Distributed Systems

03r. Part I: Homework Review

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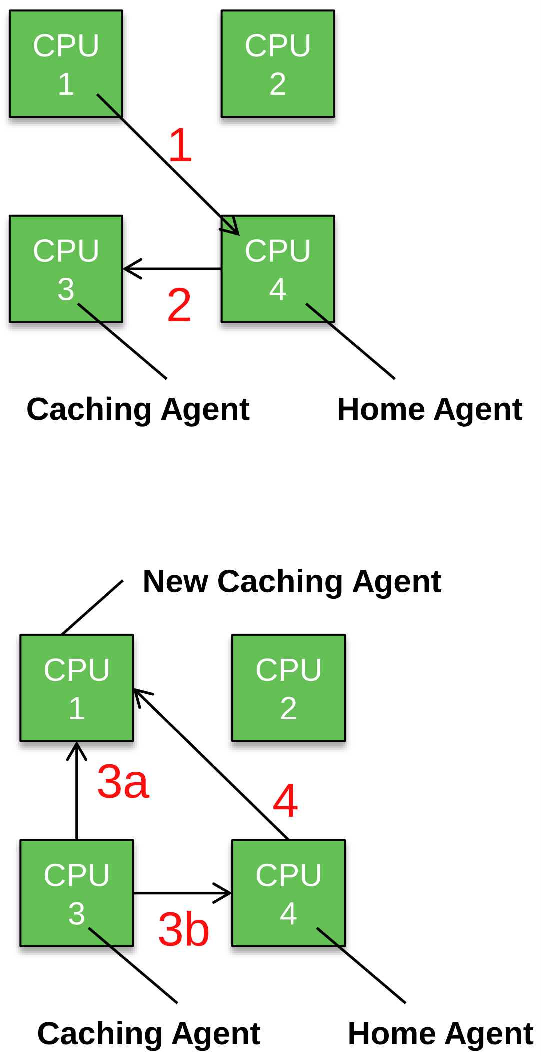
Question 1

What is the advantage of source snoop coherency behavior compared to home snoop?

- This describes Intel's support for NUMA (Non-Uniform Memory Access) using their QuickPath Interconnect – a high-speed network that connects processors in a multiprocessor system.
  - Home agent = CPU that has a connection to the memory with the data
    - Home agent keeps track of which CPU has the latest cached copy
  - Caching agent = CPU that may have or wants a cached copy

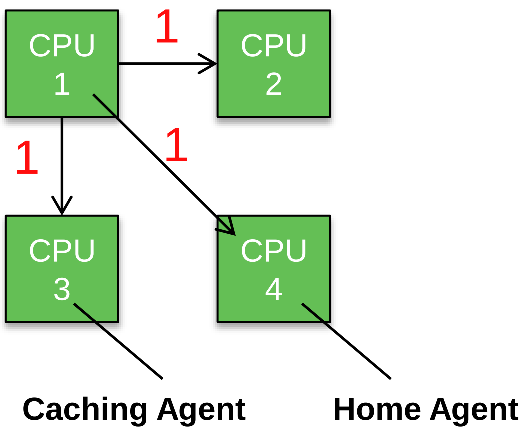
Question 1 discussion

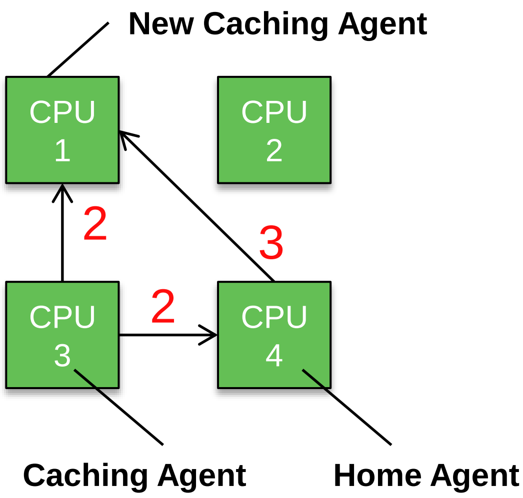
- Goal is to make sure memory is coherent
  - No processor will use out-of-date contents
- Home snoop
  1. CPU that wants to read data contacts the home agent for that memory location
  2. Home agent sends a request to the CPU that has the latest version
  3. That CPU sends the update to (a) the requesting CPU and (b) acknowledges the home agent.



Question 1 discussion

- Source snoop
  1. CPU that wants to read data contacts all other CPUs
  2. That CPU sends the data to P1 & acknowledgement to P4
  3. P4 acknowledges the end of the transaction.





Question 1

(a) What is the advantage of source snoop coherency behavior compared to home snoop?

- Answer:
  - The caching agent (the CPU that wants the data) sends requests to the home agent and all other caching agents.
  - The caching agent with the data responds directly to the requestor. Two network hops instead of three to get the data.

(b) What is the downside?

  - The technique uses more bandwidth because requests are sent to all processors

Question 2

What are three techniques used to reduce load on a system?

1. Replication
   – Multiple servers can handle the same request
   – Distributes load
2. Distribution
   – Different servers are responsible for different tasks
3. Caching
   – Save previous results: avoid contacting a server

Question 3

"*Fate-sharing*" is a key facet of the Internet's end-to-end principle.

What is meant by the term fate-sharing?

- It is acceptable to lose the state information associated with an entity if, at the same time, the entity itself is lost.
- Example
  - It is OK to lose the TCP connection if the client or server dies
  - It is NOT OK to lose the TCP connection if a router in the network dies

Question 4

What is the *end-to-end principle* in networking?

- Application-specific functions ought to reside in the end hosts of a network rather than in intermediary nodes – provided they can be implemented "completely and correctly" in the end hosts.

- Example
  - TCP provides reliable, in-order data delivery over an unreliable network
  - All the logic to do this is at the “ends” – the computers
  - Routers implement only what they have to: moving packets

Question 5

- Paper: *Distributed Garbage Collection for Network Objects*
- a proposal is introduced for managing remote object references
  - a server maintains a ***dirty*** set per object: a list of active remote references to a particular object.
  - When a local garbage collector at a client determines that the client has no more references to a remote object, it sends a ***clean*** message to the server to remote the reference from the dirty set.
- One snag is the situation where one process, *A*, passes an object reference to another process, *B*. It is possible that the garbage collector on *A* will send a clean message to the server before *B*'s dirty message is received.
- Explain how this situation is handled. Assume neither process *A* nor process *B* is the owner of the object. A simply passes the object reference to *B*.

Question 5

- Question summary:
  1. A sends a reference for a remote object to B.
  2. A doesn't need it anymore so it tells the server that it has no references (clean).
  3. B receives the object reference and tells the server that it has a reference (dirty).
  – If the server gets rid of the object after step 2, it's gone and *B* cannot access it.
- How do we fix this?

- Process A will NOT send a *clean* message to the server until it first gets an acknowledgement that *B* received the object and sent a *dirty* message to the server

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03r. Part 2: Java RMI Programming Tutorial

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Java RMI

- Allows a method to be invoked that resides on a different JVM (Java Virtual Machine):
  - Either a remote machine
  - Or same machine, different processes
    - Each process runs on a different Java Virtual Machines (JVM)
    - Different address space per process/JVM
- RMI provides object-oriented RPC

Participating processes

- Client
  - Process that is invoking a method on a remote object
- Server
  - Process that owns the remote object
  - To the server, this is a local object
- Object Registry (rmiregistry)
  - Name server that associates objects with names
  - A server registers an object with rmiregistry
  - URL namespace

```
      rmi://hostname:port/pathname
e.g.: rmi://crapper.pk.org:12345/MyServer
```

Port number

Classes & Interfaces needed for Java RMI

- **Remote**: for accessing remote methods
  - Used for remote objects
- **Serializable**: for passing parameters to remote methods
  - Used for parameters
- Also needed:
  - RemoteException: network or RMI errors can occur
  - UnicastRemoteObject: used to export a remote object reference or obtain a stub for a remote object
  - Naming: methods to interact with the registry

Remote class

- **Remote** class (remote object)
  - Instances can be used remotely
  - Works like any other object locally
  - In other address spaces, object is referenced with an *object handle*
    - The handle identifies the location of the object
  - If a remote object is passed as a parameter, its handle is passed

Serializable interface

- **java.io.Serializable** interface (serializable object)

  – Allows an object to be represented as a sequence of bytes (marshaled)

  – Allows instances of objects to be copied between address spaces
    - Can be passed as a parameter or be a return value to a remote object
    - Value of object is copied (pass by value)

  – Any objects that may be passed as parameters should be defined to implement the **java.io.Serializable** interface
    - Good news: you rarely need to implement anything
    - All core Java types already implement the interface
    - For your classes, the interface will serialize each variable iteratively

Remote classes

- Classes that will be accessed remotely have two parts:
  1. interface definition
  2. class definition
- **Remote interface**
  - This will be the basis for the creation of stub functions
  - Must be public
  - Must extend **`java.rmi.Remote`**
  - Every method in the interface must declare that it throws
    `java.rmi.RemoteException`
- **Remote class**
  - implements Remote interface
  - extends **`java.rmi.server.UnicastRemoteObject`**

Super-simple example program

- Client invokes a remote method with strings as parameter
- Server returns a string containing the reversed input string and a message

Define the remote interface

SampleInterface.java

```
import java.rmi.Remote;
import java.rmi.RemoteException;

public interface SampleInterface extends Remote {
    public String invert(String msg) throws RemoteException;
}
```

- Interface is public
- Extends the Remote interface
- Defines methods that will be accessed remotely
  - We have just one method here: *invert*
- Each method must throw a RemoteException
  - In case things go wrong in the remote method invocation

Define the remote class (Sample.java)

```
import java.rmi.Remote;
import java.rmi.RemoteException;
import java.rmi.server.*;

public class Sample
  extends UnicastRemoteObject
  implements SampleInterface {

    public Sample() throws RemoteException {  }
    public String invert(String m) throws RemoteException {
        // return input message with characters reversed
        return new StringBuffer(m).reverse().toString();
    }
}
```

- Defines the implementation of the remote methods
- It implements the interface we defined
- It extends the java.rmi.server.UnicastRemoteObject class
  – Defines a unicast remote object whose references are valid only while the server process is alive.

Next…

- We now have:
  - The remote interface definition: SampleInterface.java
  - The server-side (remote) class: Sample.java
- Next, we'll write the server: SampleServer.java
- Two parts:
  1. Create an instance of the remote class
  2. Register it with the name server (**rmiregistry**)

Server code (SampleServer.java)

- Create the object

```
new Sample()
```

- Register it with the name server (rmiregisty)

```
Naming.rebind("Sample”, new Sample())
```

- *rmiregistry* runs on the server
  - The default port is 1099
  - The name is a URL format and can be prefixed with a hostname and port: “**`//localhost:1099/Server`**”

Server code: part 1 (SampleServer.java)

```
import java.rmi.Naming;
import java.rmi.RemoteException;
import java.rmi.server.UnicastRemoteObject;

public class SampleServer {
    public static void main(String args[]) {
        if (args.length != 1) {
            System.err.println("usage: java SampleServer rmi_port");
            System.exit(1);
        }
```

Server code: part 2 (SampleServer.java)

```
        try {
            // first command-line arg: the port of the rmiregistry
            int port = Integer.parseInt(args[0]);

            // create the URL to contact the rmiregistry
            String url = "//localhost:" + port + "/Sample";
            System.out.println("binding " + url);

            // register it with rmiregistry
            Naming.rebind(url, new Sample());
            // Naming.rebind("Sample", new Sample());
            System.out.println("server " + url + " is running...");
        }
        catch (Exception e) {
            System.out.println("Sample server failed:" +
                                                  e.getMessage());
        }
    }
}
```

Policy file

- When we run the server, we need to specify security policies
- A security policy file specifies what permissions you grant to the program
- This simple one grants all permissions

```
grant {
   permission java.security.AllPermission;
};
```

The client

- The first two arguments will contain the host & port
- Look up the remote function via the name server
- This gives us a handle to the remote method

```
SampleInterface sample = (SampleInterface)Naming.lookup(url);
```

- Call the remote method for each argument

```
sample.invert(args[i]));
```

- We have to be prepared for exceptions

Client code: part 1 (SampleClient.java)

```
public class SampleClient  {
  public static void main(String args[]) {
    try {
      // basic argument count check
      if (args.length < 3) {
        System.err.println(
           "usage: java SampleClient rmihost rmiport string... \n");
        System.exit(1);
      }

      // args[0] contains the hostname, args[1] contains the port
      int port = Integer.parseInt(args[1]);
      String url = "//" + args[0] + ":" + port + "/Sample";
      System.out.println("looking up " + url);

      // look up the remote object named "Sample"
      SampleInterface sample = (SampleInterface)Naming.lookup(url);
```

Client code: part 2 (SampleClient.java)

```
    // args[2] onward are the strings we want to reverse
    for (int i=2; i < args.length; ++i)

          // call the remote method and print the return
          System.out.println(sample.invert(args[i]));

    } catch(Exception e) {
      System.out.println("SampleClient exception: " + e);
    }
  }
}
```

Compile

- Compile the interface and classes:

```
javac SampleInterface.java Sample.java
javac SampleServer.java
```

- And the client…

```
javac SampleClient.java
```

(you can do it all on one command: **`javac *.java`**)

- Note – Java used to use an RPC compiler
  - Since Java 1.5, Java supports the dynamic generation of stub classes at runtime
  - In the past, one had to use an RMI compiler, *rmic*
  - If you want to, you can still use it but it's not needed

Run

- Start the object registry (in the background):

```
rmiregistry 12345 &
```

  - *An argument overrides the default port 1099*

- Start the server (telling it the port of the rmi registry):

```
java -Djava.security.policy=policy SampleServer 12345
```

- Run the client:

```
java SampleClient svrname 12345 testing abcdefgh
```

  - Where svrname is the name of the server host
  - 12345 is the port number of the name server: rmiregistry, not the service!

- See the output:

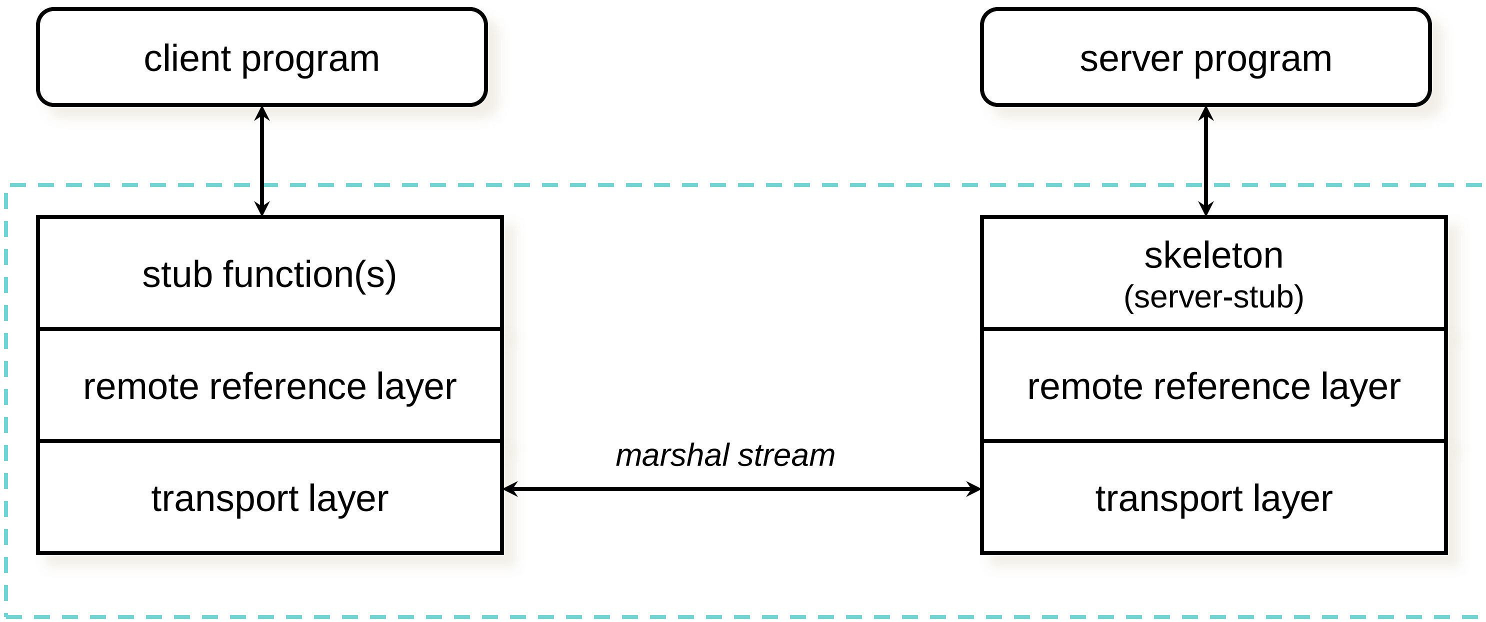
```
gnitset
hgfedcba
```

RMI
A bit of the internals

Interfaces

- Interfaces define behavior
- Classes define implementation
- RMI: two classes support the same interface
  - client stub
  - server implementation

Three-layer architecture



Server - 1

- **Server creates an instance of the server object**
  - extends UnicastRemoteObject
  - TCP socket is bound to an arbitrary port number
  - thread is created which listens for connections on that socket
- **Server registers object**
  - RMI registry is an RMI server (accepts RMI calls)
  - Hands the registry the client stub for that server object
    - contains information needed to call back to the server (hostname, port)

Client - 1

- **Client obtains stub from registry**
- **Client issues a remote method invocation**
  - **stub class creates a RemoteCall**
    - opens socket to the server on port specified in the stub
    - sends RMI header information
  - **stub marshals arguments over the network connection**
    - uses methods on RemoteCall to obtain a subclass of ObjectOutputStream
    - knows how to deal with objects that extend java.rmi.Remote
      - serializes Java objects over socket
  - **stub calls RemoteCall.executeCall()**
    - causes the remote method invocation to take place

Server - 2

- **Server accepts connection from client**
- **Creates a new thread to deal with the incoming request**
- **Reads header information**
  - creates RemoteCall to deal with unmarshaling RMI arguments
- **Calls *dispatch* method of the server-side stub (skeleton)**
  - calls appropriate method on the object
  - sends result to network connection via RemoteCall interface
  - if server threw exception, that is marshaled instead of a return value

Client - 2

- The client unmarshals the return value of the RMI
  – using RemoteCall
- value is returned from the stub back to the client code
  – or an exception is thrown to the client if the return was an exception

The end