaction on the Internet. Figure 1 illustrates the client server paradigm. The client makes

Figure 1 Client Server Paradigm

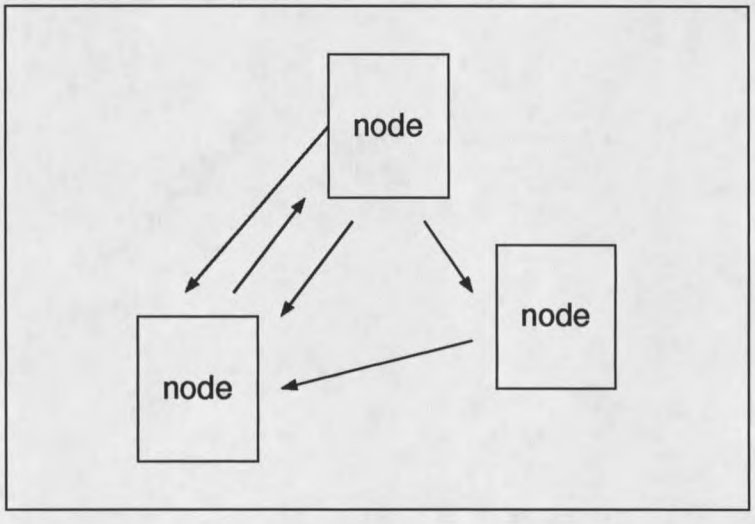



a request and the server responds by sending a reply in fulfillment of the request. The communication is synchronous in nature since the communication takes place in a lockstep fashion. The server never acts independently from a client. This model is too restrictive if the server must be proactive. For example: If the

server in Figure 1 was a MAG, the owner could benefit if it could actively search out new clients. If peer to peer processing were allowed, the MAG could communicate with other agents which represent their owner's interests. The MAG could leave its address and a message as a "calling card". Later if the owner of the agent is looking for an item, the agent could reference its DB of agent addresses and interests; and contact the MAG for further information.

In peer to peer processing, one node may actively seek out a service like a client, and later it may serve a request like a server. Figure 2 illustrates this concept. With asynchronous communication, the replies are received in a nondeterministic fashion. Each node does not know when a reply or a request

Figure 2 Peer to Peer Process Communication



will arrive. The extra work involved in peer to peer as opposed to client server is that the nodes have to keep track what reply went with which request. This extra bookkeeping isn't needed in client server since transactions occur in lockstep.

When an agent receives a message and decides that it is valid, it executes the command or program which is embedded in the message. In this fashion, a client agent's program or command is executed in the server agent's address space. If there are return values, they are returned back to the client agent.

## KQML Agents

The KQML ACL supports peer to peer bookkeeping through keywords which are imbedded in the performatives. Table 3 shows an example of an agent's request and the response received from the serving agent. This example

**Table 3** Fred's Agent Requesting Information on Roofing Nails

| Fred's Agent | |
|---|---|
| Request: | Response Received: |
| (ask-if | (tell |
| :receiver joes_hardware | :receiver fred |
| :sender fred | :sender joes_hardware |
| :language shop-talk | :language shop-talk |
| :ontology shop-talk | :ontology shop-talk |
| :reply-with (nails 3-35-95, 3:00 PM) | :in-reply-to (nails 3-35-95, 3:00 PM) |
| :content (find (roofing nails)) | :content ({(124,roofing nails)}) |
| ) | ) |

was generated with a MAG and a shopping agent; the scenario is as follows:

Fred is looking for roofing nails. He starts up his agent and asks it to search Joes Hardware to see if it carries roofing nails. Notice the keyword reply-with and its expression in Fred's request. In the tell performative which Fred's agent received as a server, the in-reply-to keyword has the same expression as the reply-with expression. This allows the agent to collate the messages it receives by context; which is defined by the reply-with, in-reply-to, and sender expressions. Notice that the date and the time are included in the context. This is so that if multiple queries are made to Joes Hardware's agent, the response's true context will be known. One more improvement that could be made is to add a random number into the :reply-with <expression>. This would allow the context to be understood unambiguously in case Fred's agent can send out more than one request per second. Since Joes Hardware's agent did not put a reply-with keyword in its performative, it is not expecting a reply.

Agents collecting information for their owners may send out dozens of requests to other agents. Instead of waiting for each response as in the client server situation, they may continue with other tasks. While doing other tasks, the agents may receive responses concurrently. The agents will organize the information they receive by context in their DB and output reports to the owners as they make progress.

# CHAPTER 4 EXCHANGE OF INFORMATION

The ability to exchange any information (that can be represented in a computer) is the ability to represent all types of information: binary, ASCII, extended ASCII, and knowledge itself.

## KQML

KQML speaking agents have the ability to exchange all forms of data because KQML does not care what is stored in the content expression. See Table 4. What is placed in the content expression is up to the implementor; it could be binary, ASCII, source code of a program,.. etc. KQML is used by agents

Table 4 Form of a KQML Performative

```
(<performative_name>
 :receiver <expression>
 :sender <expression>
 :language <expression>
 :ontology <expression>
 :reply-with <expression>
 :content <expression>
 .....
)
```

to talk to each other about data stored in the content expression.

The receiving agent discovers what is in the content expression by looking at the language field. This field describes the language of the content field. Notice that even though a given set of agents may be able to communicate due to a common ACL, they may not be able to understand the data in the content expression. They can communicate with each other about the data but they need not understand the data.

For example, if agent 99 wants to exchange a lisp program with agent 007 (a prolog executing agent), 007 is going to get the lisp program and look at the language field and see that it is not prolog. If 007 is a sophisticated agent, then it could recruit the help of another agent to run the lisp program and then receive the output from the lisp running agent. If 007 isn't smart enough to do this or 007 can't find a lisp executing agent, then 007 will have to respond with an error performative; its comment expression could contain a plea of ignorance about the sender's language.

Shop-Talk

The MAG agent and the potential client agent must speak a language/protocol called shop-talk. Table 5 describes the shop-talk language in

Table 5 EBNF Form of Shop-Talk's Syntax

<shop-talk function> ::= (<command>)

<command> ::= {<description command> (<string>)} |
{<catalog command> (<catalog number>)}

<description command> ::= find

<catalog command> ::= price | describe

<string> ::= {<upper or lower alpha char> | <number> |
<all punctuation except: \, (, ). {, }, and ",">}+

<catalog number> ::= <all integers>

EBNF. The shop-talk language expresses queries to a MAG about its catalog. One could use the find command to search an online catalog for some item which is described in the <string> field. Once the catalog number was found, the price or the entire description of the item could be requested. The <string> definition

was restricted to make parsing the content expression easy.

Table 6 shows the form of the returned data; the MAG replies to shop-talk

**Table 6** Pseudocode and EBNF of Shop-Talk Returned Values

```
<shop talk fct output> ::= "{" <ordered pair> {,<ordered pair>}* "}"
<ordered pair> ::= (<catalog number>,<data>)
if <shop talk fct output> is find | describe
    <data> ::= <description>
else
    <data> ::= <real number>
```

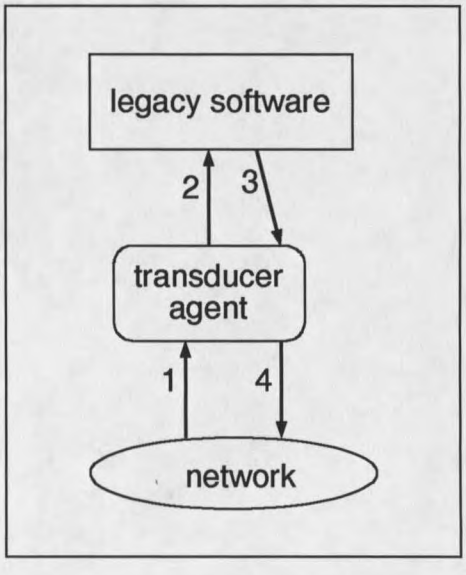
functions by returning a set. The set contains ordered pairs; the left part of the pair is always a catalog number so that describe and price would be one to one functions. The number of ordered pairs returned is determined by the context of the KQML performative: if the performative_name was ask-if, then the first match would return; or if the performative_name was ask-about, then all the matches which exist in the receiver's DB would return. Other KQML speaking agents can talk to a MAG agent but only those that understand shop-talk can query the catalog.

Agentifying Current Software

The value of having distributed access to data is obvious, but it is unlikely that people will want to rewrite the software they are using. However, since agenthood is defined by how a software component acts, software need only to speak in an ACL to become an agent. The following paragraphs discuss some techniques which allow legacy software to be made into agents.

Software for which there isn't any access to the source code can be agentified by writing a transducer agent [3]. The transducer agent accepts messages from other agents and translates the messages into a form which is acceptable to the software and then executes the software on the input. See Figure 3. The agent then captures the software's response and packages it into

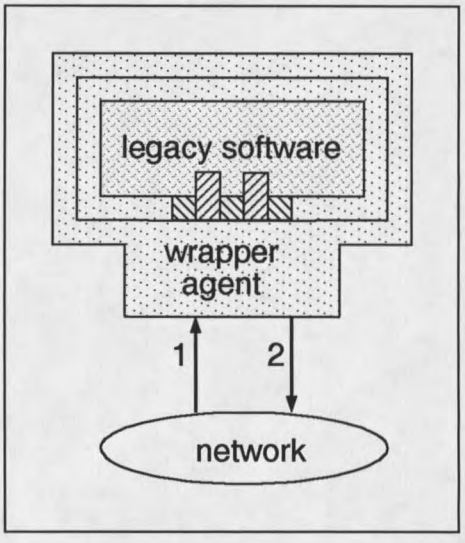
Figure 3 Transducer Agent



an ACL which is sent to the client agent. In KQML the response would be stored in the content expression.

A wrapper agent is more efficient than a transducer agent; however the source code to the software must be available [3]. See Figure 4. Code is added

Figure 4 Wrapper Agent




to the software to extract data from an ACL message. This is more efficient due to less serial communication than between an autonomous transducer agent and its software package. The data structures which the program understands can be implemented directly by the wrapper agent. The agent is not autonomous from

the software since it is part of the software's code. Genesereth and Ketchpel mention that a complete rewrite of the software could be done but they acknowledge that this method is drastic [3].

KIF

KIF (Knowledge Interchange Format) is a popular content language used with KQML [5, 13, 14]. KIF was developed for the purpose of allowing interchange of knowledge between different computer programs. KIF is able to do this because it is a formal language which allows one to express knowledge about knowledge using predicate calculus [5]. Applications of KIF agents are typically in the realm of artificial intelligence (AI).

Ontology

Agents which have a common ACL and can speak the same language need to share an ontology for effective agent interaction [11]. Agents that speak the same ACL and understand the same language may not be able to effectively communicate. For example, I can speak English but I am still not able to understand a quantum physics lecture. This is because I don't understand the jargon, units used, and how this knowledge relates. If someone gave me a sheet of paper which defined the jargon, and the units, then I could follow the lecture; the sheet of paper is called an ontology.

An ontology is a set of concepts and relations. For example: an ontology about hierarchy could define the relationships between siblings, parents, and children. The keyword, ontology, is used in some KQML performatives. (See Table 4.) A salient feature of ontologies is that if a KQML/KIF agent encounters an ontology which it doesn't know, it can have the other agent send the ontology (in KIF language) to it so that it can be added to its virtual knowledge base. Ontologies are an important AI construct, since they allow communication of concepts as well as data. The MAG agent defined the ontology as shop-talk (see Table 3) but it is not needed since the shop-talk language consists of commands which directly call functions, not a language in which functions are defined (like KIF).

## Other Methods of Distributed Computing

### RPC

RPCs can represent most forms of knowledge but only in low level data forms. Consequently, RPCs cannot exchange data with different implementations due to the lack of a standard IDL. A set of agents may have the same problem if they don't understand the same content language. However, it is possible for agents to route the content information (through the use of a common ACL) to another agent which can act as a translator.

Another drawback to RPCs is that they have only been implemented in procedural languages. Agents can have any language in its content field and the receiver can execute the language if it understands the content language.

Agents can simulate RPCs by passing remote procedures (or procedure calls) to procedure executing agents. RPCs can also be made into agents by creating a transducer agent or a wrapper agent for the RPC program.

Distributed Databases

Since most DDBs are proprietary, they do not readily communicate with other programs. To make a DDB more accessible, a transducer or wrapper agent could be created. The advantage is that the owner of a DDB does not have to reconstruct his DB files or buy a new program.

# CHAPTER 5 INFORMATION ROUTING

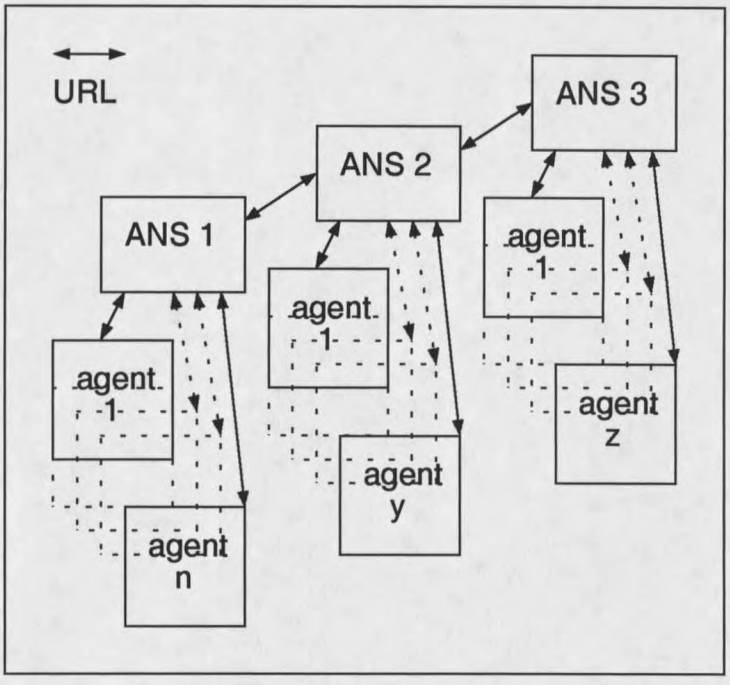
The routing of information is a critical issue in distributing information among several nodes. If the agent or RPC cannot find services to use, then they are of little benefit. There are currently several ways to route agents to information or route information to agents. Typical agent routing architectures are: Agent Name Servers, Content Based Routing, Facilitators, and Federations.

## Agent Name Servers

Agent name servers (ANS) are other agents that can be consulted by an agent which is searching for information. ANS routing was used between the MAGs and the agent shoppers; the NCSA HTTP daemon acted as a routing agent due to KAPI's support of HTTP as a transport [15]. URLs (uniform resource locators) point to other agent resources (MAGs) on the network. A user could ask an agent to find some information and give the agent a list of MAG names to query; first the user's agent would query a known ANS for URLs which point to these MAGs. The ANS would return the URLs to the agent whereupon

the user's agent could then route messages directly to the MAGs. A hierarchy of ANSs could be setup like the Internet domain name servers. See Figure 5.

Figure 5 ANS Hierarchy




If agent n is looking for an agent named y, it can consult its local ANS to see if a URL points to an agent y. If y doesn't exist, the ANS could use a URL which points to another ANS on another node and forward agent n's request. This could continue on indefinitely so there would have to be some method of bounding the number of ANS consulted and a cycle prevention scheme. The

drawback to ANS routing is that the client agent must know the name of the agent to interact with.

## Content Based Routing

If agent n doesn't know other agents which can provide a service, it can use a content base router agent (CBRA) to find suitable agents [12]. The content based router agent maintains a DB on agents' interests. A CBRA maintains this DB by agents advertising their interests to it, or acquiring agent interests as they use its services. CBRAs could also consult other CBRAs for information on agents.

The disadvantage of CBRAs is that they must maintain a DB of known agents. This could grow large as agent traffic increases. The advantage of CBRAs is that an agent does not have to have prior knowledge of an agent name which is required with the ANS architecture.

## Facilitators

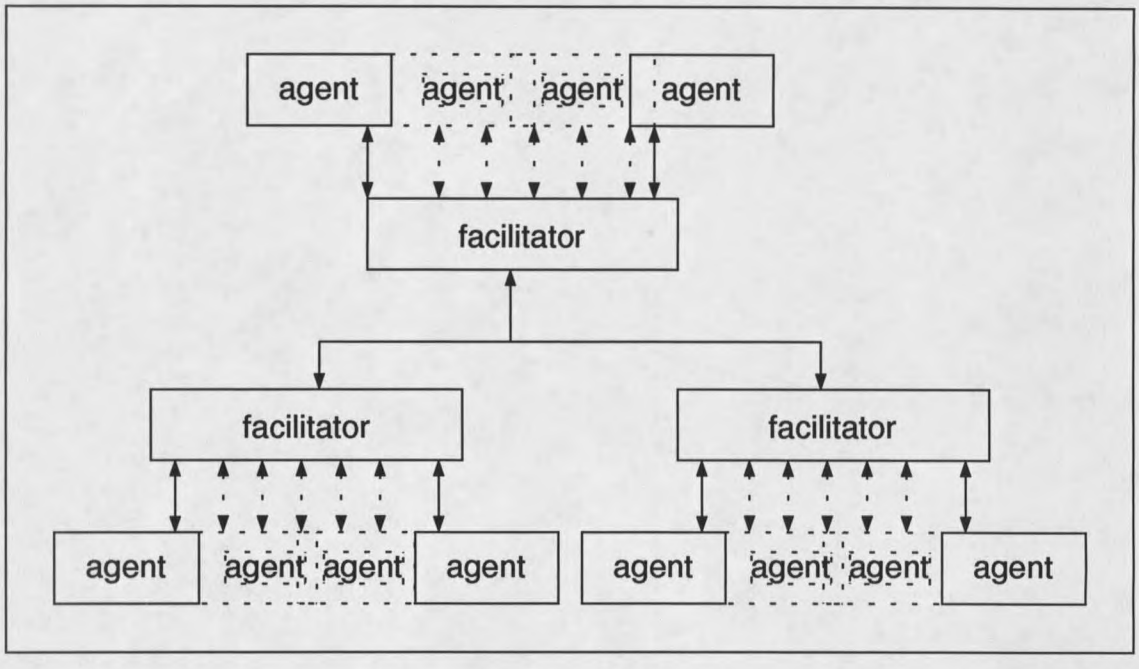
A facilitator is an agent like an ANS or a CBRA except it offers additional services. If agent n uses a different content language than agent y, then the facilitator could act as an interpreter between the two agents. There have been other uses for facilitator agents such as acting as a subcontractor, translator, mediator, ... etc. The roles of facilitators are constantly expanding [2, 6, 7, 11, 13, 14].

Facilitators can degrade agent performance. They may become a bottleneck due to computationally expensive features such as translation.

## Federation

A federation is a group of facilitators and agents arranged as shown in Figure 6. The agents which are linked to a facilitator are dependent upon it for

Figure 6 Facilitators and Agents in a Federation



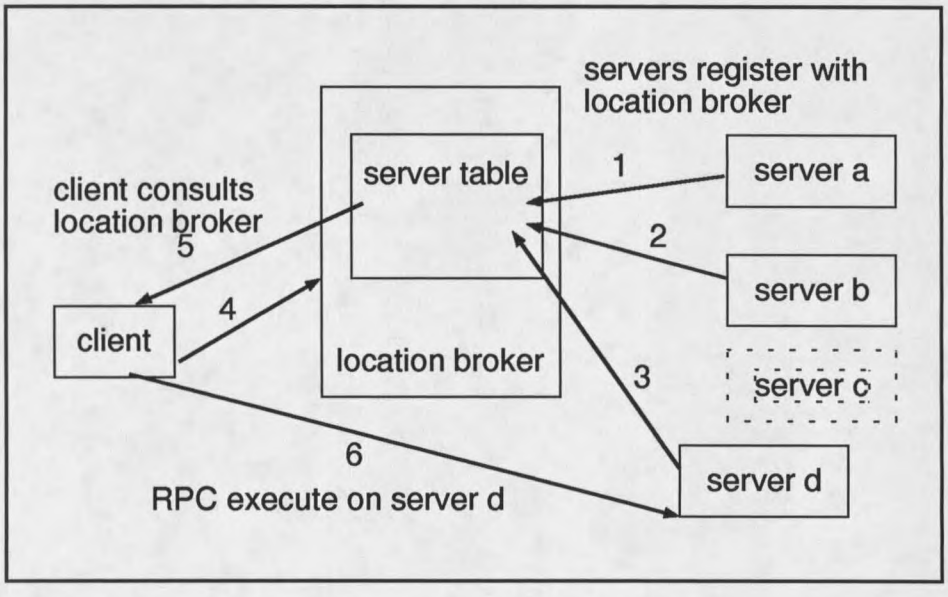

routing; the agents have given up their autonomy [7, 13, 14]. Agents provide services to, or request services from the local facilitator; and the facilitator routes agent's messages to other agents or other facilitators in the federation hierarchy.

The advantages of a federation is that the agents are less complex because they don't have to maintain information about routing. A disadvantage would be that the agents are entirely dependent on the facilitator; so if a facilitator fails, the dependent agents would be useless.

RPC

RPCs route their messages through location brokers. Location brokers are like ANS in that they return to the program a list of servers (a lookup operation) or just pick a server and call the remote procedure. Servers are registered with the location brokers at run time. See Figure 7. Location brokers

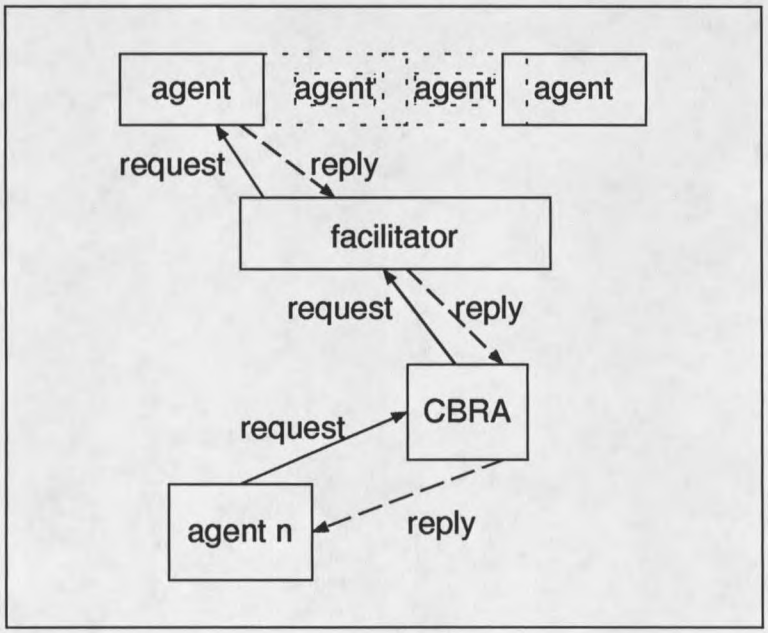
Figure 7 RPC Location Broker Routing Scheme



can be set up in a hierarchy to facilitate routing. RPCs may obviate the need of a location broker by explicitly naming the port.

RPCs do not allow dynamic routing like CBRA but they do allow routing of RPCs without knowing a server's name (unlike ANS). Agents support many more routing options than RPCs. For example: Agent n could connect to a CBRA (by knowing the CBRA's URL) which will forward the message by its content to a facilitator, which is part of a federation. The facilitator then routes the message to one of its dependent agents. After the dependent agent is finished, it sends the reply back to its facilitator which sends it back to the CBRA which in turn sends it to agent n (using n's URL which was in the sender expression). See Figure 8.

Figure 8 Agent n Uses Multiple Routing Schemes



# CHAPTER 6 SUMMARY

As shown in Chapters 1 through 4, agents can perform any function that RPCs, and DDBs can; and possibly more effectively. RPCs have an advantage in execution speed due to the brevity in typical RPC communication. However:

1) agents can communicate over a larger variety of platforms/OSs than RPCs;
2) agents are capable of peer to peer processing;
3) agents can carry data in any representation without remapping it to an IDL; and
4) agents have more routing options.

A drawback to KQML agents is that KQML is open ended: implementators are going to create new performatives which will not be supported by other agents. This can also be an advantage because implementators can create useful extensions to KQML. Agents which speak different ACLs are as incompatible as different RPC implementations; so it will be important that one common, standard ACL is selected if agents are to be widely used. Content based routing or federations are important where transparent routing is a must. However, CBRA and facilitators need more resources due to their complexity.

Agents will be very much a part of the future of the national information infrastructure. However, it is hoped that a conglomeration of different ACL standards is not used.

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