Distributed Information Processing

13th Lecture

Eom, Hyeonsang

Department of Computer Science & Engineering

Seoul National University

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Outline

- Architectures
- Peer-to-Peer Computing
  - Introduction
  - Chord
- Q&A
Architectures

Software Architecture
- How Software Components Are Organized
- How Software Components Should Interact

System Architecture
- Final Instantiation of a Software Architecture

Important Styles of Architecture for (Autonomic) Distributed Systems
- Layered Architectures
- Object-Based Architectures
- Data-Centered Architectures
- Event-Based Architectures
Architectural Styles

(a) layered architectural style

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Architectural Styles (Cont’d)

(b) The object-based architectural style
(a) The event-based architectural style
Architectural Styles (Cont’d)

(b) The shared data-space architectural style
System Architectures

- Centralized Architecture
  - Clients That Request Services from Servers
  - Support for Vertical Distribution
    - Placing different components on different machines

- Decentralized Architecture
  - Process Being a Client and a Server
  - Support for Horizontal Distribution
    - Spitting up a client or server physically into logically equivalent parts with each part operating on its own share of data set
Peer-to-Peer Architectures

**Overlay Network**
- Network in which the nodes are formed by the processes and the links represent the possible communication channels

**Structured P2P Architecture**
- Overlay network is constructed using a deterministic procedure
  - Distributed Hash Table (DHT)

**Unstructured P2P Architecture**
- Overlay network is constructed using a random algorithm
Centralized Architectures

**General interaction between a client and a server**
Application Layering

- Following Layered Architectural Style
  - User-Interface Level
  - Processing Level
  - Data level
The simplified organization of an Internet search engine into three different layers

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Multitiered Architectures

- The simplest organization is to have only two types of machines:
- A client machine containing only the programs implementing (part of) the user-interface level
- A server machine containing the rest,
  - the programs implementing the processing and data level
Multitiered Architectures (Cont’d)

Alternative client-server organizations (a)–(e)

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Multitiered Architectures (Cont’d)

An example of a server acting as client

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Structured Peer-to-Peer Architectures

The mapping of data items onto nodes in Chord

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Structured Peer-to-Peer Architectures (Cont’d)

The mapping of data items onto nodes in CAN

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Peer-to-Peer (P2P) Computing

- **Definition**
  - Computing by Sharing Data & Resources on a Very Large Scale w/o Server Requirements

- **Important Characteristics**
  - Each Node’s Resource Contribution
  - Same Functional Capabilities & Responsibilities of Nodes
  - No Central Administration
  - Limited Degree of Anonymity
  - Unpredictable Availability
  - Fault Tolerance

**Key Issue:** Efficient Data Placement & Access
1st-Generation P2P Systems

- **File Sharing and Storage Applications**
  - **Napster Music Exchange Service**
    - Use of central servers to locate files
  - **Gnutella**
    - Distributed service using scoped broadcast queries

Main Problem: Limited Scalability or No Guarantee That Files Can Be Located
2nd-Generation P2P Systems

Middleware

- Application-Independent Management of Distributed Resources on a Global Scale
  - Routing Overlay for locating nodes and objects
    - Scalable
    - Load balanced
    - Adaptive to network dynamics
    - Fault tolerant
    - Efficiently discovering
    - Secure

Implementing Key-Based Routing (KBR) Interface: Routing of Messages to a Live Node Responsible for the Destination Key

Using Randomly Distributed Keys to Determine the Placement of Objects and to Retrieve Them
## IP vs Overlay Routing

<table>
<thead>
<tr>
<th></th>
<th><strong>IP</strong></th>
<th><strong>Application-level routing overlay</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scale</strong></td>
<td>IPv4 is limited to $2^{32}$ addressable nodes. The IPv6 name space is much more generous ($2^{128}$), but addresses in both versions are hierarchically structured and much of the space is pre-allocated according to administrative requirements.</td>
<td>Peer-to-peer systems can address more objects. The GUID name space is very large and flat ($&gt;2^{128}$), allowing it to be much more fully occupied.</td>
</tr>
<tr>
<td><strong>Load balancing</strong></td>
<td>Loads on routers are determined by network topology and associated traffic patterns.</td>
<td>Object locations can be randomized and hence traffic patterns are divorced from the network topology.</td>
</tr>
<tr>
<td><strong>Network dynamics</strong></td>
<td>IP routing tables are updated asynchronously on a best-efforts basis with time constants on the order of 1 hour.</td>
<td>Routing tables can be updated synchronously or asynchronously with fractions of a second delays.</td>
</tr>
<tr>
<td><strong>Fault tolerance</strong></td>
<td>Redundancy is designed into the IP network by its managers, ensuring tolerance of a single router or network connectivity failure. $n$-fold replication is costly.</td>
<td>Routes and object references can be replicated $n$-fold, ensuring tolerance of $n$ failures of nodes or connections.</td>
</tr>
<tr>
<td><strong>Target identification</strong></td>
<td>Each IP address maps to exactly one target node.</td>
<td>Messages can be routed to the nearest replica of a target object.</td>
</tr>
<tr>
<td><strong>Security and anonymity</strong></td>
<td>Addressing is only secure when all nodes are trusted. Anonymity for the owners of addresses is not achievable.</td>
<td>Security can be achieved even in environments with limited trust. A limited degree of anonymity can be provided.</td>
</tr>
</tbody>
</table>

Coulouris, Dollimore and Kindberg  Distributed Systems: Concepts and Design  Edn. 4  ©  Pearson Education 2005
Structured P2P Overlay Networks

Supporting Higher-Level Interfaces

- **Distributed Hash Table (DHT)**
  - Basic Interface: `put()`, `get()`, `remove()`
  - E.g., Pastry

- **Distributed Object Location & Routing (DOLR)**
  - Basic Interface: `publish()`, `unpublish()`, `routeToObject()`
  - E.g., Tapestry

Ignoring/Considering Network Distances

- **Shortest Overlay-Hop Routing**
  - E.g., Chord

- **Locally Optimal Routing**
  - E.g., Tapestry
Chord Protocol [Keifer03]

Simple Key Location

```plaintext
// ask node n to find the successor of id
n.find_successor(id)
    if (id ∈ (n; successor))
        return successor;
    else
        // forward the query around the circle
        return successor.find_successor(id);
```
Cord Protocol (Cont’d)

- Scalable Key Location

\[ \text{finger}[i] = \text{successor}(n + 2^{i-1}) \]
Cord Protocol (Cont’d)

Scalable Key Location

// ask node n to find the successor of id
n.find_successor(id)
if (id ∈ (n; successor])
    return successor;
else n0 = closest_preceding_node(id);
return n0.find_successor(id);

// search the local table for the highest
// predecessor of id
n.closest_preceding_node(id)
for i = m downto 1
    if (finger[i] ∈ (n; id))
        return finger[i];
return n;

Is This Necessary?
Cord Protocol (Cont’d)

- **Node Joining/Leaving**
Cord Protocol (Cont’d)

- Properties of Chord
  - Load Balance
    - Acting as a Distributed Hash Function
  - Decentralization
    - Fully distributed
  - Scalability
    - Lookup cost growing as the log of # of nodes
  - Availability
    - Enabling the node responsible for a key to be found via automatic internal-table adjustment
  - Flexible naming
    - Using flat key-space
Reference