Mobile Agent–Based Discovery System

Rajeev R. Raje
Indiana University Purdue University Indianapolis, USA

Jayasree Gandhamaneni
Indiana University Purdue University Indianapolis, USA

Andrew M. Olson
Indiana University Purdue University Indianapolis, USA

Barrett R. Bryant
University of Alabama at Birmingham, USA

INTRODUCTION

For reasons of economy and scalability, many of the current distributed computing systems (DCSs) are realized as an integration of prefabricated and deployed components offering specific services. A critical task that the assembler of such a system needs to address is to locate and select appropriate components scattered over a network. This requires solving many research challenges. These include: (a) deployment of components and their specifications, (b) efficient searching for and gathering of appropriate specifications, (c) representation of queries, and (d) semantics of matching between queries and specifications. UniFrame (Raje, Auguston, Bryant, Olson, & Burt, 2001) is a framework that allows the seamless discovery and integration of such distributed software components. It addresses three key research issues: (1) architecture-based interoperability, (2) distributed discovery of resources, and (3) quality validation. This article presents a mobile-agent-based discovery service, which is one of the alternatives developed under research issue (2).

BACKGROUND

There have been many attempts at creating discovery services. This section reviews only a few prominent ones for the sake of brevity.

Jini (Waldo, 1999) is based on the underlying Java Remote Method Invocation infrastructure (Sun Microsystems, 1994), and thus provides a simplified interoperability. Services register themselves in Lookup Registries, which clients search to download their required services. The matching used in Jini is based on attribute comparisons.

The model used in the Ninja secure service discovery service (SSDS) (Czerwinski, Zhao, Hodes, Joseph, & Katz, 1999) to locate an appropriate service for a request is based on the concept of advertisement. SSDS tracks services in a network and allows authenticated users to locate them through expressive queries. It uses XML to describe the services and to allow complex queries. It supports the possibility of describing various attributes, such as the quality of service (QoS) parameters and associated costs, which are used in the matching process.

CORBA® (Common Object Request Broker Architecture) includes the Trader service (OMG, 2000), which uses a standardized Interface Definition Language to describe service interfaces. These interfaces provide the basis on which lookup and client invocations take place. The trader provides a simple attribute matching.

The aim of Agora (Seacord, Hissam, & Wallnau, 1998) is to provide an automatically generated, indexed, worldwide database of software products classified by their types. Agora combines introspection with Web search engines to reduce the costs of seeking components in the software marketplace. The query terms used for finding components are compared against the index collected by the search engines. The result is inspected by the user so the search can be broadened or refined based on the number and quality of matches.

Universal description, discovery, and integration (UDDI) (OASIS Consortium, 2000) defines a set of services supporting the description and discovery of businesses, organizations, and other Web service providers, as well as the Web services they provide. It utilizes Web Services Description Language (WSDL) for describing the capabilities of the services. UDDI provides a simple textual matching process by comparing each search term with various fields in a service's description.

Web services peer-to-peer discovery service (Banaei-Kashani, Chen, & Shahabi, 2004) is a decentralized discovery service with a matching capability that extends up to the semantic level. It is used to locate Web services that are geographically dispersed across a network. It uses keywords and semantically annotated WSDL to describe Web service interfaces. Each entity, called a "Servent," in this environment

serves as both client and server. When a Servent receives a query for a Web service that is not available locally, it shifts its capacity from server to client and queries the network for that specific request. For discovery purposes, a Servent formulates a query encapsulated in a simple object access protocol (SOAP) message (W3C, 2004) and propagates it over the network based on a probabilistic flooding dissemination mechanism.

SLP (Guttman, 1999) provides hosts with access to information about the existence, location, and configuration of networked services. In this framework, user agents model client applications, service agents advertise services, and directory agents cache service information. A user agent can issue service requests to specify the requirements of the client application. It can transmit a request to service agents or a directory SLP. The SLP supports matching only at the syntactical level.

The monitoring and discovery service (MDS) (Globus Alliance, n.d.; Kandagatla, 2003), a part of the Globus Toolkit, is used for discovering computational resources deployed in a Grid environment. The resources are described using a standard schema made up of keywords and can be discovered using specific characteristics. The MDS is made up of two components: the Grid information resource service (GRIS) and the Grid index information service (GIIS). The GRIS runs on resources deployed on the Grid and is an information provider framework for specific information sources. A GIIS is a user-accessible directory server at a higher level that accepts information from child GIIS and GRIS instances and aggregates it for use at a higher level.

THE MOBILE UNIFRAME RESOURCE DISCOVERY SERVICE

A majority of the previously mentioned approaches for discovering service-providing components use relatively simple schemes for describing and matching services against a request. Also, none of these alternatives uses mobile agents in the discovery process. This section provides details about the Mobile UniFrame Resource Discovery Service (MURDS), which has a hierarchical architecture and uses mobile agents to discover services deployed over a network. MURDS is an enhancement of the UniFrame Resource Discovery Service (URDS) (Siram, 2002).

URDS is a hierarchical discovery service that supports the proactive discovery of component specifications, resolves technological heterogeneity, and allows multi-level matching. URDS is one of the entities in the UniFrame approach for developing DCS from heterogeneous, distributed software components. The core concept behind UniFrame is the unified meta-component model (UMM). UMM, as described in Raje (2000), consists of: (a) component, (b) services, and (c) infrastructure.

A component in UniFrame is developed by following a specification in a standardized knowledgebase (KB) (Raje et al., 2001) and implemented in any distributed-component technology. In addition to the implementation of a component, its developer must create, following the specification format described in the KB, a comprehensive specification for it. This is the UMM specification for that component. This, as indicated in Olson, Raje, Bryant, Burt, and Auguston (2005), consists of multiple levels—syntax, semantics, synchronization, and quality of service. Such a complex specification supports multi-level matching while seeking components for a specific query.

Each component in UniFrame offers a service whose UMM description provides its specification. In addition to the functionality of the service, UniFrame emphasizes the service's QoS aspect. Each component indicates its QoS using parameters described in the UniFrame QoS catalog (Brahnmath, 2002).

The infrastructure part of the UMM defines the necessary computational fabric on which components can be deployed and their specifications can be advertised. This allows a proactive discovery of the components for specific queries. URDS provides this infrastructure in UniFrame.

Incorporating the use of mobile agents in the discovery process into URDS creates MURDS. Its architecture, shown in Figure 1, comprises the following entities: (a) Internet Component Broker (ICB), (b) Headhunters (HHs), (c) Meta-Repositories (MR), (d) Active Registries (AR), (e) Components ($C_1..C_n$), and (f) mobile agents (MA). Figure 1 also depicts their interactions. Gandhamaneni (2004) discusses these entities in detail. A brief description follows below.

Internet Component Broker (ICB)

The ICB is a collection of the following entities: q*uery manager (QM), domain security manager (DSM), link manager (LM),* and *adapter manager (AM)*. The ICB is a component broker that is pervasive in an interconnected environment. It is expected that there will be a number of ICBs deployed at well-known locations hosted by organizations supporting the UniFrame paradigm for developing distributed systems. The functions of the entities that make up the ICB are as follows:

- **Domain Security Manager (DSM):** The DSM serves as an authorization controller that handles the generation and distribution of the secret keys needed for communication between various constituents of MURDS. It enforces group memberships and performs access control checks on HHs on behalf of the ARs. For performing access control checks, the DSM has a repository of valid users (i.e., HHs, MAs acting on behalf of HHs, and the ARs) and the policies that

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