Network Applications: DNS; Socket Programming

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http://zoo.cs.yale.edu/classes/cs433/

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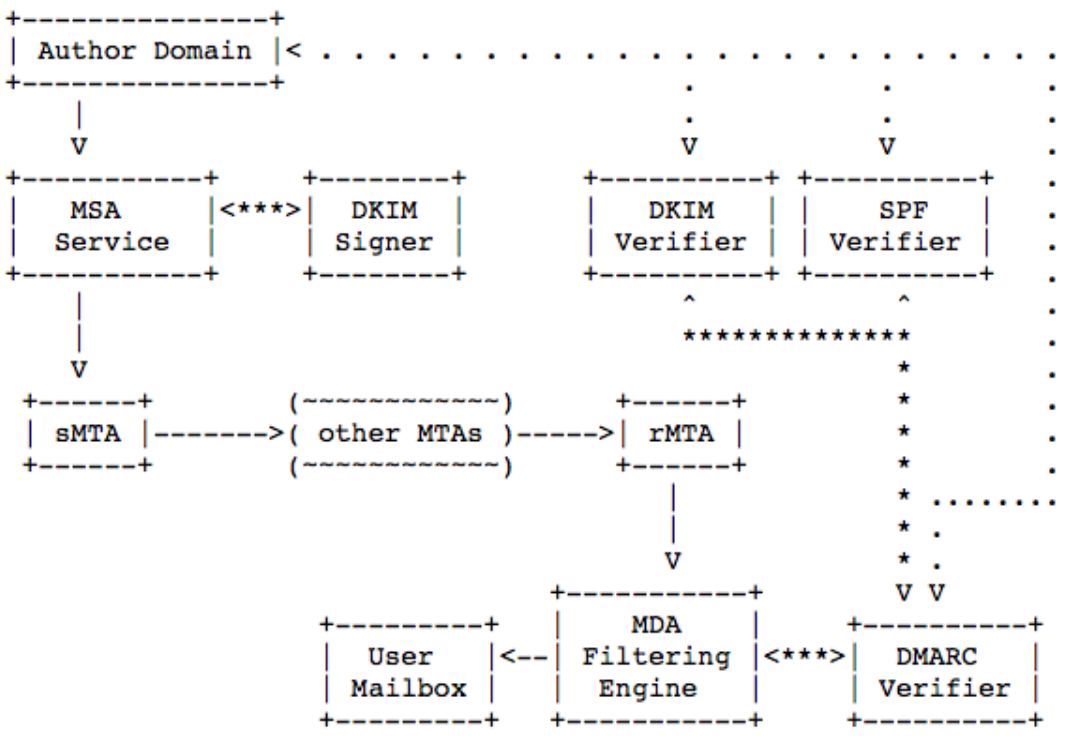
Admin

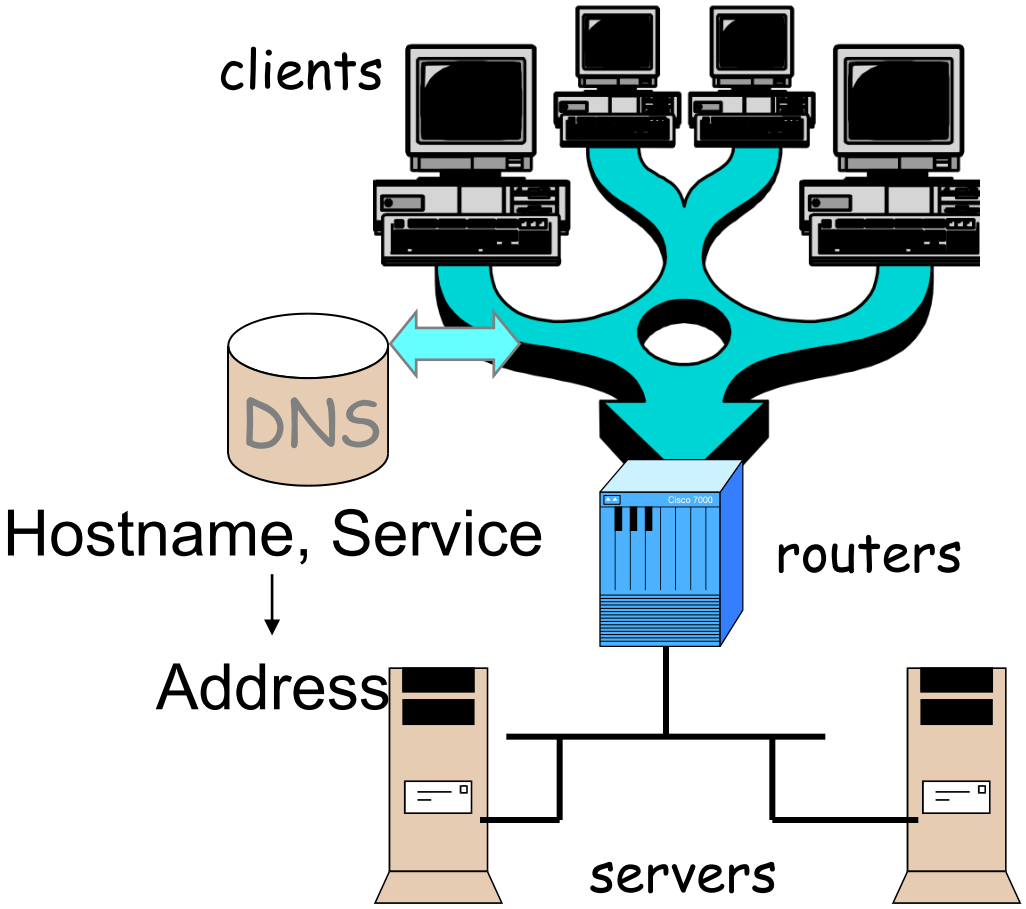
- Assignment Two to be linked on the Schedule page
- Pace slow down?

Recap: Domain-based Message Authentication, Reporting, and Conformance (DMARC) [RFC7489]

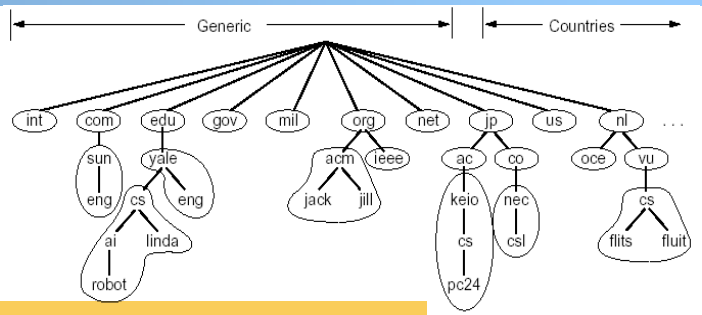


Recap: Domain Name System (DNS)

- Function
  - map between (domain name, service) to value, e.g.,
    - (www.cs.yale.edu, Addr) -> 128.36.229.30
    - (cs.yale.edu, Email) -> netra.cs.yale.edu



Summary: DNS Design Features



- Hierarchical name space and hierarchical delegation avoids administrative bottleneck/ central control, improving manageability and scalability
- Multiple domain servers improve scalability/robustness
- Native caching (control) reduces workload and improves robustness
- Flexible recursive and iterative query allows structure such as local resolver to simplify client and enable caching
- Using UDP to reduce overhead but also support TCP using the same format
- Same query and response format can make simplify basically servers
- Domain name encoding compression reduces query/response overhead
- Proactive answers of anticipated queries (server push) reduce # queries on server and latency on client

Today: approximately 1.3 million authoritative name servers listed in the .COM, .NET and .ORG zone files.

Grown from a few thousand entries to over 100 million entries. – That's scaling!

Many Other Uses of DNS

- DNSBL (black list) or RBL (realtime)
  - Spec: https://tools.ietf.org/html/rfc5782
  - See changes: https://www.spamhaus.org/sbl/latest/
  - Query dig <reverse>.zen.spamhaus.org
    - https://www.spamhaus.org/zen/

Problems/Remaining Issues of DNS

- Security of DNS itself
- Limited extensibility
  - limited query model
  - Mixed, limited query cmd and query type
    - See https://www.iana.org/assignments/dns-parameters/dns-parameters.xhtml#dns-parameters-4
- Largely a read data store, although theoretically you can update the values of the records, it is rarely enabled
- Each local domain needs servers, but an ad hoc domain may not have a DNS server

Outline

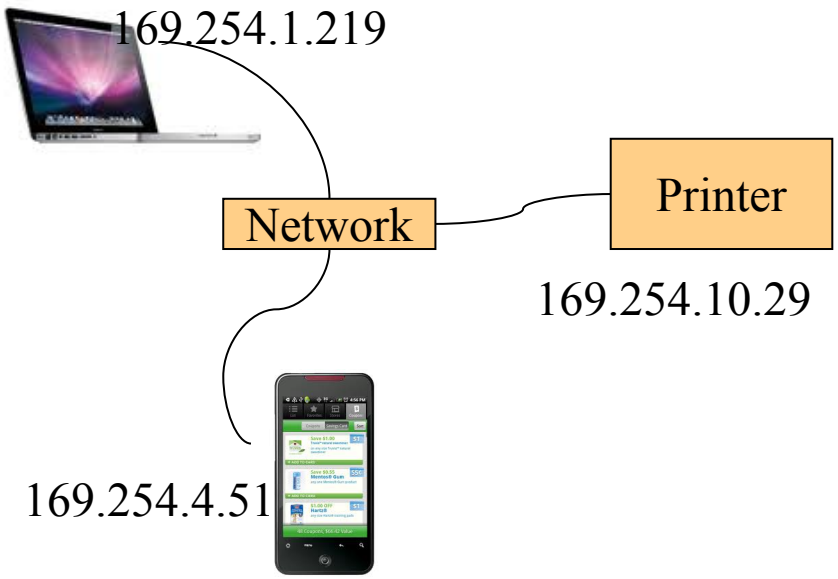
- Admin and recap
- DNS
  - Interface
  - Architecture design
  - Message design
  - Extensions/alternatives
    - service discovery

Context

- What do we need to extend standard DNS to support service discovery, say to implement Bonjour-type service discovery (discover local printers, local appletv, file-share…)?

DNS-Service Discovery Component: Multicast DNS [RFC6762]

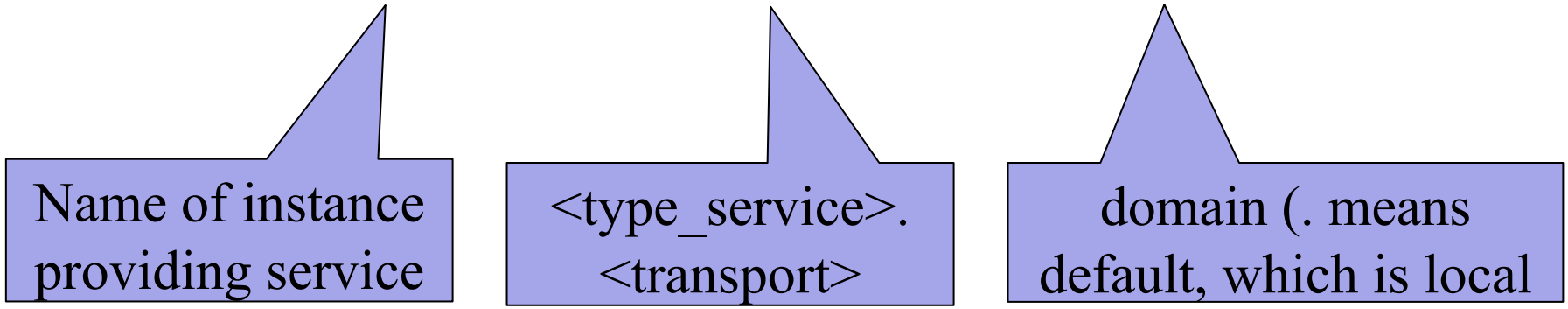
- Utilize IP multicast (broadcast medium)
  - link-local addressing
    - send to multicast address: 224.0.0.251 (address as a group name, and any host can specify that it joins the group)
- Implication:
  - each node (host) can become a responder
  - each node (host) can use multicast to announce (write) its values



DNS-Service Discovery Component: DNS-based Service Discovery [RFC6763]

- Avoid continuous adding to DNS Resource Record Type, use
  - ptr as as the only type
  - introduce an extensible service naming convention (service in name)

```
"My Test" _printer._tcp dns-sd.org.
```

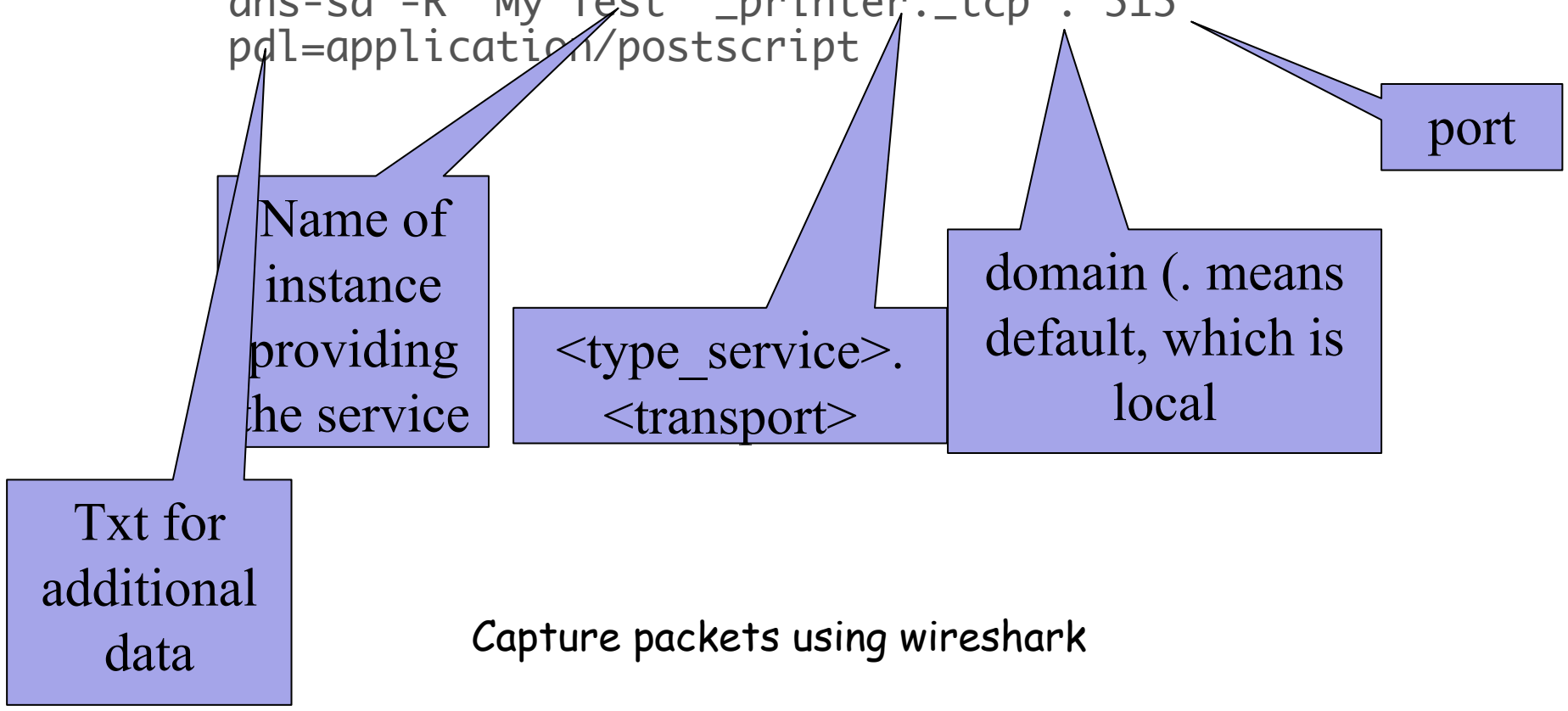


- Example: dig _http._tcp.dns-sd.org. ptr

DNS-SD Local Service Discovery

- Use the dns-sd command on Mac as example
  - Advertise (register) an LPR printer on port 515

```
dns-sd -R "My Test" _printer._tcp . 515
pdl=application/postscript
```



Capture packets using wireshark

24	15.749230	172.27.21.251	224.0.0.251	MDNS	232	Standard query response 0x0000 PTR, cache flush Ys-MacBook-Pro.local PTR, cache flush Ys-MacBook-Pro.local NSEC, ca…
25	15.750136	fe80::1c99:22de:9a…	ff02::fb	MDNS	252	Standard query response 0x0000 PTR, cache flush Ys-MacBook-Pro.local PTR, cache flush Ys-MacBook-Pro.local NSEC, ca…
26	15.946407	172.27.21.251	224.0.0.251	MDNS	172	Standard query 0x0000 ANY My Test._printer._tcp.local, "QU" question ANY Ys-MacBook-Pro.local, "QU" question SRV 0 …
27	15.946465	fe80::1c99:22de:9a…	ff02::fb	MDNS	192	Standard query 0x0000 ANY My Test._printer._tcp.local, "QU" question ANY Ys-MacBook-Pro.local, "QU" question SRV 0 …
28	16.197838	172.27.21.251	224.0.0.251	MDNS	172	Standard query 0x0000 ANY My Test._printer._tcp.local, "QM" question ANY Ys-MacBook-Pro.local, "QM" question SRV 0 …
29	16.197896	fe80::1c99:22de:9a…	ff02::fb	MDNS	192	Standard query 0x0000 ANY My Test._printer._tcp.local, "QM" question ANY Ys-MacBook-Pro.local, "QM" question SRV 0 …
30	16.450462	172.27.21.251	224.0.0.251	MDNS	172	Standard query 0x0000 ANY My Test._printer._tcp.local, "QM" question ANY Ys-MacBook-Pro.local, "QM" question SRV 0 …
31	16.450508	fe80::1c99:22de:9a…	ff02::fb	MDNS	192	Standard query 0x0000 ANY My Test._printer._tcp.local, "QM" question ANY Ys-MacBook-Pro.local, "QM" question SRV 0 …
32	16.700950	172.27.21.251	224.0.0.251	MDNS	291	Standard query response 0x0000 TXT, cache flush PTR _printer._tcp.local PTR My Test._printer._tcp.local SRV, cache …
33	16.700998	fe80::1c99:22de:9a…	ff02::fb	MDNS	311	Standard query response 0x0000 TXT, cache flush PTR _printer._tcp.local PTR My Test._printer._tcp.local SRV, cache …
34	16.805250	172.27.21.251	224.0.0.251	MDNS	232	Standard query response 0x0000 PTR, cache flush Ys-MacBook-Pro.local PTR, cache flush Ys-MacBook-Pro.local NSEC, ca…
35	16.805318	fe80::1c99:22de:9a…	ff02::fb	MDNS	252	Standard query response 0x0000 PTR, cache flush Ys-MacBook-Pro.local PTR, cache flush Ys-MacBook-Pro.local NSEC, ca…
36	17.703216	172.27.21.251	224.0.0.251	MDNS	291	Standard query response 0x0000 TXT, cache flush PTR _printer._tcp.local PTR My Test._printer._tcp.local SRV, cache …
37	17.704185	fe80::1c99:22de:9a…	ff02::fb	MDNS	311	Standard query response 0x0000 TXT, cache flush PTR _printer._tcp.local PTR My Test._printer._tcp.local SRV, cache …
38	18.808877	fe80::1c99:22de:9a…	ff02::fb	MDNS	469	Standard query response 0x0000 PTR, cache flush Ys-MacBook-Pro.local PTR, cache flush Ys-MacBook-Pro.local TXT, cac…
39	18.809057	172.27.21.251	224.0.0.251	MDNS	449	Standard query response 0x0000 PTR, cache flush Ys-MacBook-Pro.local PTR, cache flush Ys-MacBook-Pro.local TXT, cac…

Exercise

- Use the dns-sd command on Mac as example
  - Browse web pages on local machines

```
dns-sd -B _http._tcp
```

  - Advertise (register) a web page on local machine

```
dns-sd -R "My Test" _http._tcp . 80
path=/path-to-page.html
```

  - Kill the command

Network Service Discovery in Android

- Based on DNS-SD/mDNS
- Foundation for peer-to-peer/Wi-Fi Direct in Android

- See https://developer.android.com/training/connect-devices-wirelessly/nsd.html for programming using nsd

General Service/Naming Discovery Paradigm: Linda

- "Distributed workspace" by David Gelernter in the 80's at Yale
- Very influential in naming and resource discovery
- Key issues
  - How to name services/resources
  - How to write/update into name space
  - How to resolve names

The Linda Paradigm

- Naming scheme:
  - arbitrary tuples (heterogeneous-type vectors)
- Name resolution:
  - Nodes write into shared memory
  - Nodes read matching tuples from shared memory
    - exact matching is required for extraction

Linda: Core API

- out(): writes tuples to shared space
  - example: *out("abc", 1.5, 12).*
  - result: insert ("abc", 1.5, 12) into space

- read(): retrieves tuple copy matching arg list (blocking)
  - example: *read("abc", ? A, ? B)*
  - result: finds ("abc", 1.5, 12) and sets local variables A = 1.5, B = 12. Tuple ("abc", 1.5, 12) is still resident in space.

- in(): retrieves and deletes matching tuple from space (blocking)
  - example: same as above except ("abc", 1.5, 12) is deleted

- eval(expression): similar to out except that the tuple argument to eval is evaluated
  - example: eval("ab",-6,abs(-6)) creates tuple ("ab", -6, 6)

Linda Extension: JavaSpaces

- Industry took Linda principles and made modifications
  - add transactions, leases, events
  - store Java objects instead of tuples
  - a very comprehensive service discovery system

- Definitive book, "JavaSpaces Principles, Patterns, and Practice"
  - 2 of 3 authors got Ph.D.'s from Yale

Additional Pointers

- Grapevine: Xerox PARC early 1980's Birrell, Levin, Needham, Schroeder *CACM* 25(1)

- The MAIN name system, an exercise in centralized computing, Deegan, Crowcroft and Warfield, *ACM SIGCOMM* 35(5), Oct 2005

Outline

- Admin and recap
- DNS
- Implementation/programming: UDP programming

Socket Programming

Socket API

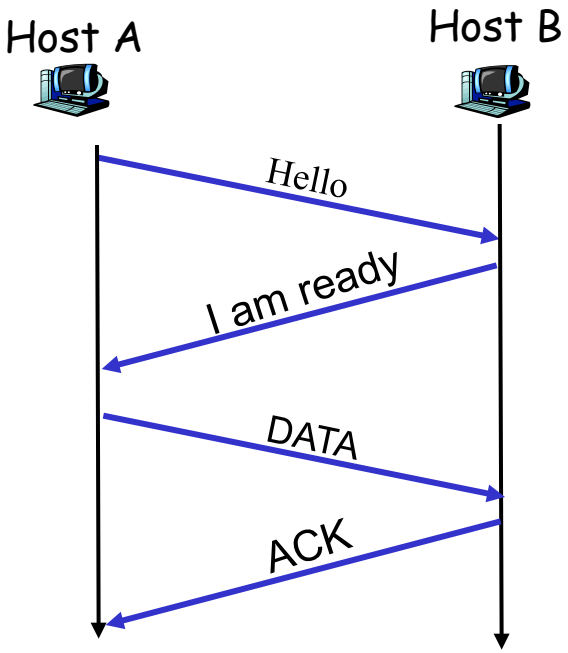
- introduced in BSD4.1 UNIX, 1981
- Two types of sockets
  - connectionless (UDP)
  - connection-oriented (TCP)

socket

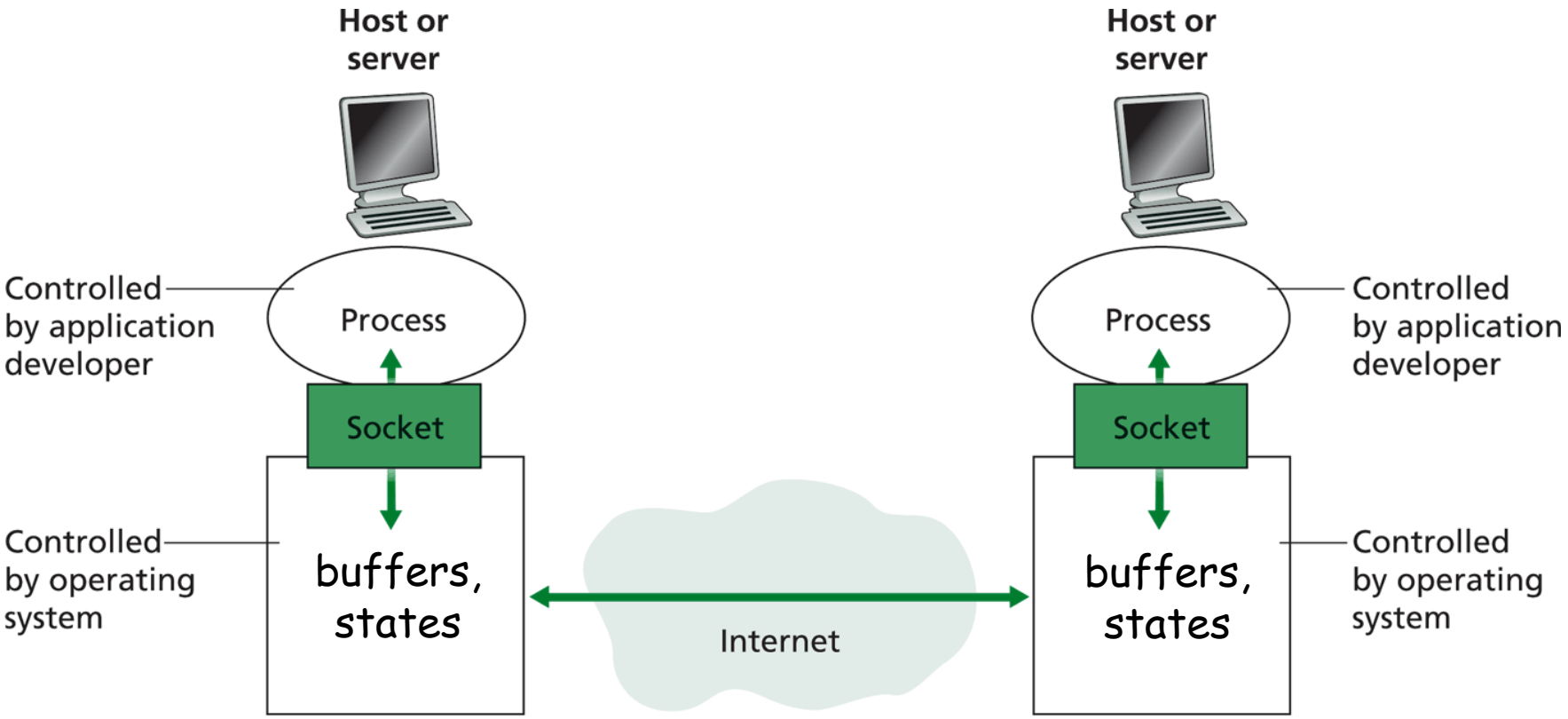
an interface (a "door") into which one application process can both send and receive messages to/from another (remote or local) application process

Services Provided by Transport

- User data protocol (UDP)
  - multiplexing/demultiplexing
- Transmission control protocol (TCP)
  - multiplexing/demultiplexing
  - reliable data transfer
  - rate control: flow control and congestion control



Big Picture: Socket



Outline

- Admin and recap
- DNS
- Basic network application programming
  - Overview
  - UDP (Datagram Socket)

Discussion

- What might the UDP API look like if you were to design it?

DatagramSocket(Java) (Basic)

- **DatagramSocket**()
  constructs a datagram socket and binds it to any available port on the local host
- **DatagramSocket**(int lport)
  constructs a datagram socket and binds it to the specified port on the local host machine.

// more methods on multiplexing control: bind, connect; see demos

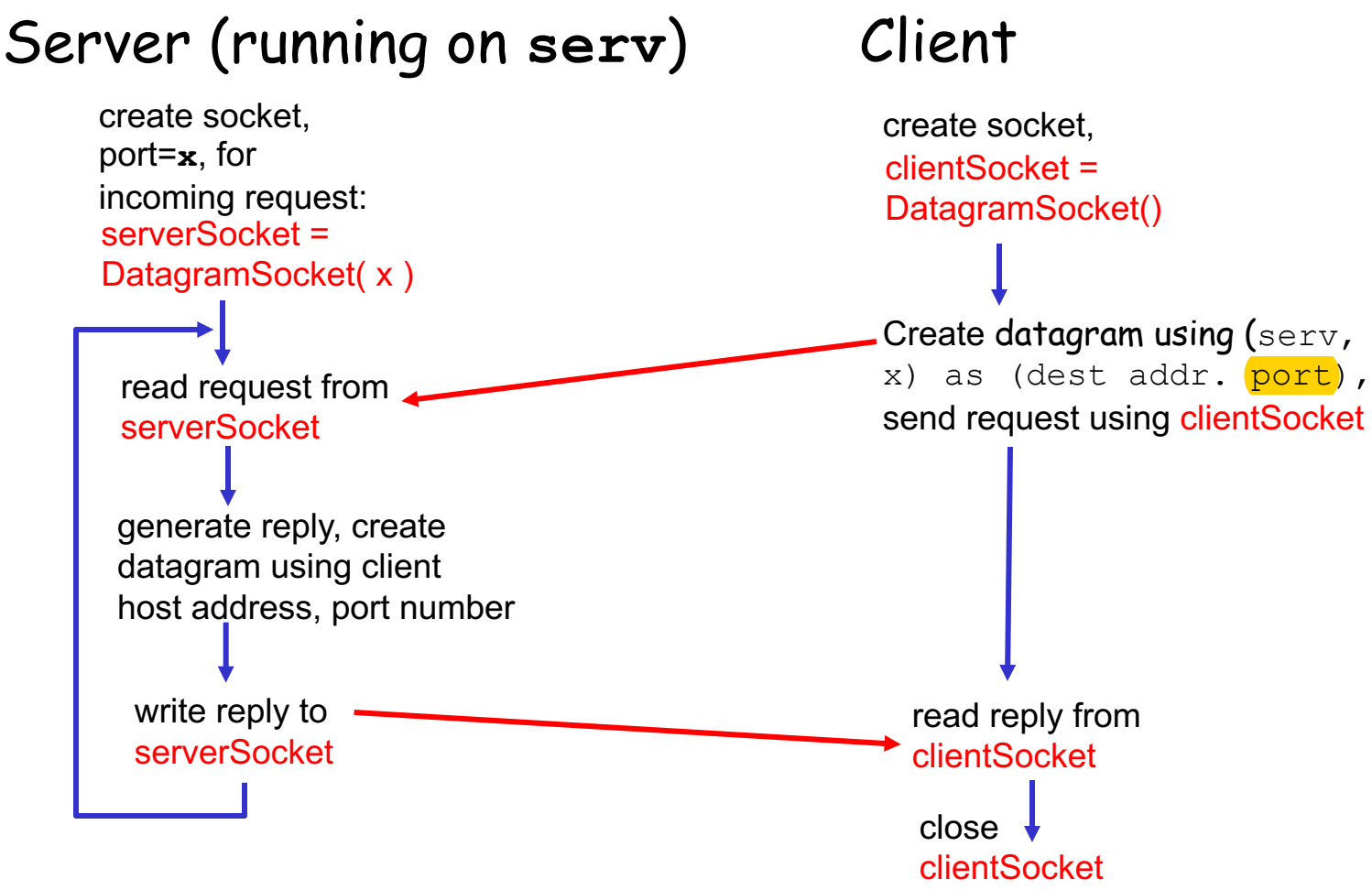
- **DatagramPacket**(byte[] buf, int length)
  constructs a DatagramPacket for receiving packets of length length.
- **DatagramPacket**(byte[] buf, int length, InetAddress address, int port)
  constructs a datagram packet for sending packets of length length to the specified port number on the specified host.
- **receive**(DatagramPacket p)
  receives a datagram packet from this socket.
- **send**(DatagramPacket p)
  sends a datagram packet from this socket.

// socket state control

- **close**()
  closes this datagram socket.

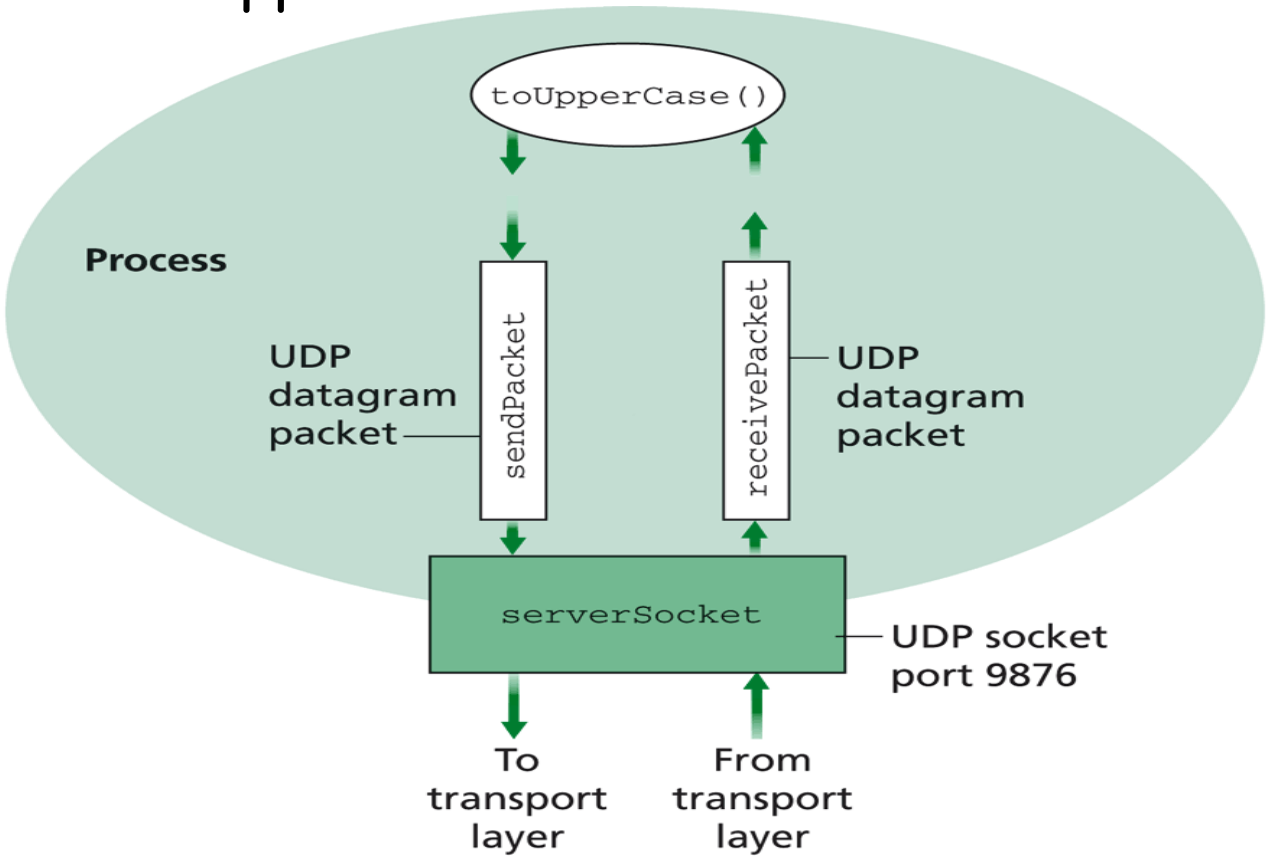
https://docs.oracle.com/javase/9/docs/api/java/net/DatagramSocket.html

Connectionless UDP: Big Picture (Java version)



Example: UDPServer.java

- A simple UDP server which changes any received sentence to upper case.



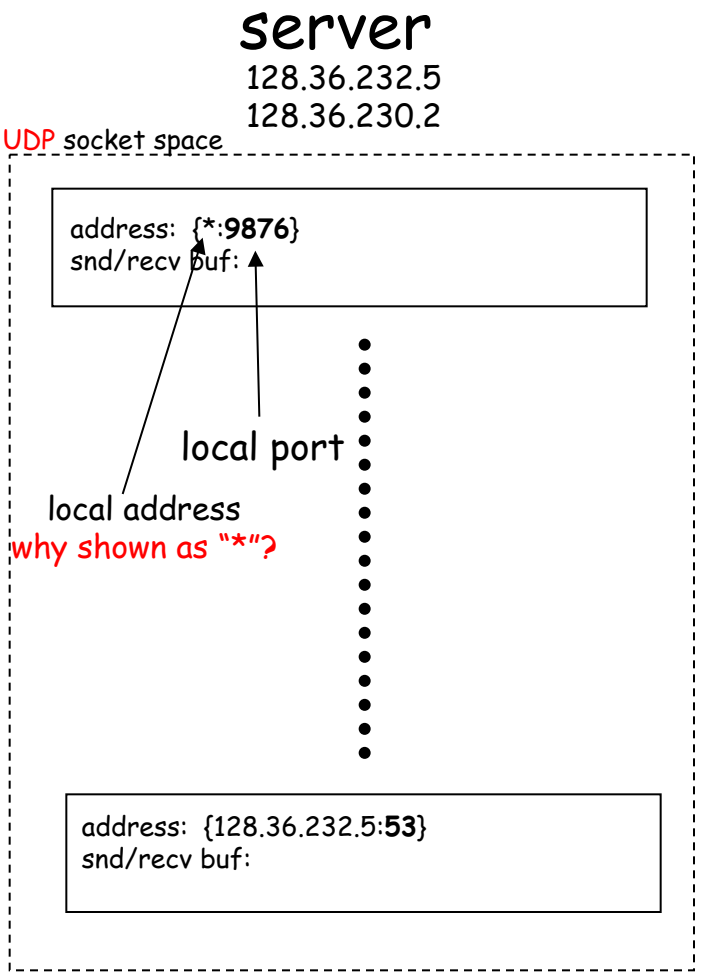
Java Server (UDP): Create Socket

```
import java.io.*;
import java.net.*;

class UDPServer {
  public static void main(String args[]) throws Exception
    {

    DatagramSocket serverSocket = new DatagramSocket(9876);
```

Create datagram socket bind at port 9876

Check socket state:
%netstat –a –p udp –n

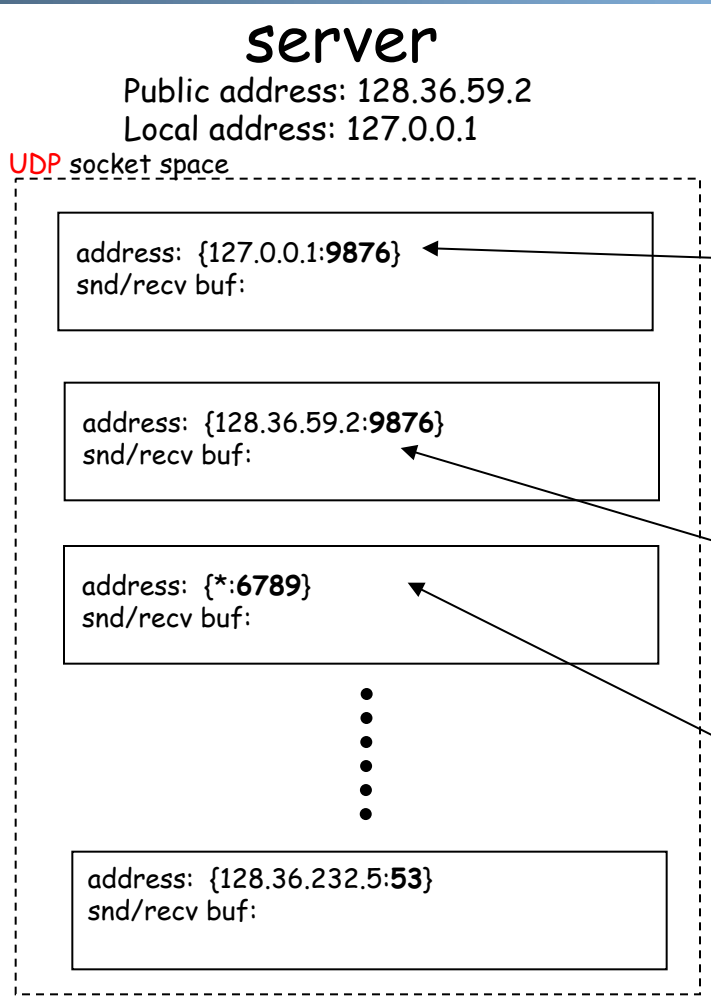
System State after the Call



"*" indicates that the socket binds to all IP addresses of the machine:

```
% ifconfig -a
```

Binding to Specific IP Addresses

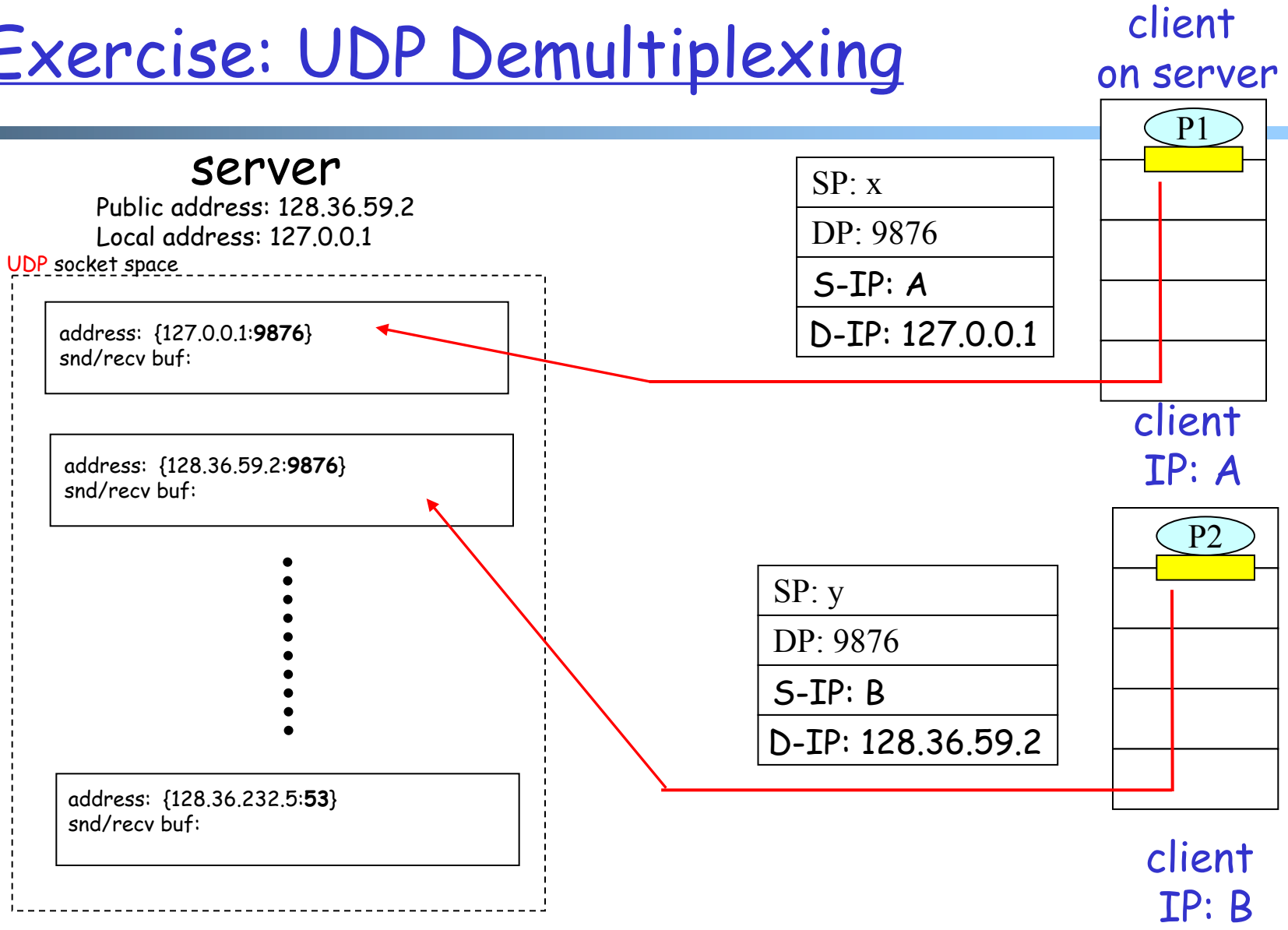



```
InetAddress sIP1 =
   InetAddress.getByName("localhost");
DatagramSocket ssock1 = new
       DatagramSocket(9876, sIP1);

InetAddress sIP2 =
 InetAddress.getByName("128.36.59.2");
DatagramSocket ssock2 = new
       DatagramSocket(9876,sIP2);

DatagramSocket serverSocket = new
DatagramSocket(6789);
```

Exercise: UDPPortScanner

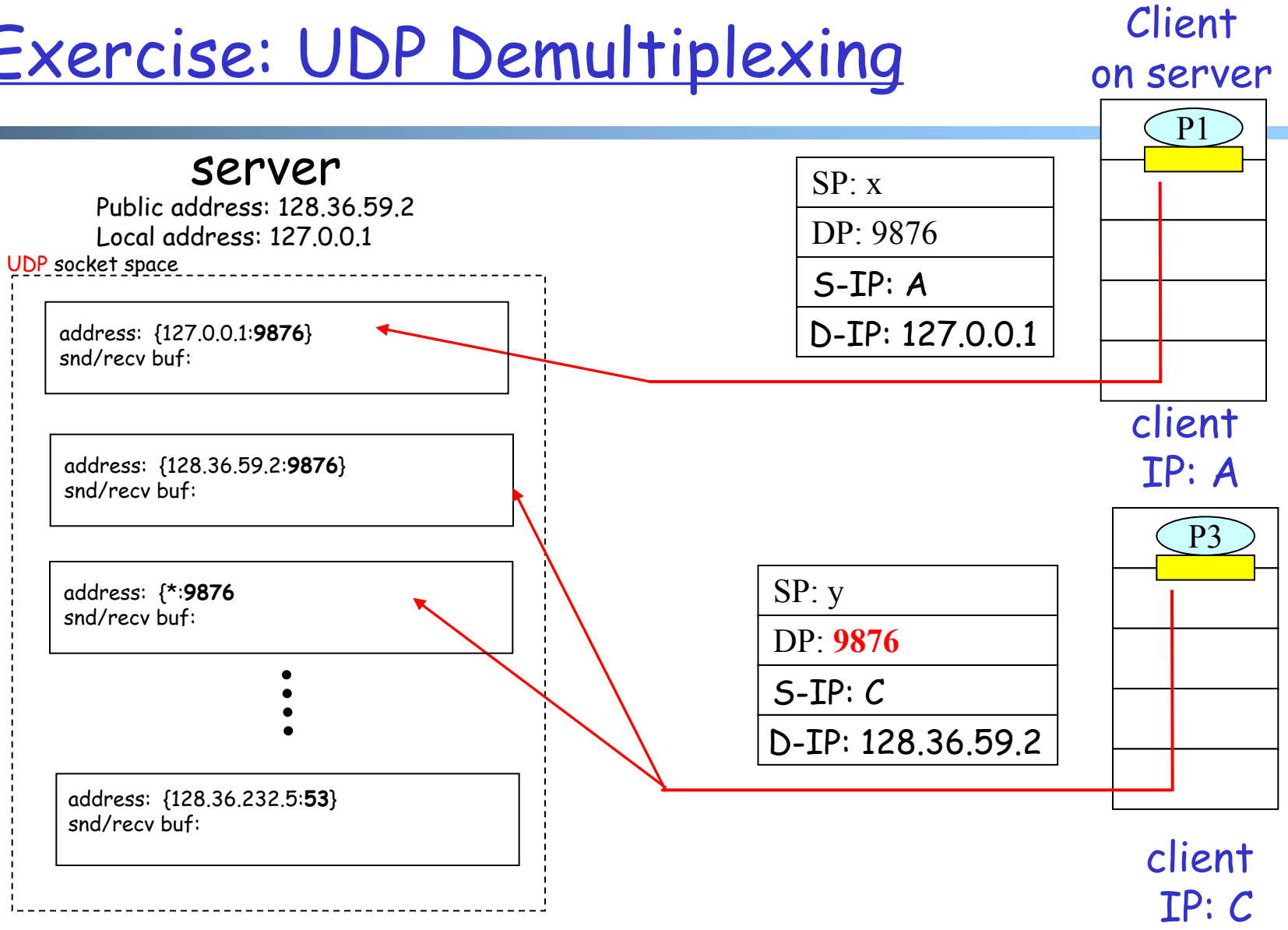
- Try to test all UDP bindings
- [sudo] lsof -i4UDP -n -P

Exercise: UDP Demultiplexing



UDP demutiplexing is based on matching state

Exercise: UDP Demultiplexing



UDP demutiplexing is based on matching state

Per Socket State

- Each Datagram socket has a set of states:
  - local address
  - send buffer size
  - receive buffer size
  - timeout
  - traffic class

See http://download.java.net/jdk7/archive/b123/docs/api/java/net/DatagramSocket.html

Example: socket state after clients sent msgs to the server

Exercise: UDPClient

- Send messages to UDPServer from local, from a zoo machine
- Use wireshark to capture traffic

Java Server (UDP): Receiving

```
import java.io.*;
import java.net.*;

class UDPServer {
  public static void main(String args[]) throws Exception
    {

      DatagramSocket serverSocket = new DatagramSocket(9876);

      byte[] receiveData = new byte[1024];
      byte[] sendData = null;

      while(true)
        {

      DatagramPacket receivePacket =
        new DatagramPacket(receiveData, receiveData.length);

      serverSocket.receive(receivePacket);
```

Create space for received datagram

Receive datagram

DatagramPacket

- **Receiving**
  - **DatagramPacket**(byte[] buf, int length)
    constructs a DatagramPacket for receiving packets of length length.
  - **DatagramPacket**(byte[] buf, int offset, int length)
    constructs a DatagramPacket for receiving packets starting at offset, length length.

- **Sending**
  - **DatagramPacket**(byte[] buf, int length, InetAddress address, int port)
    constructs a datagram packet for sending packets of length length to the specified port number on the specified host.
  - **DatagramPacket**(byte[] buf, int offset, int length, InetAddress address, int port)

Java Server (UDP): Processing

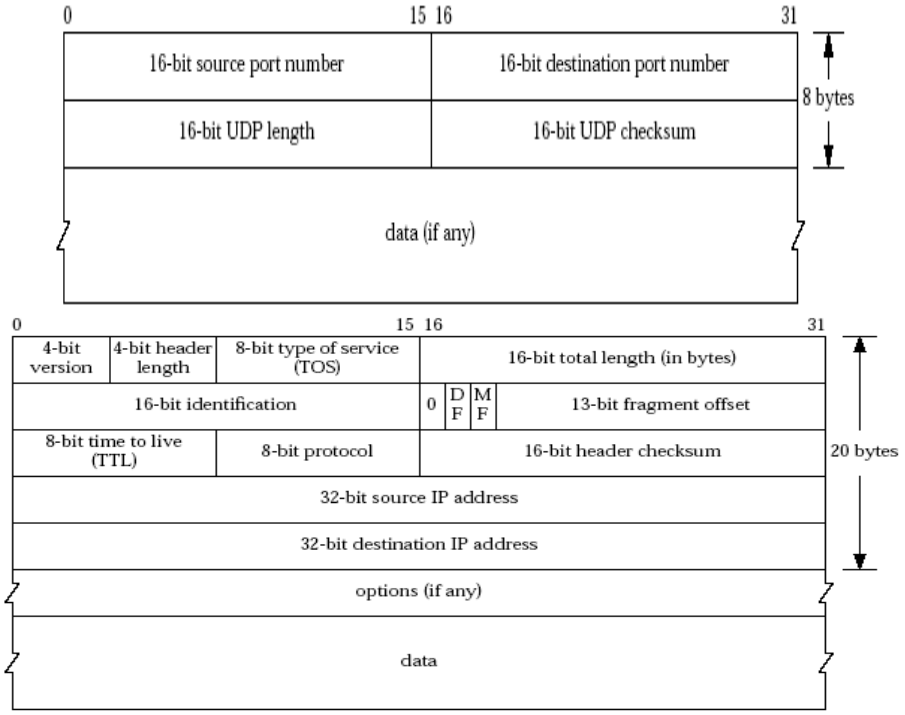
```
import java.io.*;
import java.net.*;

class UDPServer {
  public static void main(String args[]) throws Exception {

…
// process data
String sentence = new String(receivePacket.getData(),
                             0, receivePacket.getLength());
String capitalizedSentence = sentence.toUpperCase();
sendData = capitalizedSentence.getBytes();
```

getData() returns a pointer to an underlying buffer array

getLength() returns how much data is valid.

Java Server (UDP): Response

- Java DatagramPacket:
  - `getAddress()/getPort()` returns the source address/port



Java server (UDP): Reply

Get IP addr port #, of sender

```
InetAddress IPAddress = receivePacket.getAddress();
int port = receivePacket.getPort();
```

Create datagram to send to client

```
DatagramPacket sendPacket =
   new DatagramPacket(sendData, sendData.length,
                      IPAddress, port);
```

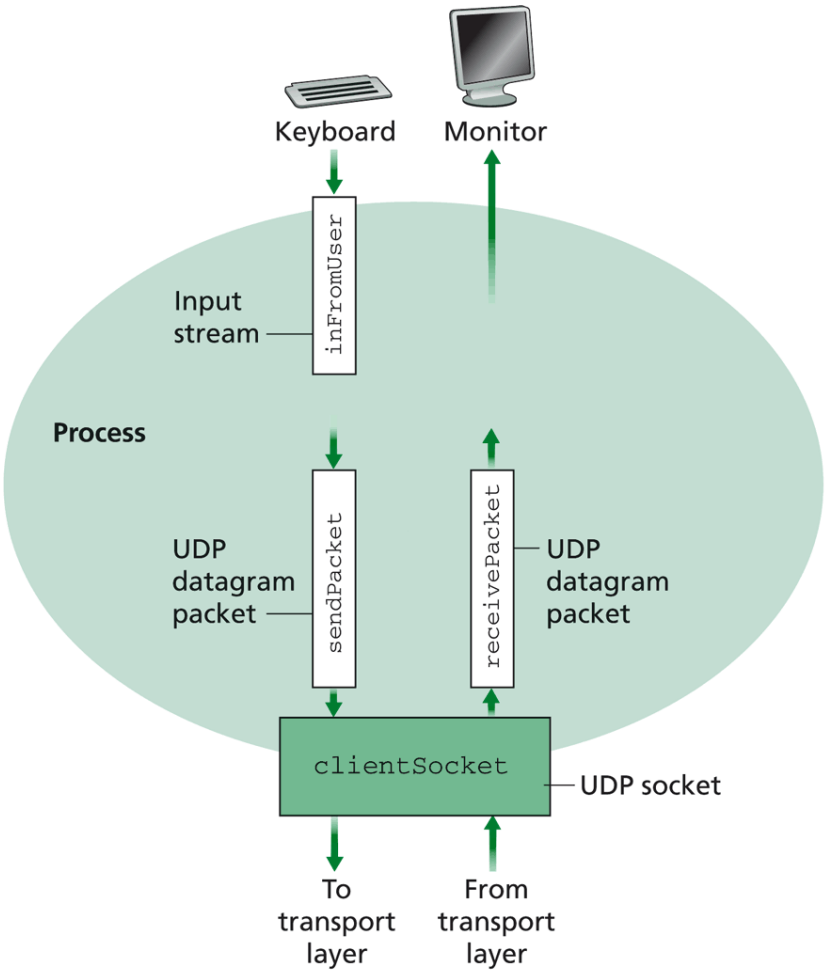
Write out datagram to socket

```
serverSocket.send(sendPacket);
    }
  }
}
```

End of while loop, loop back and wait for another datagram

Example: UDPClient.java

- A simple UDP client which reads input from keyboard, sends the input to server, and reads the reply back from the server.



Example: Java client (UDP)

```
import java.io.*;
import java.net.*;

class UDPClient {
    public static void main(String args[]) throws Exception
    {
      BufferedReader inFromUser =
        new BufferedReader(new InputStreamReader(System.in));
      String sentence = inFromUser.readLine();
      byte[] sendData = sentence.getBytes();

      DatagramSocket clientSocket = new DatagramSocket();

      InetAddress sIPAddress = InetAddress.getByName("servname");
```

Create input stream

Create client socket

Translate hostname to IP address using DNS

Example: Java client (UDP), cont.

Create datagram with data-to-send, length, IP addr, port

Send datagram to server

Read datagram from server

```
DatagramPacket sendPacket =
   new DatagramPacket(sendData, sendData.length, sIPAddress, 9876);

clientSocket.send(sendPacket);

byte[] receiveData = new byte[1024];
DatagramPacket receivePacket =
   new DatagramPacket(receiveData, receiveData.length);

clientSocket.receive(receivePacket);

String modifiedSentence =
    new String(receivePacket.getData());

System.out.println("FROM SERVER:" + modifiedSentence);
clientSocket.close();
}

}
```

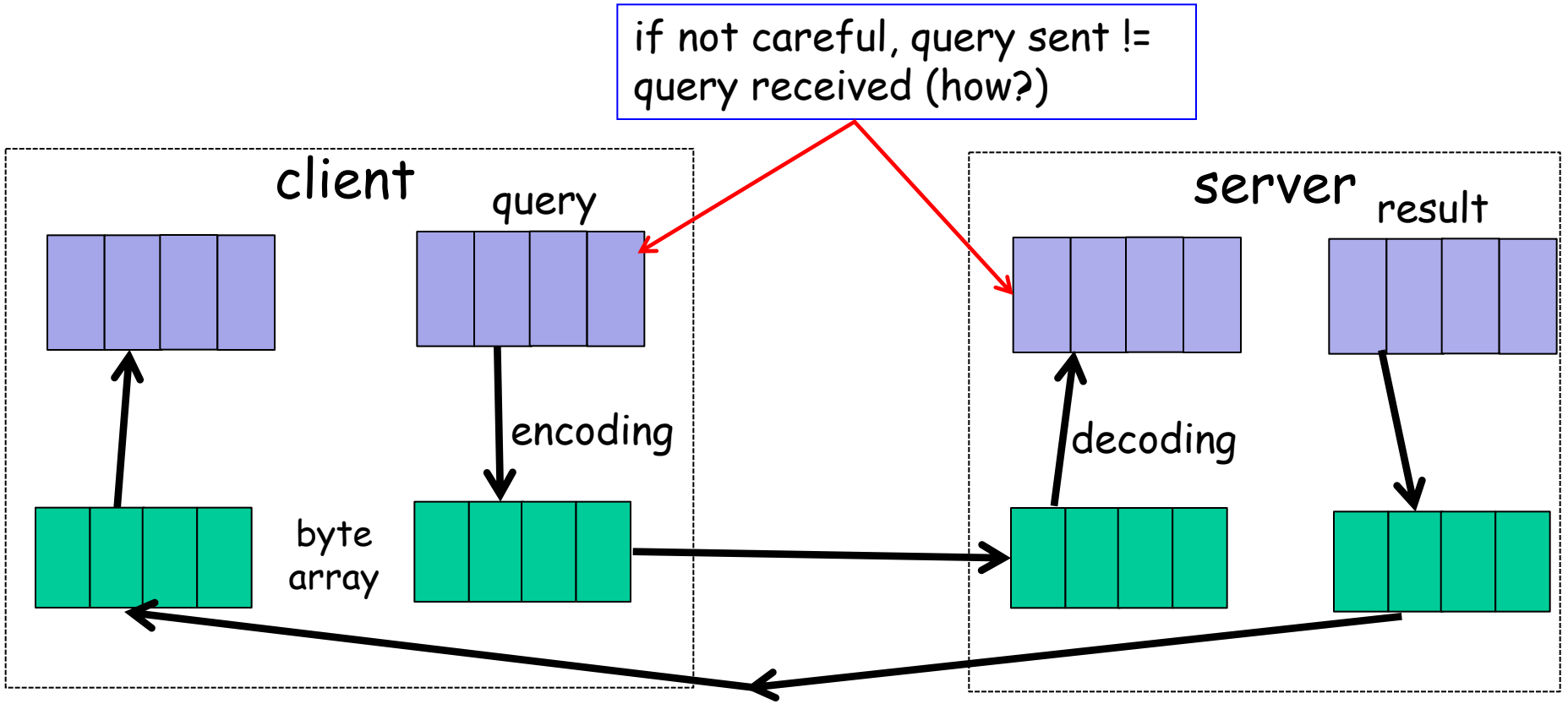
Java Server (UDP): Processing

A simple upper-case UDP echo service is among the simplest network service. Are there any problems with the processing?

```
class UDPServer {
  public static void main(String args[]) throws Exception  {

 …
DatagramPacket receivePacket = new DatagramPacket(receiveData, receiveData.length);
serverSocket.receive(receivePacket);

// process
String sentence = new String(receivePacket.getData(),
                                        0, receivePacket.getLength());
String capitalizedSentence = sentence.toUpperCase();
sendData = capitalizedSentence.getBytes();

// send
DatagramPacket sendPacket = new DatagramPacket(sendData, sendData.length,
                                                              IPAddress, port);
serverSocket.send(sendPacket);
```

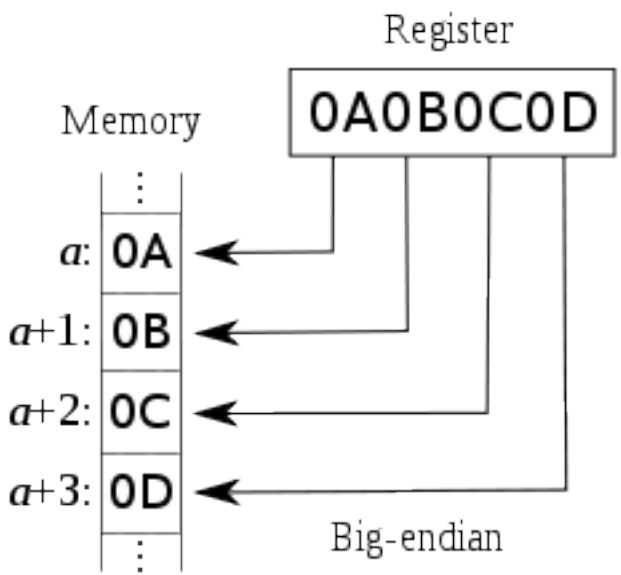
Data Encoding/Decoding

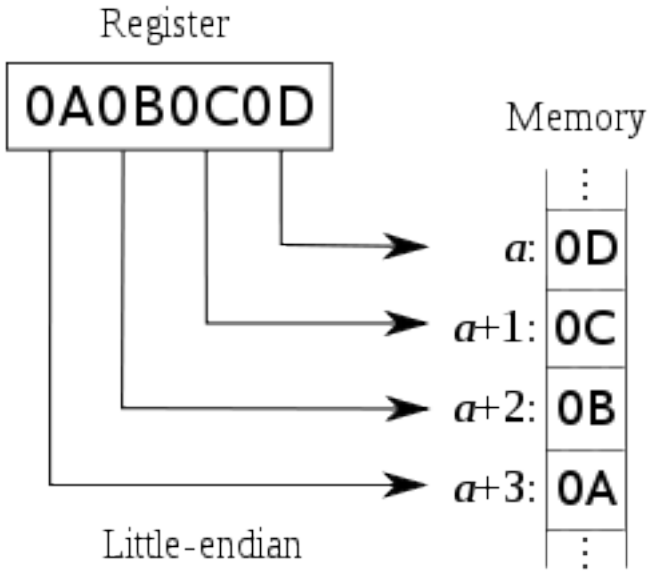
- Rule: ALWAYS pay attention to encoding/decoding of data



Example: Endianness of Numbers

- int var = 0x0A0B0C0D

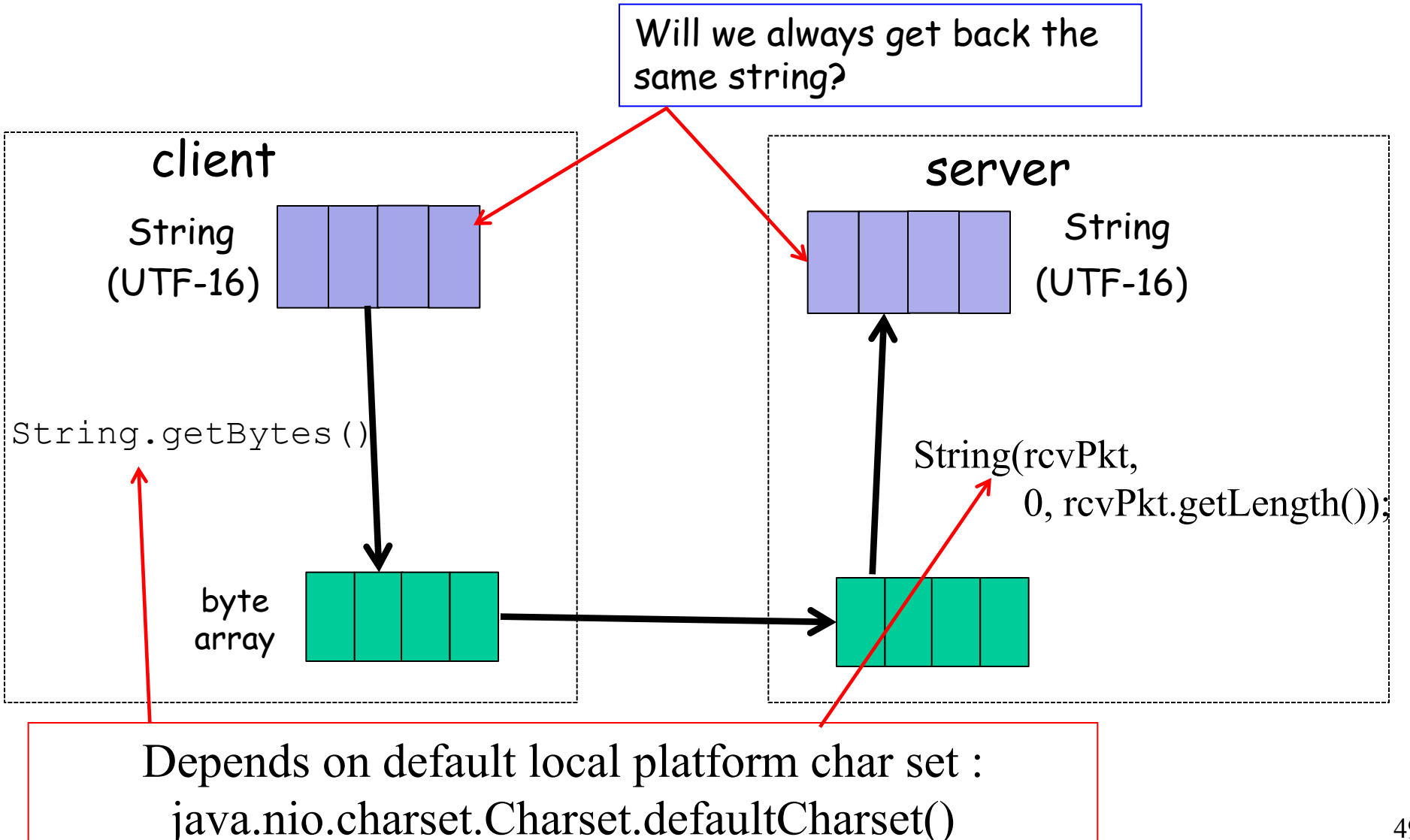




ARM, Power PC, Motorola 68k, IA-64 Intel x86

- sent != received: take an int on a big-endian machine and send a little-endian machine

Example: String and Chars



Example: Charset Troubles

- Try
  - java EncodingDecoding US-ASCII UTF-8

Encoding/Decoding as a Common Source of Errors

- Please read chapter 2 (Streams) of Java Network Programming for more details
  - Java stream, reader/writer can always be confusing, but it is good to finally understand

- Common mistake even in many (textbook) examples:
  - http://www.java2s.com/Code/Java/Network-Protocol/UseDatagramSockettosendoutandreceiveDatagramPacket.htm

Offline Exercise: UDP/DNS Server Pseudocode

- Modify the example UDP server code to implement a local DNS server.

Identification	Flags	12 bytes
Number of questions	Number of answer RRs	
Number of authority RRs	Number of additional RRs	
Questions (variable number of questions)		Name, type fields for a query
Answers (variable number of resource records)		RRs in response to query
Authority (variable number of resource records)		Records for authoritative servers
Additional information (variable number of resource records)		Additional "helpful" info that may be used