Distributed Information Processing
13th Lecture

Eom, Hyeonsang (엄현상)
Department of Computer Science & Engineering
Seoul National University
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
Architectural Styles (Cont’d)

(b) The object-based architectural style

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Architectural Styles (Cont’d)

(a) The event-based architectural style

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(b) The shared data-space architectural style

Architectural Styles (Cont'd)
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

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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

- **User interface level**
  - User interface
  - HTML page containing list

- **Processing level**
  - Query generator
  - HTML generator
  - Ranking algorithm
  - Ranked list of page titles

- **Data level**
  - Database with Web pages
  - Web page titles with meta-information
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
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

![Diagram showing data items and nodes mapped in a structured peer-to-peer architecture.](image-url)
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

Using Randomly Distributed Keys to Determine the Placement of Objects and to Retrieve Them

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

<table>
<thead>
<tr>
<th></th>
<th>IP</th>
<th>Application-level routing overlay</th>
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</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. Routing tables can be updated synchronously or asynchronously with fractions of a second delays.</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. 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>Fault tolerance</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. Security can be achieved even in environments with limited trust. A limited degree of anonymity can be provided.</td>
</tr>
<tr>
<td><strong>Target identification</strong></td>
<td>Addressing is only secure when all nodes are trusted. Anonymity for the owners of addresses is not achievable.</td>
<td></td>
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<tr>
<td><strong>Security and anonymity</strong></td>
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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

```java
// 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

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

Scalable Key Location

```c
// 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