Structured communication
(Remote invocation)
Our topics last week

Descriptive models for distributed system design

<table>
<thead>
<tr>
<th>Physical model</th>
<th>Architectural model</th>
<th>Interaction model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architectural elements</td>
<td>Communication paradigm</td>
<td>Interaction model</td>
</tr>
<tr>
<td>Communicating entities</td>
<td>Roles and responsibilities</td>
<td>Failure model</td>
</tr>
<tr>
<td>Processes</td>
<td>Architectural styles</td>
<td>Mobile code</td>
</tr>
<tr>
<td>Objects</td>
<td>Client-server</td>
<td>Proxy/Cache</td>
</tr>
<tr>
<td>Components</td>
<td>Peer-to-peer</td>
<td>Multiple server</td>
</tr>
<tr>
<td>Web Services</td>
<td>Indirect communication</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Remote invocation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Inter-process communication</td>
<td></td>
</tr>
</tbody>
</table>

Architectural patterns

<table>
<thead>
<tr>
<th>Vertical distribution</th>
<th>Horizontal distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi-tier</td>
<td>Thin/Fat Client</td>
</tr>
</tbody>
</table>
Our topics today

Descriptive models for distributed system design

Physical model

Architectural model

Architectural elements

Communicating entities
- Processes
- Objects
- Components
- Web Services

Inter-process communication
- UDP sockets
- TCP sockets
- Multicast

Indirect communication

Roles and responsibilities

Architectural styles
- Client-server
- Peer-to-peer

Placement
- Multiple server
- Proxy/Cache
- Mobile code

Architectural patterns

Vertical distribution
- Multi-tier
- Thin/Fat Client

Horizontal distribution

Interaction model

Interaction model

Failure model

Security model

Barry Linnert, linnert@inf.fu-berlin.de, Netzprogrammierung WS 2015/16
Our topics today

UDP Style request-reply protocols
• Failure model of UDP request-reply protocol

Use of TCP streams to implement request-reply protocol
• HTTP: an example of a request-reply protocol

Remote procedure call (RPC)

Remote Method invocation (RMI)
• The distributed object model
• Implementation of RMI
Middleware layers

Applications, services

Remote invocation

Underlying inter-process communication primitives:
Sockets, message passing, multicast support

UDP and TCP
Remote invocation

**UDP Style request-reply protocols**
UDP style request-reply protocol

Client

```
doOperation
   
   (wait)

(continuation)
```

Server

```
getRequest
   select object
   execute method

sendReply
   message
```

Request
message

Reply
message
Operations of the request-reply protocol (UDP)

```java
public byte[] doOperation(RemoteRef s, int operationId, byte[] arguments)
    sends a request message to the remote server and returns the reply.
    The arguments specify the remote server, the operation to be invoked and the
    arguments of that operation.

public byte[] getRequest();
    acquires a client request via the server port.

public void sendReply(byte[] reply, InetAddress clientHost, int clientPort);
    sends the reply message reply to the client at its Internet address and port.
```
# Request-reply message structure

<table>
<thead>
<tr>
<th>Field</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>messageType</td>
<td>int (0=Request, 1=Reply)</td>
</tr>
<tr>
<td>requestId</td>
<td>int</td>
</tr>
<tr>
<td>remoteReference</td>
<td>RemoteRef</td>
</tr>
<tr>
<td>operationId</td>
<td>int or Operation</td>
</tr>
<tr>
<td>arguments</td>
<td>array of bytes</td>
</tr>
</tbody>
</table>
Message identifiers

Unique message identifiers are needed for any scheme that involves management of messages to provide additional properties such as

- reliable delivery
- request-reply communication

Parts of a message identifier

- requestID, which is taken from an increasing sequence of integers by the sending process
- an identifier for the sender process, for example, its port and Internet address*  

* in UDP part of the UDP message
UDP Style request-reply protocols

Failure model of UDP request-reply protocol
Approaches to handle failures

Repeatedly send request message

- doOperation sends the request message repeatedly until either it gets a reply or it is reasonable sure the the delay is due to lack of response from the server, rather than lost messages

Discarding duplicate request messages

- Server may receive more than one request message, e.g. server needs longer than the client’s timeout to execute the command and return reply
- Problem: Operation is more than once executed for the same request
- Protocol is designed to recognize successive messages (from the same client) with the same request identifiers
Approaches to handle failures (cont.)

**Lost reply messages**

- Problem: Server has already sent the reply when it receives a duplicate request it will need to execute the operation again to obtain the result
- *Idempotent* operation is an operation that can be performed repeatedly with the same effect as if it had been performed exactly once

**History**

- Refer to a structure that contains a record of (reply) messages that have been transmitted
- Entry contains: request identifier, message, identifier of a client
## Possible Exchange Protocols

<table>
<thead>
<tr>
<th>Name</th>
<th>Messages sent by</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Client</td>
</tr>
<tr>
<td>R</td>
<td>Request</td>
</tr>
<tr>
<td>RR</td>
<td>Request</td>
</tr>
<tr>
<td>RRA</td>
<td>Request</td>
</tr>
</tbody>
</table>

- **R** = no response is needed and the client requires no confirmation
- **RR** = a server’s reply message is regarded as an acknowledgement
- **RRA** = Server may discard entries from its history

(Identified by Spector[1982])
Request-reply protocols

Use of TCP streams to implement request-reply protocol
HTTP: an example of a request-reply protocol

HTTP specifies the messages involved in a request-reply exchange, the methods, arguments and results, and the rules for representing (marshalling) them in the messages.

Fixed set of resources are applicable to all of server’s resources, e.g., GET, PUT, POST.

Additional functions

- **Content negotiation**: clients’ requests can include information as to what data presentation they can accept (e.g. language, MIME type)
- **Authentication**: Credentials are used to support password-style authentication
Client/server interaction
HTTP over TCP (original version)

1. The client requests and the server accepts a connection at the default server port or at the port specified in the URL.

2. The client sends a request message to the server.

3. The server sends a reply message to the client.

4. The connection is closed.
Client/server interaction
HTTP 1.1 over TCP

Usage of persistent connections

Connections remain open over a series of request-reply exchanges between client and server

Connection may be closed by client or server any time by sending an indication to the other participant

RFC 2616, (Fielding et al. 1999)
HTTP methods

GET
• Requests the resource whose URL is given as its argument

HEAD
• Request is identical to GET but does not return any data
• Returns all the information about the data such as time of last modification

PUT
• Requests that the data supplied in the request is stored with the given URL as its identifier either as a modification of an existing resource or as a new resource
HTTP methods (cont.)

POST

- Is used to send data to the server to be processed in some way
- Designed to deal with
  - Providing a block of data to a data-handling process such as a servlet
  - Posting a message to a mailing list or updating member details
  - Extending a database with an append operation

Additional methods: DELETE, OPTIONS, TRACE
## Message contents

### HTTP request message

<table>
<thead>
<tr>
<th>method</th>
<th>URL or pathname</th>
<th>HTTP version</th>
<th>headers</th>
<th>message body</th>
</tr>
</thead>
<tbody>
<tr>
<td>GET</td>
<td>/www.dcs.qmw.ac.uk/index.html</td>
<td>HTTP/ 1.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### HTTP reply message

<table>
<thead>
<tr>
<th>HTTP version</th>
<th>status code</th>
<th>reason</th>
<th>headers</th>
<th>message body</th>
</tr>
</thead>
<tbody>
<tr>
<td>HTTP/1.1</td>
<td>200</td>
<td>OK</td>
<td></td>
<td>resource data</td>
</tr>
</tbody>
</table>

Status code definitions and more:
http://www.w3.org/Protocols/rfc2616/rfc2616-sec10.html
Remote invocation

Remote procedure call
Issues that are important to understand the concept

- The style of programming promoted by RCP – programming with interfaces
- The call semantics associated with RPC
- The key issue of transparency and how it relates to remote procedure calls
Programming with interfaces

Modern programming languages provide a means of organizing a program as a set of modules that can communicate with one another.

Communication between modules can be by means of procedure calls between modules or by direct access to the variables in another module.

In order to control possible interactions between modules, an interface is defined for each module which specifies the procedures and variables that can be accessed.
Advantages of using interfaces in distributed systems

Modular programming allows programmers to be concerned only with the abstraction offered by the service interface and they need not be aware of implementation details.

Extrapolating to (potentially heterogeneous) distributed systems, programmers also do not need to know the programming language or underlying platform used to implement the services.

Approach provides the natural support for software evolution in that implementations can change as long as the interface (the external view) remains the same.
## RPC call semantics

<table>
<thead>
<tr>
<th>Fault tolerance measures</th>
<th>Call semantics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retransmit request message</td>
<td>No</td>
</tr>
<tr>
<td>Re-execute procedure</td>
<td>Yes</td>
</tr>
<tr>
<td>Retransmit reply</td>
<td>Yes</td>
</tr>
</tbody>
</table>
RPC call semantics (cont.)

Maybe semantics

- RPC may be executed once or not at all, it means that faults are not tolerated
- Can suffer from omission and crash failures

At-least-once semantics

- Invoker receives either a result, in which case the procedure was executed at least once, or an exception informing that no result was received
- Can suffer from crash failures and arbitrary failures

At-most-once semantics

- Caller receives either a result, then the procedure was executed once, or an exception that no results has been received
Implementation of RPC

- Client process
- Client stub
- Client procedure
- Communication module
- Client program

- Server process
- Server stub
- Server procedure
- Communication module
- Dispatcher
- Service procedure

Request
Reply
Remote invocation

Remote method invocation (RMI)
Commonalities of RMI and RPC

- Support of programming languages with interfaces

- Both are typically constructed on top of the request-reply protocol

- Offer call semantics such as *at-least-once* and *at-most-once*

- Offer a similar level of transparency, means local and remote calls employ the same syntax but remote interfaces expose the distributed nature for example by supporting remote exceptions
Remote method invocation

The distributed object model
Remote and local method invocation

**Remote object reference**: Other objects can invoke the methods of a remote object if they have access to its remote object reference.

**Remote interface**: Every remote object has a remote interface that specifies which of its methods can be invoked remotely.
A remote object and its remote interface
Actions in a Distributed Object System
Instantiation of remote objects
Remote method invocation

Implementation of RMI
Generic RMI Modules
The Communication Module

Two cooperating communication modules carry out the request-reply protocol.

Only the first three fields of request and reply messages are used by communication module:

- messageType
- requestId
- remoteReference

Communication modules provide together a specified invocation semantics, e.g. at-most-once.

The communication module in the server selects the dispatcher for the class of the object to be invoked, passing on the remote object’s local reference.
The Remote Reference Module

It is responsible for translating between local and remote object references and for creating remote object references.

The remote reference module holds a table that records the correspondence between local object references in that process and remote object references (which are system wide).

Table includes

- An entry for all remote objects held by the process
- An entry for each local \textit{proxy}
Generic RMI Modules

RMI software

client

object A
proxy for B

server

skeleton & dispatcher for B’s class

server

remote object B

Request

Reply

Remote reference module

Communication module

Communication module

Remote reference module

servant
Remote method invocation

Summary
We have we learned?

- Basic communication primitives of UDP style request-reply protocols
- Basic message structure of the request-reply protocol
- Advantages of choosing TCP for request-reply protocols
- HTTP: an example of a request-reply protocol
- Issues that are important to understand the remote procedure calls
- HTTP methods and their properties
- Importance of interfaces for RPC
- RPC call semantics
- Commonalities and differences of RMI and RPC
- Generic RMI Modules
Questions

• Describe a UDP-based request – reply protocol for remote invocation. How can the protocol handle failures due to lost request messages, duplicated request messages, lost reply messages? Why are unique message identifiers and a history needed for invocations of non-idempotent operations? How is the history used and maintained in request-reply (RR) and request-reply-acknowledge (RRA) exchange protocols?

• What are the advantages of choosing TCP for request-reply protocols?

• What role do interfaces play in remote invocation with RPC? What are the advantages of using interfaces?

• Describe the implementation of RPC.

• Describe the three RPC call semantics: maybe, at-least once, at-most once.

• How does RMI relate to RPC? What the commonalities and what are the differences?

• Describe the distributed object model of RMI with instantiations of and actions on remote objects. What is a remote object, remote object reference, remote interface, remote method invocation, local method invocation?

• Describe the generic RMI modules on client and server side with the RMI software, the communication modules and the remote reference modules.
Our topics today

Descriptive models for distributed system design

Physical model

Architectural model

Architectural elements

Communicating entities

- Processes
- Objects
- Components
- Web Services

Architectural patterns

- Vertical distribution
  - Multi-tier
  - Thin/Fat Client

- Horizontal distribution

Interaction model

Interaction model

Roles and responsibilities

- Architectural styles
  - Client-server
  - Peer-to-peer

Place

- Multiple server
- Proxy/Cache
- Mobile code

Failure model

Security model

- Communication paradigm
- Remote invocation

- Inter-process communication
- Indirect communication
Next class

**Distributed object component middleware I (Java RMI)**
References

Main resource for this lecture: