Jini – an Infrastructure for Dynamic Service Networks

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- **J**ava **I**ntelligent **N**etwork **I**nfrastructure
- **J**ini **I**s **N**ot **I**nitials

Overview

- Jini, what's that?
  - motivation
  - overview
- RMI/Serialization
- Jini infrastructure
  - lookup service
  - discovery & join protocols
  - programming example
  - more details
- Jini programming model
  - leasing
  - distributed events
- Jini services
  - transactions
  - JavaSpaces
- Summary

Jini

- Infrastructure (“middleware”) for dynamic, cooperative, spontaneously networked systems
  - facilitates writing / deploying distributed applications

Jini

- Infrastructure ("middleware") for dynamic, cooperative spontaneously network d systems
  - facilitates application

- framework of APIs with useful functions / services
- helper services (discovery, lookup,...)
- suite of standard protocols and conventions

Jini

- Infrastructure ("middleware") for dynamic, cooperative, spontaneously networked systems
  - facilitates wri / deploying distributed applications

- services, devices, … find each other automatically ("plug and play")
- added, removed components
- changing communication relationships
- mobility

Jini

- Based on Java and implemented in Java
  - may use RMI (Remote Method Invocation)
  - typed (object-oriented) communication structure
  - requires JVM / bytecode everywhere
  - code shipping
- Strictly service-oriented

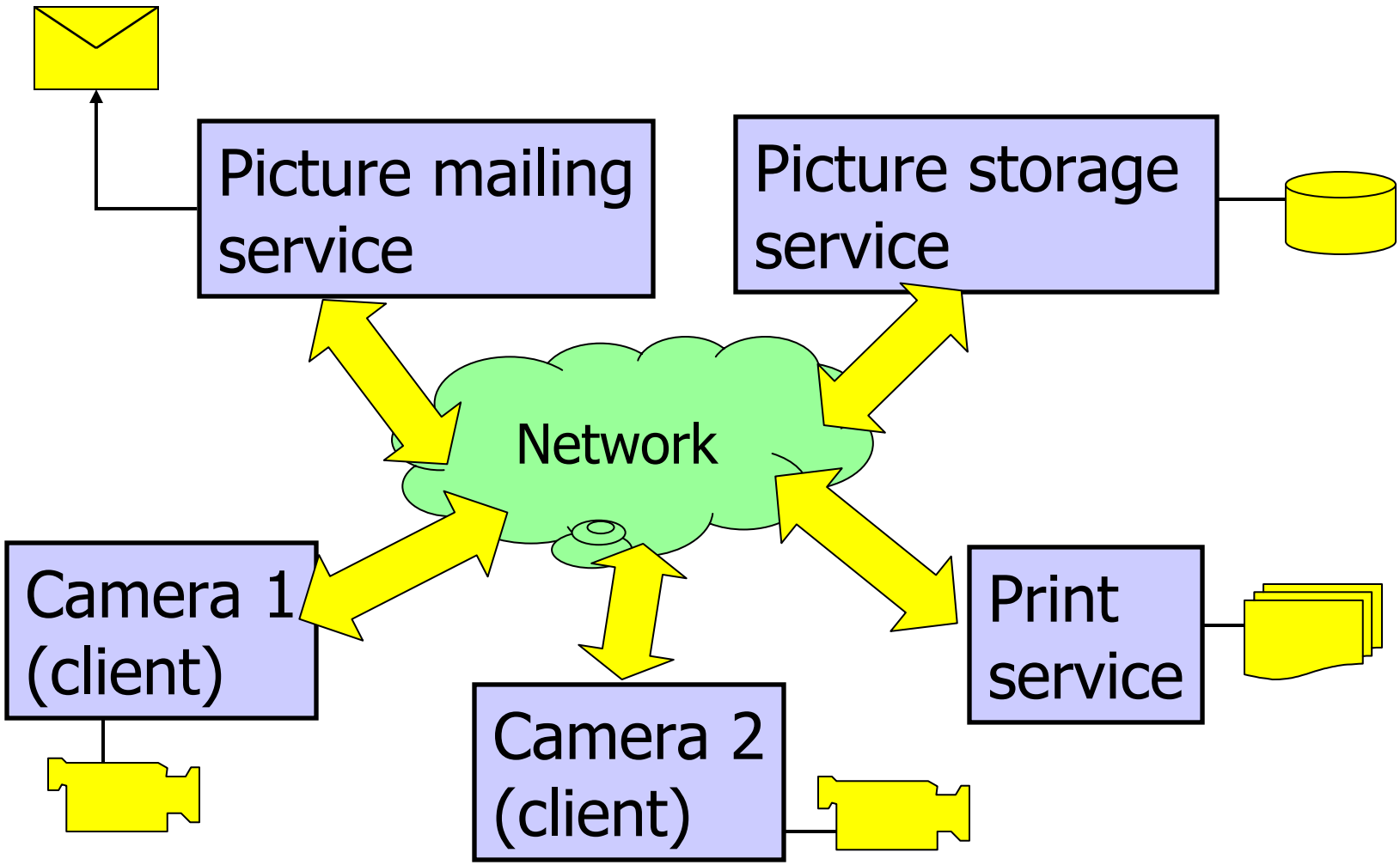
Service Paradigm

- Everything is a service (hardware / software / user)
  - like object-orientation: “everything” is an object
  - e.g. persistent storage, software filter, help desk, …
- Services are defined by interfaces and provide their functionality via their interfaces
  - services are further characterized by their attributes (e.g. “600 dpi”, “version 21.1”)

Service Paradigm

- Jini's run-time infrastructure offers mechanisms for adding, removing, and finding services
- Services (and service users) "spontaneously" form a system ("federation")

A Jini Federation



What Kind of Services?

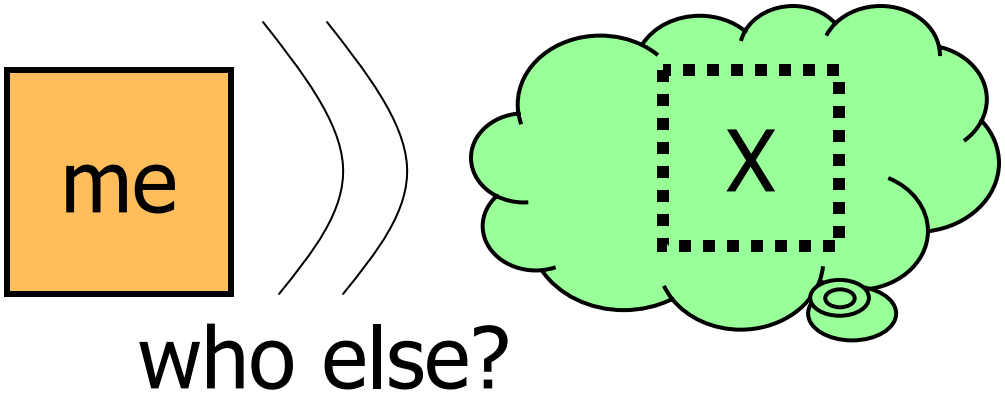
- Devices:
  - printer, fax machine, ...
  - storage, persistency, configuration, ...
  - computation, ...
- Software:
  - spell checking, format conversion, ...
  - online banking, stock trading, ...
  - tourist guide, local maps, hotels, restaurants, ...

Spontaneous Networking

- Objects in an open, distributed, dynamic world find each other and form a transient community
  - cooperation, service usage, …
- Problem: no a priori knowledge about existence, interface, functionality, and trustworthiness of services
  - “traditional” client/server model: server knows nothing about its clients, but client knows the server, its interface (API, protocol) and its functionality

Spontaneous Networking

- Objects must be able to find each other
- Must be fast, easy, and automatic



- But: what for?

What Does Tomorrow Look Like?

- Increasing number of internet users
- Powerful PDAs and notebooks
- Increasing mobility
- New wireless information devices
- Numerous mobile networked devices

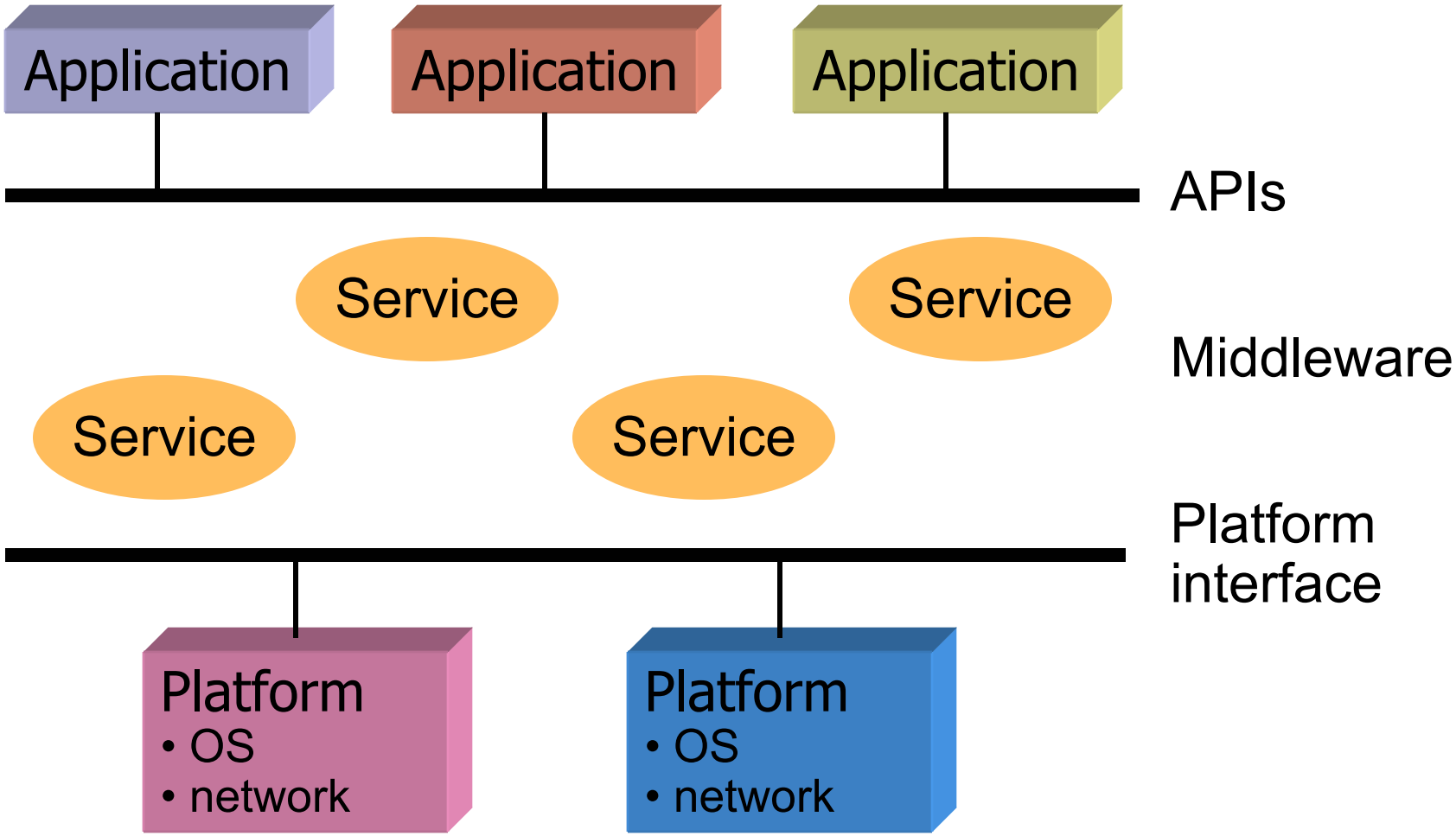
What Does Tomorrow Look Like?

- Numerous processors in embedded systems
  - e.g. software updates for your washing machine, internet-ready microwave, ...
- Trend towards ubiquitous networks and spontaneous networking / service access
  - high bandwidth, wireless, cheap

Middleware

- Approach from a different direction: “middleware”
  - components to help build and deploy distributed applications (development-time vs. run-time)
  - located between the application logic and the underlying physical network and operating system

Middleware


Application
Application
Application
APIs
Service
Service
Middleware
Service
Service
Platform
interface
Platform
• OS
• network
Platform
• OS
• network

Middleware

- Abstraction from tedious network programming wanted
- Abstraction from differing machine architectures wanted
  - problem: data encoding (e.g. big/little endian, integer size, array storage layout, ...)
- Components for recurring problems (e.g. naming service, security service, ...)

Problems with Current Middleware

- Systems hide network from programmer
  - programmers don't have to deal with the network and its inherent problems (unreliability, latency, bandwidth, ...)
  - no exception handling
- Data is moved to the computation
  - "classical" client/server paradigm
  - not always most efficient solution
  - problem: different data formats (byte-order)
  - but: program code is usually not available everywhere (different system architectures, installation, ...)

Middleware: Partial Failure

- Difference between local and remote call: total vs. partial failure
- Components might be unreachable: server crash, broken network connection, ...
- Problem: how to distinguish unreachable from slow server

Middleware: Partial Failure

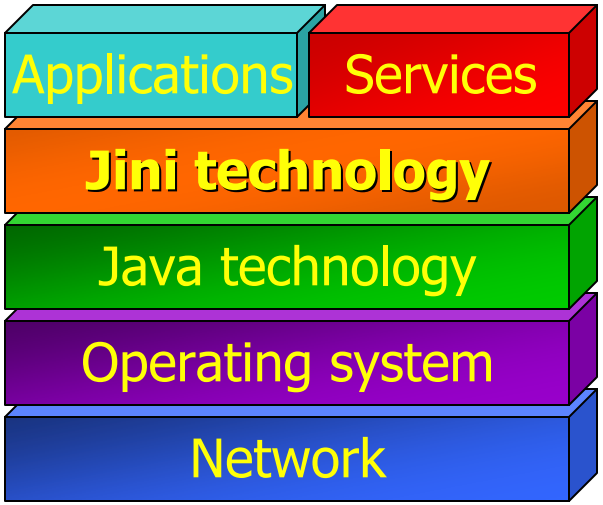
- Components / middleware have to be able to deal with partial failure
- Unreachability of one component should not (or only minimally) affect other components
  - e.g. Internet: server crash does not affect other servers
- Jini offers mechanisms to deal with partial failure

Some Fallacies of Common Distributed Computing Systems

- The idealistic view…
  - the network is reliable
  - latency is zero
  - bandwidth is infinite
  - topology doesn't change
  - there is one administrator
- …isn't true in reality
  - Jini addresses some of these issues
  - at least it does not hide or ignore them

Bird's-Eye View on Jini

- Jini consists of a number of APIs
- Is an extension to the Java 2 platform dealing with distributed computing



- Is a layer of abstraction between application and underlying infrastructure (network, OS) → "middleware"
- Extension of Java in three dimensions

Jini's Extensions to Java

- Extensions regarding networked systems

	Infrastructure	Programming model	Services
Java	• JVM • RMI • …	• Swing • Beans • …	• Transaction Service • Enterprise JavaBeans • …
Jini	• Discovery • Lookup • Join	• Transactions • Leasing • Distributed Events	• JavaSpaces • Transaction Manager

- Distinction may seem blurred

Jini's Use of Java

- Jini requires JVM (as bytecode interpreter) and (currently) RMI
  - homogeneity in a heterogeneous world
  - is this realistic?
- But: devices that are not "Jini-enabled" can be managed by a software proxy which resides at some place in the net
  - e.g. "Device Bay"
- Safety of Java applies to Jini as well
  - type safety, array bounds, sand box, ...

Able to perform discovery & join; have a JVM; ...

Jini vs. Mobile Agents

- Jini is **Java-based**
  - most mobile agent platforms are based on Java
  - Java bytecode often used as a universal machine language
  - applets are working instances of the mobile code paradigm
- Jini uses the **mobile code** paradigm
  - service proxies are sent to the client (via the lookup service)

Jini vs. Mobile Agents

- Mobile agents need an **infrastructure**
  - Jini is an infrastructure for highly dynamic distributed systems
  - Jini provides elementary services and functionality
    - e.g. agent coordination with JavaSpaces
- But: Jini is *not* a mobile agent platform!
  - further services required
  - however: Jini (and similar systems) are of general interest to computer scientists (→ ubiquitous computing, distributed systems)

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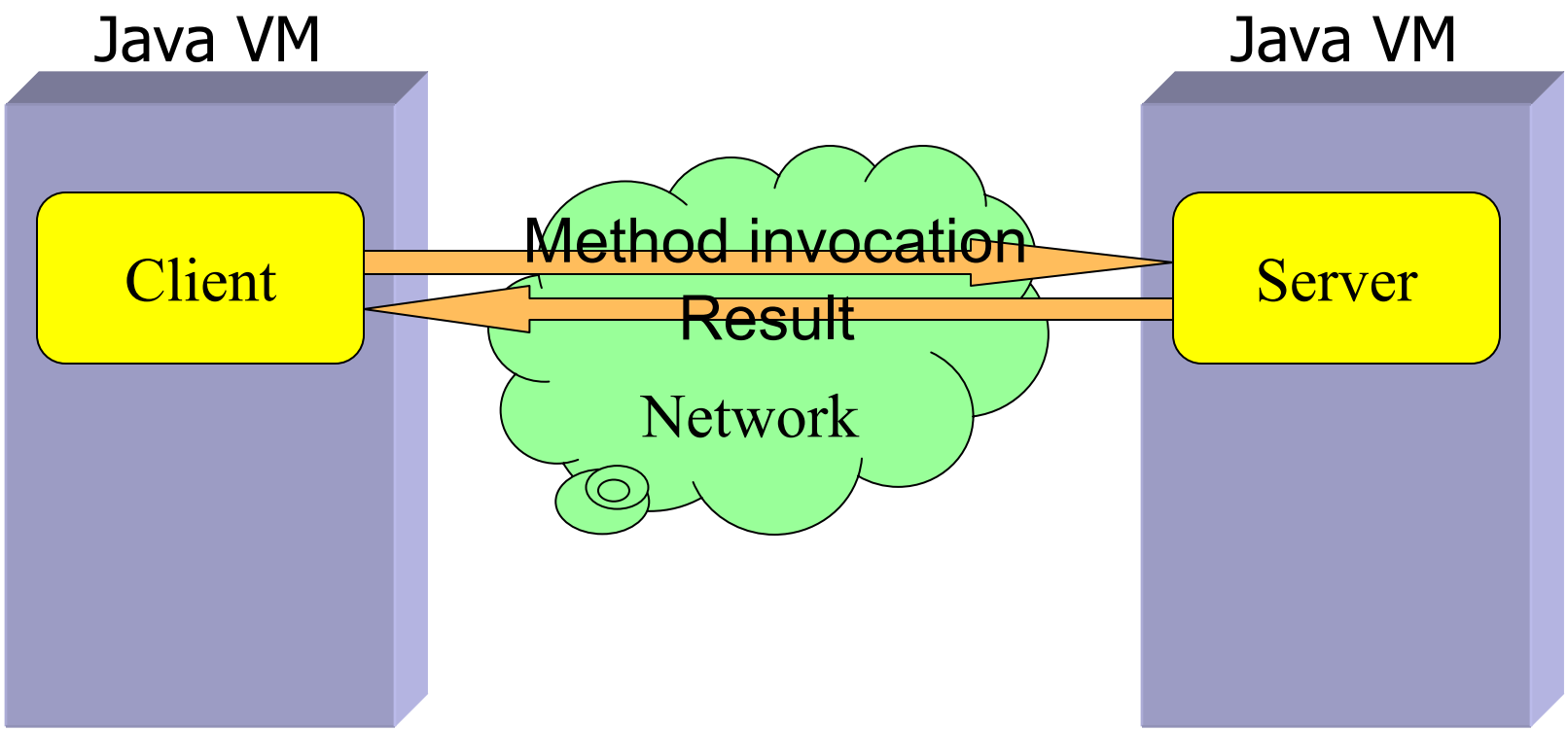
RMI: Introduction

- RMI: “Remote Method Invocation”
- Java’s native middleware
- “Regular” Java: method invocation within one Java VM
- By using RMI objects can call methods of objects running in a different Java VM
- Java VMs can be distributed among multiple machines in a network

Remote Invocation



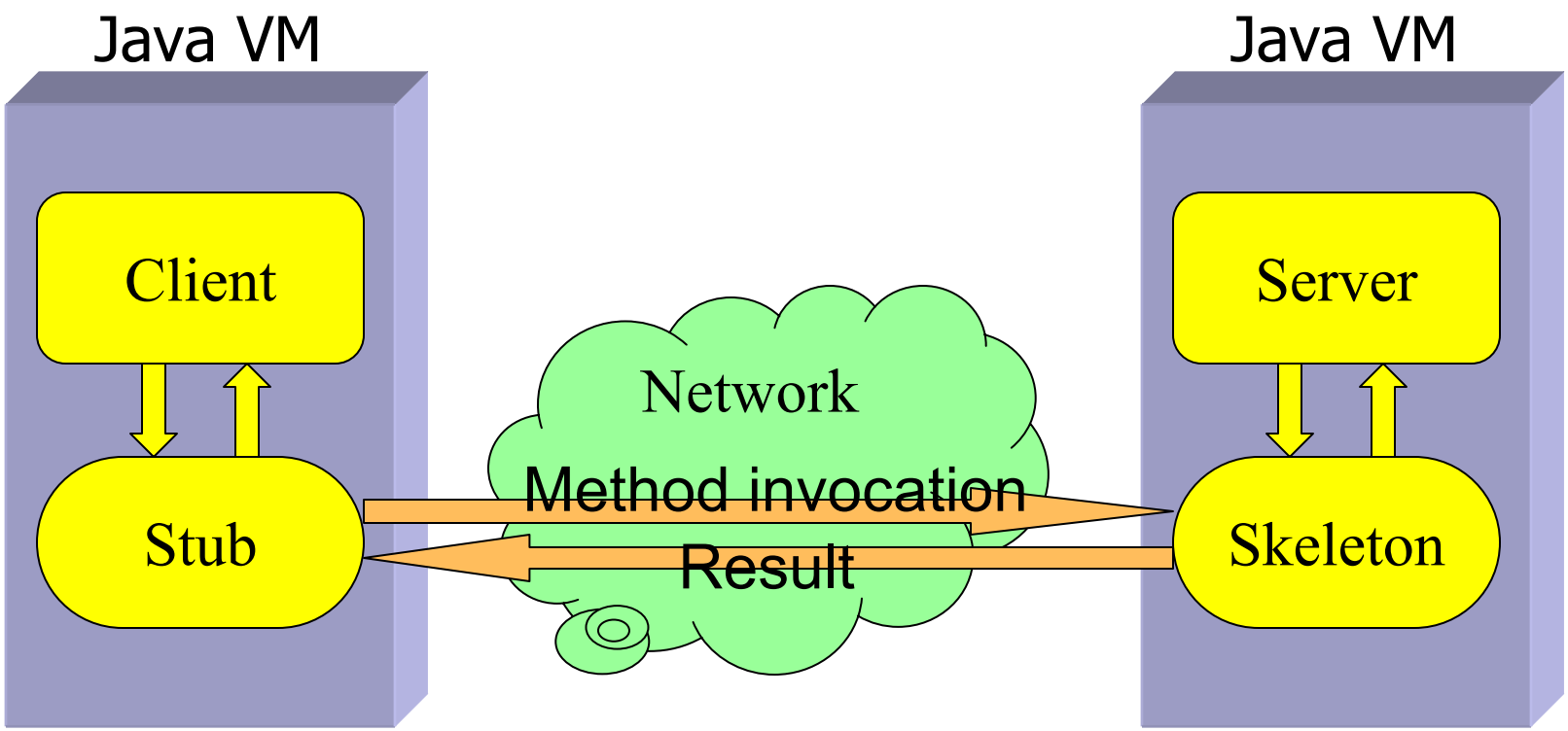
What To Use RMI For?

- Server objects offer their functionality (“services”: data, computation) to clients
- Clients can access them via a network
- RMI offers mechanism to bring clients and servers together
- Goal: clients can use remote server objects in (almost) the same way as they use local objects
  - partial failure possible
  - larger latency

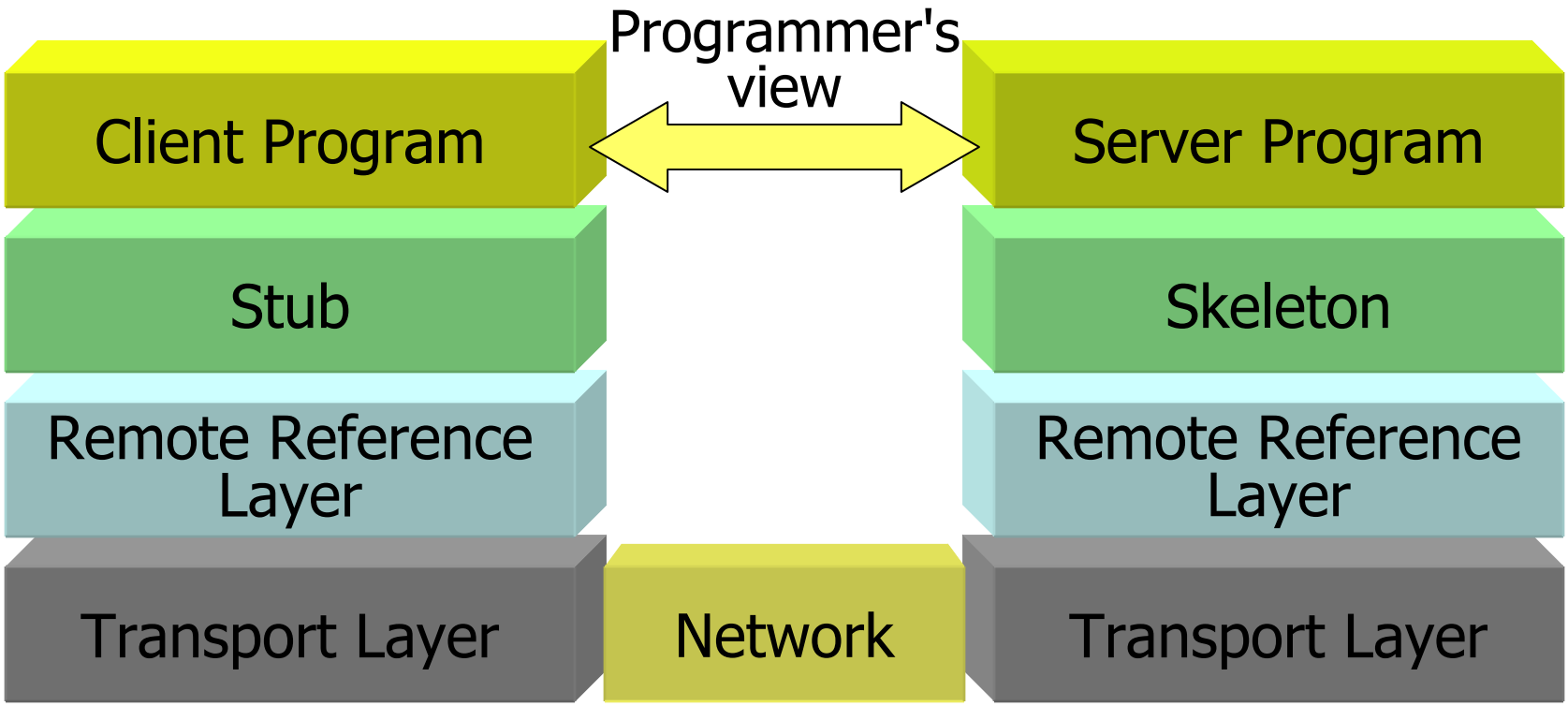
How Does RMI Work?

- Basic difference between local and remote objects: different Java VMs
- Idea: create a proxy for the remote object in the local Java VM
  - so-called “stub”
  - signatures of methods are identical to methods in remote server object
  - handles communication with remote object
- “Skeleton” in server is counterpart to stub
  - forwards parameter to “actual” server object
  - returns result to stub

How Does RMI Work?



More Details



RMI Details

- Client: invokes methods of an object
- Stub: implements “remote interface” of server object, passes on parameters
- Remote Reference Layer: maps object references to machines and objects
- Transport Layer: manages connections between machines and handles data transfer
- Skeleton: passes data to server object
- Server: implements functionality

Getting Access to Objects

- Clients must get stubs for remote objects
- RMI registry: naming service
  - mapping name (string) → object
  - location of registry (machine name and port number) must be known
  - name of server object must be known
  - e.g. "`//server.tud.de:2222/HelloServer`"
  - usually reference to first object only; grants access to further objects ("factory pattern")
  - e.g. root: database object, access to entries
- Jini

Example: Remote Interface

- Remote methods are defined by “remote interfaces”:

```
public interface Hello extends java.rmi.Remote {
  String sayHello()
      throws java.rmi.RemoteException;
}
```

- Methods can always throw `RemoteException`s
  - server or network may fail
- Interfaces are marked as remote by extending tag interface `java.rmi.Remote`

Example: Server Object

- Server implements remote interface and extends `UnicastRemoteObject`

```
public class HelloImpl
extends java.rmi.server.UnicastRemoteObject
implements Hello {
  public HelloImpl()
  throws java.rmi.RemoteException {
    super(); // UnicastRemoteObject
  }
  public String sayHello()
  throws java.rmi.RemoteException {
    return  "Hello World!";
  }
}
```

Example: Server Object

```
public HelloImpl()
throws java.rmi.RemoteException {
  super(); // UnicastRemoteObject
}
public String sayHello()
throws java.rmi.RemoteException {
  return  "Hello World!";
}
```

- `UnicastRemoteObject` handles RMI related work (make object known to RMI, relay calls)
- Server has to realize interface's functionality

Example: Server Startup

```
public class HelloStart {
  public static void main(String args[]) {
    try {
      HelloImpl obj = new HelloImpl();
      java.rmi.Naming.rebind(
           "//server.tud.de/HelloServer", obj);
    } catch (Exception e) {}
    [...wait and unregister object on exit...]
  }
}
```

- Create server object
- Register it with RMI registry
  - address/port of registry must be known
  - name for object must be supplied

Example: Client

```
public class HelloClient {
  public static void main(String args[]) {
    System.setSecurityManager(
            new java.rmi.RMISecurityManager());
    try {
      Hello obj = (Hello) java.rmi.Naming.lookup(
           "//server.tud.de/HelloServer");
      System.out.println(obj.sayHello());
    } catch (Exception e) {}
}}
```

- Security manager enables class download
- Get server's stub from RMI registry
- Use the server

Example: Deployment

- Naming Service must be running: `rmiregistry`
- Stub has to be created: `rmic HelloImpl`
  - creates classes `HelloImpl_Stub` and `HelloImpl_Skel`
  - no skeletons needed in Java 2 (option `-v1.2`)

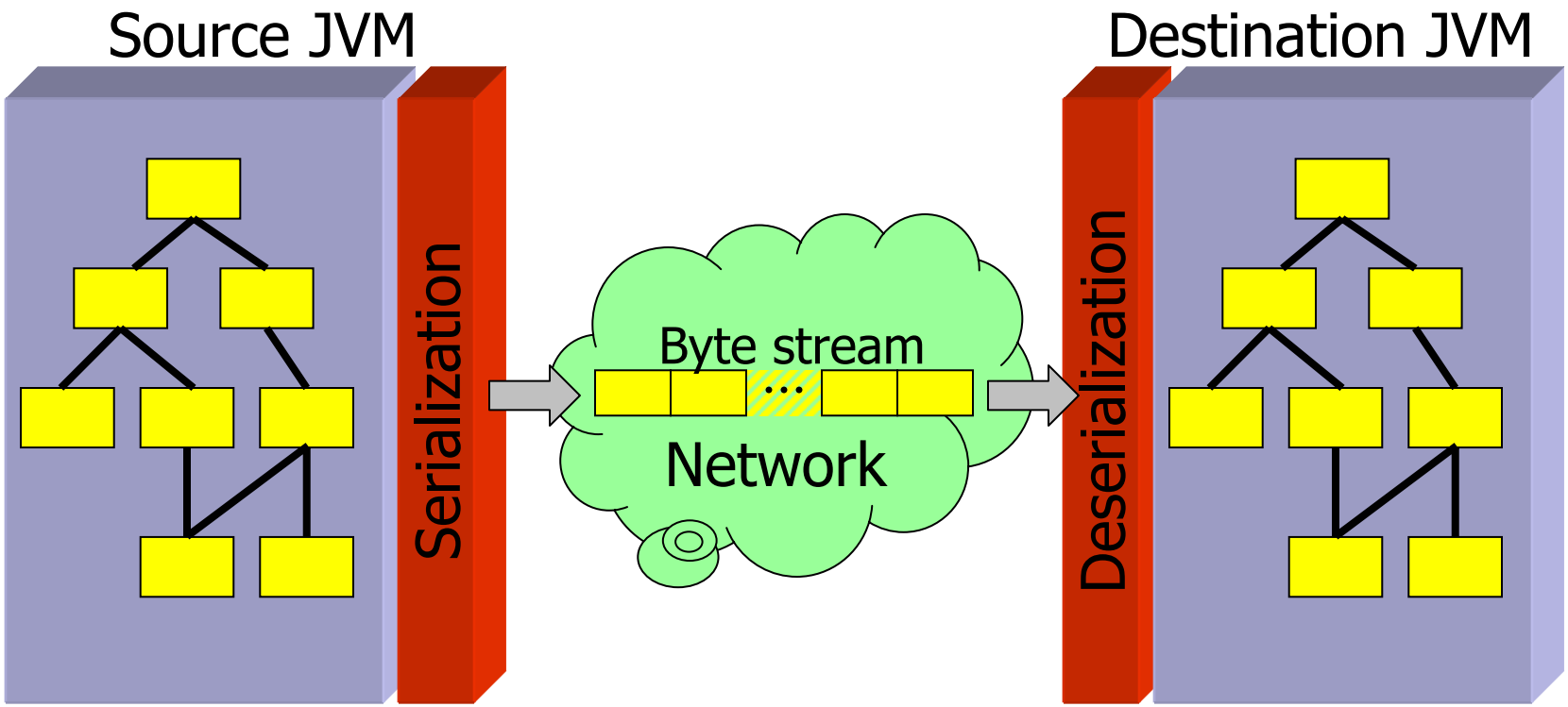
Example: Deployment

- Security policy needed to access sockets:
  - `java -Djava.security.policy=policy HelloStart`
  - `java -Djava.security.policy=policy HelloClient`
- For non-local environments classes (here: `HelloImpl_Stub`) have to be put onto an HTTP server and server's codebase has to be supplied

Serialization

- Parameters and return values (arbitrary objects) have to be transferred between client and server
- Copy of object has to be sent to remote JVM
- Solution: transform objects into stream of bytes (“serialization”)
- Problem: objects may contain references to other objects
  - all referenced objects have to be recursively serialized (“transitive closure”)

Serialization



Serialization

- Transforming an object into a stream of bytes
- Object consists of its code and its (data) state (values of variables)
- Code is stored in class files
- State is dynamic and only available at runtime
- Take a “snapshot” of this state

How Does Serialization Work?

- Realized by Java's introspection facilities
- All non-transient, non-static fields are recursively written to a byte-stream
- Simple types have predefined storage functions
- Objects' types (full class names, e.g. `java.util.List`) and signatures are written

How Does Serialization Work?

- Objects are only written once, even if referenced multiple times
- “Serial version UID” to control versions
  - calculated from the signature of a class
  - can be overridden manually to mark compatible class evolution
- Objects have to implement tag interface `java.io.Serializable`
- Predefined serialization semantics can be overridden by implementing certain functions (`writeObject()`, `readObject()`)

What Can Be Serialized?

- All primitive types (int, boolean, etc.)
- “Remote objects” (by sending serialized stubs)
- Base types (String, Integer, ...) that implement `java.io.Serializable`
- Most container classes (Hashtable, Vector, ...) if and only if they only contain serializable objects
- Some AWT and Swing classes
- Your classes, if they implement `java.io.Serializable`

What Cannot Be Serialized?

- Base types that do not implement `Serializable`
  - “wrapper classes” possible (by inheritance)
- “Low level” classes:
  - input and output streams
  - threads
  - peer classes
- Objects that reference non-serializable objects

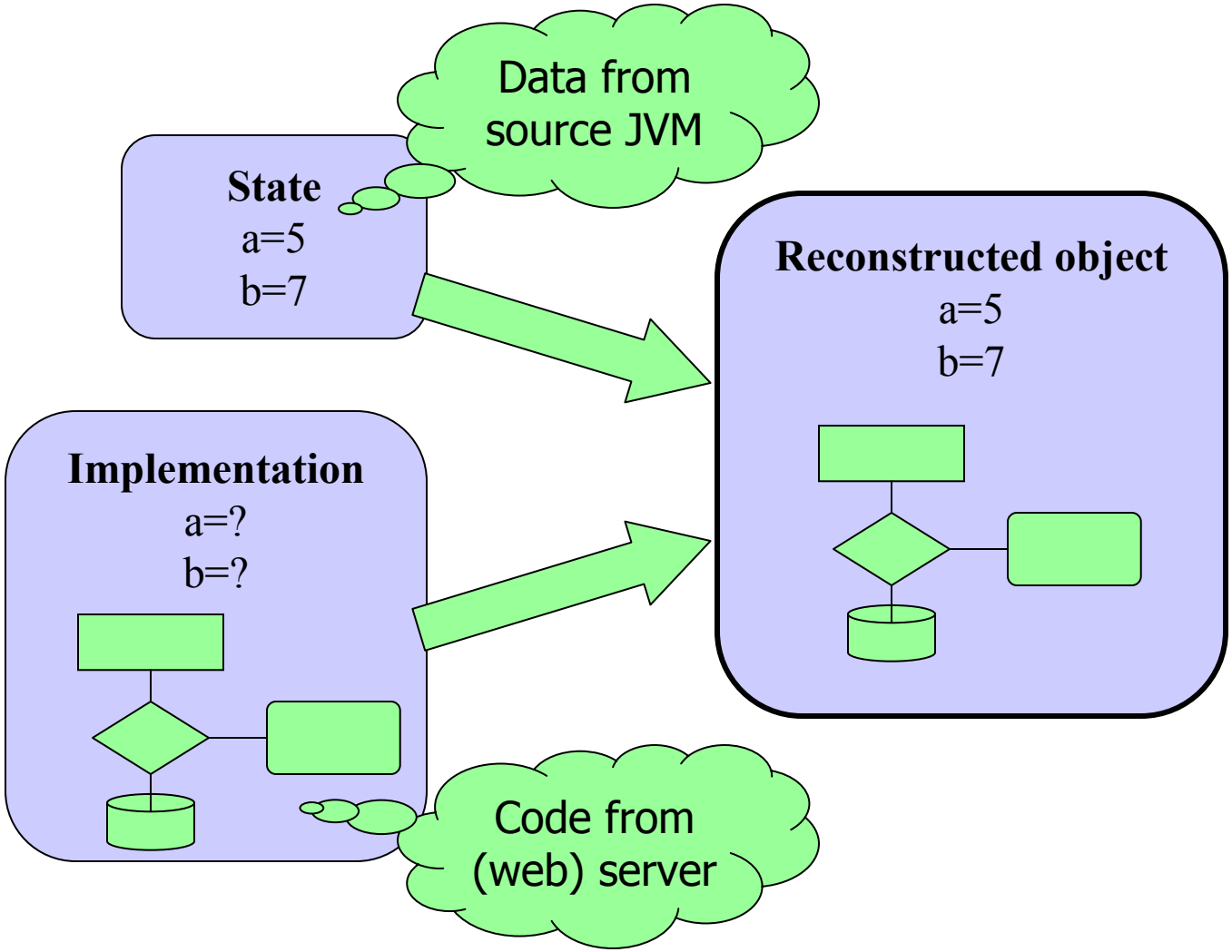
What To Use Serialization For?

- Write to file: make objects persistent
  - configurations
  - (Enterprise) Java Beans
  - to continue working on the same state later
- Write to socket:
  - to transfer objects to another JVM
  - parameter passing
  - mobile agents

Code Mobility

- Objects consists of two parts:
  - code (in Java class files)
  - state (values of attributes, execution pointers)
- RMI transfers only data state
- Problem: code is usually not locally available at recipient (i.e. not listed in its classpath)
- Solution: code can be downloaded at run-time (e.g. from an HTTP server)

Code Mobility



Codebase

- Code can be downloaded, but: where from?
- Location of code is transferred together with its state (“codebase”)
- Codebase is a list of URLs
- URL might point to
  - directory containing the class tree
  - JAR file containing the classes
- Codebase is set as a property when starting a JVM

Security

- Unknown objects are executed on local machine (like applets)
- Access restrictions desired; specified by security policies
  - fine-grained control of local resources (especially storage, network) possible
  - rights are granted based on
    - where code came from (network, local file)
    - who signed code

```
grant signedBy "sysadmin", codeBase "http://server.tud.de/-" {
  permission java.net.SocketPermission "*:1024-", "connect";
};
```

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Jini Infrastructure

- Main components are:
  - **lookup service** as repository / naming service / trader
  - **protocols** based on TCP/UDP/IP
    - discovery, join, lookup
  - **proxy objects**
    - transferred from service to clients
    - represent the service locally at the client

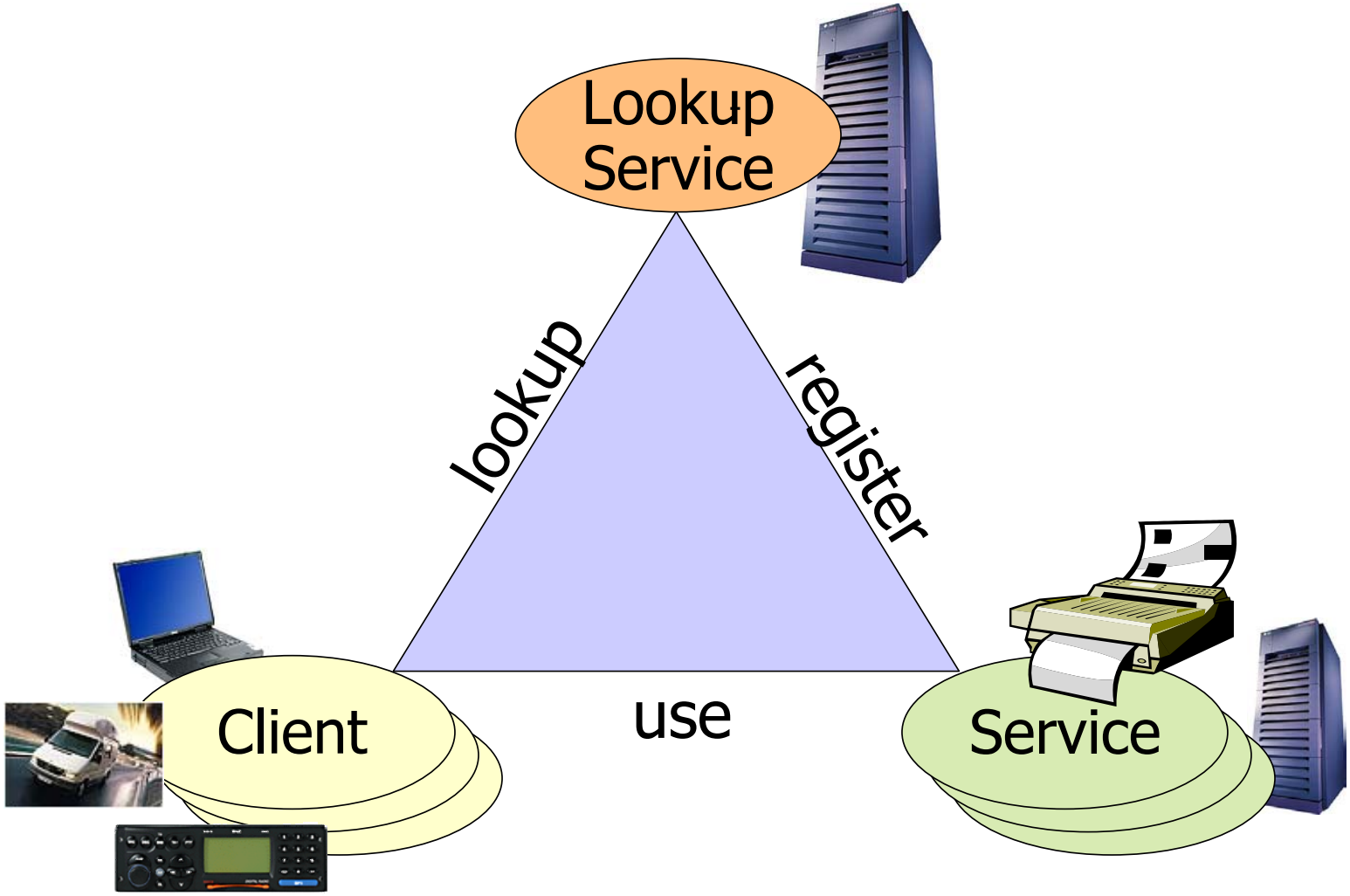
Jini Infrastructure

- Goal: spontaneous networking and formation of federations without prior knowledge of local network environment
- Problem: How do service providers and clients get to know their local environment?

Lookup Service

- Similar to RMI registry and CORBA naming service
- Repository of service providers
- Tasks:
  - registration of services (“advertising”)
  - distribution of services (clients find services)
- Main component of every Jini federation
- May be redundant and hierarchically organized (similar to DNS)

Jini Federation



Lookup Service

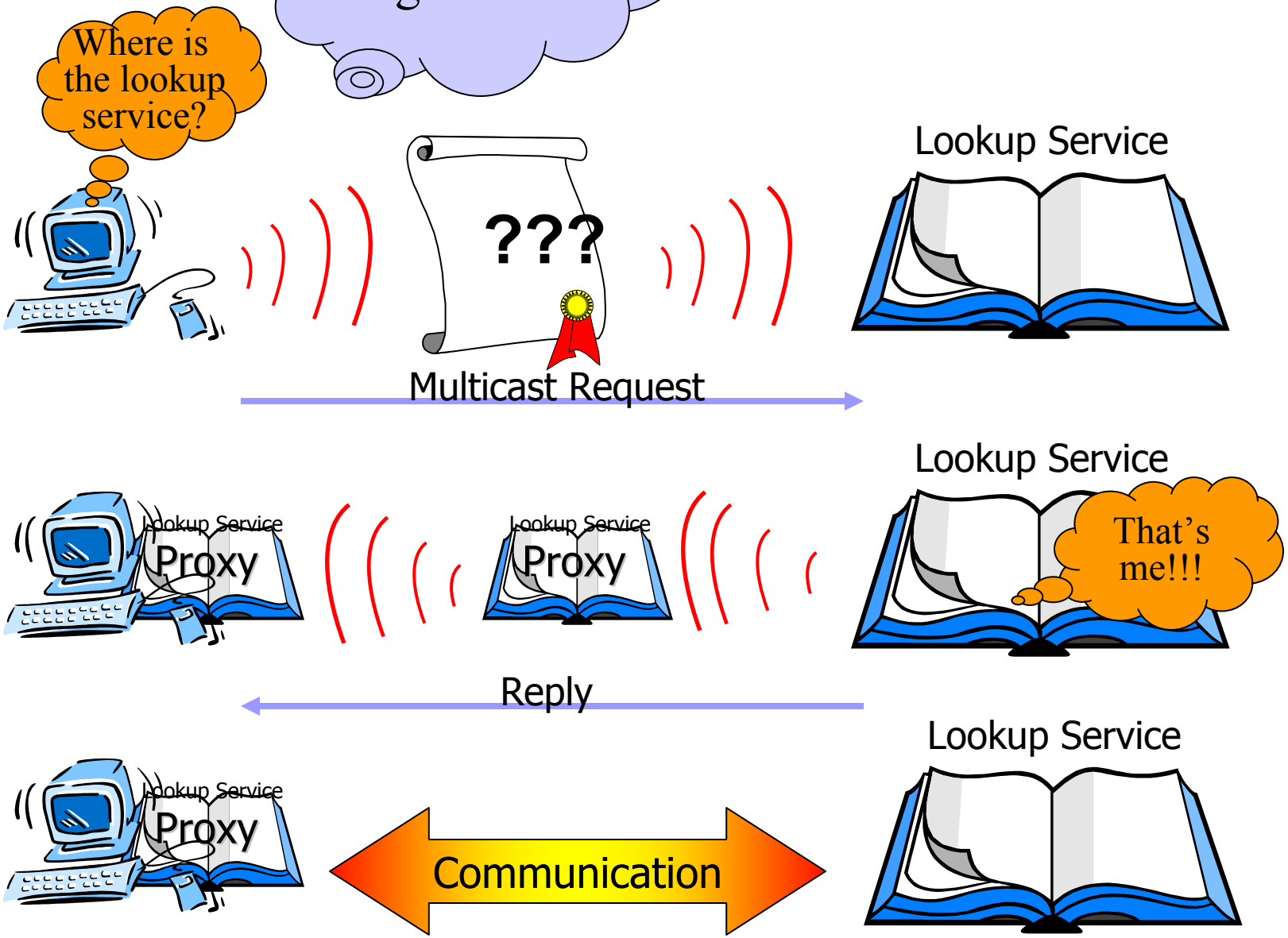
- Reference implementation uses Java RMI for communication
  - required: objects must be able to migrate through the net
- Not only name and address of a service are stored (as in traditional naming services), but also set of attributes
  - e.g.: printer (color: true, dpi: 600, ...)
  - attributes may be complex classes
    - e.g.: user interface(s)

Discovery: Finding a LUS

- Goal: Finding a lookup service without knowing anything about the network
  - to advertise (register) a service
  - to find (look up) an existing service
- Discovery protocol:
  - multicast to well-known address/port
  - lookup service replies with a serialized object (interface `ServiceRegistrar`)
    - proxy object of lookup service gets loaded to discovering entity
    - communication with LUS via this proxy

Discovery

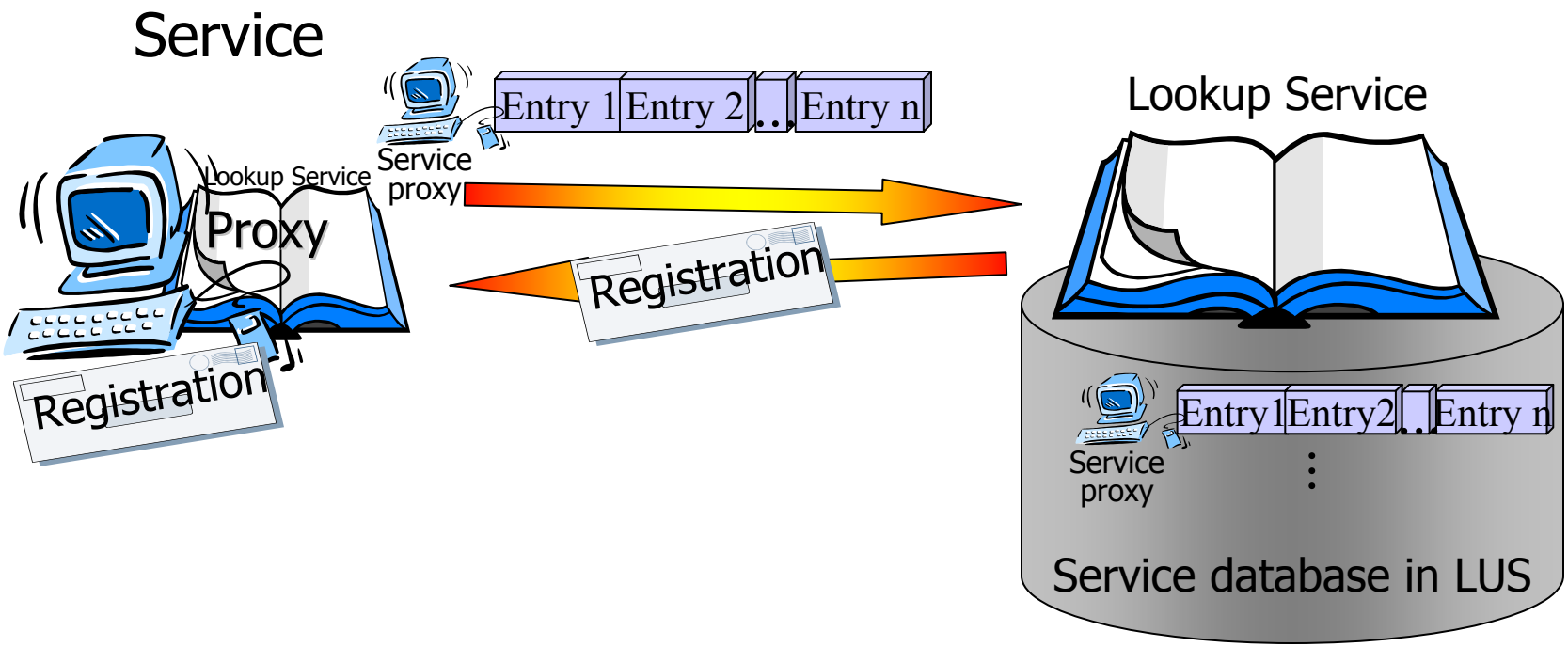
foreign network



Join: Registering a Service

- Service provider already received a proxy of the lookup service
- Provider uses this proxy to register its service (`register()`)
- Provider sends the lookup service
  - its service proxy
  - attributes that further describe the service
- Provider can now be found and used in this Jini federation

Join


Service
Lookup Service
Proxy
Registration
Service
proxy
Entry 1
Entry 2
..
Entry n
Registration
Lookup Service
Service
proxy
Entry1
Entry2
..
Entry n
Service database in LUS

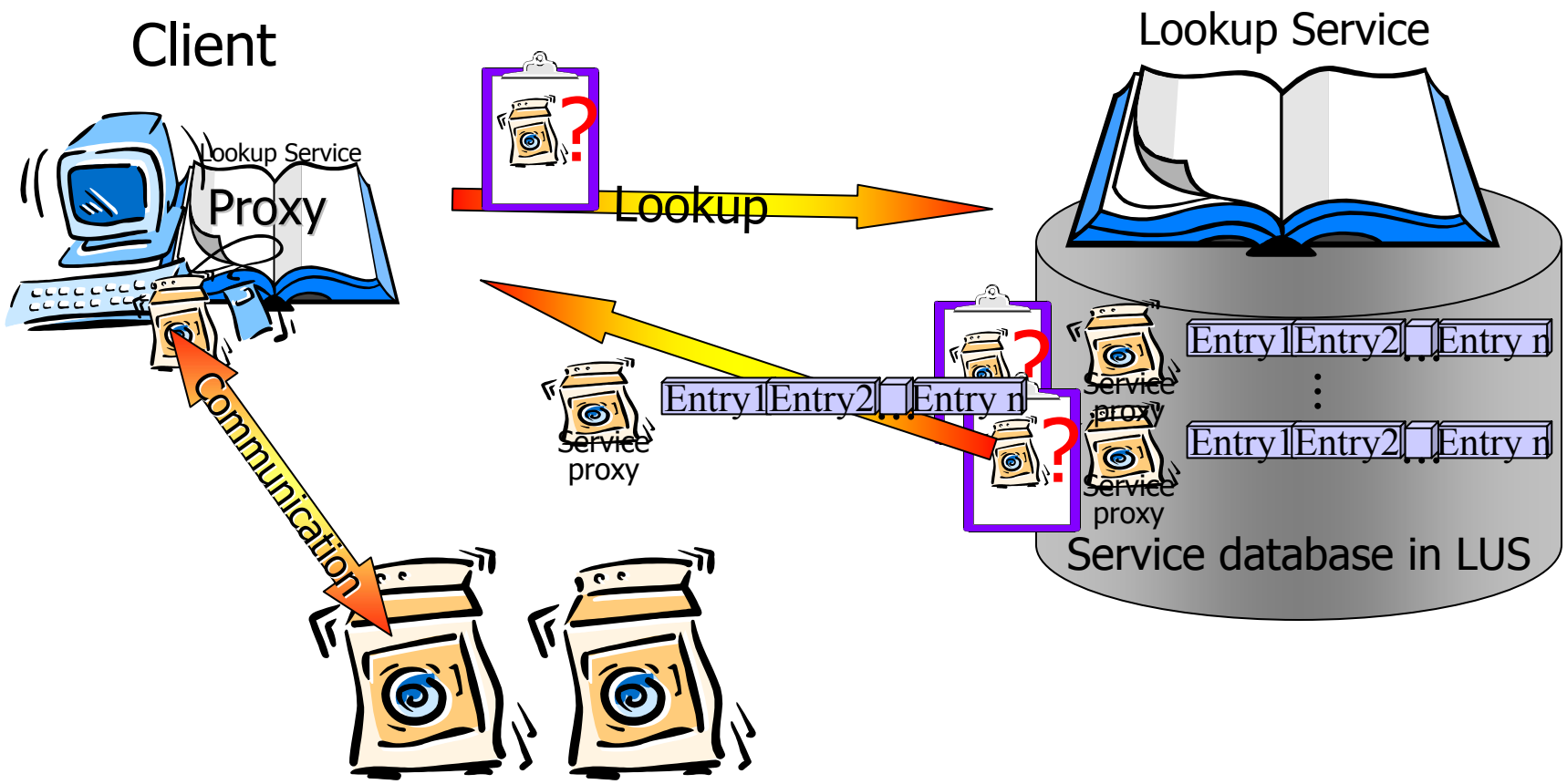
Lookup: Searching Services

- Client knows lookup service (e.g. via discovery protocol)
- Looking for certain (type of) service
- Creates query for lookup service
  - in form of a “service template”
  - matching by service type and/or attributes and/or registration number of service
  - wildcards possible

Lookup: Searching Services

- Lookup service returns one or more matches (or zero)
- Selection usually done by client
- Service use by calling functions of service proxy
- Any protocol between proxy and service provider possible

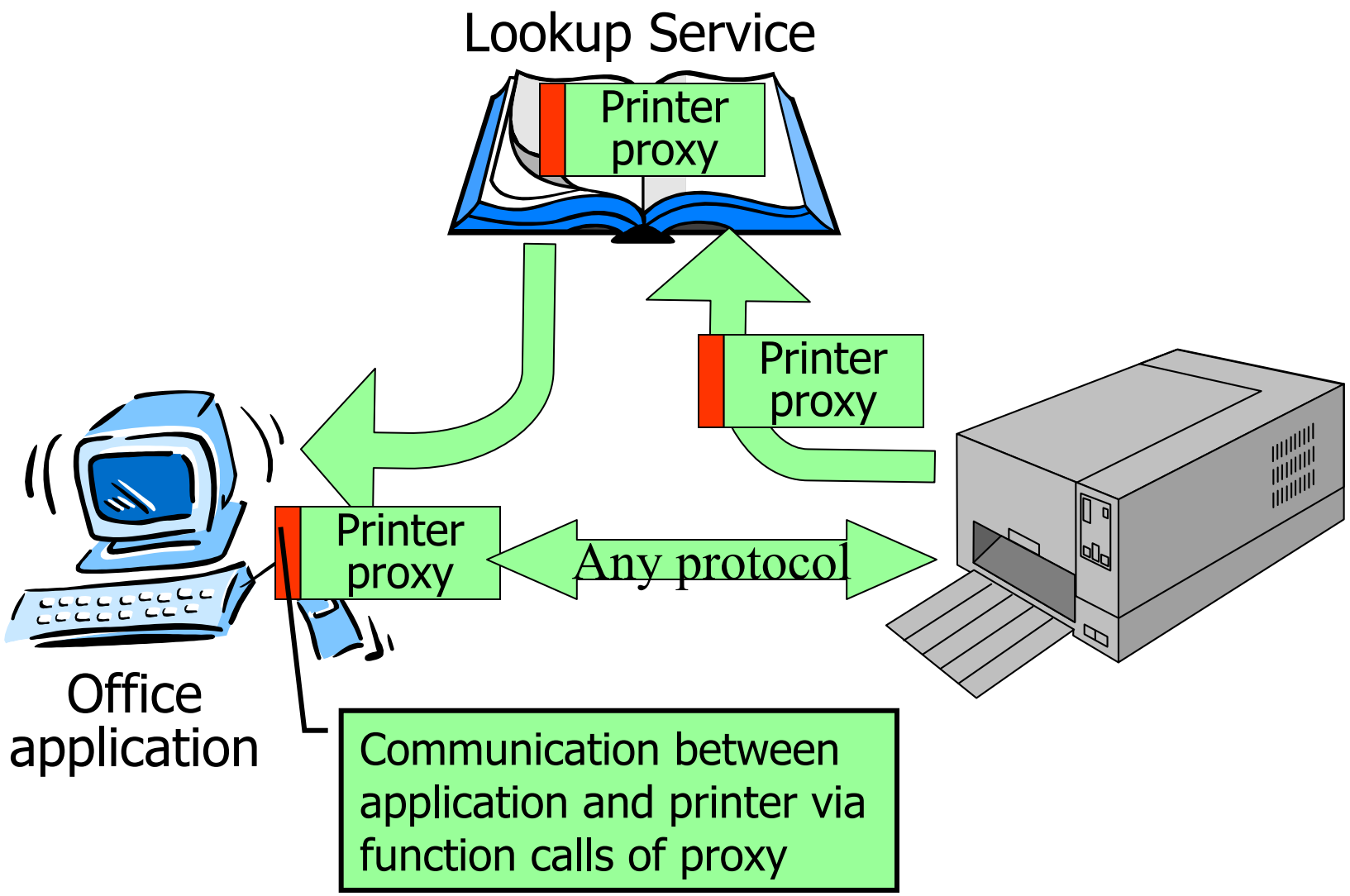
Lookup


Client
Lookup Service
Proxy
Lookup
Communication
Lookup Service
Entry 1
Entry 2
Entry n
Service proxy
Service database in LUS

Jini Programming Example

- How is a service implemented?
- How does a client get access to a service?
- How is a service described?

The "Running Example"



The "Running Example"

- Printer registers itself with the office's lookup service
- Printer provides print interface as its service

```
public interface Print extends java.rmi.Remote {
     public PrinterParams readPrinterParams()
            throws java.rmi.RemoteException;
     public SuccessCode print(Document doc)
            throws java.rmi.RemoteException;
     [...etc...]
}
```

The "Running Example"

- Implementation of service consists of provider and proxy
- Proxy is stored in the lookup service and will be transferred to clients upon request
- Protocol between proxy and service provider depends on implementation and is not stipulated by Jini
- Example uses RMI

Implementing Service Provider

```
public class PrintImpl extends
    UnicastRemoteObject implements Print {
[...]
  public PrinterParams readPrinterParams()
      throws RemoteException {
      // something should be d
  }
  public SuccessCode print(Do
      throws RemoteException {
      // something else should be done here
  }
[...]
}
```

There's no Jini in here!

Registering a Service

```
public class PrintRegistration {
 public static void main(String[] args) {
   System.setSecurityManager(
          new RMISecurityManager());
[...]
  Print service = new PrintImpl();
  Entry[] attribute = new Entry[1];
  attribute[0] = new ServiceInfo(
                 "Print Service",
                 "HyperClear", "Shiny Inc.",
                 "2000", "", "08/15");
  JoinManager jmgr = new JoinManager(service,
         attribute,
         (ServiceIDListener) new Listener(),
         new LeaseRenewalManager());
[...]
}}
```

Multicast Discovery Client

```
public class MCExample implements
DiscoveryListener {
 public static void main(String[] args) {
[...Security Manager etc...]
  LookupDiscovery ld =
  new LookupDiscovery(LookupDiscovery.ALL_GROUPS);
  ld.addDiscoveryListener(new MCExample());
[...]
 }
 public void discovered(DiscoveryEvent ev) {
   ServiceRegistrar[] regs = ev.getRegistrars();
   ServiceRegistrar reg = regs[0];
   Class[] cl = new Class[] { Print.class };
   ServiceTemplate tmpl =
         new ServiceTemplate(null, cl, null);
   Print proxy = (Print) reg.lookup(tmpl);
 }
 public void discarded(DiscoveryEvent e) {}
}
```

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Discovery

- Protocols to find lookup services
- Multicast request protocol
  - client asks for local lookup services
  - no prior knowledge of local network necessary
- Unicast request protocol
  - used to contact known lookup services
  - works across subnet boundaries and over the Internet

Discovery

- Multicast announcement protocol
  - protocol for lookup services to announce their presence
- Example: printer registers with the office via multicast, but gets service for software updates from a dedicated lookup server via unicast discovery

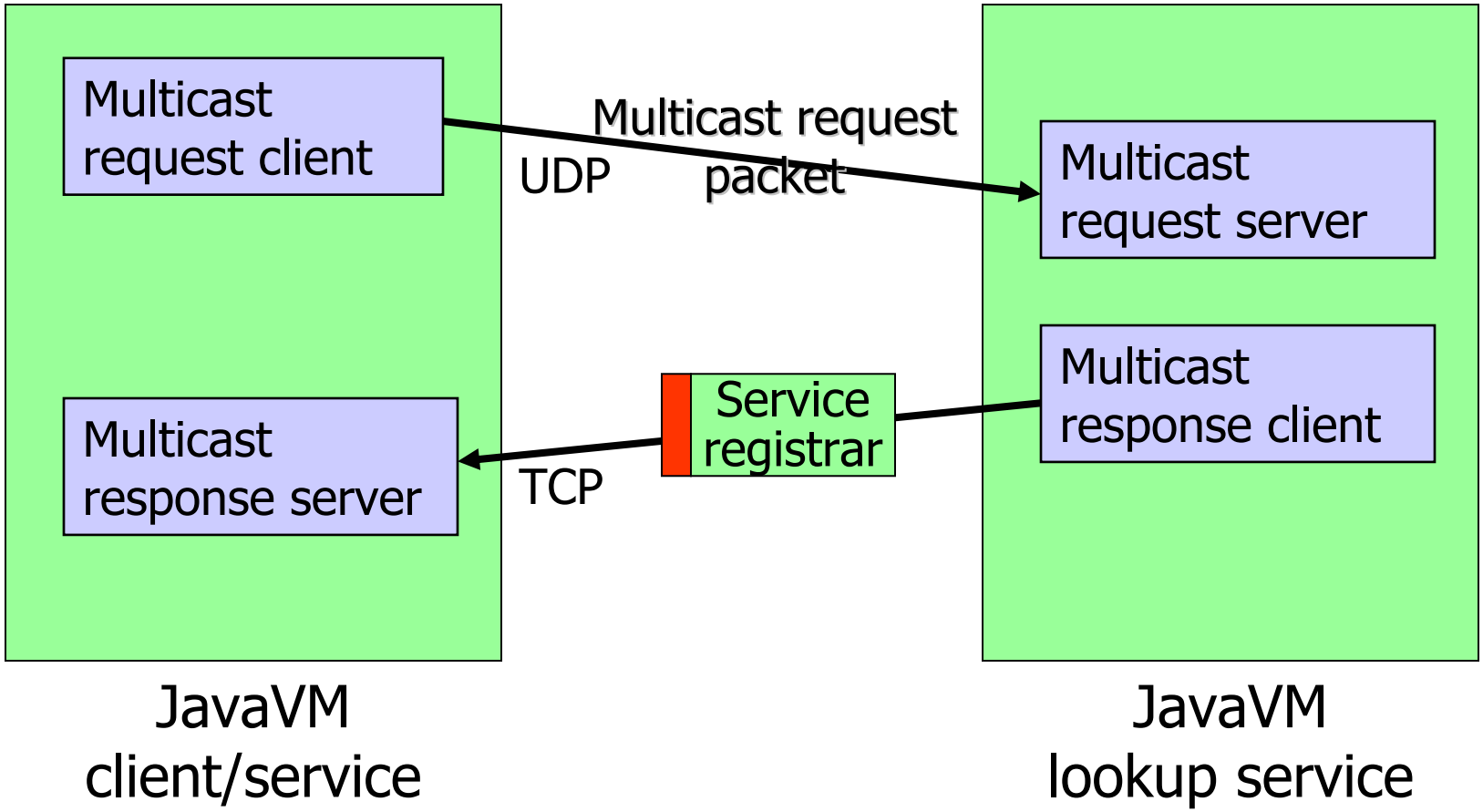
Multicast Request Protocol

- No information about the host network needed
- Active search for lookup services
- Discovery request is multicast packet
  - IP-centric
  - multicast address for discovery is 224.0.1.85
  - default port number of lookup services is 4160
    - hexadecimal subtraction: $CAFE_{16}$-$BABE_{16}$=4160_{10}

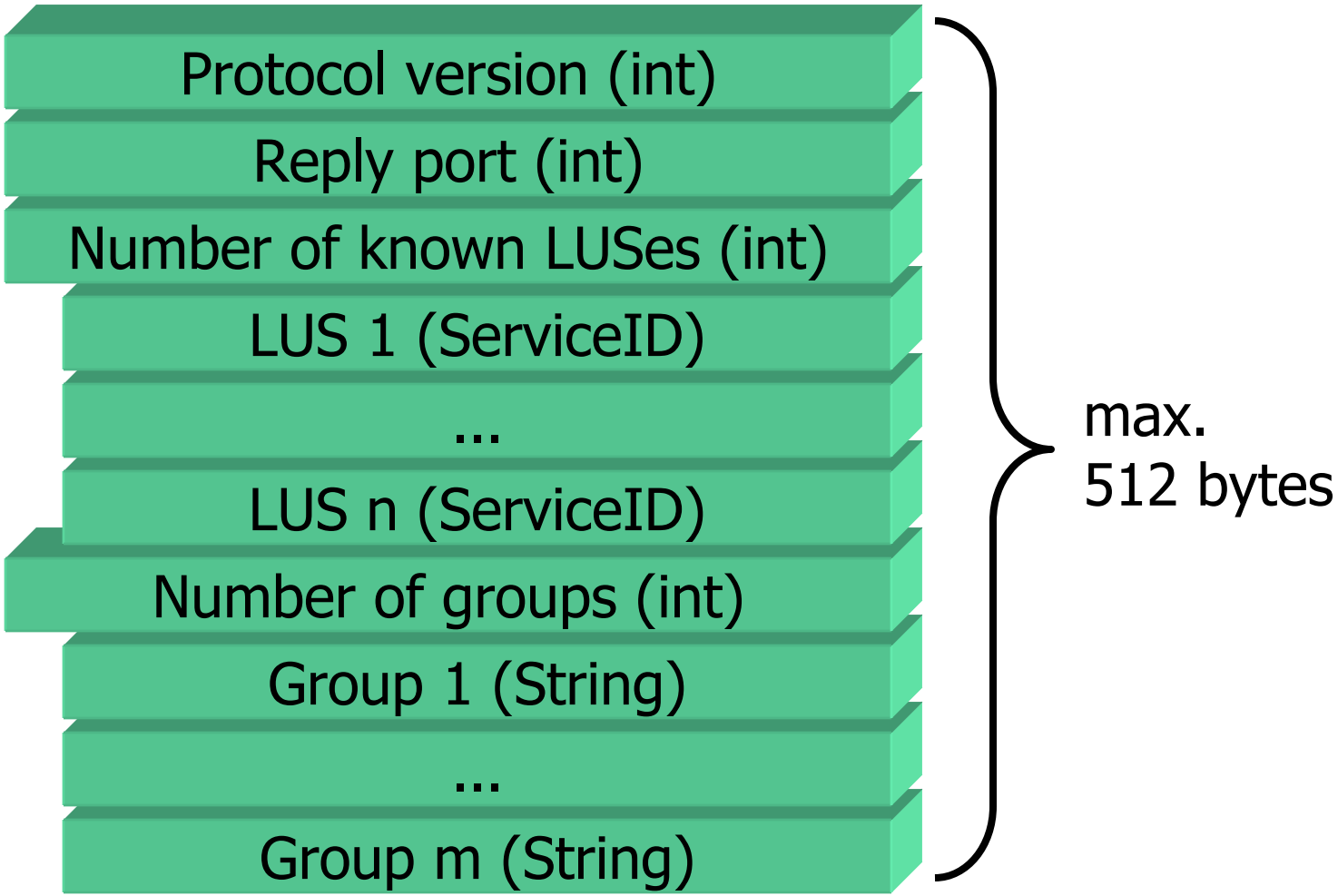
Multicast Request Protocol

- Discovery request is multicast packet
  - recommended time-to-live is 15
  - usually does not cross subnet boundaries
- Discovery reply is establishment of a TCP connection
  - port for reply is included in multicast request packet

Multicast Request Protocol

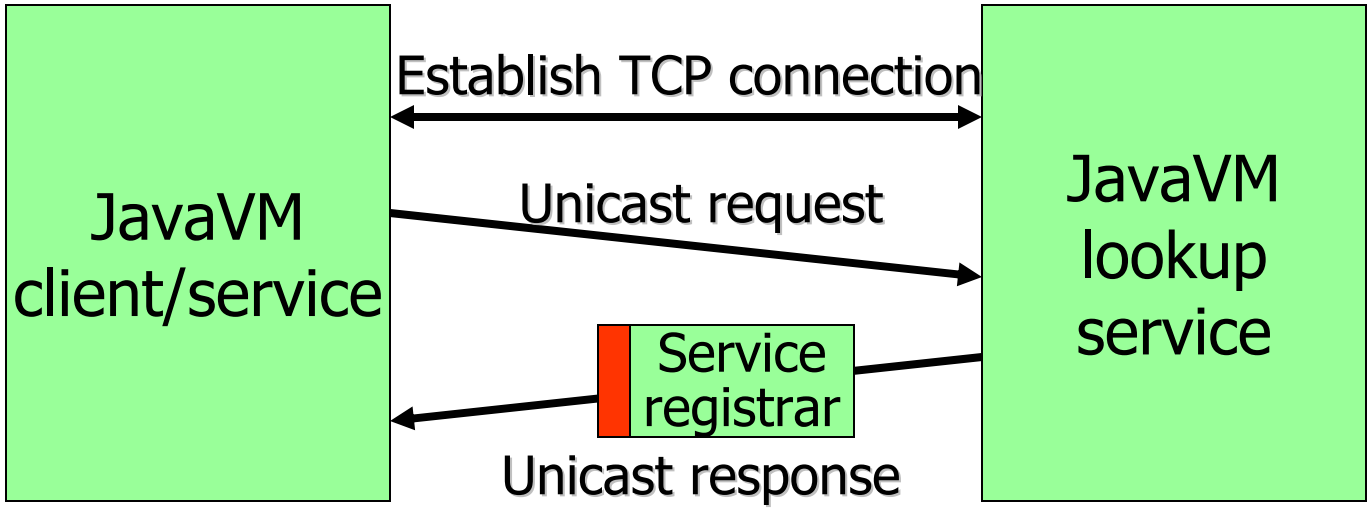


Multicast Request Packet



Unicast Discovery Protocol

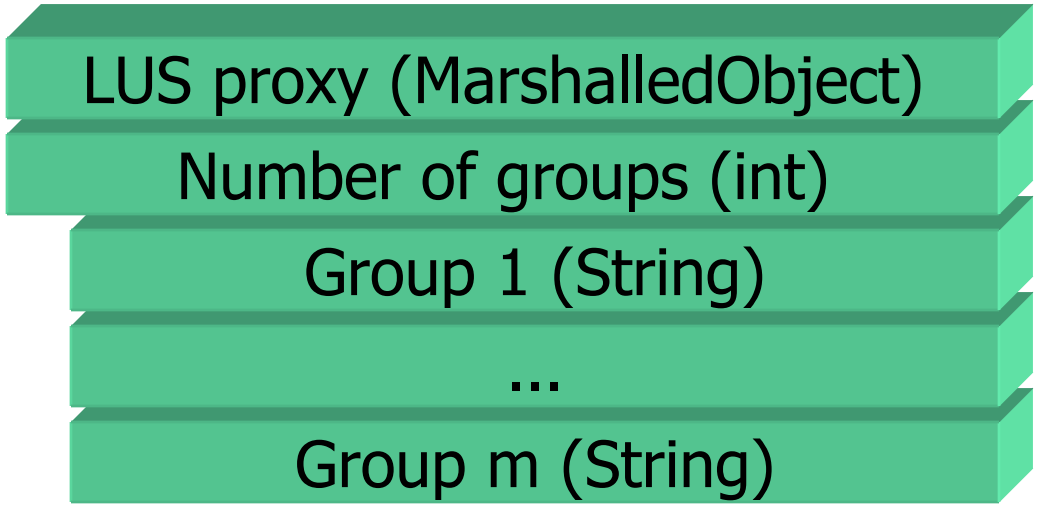
- Used to contact lookup services with known locations
- Uses TCP (unicast) connections to port 4160
- Simple request-response protocol



Unicast Packets

- Unicast Request (client → lookup service)

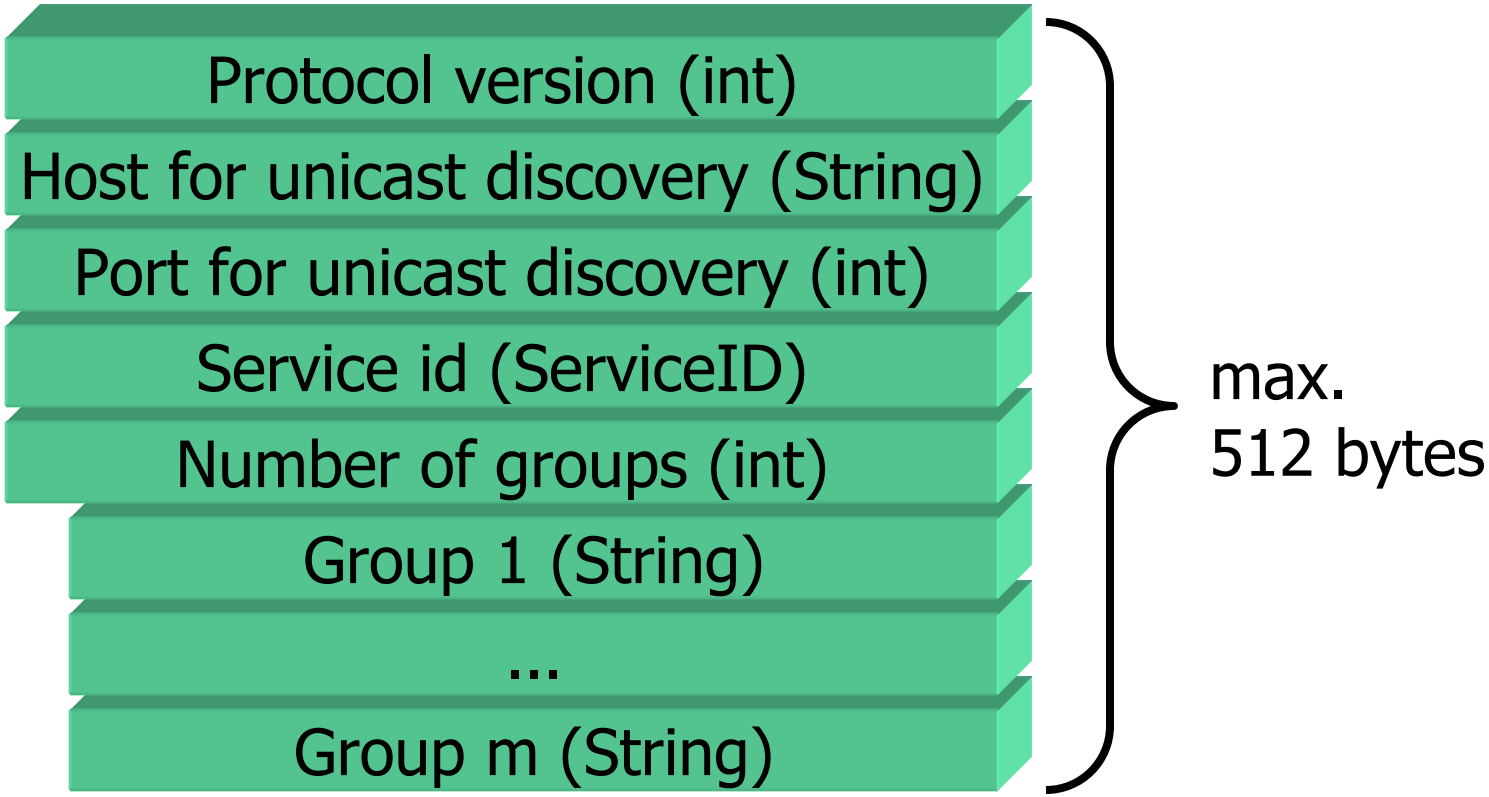
- Unicast Response (lookup service → client)



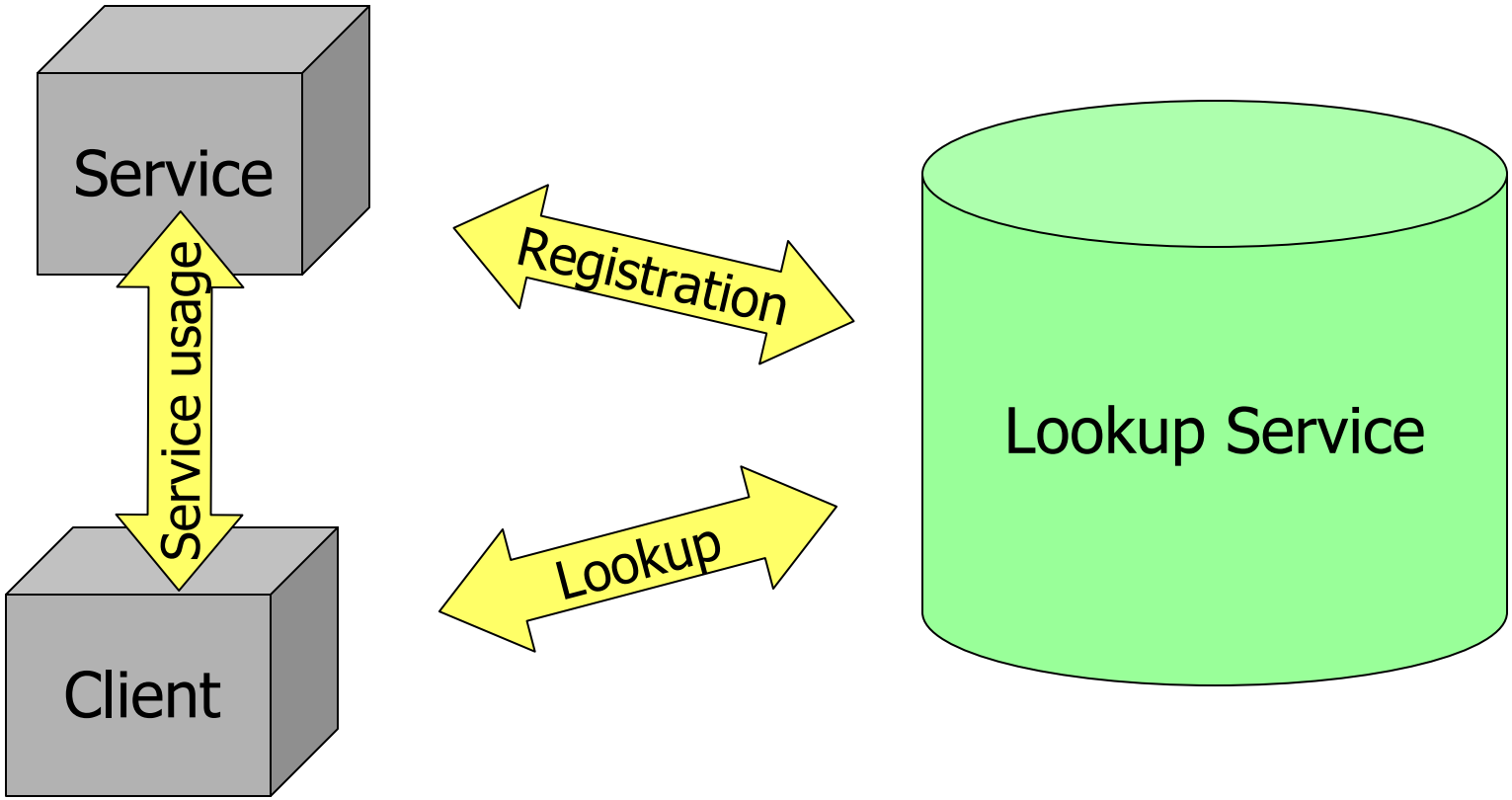
Multicast Announcement Protocol

- Used by lookup services
- Announces the availability of lookup services
- Based on multicast UDP
- Announcements are sent periodically
  - recommended: every 120 seconds
- Receivers listen for announcements on well-known port
- If not yet known, receiver starts unicast discovery of this service

Multicast Announcement Packet



Lookup Service Details



Groups

- There may be lots of lookup services in a large Jini system
- Idea: split lookup services into groups
  - group name: simple text identifier
  - clients/services always announce interest in certain group(s)
  - unwanted groups are ignored
  - services do not explicitly register for certain groups, rather with LUS that carries group
- e.g. one lookup service per department: accounting, production, research, ...

LUS: Proxy Interface

Used by service providers

```
pub          ce ServiceRegistrar {
  publi  ServiceRegistration
        register(ServiceItem item,
                 long leaseDuration)
        throws RemoteException;
  public java.lang.Object
        lookup(ServiceTemplate tmpl)
        throws RemoteException;
  public ServiceMatches
        lookup(ServiceTemplate tmpl,
               int maxMatches)
        th   ws RemoteException;
  [...
}
```

Used by clients

Join: More Features

- To join, a service supplies:

```
ServiceItem(Object service,
            ServiceID id,
            Entry[] attributes)
```

  - its proxy
  - its ServiceID (if previously assigned; “universally unique identifier”)
  - set of attributes
  - set of groups (or ALL_GROUPS)
  - (possibly empty) set of specific lookup services to join

Join: Service IDs

- To join, a service supplies:

```
ServiceItem(Object service,
            ServiceID id,
            Entry[] attributes)
```

- Service-ID is a 128 bit “universally unique identifier”
  - generated by the lookup service when registering for the first time
  - service has to reuse it for all later registrations
  - service has to make it persistent

Join: More Features

- Service waits a random amount of time after start-up
  - prevents packet storm after restarting a network segment
- Registration with a lookup service is bound to a lease
  - service has to renew its lease periodically
- Discovery and join can be handled by objects of class `JoinManager`

Lookup: More Features

- Client looks for service(s) registered with a lookup service
- Any combination of search criteria possible:
  - ServiceID
  - service type
  - certain attributes

Lookup: More Features

- Client creates `ServiceTemplate`

```
ServiceTemplate(ServiceID serviceID,
   java.lang.Class[] serviceTypes,
   Entry[] attrSetTemplates)
```

- Template filled with interfaces, entries and/or ServiceID
- Wildcards possible, represented by `null`
- Attributes: only exact matching possible (no “larger-than”, ..)
- No query language

Entries

- Difference to “traditional” naming services
- Not only a name for a service
- Properties:
  - set of attributes
    - e.g.: PrinterParams (dpi: 600, type: color, …)
  - every serializable data type is possible
  - data <u>and</u> methods
  - complex classes possible
    - e.g. different user interfaces (AWT, Swing, speech, ...)

Entries (Examples)

```
public class Name extends
AbstractEntry {
   public String name;
   public Name() {}
   public Name(String name) {
       this.name = name;
   }
}
```

```
public class AWTGUIEntry extends
AbstractEntry {
   public Panel panel;
         [...]
   public GUIEntry() {}
   public GUIEntry(Panel panel) {
       this.panel = panel;
         [...]
   }
}
```

```
public class PrinterEntry extends
AbstractEntry {
   public PrinterType type;
   public Integer pagesPerSecond;
         [...]
   public PrinterEntry() {}
   public PrinterEntry(PT type) {
       this.type = type;
         [...]
   }
}
```

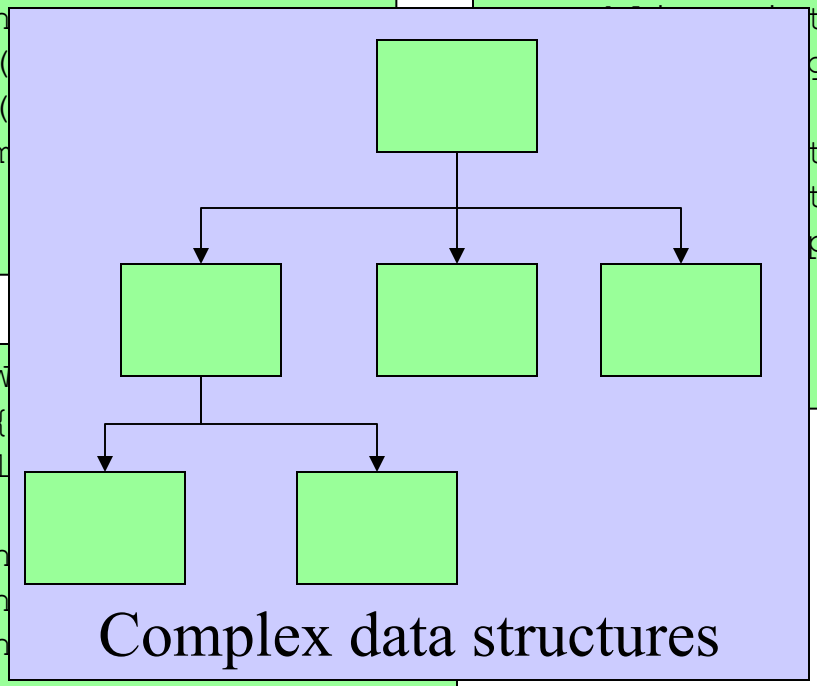
Entries (Examples)

```
public class Name extends
AbstractEntry {
    public Strin
    public Name(
    public Name(
        this.nam
    }
}
```

```
public class PrinterEntry extends
AbstractEntry {
    terType type;
    ger pagesPerSecond;

    terEntry() {}
    terEntry(PT type) {
    pe = type;
```

```
public class AW
AbstractEntry {
    public Panel
        [...]
    public GUIEn
    public GUIEn
        this.pan
        [...]
    }
}
```



Lookup Service vs. Naming Service

Naming service	Lookup service
Description by name (text) only • e.g. /devices/printers/ → printers • search by name only	Description by `ServiceItem`s • type & attributes • arbitrary search dimensions
Name implies type	Type is explicit
Standardized naming conventions	Standardized interfaces
Usually no expiration of entries (heartbeat, keep-alive)	Services have to renew their entries in the lookup service periodically (leasing)
Identified by (static) address; clients need to know address	Discovery; no network information necessary
groups can be modeled by addresses	group concept

Proxy: Features

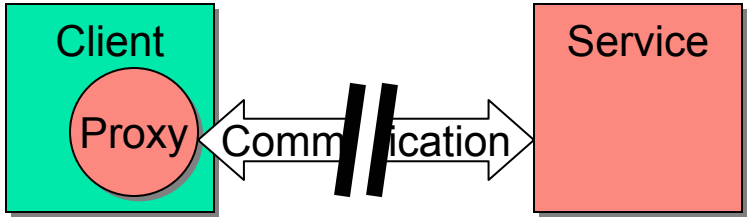
- All communication between clients and services is handled by service's proxy
- Proxy object is stored in the lookup service upon registration
- Serialized object
- Implements one or more service interfaces
- Service type is defined by the type of the interface(s)

Proxy: Features

- Upon request, stored object is sent to the client as a local proxy of the service
- If needed, client retrieves necessary classes
  - class location is stored in codebase (URL)
- Client communicates with service provider via service proxy: client invokes methods of the proxy object
- Client only needs to know interface
- Proxy implementation hidden from client

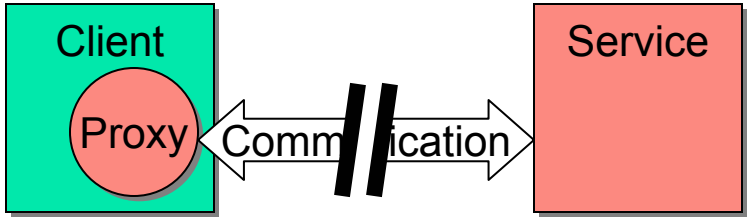
Proxy: Implementation

- Implementation of service functionality is independent from service interface
- Partition of service functionality depends on service implementer's choice
- Parts of or whole functionality may be executed by the client (within the proxy)



Proxy: Implementation

- When dealing with large volumes of data, it usually makes sense to preprocess parts of or all the data
  - e.g.: compressing video data before transfer



Jini 1.1

- More classes belong to standard Jini (i.e. `net.jini.*`), e.g. JoinManager
- Helper classes
  - JoinManager, LeaseRenewalManager
  - Discovery utilities, protocol utilities
  - ServiceDiscoveryManager & LookupCache
- Helper services
  - LookupDiscoveryService
  - EventMailbox
  - LeaseRenewalService

ServiceDiscoveryManager

- Eases handling of multiple lookup services
- Supports different access patterns: on-demand, cached, reactive
- LookupCache
  - states of LUSes are mirrored: increased communication and memory use
  - immediate access to available services
  - usefulness depends on usage scenario, especially useful for frequent and low-latency queries

LookupCache Example

```
public class LCExample {
 public static void main(String[] args) {
  System.setSecurityManager(
           new RMISecurityManager());
[...]
  ServiceDiscoveryManager sdm =
      new ServiceDiscoveryManager(null, null);
  Class[] cl = new Class[] { Print.class };
  ServiceTemplate tmpl =
      new ServiceTemplate(null, cl, null);
  LookupCache cache =
      sdm.createLookupCache(tmpl, null, null);
[...]
  Print proxy = (Print) cache.lookup(null);
[...]
 }
}
```

Groups, locators, ...

Lease renewal manager

Item Filter

Listener

Item Filter

Overview

- Jini, what's that?
  - motivation
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- RMI/Serialization
- Jini infrastructure
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  - discovery & join protocols
  - programming example
  - more details
- Jini programming model
  - leasing
  - distributed events
- Jini services
  - transactions
  - JavaSpaces
- Summary

Leases

- Lease is contract between two parties
- Leases introduce notion of time
  - resource usage is restricted to a certain time frame
  - interaction is modeled by repeatedly expressing interest in some resource:
    - I'm still interested in X
      - renew lease periodically
      - lease renewal can be denied
    - I don't need X anymore
      - cancel lease or let it expire
      - lease grantor can use X for something else

Leases

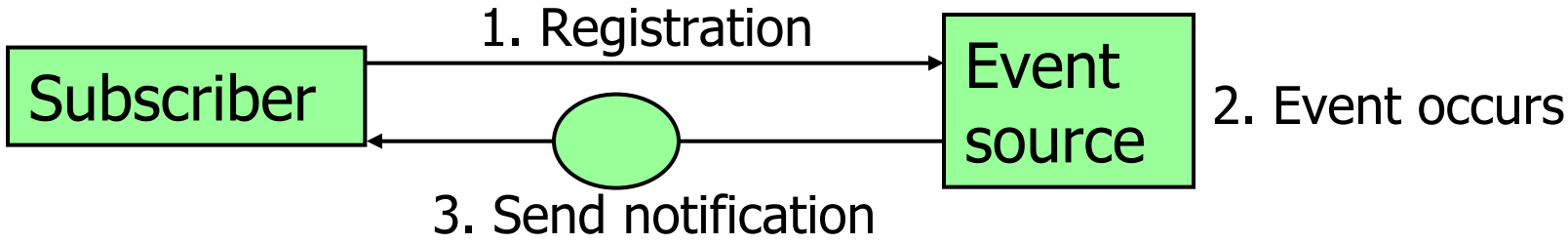
- Lease is a contract between two parties
- Lease grantor is willing to let lease taker (client) access a certain resource for a certain amount of time
- Lease can be extended (renewed) if resource access is still desired
  - extension can be denied by grantor
- Resource is released upon lease expiration or cancellation (by client)

What To Use Leases For?

- For allocating hardware and software resources intelligently
  - no administration necessary (for removal of stale resource reservations)
  - e.g. persistent storage, ...
- Distributed “garbage collection”
  - lease expired → “garbage”
- Inside Jini
  - registrations with lookup services
  - resources: transactions, event registrations

Distributed Events

- Objects in a JVM can register interest in certain events of another object in a different (remote) JVM
  - network failure
  - crossing of event notifications
  - late and lost messages
- “publisher/subscriber” model
- Architecture:

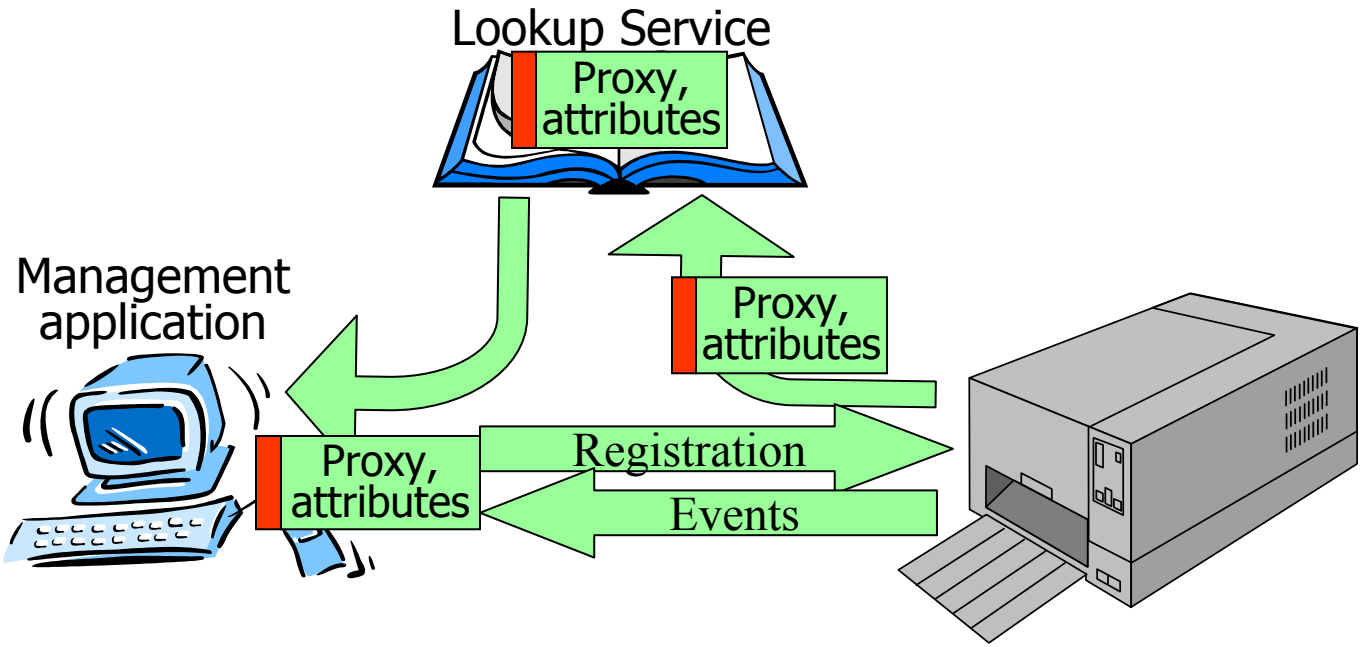


Distributed Events

- Delivery separated from event semantics
- Different delivery behaviors desired by applications, e.g. guaranteed, in-order,…
- Interfaces do not reflect particular delivery behavior
- Event mechanism can be extended to accommodate different application semantics

Distributed Events (Example)

- Management application wants to know about printers running out of paper
- Gets printer's proxy object from lookup service and registers for notifications



Distributed Events (Example)

- Printer could implement the interface:

Type of event to be notified about (e.g. out of paper).

"handback" is returned to the notified object in every notification. Used to attach arbitrary information to events.

```
public interface PrinterEvents
      extends Remote {
  public EventRegistration regist (
          long eventID,
          MarshalledObject handback,
          RemoteEventListener toInform,
          long leaseLength)
     throws RemoteException;
}
```

Registrations are leased.

Reference to the object to be notified.

Distributed Events (Example)

- Management application (or dedicated listener object) implements interface **`RemoteEventListener`**

```
public interface RemoteEventListener
extends Remote, java.util.EventListener
{
  void notify(RemoteEvent theEvent)
    throws UnknownEventException,
           RemoteException;
}
```

- Method `notify()` will be called for every event

Distributed Events (Example)

- Printer informs clients about events by sending `RemoteEvent`s

```
toInform.notify(new RemoteEvent(
    this, eventID, seqNum, handback));
```

Recipient | Event source | Event type | Sequence number | Handback

- Event is unambiguously identified by tuple <source, id, sequenceNumber>
- Notification is synchronous
  - allows event source to know that event was delivered

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Transactions

- Transactions encapsulate a number of operations
  - “all or nothing” semantics
  - operations appear to happen simultaneously (from outside transaction)
  - method to ensure consistency
- Two-phase commit protocol
  - method to perform transactions
  - Two phases:
    - vote on transaction validity
    - commit/abort operations

Transactions

- Central: a manager
  - ensures consistency: each transaction participant will ultimately “commit” or “abort”
  - performs 2PC protocol
- Example: transfer money from one bank account to another

Transactions: Properties

- Design goal: maximum flexibility, minimum number of interfaces
- Objects must implement certain interface to participate in transactions
- Traditionally transaction manager enforces certain semantics (ACID properties)
- Jini separates protocol from semantics:
  - 2PC performed by manager
  - semantics implemented by participants

Distributed Transactions in Jini...

- …are no transactions in a traditional (database) sense
- “Lightweight” transaction
- ACID properties
  - atomicity / consistency / isolation / durability
  - each participant implements these properties as he sees fit
    - e.g.: transient objects do not need persistency
  - main property is atomicity, other properties are “sometimes” optional
- Transactions are leased from manager

Transactions: Participants

- Transaction manager
  - coordinates transaction
  - Jini service
  - implements interface `TransactionManager`
- Clients
  - initiate transactions
- Transaction participants
  - objects that perform transactional operations
  - implement interface `TransactionParticipant`
  - participation is initiated by `join` operation

Transactions: Semantic Objects

- Transactions have no fixed semantics
- Participants need to know the type of a transaction ➔ “semantic objects”
  - Java type defines the kind of transaction
  - class `Transaction` tells objects to use their standard transaction semantics
- Participants accept only certain transaction types
- e.g. DBTransaction
  - requires database semantics
  - transient objects not allowed (durability)

2PC Protocol: Details

- Client starts a transaction
  - get transaction manager from lookup service (lookup `TransactionManager`)
  - call to `create()` starts transaction
    - usually indirectly via semantic object factory
- Participation in a transaction
  - participants find out about transaction upon function invocation
    - receive `Transaction` object
    - call transaction manager's `join()` method
  - implement `TransactionParticipant`

2PC Protocol: Details

- Client starts a transaction

```
public interface TransactionManager {
  TransactionManager.Created create(...);
  void commit(...)
  void abort(...)
  void join(...)
  int getState(...)
}
```

er)

ory

- Participation in a transaction

```
public interface TransactionParticipant {
  void commit(TransactionManager mgr, long id)
  void abort(TransactionManager mgr, long id)
  int prepare(TransactionManager mgr, long id)
  int prepareAndCommit(TransactionManager mgr, long id)
}
```

  - implement `TransactionParticipant`

JavaSpaces

- Tool for developing distributed applications
- Platform for exchanging objects between distributed applications (“shared blackboard”)
- “Bag full of objects”
- Realizes distributed persistency
- Jini service
  - implemented completely in Java (and RMI)
  - interaction with service via local proxy

What To Use JavaSpaces For?

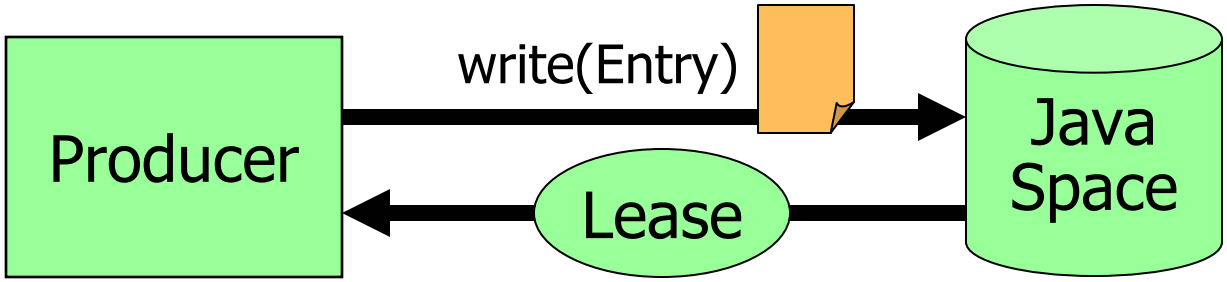
- Models “object flow”
  - e.g. producer / consumer applications
  - load-balancing
- Job-oriented view
  - jobs / events are put into the space and picked up “eventually”, e.g. workflow
- Build-in “good” properties
  - concurrent access possible
  - write / read are atomic operations
  - access within transaction possible

JavaSpaces: Objects

- JavaSpace = “a bag full of objects”
- Entries in a JavaSpace service:
  - `net.jini.core.entry.Entry` – known as `Entry` interface in Jini
  - strongly typed by Java type system
  - two entries of different classes are not equal, even if they encapsulate the same data types
    - Entry A {Integer, Char} ≠ Entry B {Integer, Char}
- Classes: include data/state and methods → behavior

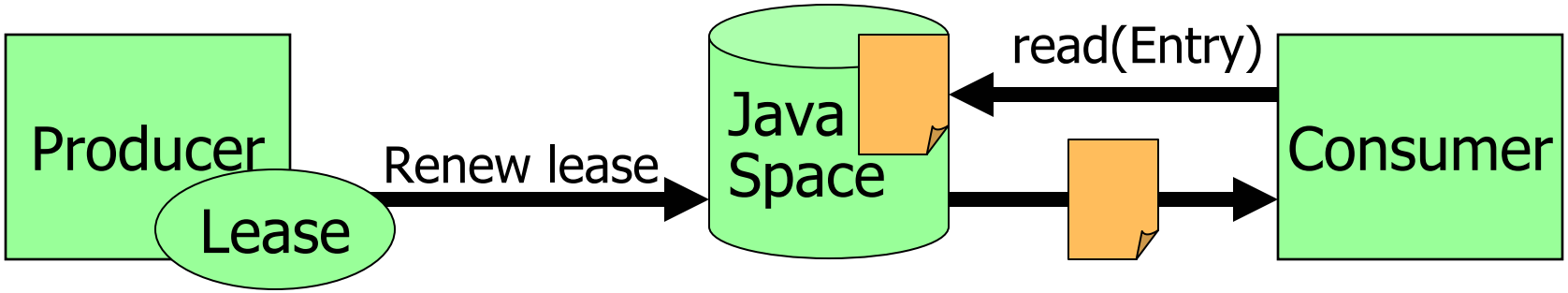
Basic Operations: Write

- `write` puts an entry into a JavaSpace
- Uses copy of the object, never the object itself
- `write` returns a lease
  - entry in a JavaSpace has a limited duration
  - “garbage collection” in a JavaSpace service



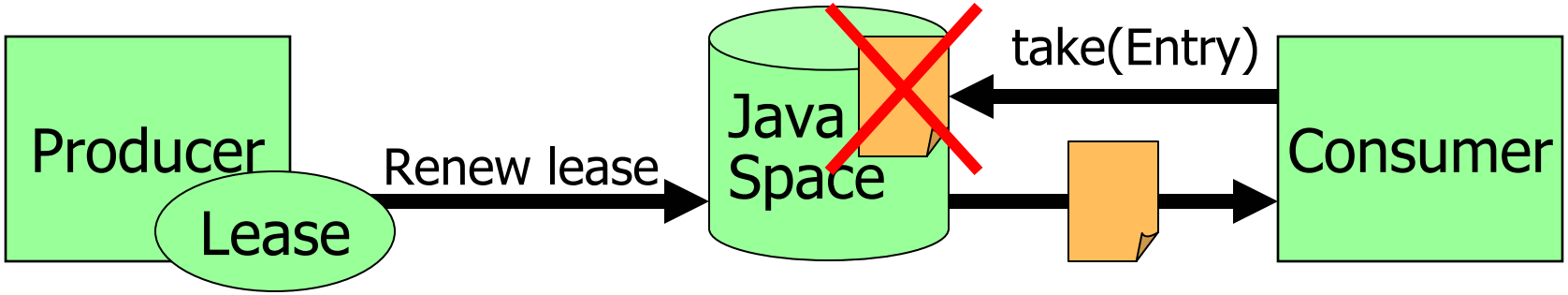
Basic Operations: Read

- uses template (`Entry`)
  - exact value match
  - matches subclasses as well
  - `null` matches everything
  - if more than one match, select and return one entry at random



Basic Operations: Read

- `readIfExists` returns `null` if no match found
  - `read` waits until matching entry was found
- `take/takeIfExists` = `read` + removal of entry



Basic Operations: Notify

- Notify listeners at arrival of certain entries
- Uses Jini distributed events
- Clients can register with a JavaSpace
  - registration requires a “matching template”
  - clients implement `RemoteEventListener`
  - registration is leased
- Order of notification unspecified
  - Note: “first come, first serve” for registered listeners on take

Peculiarities

- Operations can be part of a transaction
- Entries can be “lost”:
  - write/take may cause a RemoteException
  - meaning: “may or may not have been successful”
    - write: often unproblematic (may be repeated)
    - take: entries may be lost
    - transactions necessary
  - example: moving entries between JavaSpaces (e.g. for load balancing)
    - transactions required

JavaSpaces and Linda

- Design based on Linda tuple spaces
  - David Gelernter (Yale University)
- Differences:
  - strong type checking and objects (methods/behavior)
    - matching on tuple structure, not just data
    - templates match subclasses as well
    - all (serializable) data types can be used as data
  - multiple spaces possible
  - leasing
  - no “eval” – a JavaSpace is just a repository

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Summary

- Vision:
  - everything will be networked
  - everything will (be able to) communicate
  - ubiquitous network access
  - mobility/spontaneity as important paradigms
- Problems:
  - getting to know the network neighborhood
  - infrastructure should adapt to devices, not the other way round
  - distribution: communication, partial failure,...
- Possible solution: Jini

Conclusion

- A number of good ideas
  - simplicity,“less is more” → flexibility
  - discovery, join, lookup
  - extension of name services by attributes
  - leases, events, transactions → recurring design patterns
- Right direction
  - ubiquitous networks
  - mobility, spontaneity
- Individual concepts are not new, but together they offer new possibilities

But...

- Resource usage
  - each service usually requires a JVM
- Small devices
  - JVM and RMI required on device
  - adaptation to resource-restricted environment necessary (how?)
  - proxy objects are moved to client (memory)
- Standardized (base) interfaces
- What about the competitors (SLP, UPnP, e-speak, ...)?

Problem Areas

- Security
  - important in dynamic environments
  - user requires
    - confidentiality: encrypted communication
    - trust: authentication
  - services might use other services on behalf of the user
  - what about charging for services?
  - Java RMI security extension does not seem to be the solution
- Scalability
  - does Jini scale to a global level?

Suggested Reading

- Jini Homepage:
  `http://www.sun.com/jini`
- Jini Community:
  `http://www.jini.org`

- W. Keith Edwards: **Core Jini**, Prentice Hall, 1999
  - good motivation, very detailed
  - don’t be frightened by more than 700 pages (everything is said at least twice...)

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